AIRCRAFT NUCLEAR PROPULSION:

AN ANNOTATED BIBLIOGRAPHY

Prepared for the

UNITED STATES AIR FORCE

HISTORY AND MUSEUMS PROGRAM

by

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PREFACE

This is the fifth in a series of research studies—historical works that were not published for various reasons. Yet, the material contained therein was deemed to be of enduring value to Air Force members and scholars. These were minimally edited and printed in a limited edition to reach a small audience that may find them useful. We invite readers to provide feedback to the Air Force History and Museums Program.

Beginning in 1946, the Army Air Forces (AAF) first sponsored a study on the Nuclear Energy for Propulsion (NEPA) project. The effort progressed over the next several years after reviews by the Atomic Energy Commission (AEC) and the Massachusetts Institute of Technology (MIT). From this emerged the joint USAF-AEC Aircraft Nuclear Propulsion (ANP) program. Ten more years of studies were undertaken by governmental laboratories and industrial firms until the Kennedy administration cancelled the effort in 1961. There was, however, some useful follow-on work on high temperature materials and high performance reactors under AEC direction. Also, some of the developmental work continued under space nuclear programs. *Aircraft Nuclear Propulsion* is a comprehensive, unclassified, annotated bibliography of the U.S. government program to develop a nuclear-powered aircraft. The contract author, Dr. Bernard J. Snyder, is president of Energy & Management Consultants Corporation, based in Potomac, Maryland. He is uniquely qualified for this task by virtue of nearly forty years' experience in the nuclear energy field, including government agencies and the private sector. Dr. Snyder earned BME and MME degrees from Cornell University and a Ph.D. in nuclear engineering from the University of Michigan. He completed the manuscript in May 1996.

Jacob Neufeld, General Editor
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GLOSSARY OF ACRONYMS AND TERMS

AAF	Army Air Forces
ACRS	Advisory Committee on Reactor Safeguards
ACT	Advanced Core Test
AEC	Atomic Energy Commission
AERL	Aircraft Engine Research Laboratory
AEW	Airborne Early Warning
AF	Air Force
AFSC	Air Force Systems Command
AGARD	Advisory Group for Aeronautical Research and Development
ARIN	Aerospace Research Information Network
ANP	Aircraft Nuclear Propulsion
ANPD	Aircraft Nuclear Propulsion Department
ANPO	Aircraft Nuclear Propulsion Office
ANS	American Nuclear Society
ARB	Aircraft Reactors Branch
ARDC	Air Research and Development Command
ARE	Aircraft Reactor Experiment
ART	Aircraft Reactor Test
ASME	American Society of Mechanical Engineers
ASTR	Aircraft Shield Test Reactor
ASW	Antisubmarine Warfare
BOB	Bureau of the Budget
BSF	Bulk Shielding Facility
CAMAL(S)	Continuous Airborne Missile-Launcher and Low Level Weapon
CANEL	Connecticut Aircraft Nuclear Energy Laboratory. [“Aircraft” changed to “Advanced” after ANP cancellation in 1961]
CCR	Compact Core Reactor
CFR	Circulating Fuel Reactor
CFRE	Circulating Fuel Reactor Experiment
CIC	Coordination and Information Center
CNO	Chief of Naval Operations
DOD	Department of Defense
DOE	Department of Energy
DOE/NV	Department of Energy Nevada Operations Office
DRD	Division of Reactor Development
DTIC	Defense Technical Information Center
DTIE	Division of Technical Information Extension (later became OSTI)

EDB	Energy Data Base
ETU	Engineering Test Unit
FET	Flight Engine Test
FY	Fiscal Year
GAC	General Advisory Committee
GAO	General Accounting Office
GE	General Electric Co.
GTR	Ground Test Reactor
HOTCE	Hot Critical Experiment
HRE	Homogeneous Reactor Experiment
HTRE	High Temperature Test Reactor
IAEA	International Atomic Energy Agency
ICBM	Intercontinental Ballistic Missile
ICPP	Idaho Chemical Processing Plant
IET	Initial Engine Test
IETF	Initial Engine Test Facility
INEL	Idaho Nuclear Energy Laboratory
IRIS	Inferential Retrieval Indexing System
JCAE	Joint Committee for Atomic Energy
JCS	Joint Chiefs of Staff
JRDB	Joint Research and Development Board
KeV	Thousand Electron Volts
KIWI	Nuclear Rocket Ground Test
LCRE	Lithium Cooled Reactor Experiment
LITR	Low Intensity Test Reactor
LMCR	Liquid Metal Cooled Reactor
LMNPS	Light Mobile Nuclear Power Supply
LPT	Low Power Test
MeV	Million Electron Volts
MHD	Magnetohydrodynamics
MIT	Massachusetts Institute of Technology
MLC	Military Liaison Committee
MSA	Mine Safety Appliance Corp.
MTR	Materials Test Reactor
NACA	National Advisory Committee for Aeronautics

NAP	Nuclear Aircraft Propulsion
NARF	Nuclear Aircraft Research Facility
NBS	National Bureau of Standards
NDA	Nuclear Development Associates
NEPA	Nuclear Energy for Propulsion of Aircraft
NERVA	Nuclear Engine for Rocket Vehicle Application
NRC	Nuclear Regulatory Commission
NRTS	National Reactor Test Station
NSA	Nuclear Science Abstracts
NSC	National Security Council
NTA	Nuclear Test Aircraft
NTF	Nuclear Test Facility
NTIS	National Technical Information Service
nvt	Time Integrated Neutron Dose
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reactor
OSTP	Office of Science and Technology Policy
OSTI	Office of Scientific and Technical Information (previously called DTIE)
ppm	Parts Per Million
psig	Pounds Per Square Inch Gauge
RDB	Research and Development Board
RDD	Reactor Development Division
RECON	NASA Research Connection
REM	Roentgen Equivalent Man, a unit of radiation exposure
RG	Record Group
RTF	Reactor Test Facility
SAB	Scientific Advisory Board
SAC	Strategic Air Command
SAE	Society of Automotive Engineers
SDR	Sodium Deuterium Reactor
SFR	Solid Fuel Reactor
SHP	Shaft Horsepower
SMR	Solid Moderator Reactor
SNAP	Space Nuclear Auxiliary Power
SNM	Special Nuclear Material
SNSO	Space Nuclear Systems Office
SOR	Specific Operational Requirement
STOL	Short Take-Off and Landing
TAB	Technical Advisory Board

TBP	Tributyl Phosphate
TRA	Tubular Reactor Assembly
TRW	Thompson-Ramo-Wooldridge Corp.
TSF	Tower Shielding Facility
TSM	Test Solid Moderator Critical Assembly
TVA	Tennessee Valley Authority
VTOL	Vertical Take-Off and Landing
WADC	Wright Air Development Center
WCF	Waste Calcining Facility
WS	Weapon System
WSEG	Weapons Systems Evaluation Group
XMA	Nuclear Turbojet Engine
ZPR	Zero Power Reactor
ZPT	Zero Power Test

Introduction

Attempts by the United States government to develop nuclear-powered aircraft for military applications between 1946 and 1961 was one of the most technologically challenging programs ever undertaken. Adding to the difficulties, this development effort was a politically contentious issue throughout its fifteen-year lifetime. Because of the continuing interest in this subject, the Air Force History Support Office contracted for research of the literature and documentation in an annotated bibliography.

The origins of U.S. attempts to power aircraft by nuclear energy began with the World War II Manhattan Project. In 1945, as the war in Asia ended with the dropping of two atomic bombs on Japan, numerous ideas for use of the awesome force of the atom were considered. Controlled use of atomic energy had been demonstrated with the nuclear reactors built for the Manhattan Project, and the concept of a nuclear-powered aircraft that could stay aloft for weeks was attractive to the military. Beginning in 1946, the Army Air Forces sponsored a feasibility study, the Nuclear Energy for Propulsion of Aircraft (NEPA) project. The NEPA project was carried out by a team of industrial firms led by the Fairchild Engine and Airplane Corporation, initially located at the Oak Ridge National Laboratory (ORNL), where space was made available by the newly-formed Atomic Energy Commission (AEC). Two years later, the AEC requested that the first significant review of the NEPA project be conducted by a distinguished group of scientists and engineers organized by the Massachusetts Institute of Technology (MIT) and referred to as the Lexington Group. The Lexington Report, issued in September 1948, is often cited as the basis for proceeding further with development work on the nuclear-powered aircraft. The MIT group concluded that, with adequate resources and competent manpower for an intensive effort, flight of a nuclear-powered aircraft would take fifteen years and cost about a billion dollars.

By 1951, the AEC and the Air Force had established a joint program that was known as the Aircraft Nuclear Propulsion (ANP) program. Major industrial firms, including General Electric (GE), Pratt and Whitney, Lockheed, and Convair participated in the ANP program, along with ORNL and what became the Lewis Laboratory of the National Advisory Committee for Aeronautics (NACA). Development of a compact, high-powered nuclear aircraft engine proved to be a formidable undertaking. Research and development was required for high temperature materials, radiation shielding, and other exceptionally difficult engineering problems. Determining the radiation effects on people and equipment was another major question. Two different approaches to the nuclear-powered engine design were pursued, GE’s open cycle, air-cooled reactor, and Pratt and Whitney’s closed cycle, liquid metal-cooled concept. Among the accomplishments were the operation of a series of tests run by GE at the Idaho National Reactor Test Station, where modified J24 turbojet engines were run on nuclear power for a total of 150 hours. Also, a small nuclear reactor was flown many times aboard a modified B–36 bomber to study radiation shielding, as well as radiation effects on aircraft materials. After continuing for fifteen years and spending one billion dollars, as predicted by the Lexington group, the ANP program was cancelled in early 1961 by the new administration of President John F. Kennedy. Significant technological advances had been made, but the fundamental question—can a nuclear airplane be flown safely?—was never answered.

I sought to thoroughly research and document, in an annotated bibliography, the unclassified literature pertaining to ANP, reviewing literature from both open sources and the resources of the federal repositories, including the Air Force, Department of Energy, National Aeronautics and Space Administration, National Archives, and Library of Congress. My primary goal for this research was to provide an assessment of the literature and a research guide to a topic of continuing interest for officials of the Air Force History Support Office. Scholars interested in the ANP program should also find this bibliography of value.

Moreover, I sought information that could provide answers to questions related to this controversial program. I assumed the following broad questions covered most of those that might be addressed in a future history, and I used these questions to guide my research. These guiding questions are:

1. What were the origins of the ANP Program?

2. Were the ANP objectives clearly defined and the mission specified?

3. What changes in program objectives and mission occurred and how was the success of the program affected?

4. With the advantage of a perspective of over thirty-five years, did the program follow an appropriate course to ensure success?

5. What were the significant expenditures for the program?

6. What important technological benefits came from this program?

7. What were the fundamental and ancillary reasons for cancellation of the program?

8. Was the program an embarrassing failure, as many thought, or did any of the technological advances benefit the U.S.?

9. Can any conclusions be drawn from failure of the ANP program and the success of the U.S. Navy's nuclear ship propulsion program?

10. Will an ANP program find a place in the Air Force's future plans?

This research covers the period when the Air Force considered powering military aircraft by nuclear energy. Research began with the origins of the concept in the U.S. during the Manhattan Project in 1944, through initial feasibility studies, and continued with further engineering development and testing, to the cancellation of the program by President Kennedy in 1961. I researched literature beyond 1961 to ensure that important documents, declassified subsequent to that date, were also considered. In addition, I reviewed post-1961 documents to understand technical work that came as a follow-on to the ANP program, as well as technology benefits to other fields. Furthermore, I reviewed some oral histories and literature in related areas, such as the Naval Reactors Program, which evolved at the same time as the ANP program.

This bibliography also includes references to foreign documents. Most of these are secondary references reporting on the ANP work in this country. However, there is some indication that the U.S.S.R. had an ANP program during the Cold War years, but the evidence is not compelling. Instead, it is conceivable, based on documents reviewed, that the Russians had an effective disinformation campaign on their supposed ANP work. Further research will be needed to answer this question, and this may be facilitated by the recent opening of the Soviet archives. This is not a peripheral issue. Much of the political support which kept the American ANP program alive appears to have relied on the threat of the Soviets beating the U.S. to the achievement of the first nuclear-powered flight of a manned aircraft. The Russian success of *Sputnik* in 1957 cast a long shadow over the ANP program at a time when ANP cancellation was starting to be considered.

Almost all entries include a summary of the cited document. For a small number of documents the only information that was available was the author and title. This limited information was included for completeness. Classified documents have not been referenced in this bibliography. However, numerous unclassified sources provide a record of the development of nuclear-powered aircraft. Chief among these are:

- The Air Force History Support Office library at Bolling Air Force Base, D.C., with access to the IRIS Data Base.

- The DOE library, with access to the Energy Data Base, as well as an extensive collection of published sources, including reports of Legislative Committee Hearings and a complete set of Nuclear Science Abstracts.

- DOE/NV CIC

- DTIC

- Library of Congress

- IAEA

- NASA libraries at NASA HQ and the Goddard Space Flight Center, with access to the RECON and ARIN Data Bases.

- NTIS Data Base accessible via DIALOG.

- U.S. National Archives and Records Administration.

The approximate percentages of the entries in this bibliography from each of the principal sources are:

- DTIC 2 percent

- IRIS 4 percent
- NASA 5 percent
- National Archives 10 percent
- IAEA 14 percent
- NSA and NTIS 50 percent
- Other Published Sources 15 percent

I also sent an "Author's Query" to the *New York Times Sunday Book Review* for any information readers may have on the background of the ANP program, reasons for cancellation, and any known benefits to other fields of technology. Although this source of information may not yield anything useful, it was felt that all avenues should be explored.

Chapter 1, "Background" considers the origins of the utilization of controlled atomic energy for power. This includes references to scientific publications of the discovery of nuclear fission and subsequent popular articles by some of the early pioneers in nuclear science. One interesting reference is a 1914 book by H. G. Wells[*], written more than twenty-five years prior to the discovery of nuclear fission, and only eleven years after the first flight of the Wright Brothers. Wells projected forward to 1943, when thousands of atomic-powered aircraft (his words) were "humming softly into the sky."

Although, the U.S. ANP program had its origins in the World War II Manhattan Project, there are few specific references to ANP during this period. Starting in 1946, with an Army Air Forces-funded effort by a number of industrial firms under the direction of the Fairchild Engine and Airplane Corporation, the NEPA project continued for the next five years. References to this period appear in **Chapter 2, "Initial Nuclear-Powered Flight Efforts,"** and the reports (as are most of those referenced in this bibliography) are found at the Department of Energy's OSTI repository at Oak Ridge National Laboratory**.**

In 1951, under the direction of the Air Force and AEC, a joint program was initiated by industrial contractors with nuclear and aeronautic capabilities. Research also continued at the Oak Ridge National Laboratory. This was the beginning of the ANP program, although the term "ANP" is also sometimes used as a generic reference to development work which occurred before 1951. **Chapter 3, "ANP Contractors,"** provides references to the technical work reported by these, and other organizations. An extensive listing of about 750 technical documents are given in this chapter, reflecting the magnitude of the engineering and scientific nature of this effort.

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[*]Wells, H. G., *The World Set Free-A Story of Mankind* (London, England: Macmillan and Co., Ltd., 1914).

Much of the controversy which surrounded this program, almost from its beginning, is provided in the references of **Chapters 4 and 5, "Government Agencies," and "Political Considerations,"** respectively. A significant body of literature in these two areas remains classified and unavailable, in spite of the passage of more than forty years. In the course of preparing this bibliography, I filed requests with the National Archives under the Freedom of Information Act and the provisions of Mandatory Review (applicable to Congressional documents) to declassify approximately 300 documents. Unfortunately, this is a torpid process, since a number of different agencies must review and concur with declassification of most documents. Included in these declassification requests are documents that were only partly declassified and released as "sanitized" documents, with relevant information withheld.

To the extent they are available, declassified AEC staff papers on ANP (Chapter 4, Section a.) are a particularly useful source. Adopting a format used by the Joint Chiefs of Staff during World War II, these documents were organized by the AEC according to a subject-numeric records management system. Staff papers were prepared for the AEC commissioners either for a decision, or for their information. Each decision paper follows a standard format, including background, options and recommendations. Since the commissioners made essentially all policy decisions, these papers represent a valuable historical reference.

Two lesser-known ANP projects, the Navy's and NACA's, are referenced in **Chapter 4, Sections b. and c**., respectively. The Navy Project attempted to develop a nuclear-powered seaplane by using technology being developed for Air Force jet engines in a Navy turbo-prop aircraft, mounted in existing British seaplane airframes. NACA continued to carry out nuclear aircraft engine development for many years after President Kennedy cancelled the Air Force and AEC program.

Most of the Congressional documents listed in **Chapter 5.a., "U.S. Congress,"** are from the Joint Committee on Atomic Energy (JCAE). This was a uniquely constituted committee, having members from both the Senate and House of Representatives. Several references in **Chapters 4 and 5** should be specifically mentioned. In 1959, after thirty-six closed hearings during the prior thirteen years, the JCAE held its first public ANP hearing. The report of the JCAE Subcommittee on Research and Development for its July 23, 1959, hearing is a valuable reference, showing the strong influence of the JCAE supporting the ANP development efforts, while continuing to criticize the indecisiveness of the Air Force and the AEC. Later that same year, the Air Force published in a special fall/winter issue of the *Air University Quarterly*, a comprehensive review of the progress of the ANP program, along with an overly optimistic forecast for the future. The JCAE report is referenced in **Chapter 5, Section a**, while the Air Force report is in **Chapter 4, Section b**.

In February, 1963, almost two years after cancellation, the GAO provided an overall assessment of the ANP program. This report, referenced in **Chapter 5, Section a**, provides the best contemporary critique of the program, concluding that an R&D effort of the complexity and magnitude of the ANP could not reach its goals without maintaining stability for specified requirements. GAO noted that the Department of Defense did not furnish sufficient, and timely, guidance, and the program suffered from frequent reorientations.

Chapter 6, "Foreign ANP-Related Activities," covers references to all foreign documents that refer to ANP, whether the work was carried out in the U.S., or overseas. Since most of the details of the U.S. ANP program were classified, these documents are only able to summarize the publicly known aspects of American work. There are also a number of Soviet documents, which suggest that the Russians were conducting research on an ANP program of their own. In addition, **Chapter 6** includes references from U.S. sources that discuss a possible Soviet ANP program.

As one of the first decisions of his new administration, President Kennedy cancelled the ANP program after an expenditure of one billion dollars and with a peak of about 4000 contractor, government and military personnel. After the program was terminated, GE prepared a series of detailed technical reports that documented all of their significant ANP work. **Chapter 7, "Termination Reports"**, provides reference to this series of twenty-one GE reports, a unique historical source of information on the technical efforts of the primary ANP nuclear engine developer.

The documents listed in **Chapter 8, "Application to Other Technologies,"** cover the high temperature materials and high performance reactor development work which President Kennedy's ANP cancellation message specifically mentioned would be continued. This chapter also references other areas of technology which may have benefited from the ANP effort, covering the period both before and after ANP termination. For example, the space and nuclear rocket programs benefited from the R&D of the ANP program.

Finally, over the years since cancellation, there have been a number of retrospective evaluations, of varying objectivity, of the ANP program. Important references in this area are given in **Chapter 9, "Evaluations of ANP."**[**] Periodically articles have appeared which speculate about the future uses of nuclear power for either military or civilian aircraft. These articles are referenced in **Chapter 10, "Possible Future Flight Applications."** Many of the technically oriented articles are based on the fact that as much larger conventional aircraft become available, the ability to carry a nuclear power plant and required shielding becomes more feasible. **Chapter 11, "Illustrations,"** makes reference to photographs, drawings, and artist interpretations of what a nuclear airplane might look like, along with other pictorial information.

[**] See also, Chapter 5, Section a, *Review of the Manned Aircraft Nuclear Propulsion Program,* Comptroller General of the United States (General Accounting Office, Washington, D.C., February, 1963).

An often overlooked legacy of DOD and AEC projects terminated decades ago, are the remaining contaminated sites and facilities. In the case of the ANP program, facilities located in Idaho at the National Reactor Test Station, Connecticut, at the CANEL Facility, and the Oak Ridge National Laboratory, Tennessee, remained contaminated with radioactivity for years after the program was cancelled. Since many of the radioactive contaminants are long-lived, remediation is required in accordance with today's requirements. **Chapter 12, "Abandoned ANP Facility Environmental Effects,"** provides references to documents covering the environmental effects from some of the abandoned ANP facilities.

Transcripts of the ANP oral history interviews, referenced in **Chapter 13, "ANP Oral History Interviews,"** are available at the Air Force History Support Office. These were conducted to ensure that some of the key individuals with first-hand knowledge of, or who were involved in, the ANP program were interviewed while still available. Additional ANP oral history interviews are planned and should be available after publication of this bibliography. The General Electric Company Aircraft Nuclear Propulsion Division conducted the largest part of R&D for ANP, receiving much of the one billion dollars spent on this program. Interviews with two of the most important individuals from GE, Dr. Miles Leverett, project manager, and Gunnar Thornton, engineering manager, provide an essential technical and historical perspective. Dr. Leverett's interview is an especially important historical source, since he was involved in nuclear aircraft propulsion development almost for the life of the program, starting in 1948 (two years after it began) until termination in 1961. In the interview with Dr. Hans Bethe, 1967 Nobel Laureate in Physics and Head of the Theoretical Physics Division of the Manhattan Project at Los Alamos, proved to be a unique and objective critic of the ANP program for which he served as a consultant, as well as a member of presidential review boards.

A number of reference information data bases were searched. The largest source of references to technical reports is found in the Nuclear Science Abstracts (NSA), published by the AEC beginning July 15, 1948. Although the Energy Data Base (EDB) was expected to include all of the NSA entries, a search showed this was not the case. Only about one-tenth of the relevant ANP documents were found in the NSA entries of the EDB. Since the NSA entries are not included in any other computerized data base, I conducted a manual search of twenty-eight years of publication (with most years consisting of three volumes) to ensure a comprehensive bibliography. Even though the ANP Program was terminated in 1961, this manual search was performed for the period 1948-1975, since declassification of many documents and NSA listing occurred years after they were originally dated. I edited abstracts from the NSA as appropriate for this bibliography.

The Inferential Retrieval Indexing System (IRIS) Data Base is available only through the Air Force library computer system, and the EDB and the National Technical Information Service (NTIS) Data Bases are available via commercial DIALOG service. The Defense Technical Information Center (DTIC), which is a reference service requiring registration and payment of a fee, has two sources of ANP information. The computerized DTIC data base covers documents starting in 1953. Therefore, a manual search was necessary to locate ANP information at DTIC prior to that time. The IAEA[***] published a comprehensive listing of U.S. and

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[***] IAEA, Biographical Series No. 3, *Nuclear Propulsion* (Vienna, Austria: International Atomic Energy Agency, 1961).

foreign reports on ANP, which I have edited and included in this bibliography.

I found documents from two sources, NASA and DOE, with searches via the Internet. The NASA Center for Aerospace Information has a Technical Report Server at the Internet address: **http://www.sti.nasa.gov/casitrs.html** and abstracts of the references in the RECON and ARIN data bases were downloaded.

DOE has a document data base in their OpenNet at the Internet address: **http://www.doe.gov./html/osti/opennet/opennet.html**

Although a significant number of documents (140) were found there, only limited information is given for each entry. Further information on this source is provided in **Chapter 4, Section a, "Atomic Energy Commission."**

Since this bibliography is provided in both printed and electronic media format (WordPerfect 6.0.a), the computer disks can also be used as a specialized ANP data base for search purposes.

The location of unpublished references in the bibliography have been identified, when known. When not specifically identified, most of the AEC-funded technical reports should be found at the DOE Office of Science and Technology Information (OSTI), P.O. Box 62, Oak Ridge, TN 37831. A complete set of ANP Program technical reports covering the period of 1952 through 1965 were catalogued[****] and sent by Pratt & Whitney Aircraft to OSTI in 1965. According to Gunnar Thornton, former General Electric ANP engineering manager, the entire library of that company's ANP reports was destroyed. However, that same individual has an extensive personal collection of GE ANP reports and correspondence, which may be made available for research. Some reports from his collection are included in this bibliography.

The DOE/NV Coordination and Information Center, P.O. Box 98521, Los Vegas, NV, 89193 should have most of the reports referenced in the DOE OpenNet Data Base. Documents referenced in the IRIS data base are on microfilm and located at the Air Force History Support Office, Bolling Air Force Base, Washington, D.C.

The National Archives are a fruitful source of documents from the AEC, JCAE and OSTP (Record Groups 326, 128, and 359, respectively), but as discussed above, classification remains a problem for the researcher. Record groups for JCAE documents are at the Archives in Washington, D.C., while AEC and OSTP documents are located at Archives II, in College Park, MD. All searches at the Archives are manual.

Information from the Massachusetts Institute of Technology's Archives proved to be limited, although it was expected to be a useful source because of the MIT's early involvement in the NEPA project.

Extensive documentation exists for a comprehensive history of the ANP program, and this annotated bibliography identifies the most relevant materials. With the inclusion of approximately 1,500 entries, divided almost equally between technical and non-technical topics, this bibliography should prove of value to researchers.

[****]See Chapter 3, Section b, Pratt and Whitney Report PWAC-500, *Bibliography of Connecticut Advanced Nuclear Engineering Laboratory Reports* (Middletown, CT, December, 1965).

CHAPTER 1
BACKGROUND

"Atomic Power in Industry". *Science News Letter*, 53 (March 13, 1948): 171.

Atomic energy will have many industrial applications, but it will not be immediate, the American Society of Mechanical Engineers, meeting in New Orleans, was told by Dr. Lyle B. Borst. chairman of the Nuclear Reactor Project, Brookhaven National Laboratory, Upton, New York. Dr. Brost stated that it will be 10 to 20 years before atomic energy can compete favorably with coal as a source of industrial power. Many problems are to be solved first, but the development of atomic power is one of the most direct and foreseeable future industries. The earliest applications will probably be for mobile use, as for ships, submarines and airplanes.

Dr. Brost stated that the generation of power from the atom for peacetime use will be demonstrated at Brookhaven within the next two years, it is expected. Since the nuclear reactor is planned for research rather than for a power plant, the power generated will be a by-product. The nuclear pile will power a steam plant which will generate electricity to be used in driving cooling fans and other apparatus. Among current problems is that of operating reactors at sufficiently high heat for the conventional engine. Another problem is concerned with the economy of the fissionable material employed in getting atomic energy.

Bennett, Dwight G. "Ceramic Coatings and Ceramic Bodies for Aircraft Power Systems". 26, Sec. 1-5. University of Illinois (Department of Ceramic Engineering) Engineering Experiment Station Report. July 30, 1948. 85p.

This annual summary report presents the work done upon ceramic coatings and ceramic bodies for aircraft power systems during the twelve month period ending June 30, 1948. It consists of the following sections: temperature resistant ceramic base coats for metal; formulation and development of refractory ceramic base coats; study of the effect of ceramic coatings on the strength of metals at elevated temperatures; thermal insulation and radiation suppressive coatings; thermal insulator and protective characteristics of ceramic coatings; formulation, development, and testing of top coats and top coat bonding glasses. Also discusses fundamental research on ceramic bodies, including: hot tensile and modulus of rupture tests of ceramic bodies; a fusion study of the tertiary system of beryllia, silicon carbide; and zirconium phosphate and the investigation of metal alloy additions to beryllia.

Bruner, Fred W. "The Application of Nuclear Power to Aircraft And Rocket Propulsion". ATI-47066. Purdue University. Nov. 12, 1948. 29p.

An early discussion of the engineering problems of aircraft propulsion by nuclear energy. Report is available at the Engineering Library, Purdue University.

Sponberg, Brant L. "Means Without an End: A Short History of U.S. Thermal Rocket Programs." December 1, 1995. Winning Entry in the Robert H. Goodard Historical Essay Award Competition for 1996. Unpublished, but to be accessioned in the Air Force Historical Archives at the Air Force Historical Research Agency, Maxwell AFB, AL.

Although the author concentrates on the nuclear rocket program, he does include some information relevant to the Aircraft Nuclear Propulsion Program. He discusses the von Karman report, "Where We Stand" of August 1945, which is more optimistic about the application of nuclear power to aircraft than to rockets. Sponberg states that because of the von Karman report, the Air Force pressed Gen. Leslie Groves to establish the NEPA Project in April 1946. He further states that the NEPA Project also looked at nuclear rockets in association with the nuclear aircraft studies. Sponberg notes that Vannevar Bush, James Conant and Robert Oppenheimer had reservations about the feasibility of developing nuclear powered aircraft. The AEC's General Advisory Committee reviewed NEPA in 1948 and established the review by the Lexington Project, lead by MIT. NEPA research was initiated at ORNL in 1949, and eventually NEPA, ORNL and the NACA Lewis Research Center, Cleveland formed a technical advisory board for the program. Sponberg states that this technical advisory board countered many of the conclusions of the Lexington Group's report.

Freemen, J.W., E. E. Reynolds, and A.E. White. "A Metallurgical Investigation of Five Forged Gas-turbine Discs of Timken Alloy". National Advisory Committee for Aeronautics Technical Note No. 1531. June 1948. 55p.

This report discusses the properties of heat-resisting alloys which are dependent to a large extent on the conditions of fabrication. Because the large size of certain gas-turbine rotors has introduced fabrication procedures for which information is not available, a research program was begun to ascertain the properties of the better alloys in the form of large forging. Tests reported in the paper were made to determine the reproducibility of properties from disc to disc made by different companies and to investigate the effect of various fabrication procedures on the disc properties.

Goodman, F. Clark . "Future Developments in Nuclear Energy". *Nucleonics* 4, 2 (February 1949): pp. 2-16.

Future developments in nuclear energy, viewed primarily with respect to military applications are discussed. The possibility of nuclear-powered aircraft and submarines is explored and several diagrams of artists' conceptions of such forms of transportation are shown. The problems involved in industrial utilization of nuclear power are described and various pertinent data on the present utilization of various sources of power and their

relative efficiencies are tabulated. The cost of generating electrical power is also compared in tabular form with estimated costs of nuclear power and a chart of the estimated U.S. reserves of fissionable materials is also given.

Graff, A.P. "Some Considerations Affecting the Design of Nuclear Turbojet Engines". RAD-207(RAND) The Rand Corporation. Sept. 2, 1947. 25p.

This report is one of the first to investigate design problems inherent in applications of nuclear energy to turbojet engines. Available from The Rand Corporation.

Groves, L.R. "Atomic Power Plant". *Steel* 120, 4 (Jan. 27, 1947): 90, 93, 98.

Provides interesting insights on nuclear power written by the military director of the Manhattan Project.

Hahn, O. and F. Strassmann. "Uber den Nachweis und das Verhalten der bei Bestrahlung des Urans mittel Neutronen entstehenden Erdalkalimetalle." *Naturw.* 27(1939):11.

This pioneering paper announced the discovery of nuclear fission of uranium.

Koshuba, Walter J. "Metallurgical Considerations in the Application of Nuclear Energy for the Propulsion of Aircraft". *Metal Progress* (May 1949):635-40.

The author discusses the problems involved in the application of nuclear power to aircraft propulsion. They are as follows: (1) the choice of the type of aircraft propulsion plant will influence the selection of materials; (2) the engineering and physical-chemical properties of materials above the range of temperatures in common use must be determined, studied, and correlated; (3) the selection of materials must satisfy the nuclear requirements for a given service application of the aircraft atomic plant; (4) the weight of the complete power plant must be sufficiently low to permit its use in a practical aircraft.

Kramer, Andrew W. . "Nuclear Power for Mobile Use". *Power Generation* 53 (Feb. 1949): 78-80.

Discussed the principles of design which would have to be applied in the construction of a nuclear power plant for mobile use (aircraft and submarines). Showed diagrams of possible simple constructions for such power plants and the shielding problem is discussed in some detail. It is noted that owing to military interest in mobile applications of the nuclear reactor as a source of power, it is not unlikely that the more difficult problems encountered in such applications will be solved to produce mobile nuclear power plants before stationary power plants of this type are in operation.

Meitner, Lisa. "The Nature of the Atom". *Fortune* 33 (1946): 137-44, 185-6, 188.

An early popular article by one the pioneers in the field of nuclear physics and co-discoverer of nuclear fission. Article is of general historical interest as background to ANP.

Meitner, L. and O. Frisch. “Disintegration of Uranium by Neutrons: A New Type of Nuclear Reaction.” *Nature* 143(1939):239.

In this classic paper Lisa Meitner and Otto Frisch provided an interpretation and explanation of the fission of uranium with neutrons.

Millikan, Dr. Robert A. Quoted in the *Saturday Evening Post.* June 3, 1939.

The Nobel Prize-Winning Physicist is quoted as saying: “So far as the energy locked up in the atom is concerned, we can count that out. We can, of course, do it now through radioactivity, but I see no possibility 50 years from now of ever supplying the world’s power needs, or even a minute portion of them, from any such source.”

“Nuclear Energy in 1947". *Engineer* (January 2. 1948): pp. 24-25.

Reviewed the field of nuclear energy and its control. Current research and development work on atomic energy included the construction of low-power graphite piles, the separation of U-235 isotope, atomic weapons and the preparation of radio isotopes as a promising research tool in chemistry, biology and medicine. The work in France aimed exclusively at the civil uses of atomic energy. It was thought that at least ten years would be necessary before atomic power plants will be able to produce 250,000 kw. The adoption of nuclear fuel for naval, air and surface vessels is also discussed. It was hoped that a broader understanding of the phenomena of nuclear fission would be reached. [Researcher Note: Although ANP is not mentioned in this article, it has been included because it was one of the earlier articles that considered nuclear power for propulsion].

Shepherd., L.R. "The Problem of Interplanetary Propulsion”. *Engineers Digest* (American edition) 4 (Jan. 1947): 25,28. Condensed from *Bulletin of the British Interplanetary Society* 1 (Nov. 1946): 55-65.

Provided a highly scientific discussion of the problems involved in the development of reaction propulsion to the stage where the projection of vehicles outside the Earth's gravitational field becomes possible. Calculations indicated that it will be necessary to have an engine capable of ejecting material at a velocity in excess of 10 km. per second. The utilization of nuclear energy appeared to be most likely to be successful for the purpose.

Suits, C.G. “Nuclear Research in General Electric”. *Edison Electric Institute Bulletin* 14, 6 (June

1946): 213-6.

Discusses long range program of nuclear research that has been laid out with two main lines of attack, viz. (1) exploration of new types of nuclear reactions, especially with recently developed electron accelerators, and (2) investigation of nuclear fission for its power production possibilities. Also discusses present status of projects.

Thompson, A.S. "Power Plant Analysis". NAA-SR-19. North American Aviation Report. October 26, 1948. 51p.

This report demonstrates a general method for the preliminary thermodynamic analysis of a wide variety of power plants. Simple relationships are given for such criteria of power plant performance as thermal efficiency and power output per unit mass of fuel, in terms of aerothermodynamic variables of the cycle. An application of these relationships is made to a generalized four component power cycle with a one-component, one-phase medium. Curves are presented showing the dependence of maximum power output and cycle efficiency on overall temperature ratio of the cycle and component efficiency.

Wells, H. G. "The World Set Free - A Story of Mankind". Macmillan and Co., Ltd. St. Martin's Street, London. 1914.

In this imaginary history written in 1914 (more than 20 years prior to the discovery of nuclear fission), H.G. Wells projects forward to 1943 when thousands of atomic powered aircraft were "humming softly into the sky". Wells provides another prophetic view, when in 1956 an atomic bomb is dropped from one of these atomic powered aircraft in a world war. Wells was influenced by the discoveries of radioactivity in the previous decades, and gives credit by dedicating this book to "Frederick Soddy's 'Interpretation of Radium'." (Soddy, a British chemist, was one of the earliest workers with radioactivity). In an introduction written by Brian Aldiss to a 1988 edition of this H.G. Wells book, Aldiss notes that H.G. Wells owes much to his predecessor Winwood Reades' "Martyrdom of Man", written in 1872.

Winne, H.A. "Some Engineering and Political Aspects of Atomic Energy". *Edison Electric Institute Bulletin* 14, 6 (June 1946): 217-21. (see also *Combustion*, 18, 2, p. 35-6, August 1946).

Atomic power production schemes and engineering problems involved are discussed. Six schemes outlined utilize heat from a pile by methods of liquid convection, liquids to vapor evaporation with or without heat exchanger, gas convection radiation and fluid convection, and direct conversion to electricity respectively.

Winter, W. "Atom Powered Bombers". *Air Trials* 32, 21-23 (May 1949): 85-9.

The theoretical possibilities of using nuclear energy as a source of power for bombers and rockets are explored. It is suggested that plutonium or U^{235} would be probable fuels for the nuclear engine. The basic details of the various types of power plants which might be adapted for use with a nuclear reactor are discussed. Since the energy of fission is released mainly as heat, these are all thermal power plants, such as the steam or mercury turbine, the turbojet, the ramjet, and the rocket. In the case of the turbojet, the nuclear reactor simply replaces the familiar combustion chamber. It is noted that a 25,000 horsepower engine would require 75 tons of lead shielding and some of the problems which would result from constructing aircraft several times as large as a B-36 are discussed.

CHAPTER 2
INITIAL NUCLEAR-POWERED FLIGHT EFFORTS

"Administrative History of NEPA Project, Nuclear Energy for Propulsion of Aircraft, Oak Ridge TN", Air Materiel Command. March 22-June 30,1948.

Iris Number 00142486
Call Number 204.621
Reel 3873 Beg Frame 1747 End Frame 1769 Old Reel Number A2103

Contains history of Nuclear Energy for Propulsion of Aircraft, NEPA Project.

Air Force Historical Foundation, *Air Power Historian,* Volume VII, Number 2, (April, 1960)

Iris Number 00482364
Call Number K239.3095-1 V.7-2
Reel 15266 Beg Frame 868 End Frame 937 Old Reel Number K2714

Topics include NEPA, Nuclear Energy Propulsion for Aircraft.

Air Force Plant Representative Air Materiel Command, NEPA Division Fairchild Engine and Airplane Corporation, Oak Ridge, TN, (7/25/49-12/31/49)

Iris Number 00143716
Call Number 208.3b
Reel 3940 Beg Frame 749 End Frame 811 Old Reel Number A2170

Contains Personnel Photographs. Also contains descriptive notes of the Office of the Air Force Plant Representative, Air Materiel Command, Nuclear Energy Propulsion Aircraft Division, Fairchild Engine and Airplane Corporation, Oak Ridge TN.

Air Force Historical Foundation, *Air Power Historian*, Volume VII, Number 2, (April, 1960)

Iris Number 00482364
Call Number K239.3095-1 V.7-2
Reel 15266 Beg Frame 868 End Frame 937 Old Reel Number K2714

Topics include discussion of NEPA, Nuclear Energy Propulsion for Aircraft.

"Air Intelligence Reports". Air Defense Command. November 1948.

Iris Number 00198394
Call Number 410.608
Reel 5749 Beg Frame 1000 End Frame 1091 Old Reel Number A4007

Includes technical intelligence briefs on atomic powered aircraft.

"Air Policy for the Atomic Age". *U.S. News and World Report*, 24 (March 12, 1948):19.

Reports on the proposals of the Congressional Aviation Policy Board's which urged that nuclear propulsion for aircraft be given "...the highest priority in atomic-energy research and development, and that every resource and facility should be devoted to its early accomplishment".

Air University , Miscellaneous Correspondence (1948)

Iris Number 00481299
Call Number K239.1613-9
Reel 15249 Beg Frame 2281 End Frame 2295 Old Reel Number K2697

Air University Information Bulletin and correspondence with Naval War College and Fairchild Engine and Airplane Corporation (NEPA Project).

"Aircraft Nuclear Propulsion". *New York Times*. Editorial Page. Dec. 11, 1951.

In an editorial, the *New York Times* cautioned that, "The problems to be faced (in building an atomic plane)are for the most part new in aeronautical engineering, and they will not be solved overnight."

Anderson, David. "The Plane: Flying Boat First". *Aviation Week*, 54(June 11, 1951):21-32.

Provides a fictional description of flight in a nuclear-powered aircraft in about 1960.

"Atom Plane on Way to Drawing Board". *New York Times*. February 23, 1951. p.1.

Reports that the AEC has approved the contract with General Electric Co. to develop a nuclear-powered airplane. AEC acted after receipt of the endorsement of the nuclear airplane concept by the military Joint Chiefs of Staff. The *Times* interprets the contract signing as evidence that the nuclear-powered aircraft had been proven feasible and that was now moving into the construction phase.

Bly, F.T., et. al. "NEPA Critical Experiment Facility". NEPA-1769. Fairchild Engine and Aircraft Co. April 15, 1951. 59p.

Describes a joint effort between the NEPA Project and ORNL to prepare a facility for critical experiments for the nuclear aircraft project. The facility was located south of the Y-12 plant of ORNL and was funded by both the AEC and the AF. The facility is operated by ORNL with experiments performed on the nuclear characteristics of uranium, beryllium and stainless steels supplied by NEPA. Report includes a history of critical experimentation for the NEPA Project.

"Cheap Atom Power Due Only by 1960." *New York Times*. Jan. 26, 1947. p.18.

Reports on a national radio broadcast in which Dr. Ralph E. Lapp, Scientific Advisor of the Scientific Branch, Research Group, U.S. War Dept., forecasts atomic power for aircraft. Dr. Lapp stated that the most serious problem was shielding against harmful radioactivity.

Clarfield, Gerald H. and William M. Wieck. "Nuclear America. Military and Civilian Nuclear Power in the United States 1940-1980." Harper and Row, New York. 1984. p. 124, 147.

This book contains a brief review of the ANP Program, and includes a quotation from William L. Borden, Staff Director of the JCAE, that the ultimate weapon system would be a thermonuclear weapon carried by a nuclear-powered airplane. The authors also state that in 1945, Maj. Gen. Donald J. Keirn sought to determine the feasibility of using nuclear power for an aircraft. Keirn was Liaison Officer for the Manhattan Project, participated in the atomic bomb test at Bikini in July and August 1946, prior to his replacing Gen. LeMay as the Director of the ANP Program.

Cleaver, A.V. "Bombers or Rockets?" *Flight*, Vol.XLVIII, No. 1908. July 19, 1945.

The author was an engineer with the deHaviland Aircraft Co. In this article he discussed potential applications of nuclear propulsion to either missiles or bombers, and whether military resources should be expended in development of this power supply.

Committee on Atomic Energy. "History, 1946-53". Research and Development Board. Air Force Scientific Advisory Board. 1956.

Iris Number 00472230
Call Number K160.823
Reel 11940 Beg Frame 468 End Frame 521 Old Reel Number K1241

Contains review of problems of Committee on Atomic Energy, including aircraft nuclear propulsion. Committee on Atomic Energy was one of the first Joint Research and Development Boards(JRDB) approved; it came into being in December 1946. It met for the final time in March 1948 when a new directive enlarged authority of Military Liaison Committee (MLC) which acted as Research and Development Board (RDB) committee on atomic energy. Three chief areas of research were effects of radiation and radiological warfare, development of new atomic weapons, and nuclear energy for propulsion units. Nuclear energy for propulsion of aircraft (NEPA) was a primary concern in 1947 and until October 1948. Decision of Atomic Energy Commission (AEC) to have Massachusetts Institute of Technology undertake comprehensive study of all phases of problem of nuclear engines for aircraft breathed new life into NEPA until December 1950. Lexington Project report appeared September 30, 1948. Air Force termed report an endorsement of NEPA; RDB staff regarded report as warning that proceeding was very dangerous. In 1951, Air Force cancelled NEPA contract with Fairchild Company because it wished to contract with General Electric Company. NEPA expired and was replaced with ANP. Full scale review of ANP took place in May 1952. By 1952, advances in development of chemical fuels and techniques of refueling in flight were promising. Performance far exceeding hopes of earlier years. Air Force continued to insist that military requirement existed for ANP. The Air Force Scientific Advisory Board never passed on ANP program.

Conner, J.A., Jr. "Aerospace Nuclear Power Safety Considerations". *Aerospace Engineering* 20 (May 1960)48-59.

Discusses the potential for release of fission products to the atmosphere and the problems of direct radiation during operations. Also discusses Convair's successful flight program with the NB-36H carrying an air-cooled operating nuclear reactor in the aft bomb bay. This was also know as the Nuclear Test Aircraft (NTA) and 47 flights were conducted during July 1955 - March 1957.

Dean, Gordon. As referenced in *Scientific American* 185 (Nov. 1951):32.

Gordon Dean, Chairman of the Atomic Energy Commission, is said to have predicted, both in a speech at the University of Southern California and in testimony before a House Appropriations Subcommittee, that the U.S. would develop atomic powered airplanes within a decade.

Feynman, Richard. Letter to James A. Dewar. December 10, 1971, in James A. Dewar, "Project Rover: A Preliminary History of the U.S. Nuclear Rocket Program, 1906-1963." January 26, 1972. (Unpublished Masters Thesis, copy available in the NASA Hq., Office of History, Washington, D.C.) p.13.

Richard Feynman was requested to consider the possible applications of nuclear power for propulsion, to ensure that the U.S. government would have the patent rights. He considered nuclear propulsion applications for aircraft, as well as submarines and rockets. He did not pursue the concept when he realized the technical difficulties.

Graham, Frederick. "U.S. at Work on Project to Apply Atomic Power to Planes, Missiles" *New York*

Times. Feb. 23, 1947. P.43.

Article reports that first attempt to develop an atomic powered aircraft was initiated in July 1946 and this is the first public report. The range and speed would be almost limitless, depending on the strength of materials used. The NEPA Project is a joint effort of the Federal Government, NACA, the Army Air Forces and private industry. Many of the nation's foremost scientists, high ranking Army Officers, the Oak Ridge establishment, several chemical companies and ten aircraft companies are participating under the direction of Fairchild. The contract for the work was signed by Gen. Carl A. Spaatz, Commanding General of the Army Air Forces and J. Carlton Ward, President of Fairchild, along with representatives of the participating aircraft companies. Maj. Gen. Curtis LeMay is the Director of the NEPA Project and Gordon Simmons, Jr. is the Technical Director. (Simmons was the Chief Mechanical Engineer of the uranium gaseous diffusion plants for the Manhattan Project at Oak Ridge). Chief Engineer of the Project is Andrew Kalitinsky, formerly of the Pratt & Whitney Co. Work is underway at the NACA Cleveland Laboratory, MIT and the Fredric Flander Co. in Tonowanda, NY. The article states that, according to knowledgeable sources, the first atomic powered airplane will be pilotless because the shielding weight would make the aircraft unable to carry missiles. The participating aircraft companies and notable scientists are listed in this article.

Hinton, Harold B. "Atom Unit Reports on Studies of Uses". *New York Times*. Feb. 1, 1947. p. 3.

In the First Semi-Annual Report to Congress, the new Atomic Energy Commission Chairman-designate, David Lillenthal, indicated that the possibility of applying nuclear energy to aircraft propulsion is being studied by the AEC. This study is being conducted by the Fairchild Engine and Airplane Co. under contract to the Army Air Forces. Space and technical services have been made available at Oak Ridge, TN. The AEC had just taken over from the Manhattan District on December 31, 1946, and the four AEC Commissioners and Chairman had not yet been confirmed by the Senate. Lillenthal had previously been the Chairman of the TVA.

"History and Present Status of NEPA". Deputy Chief of Staff, Air Materiel Command. May 5, 1950.

Iris Number 00117523
Call Number 144.04-6
Reel 2780 Beg Frame 000621 End Frame 000649 Old Reel Number A1358

Nuclear Energy for Propulsion of Aircraft was established on May 23, 1946 to investigate possibilities of using nuclear energy to power aircraft.

Institute of Technology. Air Research and Development Command. "Status Report. July 1 - Dec. 31, 1956".

Iris Number 481038

Call Number K239.07D
Reel 15225 Beg Frame 658
End Frame 1135 Old Reel Number K2674

Includes information on providing officers for positions requiring application of nuclear power to propulsion of aircraft for Air Research and Development Command. Also discusses the initiation of a special course in reactor technology in cooperation with Oak Ridge School of Reactor Technology (ORSORT), Oak Ridge, TN.

Johnson, Mary Shirley and J. W. Webster. "Reflector Removal as a Means of Pile Control." NEPA-1009. Fairchild Engine and Airplane Corp. NEPA Div., Oak Ridge, Tenn. May 3, 1949. (Decl. July 18, 1961). 12 p.

The effect on reactivity of removing an all-over reflector from a square cylinder reactor is discussed, and a means of estimating the effect of removing a portion. e.g. the ends, is provided. By removing an all-over reflector from a reactor, it is possible to obtain up to about 50% change in reflector activity, this upper limit being in fast piles. The available control increases also with the thickness of the reflector, but not much is gained for thickness of more than 6 or 8 inches. It was concluded from the results obtained that adequate control could be achieved in fast and intermediate reactors without an unreasonable distortion of the reflector.

Kalitinsky, A. “Atomic Engines for Aircraft”. *Pegasus* 16 (1948): 1-4.

A future use of atomic energy as a source of aircraft power will undoubtedly produce airplanes combining extremely high speed and almost unlimited range. To achieve this, no new discoveries, but a great deal of engineering work will be required to develop the best possible type of atomic power plant. Pertinent types of power plants are all thermal, since fission energy is released predominantly in the form of heat. Practical possible types of an atomic power plant are the closed-cycle turbine, which may be a steam or mercury turbine; the turbojet; the ramjet; and the liquid-propellant rocket atomic power plants. The original cycles of these power-plant types would be mainly maintained, but a nuclear reactor will take the place of the boiler in the conventional steam turbine while assuming the function of the combustion chamber in the turbojet engine.

Many of the engineering problems, which lie in the path of the practical realization of atomic aircraft power plants, are connected with the use of high temperatures which affect the vital specific fuel consumption, a problem still aggravated by the heat transfer aspects. Other problems include the protection of the uranium in the reactor against corrosion by the working fluid, and weight conditions, since large amounts of shielding mass are needed to stop radiations emitted during the fission process.

Kalitinsky, A. .“Atomic Power and Aircraft Propulsion”. *Journal of the Society of Automotive Engineers*, Preprint (1948) 25 p.

The development of atomic energy as a source of power will require the aid of the engineering profession, and engineers will need to acquire a knowledge of the atomic sciences. As a first step in this direction, this paper discusses in simple language the structure of the atom, how it is held together, radioactivity controlled release of atomic power, uranium fission, the chain reaction, nuclear fuels, and control and shielding of the reactor. It is explained that for the combination of high performance and long range, atomic propulsion excels all other means. Engineering problems which confront developers of atomic aircraft power plants concern transfer of heat from the reactor to the working fluid separation of the uranium in the reactor from the working fluid, and reducing the weight of the shielding to confine neutrons an gamma rays.

Kalitinsky, A., Chief Engineer, NEPA Division, Fairchild. Letter to Dr. Hugh Dryden, Director, Aeronautical Research, NACA, Washington, D.C. October 1, 1947. Available in NASA Hq., Office of History, Washington, D.C.

Kalitinsky notes visits of five NEPA Project staff to NACA-Cleveland Laboratories in September 1947 to discuss analytical and experimental heat transfer studies underway at NACA which "may be of great immediate value to NEPA". The NACA approaches are considered much simpler that NEPA's and will be very useful for the 100-10,000 calculations anticipated.

Kalitinsky, A., Chief Engineer, NEPA Division, Fairchild. Letter to Dr. Hugh Dryden, Director, Aeronautical Research, NACA, Washington, D.C. March 9, 1948. Available in NASA Hq., Office of History, Washington, D.C.

Makes reference to January 16, 1948 Dryden letter which discussed heat transfer from high temperature surfaces to fluids. Kalitinsky requests additional technical information from NACA regarding pressure drop and heat transfer for high velocity fluids and high rates of heat input. He asks for NACA experimental pressure drop data that can be used to confirm the NEPA Project's analytical approach. He also asks for confirmation that NEPA's use a NACA developed heat transfer correlation is valid for high temperatures and high rates of heat input.

Kalitinsky, A., Chief Engineer, NEPA Division, Fairchild. Letter to Dr. Hugh Dryden, Director, Aeronautical Research, NACA, Washington, D.C. July 7, 1948. Available in NASA Hq., Office of History, Washington, D.C.

Requests data of a typical axial-flow compressor performance map with a high inlet flow Mach number. Information is needed for NEPA design studies of nuclear turbo-jets.

Kenton, John E. "Who's Who in the Aircraft Nuclear Program." *Nucleonics* 14, 8 (August 1956):74-76.

Provides an excellent overview of the ANP Project participants and the background of each organization's involvement. Discusses the origins of the program with the Manhattan District making space at Oak Ridge for the NEPA Project team headed by Fairchild Engine and Aircraft Corp. The article, written by the News Editor of *Nucleonics*, claims that there was "fierce opposition" to the NEPA work, implying, but not specifically stating, that the opposition came from the Manhattan Project participants. The author claims that the technical review by the Lexington Project was expected to "scuttle the program", but instead "vindicated the faith in the potential of nuclear flight." Later, the article states that members of the JCAE have, in retrospect, expressed regret that the ANP Program did not have a Rickover of its own. Both Sen. Jackson and Rep. Melvin Price are quoted . Jackson believes that the project is now being accelerated; Price states his disappointment that there has not been a nuclear-powered airplane flying by now, but feels the program is now moving ahead.

Long, W.H. "Study of generalized diluents in reactors of fixed geometry." NEPA-1590. Fairchild Engine and Airplane Corp. NEPA Div., Oak Ridge, Tenn. Oct. 20, 1950. 64 p.

Calculated critical masses as a function of diluent cross sections are presented graphically for reactors of a fixed size. Four moderators, Be metal, BeO, and two Be_2C with added graphite were studied and compared. Various effects such as production spectra and variation of critical mass with core diameter are studied.

MacDonald, Angus "A Study of the Uranium-Bismuth Alloy Circulating Fuel Reactor." NEPA-1783. Fairchild Engine and Airplane Corp. NEPA Div., Oak Ridge, Tenn. Mar. 1, 1951. (Decl. July 18, 1961). 34p.

A preliminary design is presented of a water moderated bismuth circulating fuel reactor. The reactor consists of 55 stainless steel tubes through which the solution of U and Bi flows.

McAdams, M.H. "Informal Monthly Reports of MIT Projects DIC 1-6489 for the Period Oct 18, 1946 to June 30, 1948". (Reports 1-20, inclusive). Mass. Inst. of Tech., Cambridge, MA. Nov. 1946. P.312.

Work performed in connection with the application of nuclear energy to propulsion is reviewed. The problem of heat transfer at high f1ux density from metal to water has been studied extensively by means of an electrically heated platinum wire submerged in water. A continuous flow apparatus, in which steam flows through a heated passage has been designed, and its performance has been analyzed for a number of variables.

Mitchell, T. R. "Critical Masses in Operable, Air-Cooled Beryllium Carbide Moderated Reactors." NEPA-1263. Fairchild Engine and Airplane Corp. NEPA Div., Oak Ridge, Tenn. Jan. 10, 1950. (Decl. July 15. 1961). 26p.

The criticality requirements of nuclear reactors at operating conditions are presented. The effects of high temperature, coolant, coating and fission product poisons were incorporated in the calculations for the determination of critical reactor sizes and uranium requirements after 100 hours of continuous operation at 600,000 kw.

Mitchell, T. "Critical Reactor Requirements for Uranium Carbide-Beryllium Carbide Graphite Systems". NEPA-950. R. Fairchild Engine and Airplane Corp. NEPA Div., Oak Ridge, Tenn. Mar. 15, 1949. 45p.

The criticality requirements of nuclear reactors using enriched UC_2 and moderated by Be_2C are given. Calculations were based on neutron diffusion theory and performed over wide ranges of core composition, reflector thickness and free flow ratio. The results are presented graphically to show clearly the interrelations between reactor size, uranium requirement, reactor weight, core composition, reflector thickness, and free flow ratio.

Mooneyham, A. 0. "Critical Reactor Sizes and Weights for Uranium Carbide-Graphite Systems." NEPA-592. Fairchild Engine and Airplane Corp. NEPA Div., Oak Ridge, Tenn. June 15, 1948. (Decl. July 14, 1961). 31p.

Criticality requirements for cylindrical, air-cooled, room temperature, homogeneous uranium carbide-graphite reactors utilizing completely enriched uranium and having graphite reflectors were determined. Results are presented in the form of graphs relating uranium weight, total reactor weight, reactor size, core composition, reflector thickness, and free flow ratio. The data are intended only for assisting in the selection of design points from a wide range of variables, and are not considered adequate for prediction of critical masses in actual critical assemblies. Some neutron flux spatial distributions are given. Also included are neutron flux energy distributions, fissioning energy distributions and mean times between fissions for several reactors without reflectors.

Mooneyham, A. 0. "Comparative Critical Conditions in Simple Nuclear Reactors." NEPA-1100. Fairchild Engine and Airplane Corp. NEPA Div., Oak Ridge, Tenn. Aug. 1, 1949. (Decl. July 18, 1961). 18p.

The physical and nuclear properties of simple critical reactors are compared. Those considered include homogeneous, gas-cooled, enriched, cylindrical. and room temperature reactors containing hydrogen and beryllium oxide,

Muckenthaler, F.J. "Where Have the Neutrons Gone: A History of the Tower Shielding Facility". Joint American Nuclear Society (ANS)/European Nuclear Society International meeting on: "Fifty years of controlled nuclear chain reaction: past, present, and future" in Chicago, IL, Nov 1992. pp. 15-20.

In 1946, the U.S. Air Force selected the Fairchild Engine and Airplane Corporation as the responsible organization for directing the Nuclear Energy for Propulsion of Aircraft (NEPA) project. At about this time, the Oak Ridge National Laboratory (ORNL) was putting into operation a facility that used a beam hole through the graphite reactor shield as a source of neutrons into which shield samples could be inserted. Since the laboratory had this facility, it was asked to cooperate in NEPA's needs. As time passed, more and more ORNL personnel became involved in NEPA work occurring at the laboratory, and in September 1949, the U.S. Atomic Energy Commission (AEC) designated ORNL as the agency for continuing the AEC's share of a joint technical program that was established in conjunction with the U.S. Department of Defense and the National Advisory Committee for Aeronautics. The purpose of the program was to develop a nuclear-powered aircraft. The laboratory was asked to study the neutronics aspect of the project, which included the relatively new discipline of reactor shielding. Since the weight and distribution of the shields would substantially affect the shape and size of the plane, it was imperative that the shield design be accurate and timely. It was concluded that the surest, fastest, and most economical way to verify calculations was through the use of full-scale mock-ups. This decision led to the building of what has been known as the Tower Shielding Facility.

Neely, Frederick R. "Why Atoms Don't Fly: Atomic Engines". *Collier's* 121 (April 10, 1948):30.

A pessimistic popular article in which the author states that the Air Force concept of atomic powered aircraft is a failure. He indicates that to protect the crew from radiation the atomic power generator would need to be surrounded with 75 tons of shielding.

"NEPA New Engineering Problem". *Aviation Week* (1948) 29.

Development of atomic power for aircraft, as well as other installations, is now predominantly an engineering problem. More is probably known about uranium fission than about basic mechanisms of combustion or supersonic aerodynamics. The main advantage of atomic propulsion for aircraft is the possibility of combining high performance and long range, since the fuel supply would remain nearly constant. The problem of protection against radiation damage is resolvable into two considerations - "shielding" and "canning". Crash danger would lie not in the reactor continuing to function but in the "ash" products of fission already formed at the time of the crash. Various basic types of power plants could be adapted to use atomic energy for aircraft propulsion, such as turbine, turbojet, ramjet, and rocket types.

"NEPA". *Scientific American* 185 (April 1951):32-33.

Reports that Fairchild Engine and Aircraft Co. "has completed its contract" on the four-year-old NEPA Project, and the project is being terminated. Reference is made to unidentified newspaper stories that the Air Force has indicated that the end of the NEPA Project meant that the theoretical phase of the study was completed and the nuclear airplane engine was ready to proceed to the "blueprint stage". Quotes the official announcement that "other projects in the field of nuclear-powered flight will be continued". Article questions if the basic problems have been overcome, and quotes Lawrence Hafstad's (AEC Director of Reactor Development) statement in the summer 1950 that: "The aircraft propulsion project should be continued in an extensive study phase, both theoretical and experimental, for the next two or three years. By that time data might become available to permit reevaluation and a more decisive conclusion."

"Our Own Armaments Race: Services Rush Novel Weapons to Win Funds". *U.S. News and World Report*, 26(May 20, 1949):11.

Reports that Defense Secretary Louis Johnson has accepted the Air Force's theory of national defense that one basic weapon, capable of winning a war by itself, be developed, instead of diluting efforts by trying to develop many different weapons. The Air Force advocated that one basic weapon be the nuclear-powered aircraft.

"Predicts Atom will End Limit on Plane Range". *Chicago Tribune*. October 11, 1945.

Early, optimistic article that underestimated the technological difficulties, while overstating the military benefits of nuclear flight. One of the many popular press reports about the limitless benefits of nuclear energy that followed the end of World War II. with the atomic bombing of the Japanese.

"Report of the Shielding Board for the Aircraft Nuclear Propulsion Program". ANP-53. Fairchild Engine and Airplane Corp., NEPA Div., Oak Ridge, TN. and Oak Ridge National Lab., TN. Oct. 16, 1950. 225p.

Subjects included in the shielding report are: weights of shields, choice of coolant, design, specifications, requirements for delayed radiation, minimum weight considerations, and shielding of homogeneous or circulating fuel reactors with unit shield, design of divided shields and relationship between shielding and aircraft design.

Rubin, Theodore, Henry E. Stern and Fritz W. Mezger "An Axial Control Rod in Cylindrical Reactors." NEPA-1207. Fairchild Engine and Airplane Corp. NEPA Div., Oak Ridge, Tenn. Nov. 15, 1949. (Decl. July 18, 1961). 50 p.

The effects of an axial absorber type control rod in terms of flux and power distribution and change in reactivity are examined. The effects of slug removal on reactivity is also examined. Cylindrical reactors with wide ranges of Be_2C-UC_2 molecular ratios were considered.

Sarnoff, David. Quoted in *Fortune Magazine.* January 1955.

The Chairman of the Radio Corporation of America is quoted as saying: "It can be taken for granted that...ships, aircraft, locomotives and even automobiles will be atomically fueled... I do not hesitate to forecast that atomic batteries will be commonplace long before 1980."

Shaw, H. L. and F. N. Boulger. "Survey of Nonmetallic Liquid Coolants for Nuclear-Power Piles." NEPA-1476. Battelle Memorial Inst., Columbus, Ohio. May 26, 1950. For Fairchild Engine and Airplane Corp. NEPA Div., Oak Ridge, Tenn. 31p.

A comprehensive survey of the literature was made in an effort to identify nonmetallic materials of possible usefulness as liquid coolants. Materials having maximum melting points of 1000 deg.F. and boiling points of 1200 deg.F. were considered. but boiling points above 2200 deg.F. were preferred. Melting points, boiling points, densities, heat capacities. and thermal conductivities were tabulated. Approximately 190 materials appeared to have melting and boiling temperatures in a suitable range. A paucity of thermal conductivity and heat-capacity data prevented further estimates of suitability of all but nine of these materials. Of these nine nonmetallics, only sodium hydroxide appeared to offer possibilities when considered according to the NEPA formula.

Simmons, G., Jr., Technical Director, NEPA Project, Oak Ridge, TN. Letter to Dr. G.W. Lewis, NACA-Hq., Washington. May 12, 1947.

The participation of NACA in the NEPA program is discussed, with reference being made to early meetings of the NEPA Board of Consultants (May 25, 1946) and with NACA-Cleveland (August 1, 1946). Simmons states that the Wright Field Army Air Force representatives have informed the NEPA Project that NACA would provide technical support. He also explains that the AAF, with the approval of the AEC, has delegated the overall responsibility for this program to the NEPA group. Simmons proposes a mechanism to effectively apply the NACA technical expertise and facilities to this project.

Sims, F. "Final Status Report of the Fairchild NEPA Project". NEPA 1830. Undated, but presumably 1951. 246 p.

A very comprehensive report prepared at the conclusion of the Fairchild Engine and Aircraft Co.'s work on nuclear-powered aircraft. This work was sponsored principally by the U.S. Air Force with assistance of the Bureau of Aeronautics of the U.S. Navy, and in cooperation with the AEC and NACA. Among the conclusions from this work was that a nuclear power plant can be developed which will propel a manned bomber at Mach 1.5 at 45,000 ft. The aircraft would be the size of present-day bombers and its range for all intents and purposes would be unlimited. Smaller, subsonic aircraft, operating at lower altitudes could be built significantly sooner. This report includes technical details of design and development work, as well as a history of the project and a complete list of all companies that participated with Fairchild. The origins of the concept of nuclear propelled aircraft is reported to be as a result of the Air Materiel Command's desire to find fuels with a higher energy value per pound of weight than conventional aircraft fuels. As a result, then Col. Donald J. Keirn requested information on atomic energy from Dr. Vannevar Bush of the Manhattan Project. Also, this report corroborates Alvin Weinberg's statement(see reference) that Gordon Simmons, Jr., an engineer at the Oak Ridge gaseous diffusion plant, made the suggestion to pursue nuclear propulsion for aircraft to J. Carlton Ward and Sherman Fairchild of the Fairchild Co.

Stuart, John. "Jackson Cautions on War by 'Fumble' ". *New York Times*. Sept. 17, 1946. p. 13.

Maj.Gen. Curtis E. LeMay, Deputy Chief of Air Staff for Research and Development, is quoted as saying that it had “become clear that a nuclear-powered aircraft is not essentially beyond attainment”, after the NEPA Project had been underway for a year.

“Survival in the Air Age”. The President’s Air Policy Commission. U.S. Government Printing Office. 1948.

This Commission recommended that the aircraft industry be supported with massive purchases of aircraft, in spite of the post-war cutbacks. In the section dealing with R&D, only one paragraph was devoted to nuclear propulsion, while guided missiles and electronics each had two full pages of discussion. However, the report did call for “vigorous action ...to intensify research in this field (nuclear propulsion)”.

“The NEPA Technical Program.” Fairchild Engine and Aircraft Corp., NEPA Division. June 1, 1948. 74p.

In this early presentation of their NEPA work to the Lexington Project Team, Fairchild staff under the direction of Gordon Simmons, Jr., reviewed the aircraft requirements, and engineering and analysis approaches for the following topics: heat transmission, reactivity, radiation protection, experimental engineering, materials and chemistry, experimental physics, controls and instrumentation, aircraft and power plant design. Includes listing of Lexington Project Team participants and affiliations. Also includes notes, calculations and comments on Lexington Report draft chapters by Project Team Member, Miles C. Leverett.

“The Truth about a U.S. Atomic Plane”. *U.S. News and World Report.* Dec. 12, 1958.

Reports, in question and answer format, an interview with Maj. Gen. Donald J. Keirn, Chief of the Nuclear Plane Project. Includes discussion of the possible Russian ANP Project, with Keirn saying he does not know if the Russians have a successful program, or not. Keirn states that the Russians might be able to fly a nuclear-powered aircraft before the U.S., because our program is not currently oriented to produce a flying test bed, before achieving a better understanding and solution of the technical problems.

Von Karman, Theodore. “Where We Stand”. First Report to General of the Army H.H. Arnold on Long Range Research Problems of the Air Forces. AAF Scientific Advisory Group. August 22, 1945.

This report by the Director, Scientific Advisory Group, Army Air Force, includes a chapter on “Atomic Energy for Jet Propulsion”. Von Karman states that “spectacular improvements” in range and speed of aircraft can only be achieved from the use of atomic energy, not conventional fuels. He concludes that the possibilities for the development of nuclear energy for jet propulsion deserves the immediate attention of the Air Force and that the agency now in control of this technology (presumably the Manhattan Project) is taking no action to develop nuclear energy for flight applications.

Ward, J.C., H.J. Stover and W.H. Mc Adams. "Heat Transfer Lectures - Vol. I." NEPA-304-IER-10. Fairchild Engine and Airplane Corp., NEPA Div., Oak Ridge, TN. Dec. 1948. P.277.

A series of heat transfer lectures given at a NEPA symposium in Oak Ridge are presented. The lectures dealt with: a summary of the elements of heat transfer; high densities of heat flux from metal to water; calculations of conduction; the measurement of rapidly changing temperatures; prediction of recovery factors; pressure drop in commercial exchangers; exploding a heat transfer myth; heat transfer from hot to boiling water; heat transfer equipment; use of network analyzers for solving thermal and stress problems; heat transfer to granular materials; effect of solar radiation at high altitudes, and infrared radiant heating.

Ward, J. Carlton, Jr. "Testimony before Senate Subcommittee of the Committee on Interstate and Foreign Commerce". Eightieth Congress, First Session. May 17, 1947. Transcript pp. 44-51.

Ward, President of the Fairchild Engine and Aircraft Corp., New York, testified on the situation in the U.S. aircraft industry after the war. He spoke as the chairman of the Industrial Preparedness and Planning Committee of the Aircraft Industries Association. He discusses the lead time needed during WWII. to get the U.S. aircraft industry up to full production capacity and cites the need for continued research and development of new concepts. He discusses, in general terms, the NEPA Project, which his company is managing for the Army Air Force. He states that "...America would not be very wise if it did not use all of its resources to find out if it can do it (aircraft propulsion by nuclear energy), and also if whether it can be done at all, because if another nation did it first, we would be far more vulnerable than we are today...". In response to the question of how atomic bombs would be delivered in the future, Ward responded, "An atomic plane, limited in range only by sandwiches and coffee for the crew."

Whitman, Walter. "Nuclear-Powered Flight". A Report to the Atomic Energy Commission by the Lexington Project. LEX P-1. September 30, 1948.

In 1948, the AEC contracted with the Massachusetts Institute of Technology for a group of prominent scientists, assembled as the "Lexington Project", to review the work being done in the field of aircraft nuclear propulsion. This report is usually referred to as the "Lexington Report" in the literature on the ANP Project. This report was the outcome of the first comprehensive evaluations of the concept of utilizing nuclear power for aircraft propulsion, specifically reviewing the NEPA Project. In 1947, the DOD Research and Development Board requested the AEC to review all work on nuclear propulsion for aircraft and establish a single unified program. AEC engaged MIT to make the review. The review was conducted by a group of distinguished scientists and engineers, mostly from MIT, and headed by Walter Whitman, the Chairman of the MIT Chemical Engineering Dept. The Lexington Report concluded that, although success could not be guaranteed, there was a strong possibility that some version of nuclear-powered flight could be achieved if adequate resources and competent manpower were put into the development. Furthermore, the report stated that an intensive effort will be required if a nuclear-powered aircraft is to fly in 15 years and integration of work on reactors, power plants, materials and other components is essential for efficient progress toward that goal. The report recommended that, if it was decided as a national policy that the high cost in technical manpower, fissionable material and money could be justified, a strong development program should be undertaken. An estimate was made that the successful flight of a nuclear-powered aircraft would take about 15 years and cost about $1 billion. The report also stated that a vigorous and realistic aircraft reactor development program during the next few years should contribute to, and benefit from other aspects of the AEC's Reactor Development Program. Frequent reference is made to this seminal report in subsequently justifying continuing ANP work.

"Why Not Atom-Powered Plane?" *Aero Digest* 68**,** 4 (1954): 21-3.

Consensus of opinion of group of top-level aircraft, engine and research engineers was that American aircraft industry has know-how, experience and aeronautical engineering data needed to build A-plane now.

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CHAPTER 3
ANP CONTRACTORS

a. GENERAL ELECTRIC CO.

"AEC-AF Organization". File from Gunnar Thornton, former Engineering Manager, GE-ANP Project. Private Communication. To be accessioned in the Air Force Archives at the Air Force Historical Research Agency, Maxwell AFB, AL.

File contains Organization Functional Statements and Organization Charts for the Air Force and GE-ANP. Includes numerous documents which show the organizational evolution from 1951-54.

"Advanced Configuration Study Power Plant Description and Comparison". XDC-60-2-2. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Feb. 29, 1960 (decl. Sept. 20, 1973). 251p.

A comparative evaluation of the three basic nuclear powered turbojet configurations and turbofan and turboprop variations is presented. Information is presented concerning power plant structure, the reactor, nuclear shielding, turbomachinery, control system, power plant cooling, remote handling, materials development, component development, and studies of alternate components and arrangements.

Ahrends, S.W. "HTRE No. 1 Reactor and Control System Simulator". APEX-338. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Dec. 20, 1955 (Decl. June 9, 1961). 29p.

The simulation of the HTRE No. 1 reactor and control system is described. This simulator was developed for use with a heat transfer simulator and an X-39 engine simulator as an aid in defining the safe operating region and characteristics of the HTRE No. 1 power plant.

"Aircraft Nuclear Propulsion Department. Engineering Progress Report No. 37, July 1, 1960-September 30, 1960." APEX-37. Aircraft Nuclear Propulsion Dept., General Electric Co., Cincinnati, OH. Sept. 1960. Decl. June 3, 1982. 151p.

Objective is the development of high-performance direct-air-cycle nuclear power plants suitable for the propulsion of aircraft at Mach 0.8 to 0.9 at 35,000 feet for 1000 hours. The initial step in the development of the flight power plant is the Advanced Core Test (ACT), a reactor test in the single-engine integral in-line configuration. The ACT assembly (designated D-14O-E1) has a ceramic reactor and X-211 turbomachinery. Performance specifications and design parameters for the D-14O-E1 are derived from the flight power plant requirements. The Advanced Core Test will demonstrate the capabilities of the ceramic reactor and associated equipment in the single-engine integral in-line power plant configuration. Major effort during the quarter has been applied to the design and development of components for the ACT D-140-El test assembly.

"Approaches to Aircraft Nuclear Propulsion". General Electric Co. Undated, but probably 1959. 18p.

This publicity brochure provides an overview of the ANP Program for laymen. Includes illustrations of the basic design of the HTRE power system and test assembly. Also discusses some of the operational features anticipated for a nuclear powered aircraft.

"Are You Overlooking Some of the Most Critical Challenges in the Materials Field?" *Aviation Week,* Dec. 29, 1958. p.79.

Advertisement for materials scientists and engineers for the ANP Program at GE. Emphasizes the need for high temperature materials development for the small, high density reactor required for nuclear propulsion.

Arnold, K.W. "Nuclear Reactor Control Sensors. A Survey of Commercially Available Neutron Detectors for Possible Application to ANP Control Systems.". DC-60-4-174. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Apr. 28, 1960. 31p.

Fundamental principles of operation, commercial availability, and development information applicable to neutron sensors used with reactor control systems are presented.

Baker, J.K. "Estimated Photoneutron Power Levels for the D-140-E1 Reactor". DC-60-8-58. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Aug. 9, 1960. 9p.

A series of curves showing the estimated photoneutron power level in the D-140-El reactor after any operating history shown for shutdown times of up to 25 days.

Baker, J. K., and J.C Gelhard. "Analog Computer Study of the P-212 Power Plant Control". XDC-59-1-105. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Dec. 1, 1958 (Decl. Sept. 17, 1973). 56p.

An analog computer study was made of the P-212 power plant in order to determine its control characteristics. A description of the power plant, and the assumptions, basic equations, and methods used in developing the power plant control simulator are given with the resulting computer diagrams. Some typical results obtained using the simulator are included.

Baker, R. F., C. C. Gamertsfelder. and R. F. Gentzler. "Reactor Damage Experiment". For General Electric Co., Cincinnati, OH. *Nuclear Sci. and Eng.* 2, 1, Suppl. (June 1959): 211-12.

An experimental program was initiated to obtain a better understanding of the nature and magnitude of reactor damage and the resulting radiological hazards resulting from loss of coolant flow to an air-cooled reactor operating at power. The experiment was performed at NRTS in the HTRE-2 central void. The HTRE-2 was carried in the Core Test Facility which was coupled to the Initial Engine Test Facility. The IETF provided power, control instrumentation and provision for routing the engine exhaust up a stack. One metallic

element was fitted into the central void and allowed to overheat by closing the air flow valve. Temperatures and power levels were recorded during the test and downwind fall-out was measured.

Baker, R.E. "The Significance of the Cleaning Problem in Aircraft Nuclear Propulsion". TM-7593. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. p. 38-41

The HTRE and its off-gas monitoring and disposal problems are discussed.

Barnett, D. E.(General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati) and S. L. Kalfus (General Electric Co. Jet Engine Dept. Cincinnati). "Gamma Irradiation of X-211 Engine Accessory Systems." NP-9333(vol. iv.).Paper 1 of Fourth Radiation Effects Symposium, September 15-16, 1959, Cincinnati, Ohio. General Session Papers. 32p.

Gamma irradiation tests were conducted on the fuel, lube, and hydraulic systems of an aircraft gas turbine at radiation levels of 1.2×10^6 to 2.4×10^7 ergs/gm/hr for periods up to 260 hr. No serious thermal or mechanical malfunctions occurred as a result of the radiation environment. Radiation effects were observed on the organic fluids and elastomers used in test systems by changes in such properties as viscosity and neutralization number.

Bauer, P., F.H. Welch, and E.P. Kibb. "Irradiation Testing of XMA-lA Shield Materials". TID-6248. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. May 7, 1959. 34p.

The results of the irradiation tests on (a) Beryllium-boron, (b) Borided tungsten alloy, (c) Lithium hydride, (d) Boron stainless steel, and (e) Beryllium oxide-boron are discussed. Data from the tests are included. The tests were conducted to simulate 100 hour operation of the XMA-1A power plant at the design temperatures and nuclear fluxes.

Baum, J.J. and S. N. Stilwell. " Measurement of the Specific Heats of Two Moderator Materials". DC 58-12-124. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Dec, 10, 1958. 25p.

The specific heats of two reactor moderator materials were measured with an accuracy of ± 1% at 35 to 90°C using an adiabatic vacuum calorimeter. Curves showing the specific heat versus temperature of both solid materials are shown and some general aspects of calorimetry methods are discussed.

Baxter, W.G., V.L. Gelezunas, and J.R. Miller. "Control Rod Poison Tip Materials Development for HTRE No. 3." DC 60-6-53. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. June 6, 1960. 27p.

In the HTRE #3, the control rod poison tips are required to operate at 1650°F for 300 hours, withstand thermal and mechanical shock, have a worth of 0.18 $\Delta K/K$ in a rod 20 in. long and 0.7 in. diameter and be capable of operating in a distorted guide tube (due to reactor-shield misalignment and differential thermal expansion). To meet these criteria, the poison tip developed consists of five four-inch cylindrical segments of 42 wt %Eu_2O_3 -58 wt % Ni core material clad with special low Si nichrome and joined together by Inconel X bearing straps. The development evolution leading to these materials and the hydrostatic pressing process used in their fabrication is described.

Beeler, J.R. "Solid State Physics Series. Fission Fragment Recoil Loss from Two-Region Arrays of Slabs and Cylinders". TED-11572. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Aug. 1960. 26p.

The fixed range, isotropic source model was used to estimate the fission-fragment absorption distribution in two region systems with slab and cylindrical geometry.

Beeler, J. R. and J. D. Popp. "Monte Carlo Research Series: Two Programs for Computing Slowing down Probability in an Infinite Homogeneous Medium." DC-58-8-64. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Aug. 4. 1958. 20 p.

Two programs with 200-level cross section and slowing down tally resolution are described and compared. Sample computations for a Be and hydrogenous moderator system are given. An additional series of computations for a hydrogenous moderator system were made to define the effect of the number of histories on the precision of the results. Programs are coded for the IBM 704 computer.

Beeler, J. R. "Monte Carlo Research Series: Two Experiments on Void Gap Effects in a One Dimensional Heterogeneous System." DC-58-5-97. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Apr. 25, 1958. 27 p.

The diffusion length, escape fraction and absorption point distribution were computed for a one-dimensional heterogeneous system of alternating solid and void segments. These results are compared with those computed for the homogeneous counterpart of the heterogeneous system.

Beever, E.R. "An Investigation of Radiation Dose and Distribution over the Body Received While Working in a Heterogeneous Radiation Field 'Ground Handling'". APEX-314. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Mar. 14, 1957. 21p.

Measurements were made of the body radiation dose received by the ground crew working in the radiation field in and around a radioactive jet engine systems panel. Doses received at various parts of the body were measured for two men working in the radiation field. It was found that the dose received was not uniform but could be predicted when the radiation field is well known. It was also found that the total dose could be materially reduced by the use of simple selective shielding of particularly active sources and by the careful selection of materials to be incorporated in systems susceptible to irradiation.

Bell, R.W. "Report on Air Flow Tests of a Narrow Collector Passage with Eight Transverse Feeder Slots (Applicable to 140EI Forward Shield Design Studies)". APEX-650. General Electric Co., Flight Propulsion Lab. Dept., Cincinnati, OH. Feb. 21, 1961. p21.

Previous analytical studies have indicated that a constant area collector passage with transverse feeder slots will, if the collector passage is narrow, suffer severe momentum losses in axial pressure distribution. These studies also predicted that the losses can be minimized by stepping the width of the collector at each feeder exit, and by turning the feeder exit parallel to the collector passage. These effects are verified by a study of a simplified design employing eight transverse slots of uniform slot width, separated by slabs of uniform thickness.

Bell, Harry E. " Shim Control System and Safety Actuator Control System for Project 102 (D-102-A) Reactor." DC-58-1-72. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Jan. 9, 1958. 41p.

The components used in the shim and safety circuits of HTRE 3 are listed. A general discussion of each component is included with the basic operating features of the system.

Bergsten, L. A. and D. H. Culver (ed.). "P-1 Nuclear Turbojet. Comprehensive Technical Report, General Electric Direct-Air-Cycle Aircraft Nuclear Propulsion Program." APEX-902. General Electric Co. Flight Propulsion Lab. Dept., Cincinnati. Nov. 30, 1961. 72 p.

The design of the reactor for a direct-air-cycle nuclear Power Plant is described. Presented are the bases for selection of the moderator, fuel element material and shape, basic reactor configuration, design point selection, and turbomachinery selection. Details are presented of the methods used to flatten power radially and longitudinally, verify nuclear design (critical mockup and shield mockup), and fabricate fuel elements. The control system and its components are described, including the control console and instrumentation. The design of the shield and moderator cooling systems are reported. The modification of conventional turbomachinery are included: in-pile combustors, ducting and duct arrangement, valving, and the turbomachlnery controls. The Propulsion Unit Test, for chemically simulating reactor operation, is also described.

Blumberg, Ben, Jr. "IET Phase I Test Request." DC-59-5-221. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. May 21, 1959. 41 p.

A test request for the Phase I testing of the D102A at the IET facility is presented. Included are test requests, purpose of tests, data required, and special operating instructions and limitations.

Blumberg, B., C.C. Hussey, R.E. Tallman. "XMA-l Fuel Turbojet". APEX-907. General Electric Direct-Air-Cycle Aircraft Nuclear Propulsion Program, Bifano, N.J.; General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. June 15, 1962 (Decl. Sept. 12, 1973). 268p.

Information on the XMA-1 nuclear turbojet engine is presented concerning power plant specifications, biological shielding, turbomachinery, controls, test support equipment, and remote handling equipment.

Brassfield, H.C. "Production of Pebble-Type Fuel Elements". APEX-377. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. June 1955 (Decl. June 16, 1961). 18p.

A capillary drop method of producing spherical shapes of brittle materials of less than 0.1 inch in diameter was developed. It appears to be a feasible means for producing large numbers of pebble-type fuel development cores. Coating of pebble-type fuel element cores by the coating-pan technique, though not adequately developed, showed promise.

Brenton, R.F. "Low Power Flux Map and Power Calibration of Susie Reactor." DC-60-6-722. General Electric Co., Aircraft Nuclear Propulsion Dept., Idaho Falls, ID. June 13. 1960. 60p.

Measurements for a flux map of the Susie reactor using gold foils are presented. Data from a reactor power determination are included.

Breslauer, S.K. "Analysis of Xenon Reactivity Prediction on the HTRE-1." DC-60-4-118. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Apr. 11, 1960. 38p.

To determine the effectiveness of ANP methods in predicting xenon poisoning, and to determine which analytic method is best employed, a comparative study was made of the xenon 135 poisoning in the HTRE-1 core using all the major diffusion theory models normally utilized in reactor analysis at ANP. Detailed procedures and data necessary for each calculation are included in the report. Results indicate excellent agreement among the three primary methods of calculation, two-group matched savings procedure, multigroup matched buckling procedure, and a perturbation calculation. However, the analytic values are 50 to 70% of the experimental xenon reactivity. This discrepancy is believed due in part to the limitations of the physical model of the thermal neutron flux incorporated in the present treatments. Discrepancies in the xenon absorption cross section may contribute to the inconsistent results. Physical measurements of the reactivity may also be somewhat in error. Calibration of the control rods varies with temperature, age, etc. On some runs there was a question as to whether all the rods were latched up. Doppler broadening of Xe^{135} thermal resonance and inaccuracies due to incorrect nuclear constants were investigated. Neither effect was large enough to explain the experiment-theory difference.

Brunso, J.M. "Moderator Transient Temperature Study." DC 58-5-51. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Apr. 29, 1958. 40p.

An IBM 704 computer program is presented to perform a moderator transient temperature study for determination of the fuel element and moderator temperatures as a function of time upon sudden or accelerated reactor power levels.

Buden, D. and R.F. Miller. "Direct Cycle Nuclear Power Plant Stability Analysis". DC 60-7-31. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. July 6, 1960. 30p.

A power plant with a nuclear reactor substituted for the conventional chemical interburners in a jet engine is analyzed for stability. No longer is the instantaneous power generated by the heat source the same as the instantaneous power delivered to the turbine. A mathematical criteria is developed and tested using HTRE-3 data. The analytical results indicate at high operating speeds, the power plant is stable, but a region of instability exists at lower speeds. Power plant test at the Idaho Test Station verifies the analysis. Methods for controlling the power plant in the region of instability are discussed. The use of a high response speed control will act to stabilize the power plant.

Cain, D.E. "Recommend Pneumatic Shim and Scram Components for ANP Reactor Control Rods." 57GL240. General Electric Co., General Engineering Lab., Schenectady, NY. For General Electric Co. Aircraft Nuclear Propulsion Dept., Evendale, OH. July 19, 1957. 22p.

Assembly drawings present recommendations based on experience with pneumatic shim-scram rods developed for the Aircraft Nuclear Propulsion Department.

Carver, J.G. "Description and Preanalysis of Proposed BSF Nuclear Heating Measurements".TID-21988, pp 5-41. General Electric Co., Aircraft Nuclear Propulsion

Dept., Cincinnati, OH. Nd (Decl. Oct. 20, 1971).

Proposed nuclear heating measurements in the ORNL Bulk Shielding Facility are described. Results of the preanalysis, based on point-kernel calculations, are presented.

Carver, J.G. "Interim Report on Buildup Factors for Heating Calculations". TID-21988, pp 71-90. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. No Date. (Decl. Oct. 20, 1971).

Several of the different types of buildup factors which have been defined and tabulated are discussed and the criteria for choice of a particular type for use in computing gamma ray heating rates are examined.

Chandler, B.A., P.E. Reis, and J. Holowach. "Effect of Surface Oxidation of Fuel Elements on Pressure Loss". DC-57-9-32. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati. OH.
Aug. 21, 1957. l6p.

Experimental flow studies of Nichrome concentric ring fuel elements indicated that a pressure loss increase of 10 % during a structural test at operating temperature may be wholly the result of increasing surface roughness due to oxidation. Studies were made on three specimens which were subjected to high temperature structural tests in the burner rig and on an artificially roughened sandblasted element.

Chu, J.C. "Friction Factor in Fuel Element Cartridge". DC-59-1-153. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Jan. 12, 1959. 26p.

An alternate method of correlating fuel element pressure drop is considered. The conclusion reached is that this method appears to be about as accurate but somewhat less easily applied than the original friction factor multiplier concept. Consequently the friction factor multiplier approach will still be used for pressure drop correlation and computation.

Clark, R.H., J.G. Carver, R. F. Brenton, W.L. Weiss, and R.F. Rohrer. "Test Data from the 2π Solid-Angle Shield Cover Experiment". APEX-439. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Dec. 19, 1958. 246p.

The experimental data are the results of tests conducted at the Oak Ridge Tower Shielding Facility in which 2π solid-angle covers were used on both the reactor shield and crew shield. These tests were conducted to provide basic air and ground scattering data, as well as to determine the minimum requirements for facilities needed to develop a nuclear aircraft shield. The data am presented as recorded. Some of the more important data have been selected and grouped to show the effects of the 2π covers.

Cohen, R.M. "Results of Nuclear Parameter Study of Pentalene Moderated Reactors". APEX-237. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Nov. 24, 1954 (Decl. July 6, 1961). 13p.

A nuclear perameter study of pentalene moderated reactors was completed to determine quantitatively the optimum design region in which both the uranium investment and core diameter are reasonably low. The variables investigated were moderator volume fraction (via variable tube spacing), fuel loading, and fuel tube structural material Beryllium and 9% Cr-1% Mo stainless steel). Two different tube sizes were considered in the study, one necessitating 85 tubes, and the other a 55-tube configuration, each providing identical free flow areas for operation of two 25:1 compression ratio engines. Criticality data are presented as graphs of uranium Investment versus pentalene volume fraction for each of the four core structures, using as a basis for comparison 6%, 8%, and 10% excess reactivity (allowance for control).

Cohen, Robert M. and H.R. Dries. "Generalized Xenon Poisoning Curves for Use in Reactivity Calculations". DC-55-8-109. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Aug. 25, 1955. 8p.

The ratio of Xe^{135} concentration to that of U^{235} for reactors operating in the thermal flux range of, 10^{13} to 10^{15} neutrons/cm^2/sec is presented graphically. Equilibrium Xe calculations were carried out for reactor operating temperatures at 68.8 to 2100°F, while the effect of reactor shutdown time on Xe concentration was calculated for a thermal rise of 1500°F.

Collins, C. G. "Measurement of Fission Product Leakage During Irradiation Test of Fuel Elements." DC-55-7-96. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. July 13, 1955. 34 p.

Progress is described in the development of two procedures for detecting fission product leakage during radiation tests of fuel elements. Use of these procedures will permit the measurement of leakage rates in tests of fuel elements containing deliberately introduced flaws and aid in establishing inspection specifications for production fuel elements. One procedure evaluated consists of collection of the fission products in activated charcoal and subsequent analysis for individual isotopes by gamma spectrometry. It yields results which appear accurate within a factor of two and it is sufficiently sensitive to detect a leakage rate of about one-tenth of that permissible for fuel elements tested. A second procedure studied consists of gross activity measurements in a fraction of the total air flow of the testing facility using a charged wire collector and scintillation counter. This procedure yields quantitative results when the fission fragments escape immediately after formation and it is useful as a continuous monitor of fission fragment leakage. Both procedures appear applicable to MTR and HTRE conditions.

Collins, C.G. "Application of Radiation Effects Data to Design and Development Problems". NP-7365 (Vol. 1) (Paper 1). General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Third Semi-Annual Radiation Effects Symposium, Atlanta, GA, October 28-30, 1958. Volume 1. General Session Papers. 18p.

A summary is presented of the concepts and procedures utilized in applying radiation effects data to the solution of design problems and comments on developments of the past year. Conceptually, application of radiation effects data involves the comparison of observed effects on materials properties with the requirements of anticipated application. Following a description of the over-all procedure, the bases, limitations, and recent developments in the steps are reviewed. The discussion is limited to organic materials.

Collins, C.G. "Review of Radiation Effects Studies at the Aircraft Nuclear Propulsion Department of the General Electric Company". Papers Prepared for Radiation Effects Review Meeting, Congress Hotel, Chicago, July 31-August 1, 1956". TID-7515 (Pt. 2). General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. p.329-72.

Summaries are presented of data on radiation damage to elastomers, plastics, and organic liquids, and the relationship of damage by different types of radiation is discussed from the viewpoint of applying the data to estimate the stability of these materials in engineering applications. Experimental measurements are reported which indicate that the gas evolution from boric acid solutions is correlatable with the difference in energy absorption from neutrons and gammas. Radiation damage to Teflon--U_3O_8 fuel elements for critical experiments is also described.

Comassar, S. "Aircraft Nuclear Propulsion Application Studies". General Electric Co., General Electric Direct-Air-Cycle, Aircraft Nuclear Propulsion Program, Nuclear Materials and Propulsion Operation, Cincinnati, OH. Apr. 30, 1962 (Decl. Sept. 12, 1973). 154p.

Summaries of advanced application studies of nuclear power plants performed by the Aircraft Nuclear Propulsion Department of the General Electric Company are presented. Subsonic aircraft applications studies are described. Both existing and parametric or "paper" aircraft are investigated. Turbojets, turbofans, and turboprops are considered, utilizing direct-air, indirect-liquid-metal, and liquid-circulating-fuel cycles. Studies of supersonic aircraft powered by direct-air-cycle turbojet engines are presented. Both high-speed, high-altitude systems and the hunter/ killer mission are investigated. Nuclear ramjet, turbojet, and rocket missile applications are discussed. A study of the feasibility of applying nuclear turbojet power plants to the "Snark" missile is included. The nuclear ICBM application is reported here because its mission places it more logically in the missile than in the rocket category. The nuclear rocket applications include work done in 1956 on heat-transfer rockets and more recent studies of the NERVA-Phoebus system. A concept of a gas-fission rocket propulsion system studied in 1956 is also presented. A study on nuclear-powered helicopters, nuclear hydrofoil propulsion, an examination of gas-cooled reactors for portable power plants in accordance with Army requirements, an analysis of helium-cooled, closed-cycle power plants for turbojets, compressor-jets, and turboprops, and a study of nuclear turboprop airship application are included. Several of the land, sea, undersea, and space applications of the 601 series of power plants are discussed. These are compact, integral, neon-cooled, closed-cycle, fast-reactor power plants that illustrate the strides made in gas-cooled nuclear reactor technology from the beginning to the end of the ANP program. A concept of aerospace nuclear propulsion is described that would permit flight from the Earth to Mars, inspection of that planet, and return, by re-entry, to Earth. The basic concept for this mission is the utilization of a single turbojet in dense atmospheres, and as a pure rocket in the vacuum of space.

Conn, P.K., P.W. Davis, G.L. Hammons, F.C. Robertshaw, and M.A. Strauss. "Progress Report - Fuel Element Task Force Applied Materials Research". DC-58-1-1. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Dec. 31, 1957. 52p.

Studies in support of the development of Fe-Cr-Al-clad Nb-UO_2 core fuel ribbons are described. The work centers primarily on the following areas: (1) mechanism of ribbon failure under thermal cycling conditions. (2) formation of uranium metal in the core and diffusion to the cladding, (3) compatibility of ribbon components, (4) coatings for increased oxidation resistance of the ribbon. and (5) alternate approaches to hardware and over-all fuel element design.

Cook, R.G., M.B. Goldstein, C.W. Moon, and W.Z. Prickett. "Gas-Cooled High-Temperature Nuclear Reactor Design Technology. 4. Cellular Metallic Fuel Reactors." APEX-800 (Pt.B). General Electric Co., Flight Propulsion Lab. Dept., Cincinnati, OH. June 30, 1962. 271p.

Design technology for gas-cooled high-temperature nuclear reactors is described. Particular emphasis is placed on the design of cellular metallic fueled, hydrogen moderated reactors. The information is presented in sections concerning reactor configuration key considerations, and thermal, nuclear, and mechanical design.

Cooley, W. C. "Nuclear Aircraft Power Plants Utilizing Liquid Circulating Fuel Reactors." APEX-135. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. June 1, 1953. (Decl. June 9, 1961). 65p.

Results are presented for a design study for a series of nuclear power plants for manned turbojet bombers. Each power plant utilizes a liquid circulating fuel reactor, a ternary heat-transfer system and a quasi-unit shield. The reactor discussed specifically is the ORNL Fireball and the power plants analyzed use, respectively, 8, 6, or 4 modified General Electric J-73 turbojet engines. Performance estimates are presented and comparison is made with two advance design direct-cycle power plants. A bibliography of reports pertinent to the study is included.

Cooperstein, R. "BeO Standard." DCL 59-8-93. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Aug. 10, 1959. 19 p.

Standard BeO specifications used at Atomics International, Lawrence Radiation Laboratories, and General Electric Aircraft Nuclear Propulsion Department are presented.

Corker, G.E. “A Reactor Power Servo Input Applicable to the Control of Any Type Of Nuclear Reactor.” DCL-57-1-129. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Jan.29, 1957 (Decl. Sept. 8, 1961). 12p.

An invention disclosure which reveals an electrical servo input such as required to select and maintain a given reactor power level is presented. This servo input is applicable to the control of any type of nuclear reactor and is rather unique in that it is a relatively simple way of accomplishing so many of the desirable control functions required in reactor design and operation. The servo input is also applicable to low power research reactors whose prime function is to produce neutron and gamma radiation at various energy levels.

Coyle, F. J.; R. L. Rio and L T. Berkland. "Irradiation of an Aircraft Hydraulic Constant Speed Drive." NP-9333(Vol. IV) General Electric Co. Aircraft Accessory Turbine Dept., Lynn, Mass. Paper 7 of Fourth Radiation Effects Symposium, September 15-16, 1959. Cincinnati, Ohio. General Session Papers. 16p.

The effects of radiation on the operation of a ball piston hydraulic constant speed drive were studied. The drive was exposed to a total dosage of 5×10^7 r. Tests conducted during and after the irradiation indicated that the drive operated satisfactorily and was unaffected by radiation.

Crocker, A. R. “Testing Aircraft Nuclear Power Plants”. *Aeron. Engng. Rev.* 16**,** 12 (1957):5-30.

Covers techniques, procedures, and restrictions involved in facilities at Idaho Test Station of General Electric Co's Nuclear Propulsion Dept. Discusses preparation for tests, instrumentation and operation of aircraft nuclear power plants and basic design of data handling system.

Daniel, H.S., J.I. Trussell and M. L. Halterman (ed.). "Core Test Facility Comprehensive Technical Report General Electric Direct-Air-Cycle”. APEX-903. Aircraft Nuclear Propulsion Program General Electric Co. Flight Propulsion Lab. Dept., Cincinnati. Mar. 8, 1962. 139 p.

A summary description is presented of the Core Test Facility (CTF) that was used in the first two Heat Transfer Reactor Experiments (HTRE No. 1 and No. 2), which were conducted at the Idaho Test Station. The CTF consisted of shielding, an air supply, and other necessary auxiliaries and services which were combined into assemblies in order to test a succession of direct-cycle cores, fuel elements, controls, and other components.

Darley, J.W. "Meeting in D.R. Shoult's Office Regarding Project '100' & Project 'CTF'." GE-ANP Dept., Cincinnati. May 6, 1954. 6p.

Reports on a meeting held on May 4, 1954 in which the organization, tasks, budget and schedule for Project "100" were presented. Gunnar Thornton is in charge of this project. The project includes the construction of three reactor cores which are to shipped to Idaho for testing. Project "CTF" (Core Test Facility) was also discussed by F.C. Linn, including status, budget and schedule. The engine program was discussed by J.M. Krause. The ANP Dept. has 15 engines, with 12 to be modified to the x-39 configuration. Engine operating temperatures will be pushed up from 1400 to 1500 deg.F. Two unmodified J-47's will be shipped to Idaho for remote handling practice and experimental operation on the Idaho Experimental Test Pad.

Delaney, J.A. "Digital Analysis of Fission Product Buildup and Decay- EA Problem No. 7-1156- ANP Program No. 153- Task 433211- Job No. 51446. DC-59-11-85. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Apr. 3, 1959. 61p.

The ANP 704 Digital Program No. 153 computes the concentration of a particular radioactive isotope due to radioactive buildup and decay of fission products. From this value is calculated the final answer of the program, the percentage escape rate. Times are given by specifying the dates and time of day when the particular phases of the test were completed.

Delson, E.B. "Navy Seaplane Power Plant Study; Compact Core Reactor Type. Volume IV. Control System". APEX-260. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Apr. 1956. 70p.

The development of a proposed integrated control system for the operation of an aircraft power plant consisting of an NDA compact-core reactor and the General Electric X310 engine is discussed. Included are the formulation of transfer functions for the control components and the development of the electronic analog simulator with which the transient studies were performed. The satisfactory operation of the integrated control system is indicated by the response of the composite electronic analog simulator to various disturbances of control parameters.

DeRosier, T.A. "Gas Cooled High Temperature Nuclear Reactor Design Technology. Vol. 8. Control Design Factors." APEX-800 (Pt. F). General Electric Co., Flight Propulsion

Lab. Dept., Cincinnati, OH. June 30, 1962. 104p.

Design technology for gas-cooled high-temperature, nuclear reactors is described by recounting the solutions to reactor design problems used for the direct air cycle portion of the Aircraft Nuclear Propulsion Program. Major shield and control system design problem solutions as related to the reactor are also recounted. In several sections, the control philosophy, design factors, and the design verification are considered. It is noted that these are the three major phases in the design and development of a control system.

DeRosier, T.A. and H.D. Clapper (ed.). "Controls and instrumentation Comprehensive Technical Report, General Electric Direct-Air-Cycle, Aircraft Nuclear Propulsion Program". APEX-912. General Electric Co. Flight Propulsion Lab. Dept., Cincinnati. May 16 1962. 132.

A compilation of reports on the more worthwhile technology and hardware development efforts for the control system of an aircraft nuclear power plant is presented. However, the major emphasis is on the development efforts applied to the reactor control rather than to the turbomachinery control. The philosophy of control, analysis and simulation techniques, and some of the systems that were proposed and investigated are discussed. Power plant simulation is described. The various actuator designs that were considered as possible solutions to such problems as high temperature. Lithium hydride property information as established by, or for, the Aircraft Nuclear Propulsion Department of General Electric is summarized. Data are presented on density, thermal conductivity, thermal expansion, viscosity, vapor pressure, dissociation pressure, compressive strength, compressive creep, modulus of rupture, modulus of elasticity, and modulus of rigidity. Poison rods located behind the turbomachinery compressor and backup safety actuators are also described. Much of the electrical component effort was directed toward obtaining equipment capable of operating in the nuclear and temperature environment of a supersonic aircraft while meeting established reliability, size, and weight requirements. The efforts on the sensors, primarily for measurement of temperature and neutron power level, that were necessary for the control of the reactor are discussed.

Devens, Fred G. "Data Report-- D102 A2 Power Plant Testing- IET 13". DC-59-4-710. General Electric Co., Aircraft Nuclear Propulsion Dept., Idaho Falls, ID. Apr. 3, 1959. 61p.

Pertinent test data obtained on the D102 A2 Power Plant at the Initial Engine Test Facility prior to the fuel element over temperature event on November 18, 1958, are presented.

DeWeese, J.L. "Report on Curved-tube Push-Pull Control for 1000°F Operation." DC 60-4-63. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Mar. 1960. 19p.

Requirements are given for a workable push-pull control system using flexible push rods. The design philosophy of the curved-tube push-pull control system is discussed and test data on this system which verify this philosophy are given.

Dries, H. "Nuclear Data Compilation, D-102A Reactor." DC-58-3-128. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Feb. 5, 1958. 55 p.

A compilation of all the nuclear data pertinent to the analysis of the D-102A reactor is presented. A general description of the reactor, the equivalent nuclear configuration, calculated data on cell correction, two group constants, and flux distributions are included.

Duane, B.H. "Neutron and Photon Transport: Plane, Cylinder, Sphere (Digital Computer Programs)". APEX-394; XDC-58-5-167. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati. July 31, 1957. 133p.

Digital computer Program S constructs neutron and proton transport theory solutions having plane, cylindrical, or spherical symmetry. Lattice detail in geometry, energy, and momentum-angles is flexible. Anisotropic scattering-transfer is neglected. For aircraft nuclear propulsion applications, the initial version of the program developed as the Los Alamos SNG Neutron Code has been generalized to include the effects of time-delayed neutron or photon production and to provide the flux adjoint. The input consists of geometry, material concentrations, collision cross sections, scattering-transfer cross sections, fission multiplication cross sections, inverse period Laplace time-transform of fission production spectra, and Laplace time-transform of fixed source distribution. The output includes reactivity, critical size, flux distribution, adjoint distribution, and power distribution.

Durrill, D.C. and R.D. Dwigans. "New Multi-Cell Facility in Idaho, Sixth Hot Laboratories and Equipment Conference, March 19-21, 1958, International Ampitheatre; Chicago, Illinois". TID-7556. General Electric Co., Aircraft Nuclear Propulsion Dept., Idaho Falls, ID. pp. 73-80.

Construction of a new facility comprising four small hot cells is nearly complete at the Aircraft Nuclear Propulsion test station operated by the General Electric Company in Idaho. Special features include split-level operating areas, concrete-filled vault-type doors for personnel and equipment entry, a remotely-operated underfloor dolly systems and a remote vacuum cleaning and wash down system.

Eagle, R.A. and A. L. Ross. "Steady-State and Transient Thermal Stresses in a Tube Subjected to Internal Heating". APEX-460 (Rev.). General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Oct. 1955. 32p.

A method of solution is presented for thermal stresses caused by either steady-state or transient heat flow in an internally heated tube. The heat conduction equations are solved by the method of finite differences and are programmed for solution by high-speed digital computers. By coding the problem for computers of this type, thermal stresses for tubes of different materials, thermal properties, and heat-generation histories are readily attainable.

Eagle, H.A. and F.D. Kreiger. Vibration Analysis of P-103 Shim Scram Control Rod System." DC-60-3-124. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Mar. 15, 1960. 88p.

Results of the analytical and experimental vibration investigations concerning the P-103 Shim-Scram Control Rod System are presented. Resonant frequencies of the system predicted by the analytical study were correlated with the experimental results. A report of the experimental test is included.

Eckart, E.C. "Continuous Simulation of Reactor Power over Many Decades." DC-61-2-46. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Feb. 9, 1961. 38p.

A reactor simulation was developed which can operate through many decades of power level. It was particularly designed for providing startup simulation in the power plant operator trainer. Relays were used to provide a method of automatic re-calibration which makes it possible to represent a variable that exceeds the normal two-decade range inherent in an analog computer. Applications of this simulator to actual startup control system analysis are discussed.

Elkins, J.D. "Irradiation of Six 6BF204 Fuel Specimens in the LITR C-48 Facility. TM-65-1-19. General Electric Co., Cincinnati, OH. Nuclear Materials and Propulsion Operation, Oak Ridge National Lab., TN. Apr. 22, 1964 (Dec;. Nov. 4, 1971). 15p.

Six 6BF204 fuel elements were irradiated in the LITR C-48 facility for approximately 550 hours at a maximum temperature of 1232°C. The irradiation history and results of gamma spectrometric analyses of the sample traps are tabulated.

Emmert, Robert I. "The Design of the HTRE-3 Automatic Control". DC-57-9-107. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Sept. 12, 1957. 93p.

The design of the feedback control loops in the reactor control system for the HTRE-3 reactor is presented. The status of the control is given at the end of theoretical design, computer simulation, and test operation. The items discussed include the dynamic rod position loop, the power range flux control loop, the intermediate range flux control loop, and the temperature control loop. The final result is the closed loop transfer functions of the loops in analytical form.

Feathers, L.A. “Reactor Mechanical Design,, Advanced Configuration Study”. DC-60-5-71. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. May 12,1960 (Decl. Sept. 13, 1973). 134p.

The mechanical designs of those reactors considered in the Advanced Configuration Study are presented. The ceramic reactor proposed for the P140 power plant is discussed in detail and the characteristics and dimensions are also presented for reactors, both ceramic and metallic, and for the alternate power plants.

Ferguson, M. H. (ed.) "HTRE No. 2- Project 101 Operation Handbook for Reactor A4 and A5 Code 22." DC-57-6-126. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. June 1, 1957. 209 p.

A description and operating procedures for HTRE No. 2 are presented. Diagrams, drawings, and photographs are included.

Fischer, P.G., F.D. Wenstrup, and T.A. Hoffman. “Program ODD- A One-Dimensional Multigroup Reactor Analysis Program for the IBM-704.” DC-61-2-97. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Feb. 10, 1961. 60p.

An initial users manual is presented for Program ODD, a one-dimensional multigroup diffusion theory, reactor analysis program which utilizes the revised ANP nuclear data system. The physical and mathematical models used in the calculations are discussed. but complete program documentation was postponed until after the installation of the IBM--7090 computer.

Fleming, John J. “Front Shield Fabrication: XNJ140E-1". APEX-741. General Electric Co., Flight Propulsion Lab. Dept., Cincinnati, OH. June 29, 1961 (Decl. Oct. 29, 1971). 45p.

The status of fabrication work and plans and manufacturing information are presented for the XNJ 140E-1 aircraft reactor front shield at the time of project termination.

Fleming, John J. “Rear Shield Fabrication”. APEX-742. General Electric Co., Flight Propulsion Lab. Dept., Cincinnati. June 29, 1961 (Decl. Oct. 29, 1971). 44p.

The status of fabrication work and manufacturing instructions are presented for the XNJ 140E-1 aircraft reactor rear shield at the time of project termination.

Focke, A. E. "Summary of MTR tests in HT-1 Facility." XDC-59-8-206. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Sept. 8, 1959. 58 p.

A summary of all GE-ANP metallic fuel element tests in the HT-I facility of the Materials Testing Reactor is given.

Foster, D. F. "Experiments at the ETR and MTR". TID-7593. General Electric Co, Aircraft Nuclear Propulsion Dept., Idaho Falls, ID. p. 47-50.

The pre-stack disposal treatment of effluents from ETR and MTR tests of ANP fuel elements is described. It consists of a particle removal stage, iodine removal, and a decay-filter system. The filter system uses two silver-plated fiber beds with absolute filters and a delay tank between.

Fourth Radiation Effects Symposium, September 15-16, 1959, Cincinnati." NP-9333(Vols... I-IV.). General Session Papers. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. (Vol. 1. 135p., Vol. II. 184p., Vol. III. 179p., and Vol. IV. 214p.).

GE presented 28 papers at the Radiation Effects Symposium on the ANP Project.

Fraembs, D.H. "Experimental Results, P127 Preliminary Critical Experiment". APEX-638. General Electric Co., Flight Propulsion Lab. Dept., Cincinnati, OH. Aug. 5, 1960. 26p.

The preliminary mockup Moderating Oxide Pieces (MOP-1)of the P127 offset twin-engine design was constructed and operated in the SMR matrix facility. Reactivity, power, fission flux, and worths were measured. The results are presented and, in some cases, are compared with analytical predictions.

Frank, F. J. "Single Engine Shield Mechanical Design Study." DC-58-8-192. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. July 22, 1958. 47 p.

The mechanical design and aero-thermodynamic evaluation of an air-cooled front shield which is incorporated in the single-engine, shaft-through-core reactor, and X-211 engine are described. The front and rear plugs are of the annular type.

Friedman, S.T. "An Analysis of Late 1957 and Early 1958 Lid Tank Experiments Pertaining to XMA-1 Shield Design". APEX-524. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati, OH. June 1958. 52p.
Experiments performed at the ORNL Lid Tank Shield Facility are analyzed. A lengthy discussion of secondary gammas and their relevance to XMA-1 shield design in light of these experiments is given. Information about the suppression of secondaries with boral and about the relative merits of Hevimet, (uranium and stainless steel) as gamma shielding materials is presented.

Friedman, A., L.M. Slater, H.K. Alan Kan, and L.M. Sharpe. "The Effect of Reactor Radiation and Temperature on Silicon Junction Diodes." APEX-462. American Nuclear Science Corp. New York. Feb. 1959. 173p. General Electric Co., Aircraft Nuclear Propulsion Dept.

The effects of high temperature (up to 300°C) and reactor radiation on silicon junction diode forward and reverse characteristics, switching characteristics, noise, Zener voltage, and Zener slope characteristics were measured using three positions in the BNL Reactor. Eleven types of commercial silicon junction diodes were irradiated. The response to irradiation was found to vary greatly among diodes even of the same type.

Funston, E. S. "Evaluations of Effect of UO_2 on the Core Strength of Stainless Steel Fuel Elements (Task 7306)". DC-52-25-70. General Electric Co. Aircraft Nuclear Propulsion Project, Lockland, Ohio. May 12, 1952. (Decl. July 18, 1961). 14p.

A test procedure was established for evaluating the core strength of stainless steel fuel elements at temperatures to 1800 deg.F. This evaluation, known as a transverse rupture test, measures the short time tensile stress required to rupture a specimen in a plane parallel to the surface of the sheet. The strength of commercial 309 stainless steel, 12 mils thick, was tested by this procedure and compared favorably with tensile strength data reported in the literature.

"Further Nuclear Analysis of ZPT And LPT Reactor Runaways as Requested by the Reactor Safeguard Committee." APEX-117. General Electric Co. Aircraft Nuclear Propulsion Project, Cincinnati. Nov. 1952. (Decl. June 16, 1961). 32p.

A nuclear analysis of possible runaway in ZPT and LPT reactors is presented. Particular attention is directed to the effects of vaporized fuel clement redistribution on reactivity, amount of energy released by reactor implosion initiated runaway and comparison of estimated energy release by ZPT and LPT with results of accidental ZPR-1 runaway at Argonne.

Gabriel, S.W., G.R. Lewis, and L.S. Masson. "Data Results from LPT No. 3-4 and LPT No. 3-5". DC 59-10-707. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Oct. 1, 1959. 102p.

The critical experiment results from LPT #3-4 and #3-5 are presented. The mockup HTRE #2 reactor was used as the parent core. Power distribution measurements, rod calibrations, and gamma dose rate measurements were made on inserts L1F, L1C, and on three modified parent core fuel cartridges placed in tubes 6, 11, and 29 of the parent core. The experiments were carried out at LPT during the period from March 19, 1959 to May 12, 1959.

Gamertsfelder, C.C., B. Blumberg, and T. W. Schoenberger. “Addendum to D102A Hazards Report”. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Apr. 15, 1959 (Decl. June 16, 1961). 96p.

Further evaluation of the assembly is presented with regard to the hazards involved in the continuation of Heat Transfer Reactor Experiment No. 3. This additional evaluation was made taking into consideration the conditions leading to the power excursion of November 18, 1958. Operation of the rebuilt core is scheduled to start in July of 1959. The reactor is essentially the same as was tested up to November 1958. The fuel is completely replaced with fuel cartridges of the same design. Most of the moderator assemblies were salvaged. However, all moderator assemblies were modified slightly to correct an interference condition. The control rod guide tubes also required partial replacement. Limitations in operating procedure are more explicitly defined. These, and the modifications in design, are described in detail. Further information concerning the probability and seriousness of reactor accidents is also included.

GE-ANPD Revised Annual Program Report: USAF Contract Year 1957, 1958, 1959 AEC Fiscal Year 1957, 1958, 1959". APEX-350. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Jan. 10, 1958 (Decl. Sept. 12, 1973). 128p.

The development, design, fabrication; and preparation for the all-nuclear flight of the XMA-l nuclear propulsion reactor are described. Heat transfer tests and component design are reviewed. Costs for reactor development and testing are presented.

GE-ANPD Annual Program Report: USAF Contract Year 1958, 1959, 1960 AEC Fiscal Year 1958, 1959, 1960". APEX-353. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Feb. 15, 1958 (Decl. Sept. 12, 1973). 137p.

The development, design, fabrication, and preparation for the all-nuclear flight of the XMA-l nuclear propulsion reactor are described. Heat transfer tests and component design are reviewed. Costs for reactor development and testing are presented.

Gelezunas, V. L. "Progress Report on Evaluation of Clad Hydrided Zirconium as Solid Moderator." DC-56-5-157. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. May 22, 1956. 21 p.

Permeation loss rates of hydrogen from hydrided Zr and Mo clad Zr are reported as a function of temperature. A schematic of the apparatus for obtaining these data is included. A study was initiated to determine the effect, of thermal cycling on clad hydrided Zr. The samples were clad with Mo or Nb with an outer coating of stainless steel and were cycled from 700 to 1700 deg.F. with no serious deleterious effects. Various phenomena associated with these results are discussed. Radiation effects testing of hydrided Zr in a beam hole was conducted at 1450 deg. F. No marked diffusional movement of H in clad Zr was found and radiation appears to have no effect on H diffusion in moderator or cladding.

Gorker, G. E. "Control Problem Areas in the Design of Nuclear Aircraft Power Plants". General Electric Co., New York. Presented at Nuclear Engineering and Science Conference, held at Chicago, March 17 to 21, 1958. Preprint 111, Session 25. American Institute of Chemical Engineers. 1958. 26p.

Presents discussion of control problem areas associated with aircraft reactor power plants, some of which are common knowledge and others which are less familiar, The behavior of a reactor is compared to the more familiar chemical burner so that the reader may notice some of the differences between the two heat sources. Nuclear instrumentation and control system concepts are discussed to some extent so that more detailed problem areas become apparent. This information may prove to be of some value as a guide to the development of control components intended for reactor applications.

Granger, H.E., E.P. Jacobs, and N.L. Scheidler. "Detailed Operating Heat Generation Rates in XMA-1A Side Shield". DC-59-3-102. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Mar. 13, 1959. 27p.

This report presents predictions of detailed operating heat generation rates in the XMA-1A side shield. The shield is considered cylindrically symmetric; the effects of bearing beams and sensor wells are not taken into account. The heating effects considered are core gamma ray absorption, kinetic energy loss of neutrons, and alpha reactions in B-10 and Li-6. In some areas estimates of duct scattering effects are included.

Greenwald, W.E. and 0.P. Kerr. "Impact Deformation Test No. I with Simplified Aircraft Model". TID-6641. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. July 31, 1960. 29p.

To evaluate an analytical approach to the impact deformation of a simplified aircraft structure in which the crew compartment, reactor. and fuselage form a double spring mass system, a high velocity impact test was performed on a physical model. The model. consisting of cylindrical 4- and 6-lb masses separated from each other and from the 50-lb projectile by thin-walled aluminum cylinders, was instrumented with strain gages at various locations, an accelerometer in each of the two masses, and marked with reference lines for photographic measurement of the collapse and motion. The displacement and accelerations measured confirmed theoretical predictions in most cases. A notable exception was the apparent dynamic critical buckling strengths, which were considerably larger than those predicted.

Haffner, J.W., J.J. Loechler, and J.E. MacDonald. "An IBM 704 Program Report, Aircraft Nuclear Propulsion Shielding Program 10-0". APEX-503. General Electric Co.,

Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Mar. 1958. 36p.

Shielding Program 10-0 calculates the fast neutron dose rate at a shielded point detector due to both direct-beam and single-scattered radiation in a homogeneous, infinite medium from an anisotropic point source. The detector shield and the angular distribution associated with the point source are both assumed to be symmetric about the source-detector axis, The fast-neutron-source energy spectrum may be approximated by ten discrete energies. Exponential attenuation may be considered on either leg, as desired. The dose rate arising from the source spectrum is obtained by summation of the dose rates computed for each initial energy and for the rear, side, and front of the detector shield.

Haffner, J.W. "Duct Mockup Experiments at the Convair Ground Test Reactor". APEX-364. . General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. July 1956 (Decl. June 16, 1961). 35p.

An analysis of the Convair Ground Test Reactor experiments on the simplified annular duct mockup has been carried out. The fast-neutron duct leakage was found to be -estimable to within a factor of 2 for annular ducts in water. Gamma-ray duct leakage is approximately one order of magnitude less than the fast-neutron duct leakage.

Hanchon, K. B. and M.L. Pope. "Shielding Computer Program 19-0, Fast Neutron Removal Cross Section Computation". TID-11570. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Oct. 4, 1960. 31p.

Shielding Computer Program 19-0 computes fast-neutron effective removal cross sections for those calculations of fast neutron penetration that combine an influence function of the Albert-Welton form with an integration over a disk or cylindrical source.

Harper, Paul W. and Louis W. Habel. "Results of Cold Flow Performance Tests on a 1/4-scale HTRE 3 Reactor-Shield Mockup." DC-60-5-112. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Apr. 19, 1960. 67p.

An experimental investigation was made using air at ambient temperature to determine the aerodynamic characteristics of an approximately 1/4-scale model of HTRE 3. A combination of front and rear plug geometries was developed that produced a reactor flow distribution that was within ±2.5% of being constant in a radial direction. No circumferential variations in reactor flow were noted which could be attributed to the front plug inlet scroll with either 1 or 2 engine operation. Of the four front plug configurations tested, the one most similar to the HTRE 3 design, had the lowest total pressure loss. Two rear plug configurations were found unacceptable from the standpoint of both reactor flow distribution and pressure loss. A third rear plug configuration, which was chosen for the HTRE 3 design, had little effect on the reactor flow distribution produced by the front plug. In addition, the rear plug used for HTRE 3 had only about 53% of the total pressure loss of

the better of the other two rear plug configurations. Several low speed runs made to determine reactor aftercooling performance indicated no significant flow deviations in the reactor flow distribution at tube Reynolds numbers approaching laminar conditions.

Helms, I. L., Jr. "Report of Invention on Nuclear Fuses." DC-55-6-133. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. June 23, 1955. 15 p.

Nuclear fuse designs are described which have operating times of 1 to 2 milliseconds and are temperature compensated. Diagrams to illustrate design and operation are included.

Hemby, J.R. "Proposed D140EI Afterheat Removal System. TID-25539. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. June 23, 1960 (Decl. Oct. 19, 1971). 117p.

Analyzes the proposed cooling air rates now required to remove the decay heat accumulation in the various powerplant components following shutdown from specific operating histories and post-shutdown positions.

Henderson, W. B. "AC-111 Criticality Studies." APEX-271. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Feb. 23, 1956. (Decl. June 9, 1961). 12p.

Parameter studies of a homogeneous reactor for a single-engine power plant are presented. Effective multiplication as a function of moderator volume fraction and fuel inventory is computed for a standard configuration of core plates, reflector, and island.

Hendry, W. J. and Walter J. Koshuba. "Nucleonics in Flight". For General Electric Co., Cincinnati, OH. *Metal Progress* 8O, 2 (Aug. 1961): 132, 134, 138-9, 142, 144.

The manufacture of various fuel elements designed to be a part of reactors for nuclear powered aircraft and space vehicles is discussed. Progress made in developing high temperature metals for ceramic coated fuel elements for improved oxidation resistance is described. A 1% Zn-Nb alloy possesses exceptionally good properties for fuel element coatings. Also described are processes for the fabrication of ceramic and cermet fuel elements and the coatings used for the basic uranium dioxide fuels.

"High-Temperature Materials and Reactor Component Development Programs. Volume III. Reactor Component Development. First Annual Report." GEMP-106C. General Electric Co., Flight Propulsion Lab. Dept., Cincinnati, OH. Feb. 28, 1962. 38p.

Work in process on reactor component development during calendar year 1961 is reported. Eight specific development programs are reported including those on circulating ball reactivity control with capability of operating around sharp bends, static switching utilizing solid-state devices, capacitance temperature sensors based on the change in dielectric constant of alumina or beryllia vs. temperature change, high-temperature extension of conventional nuclear sensors (fission counters and d-c ionization chambers), nuclear sensors for monitoring and controlling high- temperature, high-performance reactors, high-temperature, fasteners involving stress relaxation of Inconel bolts and nuts up to 600°C, fasteners for remote maintenance, and Monte Carlo program for nuclear analysis of complex reactor and shield systems. Results indicate the positive feasibility of moving small magnetic rods with a length-to-diameter ratio of approximately two, by means of a linear electrical induction-type drive; moving balls of magnetic material does not appear feasible. In other work, a temperature sensor, basing its sensing ability on the change in dielectric of alumina with temperature, was successfully operated up to 1000°F, and two fission counters demonstrated satisfactory operation to 1500°F for times in excess of 150 hours each.

Highberg, J.W., K.J. Skow, R.F. Brenton, J.F. Kunze, D.A. McKenzie, C.B. Cannon, C. Davidson, and A.F. Clark. DC-60-6-735. “Preliminary Data Report IET Test Series No. 18 Phase II Testing of the D102A2 Power Plant”. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati, OH. June 17, 1960. 288p.

The preliminary test data resulting from the testing of the D102A2 power plant in the initial Engine Test Facility at the Idaho Test Station for the period from December 23, 1959 to February 8, 1960, are presented.

Hiser, P.K., M.E. Ward, A.D. Silcox, and R.H. Willsey. “Electrical Control System Components for Starting Aircraft Propulsion Reactors”. For General Electric Co,, Cincinnati, OH. Presented at Nuclear Engineering and Science Conference, April 6-9, 1959, Cleveland, OH.

Components for an aircraft reactor startup control system are described. Major design considerations for the electrical circuitry and the mechanical configuration are outlined and briefly discussed, The system described includes both vacuum tube and magnetic amplifier circuits.

Hoefer, J. A. "Summary Hazards Report for Critical Experiments with the HOTCE Reactor." APEX-345. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Nov. 20, 1957. 42 p.

A solid-moderated critical assembly designed to operate at elevated temperature is described. The experiment program and operating procedures planned for various temperatures are outlined. The hazards of operating the HOTCE in the Low Power Test Facility at the Idaho Test Station were analyzed and the results are set forth in terms of energy and fission fragment release as well as the effect on the surrounding area.

Hoefer, J. A. "Summary Hazards Report for Critical Experiments with TSM Reactor." APEX-254. General Electric Co. Aircraft Nuclear Propulsion Dept. Cincinnati. July 10, 1956. (Decl. June 9, 1961). 57p.

A critical assembly designed to faithfully mock-up the solid moderator, HTRE-3 direct air cycle reactor is described. The experiment program and operations procedures planned are outlined. The hazards of operating the TIM in Evendale were analyzed and the results set forth in terms of energy and fission fragment release as well as the effect of this release on the test cell and the surrounding area outside Building D.

Holowach, J. and Fred J. Frank "Flow distribution studies using lead acetate and hydrogen sulphide gas." DC-57-10-39. General Electric Co, Aircraft Nuclear Propulsion Dept., Cincinnati. Sept. 26, 1957. 19 p.

A flow visualization technique was developed using a hydrogen sulfide-lead acetate reaction, to determine the flow distribution in an A-2 fuel cartridge. Results show that the coolant flow is essentially straight with little interstage mixing. Mixing is confined radially to adjacent annuli and circumferentially at the most, to one quadrant or 90 degrees. In order to mitigate the power scalloping problem found in most reactor designs, it was proposed to swirl the air 360 degrees while passing through an 18-stage cartridge. The hydrogen sulfide gas-lead acetate reaction technique was used to determine the flow pattern in three XR-27 fuel elements with all ribs turned 20 degrees to the element axis. This design produced approximately a 12 degree turn of the air. Further tests on pressure loss and structural qualities are planned for the angled rib design. The flow visualization technique of using a hydrogen sulfide-lead acetate reaction produced excellent qualitative flow patterns and has possibilities, with further refinement, of obtaining quantitative results.

Holowach, J., and R.M. Fincel. “Water Vapor Corrosion of Uncoated BeO Fuel Tubes”. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Dec. 6, 1960 (Decl. Sept. 17, 1973). 6p.

Three depleted BeO fuel tubes of 0.2-inch bore and 4.2 inches long were tested at 2500°F and 20 scfm of air with a 1.25% water vapor content to determine the effect of water vapor corrosion on the friction factor for periods of 4 to 8 hours. Pressure drop measurements before and after the test showed a maximum increase of about 3%.

“HTRE-1 Survives Damage Experiment”. *Nucleonics* 17, 9, (Sept. 1959): 110.

The results of an experiment in which the reactor ran at full power with the air-coolant flow deliberately blocked in one fuel-element channel are discussed.

Huffine, C.L. “Solid Moderator Development--Milestone D. Evaluation of Clad Hydrided Zirconium as Solid Moderator”. DC-56-12-37. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Nov. 29, 1956. 42p.

Results are summarized of evaluation testing of small scale specimens of clad hydrided zirconium to determine feasibility of use as solid moderator in militarily useful aircraft reactors. Included are results of static thermal tests, gradient thermal tests, cyclic thermal tests, and radiation damage tests. In general, results were encouraging and no serious deterrent to the proposed use of the material was found.

Huffine, Coy L. “Feasibility Study of Clad Zirconium-Hydrogen Alloys as Solid Moderators”. Apex-305. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. June 17, 1955 (Decl. June 9, 1961). 25p.

Work was conducted to demonstrate the usefulness of clad ZrH as solid moderator material. Specimen fabrication, stability tests, and longitudinal temperature-gradient tests are described. No loss of hydrogen from clad moderator sections was observed in 100-hour periods at temperatures below the equilibrium formation temperature of the alloy.

“Interim Report on Advanced Core Test Hazards”. APEX-573. General Electric Co., Nuclear Propulsion Dept., Cincinnati, OH. Sept. 26, 1960 (Decl. Sept. 12, 1973). 261p.

A description of the Advanced Core Test assembly and an evaluation of the hazards associated with the operation of this assembly are presented.

Juenke, E.F. “Preliminary Evaluation of a Proposed Fuel Material for High Temperature Reactors”. DC 59-11-3. General Electric Co, Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Oct. 28, 1959. 5p.

Results are reported for preliminary experiments to determine the stability of solid solutions of UO_2 and ThO_2 in air at temperatures of 2500°F and above. The results are compared with those obtained by workers at Argonne during development work on the Borax IV experimental breeder reactor. It is concluded that further evaluation of the system at temperatures above 2500°F is required.

Kepple, J. G. and S. R. Lenthan. "Calculated Secondary Heat Generation in the D102A Reactor." DC-58-8-191. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati. Aug. 21, 1958. 36 p.

The calculated results of secondary heating in the D102A reactor assembly are presented.

The principal components include the reactor core, front and radial reflectors, tube sheets, Inconel pressure vessel, and shield. Heating effects considered were neutron moderation, core produced gammas, and extra-core neutron capture gammas. Data on distribution of heating among the various reactor comments are also included.

Kerr, G. P. (Ed.) "Summary Hazards Report for Critical Experiments with TRA-2 Reactor." APEX-155. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Apr. 2, 1954. (Decl. June 9, 1961). 130p.

The TRA-2 (Tubular Reactor Assembly), a water moderated reactor using fuel elements composed of 93.4% enriched U as U_30_8, impregnated Teflon, was designed in order to perform critical experiments to verify the anticipated nuclear and power distribution characteristics of a tubular type aircraft reactor. The core of the TRA-2 is a mockup of the HTRE core. The reactor core is mounted in a hexagonal water tank. Complete descriptions and designs are given for all reactor components. Also included are detailed plans of normal reactor operation, the normal schedule of chemical processing and disposal of reactor products, complete descriptions of safety mechanisms, an analysis of risks and hazards, and the extent of radioactive material and damage to be expected if failure occurs. Included in appendices are lists of the components of the control and safety systems, analyses of the dosage to be expected from radioactive clouds and from cloud rainout, and a discussion of the internal fuse for the TRA-2 reactor.

Kerr, G.P. (Ed.). "Summary Hazards Report for Critical Experiments with TRA-2 Reactor." APEX-155. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Apr. 2, 1954. 130 p.

The TRA-2 (Tubular Reactor Assembly), a water moderated reactor using fuel elements composed of 93.4% enriched U as U_30_8 impregnated Teflon, was designed in order to perform critical experiments to verify the anticipated nuclear and power distribution characteristics of a tubular type aircraft reactor. The core of the TRA-2 is a mockup of the HTRE core. The reactor core is mounted in a hexagonal water tank. Complete descriptions and designs are given for all reactor components. Also included are detailed plans of normal reactor operation, the normal schedule of chemical processing and disposal of reactor products, complete descriptions of safety mechanisms, an analysis of risks and hazards, and the extent of radioactive material and damage to be expected if failure occurs. Included in appendices are lists of the components of the control and safety systems, analyses of the dosage to be expected from radioactive clouds and from cloud rainout, and a discussion of the internal fuse for the TRA-2 reactor.

Kerr, E. P. (ed.) "Summary Hazards Report for Zero Power Tests with the R-1 Mockup Reactor." APEX-110. General Electric Co. Aircraft Nuclear Propulsion Project, Cincinnati. Oct. 1952. (Decl. June 16, 1961). 99 p.

A proposed test is outlined to verify nuclear characteristics of the first air-cycle aircraft reactor. The program includes experiments on power distribution, rod reactivity, thermal flux traverses. and temperature effects on moderator and fuel elements. The R-1 mockup reactor used in the experiments is similar to the design reactor.

Ketron, W.V. “Post-Irradiation Metallographic Analysis of MTR-GE-ANP-lV1 and 1Y1.” DCL-60-1-73. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Apr. 17, 1959. 19p.

Data obtained in a microscopic analysis of these two samples are presented. The samples were identical corrugated Ni-Cr alloy type experimental fuel elements. Results are described and shown in plates.

Kuhlman, W.C. and J.W. Glasgow. “Preliminary Report on Thermocouples for Fuel Element Plate Temperature and Control”. DC-57-1-95. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Jan. 16, 1957. 17p.

The development of sheathed thermocouple materials and techniques for applying them to fuel cartridges is described. Sheath material tests were made which indicate that Pt-20%, Rh, Inconel, and Nichrome V would be satisfactory. Methods for making the junctions with fuel elements are described. The development of air couples for control purposes is discussed.

Lane, R. K. "The Effect of Beryllium, Photoneutrons on Reactivity." XDC-58-4-58. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Mar. 11, 1958. (Decl. June 9, 1961). 24 p.

A method of calculating the contribution to reactivity from beryllium photoneutrons is presented. The analysis includes a gamma slowing down density calculation which may be useful for gamma heating calculations.

Lane, J.A. “Review of the Feasibility of the Air Cycle Nuclear Reactor”. ORNL Report addressed to A.M. Weinberg. November 29, 1951. 37 p.

This is a technical critique by ORNL of a preliminary air cycle nuclear aircraft engine design as presented in GE Report DC-51-9-28, “Preliminary Design of an Air Cycle Reactor and Shield”. This design was done by the Engineering Division, GE ANP Project, Oak Ridge, TN Sept. 26, 1951. ORNL asserts that a number of design omissions, including an underestimate of the inherent difficulties of the air cooling cycle, make unreasonable a short time schedule for building this reactor.

Layman, Douglas C., Thornton, Gunnar. “Remote Handling of Mobile Nuclear Systems”. TID-21719. General Electric Co. Aircraft Nuclear Propulsion Dept., Nuclear Materials and

Propulsion Operation, Cincinnati, OH. 1965. 655p.

Technology developed during the Aircraft Nuclear Propulsion program is described. Information is given on: nuclear systems and the Idaho Test Station; remote-handling procedures and support equipment; general-purpose facilities and tools; facilities and equipment in the shop building; related services; mechanical parts; shielding calculations; radiation effects; and health physics. Data on specification for a hot-shop wall-mounted boom and manipulator, specifications for radioactive core service area wall-mounted boom, remotely handled electrical connector, methods of calculating induced activity, and radiation calculations are appended. Also includes useful photographs and other illustrations.

Lenihan, S. R. "Investigations of Some Problems in Formulation of Monte Carlo Analyses of Gamma Ray Heating in Reactors." DC-59-3-119. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. July 8, 1958. 87 p.

A compilation of three separate investigation reports in various areas of formulation and programming Monte Carlo analyses of gamma ray heating in reactors is presented. Information is included on gamma ray total attenuation coefficient, the absorption fraction, the pair production fraction, and a graphical method of jump length sampling. The jump length sampling method is applicable to neutron Monte Carlo programs as well as the gamma ray program, and can also be extended to deep penetration studies. A graphical method of sampling the Klein-Nishina formula for the differential cross sections for Compton scattering of unpolarized gamma rays is presented, and a proposed ray tracing method for a geometry described by a non-intersecting set of closed cylindrical surfaces is described.

Leverett, M. C. "Aircraft Nuclear Propulsion". *Aeron. Eng.. Rev.* 11, 1 (1952): 29-33. See also: *Eng.. Digest* 12, 12 (1951): 391-94; *Flight 61,* 2252 (952): 330-3l; and *Shell Aviation News* (1952): 7-10.

Discusses principles underlying nuclear-powered flight, possible methods of achieving it, and some problems that are involved. (Author was GE-ANP Project Manager).

Leverett, M. C. “Some Views of Aircraft Nuclear Propulsion”. Preprint in Meeting of the Metropolitan Section of the SAE, Mar. 24, 1959, Society of Automotive Engineers, Inc., New York, N. Y. (Paper No. S 191).

Leverett, M. C. “Low-Flying Atom Plane May Be Our Winning Play”. *SEA J.* 67**,** 7 (1959): 112,115.

Leverett, Miles C. “Developments in Aircraft Nuclear Propulsion”. General Electric Co., Flight Propulsion Division, Aircraft Nuclear Propulsion Dept., Cincinnati. No Date, probably late 1960 or early 1961.

Presentation made by the GE-ANP Project Manager which discusses new information on the development of the ANP Program. Discusses the key characteristics and military utility of ANP, including the ability to fly essentially unlimited distances at low altitudes to avoid radar detection, to provide a mobile launch platform for missiles, eliminating the need for most foreign air bases, and providing continuous reconnaissance capability. The HTRE testing is discussed and an explanation is given of the design changes necessary to upgrade the HTRE-3 to a flight design. Presentation includes illustrations and technical data on the HTRE-3.

Leverett, Miles C. “Desirable Properties in a Liquid Coolant.” DC-52-31-58. GE-ANP Div. , Cincinnati. Letter to Dr. Alvin Weinberg, Director, Oak Ridge National Laboratory. Nov. 14, 1952. 2p.

The GE-ANP Project requested specific information on the fused salt coolant which comes closest to satisfying the requirements for a nuclear aircraft power plant liquid coolant.

Link, Bruce W. and Richard G. Clark. "Critical Experiment for HTRE-III." *Nuclear Energy*, 205-9 (May 1961).

The TSM (Tubular or Test Solid Moderator) critical experiment for the HTRE-III. reactor is described. The designs of the control system, moderator, and diffusion barrier are discussed.

Linn, F.C. and Culver, D.H. (ed.). "Heat Transfer Reactor Experiment No. 3, Comprehensive Technical Report, General Electric Direct-Air-Cycle Aircraft Nuclear Propulsion Program.” APEX-906. General Electric Co. Flight Propulsion Lab. Dept., Cincinnati. 206 p.

The Heat Transfer Reactor Experiment No. 3 (HTRE No. 3), a solid-moderated nuclear power plant with a horizontal reactor, is described. The objectives and accomplishments of the program are presented in addition to nuclear, thermodynamic, and control system design data. The power plant and components, including the reactor, shield, turbomachinery, controls, and test support equipment are described, and the low-power and operational tests are discussed. Manufacturing techniques, component testing, and materials developments are also presented. The objective of the HTRE No. 3 program was to provide the technical information needed for the design of a ground test prototype power plant and to test methods of design analysis and performance prediction.

Long, William H. and Jane Sewell, compilers. “Nuclear Analysis Data Book”. DC-53-2-79. Nuclear Analytical Section, GE-ANP Project. Undated, but probably 1953.

This report consolidates data of most importance to the Nuclear Analysis Section in one report. It covers the following reactor configurations which are currently under consideration: R-1/IET, IET Critical Experiment, Zero Power Test, Advanced Configuration Reactors.

MacDonald, J.E., J.T. Martin and J.P. Yalch. “Specialized Reactor-Shield Monte Carlo Program 18-0". TID-1168. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Jan.13, 1961. 117p.

Specialized Monte Carlo Program 18-0, GE-ANPD Program 349, is a digital computer program that applies Monte Carlo methods to simulate neutron and gamma ray life histories in reactor shield assemblies. The code is specialized to provide only as much geometry and importance sampling capabilities as are needed for analysis of selected reactor-shield assemblies.

Magee, C. B. "Some Aspects of Control Material Selection for Relatively High Temperature Reactors." DC-58-11-144. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Nov. 14, 1958. 54 p.

Information on the absorption of neutrons by nuclides and the dependence of absorption cross sections on neutron energy is presented. A comparison of the absorptive properties of several specific materials based on their relaxation lengths is included.

Maier, R.J. (comp.). “Bulk Shielding Reactor Nuclear Heating Experiments”. TID-21988. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Feb. 26, 1960 (Decl. Oct. 20, 1971). 304p.

Included are nine reports on nuclear heating of shielding systems of potential application in aircraft reactors. The experiments were, conducted in the Bulk Shielding Facility on various slab shield arrays.

Maier, R.J., comp. “Reactor Analysis Nuclear Heating Methods”. TID-21989. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Feb 26, 1960 (Decl. Oct. 21, 1971). 117p.

Results of the various calculations in the form of heating rates and distributions for the D101E reactor components are presented. Various methods of analysis used are summarized. Calculated average heating rates and distributions are given for each active core component as well as for end and radial reflectors. Afterheating rates are given for 12 and 50 hours of operation at 50 MW. A discussion of some of the uncertainties and assumptions to given along with other pertinent information (drawings. charts, tables. etc.) necessary to understand the methods and to apply the results. The energy released from all sources and the resulting energy depositions are tabulated. and show that 99.8% of all fission energy remains in the reactor.

Manning, Lindley. “Swirl Flow Pressure Losses in Concentric Ring Fuel Elements.” General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Feb. 23, 1960. 19p.

Swirl angles up to 20° were produced by canting the combs in the outer annulus of a concentric ribbon type fuel cartridge. The frictional pressure drop with canted combs was up to twice the loss with uncanted combs.

McCurdy, J. “Tube Bundle Calculations”. DC-57-11-176. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Nov. 22, 1957. 35p.

The digital technique for computing the distribution of weight flow in each tube in a bundle of tubes as a percentage of the average weight flow for one tube in the tube bundle and the pressure levels throughout each tube is presented. The computations are based upon equations which are given.

McDaniel, Bill M. Airflow Test of Stamped Moderator Assembly”. DC-59-5-182. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. May 14, 1959. 11p.

An unclad, zirconium hydride ($N_H = 4.0$) stamped assembly 1.5 in. in diameter and 2.34 in. long with one 1/2-in. diameter cooling hole was tested for structural integrity. The test specimen was run for 100 hours with 33 cycles, each cycle consisting of a heating period of 30 minutes, a dwell period at a maximum temperature of 1200°F for 3 hours, and a cooling period to 900°F which required 30 minutes. At the completion of the test no longitudinal, radial, or surface cracks were observed by x ray, and bonding appeared to be even better than before test.

McLay, T. D. and R. J. Campbell. “Insulation Attachment by Welding for an Aircraft Nuclear Propulsion Power Plant. (Involves Special Techniques and Is Best Carried out with the Gas Tungsten-Arc Spot-Welding Process).” General Electric Co., Cincinnati. *Welding J.*, 40 (Oct. 1961): 1019-28.

The data presented show that it is feasible and practices to weld individual sheet metal pad assemblies on the inside surface of the aft plug shield, combustor, header, and ducting of an aircraft nuclear power plant. The sheet metal assemblies hold fibrous thermal insulation which increases the service life of the covered material to several hundred hours and withstands service temperatures of 1600 deg. F. The gas tungsten-arc spot-welding process gives greater reliability when employed for joining the insulation spacer to the structural wall, as compared to resistance and arc stud welding. The techniques and procedures could be applied to several different varieties of deep hole welding operations.

McLay, T.D. "Insulation Attachment by Welding for an Aircraft Nuclear Propulsion Power Plant". General Electric Co., Flight Propulsion Lab. Dept., Cincinnati, OH. August 1961. 24p.

The design, fabrication, and attachment of sheet metal insulation pads for protection of fibrous insulation in a high-velocity airstream are described. Three welding tungsten inert gas welding techniques were evaluated for attachment of the pads to the structural wall. It is concluded that it is feasible and practical to insulate hot ducting on an aircraft nuclear power plant for service temperatures of 1600°F and service life of several hundred hours. The tungsten inert gas spot welding process was the most successful process.

McLennan, J. A. "Reactivity of the Critical Experiment as a Function of Gap Width". AECD-3958. General Electric Co. Aircraft Nuclear Propulsion Project, Cincinnati (1952 Decl. 1955) 15 p.

The split reactor of the Aircraft Reactor Critical Experiment is analyzed, using a single-energy, group-diffusion approximation. A further approximation is introduced in that the two halves of the reactor are treated as parallelepipeds rather than half-cylinders. The reactivity of the reactor is obtained as a function of the separation of the two halves, both for the "standard" U concentration and for various greater concentrations.

McVey, John W. "D102A Power Plant Disassembly Procedure." DC-61-6-16. General Electric
Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Oct. 16, 1959. 57p.

The proper steps and sequence to disassemble the D102A Power Plant in a safe, pre-determined manner are listed.

Mehall, F.E. "Foreign Gas Cooled Reactors". DC-60-10-154. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Oct. 14, 1960. 8p.

A compilation of information on gas cooled reactors located outside the U. S. is presented. Key design information is tabulated on reactors in operation, under construction, and planned in seven nations.

Meier, J.E. "Investigation of a Corrugated Shell as an Elastic Support of a Bundle of Rods. Appendix B: Corrugated Shell Analysis for a High-Temperature-Reactor Radial Support System." APEX-616. General Electric Co., General Engineering Lab., Schenectady, NY. For General Electric Co. Flight Propulsion Lab. Dept., Cincinnati, OH. April 14, 1961. 314p.

Application of knowledge and formulas developed in the report "Investigation of a

Corrugated Shell as an Elastic or a Bundle of Rods" (APEX 615) to the D140E Reactor is discussed. The calculations are based on the D140E Reactor supported by leaf springs in a smooth shell and on the calculated profile of radial thermal differential expansion between the core and shell.

Mezger, F.W. "Accident Mechanisms for Nuclear Aircraft Using XNJ140E Power Plant". General Electric Co., Cincinnati, OH. Nd (Decl. Sept. 20, 1973). 156p.

Those accident mechanisms which release a significant amount of radioactivity and which could occur in nuclear aircraft using the XNJ140E power plant are analyzed. The accidents considered are core meltdown; at-power runaway; startup runaway; meltdown-induced runaway; compaction-induced runaway; and immersion-induced runaway. The chain of events and the radioactive and toxic isotope release associated with each of these accidents are described. The relative probabilities that these accidents will release hazardous isotopes at the airport, in the flight corridor, in flight, and in the ocean are estimated. Absolute probabilities are estimated in terms of present aircraft experience. The use of countermeasures and design features to reduce accident possibilities is discussed. Areas are identified for which further work is indicated.

Mezger, F. W. "Analysis of LPT and ZPT Reactor Runaways." APEX-213. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. June 1, 1953. 132 p.

An analysis was made of possible Low Power Test and Zero Power Test runaways and results are given even though neither test will actually be run. Vaporization of the fuel elements is considered.

Miller, H. "Developments in Field of Direct-Air-Cycle Aircraft Nuclear Propulsion Systems". Society of the Automotive Engineers. Paper No. 92 B for Meeting Sept. 29-Oct. 4 (1958) 14 p.

Progress report deals with General Electric's heat transfer reactor experiment No. 1 (HTRE-1) designed to test and verify design of nuclear system. The power plant consists of air cooled, metallic fuel elements, in a water moderated reactor operating a turbojet engine. GE has this nuclear power testing facility at the Idaho test station along with a radioactive materials laboratory.

Miller, W.T. and M. H. Ferguson. "Maintenance Handbook D102A Control System." DC-59-6-15. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. June 15, 1959. 301p.

Descriptions, photographs, block diagrams, schematics, and specifications for power supplies, servo units, source range, intermediate range, power range, selector amplifier, shim control amplifier, safety bus circuits, temperature loop, shim and safety rods, and miscellaneous circuits for the D102A control system are given.

Miller. W.T. and M.H. Ferguson. "Handbook of Service Instructions-D102A Control System, Relay, Lamp, and Meter Circuit." DC-59-6-143. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. July 1, 1959. 145p.

A manual of the latest revisions of the relay, lamp, and meter circuits of the D102A control system is presented replacing the original manual DC-58-4-199. The manual was revised to aid in the initial checkout of the modified control system and the servicing of the electrical and electronic components. The over-all system is broken down into smaller functional units and all terminal points and connector pins associated with the individual circuit are given. Many wire numbers, master terminal board, coupling plug, and dolly junction box destination points were added to the sketches and additional sketches are shown.

Mills, R.R., Jr., and J. Heck. "XMA-lA Front Shield Plug Thermodynamic Appraisal". TID-14875. Aircraft Armaments, Inc., Cockeysville, MD. For General Electric Co., Nuclear Propulsion Dept., Cincinnati, OH. Nov. 1959. 443p.

The Transient Heat Transfer analyses of the thermodynamic characteristics of the XMA-1A Front Shield Plug configuration investigated in detail various geometrical regions of the configuration during steady operation of the plug and during the cooling process. In addition, certain regions were investigated, in a preliminary manner, for the slow start-power transfer process.

Mills, Robert R. "XMA-1 Front Plug Thermodynamic Appraisal. Phase 1". TID-14876. Aircraft Armaments Inc., Cockeysville, MD. For General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. May 1959. 179p.

The results are presented of the investigations conducted during the Phase I program of the thermodynamic characteristics of the front plug configuration during the transient heating (startup), steady state, and transient cooling (shutdown) periods of operation.

Minnich, S. H.; M. Cohen; J. S. McCullogh; and H. E. Brown. "Critical experiment data and supporting analysis for the AC-100A reactor." APEX-229. Work Performed during January 15, 1954 to March 1954. General Electric Co. Aircraft Nuclear Propulsion Dept. Cincinnati. May 12, 1954. Dec. June 9, 1961. 88p.

Preliminary experimental and analytical data are given. Included are discussions of control rod values, power distributions, reactivity coefficients of various fuel elements and limited reflector measurements. Discussions of two group constants, cell corrections, control rods, power distributions. reflector and tube sheet analysis are also included in appendices.

Mitchell, T.R. "Alternate XMA-1 Power Plant Study". DC-59-2-1. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Mar 1959 (decl. Sept. 13, 1973). 129p.

The results are presented of single-engine power plant studies which were performed to obtain comparisons among the different types of single-engine power plants and the XMA-1C power plant from the standpoint of performance (thrust/weight ratio), frontal area, and ease of development, maintenance and remote handling. The single-engine power plant designs were developed using the same materials, design criteria and technology which were employed in the design of the twin-engine XMA-1C power plant. Power plant design layouts, weights, thrusts, and frontal areas are presented, as well as a summary of the effect of the various power plants on aircraft performance.

Moon, C.W., R.E. Motsinger, J.M. Crook and C.S. Robertson, Jr. "High-Temperature Nuclear Reactor Design Technology; Influence of Performance Requirements on Power Plant Component Specifications; Reactor Design". General Electric Co. Flight Propulsion Lab. Dept., Cincinnati. June 30, 1962. 229 p.

Design technology for gas-cooled high-temperature nuclear reactors is described by recounting the solutions to reactor design problems used for the direct air cycle portion of the national Aircraft Nuclear Propulsion Program. Major shield and control system design problem solutions as related to the reactor are also recounted. General characteristics of nuclear-powered gas-turbine cycles of gas-cooled reactors and of shields are discussed and means are indicated for relating those characteristics to basic requirements of the nuclear reactor.

Morand, R.F.; R.R. Gehring (ed.). "Remote Handling, Comprehensive Technical Report, General Electric Direct-Air-Cycle, Aircraft Nuclear Propulsion Program." APEX-911. General Electric Co., Flight Propulsion Lab. Dept., Cincinnati. Dec. 13, 1961. 63 p.

General purpose equipment and procedures are described which were developed for the remote handling of irradiated aircraft power plants and associated subassemblies. At reactor operating cells, the operating personnel was shielded and the cells unshielded. The separate facilities were abort one mile apart, connected to a locomotive turntable by means of a four-rail track system. Remote handling devices utilized in dismantling and inspection of radioactive power plants included an overhead manipulator, four wall-track-mounted manipulators, several master slave manipulators, periscopes, a tube-loading machine, and a core-removal fixture. General-purpose equipment such as manipulators and overhead cranes were augmented with special purpose tooling to satisfy the specific needs of the various power plants. General viewing was by direct viewing shielded windows along the walls of the hot shop. The Flight Engine Test Facility was built to handle irradiated power plants mounted in aircraft. A self propelled, shielded cab with manipulators was developed for working in the FET on nuclear power plants shortly after they were shut down. Photographs of the equipment are included.

Motsinger, R.E., ed. “P122C1 AND P122C3 Analytical Performance Evaluation Summary”. General Electric Co., Flight Propulsion Lab. Dept., Cincinnati, OH. Sept. 1961 (Decl. Oct. 29, 1971). 159p.

The status of the folded flow program at the time of the contract termination is given in terms of design and analysis results, including power plant and component drawings, performance and weight objectives; and, analyses results in areas of stress, nuclear, and aerothermal. Coverage is given to the P122CI subsonic and to the P122C3 supersonic versions of folded flow application. Indications were that the P122CI design objectives would be met within about five percent in terms of power plant weight, and that the effect of this discrepancy on airplane performance was essentially negligible. However, radiation dose levels to the side of the shield were in excess of limits established for the D140E predecessor power plant.

Mott, James E. “Operation and Performance of Temperature-Control Circuit Project 102, Control System”. DC-58-8-231. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Aug. 27, 1958. 71p.

A report on the theory of operation, design, calibration and test, and the performance of a temperature-control circuit for project 102 is presented. The various components are discussed and typical circuit data are presented along with schematic drawings, sketches. and photographs. Tests of transient response and steady-state accuracy of the temperature-control circuit, operated in connection with both the control system mockup and the final manufactured system, gave satisfactory results.

Muehlenkamp, G.T. “Evaluation of Full-Length HTRE-Al Cartridges Tested in ANP Burner Rig”. DC 55-11-17. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Oct. 31, 1955. 17p.

The results obtained from the visual and metallographic examination of the second and third full-length HTRE-Al cartridges after operation in the GE-ANP burner rig facility are presented. The extent of damage to the stages and rings comprising these cartridges is given. Evaluation of the condition of these cartridges after burner rig testing with respect to operation in the reactor was difficult due to the non-uniformity of the indicated temperatures and the burner rig. The results of metallographic examination revealed some areas for improvement in the quality of the elements.

Ness, A. J. "Computer Evaluation of Annular Reactor Analytic, Two-Energy Group Analysis." DC 57-1-18-704. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Dec. 15, 1956. 15 p.

Program completes fast and slow flux and fission source distribution at lattice points between two given radii in a bare annular reactor having a central control rod. The problem is computed on the IBM-704. Machine operation time is approximately thirty seconds per case.

Newton, G.W. "Comparison of Direct- And Indirect-Cycle Nuclear Turbojet Engines". XDCL-60-12-126. General Electric Co., Nuclear Materials and Propulsion Operation Cincinnati, OH. Dec. 1960 (Decl. Sept. 20, 1973). 63p.

Current information on the direct-cycle nuclear turbojet power plant is compared with available information on the indirect-cycle power plant. Both cycles have predicted operational thrust-to-weight performance sufficient to equal that specified by Department of Defense guidance. They have promise of development to advanced versions that could power a modification of the B-70 airplane. The direct cycle is considered more reliable, more feasible, and safer than the indirect cycle. It is closer to useful application by several years.

Noyes, R.N. "Aerothermodynamics". General Electric Co., General Electric Direct-Air-Cycle, Aircraft Nuclear Propulsion Program, Nuclear Materials and Propulsion Operation, Cincinnati, OH. Dec. 6, 1961 (Decl. Sept. 12, 1973). 107p.

The methods and techniques developed for use in the thermal design of nuclear aircraft propulsion reactors are presented. Information and references are given on the analytical and experimental work required to design and evaluate the proposed high performance air cooled fuel elements. Methods of optimizing the thermal designs, particularly by the use of high speed electronic digital computing equipment are discussed. The computer programs developed to provide accurate performance predictions are identified and described. Means for matching the coolant-flow to the predicted internal heat generation rates in the non-fueled components are discussed. Test methods and results are indicated and significant equipment and instrumentation information provided. The relationships of reactor pressure losses and of localized perturbances to power plant performance are indicated, and the detailed analyses which were required to identify and predict these effects are discussed.

Noyes, R.N. "The Design Point Performance Shaped Wire and Ribbon Type Fuel Elements Based on Recent Experimental Data." DC-55-7-13. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. June 30, 1955. 16p.

The design point performance of shaped wire and ribbon type fuel elements of such geometry as to be used in solid moderated systems is discussed. Using the ratio of total pressure at core exit to total pressure at core inlet as an index of performance, this ratio was computed to be 0.692 for ribbon type fuel elements, 0.666 for shaped wire elements having un-fueled spacers. and 0.771 for shaped wire fuel elements having fueled spacers. The results indicated that for a longitudinal flat power distribution curve, the present core size is too small to handle the airflow from two 400 lb/sec engines at the design point flight condition of Mach 0.9 at 35,000 ft altitudes. It was concluded that if shaped wire fuel elements having fueled spacers are used in a core having a drooping power characteristic in the exit stages, the resulting total pressure ratio will be up to the design point value of 0.796.

Noyes, R. N. "Correlation of Shaped Wire Type Fuel Element Data in Form Application For Prediction of Pressure Loss with Heat Addition." XDC-55-5-123. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. May 12, 1955. l2 p.

The test data reported in XDC 55-2-43 was re-correlated into a form which would be applicable for the prediction of pressure loss with heat addition, With the exception of 17 out of some 150 data points, friction factor variation was restricted by a range of 10% around a mean correlation line. An example is worked out to illustrate the use of this correlation in predicting pressure drop with friction.

O'Brien, R.B. "Experience with Non-Filtered Air Systems at the Idaho Test Station". TID-7593. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. pp. 42-6.

Experimental direct-cycle aircraft nuclear power plants are ground tested at the ANP Area, National Reactor Testing Station, without air cleaning. Effluent hazards are minimized by a system of meteorological control. To date, this system has proved to be successful in controlling the doses to humans and may prove to be adequate for full-scale aircraft power plant tests. Even if air cleaning of the effluent proves to be necessary in the future, a meteorological control program will serve to reduce the requirements of the air cleaning system, thereby reducing its cost.

Orr, W. L. and R. M. Cohen. "D-102-A Fuel Element Nuclear Design." XDC-58-1-137. General Aircraft Nuclear Propulsion Dept., Cincinnati. 57. (Decl. June 9, 1961).

Design specifications for Project 102 fuel elements are documented. The design philosophy and the nuclear design procedures are also discussed. Nuclear performance predictions for the elements are presented in the form of radial heat flux distributions for various cell locations. The effects of circumferential power scalloping on heat flux distributions are shown for a number of cell locations in terms of sector distributions.

Peterson, J.A. and D.M. Page. "Design and Performance of Secondary Cooling Systems for the XMA-1 Power Plant for Subsonic Applications". GV-58-27-30. General Electric Co., California Advanced Propulsion Systems Operation, San Ramon, CA. July 21,1958. p. 69.

In this report, the best designs of secondary cooling systems are evolved, one for each of three modes of power plant operation, for the subsonic application of the XMA-l power plant. The performance of these systems was evaluated and the operation of the variable geometry features and control system requirements are described.

Peterson, M.B. and S.F. Murray. "Investigation of Possible Bearing Materials and Lubricants for Temperatures above 1000°F." APEX-624. General Electric Co., General Engineering Lab., Schenectady, NY. For General Electric Co. Flight Propulsion Lab. Dept., Cincinnati, OH. Apr. 15, 1959. 78p.

An exploratory investigation of bearing materials and lubricants was conducted to determine the feasibility of using various materials and lubricants for sliding and rolling contacts at temperatures above 1000°F and to obtain a better understanding of sliding processes at such temperatures. Screening tests were run on materials and lubricants in sliding contact at 1000°F and 1600°F and in rolling contact at 700° and 1000°F. Journal bearing tests were also run at temperatures up to 1600°F with those materials and lubricants that seemed promising from the screening tests. Rolling ball tests were conducted at 700° and 1000°F on materials that seemed feasible as ball bearing materials; some lubricant tests were also run with the same device. Finally, data were obtained on various lubricants at 500° to 700°F on the Shell 4-Ball Tester.

Plastino, Gene G. "Procedure, Material, Equipment and Facilities Requirement for Decontamination of D140E-1 Power Plant." DC-60-10-726. General Electric Co., Aircraft Nuclear Propulsion Dept., Idaho Falls, ID. Oct. 13, 1960. 32p.

An outline is presented concerning the methods, procedures, materials, equipment, and requirements for remote and/or manual decontamination of the X-211 turbomachinery. Discussions are included concerning chemical and physical aspects of the plate-out particulate, material classification, decontamination solutions and equipment.

Powell, W.C. and A.W. Ratliff. "Interim Report on HTRE No. 3 Thermodynamic Data." DC-60-4-22. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Mar. 31, 1960. 61p.

Data are presented which were taken during the Phase H testing of HTRE No. 3 after an endurance run of 127 hr at 33 MW with a turbine inlet temperature of 1330°F, 65 hr of the run being continuous. Interpretations of the data and comparisons with predictions are given.

Powell, W.C. "Temperature Response of D-102-A2-W CORE Components to Startup". General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Aug. 24, 1959. 40p.

temperatures of core components are shown as a function of time after reactor startup for a range of reactor powers and air flow rates.

Powell, W. C. "HTRE No. 3 Thermodynamic Performance." DC-60-9-67. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Aug. 12, 1960. 70 p.

Thermodynamic data from all HTRE No. 3 testing to date were condensed, compared with predictions, and interpreted wherever possible.

"Preliminary Engineering Description and Preliminary Specifications of XNJ140E-1 (Advanced Core Test) (Final Issue)". General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Feb. 15, 1961 (Decl. Sept. 20, 1973). 235p.

A preliminary engineering description and preliminary specifications for the XNJ140E-1 engine to be operated as the Advanced Core Test at the Idaho Test Station are presented. The Advanced Core Test program is a test of a prototype of the direct-air-cycle nuclear turbojet engines being developed by the General Electric Company Aircraft Nuclear Propulsion Department. The XNJI40E-1 engine contains an advanced ceramic reactor and utilizes X211-E1 turbomachinery arranged in an integral in-line configuration. The XNJ140E-1 engine is being designed in accordance with parameters established for an objective power plant meeting current Department of Defense nuclear-flight guidance.

"Preliminary Triple Flange Temperature Distributions." TID-14874. Aircraft Armaments Inc., Cockeysville, MD. For General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. July 27, 1959 (Decl. Oct. 19, 1971). 36p.

Computer calculated values were used to plot curves of XMA front shield plug temperature distribution in the triple flange region.

Prickett, W.Z. "General Reactor Sizing Techniques. Volume 1. Aerothermodynamic Optimization". APEX-723A General Electric Co., Flight Propulsion Lab. Dept., Cincinnati, OH. June 1961. 45p.

A method is presented for the aerothermodynamic optimization of the net power and/or propulsive thrust per unit reactor free flow area of a nuclear power plant operating on the Brayton cycle. A system so optimized will translate into the minimum size, therefore the minimum weight, nuclear system for any selection of reactor materials lifetime, and fuel loading. The theory and development of the thermodynamic optimization process. the importance and effect of various parameters, and specific methods to be employed in the optimization of the various form of the Brayton cycle are discussed. A sample calculation for the case of the ramjet application is included. The results of the application of these techniques to any Brayton cycle system may be used in conjunction with nuclear sizing

methods, for beryllium-moderated reactors, to determine the required reactor size as a function of fuel loading and reactivity requirements.

"Project 101 Quarterly Task Report, April-June 1960. DC-60-6-1". General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. June 1960 (Decl. Sept. 13, 1973). 405p.

Information on the design and development of an aircraft propulsion reactor is presented concerning design studies of alternate reactor configurations, selection of reference configuration for D140 power plant, core components, and fuel and other ceramic components.

Provost, J.D. "A Description and Operating History of the MTR HT-1 Loop. Test Reactors Meeting for Industry, Idaho Falls, Idaho, May 13-15, 1959. Part II, Utilization of Test Reactors". IDO-16520. General Electric Co, Aircraft Nuclear Propulsion Dept., Idaho Falls, ID. pp. 241-54.

A general description is given of General Electric Company -ANPD in pursuing its work toward direct cycle aircraft nuclear propulsion at the Materials Testing Reactor in Idaho. The HT-1 loop auxiliary and supporting equipment is described including inpile tubes and removal casks. Operational experience is given on procedures such as sample removal, inpile tube change-out, and flux measurement.

Pryor, W.A. "Aircraft Nuclear Propulsion Department Nuclear Safety Guide". APEX-715. General Electric Co., Flight Propulsion Lab. Dept., Cincinnati, OH. June 1961. 29p.

The limitations and operating techniques which were in effect at ANPD for the prevention of criticality accidents are summarized. The standards followed by the atomic industry were followed; however, the safe mass of U^{235} moderated with beryllium oxide and hydrogenous materials was based upon criticality experiments conducted at ANPD. Although the guide was primarily for the use of the ANPD nuclear safety control organization, it may also be of assistance to designers and operating management in maintaining nuclear safety.

Reed, L.L. "Post-Operational Examination of ANP-ICR2B: Gamma Scanning and Burnup Analyses". DC 59-10-749. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Oct. 21, 1959. 8p.

Absolute disintegration rates of Zr^{95} were determined for three positions on five fueled tubes and one position on two fueled tubes from ANP-ICR2B. Radiochemical separations for Zr^{95}, Cs^{137}, and Ce^{144}, and total uranium on one of the tubes allow the calculation of percent burnup. The percent burnup on all tubes as calculated from the gamma scanning data averaged 0.94%.

Renaker, John N. (ed.) "SMR Summary Hazards Report." APEX-200. General Electric Co, Aircraft Nuclear Propulsion Dept., Cincinnati. June 15, 1955. (Decl. June 16, 1961). 58p. (APEX-206 supplements and covers errata for this report).

The SMR, Solid Moderator Reactor, is a critical assembly designed to predict the characteristics of a direct-cycle aircraft reactor. The design, operation and potential hazards of this assembly are presented and discussed.

Riley, D.R. and B.R. Thompson. “Stress Analysis of Metallic Fuel Elements--Structural Memo No. 41". DC-60-2-285. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Feb. 16, 1960. 43p.

Stresses and deflections, resulting from a nuclear operation design point, are presented in tabular and graphical form for the highest stressed fueled cylinder of each of the following configurations: 102, 103A-9 Ring, 103A-15 Ring, 103B-Reference Shell, and 103B-Internal Support (2 Supports). Results are given over the full length and around the full circumference of the cylinders.

Riley, D.R., B.R. Thompson, and A. Monfort. “Stress Analysis of Metallic Fuel Elements--Structural Memo No. 36". DC-60-1-60. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Jan. 8, 1960. 113p.

Stresses and deflections resulting from drag loads and differential temperature expansions are calculated for five different concentric ring fuel element configurations. The five configurations are: 102, 103A-9 ring ETR, 103A-15 ring, 103B-reference shell, and 103B-internal support. Calculations are made for each configuration at constant temperature, burner rig, and nuclear operating condition. Beam stresses are plotted and cylinder stresses and deflections are tabulated for each configuration operating condition.

Riley, D.R. “Use of Maxwell’s Influence Coefficients in Fuel Element Analysis.” DC-59-8-86. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Apr. 30, 1959. 29p.

Equations were developed for the structural analysis of a concentric ring fuel element assembly. The loading conditions covered by the equations are explained.

Roberts, R. “ Test of P-102 Primary Shield Bolts”. DC-58-9-35. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Sept. 3, 1958. 40p.

Torque tests were conducted on each type of bolt used in the P-102 primary shield components to obtain test data for use in the shield assembly. The torque value ranges needed to obtain the design preload for each bolt were determined. Actual assembly conditions were duplicated as to materials, nuts, and washers.

Robertson, C.S. " Fuel Element Nuclear Design Program". XDC-59-11-94. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Oct. 26, 1959. 35p.

ANP 704 digital program No. 381, which was used to perform the bulk of the nuclear calculations for the D103A fuel element design is described. This program handles the iterative fine power flattening of concentric ring fuel elements of the D103A type. Input consists of gross element geometry, basic nuclear data and various mechanical parameters. Output consists of the fine geometry of the element, the fine power profile, and partially processed thermodynamic data. The thermodynamic data are also punched in a form suitable for use as input to ANP program No. 23, Flow Through Heated Annuli.

Ross, Arthur L. "Thermal Stress Analysis of Finite Sections". APEX-480. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Jan. 20, 1959. 16p.

A general method is described for finding the thermal stresses in finite, simply connected regions. The method is applicable to plane-stress or plane-strain problems and makes use of the analogy between the problems of the bending stresses of clamped plates and those of thermal-plane stresses.

Russell, J.A., S.F. Hemmenway, J.L. Scharf. and P.C. Sharr. "Magnetic Automatic Power-Range Control for An Aircraft Nuclear Reactor". For General Electric Co., Cincinnati, OH. *Communication and Electronics* 50 (Sept. 1960): 379-84.

Control system philosophy for an aircraft nuclear power plant is discussed. Advantages are asserted for a power range magnetic control system with a minimum number of moving parts. Control system elements and computing devices are described. Performance of a "bread board" version of the control system is evaluated.

Schmidt, R.F. "Electrical Resistance as an Indicator of Fuel Element Cracking." DC-60-11-103. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Nov. 16, 1960. 11p.

Measurements were made on a simulated fuel element to determine what effect partial occlusions, normal to the cross section, have on the end-to-end electric resistance of the element. Calculations based on the results show that it is probably feasible to use electric resistance as an indicator of crack occurrence.

Schmill, W.C., and R.G. Fogg. "Potentialities of the Nuclear-powered Turboprop. XDC-57-7-59. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. July 1957 (Decl. Sept. 13, 1973). 92p.

The use of propulsion reactors for large subsonic turboprop aircraft to discussed. The military applications for the nuclear turboprop-powered aircraft are analyzed. Design parameters for turboprop propulsion system are presented.

Schnorr, F.W. "Design, Development, and Testing of a 400°F Gear-Type Air Motor." DC-61-6-17. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. June 1, 1961. 68p.

The design, development, and environmental testing of a servo-type pneumatic rotary air motor for use with a nuclear reactor control system is reported.

Schoenberger, T.W.X. " D102A Data Book, 8th Issue". DC-59-8-22. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. July 29, 1959. 513p.

Design modifications effected during rebuilding of the D102A turbojet reactor after a power excursion are described. Included are revisions to moderator latching, orificing, and attachment. Modifications on the control system design to prevent recurrence of the incident are also reported. Nuclear and-thermodynamic data are also included along with information on shielding, structures, accessories, remote handling, and controls.

Schwartz, D.B., B.W. Mouring, and D.W. Ruark. "XMA-1A Rear Shield Plug Thermodynamic Appraisal". TID-14877. Aircraft Armaments, Inc., Cockeysville, Md. For General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Nov 1969. 214p.

The results of a thermodynamic appraisal of the XMA-lA Rear Shield Plug are presented. The Transient Heat Transfer results presented were obtained by the application of steady state data and estimated transient operating characteristics for scram. An uncertainty factor of 2 was applied to all nuclear heating rate predictions utilized in these analyses. Complete temperature estimates resulting from the revised geometry are included.

Serkiz, A.W. "D140E1 Radial Shield and Pressure Vessel Aerothermal Analysis. APEX-739. General Electric Co., Flight Propulsion Lab. Dept., Cincinnati, OH. July 6, 1961 (Decl. Oct. 29, 1971). 33p.

The termination status of the D140E1 Radial Shield and Pressure Vessel aerothermal analysis is presented. The status of analysis and design, design problems, and proposed solutions is summarized.

Shoults, D.R. "Tests of a Direct Cycle Nuclear Turbojet System". A/CONF.15/P/465. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. For the Second U.N. International Conference on the Peaceful Uses of Atomic Energy, 1958. 1958. 11p.

This paper discusses research and development effort on a direct-cycle air-cooled nuclear reactor and propulsion equipment. The reactor experiment was designed, constructed, and tested during the period 1953 to 1956 to prove the feasibility of operating a turbojet engine from the heat produced by an air cooled reactor. A description is given of the reactor, turbomachinery, shielding, control system, and associated equipment used in the first propulsion system test which was run in 1956. The system consisted of a modified J-47 turbojet engine arranged so that compressed air from the compressor was ducted through a shielded reactor and a chemical combustor in series before passing through the turbine and exhaust nozzle. The experimental reactor was based on a unique design concept in which a water moderator at low temperature is contained in an aluminum core structure. The air cooled metal fuel elements containing enriched uranium were arranged in passages running through the reactor. Thermal insulation was provided to protect the aluminum structure from the high temperature fuel elements and air, and to reduce heat losses to the moderator water. The entire reactor shield and turbojet assembly was mounted on a four-rail flat car for easy transfer by a shielded locomotive from the test site to the maintenance facility, where reactor disassembly, repair, and maintenance were performed by use of remotely controlled handling equipment. A description of the test facility with its underground control room, instrumentation, and data processing system is presented as well as a description of the large maintenance facility and various types of remote handling equipment. Test operating experience is presented which includes data on the operating characteristics of the system; the nuclear, thermal, and mechanical behavior; the radiation levels experienced; and the remote disassembling, repairing, and servicing the propulsion system. The paper includes photographs and charts describing the equipment, facilities, and test operation. This test program proved the feasibility of operating a turbojet engine exclusively on nuclear power. During the series of tests, the total nuclear energy produced was greater than 5000 megawatt hours.

Shoults, D.R. "Program Framework." DC 53-11-66. GE-ANP Dept., Cincinnati. Oct. 29, 1953. 2p.

D.R. Shoults, General Manager, GE-ANP Dept., Cincinnati, addressed this memorandum to all managers and supervisors. He provides a Program Framework which depicts the overall Dept. plans and objectives, in light of recent program re-alignments. The major program highlights are: HTRE - nuclear testing targeted to begin in early 1956; Ground testing of a tactically useful ANP Plant - Targeted to take place sometime in 1959, with further testing for flight-qualification purposes using a test-bed aircraft planned to immediately follow early ground tests; First flight of a complete and integrated tactically-useful ANP System- targeted to take place around the end of 1962.

Showlater, J.A. "Compilation of Unclassified Project 102 Controls and Instrumentation Schematic Diagrams. Drawings and Photographs". DC 59-8-127. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Aug. 14, 1959. 136p.

A compilation is presented of drawings, photographs, sketches, and curves relevant to the D102-A system. It covers the reactor, engine, and auxiliary control systems with most emphasis being placed on the reactor control system.

Showlater, J.A. “Compilation of Unclassified Project 102 Controls and Instrumentation Schematic Diagrams, Drawings and Photographs.” DC 59-S-127. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Aug. 14, 1959. 136p.

A compilation is presented of drawings, photographs, sketches, and curves relevant to the D102-A system. It covers the reactor, engine, and auxiliary control systems with most emphasis being placed on the reactor control system. These drawings and photographs are assembled for reference and instruction purposes.

Smith, M.R. “Core Heating Effects Due to Gamma Liberated Secondary Electrons”. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Jan. 6, 1958. 17p.

The design of small ionization chambers used to determine the core heating effects from gamma liberated secondary electrons is described. The suggested ionization chambers are of such configuration as to be used in the TSM reactor and specifications are given for chambers to be constructed of several different moderator materials.

Spera, R. J. "Possible Use of Electromechanical Release Mechanisms for a Compressed Gas-Boron Powder Nuclear Fuse." XDC-55-5-125. General Electric Co. Aircraft Nuclear Propulsion Dept. Cincinnati. May 26. 1955. 58 p.

Electromechanical devices were found to be impractical as release mechanisms for nuclear fuses. The quantity of energy required to release the compressed gas of the fuse is much greater than the amount that can be stored within the fuse volume.

Stankevicz, J.E. and R.N. Noyes. “Predicted Radial Temperature Distributions from Transient Temperature Measurements in a Hollow BeO Cylinder.” DC-60-2-84. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Feb. 3, 1960. 15p.

Results of cooling tests conducted on a hollow BeO cylinder are presented. This tube was heated on the outside by thermal radiation from surrounding lamps, and cooled by a constant air-flow rate through the center hole. Thermocouples were embedded in the tube-wall thickness at three different axial positions along the tube. The test procedure was to allow the sample to come to equilibrium temperature with the lamps on and no air flow, and then turn on the air flow (with the lamps still on) and observe the temperature-time history of each of the three thermocouples during the cooling process. The purpose of these tests was to obtain experimental data from which stress levels within the BeO cylinder could be obtained. As a necessary intermediate step in the final determination of the stress pattern, an analysis was made to determine the radial variation of temperature within the tube wall material as a function of time.

Stanley, M. J. "Supplement 1 to APEX 515, Cross Sections for Reactor Analysis." XDC-59-11-72. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Oct. 26, 1959. 33 p.

Since the publication of APEX 515, "Cross Sections for Reactor Analysis", new records were added to the IBM 704 nuclear data tape. The purpose of this supplement is to acquaint the users of the nuclear data tape with the latest additions and to document the cross section data. The new or revised records pertain to the atomic mass number 234, 235. 236, and 238 isotopes of uranium, rhenium, iron, nickel, chromium and niobium.

Stanley, R. A. and J. Holowach. "Structural Evaluation of a Corrugated Fuel Element." DC-57-11-65. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Nov. 4, 1957.
16 p.

A series of burner rig tests was completed on a corrugated type fuel element which shows the high mechanical strength of a corrugated type construction. An AR-7 type fuel element was successfully tested for 100 hours at a gas temperature of 1730 deg.F. and a dynamic head of about 9 psi.

Starling, H. S. and R. I. Emmert. "An Operational and Maintenance Guide for the HTRE No. I Servo System." XDC-55-11-101. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Nov. 21, 1955. 37 p.

The guide includes an introduction, a section on the function of the servo loops and shim circuit and a section containing a description of the components and gain and balance adjustments with a check-out procedure section.

Storrs, C. L. and D. C. Foster. “Proposed Side Loop at the IET”. TID-7593. General Electric Co. Aircraft Nuclear Propulsion Dept., Idaho Falls, ID. p. 41-51.

The side-filter loop at IET is described. This facility is to provide pilot plant experience for a full-scale filter design. It draws off 5 to 10% of the IET exhaust and passes it through an electrostatic precipitator. It has a capacity of 14,000 cfm up to 900°F.

Structural Analysis of the ANP Concentric Ring Fuel Element”. APEX-634. General Electric Co., Flight Propulsion Lab., Cincinnati, OH. June 1961. 20p.

During the development of the direct-air cycle concentric ring fuel element it was necessary to make a detailed structural analysis of the configuration. The analytical formulation of the structural analysis and experimental verification are described.

"Summary Report of HTRE No. 3 Nuclear Excursion". APEX-509. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, Ohio. [no date] 148p.

A power excursion and fuel element meltdown in the HTRE No. 3 prototype aircraft power plant are discussed. The cause of the power excursion, safety actions, and the mechanism of reactor shutdown are considered.

Swope, R. R. "Assembly, Installation, Operation and Control Instructions for D102A Nuclear Sensors." DC-58-8-116. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Sept. 1, 1958. 127 p.

A handbook is presented In which the assembly, installation, operation, and control of the nuclear sensors for the D102A power plant are described.

Swope, R.R. "Assembly, Installation, Operation and Control Instructions for D103A Nuclear Sensors. DC-60-2-22. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Feb. 15, 1960. 89p.

A description is presented of the assembly, installation, operation, and control of the D103 power plant nuclear sensors.

Szekely, T. "A-136 Nuclear Turbo-ram Power Plant (Invention Disclosures). APEX-727. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Apr. 10, 1961 (Decl. Sept. 12, 1973). 102p.

A new concept of a nuclear direct-cycle turbo-ram power plant, the A-136, is described. Information is presented on the power plant cycle arrangement of components, mechanical design, reactor materials, thermal and nuclear design, reactor kinetics and controls design, shield design, and estimated preliminary performance. The cycle of the A-136 is designed to exploit the high temperature capabilities of promising new reactor materials without increasing the temperature demands for turbine operation. The cycle and high-temperature reactor are mutually employed to broaden the all-nuclear atmospheric flight spectrum. Also, the A-136 is the first effort to develop a direct cycle atmospheric propulsion reactor that may be used for ram-rocket propulsion in more advanced nuclear space plane systems.

Szekely, T. "Direct Cycle Reactors for Aircraft Nuclear Propulsion". For General Electric Co. Presented at Nuclear Engineering and Science Conference, Chicago, March 17-21, 1958. Preprint 93, Session 11. American Institute of Chemical Engineers. 11p.

The design requirements of direct air-cycle reactors for application to aircraft nuclear propulsion are briefly presented. A summary is provided on reactor design problems arising from the interaction of thermodynamic, nuclear, geometric and aerodynamic criteria for optimum design. Also presented are parametric curves which are helpful in design optimization of the reactor.

Terrall, J.R. “Reactor Kinetic and Temperature Equations”. DC-55-10-78. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Aug. 15, 1955 (Decl. June 16, 1961). 22p.

The kinetic and temperature equations for a direct cycle reactor of the GE-ANP type are considered, with the goal of obtaining time-varying fuel element temperatures and their output air temperature as these quantities depend on inlet air temperature and mass flow and on control rod motion; which are assumed given as functions of time. Supplementary information provided in the course of the calculations includes the time variation of reactor power. The main assumption made is that the space-energy characteristics of the reactor flux go from one equilibrium condition to another no matter what time variations are occurring. With the results presented here, an electronic analogue computer can be used as a reactor simulator in conjunction with a real engine and reactor control system to obtain fairly realistic information on the whole reactor-engine system. An important feature of the method presented here is that fuel and air temperatures can be found anywhere in the reactor by using only the characteristics of the air entering the core, and the fissioning rate.

Thome, P.G. and Nicoll, H.E. "Thrust Requirements for Supersonic Airplanes". DC-60-5-24. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Apr. 28, 1960 (Decl. Sept. 13, 1973). 46p.

The cruise and take-off thrust requirements of nuclear supersonic airplanes designed for Mach numbers of 1.5, 2, 2.5 and 3 are presented. The requirements are expressed as a function of power plant plus crew shield weight and flight altitude. The total weight of the nuclear propulsion system was varied from 140,000 pounds to 340,000 pounds and the flight altitude from 20,000 to 80,000 feet in addition the thrust requirements of a nuclear version of the B-70 are given as a function of total nuclear propulsion system weight and flight Mach number.

Thornton, Gunnar. “Shielding Information Design by Nuclear Analysis Section at the Initial Engine Test (IET).” Letter to J.A. Hunter. General Electric, ANP Dept., Cincinnati. Feb. 26, 1953.

Recommends that the shielding measurements at the IET be restricted to very simple measurements of thermal neutron flux and gamma and fast neutron dose rates.

Thornton, Gunnar. “Recommendations for GE-ANP Test Program.” Memorandum to A.E. Focke. General Electric, ANP Dept., Cincinnati. July 1, 1953.

Recommendations for future ANP test program for materials and fuels to be tested in the MTR.

Thornton, Gunnar. "Comments on Engineering Test Reactor." DC-55-4-143. Project 100 Memorandum to C.S. Larkin, Thermodynamics Analysis. GE-ANP Div., Cincinnati. April 12, 1955. 3p.

Provides design input from the Project 100 Manager, GE-ANP for the Engineering Test Reactor (ETR) under design by the Phillips Petroleum Co. (in Idaho). These comments, based in part on the author's experience with the Materials Test Reactor, are to ensure maximum access to an experimental area outside the reflector to conduct very large tests in lower radiation fluxes, and to improve access to the reactor top. Thornton believes that the GE ANP Dept. should obtain an ETR for its own use, or for the use of the GE Atomic Products Division.

Thornton, Gunnar. "Selection of Design Features for Technical Design Reports." DC-55-9-81. GE-ANP Dept., Cincinnati. September 12, 1955. 1p.

Records the design configuration decisions made for the Dec.1, 1955 technical design report for the WS-125a project. These decisions were established by the Advanced Design group and are subject to change. The following apply to both the single-engine and multi-engine power plants: Fuel elements - ribbon type concentric ring, material not selected; Moderator - zirconium or yttrium hydride with circular holes for fuel; Reflectors - beryllium; Control - movable rods for multi-engine, reflector control for single engine designs. Present plans are to decide between the single or multi-engine designs by Oct. 15, 1955.

Thornton, G., S.H. Minnich, C. Heddleson and D.H. Culver (Ed.). "Heat Transfer Reactor Experiment No. 1. Comprehensive Technical Report, General Electric Direct-Air-Cycle, Aircraft Nuclear Propulsion Program". APEX-904. General Electric Co. Flight Propulsion Lab. Dept., Cincinnati. Feb. 28, 1962 196 p.

The Heat Transfer Reactor Experiment No. 1 is described. Design data are presented, including a general description of the test assembly, the nuclear characteristics of the reactor, fuel element thermodynamic characteristics, and the control system. The three series of test runs are also described and the test results summarized. The general objectives of Heat Transfer Reactor Experiment No. 1 were to demonstrate the feasibility of the direct air cycle system by operating a turbojet engine on nuclear power, to demonstrate the adequacy of reactor design features, and to evaluate aerothermodynamic and nuclear characteristics of the reactor for use in the design of militarily useful aircraft power plants.

Thornton,G. and B. Blumberg. "ANP HTRE's Fulfill Test Goals". For General Electric Co., Cincinnati, OH. *Nucleonics* 19, 1 (Jan. 1961): 45-51.

Performance results from the Heat Transfer Reactor Experiment (HTRE) test series have measured up to or exceeded expectations. The series has involved three reactor systems (HTRE-1, HTRE-2, and HTRE-3) and two reactor concepts (water-moderated and ZrH-moderated). HTRE-1 achieved a number of full-power runs which demonstrated

conclusively the feasibility of operating a jet engine on nuclear power, and easily passed a 100-hr endurance test at fuel temperatures to 1850°F, operating a single J-47 jet engine at power levels of 18.5 MW. The HTRE-2 consisted of a mechanical modification of HTRE-l to serve as a test facility for advanced fuel and moderator sections. The HTRE-3 system differed from HTRE-1 and -2 in that it had a solid ZrH-moderator and an air-cooled core structure, where the others were water-cooled and -moderated. The HTRE-3 system was tested with parallel J-47 engines at 32.4 MW. Since the HTRE-3 core was designed for air flow of 850 lb/sec and the requirements of the jets were 123 lb/ sec, it is seen that when coupled to an engine system of greater capacity the HTRE-3 could conceivably develop a correspondingly higher power level. The design concepts and operational characteristics of the three reactor systems are described. Specifics are given on the performance of HTRE-3. Design, mechanical, nuclear, and thermodynamic data are included for HTRE-I.

Thornton, Gunnar. “Flight Test of HTRE #1 Reactor Engine System.” DC 55-4-112. Memorandum to Dr. Miles C. Leverett, Manager-Engineering. GE-ANP Div., Cincinnati. April 19, 1955. 2p.

Thornton suggests that GE-ANPD re-examine the possibility of operating the HTRE-1 reactor engine system with the liquid moderator and a simple shield in an airborne B-36 aircraft. He estimates this could be done in late 1957 or early 1958. The incentive for this early flight is that past experience indicates that problems inherent in an airborne system cannot be adequately addressed by ground testing alone. Thornton suggests that either GE-ANPD (in cooperation with Convair) or another contractor should obtain Air Force approval to proceed. If GE is unwilling to undertake this project, he suggests that GE offer its cooperation to the Air Force in setting up another contractor by transferring the design, and providing the engine and a set of fuel elements. The other contractor could be AGT (Aeorojet General), some other GE Defense Products Dept., or General Dynamics Corp.(GD). GD would be a logical choice since they have announced their intent to participate in the nuclear power field. Recognizing that GE management and stockholders would find it unattractive to set up a competitor in this business, he believes that the need move up the schedule for national defense purposes is an overriding consideration.

Thorson, J. W. "Reactor Controls Analysis." APEX-291. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Aug. 1, 1956. 30 p.

The approach (up to August 1956) to reactor controls analysis, as carried out by the GE-ANPD, is summarized and reviewed. For purposes of illustration, the results of the HTRE No. 3 preliminary controls analysis are outlined. Uncertainties in existing methods lead to probable errors of the order of +/- 30% in estimates of reactivity worth. Incorporation of undesirable large safety factors in a given design and resultant losses in performance are costly penalties for these uncertainties. A program is presented of controls analysis methods development which should reduce the current inherent errors considerably and improve the state of the art.

Todd, Miles J. “The Use of Depleted Uranium in the AC-110 Shield”. DC-55-12-110. General

Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Dec. 21, 1955. 18p.

Depleted uranium was proposed as the dense shielding material for the AC-110 powerplant. The results of a literature search and discussions with personnel at Hanford regarding the use of this material indicated that dimensional instability under thermal cycling at elevated temperatures is such that its use does not appear very promising at this time. Other dense shielding materials, some of which may prove more satisfactory than depleted uranium, are briefly described.

Treinen, R.L. "D14OE1 Control Nuclear Sensors". APEX-747. General Electric Co. Flight Propulsion Lab. Dept., Cincinnati, OH. July 1961. 24p.

The designs of the D140EI control nuclear sensors and the evaluation testing accomplished are described. Sensor packaging for mounting to the reactor shield assembly is discussed as are problem areas and recommendations.

Tupman, L.M. "Start-Up Instrumentation". DC-55-7-61. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. July 15, 1955. 36p.

Startup instrumentation for the HTRE-1 is described. Included are test results, calibration adjustments, and maintenance voltage charts. The prototype of this equipment was operated in the controls mockup.

VanVleck, L.D., J.H. Lofthouse, and R.B. O'Brien. "Comparison of Predicted and Measured Effluent Behavior and Summary of ACT Dose Calculations". TID 6934. General Electric Co., Aircraft Nuclear Propulsion Dept., Idaho Falls, ID. Nov 15, 1960 (Decl. Oct. 20, 1971).

The experience in a number of reactor-insert tests at the ANP Idaho site with respect to the agreement between the predicted and measured behavior of radioactive effluent in the environment is summarized. The measured data of interest in the determination of the radiation dose to downwind areas are included. Dose predictions are presented for the ACT operating 800 hours per year at the FET as well as for the localized melting accident. It is concluded that operation of the ACT can be carried out as proposed without exceeding permissible dose limits.

Walsh, E.P. "List of Product Related Tests in the Field of Aircraft Nuclear Powerplants." DC-57-4-54. General Electric, ANP Dept., Cincinnati. April 4, 1957.

This list was prepared to document basic information which was used to plan ANP test facilities.

Ward, W. H. "A Study of a Reactor Control System Using an Air Turbine Actuator." DC-58-4-166. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. April 23, 1958. 39 p.

Reactor flux control utilizing an air turbine motor as a control rod actuator is examined. The results of a stability analysis are presented together with an examination of the non-linearity

introduced by limiting the velocity of the control rod. An analog computer study was also performed to verify the stability analysis and quantitatively determine the effects of control rod limiting velocity. The conclusion is that the system will be stable for any reasonable amount of saturation. Further a limiting velocity of 0.35% reactivity per second or greater will not materially effect the transient response of the system. The main question concerning the air turbine motor that needs further examination is the mechanical reliability.

Watrous, D. L. "Reactor Control Components Study. Part Ii. A Pulse Relaxation Amplifier Circuit Analysis." DC-59-7-2. General Electric Co. General Engineering Lab., Schenectady, N.Y. For General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Jan. 27, 1959. 36 p.

An analysis was made of a basic pulse relaxation amplifier (PRA) circuit. Several reactor pulse tests were conducted to gain practical design information. A typical PRA amplifier was built and evaluated. Finally, a set of design requirements were formulated.

Wells, F. E. "Stresses in Hexagonal Tubes." DC-61-3-128. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Mar. 27, 1961. 8p.

Experimental work on hexagonal tubes with D/W ratios of 0.728 and 0.67 is described. Tests showed that the stresses resulting from internal pressure are a combination of bending stress and hoop stress, resulting in the maximum stress occurring on the I.D. of the tube at the thickest point.

Wetzel, D. E. "Nuclear Analysis of the HOTCE Reactor. Part 1. Reactivity-Temperature Relationship." XDC-59-10-201. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Sept. 1, 1959. (Decl. July 6, 1961). 26 p.

An analysis of the Hot Critical Experiment (H0TCE) performed at the Low Power Test Facility at the Idaho Test Station is presented, and current analytical methods of determining temperature effects an reactivity in heterogeneous, hydrided zirconium moderated reactors are evaluated. Results show good theory-experiment agreement on system multiplication at 68 deg.F., however temperature effects while having the correct sign, were of incorrect magnitude. Indications are that the inability of current analytical methods to predict correct magnitude of temperature effects is due to the incorrect treatment of thermal and non-thermal neutrons in the slowing-down calculation.

Wilks, P.H. "The Release of Fission Products from Reactor Fuel. A Literature Survey." APEX-474. General Electric Co ., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Mar. 23, 1959 (Decl. June 1, 1961). 33p.

A discussion of available data on fission product release is presented. The survey is divided into data from actual incidents, field release experiments, laboratory release from fuel element samples, and pyrometallurgy. An author index and an alpha-numerical index are included.

Willsey, Robert H., Paul K. Hiser, Merle E. Ward and Archie D. Wilcox. "Reactor Startup Control Component Development." DC-58-8-223. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Aug. 27, 1958. 76 p.

Some of the reactor startup control electrical components currently being developed in the ANP Department are described. The system function, electrical performance requirements, sensitivity to temperature, and the size and shape characteristics are described. Planned environmental tests and development goals are listed. Component life in nuclear radiation fields is estimated. Block diagrams, electrical schematics, response plots, photographs and drawings are used to give an up-to-date picture of the status of these developments. The automatic checkout feature of the *system is* presented and described.

Woike, O. G. "Introduction to Nuclear Propulsion, Lectures on Mechanical Design." GEMP-1900. General Electric, ANP Dept., Cincinnati. No Date. 66p.

Presents a discussion of the mechanical design of the gas-cooled high temperature nuclear reactor for the GE-ANP Program.

Woodbridge, J. 0. "Inspection Data on Moderator Tubes for Insert 1-D." DC-58-3-37. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Mar. 4, 1958. 17 p.

The history and inspection information are presented on the seven clad hydrided-zirconium moderator tubes used in the I-D assembly for HTRE-2 one-tube burnout tests.

Woodbridge, J. 0. (ed.). "Preliminary HTRE No. 1. Project 100 Operation Manual 21, Reactor Assembly. Core 'A.'" XDC-55-9-158. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. Sept. 28, 1955. (Decl. June 9, 1961). 211p.

A compilation is given of the information directly concerning operation of the Heat Transfer Reactor Experiment, Reactor Assembly Core A. An introductory discussion includes a general description of the HTRE and the Reactor Assembly Core A, power plant characteristics and detailed descriptions of the control, instrumentation and auxiliary systems. A discussion on operational techniques, includes descriptions of checkouts, operating limits, startup procedure, period range, power range and shutdown procedures and safety precautions.

Wysnewski, R. E., and E.P. Jacobs. "Investigation of Thermal Shield Poisoning Effects on the P140B Shield". DC-60-5-11. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. May 5, 1960 (Decl. Sept. 13, 1973). 18p.

The results of an investigation boron and gadolinium poisoning in the thermal shield of the P140B third iteration design are presented. Six separate cases were studied in order to determine the effects of various thermal shield poisons on heating rates along a radial traverse in the side shield and on the gamma dose rate at 50 feet out the side. The use of enriched boron only in the pressure pads results in the lowest side shield hearing rates of all cases studied. Results also indicate that natural boron in both the thermal shield and pressure pads is a more effective thermal poison than gadolinium.

Zeman, K.P., W.R. Young, and L.F. Coffin, Jr. "Friction and Wear of Refractor Compounds".
APEX-625
General Electric Co. Research Lab., Schenectady, NY. May 1959. For General Electric Co. Flight Propulsion Lab. Dept., Cincinnati, OH. 83p.

A search was made for bearing materials that will perform satisfactorily in aircraft nuclear power plants with low friction and wear in an air atmosphere of 2000°F or higher. Refractory compounds for use as bearings were investigated as well as the possibility of employing various materials, both metallic and nonmetallic, as lubricants for these compounds.

b. PRATT & WHITNEY AIRCRAFT CO.

Alessandro, L.P. "Heat Generation in the Reactor Shield of the NJ-18A Powerplant. FXM-4929. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Jan. 16, 1961 (Decl. Sept. 20, 1973). 12p.

The calculations which were performed to determine the total heat generation in the reactor shield of the NJ-18A powerplant are summarized. The heating in the shield is the result of the energy release accompanying gamma attenuation, neutron energy degradation and neutron capture in the Li^6 (n, α) reaction in the LiH portion of the shield. The method used to determine the heating in the shield to essentially the same as that used by the SC-1 code. The method consists of dividing the shield into conical rings and integrating the power density over the volume of the ring. Non-sphericity factors are then used to convert the spherical volume elements to the actual shape of the shield. These factors vary with position around the reactor. A 3.11 cm layer of depleted uranium around each reactor limits the maximum γ-dose rate at 50 feet to 10,000 rem/hr.

Andrews, N. D. "Estimated Performance and Weight of a Twin Power Package Using Two 120 MW Element Reactors". PWAC-141. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Nov. 9, 1955. 13p.

Estimated performance and weight are presented for two power package powerplants arranged to power one airplane. Each power package contains one 120 MW solid fuel element reactor. Each reactor is closely coupled to one, two, or three nuclear-chemical turbojet engines each of which has a sea level static airflow of 400 lbs/sec and a design compressor pressure ratio of 7/1. The two engines, reactor and associated pumps and equipment are completely contained in a streamlined pod. The results presented include net thrust, thrust specific fuel consumption, reactor power, airflow and a breakdown of the power plant weight.

Andrews, N.D. "Performance Group Progress Report, April 1958". CNLM-749. Pratt and Whitney, Aircraft, Middletown, CT. May 6, 1958 (Decl. Jan. 12, 1976). 5p.

Performance studies of proposed nuclear propulsion systems for the Princess airplane are presented. The Princess was a proposed nuclear powered seaplane for the Navy.

Bearsley, G.E., Jr. "Fifth Monthly Progress Report". CNLM-1101. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Sept. 15, 1958 (Decl. Jan. 6, 1976). 3p.

Design studies for the reactor powerplant for the Princess airplane are described.

Bellow, B. and R. Chapman. "Reactor Poisoning." FXM-1071. Pratt and Whitney, Aircraft Div., United Corp., Hartford, CT. Mar. 2, 1955. 20p.

An investigation was made of the poisoning effect of the fission products of U^{235} in the fireball reactor. The problem was divided into two parts: to find the poison concentration in the reactor fuel after a length of time and to find the change in the average number of neutrons produced per fission for various concentrations of the poison. The reactivity due to each of the isotopes was calculated and the sum of these reactivities was found. The total reactivity was plotted at 1000 hours on a graph of reactivity versus operation time.

Beltracchi, L., P. Gurski. "Control Study of 80 MW Powerplant Test". FXM- 4413. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Jan. 26, 1960 (Decl. Sept. 20, 1973). 56p.

The basic control system for the 80 MW test of the PWAR-11C with a JN-58 engine consists of maintaining the core exit lithium temperature by means of the control drums and maintaining liquid metal temperature rises by variation of liquid metal pump speed. The control drums operate from a temperature error between a requested and a measured temperature of the core exit lithium. The lithium pump operates automatically to maintain a 400°F lithium temperature rise through the core. The NaK pump operates automatically to maintain a 400°F NaK temperature rise through the intermediate heat exchanger. The only parameter scheduled in this control is the core exit lithium temperature. Core exit lithium temperature and radiator inlet airflow and air temperature determine power. The operation of the heat loop was found to be satisfactory in dissipating transient and afterheat of a reactor scram.

"Bibliography of CANEL Reports". PWAC-500, Vol. I and II. Pratt & Whitney Aircraft Corp., Div. of United Aircraft, Middletown, CT. December 1965. P.592.

This bibliography of all reports produced at the CANEL facility during the period 1952 through 1965 was prepared to catalog technical work on the ANP Program, as well as other nuclear work. The bibliography contains the report number, title, author, date published, and classification. Over 9,000 reports, both external and internal are included. The Division of Technical Information Extension (DTIE) at Oak Ridge, TN was designated as the primary recipient of the reports in the CANEL Library. If more than one copy was available, additional copies were delivered to Lawrence Radiation Laboratory, Livermore CA.

Bigelow, C.C, H.C. Gray, D.E. Robinson, G.H. Rowe, M.E. Shank, C.R. Soderberg, and N.H. Triner. Discussion of Columbium-1.0 Zirconium Alloy Properties Relative to the PWAR-11C Reactor Structural Design". CNLM-2487. Pratt and Whitney Aircraft, Middletown, CT. Aug. 31, 1960 (Decl. 31 Oct 1972). 80p.

Examined properties of Nb-l Zr alloy for use in components of aircraft nuclear power plants. Mechanical properties data showed that the material was well understood and that it had no adverse properties. By the selection of criteria and analysis of the structure, the niobium-1 zirconium alloy has adequate strength and ductility at the temperature levels in which it is required to perform. The main emphasis was on the reactor structural design; the results of the pressure vessel analysis are presented in detail as typical of the approach.

Bigelow, C.C., D.T. Hedden, and E.C. Crume. "Preliminary Hazards Report for a Reactor Experiment at NRTS, July 1960". Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab. Middletown, CT. Apr. 1, 1961 (Decl. Sept. 20, 1973). 321p.

This report was submitted to the Atomic Energy Commission for review by the Advisory Committee on Reactor Safeguards and Hazards Evaluation Branch to obtain approval to proceed with final design and construction of a nuclear reactor test facility at the National Reactor Testing Station in Idaho. The purpose of the report was to demonstrate that a 10 MW reactor test system can be operated safely in the proposed facility with acceptably small risk to the public. The proposed 10 MW reactor experiment was to be conducted by Pratt & Whitney Aircraft as a major step in the development of an aircraft nuclear powerplant. Preliminary design criteria were prepared for modifying the Initial Engine Test (IET) facility to provide a technically adequate and safe facility for this purpose. The new facility, called the Reactor Test Facility (RTF), differed from the previously proposed Connecticut Aircraft Nuclear Engine Laboratory (CANEL) facility in its geographical location, elimination of the containment vessel, installation of the test system on a rail-mounted dolly and the introduction of a separate Assembly Building and Hot Shop connected to the test facility by a rail system.

Bigelow, C.C., D.T. Hedden, E.C. Crume. "Preliminary Hazard Report for a Reactor Experiment at CANEL, July 1959". Pratt and Whitney, Middletown, CT. Jan. 30, 1961 (Decl. Sept. 20, 1973). 396p.

The report analyzed various hazards that might be associated with the testing of 20 MW lithium-cooled reactor experiment in the NTF. The manner in which these hazards have been considered and evaluated was presented. Prior to startup and test, a final hazards report was to be issued covering the final details of construction, control and operation of the reactor and the "as built" facility. The NTF provided the capability for assembly, nuclear testing and disassembly of the 10 MW lithium-cooled reactor experiment. It provided positive containment of all the fission products which might be released from the reactor core as a result of the maximum credible nuclear accident.

Black, J.R. and U. Matrella. "In-Pile Capsule Design Report for a UC Fuel Specimen (Type 19e) Operating at 2200°F and 1.5 Kw/cc (A-He Barrier)". TIM-780 (Suppl. 10) (Rev. 1). Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Apr. 29, 1964 (Decl. Oct. 20, 1971). 2p.

Bliss, P. "Liquid Metal Instrumentation Practice". Nuclear Process Instrumentation and Controls Conference Held in Gatlinburg, Tennessee, Pratt and Whitney Aircraft Div., United Aircraft Corp. Middleton, Conn., May 20-22 (1958): 86-101.

The techniques of instrumentation for liquid metal systems as practiced at Pratt and Whitney Aircraft CANEL are reported. The fabrication, testing, and performance of clad thermocouples, liquid metal pressure transmitters, leak detectors, liquid metal level indicators, and electromagnetic flowmeters are described.

Bronke, V., J. Brueger, W. Gray, and R. Smith. "NJ-11A Powerplant Characteristics Summary". PWAC-201. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Sept. 16, 1957 (Sept. 20, 1973). 59p.

Data on a two-engine lithium-cooled powerplant for the minimum-altitude mission are presented. The selection of power plant characteristics was based on the criterion of obtaining maximum transonic speed at sea level consistent with reasonable powerplant weight. The heat source of the power plant is a solid-fuel-element reactor utilizing a columbium alloy as structural material. Heat is removed from the reactor by liquid lithium piped directly to the engine radiators. The reactor at its design condition is capable of producing 350 MW of heat. For the minimum altitude application, however, the maximum reactor power that the two engines are capable of absorbing on a standard day at the Mach 1.1 sea-level radiator design point is 312 MW. At this condition, the temperature of the lithium entering and leaving the reactor is 1250°F and 1650°F, respectively.

Bronke, V. and W. Gray. "Minimum Altitude Nuclear Bomber Powerplant Characteristics Summary". PWAC-187. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab. Middletown, CT. July 8, 1957 (Decl. Sept. 20, 1973). 57p.

Data on a sodium-cooled two engine power plant for the minimum-altitude mission are presented. The selection of power plant characteristics was based on the criterion of obtaining the maximum speed at sea level consistent with reasonable power plant weight. The heat source for the power plant is a solid-fuel element reactor of stainless steel construction. Heat is removed from the reactor by liquid-sodium which is pumped through intermediate heat-exchangers where the heat is transferred to the liquid NaK. The liquid NaK is circulated to the engine radiators where the heat is transferred to the engine airflow. The reactor core used for this power plant is identical with that used for the W-1-125A power plant study and is capable of producing a maximum power of 250 MW. At this power sodium enters the reactor at 1050°F and leaves at 1600°F, while the NaK enters the radiators at 1520°F and leaves at 900°F. For the minimum altitude application, however, the maximum reactor power which the engines are able to absorb is 200 megawatts at a Mach number of 1.2 at sea level. The shielding estimates made for this power plant are consistent with the actual power which the powerplant is able to develop.

Bronke., V. and W. Gaffin. "Nuclear Pod-Mounted Turbojet Powerplant Characteristics Summary". PWAC-262. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab. Middletown, CT. Nov. 21, 1958. 14p.

Information is presented on a power plant intended for application to subsonic airplanes, such as logistics carriers, personnel carriers, airborne alert missile launchers, and airborne early warning airplanes, which require a large portion of the fuselage volume to be shielded to relatively low radiation levels. The power plant consists of two wing-mounted pods, each containing two nuclear turbojet engines and one lithium-cooled, solid fuel element reactor.

Brueger, J., and V. Bronke. "Characteristics Summary of Nuclear Turboprop Powerplants". PWAC-217. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Jan. 2, 1958 (Decl. Sept. 20, 1973). 25p.

Pratt & Whitney Aircraft is investigating the use of sodium-cooled and lithium-cooled solid fuel-element reactors for several possible manned aircraft applications. Data for two configurations of nuclear turboprop powerplants for application to logistics type airplanes are presented. These powerplants are made up of sodium-cooled solid-fuel-element reactors coupled to nuclear-chemical T57 turboprop engines. The selection of powerplant characteristics was based on the criterion of maximum payload resulting from a logistics airplane performance study. Each of the two powerplant configurations for which data is given has four engines. Powerplant A consists of two wing-mounted, 60 MW, solid-fuel-element reactors each of which is coupled to two engines. Powerplant B has a single, fuselage-mounted, 120 MW, solid-fuel-element reactor coupled to the four engines. One half of Powerplant A, one reactor and two engines, is considered to be an independent unit.

Brueger, J., and W. Gray. "Weapons System 125A Nuclear Bomber Powerplant Characteristics Summary". PWAC-188. Pratt and Whitney Aircraft, Middletown, CT. July 1, 1957 (Decl. Sept. 4, 1973). 91p.

Data on two, three, and four engine powerplants for the nuclear cruise, chemical-dash, WS-125A mission are presented. The selection of powerplant characteristics, i.e., the reactor power and radiator dimensions, was based on the criterion of the maximum dash penetration radius resulting from an airplane performance study using the four engine powerplant. The heat source of each powerplant is a solid fuel element reactor of stainless steel construction. Heat is removed from the reactor by liquid sodium which is pumped through intermediate heat-exchangers where the heat is transferred to liquid NaK. The liquid NaK is circulated to the engine radiators where the heat to transferred to the engine airflow. At design conditions. the reactor produces 250 MW of heat, and the sodium enters the reactor at 1050°F and leaves at 1600°F, while the NaK enters the radiators at 1520°F and leaves at 900°F.

"Budget Estimate, FY 1961" CNLM-1613. Pratt and Whitney Aircraft, Middletown, CT. 1961 (Decl. Jan. 12, 1976). 50p.

Budget estimates for the program for development of aircraft propulsion reactors are presented.

Butler, E.N., U.A. Mattrella, K.R. Thoms. "In-Pile Capsule Design Report for UN Fuel Element Specimens (Type 18B) Operating at 0.4 Kw/cc and 2000°F." TIM-781. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Jan. 22, 1964 (Decl. Oct. 20, 1971). 17p.

"Career Opportunities in Nuclear Aircraft Propulsion". Pratt and Whitney Aircraft Co. , Division of United Aircraft Corp. East Hartford, CT. Advertisement in *Scientific American.* Sept., 1954.

Discusses opportunities for scientists and engineers in the ANP Program which is now expanding. Immediate need indicated for nuclear engineering experience in thermodynamics, heat transfer, controls, reactor physics, high temperature metallurgy, etc.

Carlson, C.E. and F.F. Felber, Jr. "Irradiation and Examination Report of Capsule PW 26-523". TIM-855 (Suppl. 6). Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Feb 2, 1965 (Decl. Oct. 19, 1971). 11p.

Capsule PW 26-523 contained a single test specimen consisting of hyperstoichiometric UC fuel of low density in tantalum lined Cb-1Zr alloy cladding. The test specimen was ran for 944 hours at 2190°F at an average power density of 1.4 KW/cc to 0.87 a/o uranium fission burnup. Chemical analysis of the cladding, after removing the Ta liner, indicated a carbon pickup of from 90 to 560 ppm. Porosity of the fuel was primarily intergranular and was estimated to be 10-20 v/o. Voids were not interconnected. Because of the low density (80% of theoretical), it was expected that the gas release would be considerably higher and, consequently, the fuel swelling would be much lower. The fact that this did not occur may be attributed to the lack of interconnected fuel porosity, which resulted in fission gas pressure buildup in the closed pores.

Cole, Phipps. "Delayed Neutrons in `Fireball'". FXM-411. Pratt and Whitney Aircraft Div., United Aircraft Corp., Hartford, CT. May 11, 1953. 5p.

A study was made of delayed neutrons in the Fireball Reactor. For the physical configuration of the fireball, delayed neutrons are shown to be approximately 20%; as effective as in a non-circulating reactor.

"Construction of Four Monoblock Seal Test Stands for Endurance Testing". CNLM-2605. Pratt and Whitney Aircraft, Middletown, CT. May 23, 1960. 5p.

A relatively simple, but reliable, seal endurance test start is described. The seal specimen will require oil for cooling and lubrication. In order to facilitate this, it is suggested that the oil system presently located in X526 and X525 be piped to the endurance test area.

"Control System Analysis of the NT-15 Nuclear Turboprop Powerplant". PWAC-270. Pratt and

Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Feb. 1, 1959. 81p.

The results are presented of digital and analog computer studies of the control system of the NT-15 nuclear turboprop power plant proposed for installation in the Princess flying boat. The propulsion system proposed for the installation includes the nuclear power plant and four chemically fueled Pratt & Whitney Aircraft T-34 turboprop engines. The nuclear power plant comprises a PWAR-13 reactor, the liquid metal system necessary to transport heat energy from the reactor to the engines and two Pratt & Whitney Aircraft T-57 turboprop engines. The T-57 engines may be operated individually and independently on nuclear heat, chemical fuel or a combination of the two. The Princess installation has the capability of cruising on nuclear heat only. Takeoff and landing are accomplished on chemical fuel with both T-57 and T-34 engines operating.

deGanahal, C.F. II., and N.D. Andrews. “Estimated Weight Scaling Data For a Twin Power Package Using the Solid Fuel Element Reactor”. PWAC-142. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Dec. 15, 1955. 6p.

Estimated data are presented for scaling the component weights of the power package consisting of a solid fuel element reactor closely coupled to one, two, or three nuclear-chemical turbojet engines each of which has a sea level static airflow of 7/1. The data presented are in the form of curves which enable scaling the weight of the NaK system components and the turbojet engine from a reactor power of 40 MW to 100 MW per engine and the weight of the reactor, shielding and intermediate heat exchanger system from a total reactor power of 40 MW to 300 MW.

“Design and Testing of Columbium-1 Zirconium Reactor Pressure Vessels”. PWAC-371. Pratt and Whitney Aircraft, Middletown, CT. Oct. 15, 1962 (Decl. Oct. 31, 1972). 79p.

The design and test programs are described for columbium-1 zirconium pressure vessels for lithium-cooled aircraft reactors.

Dickson, J.A.(ed.). “Pratt and Whitney Sodium-Stainless Steel Fast Reactor”. PWAC-239. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Sept. 1, 1958 (Decl. Sept. 20, 1973). 122p.

The conceptual design of the PWAR-239 aircraft propulsion reactor is described in detail.

“Discussion of Liquid Metal System Integrity and Aircraft Shielding Questions". Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Mar. 22, 1961 (Decl. Jan. 12, 1976). 12p.

The design, fabrication, and development of the NJ-18 power package is being conducted in order to eliminate possible liquid metal leaks. However, should an inadvertent leak occur, provisions to handle the problem are designed into the system: (1) secondary containment around all liquid

metal components. (2) damage control valves, (3) leak detection systems, (4) liquid metal dump systems, (5) fire barriers, (6) jet engines capable of operation on both jet fuel and nuclear power, (7) two reactors, only one of which is required to supply the airplane full thrust requirement at cruise, and (8) four engines, only two of which are required to fly the airplane in an emergency. Nuclear powered aircraft shielding studies of the liquid metal cycle show that large shielded payload compartments are possible with relatively low radiation dose levels emanating from the powerplant reactor shield for subsonic aircraft. Large shielded payload compartments are possible for supersonic aircraft; however, higher radiation dose levels must be accepted outside the reactor shield.

Dytko, E.R., R.M. Kuhns. "Fueled BeO for Nuclear Reactors". CNLM-3160. Pratt and Whitney Aircraft, Middletown, CT. Nov. 25, 1960 (Decl. Sept. 17, 1973). 23p.

Fuel pins containing UO_2-65 vol % BeO pellets are to be used in a Li-cooled high intermediate spectrum reactor for aircraft use. The irradiation performance of the fuel element is described (15 figures). A method is described for making pressed compacts of nuclear fuel . A die cavity is loaded with a mixture of coated fuel particles, polymerizable resin, and granular matrix material such as graphite and heated so that an even temperature exists throughout the contents.

"Engineering Proposal for Support of Additional Research and Development Work on Materials and Propulsion Equipment Components of Aircraft Nuclear Propulsion Systems". CNLM-2307 (SUPPl. 1). Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Mar. 18, 1960 (Decl. Dec. 8, 1975). 9p.

Proposed research and development work is outlined concerning powerplant performance analysis, engine components, radiators, materials, liquid metal system components, instrumentation, and controls.

"Engineering Design Status Report on the PWAR-5A Test Reactor March 15, 1958". PWAC-200. Pratt and Whitney Aircraft, Middletown, CT. No Date. (Decl. Oct. 31, 1972). 365p.

Engineering, design. and physics information for the solid fuel sodium-cooled test reactor (PWAR-5) is presented. Design criteria, reactor core, coolant loops, materials. shielding, control and instrumentation, and critical experiments are considered.

"Estimated Performance and Weight Data for All-Nuclear Sea Level Powerplants". CNLM-149. Pratt and Whitney Aircraft, Middletown, CT. August 20, 1957. (Decl. Jan. 12, 1976). 3p.

Performance and weight data for lithium- and sodium-cooled aircraft propulsion reactors are presented.

Fader, W. J. and R. C. Harrison (Pratt & Whitney CANEL, Middletown, Conn.). "The Determination of the Period Reactivity Relation and Open-Loop Reactor Transfer Function from Rod-Drop Decay

Data." *Nuclear Sci. and Eng.*, 11: 405-14 (Dec. 1961).

Reactor period-reactivity relations and open-loop transfer functions may be determined directly by numerical integration of rod-drop neutron decay data without analysis of delayed neutron period and abundance values. Period reactivity relations obtained by this method for two critical assemblies with and without beryllium in the core and reflector are compared with corresponding results calculated from the "in-hour" equation. Results of the application of the rod-drop experiment to the determination of the open loop reactor transfer function are given for the beryllium-moderated assembly.

Fader, W.J., J. Krause, and L.A. Cavanaugh. “CCA-3 Critical Experiment Program Report”. PWAC-313. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Jun. 30, 1961 (Decl. Sept. 20, 1973). 213p.

Engineering design studies were made at CANEL of a proposed 250 MW aircraft reactor, PWAR-12, a lithium-cooled fast reactor with columbium-clad columbium-uranium dioxide cermet fuel elements, and of a 10 MW test reactor version, PWAR-12C. In support of the design studies, a series of critical experiments were undertaken at the CANEL Nuclear Physics Laboratory on CANEL Critical Assembly No. 3 (CCA-3) to investigate a characteristics of the PWAR-12 reactors. A brief description of the PWAR-12 reference design is presented. Descriptions of the critical assembly equipment and instrumentation are included. The experimental results are summarized.

Fish, R.W. “Fission Gas Accumulation in the PWAR-11 Ceramic Fuel Elements”. FXM-4014. Pratt and Whitney Aircraft, Connecticut Engineering Lab., Middletown, CT. Mar. 26, 1959 (Decl. Sept. 20, 1973). 9p.

Data on calculated fission gas production for 200-MW operation of PWAR-11 fuel elements are presented. All gaseous fission- product decay chains are examined for use in estimating concentration of gaseous products at any time after startup.

Fish, R.W. “Helium Generation in the Ceramic Fuel Elements”. FXM-4015. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Apr. 3, 1959 (Decl. Sept. 20, 1973). 7p.

The basis for experiments to determine the extent of helium generation in ceramic fuel elements operating in reactors incorporating Be moderators and reflectors is presented. Neutron reactions with BeO are discussed along with neutronics of the 200-MW PWAR-II fuel pin.

Frankfort, J.H. “Design Criteria for a Full Power Test Facility”. WKNL-62. H. Walter Kidde Nuclear Labs., Inc., Garden City, NY. June 20, 1956 (Decl. Oct. 18, 1971). 133p. For Pratt and Whitney Aircraft, East Hartford, CT.

The Full Power Test Facility described will furnish data on the nuclear and process characteristics of an aircraft-prototype, circulating-fluoride fuel reactor operating at a power level of 300 MW. Operation of this facility chronologically follows operation of the Low Power Test Facility in the nuclear aircraft development program. The facility design criteria given do not represent a completely finalized set of specifications. Rather, they are intended to furnish sufficient information to enable establishment of the final design. The specifications given cover the equipment necessary for operation of the reactor and for removal of the heat generated in the fuel.

Gaffin, W. "Applications of Advanced Liquid Metal-Cooled Reactors, April 15, 1959". PWAC-276. Pratt and Whitney Aircraft, Middletown, CT. Apr. 22, 1959 (Decl. Sept. 12, 1973). 37p.

Many possible applications of lithium-cooled, moderated reactors have been considered in more or less detail, and several of these applications showed sufficient promise, from a technical standpoint to warrant further study. Summaries of the characteristics of the more promising applications are presented.

Gaffin, W.O. and Perry, P.I. "Nuclear Turboprop Powerplant Preliminary Performance and Installation Data". PWAC-405. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. June 25, 1963 (Decl. Sept. 5, 1973). 22p.

Preliminary estimates are presented of the performance, weight dimensions and handling requirements of a nuclear powered turboprop powerplant for use in a large, low speed, long endurance airplane. Because of a shortage of time and the lack of definition of airplane requirements, the powerplant has not been completely optimized for the mission. However, the estimates should prove adequate for preliminary feasibility studies.

Gary, W. "NJ-12B Supersonic Bomber Power Plant Performance Characteristics Summary". PWAC-242. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Apr. 1, 1958 (Decl. Sept. 20, 1973). 62p.

The power plant described is intended for application to a strategic bomber with an all-nuclear supersonic cruise capability. The characteristics of the power plant, i.e., the reactor power, liquid-metal temperatures and radiator dimensions, were chosen on the basis of an airplane study to provide the maximum flight Mach number. The results of the study indicate that the system is capable of speeds exceeding a Mach number of 2.0 at 40,000 feet altitude. The power plant heat source is a stainless steel, sodium cooled fast neutron reactor. The high neutron energy spectrum results in low sodium activation, and permits circulation of the reactor coolant directly to the engine radiators. The need for an intermediate heat-exchanger and its associated equipment is thereby eliminated. At the design condition, the reactor produces 350 MW of heat; sodium enters the reactor at 1250°F and leaves at 1650°F. The high sodium temperature is the maximum temperature which makes feasible the use of stainless steel as the reactor structural material.

"General Work Plan Reactor Program, May 1, 1961- September 30,1961". CNLM-3642. Pratt and Whitney Aircraft, Middletown, CT. 1961 (Decl. Jan. 12, 1976). 46p.

Information on the development of aircraft propulsion reactors program, concerning the general program, master program schedule, program schedule for May 1961 to December 1961, program cost breakdown, and program material breakdown.

"Giving Work Classes by Number and Description". CNLM-1344. Pratt and Whitney Aircraft, Middletown, CT. 1964. 12p.

Specific projects in the program for development of a nuclear aircraft engine are described.

Gray, W., J. Brueger, J. Larson, and K. Andrews. "All-Nuclear Supersonic Bomber Powerplant Characteristics Summary". PWAC-180. Pratt and Whitney Aircraft, Middletown, CT. June 3, 1957 (Decl. Sept. 12, 1973). 35p.

The use of lithium-cooled solid fuel element reactors for an all nuclear supersonic mission is described. The characteristics of the powerplant, i.e., the reactor power and radiator dimensions, were selected based on the results of an airplane performance study. The criterion on which these were selected is the maximum flight Mach number on the airplane. The heat source of the power plant is a solid fuel element reactor with a columbium alloy as the structural material. Heat is removed from the reactor by liquid lithium which is piped directly to the engine radiators. At design conditions, with the reactor producing 350 Mw of heat, the lithium enters the reactor at 1350°F and is heated to 1650°F. The maximum fuel element surface temperature under these conditions is 1700°F. The hot lithium temperature of 1650°F was selected as being the feasible temperature to use with engine radiators that have stainless-steel-clad Copper fins. A higher temperature would require the use of a more oxidation-resistant fin material which would have poorer heat-transfer characteristics.

Green, R.S. "Development Plan for NJ-18A Power Package Flight Test Program, 1963-1967". CNLM-3317. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Jan. 24, 1961 (Decl. June 12, 1976). 34p.

The Pratt & Whitney Aircraft plan for the flight test portion of the engineering and development of an indirect cycle nuclear propulsion system capable of satisfying the requirements of the Convair NX2 airplane is presented. The planning covers the power package scheduling and costing involved in: (1) a flight test-bed program devoted primarily to propulsion system development and (2) a nuclear powered aircraft development program devoted primarily to the resolution of practical nuclear aircraft operation. These two major programs of flight testing will be conducted in two NX2 aircraft. The program plans, schedules, and cost estimates presented are contingent upon a continuing program from 1960 through 1965 with funds, additional facilities, and new facilities being made available as required.

Hahnel, W.F. and Stebbings, R.C. "PWAR-11C Core Removal". Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. June 21, 1960 (Decl. Jan. 15, 1976). 7p.

Directions are provided for the removal and disassembly of the core of PWAR-11C. This operation is to be done remotely in an inert atmosphere 72 days after the test reactor is shut down.

"HE-12CL Test Heat Exchanger". CNLM-3143. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Nd. 3p.

Specifications for the HE-12CL heat exchanger are presented.

Hedden, D.T., and D.B. McFarlane. "CTF Summary Hazards Report". TIM-425. Pratt and Whitney, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Oct. 15, 1957 (Decl. Oct. 19, 1971). 150p.

The development of a nuclear power plant under the Nuclear Propulsion Program required a facility for reactor testing. Detailed design criteria were prepared for such a facility, called the Contained Test Facility (CTF). The various hazards that might conceivably be associated with aircraft reactor testing in the CTF are described.

Hirakis, E.C. "Materials engineering Meeting". CNLM-2381-14. Pratt and Whitney Aircraft, Middletown, CT. July 18, 1960. 6p.

A comprehensive coatings development program is in progress at CANEL. Its objectives are the development of coating materials and methods for the oxidation protection of columbium alloy structural elements in high temperature air operation. The effort is oriented toward the development of a combination of coating properties as follows: impact, erosion and abrasion resistance; high thermal conductivity and ability to withstand steep temperature conditions; resistance to air oxidation at the operating temperature and below; and the ability to retain the described physical and chemical properties for an extended period of time under the combined influence of fluctuating mechanical stress and high temperature environment. Although certain coating methods have been stressed in the research work so far completed, no effort has yet been made to eliminate any coating process from consideration because of the complex configuration requirement. Rather, all commercial methods are being utilized, and some laboratory processes are being explored.

"How the CANEL Project Test Chamber Was Made". Pratt and Whitney United Aircraft Corp. *Iron Age* 181, 9 (1958): 106-07.

Johnson, C.W., Jr. "High Power, Extreme Endurance Mobile Reactor Concept with Aircraft Nuclear Propulsion Potential". FXM-4917. Pratt and Whitney Aircraft, Middletown, CT. Dec. 19,

1960 (Decl. Sept. 20, 1973). 15p.

A high power (300 MW), mobile reactor is described which offers extreme nuclear endurance potential (over one million MW-hrs) through the use of a moveable core consisting of four partially fueled drums. In addition, optimized pressure drop and heat transfer properties are provided, as well as a practical means of fission gas removal, by use of plates for fuel elements. For immediate application an enriched UO_2 - BeO matrix, 140 liter core is suggested which, with an unenriched UO_2 - BeO reflector, would be contained in an 18 inch radius spherical pressure shell. 300 MW capabilities are anticipated. Core and reflector size, and consequently shield weight, could be significantly reduced by use of UC or U^{233} as basic fuel materials.

Larson, J. “Advanced Nuclear Turbojet Powerplant Characteristics Summary for Supersonic Aircraft”. PWAC-275. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Mar. 13, 1959 (Decl. Sept. 12, 1973). 27p.

The estimated powerplant characteristics of an advanced nuclear powerplant intended for use in a nuclear supersonic manned airplane is contained in this report. This nuclear powerplant consists of a 575 MW, high temperature, lithium-cooled, solid fuel element type reactor coupled to six turbojet engines especially designed for a supersonic nuclear airplane. The lithium coolant passes from the reactor at 2000°F directly to the engine radiators without the use of an intermediate heat exchanger. The engines are fitted with burners enabling the thrust produced by the nuclear powerplant to be augmented by the use of chemical fuel for the take-off, transonic acceleration and landing portions of the flight. The powerplant components have been selected for a maximum thrust-to-weight ratio at Mach 3 and 55,000 feet altitude on nuclear heat only operation compromised for net thrust produced with chemical fuel augmentation during the transonic portion of flight. The powerplant data presented, therefore, are primarily applicable to an all supersonic mission on nuclear heat alone. Weight data are tabulated for the 575 MW powerplant. The engine envelope based on preliminary radiator size estimates is illustrated. A liquid metal system flow schematic and piping data are included. Shield information including reactor shield outline assumptions, weights, and direct dose pattern at 50 feet is also included. Estimated performance on nuclear heat only operation mid nuclear heat plus burning is presented for an envelope of flight conditions.

Larson, J. “Advanced Nuclear Ramjet Supersonic Bomber Powerplant Characteristics Summary”. PWAC-259. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Oct. 15, 1958 (Decl. Sept. 20, 1973). 41p.

The results of a performance analysis of an advanced nuclear ramjet powerplant for a supersonic bomber are presented. The powerplant uses a 350 MW lithium cooled reactor coupled to ramjet engines. The weights, geometries, and performance characteristics of the system are described.

Larson, J. “ Pratt and Whitney Aircraft Nuclear JT-11 Turbojet Powerplant Characteristics Summary.”

PWAC-274. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab, Middletown, CT. Mar. 16, 1959 (Decl. Sept. 12, 1973). 43p.

The power plant data and shielding information presented describe a nuclear power plant containing a lithium-cooled, solid-fuel-element type reactor coupled to six modified Pratt & Whitney Aircraft J-58 Mod. 1A turbojet engines. This power plant incorporates an intermediate heat exchanger with lithium as the fluid circulating in the primary loop and NaK as the fluid circulating in he secondary loop. The engines are fitted with burners and afterburners enabling the thrust produced by the nuclear power plant to be augmented by the use of chemical fuel. Weight data are tabulated for 350 MW and for 575 MW power plants. Flow schematics A the liquid metal system and of the bleed-air ducting are illustrated. Based on assumed conditions, shield information, including weights and direct dose pattern at 50 feet, is given for several reactor installations. Estimated performance of the 350 MW and of the 575 MW power plants is presented for nuclear heat only operation, and for nuclear heat plus interburning operation within an envelope of subsonic flight conditions. Performance on nuclear heat plus interburning and maximum afterburning is given for the 50 MW power plant up to a speed of Mach 3. Partial afterburning performance data at Mach 3 is shown for altitudes between 65,000 and 82,000 feet.

Larson, J. “NJ-11 Power Plant Characteristics Summary”. PWAC-193. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Aug. 1, 1957 (Decl. Sept. 12, 1973). 101p.

The NJ-11 power plant for the nuclear cruise-chemical dash WS-125 A mission is described. Characteristics surveyed include power plant performance, weight estimation, component drawings, control system, and reactor shield.

Larson, J. “Nuclear Ramjet Supersonic Bomber Powerplant Characteristics Summary”. PWAC-257. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Aug. 22, 1958 (Decl. Sept. 20, 1973). 66p.

An investigation of nuclear propulsion systems for supersonic manned bombardment aircraft has resulted in the conclusion that ramjet engines coupled to a lithium-cooled reactor might make flight speeds greater than Mach 3 attainable in an all-nuclear supersonic bomber. The power plant performance characteristics of two all-nuclear ramjet power plants estimated to be capable of propelling an airplane at the above speeds are presented. Each of these powerplants utilizes the heat generated in a 350 MW lithium-cooled solid fuel element type reactor with a 1750°F lithium temperature leaving the reactor. The first of these power plants presented incorporates an intermediate heat exchanger with lithium in the primary loop and NaK in the secondary loop and represents a power plant believed to be attainable in a reasonable time with normal development. The second of these nuclear power plants does not utilize an intermediate heat exchanger and the lithium is circulated directly to the radiators. This represents an advanced power plant because construction materials for the radiator that are oxidation resistant and corrosion resistant to lithium are not foreseeable without a major advance in metallurgy.

"Liquid Cycle Aircraft Reactor: Design and Evaluation". CNLM-626 (Rev.). Pratt and Whitney Aircraft, Middletown, CT. Mar. 10, 1958 (Decl. Jan. 12, 1976). 50p.

Reported progress in the development of a liquid-cycle aircraft propulsion reactor.

"Liquid Cycle Aircraft Reactor: Design and Evaluation". CNLM-519. Pratt and Whitney Aircraft, Middletown, CT. Jan. 20, 1958 (Decl. Jan. 12, 1976). 49p.

Reported progress in the development of a liquid-cycle aircraft propulsion reactor.

"Liquid Cycle Reactor-Advanced Applications: Research and Development". CNLM-1609. Pratt and Whitney Aircraft, Middletown, CT. Apr. 22, 1959 (Decl. Jan. 12, 1976). 67p.

Reported progress in research and development on liquid-cycle aircraft reactors. The program included advanced applications and low-power testing.

"Lithium-Columbium, Solid Fuel Element, Fast Reactor". PWAC-271. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Aug. 7, 1959 (Decl. Sept. 20, 1973). 270p.

The engineering design study of a proposed aircraft reactor, PWAR-12, and its low power test reactor version, PWAR-12C is described. Information is presented concerning engineering design, reactor physics, test operation and materials of design.

"Materials Engineering Meetings (With Identification of Other Reports)". CNLM-2381-17. Pratt and Whitney Aircraft, Middletown, CT. Oct. 26, 1960. 4p.

A complete materials list was presented specifying the type of material required and its location in the reactor system. Included were lubricants, gases, fuels and coolants as well as the materials required for structural members, shielding, insulation, bearings, seals, pumps, moderators, reflectors, controls, heat exchangers, radiators, and cold traps. Additional materials data are required to reflect the increased time at elevated temperature and the additional time required for shutdown.

Mattrella, U. "A Bearing Evaluation for In-Pile Application". TID-5885. Pratt and Whitney Aircraft, Middletown, CT. Jan. 7, 1958 (Decl. Oct. 19, 1971). 10p.

The results of the 1000 hour bearing endurance tests for the aircraft reactor fused salt pump drive motor indicated that dry (non-lubricated) bearing operation was feasible in a salt vapor-helium atmosphere when operated at the speeds and under the loads described. It is recommended that a bearing composed of M-2 steel alloy balls and races with an Inconel "X" silver plated separator be used.

Meyer, Robert M., ed. "Nuclear Powerplant for Navy Pre-prototype Airplane". PWAC-260. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Oct. 1, 1958. 33p.

A nuclear powerplant design for the Princess airframe which meets the Navy's requirements for a preprototype airplane is selected. The conclusions on which the selection of the nuclear powerplant design was based are presented, and a resume is given of the status of reactor technology and the research and development work which supports this selection.

Miller, A.D., and Craig, R.A. "Uranium Mononitride-Niobium Cermet Fuel: Status Report. TIM-698. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. July 27, 1961 (Decl. Sept. 12, 1973). 24p.

Potential liquid cooled reactor applications directed to the program to the UN -Nb or Nb alloy dispersion system. Methods were developed for the preparation of high quality UN powder and for consolidation of Nb-33 vol% UN bodies by a unique resistance "sinter-pressing" technique, utilizing a commercial three phase resistance welding machine. Thermal stability of high density "sinter-pressed" compacts was found to be good to temperatures up to 3400°F. Other tests showed that the Nb-UN cermet was compatible with lithium at temperatures up to 2200°F up to 250 hours. Preliminary irradiation evaluation clad with a Nb- 1% Zr alloy showed no swelling or other physical changes and negligible fission gas release at burnups of 0.9 and 1.4 at % ^{235}U with calculated surface temperatures of 1700°F and centerline temperatures of 2150°F.

"NJ-6A, NJ-8A Engine Performance Summary". PWAC-175. Pratt and Whitney Aircraft, East Hartford, CT. Apr. 1, 1957. 132p.

The weights, design characteristics, and performance of the NJ-6A and NJ-SA nuclear turbojet engines are presented. These engines are assumed to be nuclear conversions of the Pratt & Whitney Aircraft J-91 engine. The NJ-6A was designed to meet the requirements for high altitude supersonic flight. The NJ-8A was designed to meet the requirements of low altitude, subsonic flight. Both engines can be operated on nuclear heat alone, nuclear heat plus conventional fuel, or conventional fuel alone.

"Nuclear JT4D-2 Turbofan Powerplant Characteristics Summary". PWAC-279. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Apr. 6, 1960 (Decl . Sept. 20, 1973). 26p.

Performance and weight data for a nuclear power plant based on the use of a modified version of the JT4D-2 turbofan engine are presented. The powerplant is a lithium cooled reactor using intermediate heat exchangers and with a secondary NaK coolant system to transfer heat to the engine radiators.

"Nuclear Engineering Program". PWAC-168. Pratt and Whitney Aircraft, East Hartford, CT. Mar. 15, 1957 (Decl. Nov. 3, 1975). 15p.

Preliminary estimates were presented of the size and performance of four nuclear power plants proposed for an airplane which can cruise at supersonic speeds without any chemical fuel thrust augmentation. The reactor was an advanced solid-fuel-type cooled by lithium and the engines were modified Pratt & Whitney Aircraft J-91 turbojets. The engines and reactor were matched at Mach 2.0 and 45,000 feet altitude and performance data for maximum thrust was presented for off-design operation. This data was based on an assumed power plant and was to be revised following the completion of a component Optimization which was under way. Part-load performance was not presented.

"Nuclear Aircraft Propulsion System Development Schedule". CNLM-3490. Pratt and Whitney Aircraft, Middletown, CT. Mar. 6, 1961. (Decl. Jan. 12, 1976). 28p.

Discussed specifications for nuclear powered aircraft. Presented component and materials performance requirements, and outlined development program schedules.

Parks, A.J. " Final Report of the In-Pile Convection Loop Project." TIM-482. Pratt and Whitney Aircraft Div., United Aircraft Corp., Connecticut Aircraft Nuclear Engine Lab., Middletown, CT. Feb. 21, 1958. 21p.

A summary is presented of development, irradiation work, and post-irradiation examination of the Pratt and Whitney in-pile thermal convection loops containing molten modified ORNL composition 30 fuel. It was found that the compatibility of the fluoride fuel with Inconel and Inconel X wage reasonably satisfactory at 1200°F and the stability of the fluoride fuel in the loop was also satisfactory. It is noted that prediction of thermal neutron fluxes and maintenance of fixed-level power in the MTR was not feasible under the experimental conditions.

Parks, G.U. "Weekly Progress Report, August 24-28, 1964". CNLM-5700. Pratt and Whitney Aircraft, Middletown, CT. Sept. 1, 1964 (Decl. Jan. 6, 1976). 4p.

Reported progress in the design and development of an aircraft propulsion reactor.

Parks, G.U. "Weekly Progress Report, November 16-20, 1964". CNLM-6M. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Nov. 1964 (Decl. Jan. 9, 1976). 6p.

Progress was summarized on reactor design studies and component development tests.

Perry, P.L, and J.W. Walton, editors. " Preliminary Investigation of Accident Mechanisms of the Indirect Cycle Aircraft Nuclear Propulsion System". PWAC-316. Pratt and Whitney Aircraft, Middletown, CT. Dec. 15, 1960 (Decl. Sept. 20, 1973). 119p.

The accident analysis of the indirect cycle aircraft nuclear propulsion system considers only the more severe accident conditions. It has been assumed that, in general, the accident analyses performed for the PWAR-11C reactor will pertain for the less severe accident conditions. Since the PWAR-11C reactor is a stationary test reactor operated at 10 MW and identical to the flight reactor, PWAR-11, except for core orificing, it is considered necessary to investigate only those accidents which are dependent upon operating power and those accidents which are possible due to the mobility of an airplane. The configuration of the NJ-18A powerplant, which utilizes train PWAR-11 reactors, was used in this analysis.

"Plan for NJ-18A Power Package Ground Test Program 1961-1965". CNLM-3143. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Jan. 24, 1961 (Decl. Jan. 12, 1976). 189p.

Plans for the engineering and development, including initial testing, of an indirect cycle nuclear propulsion system suitable for the Convair NX2 Airplane.

"Powerplant Characteristics Summary. Section II". PWAC-144 (Sec. 2). Pratt and Whitney Aircraft, East Hartford, CT. Feb. 2, 1956. 94p.

Performance data are presented for the NJ-2B aircraft powerplant. The powerplant consists of a sodium cooled reactor and turbojet engines operable on both nuclear and chemical energy.

"Powerplant Characteristics". PWAC-183 (Suppl. 1). Pratt and Whitney Aircraft, Middletown, CT. No Date. (Decl. Jan. 12, 1976). 5p.

Revised estimates of shield weight, reactor dose pattern, and reactor shield envelope for the lithium cooled WS-125 A powerplant are presented.

"Preliminary Specification for PWAR-6 Control Rod Drive System". Pratt and Whitney Aircraft, East Hartford, CT. No Date. (Decl. Dec. 9, 1975).

Design requirements for a control presented for a control rod drive the PWAR-6 reactor.

"Preliminary Installation and Performance of the NT-15 Powerplant". PWAC-263. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Dec. 15, 1958. 55p.

A preliminary description and estimated performance of a nuclear turboprop power plant suitable for application to the Princess flying boat are presented. This power plant, consisting of a nuclear reactor heat source with unit shielding, two modified T-57 turboprop engines and associated heat exchange equipment, is estimated to provide sufficient power to fly the Princess airplane, at maximum gross weight with adequate climb margin, at 220 knots and 10,000 feet altitude on nuclear power alone. Based on the preliminary engineering studies made to date, the power plant described is believed to be the most practical design for the Princess airplane application.

“Preliminary Specification for the Helium System of the Liquid Metal Pumps”. FPS-C-59. Pratt and Whitney Aircraft, East Hartford, CT. No Date. (Decl. Dec. 10, 1975). 8p.

Design requirements for the helium system of the liquid metal pump seals, expansion, tank or sump, and associated lubricating oil sumps are described.

“Presentation to a Committee From the National Academy of Sciences”. CNLM-3415. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Feb. 14, 1961 (Decl. Dec. 8, 1975). 49p.

Presented information on the objectives of the CANEL aircraft reactor program.

“Proposal for Amendment to Contract NOAS 58-662-c Covering Engineering Studies And Development of Components for Aircraft Nuclear Propulsion Systems. CNLM-1304. Pratt and Whitney Aircraft, Middletown, CT. Dec. 15, 1958 (Decl. Jan. 12, 1976). 30p.
Information is presented concerning the development cost for the aircraft propulsion reactor, development of liquid metal-to-air radiation design, development of temperature sensors, and development of liquid metal pumps.

Puechl, K. H. Preliminary Design of a 45 MW Engineering Test Reactor for the Connecticut Aircraft Nuclear Engine Laboratory." Kidde (Walter) Nuclear Labs., Inc., Garden City, New York, WKNL-64, July 19 (1956) 79 p.

A preliminary engineering study of a low-temperature, high-flux test reactor, operating at 45 MW, to be used for in-core irradiation of experimental loops is presented. This reactor, water-moderated and cooled and Be-reflected, uses enriched U-Al alloy fuel elements. It is similar to, but simpler than, the Materials Testing Reactor and uses Engineering Test Reactor fuel elements. Its initial loading requires 5.2 kg of U-235, its life at full power is 21 days, and its average burnout at end of life is 22.5%.

Randall, D.G., and F.D. Dloss. “Design Fabrication and Test of A 1500°F NaK-NaK Heat Exchanger. PWAC-337. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. June 30, 1961 (Decl. Sept. 20, 1973). 82p.

HE-12CL is a completely welded, tube and shell, unbaffled heat exchanger unit fabricated at CANEL from Type 316 stainless steel. It was operated using NaK (56 percent Na) on both tube and shell sides, with countercurrent flow, at liquid metal temperatures to 1500°F, flow rates to 657 gpm and pressures to 150 psig, for a total time of 1140 hours. Three hundred and thirty hours of heat-up, purification, and performance testing were followed by 774 hours of endurance testing. The first structural failure, leakage between tube and shell sides, was detected after 560 hours of operation, of which 230 hours were at the endurance condition; 590 additional hours of operation, including 544 hours at the endurance condition, increased the internal leakage rate and ultimately caused a failure from shell aide to atmosphere, necessitating test termination. The following observations can be drawn from the test: (1) The primary cause of failure was excessive creep of the heat exchanger structure at the hot (1500°F) end of the unit. (2) A secondary cause of failure may have been tube vibration near the hot end tube sheet. (3) No serious corrosion effects were observed. (4) Tube side mass transfer deposits were found on some tubes to ten mils thick. (5) The tubeside pressure drop was slightly lower than predicted values: the shell side pressure drop was approximately 40 percent lower than predicted. (6) The test rig, previously untried, was satisfactory in both reliability and performance with only minor exceptions.

“Reactor Research and Development Through September 1959". CNLM-875. Pratt and Whitney Aircraft, Middletown, CT. July 1, 1958 (Decl. Jan. 12, 1976). 22p.

Research and development devoted to materials and fuels for high-performance lithium-cooled aircraft reactors is described.

Rest, E.S., J.D. Pomeroy, and H.C. Woodsum. “Shield Optimization Code”. PWAC-198. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. 1957 (Decl. Sept. 20, 1973). 151p. .

A method has been devised and a code written for the IBM 704 computer which will optimize (minimize) reactor and crew compartment total shield weight. Such optimization is based on the gamma and neutron dose rates in the crew compartment being specified values. The basic input required by the code are dose curves at 50 ft for primary γ gamma rays, secondary γ rays (those born in the shield), and fast neutrons, vs. shield thickness. Also, information is required concerning the system geometry, shielding materials, and mission specifications. The output consists of the optimum shield-thickness distribution, weights of reactor shield and crew compartment shield, and the direct dose pattern around the reactor at 50 ft.

Richings, H.J., W.G. Kennedy, E. V. Sandin, and E.C. Crume. “Hazards Summary Report on Critical Experiment Program No. 2 at CANEL, October 1958". PWAC-2133. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Dec. 15, 1959 (Decl. Sept. 20, 1973). 143p.

The critical experiment program performed at CANEL on the moderated lithium-cooled solid fuel reactor is described. Hazards related to this particular series of critical experiments are discussed. The operation of the experimental assembly is described. Safety features of the building, equipment and operations are pointed out. Possible accidents and the resulting hazards to surrounding areas are analyzed.

Sandin, E.V. "Tritium Production and Li^8 Bremsstrahlung Data". CNLM-5763. Pratt and Whitney Aircraft, Middletown, CT. June 15, 1964. 3p.

Calculations using recent cross section data for the Li^7 (n, 2n) He^4 reaction and including the Li^6 (n, t) He^4 reaction were made using neutron flux data from a machine calculation. The reactor model used was an early 8 MW conceptual design. The indicated amounts of tritium produced per Megawatt per hour for each lithium isotope were: from Li^7, 9.6 x 10^{17} atoms/MW hr, Li^6, 4.2 x 10^{16}. This is a total of approximately 1000 curies for a 10,000 hr, 2.2 MW test or 4000 curies for a 10,000 hr, 8.8 MW test. The only readily available data on Li^8 Bremsstrahlung is a calculation of the dose to the payload some 30 feet away from the primary system in a flight configuration. The major source is the boiler due to its small tubes which provide little attenuation in the lithium before the Li^8 betas strike columbium. Scaling this data for the boiler using a $1/R^2$ dependence yields a dose rate of 120 rads/hr @ 3 feet from the boiler. The dose to the payload due to the rest of the piping is about equal to the dose from the boiler so that the dose near any particular pipe will be considerably lower than the dose near the boiler.

Schmickrath, B.A. "Monthly Progress Report, October 1957." CNLM-380. Pratt and Whitney Aircraft, CANEL, Middletown, CT. Nov. 26, 1956 (Decl. Jan. 9, 1976). 15p.

Aircraft propulsion reactor design performance data and component performance testing results are presented.

"Shield Specification No. 1025 (Reactor CRS-1018)". CSS-1025. Connecticut Advanced Nuclear Engineering Lab, Pratt and Whitney Aircraft, Middletown, CT. Jan. 13, 1960. (Decl. Jan. 8, 1972)). 6p.

The purpose of this study was to provide shield data for application in the Convair CAMAL mission. The design dose was reduced by 10% to allow for heat exchanger dose. The results are summarized in the attached Shield Weight Summary.

"Statement of Work. October 1, 1961- September 30, 1962". CNLM-3814. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Aug. 31, 1961 (Decl. Jan. 9, 1976). 9p.

Engineering design and physics work on a high temperature liquid metal-cooled, reactor experiment with supporting research and development in the areas of fuel elements, coolants and critical experiments, liquid metal components, controls, and materials are reviewed. Certain structures. hydrodynamic, and components tests which were active under contract AT(11-1)-229 for use in advanced aircraft propulsion systems, and which provide basic technical information useful in broad reactor applications are continued.

Strough, R.I. "Progress Report for the Month September 1957". CNLM-283. Pratt and Whitney Aircraft, Middletown, CT. Oct. 14, 1957 (Decl. Jan.12, 1976). 8p.

Progress in reactor engineering associated with aircraft propulsion reactors is briefly reported.

"Technical Program Summary of the Connecticut Aircraft Nuclear Engine Laboratory". CNLM-2665. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. June 27, 1960 (Decl. Jan. 12, 1976). 77p.

Information is presented concerning the low power reactor experiment, advanced reactor engineering and design, reactor physics, heat transfer and propulsion system component development, controls and instrumentation, reactor materials, liquid metal corrosion testing, and propulsion reactor performance evaluation.

Tiedemann, H. J. "Normalized Performance Parameters for a Chemical-Nuclear Turbojet of 7/1 Compressor Pressure Ratio Using 1500 deg.F. Fluoride Fuel". PWAC-97-B Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Sept. 7, 1954. 31p.

Performance parameters normalized at an altitude of 35,000 feet for various degrees of afterburning are presented to aid in determining flight performance at altitudes above 35,00 feet.

Tiedemann, Harold J. "Data on Two Liquid Metal Turbojet Powerplants Utilizing the Circulating Fuel Reactor with a Fluoride Fuel Temperature of 1700 deg.F.". PWAC-81. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Dec. 3, 1953. 13p.

The performance for various flight conditions is compared for two 300 MW circulating fuel aircraft reactors coupled to liquid metal heated turbojet engines.

Tiedemann, H.J. "Estimated Performance Data for a Chemical-Nuclear Turbojet of 7/1 Compressor Ratio Using 1500°F Fluoride Fueled and an Afterburning Temperature of 3200°F". PWAC-97 (Suppl. A). Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. June 30, 1954. 22p.

Estimated performance data are presented for the ten engine configurations of PWAC-97 at an afterburning temperature of 3200°F.

Tiedemann, Harold J. "Off-Match Point Performance of the Liquid Metal Turbojet With a Circulating Fuel Reactor". PWAC-85. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Dec. 31, 1953. 85p.

A series of aircraft powerplants using liquid metal turbojets with circulating fuel reactors was investigated for off-match point performance, weight, and geometry. The results of the power plant comparisons for various flight conditions are presented.

Treciokas, V.P. and K.J. Kelly. "Materials Engineering Meeting". CNLM-2381-6. Pratt and Whitney Aircraft, Middletown, CT. Apr. 8,1960. 5p.

Because fibrous materials have the best thermal insulating properties, degassing and stability tests were started with duPont potassium titanate and an alumino-silicate, Fiberfrax. Tests in vacuum have shown that the potassium titanate decomposes at 1800 deg.F. and is unsatisfactory under these conditions. The material is stable in air at 1800 deg. F. The Fiberfrax lost considerable water at 400 deg. F. and also degases at 1800 deg. F. Pelletized Al_20_3 and ZrO_2 are considerably better than the Fiberfrax. Preliminary results based on weight gained by 2000 deg.F. Cr-1, Zr alloy tabs exposed for 50 hours to flowing argon were obtained concerning the effectiveness of gas purification systems. The data indicate that acceptable gas purity can be obtained from a synthetic zeolite, hot titanium purification system by optimizing gas flow and purifier temperature. Tests with 1800 deg.F. lithium of higher-density, arc-melted specimens prepared at CANEL showed no metallographic change and no cracking.

Wills, D.F., and R.R. McMath. "Nuclear Aircraft Liquid-Metal Valve Development Program". PWAC-228. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Nd (Decl. Sept. 20, 1973). 48p.

Activities in the liquid-metal valve development program are summarized under the following headings: valve requirements and specifications; design studies; materials and fabrication problems; test program; flow and controls problems; current work; and proposed program.

c. CONSOLIDATED VULTEE, CONVAIR, GENERAL DYNAMICS

Anderson, D.G. “Argon Activation Experiment”. NARF-60-16T (Add.1). General Dynamics/Fort Worth, Div. of General Dynamics Corp, Fort Worth, TX. July 24, 1961. 19p.

Additional irradiated argon measurements for the Air craft Shield Test Reactor and results of the initial studies on the exhaust effluent from the dry-pool environment of the 3-MW Ground Test Reactor (GTR) are reported. With the ASTR in the 2π geometry of Configuration II, no detectable amounts of argon-41 were present in the air above the reactor at a power level of 2 MW. With the GTR in the irradiation closet of Configuration III (4-inch water reflector), an argon activity of 0.5 x 10^{-10} µc/cc-watt was generated in the dry side of the pool.

Bauerlein, R.R. “Effects of Irradiation on Plastic Laminates”. NARF-59-8T. Convair, Fort Worth, TX. Feb. 26, 1959. 16p.

Twelve kinds of laminates commonly used in modern aircraft construction were tested to determine their usefulness in a nuclear-powered aircraft. Of these 12, six were impregnated with phenolic resin, four with epoxy resin, and two with polyester resin. All test specimens were subjected to six types of tests. Static irradiation at ambient, temperature by fluxes as great as 9.3 x 10^2 ergs/g(C) combined with 1.2 x 10^{15} fast neutrons/cm^2 did not affect the mechanical and physical properties of the laminates. The laminates discussed in this report that meet qualified design criteria for non-nuclear aircraft are suitable for similar applications in nuclear aircraft, provided the exposure does not exceed the above values.

Bauerlein, R. R. "Effects of Irradiation on Plastic Laminates". NARF-59-8T. Convair, Fort Worth, Tex., (1959) 16 p.

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Bostick, L.M. “ASTR Source Terms”. NARF-60-2T. Convair, Fort Worth, TX. Apr. 30. 1960. 65p.
Source terms (gamma and neutron leakage) for Aircraft Shield Test Reactor Configurations 3, 4, 5, and 15 were calculated by a penetration method which employs moments-method solutions of the Boltzmann transport equation. Both primary and secondary gamma rays were considered. Comparisons are made with direct-beam dose rates measured in the horizontal midplane of the ASTR by direct-beam-shield technique. The gamma and neutron spectra, calculated at discrete

energy levels, are compared with available experimental data. On the average, the calculated total leakage dose rates are within 25%, of those measured. The largest discrepancy is for ASTR configuration 4 where the calculated neutron leakage is 52% high. It is assumed that the ASTR leakage is symmetrical about the cylindrical axis of the ASTR and may be represented by measurements in the horizontal midplane. It is shown that the affect of the measured irregularities in the leakage outside the horizontal midplane does not alter the conclusions of the analysis seriously.

Carver, K.B., K. B. Carver, W.E. Ivie, Jr., A.M. Liebschutz, and G. S. Weller. "Activation Handbook For Aircraft Designers". NARF-55-55T (Vol.1, Pts. 1 and 2). Consolidated Vultee Aircraft Corp., Fort Worth, TX. July 1, 1955. 726p.

Parts I and 2 were issued separately but are cataloged as a unit. This handbook contains the thermal neutron gamma activation tables of 169 aircraft alloys for various irradiation and decay times.

Cranford, W. and R. A. Miller. "Results of an optimization procedure." TID-6302. Convair, Fort Worth, Tex. Paper 10 of papers from Seventh Semiannual Shielding Information Meeting. October 14-15, 1959. 10p.

Some results are reported on reactor and crew-compartment shields minimized by an optimization procedure called GYPSY. For a fast-neutron shield, the question of the adequacy of using a representative point source appears to be settled affirmatively. The effect of optimization of a crew shield for different point detector positions was investigated.

"Development of a High-Temperature Nuclear Radiation-Resistant Pneumatic Power System for Flight Vehicles." ZR-1001-4. Fourth Monthly Progress Report, Phase I Reporting Period. December 21, 1960 to January 20, 1961. Convair, San Diego, Calif. 98p.

Activities in a program to develop high-temperature nuclear-radiation-resistant power systems for operational support of flight vehicles are described. Progress in the areas of dynamic system studies, material studies, and power systems is described.

"Development of a High Temperature Nuclear Radiation Resistant Pneumatic Power System for Flight Vehicles. Monthly Progress Report No. 2, Phase 1." ZR-1001-2. Reporting Period, November 5, 1960 to November 21, 1960. Convair, San Diego, Calif.

The compilation of material data and a review of material development was initiated. System analysis was initiated to establish a comparison between high pressure systems powered by compressors or cryogenic gas sources, and low-pressure systems powered by direct ram air or a cryogenic gas source. The analysis is designed to permit selection of an optimum system for procurement purposes later in the program. A literature survey on component design was initiated.

Dewar, M. A. "Description of the ASTR Shield". NARF-55-96T. Convair, Fort Worth, Tex. (1956) 24 p.

A detailed description of the entire ASTR Shield is presented. This description covers dimensions, materials and, where appropriate, material weights and tank capacities.

Eggen, J.B., R.L. French, and A. Reetz, Jr. "Fast Neutron Spectra and Dose-Rate Calculations". Convair, Fort Worth, TX. *Health Physics* 5 (June 1961): 119-25.

A method and its application for calculating fast neutron spectra and dose rates about the Lid Tank Facility source plate, the Bulk Shielding Reactor, and the Aircraft Shield Test Reactor are described.

Esenwein, August C., Vice President, Convair. Letter to Brig. Gen. Donald J. Keirn, Chief ANPO, AEC. August 11, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

In response to a July 28 request from Keirn, Convair provided a forecast on the usefulness of nuclear propulsion for commercial aircraft. The primary fact favoring commercial use of nuclear power is energy content of nuclear fuel versus chemical fuels. Mitigating factors listed were added shielding weight, incomplete "combustion" of nuclear fuels before reprocessing, expensive, enriched fuel needed for low weight engines, and the hazard of accidental release of radioactive fission products. After several generations of military nuclear-powered aircraft of about eight years each, commercially profitable nuclear engines are predicted to be thirty to fifty years away. He feels that cargo, not passenger, airplanes will be the first application, with lower shielding requirements.

"First Semiannual 125-A Radiation Effects Symposium, May 22-23". NARF-57-19 T (Vol. 2). Convair, Fort Worth, Tex. (1957) 140 p.

Papers are included on: the effect of radiation on diode characteristics, some observations of the effect of radiation on the refractive indices of certain gases, electromagnetic noise propagation observation in the vicinity of a nuclear reactor, gamma spectra measurements of the neutron-induced activity of two jet engines, design of radiation effects testing reactors, design of radiation effects experiments, the rate of production of interstitial vacancy pairs for several neutron flux spectra, Monte Carlo analysis of the annealing of Frenkel defects, radiation effects analysis methods for nuclear aircraft design, and neutron activation of aviator's breathing oxygen.

"First Semiannual 125A Radiation Effects Symposium, May 22-23, 1957". NARF-57-19T (Vol. 4). Convair, Fort Worth, TX. 187p.

Topics discussed include: a description of the Battelle, Radiation Effects Information Center; the effects of high-energy, high-intensity radiation on organic fluids; the effects of nuclear radiations on rubberlike materials; the effects of radiation on semi-conductors; the effects of irradiation on the performance of electronic equipment; the design of electronic systems to operate in a nuclear environment; the performance of closed circuit equipment for remote viewing in high radiation fields; effects of radiation on the performance of commercial electric motors insulated with Alkanex; the effects radiation on the stability of operating components of a jet engine control system; and determination of the body radiation dose received while working in a multiple source radiation field typical of that encountered in radioactive systems maintenance.

"Fission Product Field Release Tests--Experiment Design". FZM-1707. Convair, Fort Worth, TX. June 6, 1958. P.65

The current status of planning of tests proposed to determine the behavior of selected fission products released to the atmosphere under conditions simulating nuclear aircraft melt down is presented. The plan includes two series of experiments: in the first series, HTRE-type elements containing long-lived isotopes, chief among which is Cs^{137}, will be used, and in the second series, freshly irradiated HTRE-type elements containing I^{131} and Xe^{133} will be used. These fission products are to be released at ground level by induction melting, under 3 lapse conditions, and 3 inversion conditions, along with release of fluorescent tracer and smoke. The ground activity will be measured, and smoke plume movement will be photographed.

"Fission Products Field Release Test-1". NARF-59-32T. Convair, Fort Worth, TX. Sept. 1959. 399p.

Fission Products Field Release Test I was performed to check and resolve uncertainties in the currently used methods of safety analysis for nuclear aircraft. Specifically, the test was made to evaluate release percentages, airborne radioactivity, and diffusion and deposition characteristics of fission products from melted aircraft reactor fuel elements. A corollary objective was to determine the retention and distribution of the released fission products in animals located within the release network. A highly instrumented fan-shaped grid having seven concentric arcs with a maximum radius of about five miles was used to collect cloud diffusion, meteorological. radiological. radiobiological, and radioactivity deposition data. Release percentages, size of aerosols, deposition velocities, external and internal dose, fluorescent tracer behavior, and atmospheric diffusion were determined.

Gabro, A.N. and L.G. Mooney. "ASTR Fast-Neutron and Gamma-Ray Spectral Measurements". NARF-60-21T. Convair, Fort Worth, TX. Jan. 15, 1961. 64p.

Gamma and fast-neutron radiation spectra from the Airborne Shield Test Reactor are determined. Gamma-ray spectral measurements are presented for the following experimental arrangements: (1) In a horizontal plane through the centerline of the ASTR, at $\theta = 0°$ through 180°, at a 63-ft separation distance, for ASTR configuration 3 with a boral cover on the ASTR and the ASTR shield water borated, and using a collimated detector; and (2) in the small cylinder (geometry D), at $\theta = 0°$ at a 33-ft separation distance, for ASTR configuration 3 with the boral cover off the

ASTR and the ASTR shield water not borated, and using a bare-crystal uncollimated detector. Fast-neutron spectral measurements were made in a horizontal plane through the centerline of the ASTR at a 33-ft separation distance, and are presented for (1) θ = O, 105, and 120 deg. for ASTR configuration 3; (2) θ = 105 deg. for ASTR configuration 5; and (3) θ = 90° for ASTR configuration 15.

Gardner, J. R. "Reactor Power Calculator". NARF-58-18 T. Convair, Fort Worth, Tex. (1958) 23 p.

An electro-mechanical power calculator was developed for use with the Aircraft Shield Test Reactor (ASTR) and the Ground Test Reactor (GTR). The computer solves the equation, P = Q L T**,** by means of a flow rate amplifier which supplies a voltage that is linear with flow rate, and a null balance servo system which produces a potentiometer shaft position that is linear with the temperature differential existing between the coolant water flowing into and out of the reactor. The computer contains its own power supply and reference supplies as well as a self-contained "Low-Flow" alarm system.

Gardner, A. H. ."Miniaturized Wide Band Linear Preamplifier, for Airborne Use". (Convair Model PA-1-2). NARF-56-71. Convair, Fort Worth, Tex. (1956) 16 p.

A general-purpose, miniaturized, wide-band, linear preamplifier has been designed and built for use in the nuclear test airplane. This preamplifier (Convair Model PA-1-2) is similar electrically to the ORNL Model A-1 preamplifier. Laboratory tests of the 30 production preamplifiers already built show that they are linear within ± 10% for input signal between 0 and 60 millivolts and have a 1 megacycle band-pass. The preamplifiers operate satisfactorily at ambient temperatures of 75 ± 15 deg.F., at altitudes up to 40,000 ft, and at vibratory accelerations up to 14 g with the preamplifier assembly shock mounted. Consideration is being given to improvements which will increase the range of temperature, altitude, and vibration. The circuitry and mechanical structure of the preamplifier and the tests performed on it are described.

Greenhow, W.A. and F.W. Smith. "Attenuation of Electromagnetic Energy Through the Ionized Cloud Surrounding an Airborne Reactor". NP-9333 (Vol. I.). Chance Vought Aircraft, Inc., Dallas, TX. Paper 4 of Fourth Radiation Effects Symposium, September 15-16, 1959, Cincinnati, OH. General Session Papers. 19p.

A theoretical analysis of the electromagnetic energy attenuation through the ionized cloud surrounding an airborne reactor was made to determine communications power losses. The results show that power losses should not amount to more than one db for VHF for an airborne reactor operating at power levels less than 800 MW if the antenna is located at least 10 ft from the reactor. Reflection of electromagnetic energy from the ionized region was not significant except at the very low end of the frequency spectrum which is below frequencies considered for use in telemetry systems. Includes 25 references.

" Guide for Health Physics Procedures on a Proposed Nuclear Air Base". WADC-TR-59-692. Convair, Fort Worth, TX. Oct. 1959. 167p.

Based on an analysis of proposed nuclear aircraft operational base activities, a complete health physics organization is described. A series of job titles and descriptions is listed giving the job specialty, duties, responsibilities and qualifications for each person required in the organization, as well as the duties, functions, and procedures for each branch. Sample schedules for instrument calibration are included. Specific procedures are detailed for area and personnel monitoring functions, including health physics procedures for each area and building, and film dosimetry bioassay and *in vivo* counting procedures. A complete program of environmental radioactivity surveillance for an area of approximately 30,000 square miles is described. Emergency procedures and practices are described, and a schedule of emergency action for a hypothetical major disaster is included.

Hayes, R. R. and D. H. Rusling. "NTA Instrumentation Systems". NARF-57-15T Convair, Fort Worth, TX. June 10, 1957. 50p.

The Nuclear Test Airplane (NTA), a B-36 modified to carry a reactor, is instrumented to measure fast-neutron dose rate, gamma dose rate. and thermal-neutron flux. Most of the instrumentation is located in a capsule suspended in the forward bomb bay and controlled remotely from a panel in the crew compartment. Radiation detectors are located in the crew compartment and throughout the fuselage at fixed distances from the reactor.

Henry, R.L. "Multilayer Shield Experiment IV, OTF III". NARF-58-40R; MR-N-222. Convair, Fort Worth, TX, for General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. Oct. 9, 1958. 51p.

A series of shield tests were conducted at the Nuclear Aircraft Research Facility at Convair-Fort Worth to obtain shield design information for nuclear aircraft reactors. This document contains the experimental results of one of these tests. In the experiment, slabs of various shielding materials were assembled in different arrangements into shield mock-ups. These assemblies were then placed in the Outside Tank Facility and subjected to radiation from the Ground Test Reactor. External measurements were taken with dosimeters and BF_3 counters; and internal measurements, with foils and chemical dosimeters. Results indicate that zirconium hydride is a good attenuator of gamma rays and fast and thermal neutrons, that the relaxation lengths for zirconium hydride in a BeO matrix are the same for fast neutrons and gammas, that fast neutrons and gamma rays are attenuated exponentially in zirconium hydride, and that there is relatively little production of secondary gamma radiation in zirconium hydride due to thermal neutron capture and inelastic scattering of fast neutrons. Lead, especially in large thicknesses, seems to produce a relatively high secondary gamma dose rate. Although thermal neutron shielding, when placed forward of uranium in a shield mock-up, does lower the gamma dose rate, the reduction is not great.

Johnson, P. M. "Radiation Effects Manual - Rubber and Rubber Products." REM-899. Convair, Fort

Worth, Tex. Oct. 26, 1959. 550p.

Data are presented on radiation effects to natural and synthetic rubber and rubber products found in aircraft. The rubber products covered include aircraft tires and tire materials, gaskets, O-rings, packings, and hoses and hose materials. All available information on samples. test methods, and irradiation conditions is recorded.

Kress, B.A. "Equipment Modifications for the ASTR-TSF Experiment". NARF-58-32T. Convair, Fort Worth, TX. July 28, 1958. 41p.

The modifications made to the Aircraft Shield Test Reactor(ASTR)and to its auxiliary equipment and new equipment fabricated specifically to meet the requirements of the experimental program at the Oak Ridge Tower Shielding Facility (TSF) are described. The experiments with the ASTR at the TSF entailed hoisting equipment to various heights up to 186 feet. For the experiments, extensive changes in the reactor shell, the reactor control system, the coolant and shield water system, and in ground support equipment were necessary. In addition, suspension systems for the reactor and crew compartment had to be devised and constructed.

Leonard, B.P., W. P. Kunkel, L. V. Woodruff, and J. W. Harris. "Report on the Experimental Data Obtained With the 2 π Shield". Consolidated Vultee Aircraft Corp. Jan. 15, 1954. 38p.

The necessity for performing structural scattering experiments near the ground has led to a search for a means of eliminating ground scattering from the results. It was thought probable that, in the case of the Co^{60} experiments a 2 π source shield might prove effective. This experiment was performed to determine the effect of placing a Co^{60} source at the center of a square lead shield 4-in. thick and 24 in. on a side. Specifically, it was desired to determine: (1) the sharpness of the reduction in dose rate at the edge of the shield (at the surface joining the shielded and the unshielded hemispheres), (2) the dose rate in the shielded hemisphere and (3) the ratio of the dose rates due to the back-scattered and the direct radiation at various positions in the unshielded hemisphere. The reduction in dose rate at the edge of the shield was observed to be extremely sharp, going from a maximum to background in slightly more than 2°. The dose rates recorded at several positions in the shielded hemisphere were at the background level. The ratio of the dose rates due to radiation scattered from about 1.5% to slightly less than 5%.

Leverett, J.K. and C. Harold Beasley. "An Investigation of Lens Opacity on Personnel Operating a Portable Nuclear Reactor". For Convair, Fort Worth, TX. *American Industrial Hygiene Assoc. Journal* 21 (Feb. 1960): 4-6.

Results are reported from investigations of lens opacity in personnel exposed to many types and intensities of radiation while operating a portable polonium-beryllium neutron source, the Ground Test Reactor, and the Aircraft Shield Test Reactor. Yearly examinations were made on employees subject to neutron radiation exposures. None of the people examined had received excessive radiation exposure. Lens opacities were found in 24 of 655 examinations. Fifteen were of the congenital variety and 9 were developmental.

Levine, J. H. and W. F. Ekern . "Radiation Effects-A Major Influence in Designing Electronic Systems for Use in Nuclear-Powered Aircraft." NP-9333(Vol.IV.). Convair, Fort Worth, Tex. Paper 8 of Fourth Radiation -Effects Symposium, September 15-16, 1959, Cincinnati, Ohio. General Session Papers. 30 p.

The problem of determining and combating the effects of radiation on electronic materials and components in a nuclear aircraft is discussed. Transient. permanent, and secondary radiation effects are described and examples given. Methods of radiation damage analysis, the weak link concept and analog computer simulation, are discussed. An example of system analysis using the link concept is given.

Lewis, Craig. “Nuclear Test Bomber Provided Valuable Shielding Data”. *Aviation Week*. Dec. 22, 1958. p.64-9.

Describes airborne reactor testing for radiation effects, without scattering from the ground. Flights of the modified B-36 with the reactor involved the ASTR which had a maximum power level of 1000kW and weighed more than 20 tons.

“Maintenance of ASTR Ground Handling Equipment”. NARF-55-83T. Convair, Fort Worth, TX. Dec. 23, 1955. 183p.

The description and maintenance data are given for the major items of the ASTR ground handling equipment, including the ASTR reactor, the remote hook, the lifting yoke and power dolly, and the loading platform.

Marjon, P.L. “Television Inspection Camera Mobility Experiments”. NARF-59-21T. Convair, Fort Worth, TX. June 1, 1959. 33p.

The application of closed-circuit television in the inspection of nuclear aircraft is under study at Convair, Fort Worth. Previous testing demonstrated that televised viewing of aircraft components is a satisfactory substitute for normal viewing. A continuation of the experimental investigation of remote inspection is described. These tests were performed to resolve only the uncertainties connected with camera deployment. From a simulation of a shielded inspection vehicle cab, a man controlled the movement of a camera in maneuvers representative of aircraft remote-inspection motions. On different test setups the effect of changing the physical layout of the equipment was evaluated and an optimum arrangement of an inspection vehicle was determined. The objective was realized of ascertaining a configuration which does not require special skill in operation and which is relatively uncomplicated in construction.

Marjon, P. L. “Reactor Fuel Element Inspection”. NARF-57-43 T. Convair, Fort Worth, Tex. (1957)

64 p.

Fuel elements from the Aircraft Shield Test Reactor and the Ground Test Reactor were inspected to determine physical condition and corrosion damage. Although several types of corrosion were in evidence, no fission product activity was detectable on the fuel elements.

Marjon, P. L. “Radiation Protection Characteristics of Partial Shields for Nuclear Aircraft Servicing”. Convair, Fort Worth, TX. Apr. 21, 1958. 45p.

An experimental investigation was made to determine the limiting radiation field parameters in the use of the partial shield concept for ground support applications of nuclear aircraft. When used in the presence of multiple sources of radioactivity, such as an activated airplane, the partial shield can reduce the radiation exposure of a mechanic to that amount which originates in his immediate work area, by providing shielding on all sides except for an opening through which work is performed. Another feature of the partial shield concept is that it utilizes the higher total radiation dose which the hands are permitted to receive over the allowed total body tolerance. A reactor fuel element was used as a source to investigate the radiation protection characteristics of two elementary versions of the partial shield concept. One is the open-front type, which is simply a shield box with a work opening. The other is the body-shielded, open front type. This type is similar to the open front version except that it has an additional body shield inside the box. Field conditions are defined in which direct maintenance would be possible on a nuclear airplane by use of these types of partial shields.

Marjon, P.L. and B. A. Kress. “Remote Handling Experiment’. NARF-57-16 T. Convair. Fort Worth, Tex. (1957) 34 p.

An exploratory experiment in the completely remote maintenance of radioactive aircraft components is described. A method of approach to the problem is established and information is presented which will enable more realistic investigations in the remote handling art for aircraft applications.

Marjon, P.L. “A Nuclear Ground Support Experiment with Quick Disconnect Devices”. NARF-59-24T. Convair, Fort Worth, TX. June 29, 1959. 25p.

An experiment in remote handling was conducted to provide information on equipment needs for ground support of nuclear aircraft. Representative, commercially available components with quick-operation features were used in remote handling tests. An evaluation was made of the causes of difficulties encountered in remote operations. Recommendations are made to guide the design of handling equipment for nuclear airplane maintenance applications.

Marjon, P.L. and S. N. Kemp. "Experimental Evaluation of Partial Shield Configuration". NARF-59-17 T. Convair, Fort Worth, Tex. (1959). 33 p.

An experimental study was conducted on partial shields to resolve problem areas in the design of ground support equipment for nuclear aircraft servicing. The use of test versions of partial shields in various airplane maintenance situations was evaluated. General shield configurations and interior layouts are recommended which permit work on items in front of, above, or underneath the partial shield. Tools and equipment are described which permit shielded work to be accomplished in times that compare favorably with unshielded work performance.

"Material and Component Utilization for Nuclear-Powered Vehicles (Radiation Effects Design Data)." FZA-54-026. Convair. Fort Worth, Tex. Sept. 30, 1959. 203p.

A study of material and component utilization for various radiation levels was prepared. Material utilization (MU) factors based on material or component functional thresholds and various nuclear radiation levels are employed. An MU factor is defined as the quotient of the material or component functional threshold divided by the nuclear radiation level. A list was prepared of MU factors normalized to one hr. based on available radiation effects data. The procedure required by the user of the MU factor listing is delineated. An example utilizing this procedure is discussed. It is intended to convey to the aircraft designer the necessary data required to evaluate various candidate materials and components in various nuclear-radiation environments.

McGuffin J.B., C.W. Dickenson, D.F. Ross, W.T. Kowalewski, and J.T. Pancost. "3 MW ASTR". NARF-61-19R. General Dynamics/Fort Worth., Div. of General Dynamics Corp., Fort Worth, TX. Aug. 18. 1941. 287p.

A description of the 3-Mw Aerospace Systems Test Reactor and its associated systems is presented. The design characteristics are described, followed by a description of the special handling tools and their use. The reactor instrumentation and controls, their safety features, their method of operation, calibration, and setup are described. All the hydraulic systems are discussed. The methods used in checking out the reactor from zero power to its design power of 3 Mw are outlined. The subsequent operating experience gained from actual operation of the ASTR in an experimental program is described.

Miller, R. A. and W. Cranford. "Shield System Optimization: a Parametric Study". NARF-58-24T. Convair, Fort Worth, TX. June 16,1958. 34p.

In the first application of the gradient nonlinear programming procedure to optimization of the total weight of a divided shield system, a point source was assumed and crew compartment dose rate and reactor leakage constraints were applied. To make the results more realistic, the gradient nonlinear programming procedure was extended so that the effects on shield shape of different locations of a point source and a point detector can be studied. The weight function is minimized subject to a nonlinear dose rate constraint, reactor leakage constraints, and maximum radius constraints, all of which are expressed as linear inequalities. Included here is an outline for the mathematical formulation of the procedure to be used in the numerical computations.

Morgan, C.E. "Effect of Radiation on the Critical Shear Stress of a Metal Single Crystal". NP-7365 (Vol. 3) (Paper 31). Convair, Fort Worth, TX. Paper 31 of the Third Semi-annual Radiation Effects Symposium (Held in Atlanta), October 28-30, 1958. Volume 3. Aircraft Systems and Materials Papers. 10p.

A mechanism is postulated to account for the radiation hardening of a metal single crystal. The mechanism is based on a lattice defect consisting of interlocking dislocation rings. According to this model, the critical shear stress of a metal single crystal varies as the cube root of the integrated fast neutron flux.

Morgan, L. L. "Radiation effects on aircraft pressure and fuel tank sealants." NP-9333 (Vol. IV.) Convair, Fort Worth, TX. Paper 9 of Fourth Radiation Effects Symposium, September 15-16, 1959, Cincinnati, Ohio. General Session Papers. 26p.

Irradiation tests were conducted on sixteen types of polysulfide-base aircraft pressure and fuel tank sealants. Tensile and peel specimens were irradiated In air and fuel to a maximum of 2.5×10^{14} ergs/gm/y and 1.5×10^{16} nvt, (E>0.33 Mev).

Nance, J. C. "Temperature Coefficient of Aircraft Shield Test Reactor". *Nucleonics* 14, 8 (Aug. 1956):98.

The temperature coefficient of reactivity of Convair's Aircraft Shield Test Reactor has been measured for two core loadings. The results are presented.

Nance, J.C., comp. "Calibration of the ASTR". NARF-57-48-T; FZK-9-090. Convair, Fort Worth, TX. Nov. 1, 1957. 137p.

The Aircraft Shield Test Reactor is a one Mw, Convair-built reactor designed primarily to provide a radiation source for airborne shielding studies related to the Aircraft Nuclear Propulsion project. Early experiments performed with the ASTR to determine its characteristics are reported. The purposes of the experiments were: to assemble all reactor components into an operating system, to determine the controllability of the reactor, to establish the important nuclear characteristics of the reactor, to establish an absolute low power calibration of the reactor and to determine the linearity of reactor instrumentation. Results of the above experiments have proven the adequacy of the reactor system from the standpoint of safety, operability, and reliability.

Nance , J. C. and L. W. Perry. "Aircraft Shield Test Reactor". Convair, Fort Worth, TX. *Nucleonics* 16, No. 1(Jan. 1958): 58-61.

Description of the ASTR design, cooling system, ground and flight testing, and handling and operation are provided.

Nance, J. “Temperature Coefficient of Aircraft Shield Test Reactor”. *Nucleonics* 14,8 (1956) 98 p.

The temperature coefficient of reactivity of Convair's Aircraft Shield Test Reactor has been measured for two core loadings and the results are presented.

“NARF Facilities Handbook”. FZK-185. General Dynamics/Fort Worth. Div. of General Dynamics Corp., Fort Worth, TX. Mar. 1964. 162p.

This handbook gives an inventory of the capabilities of the facility, which includes the Ground Test Reactor, Aerospace Systems Test Reactor, and Reactivity Test Assembly as well as supporting facilities. The nuclear-instrumentation and irradiated-materials laboratories are discussed, and various equipment, devices, and services are described.

Nelson, E.G. and W. L. Hopper. “Controlled- Temperature Submersible Irradiation Chamber Design”. NARF-59-12T. Convair, Fort Worth, TX. Mar. 10, 1959. 37p.

Three boral-clad submersible irradiation chambers capable of being heated or cooled to temperatures between 65 and 400°F were designed and built to permit irradiations of aircraft materials and components under controlled-temperature conditions while positioned adjacent to the Ground Test Reactor. Design features and performance characteristics are described and discussed.

“Nuclear Powered Aircraft Studies”. *Aviation Week*. Nov. 10, 1958. p.37.

Reports that nuclear powered aircraft studies will be continues through March 1959 at the Convair Division, General Dynamics Corp., Fort Worth, TX under a $2,671.557 contract awarded by the Air Force.

Patoski,V.A.; P.L. Marjon. “Partial Shield Remote Maintenance Experiment”. NARF-58-23 T. Convair, Fort Worth, Tex. (1958). 30 p.

An exploratory investigation was made to determine the feasibility of applying the partial shield concept to airplane servicing. The objective of this experiment was to determine the extent of the development effort which would be needed to implement the partial shield concept and to indicate major problem areas. In this experiment, a mechanic using long-handled tools performed several inspection and maintenance tasks on a B-47 airplane from within a partial shield mock-up. It was found that a mobile partial shield can be used at some locations and for some tasks on a contemporary airplane. Although this experiment was quite limited in scope, it showed that partial shields are feasible. Furthermore, experience was gained which will aid in establishing the development

requirements for an engineered system.

"Procedures for System Panels Test No. 2". NARF-56-27 T. Convair, Fort Worth, Tex., (1956) Addendum 1: 110 p.;
Addendum 2: 108 p.; Addendum 3: 104p.; Addendum 5: 54 p.; Addendum 9: 113 P.

In this test, existing aircraft systems mounted on test panels will be irradiated, using the Ground Test Reactor as the source. The Ground Test Reactor will be placed in the dry pool, and the panels to be irradiated are grouped around the reactor inside the pool. Measurements will be made of the physical properties and. operating characteristics of the panel before, during, and after irradiation. Essentially, the equipment consists of a J-57 turbojet engine, and jet engine hydraulic and electronic systems. The GTR will be used to irradiate aircraft structures, components, and equipment. Procedures for exposure, testing, and handling of hydraulic and pneumatic systems are outlined.

"Radiation Effects- Methods and Data". NARF-58-43T. Convair, Fort Worth, TX. Oct. 7, 1958 (Decl. Nov. 28, 1958). 402p.

The best current methods of radiation damage and compilation of available substantiating data are presented. A description of analytical methods is given including application of the techniques to integrating radiation damage considerations and limitations to aircraft system design. The state of the art of radiation damage analysis is discussed, including those factors which need to be determined in more detail. Functional thresholds for aircraft materials and components are presented.

"Radiation Effects - Methods and Data". NARF-58-43 T. Convair, Fort Worth, Tex. (1958) 402 p.

The best current methods of radiation damage analysis and compilation of available substantiating data are presented. A description of analytical methods is given including application of the techniques to integrating radiation damage considerations and limitations to aircraft system design. The state of the art of radiation damage analysis is discussed, including those factors which need to be determined in more detail. A presentation and substantiation of functional thresholds for aircraft materials and components are presented.

"Results of System Panels Test Number 2, Addendum 1". NARF-58-IT (Add. 1). Convair, Fort Worth, TX. Jan. 6, 1958. 157pp.

The results of irradiating five test panels supplied by Pratt and Whitney are presented. The panels contained a J-57 engine, a hydraulic pump loop, various types of transducers and electronic control components, an alkylbenzene pump loop, fuel control units, power supplies and amplifiers. Metallic sub-assemblies and individual parts showed no apparent damage. Performance of some components changed as a result of teflon embrittlement and deterioration. Methyl alcohol proved to be an unsatisfactory fluid for use in a turbojet fuel-control temperature-sensing assembly. Transistors and silicon diodes failed. Electronic components using current production capacitors. resistors, and vacuum tubes showed negligible effects.

"Results of System Panels Test Number 2". NARF-58-1T (Add.5). Convair, Fort Worth, TX. Sept. 6, 1958. 177p.

The results of this investigation indicate that some of the characteristics of the reinforced plastic laminates tested improved, some remained constant, and others were harmed by the mixed flux environment of gamma radiation (20 x 10^6 roentgens) and neutrons (3.5 x 10^{14} neutron/cm^2). Three jet fuels irradiated as part of the test program underwent small changes in composition commensurate with total dose but with a major decrease in thermal stability. The degrading effect of the combined neutron-gamma flux appears to be mainly due to the gamma flux level and possibly to solution of iron. A wide variety of synthetic oils (esters, hydrocarbons, and silicones) were irradiated during the test to determine their sensitivity to reactor radiation. Results are included. The effects of nuclear radiation on the tear resistance characteristics of 2024-T8I and 7075-T6 aluminum alloys and type 422 corrosion-resistant steel were investigated. The low-level irradiation had no detectable effect upon the tear resistance of these materials. Two standard and three experimental types of chaff were irradiated statically. These samples received a total dose of 2.0 x 10^7 r and a total flux of 2 x 10^{14} nvt. There was no noticeable radiation damage to the chaff itself. A Bendix aircraft brake assembly was irradiated statically. The assembly was exposed to an average integrated neutron flux of 5.5 x 10^{14} n/cm^2 and a gamma dose of 6 x 10^6 r. No radiation damage was detected after this exposure. Two oils and one fuel were irradiated. The oil and fuel samples were subjected to an integrated neutron flux of 1.2 x 10^{14} n/cm^2 and a gamma dose of 1 x 10^7 r. A selection of sealants, elastomeric materials, fabrics, plastics, wire insulation, finishes, bonded metal, and thermal insulation material along with corrosion test samples and a simulated seaplane hull bottom were irradiated statically. Radiation damage was detected in the sealants, elastomeric materials, fabrics, and wire insulation.

"Revised Activation Handbook for Aircraft Designers". NARF-57-50 T. Convair, Fort Worth, Tex. (1957) 406 p.

This handbook contains a compilation of essential information on activation phenomena and the means of extending these expressions to particular cases of interest to nuclear aircraft design engineers. Thermal neutron gamma activation tables are included for a number of aircraft alloys for various irradiation and decay times. Necessary information is included for the calculation of activation gamma dose rates from the individual radioisotopes of a number of materials. Theories are reviewed which form the basis for the fundamental equations, and calculation methods are described.

Ross, D.F. "Optimization of Reactor Coolant Flow for the Aircraft Shield Test Reactor". NARF-60-29T. Convair, Fort Worth, TX. Oct. 31, 1960. 88p.

The coolant flow for the 3-MW ASTR was optimized by orificing the fuel-element locations in proportion to the power generated at each location. Measurements following the orifice installations indicated uniform outlet coolant temperature from the fuel element locations. The successful orificing technique resulted in a 26% increase in the maximum feasible power of the reactor.

Schaeffer, N.M. "Aircraft Shielding Experiments at General Dynamics Fort Worth, 1950 to 1962". *Trans. Am. Nuc. Soc.* 66 (Nov. 15-20, 1992). 1992 International Conference on Fifty Years of Controlled Nuclear Chain Reaction: Past, Present, Future. Chicago. pp. 426-7.

Paper provides an overview of the Convair/General Dynamics shielding work at the Nuclear Aircraft Research Facility in Fort Worth. Initially a prototype B-36 aircraft was used on the ground with a large Co^{60} source. The next phase used the Ground Test Reactor (GTR) inside the aircraft. Finally, the Aircraft Shield Test Reactor (ASTR) was flown as a radiation source within a specially modified B-36, called the Nuclear Test Aircraft (NTA). The nose of the NTA was modified as a lead and borated rubber shielded 4-man crew compartment. The reactor was located in the aft bomb bay. Neutron and gamma ray measurements were made in a half-scale compartment in the forward bay and also in the crew compartment. Radiation measurements were also made in the B-50 chase plane. The NTA made 17 flights from Feb. 1956 to Mar. 1957 at altitudes from 1000-37,000 ft. The reactor, half-scale compartment and crew compartment were subsequently used for measurements at the Oak Ridge Tower Shielding Facility.

Schaeffer, Norman M. "Aircraft Shielding Experiments at General Dynamics, Fort Worth, 1950-62". Schaeffer Associates, Fort Worth, TX. p.31.

Discusses the X-6 and X-9 aircraft (modified B-36's) planned to be a nuclear propulsion test bed, and a shield test vehicle, respectively. In 1950, the Nuclear Aircraft Research Facility (NARF) was established at Consolidated-Vultee Aircraft (later named Convair, and then General Dynamics, Fort Worth). A modified B-36, called the Nuclear Test Aircraft (NTA) was flown with a special shielded crew compartment and the Aircraft Shield Test Reactor (ASTR). The ASTR could have been jettisoned if a malfunction had occurred, and the nuclear engineers aboard were parachute trained. Fortunately, this never happened. The NARF also included the Ground Test Reactor (GTR) and the Outside Test Facility (OTF), along with numerous other test facilities. Includes photographs of the NTA, with the ASTR, (in flight and on the ground), the GTR and the OTF. The author describes how the day after Pres. Kennedy canceled the ANP Project on March 28, 1961 an ANS North Texas Section Symposium on Nucleonics in Flight started and several papers were withdrawn, including the keynote address. Research on shielding continued until 1970 at the General Dynamics facility, extending the benefits of ANP shielding technology to other nuclear applications.

Schmitt, R.A. and R.A. Sharp. "Measurement of the Range of Recoil Atoms. Paper 32, Third Semi-Annual Radiation Effects Symposium. Atlanta. October 28-30, 1958. Volume 3. Aircraft Systems and Materials Papers. NP-7365. General Atomic Div., General Dynamics Corp., San Diego, CA. 9p.

An important problem in the interpretation of radiation damage and sputtering phenomena is the evaluation of the range of an atom which moves through a lattice after having received an initial energy of 10 to 100 kev. An experiment is described in which atoms with initial energies in this range were produced by irradiating suitable targets with high-energy bremsstrahlung gamma rays, and the products of photonuclear reactions, such as photoneutron (γ, n) transmutations. were observed. The photon spectrum of the gamma rays was continuous from 0 to 24 Mev. The energy spectra of evaporated neutrons were centered at about 1.5 Mev.

Sheffield, R.D. "Shield System Optimization--Gradient Non-linear Programming". NARF-57-62T. Convair, Fort Worth, TX. Dec. 30, 1957. 40p.

A procedure is developed for minimizing a nonlinear function of n variables subject to inequality constraints. Under suitable assumptions concerning convexity of the functions, a unique minimum is attainable by the method. The technique is applied to optimization of the total weight of a divided shield system subject to a prescribed dose rate level permitted in the crew compartment and to reactor leakage constraints. The procedure consists of two phases: a dose rate reduction phase followed by an isodose-rate weight reduction phase. Provision is made for satisfying the reactor leakage constraints which are expressed as linear inequalities. The process is iterative and provides a convergence criterion depending upon equality of certain weight-dose coefficient ratios.

Shockley, R.F. and W. R. Miller. "Environmental Radioactivity in the NTA Test Area and Flight Corridor". NARF-57-51T. Convair, Fort Worth, TX. Nov. 25, 1957. 81p.

Baseline levels of radioactive content of air, soil, water, and vegetation were established prior to both the 1955 Nevada weapons tests and the first flight of the Nuclear Test Airplane. Subsequent samples were taken and the activity levels were compared with the baseline levels. As expected, the radioactive content of the samples increased as a result of nuclear detonations. Between series of weapons tests the levels, in general, returned to the values established prior to the 1955 series. Since early summer of 1956 however, the levels have consistently remained above the baseline values. Analysis of the data and a study of the operational history of the Nuclear Test Airplane led to the conclusion that there was no change in the environmental radioactivity attributable to operation of the

Nuclear Test Airplane.

Shockley, R.F., comp. and ed. "Health Physics Activities During Period IV, October 1,1954 to September 30, 1955". NARF-56-4T. Convair, Fort Worth, Tex. May 4, 1956. 85p.

The organization of the Health Physics Group is briefly described. Photographs of radiation detection instruments and equipment used by the group are included. Results of radiological environmental monitoring surveys are presented.

"System 125-A: Preliminary Radiation Effects Analysis, (Tarpon) Experimental Airplane". FZA-25-123. General Dynamics Corp., Aerospace Div., Fort Worth, TX. Oct. 15, 1957. 124p.

Assuming a 50 hr. design goal for system design, and a 500 hr. design goal for airframe design, some of the systems contained within the Tarpon will fall short of their design goal; indeed primarily as a result of the extensive use of Teflon in the B-58 systems, some would malfunction after as little as one hour of nuclear flight. Systems which will require modification include the hydraulic system, pneumatic system, oil system, flight control system and chemical engines.

Travis, C. M. and B. M. Lasater. "NTA Frequency and Voltage Monitoring Systems". NARF-56-26T. Convair, Fort Worth, TX. Dec. 5, 1956. 53p.

In developing instrumentation for the Nuclear Test Aircraft (NTA), it was found that certain instrumentation was sensitive to variations in the frequency and amplitude of the power sources. It was also found that the fast-neutron dosimeters and anthracene scintillation dosimeters were quite sensitive to variations in the high voltages used with their detectors. To allow compensating corrections to be made to the data obtained, two monitoring systems were developed. The voltage and frequency monitor has proved very satisfactory, having operated for six months with only one malfunction. The high-voltage monitor has proven less satisfactory because of excessive drain on the batteries being monitored.

"Under Way ...the Development of Nuclear Aircraft at Convair, Fort Worth". *Aviation Week.* October 10, 1955.

Advertisement for engineers and physicists to work on nuclear analysis, design and experimentation in the fields of shielding, radiation effects and nuclear aircraft technology. A company sponsored in-plant program offered graduate degrees in Nuclear Engineering.

"Material and Component Utilization for Nuclear-Powered Vehicles (Radiation Effects and Design Data)". FZA-54-026. Convair, Fort Worth, TX. Sept. 30, 1959. 203p.

A study of material and component utilization for various nuclear radiation levels was prepared. Material utilization (MU) factors based on material or component functional thresholds and various nuclear radiation levels are employed. An MU factor is defined as the quotient of the material or component functional threshold divided by the nuclear radiation level. A list was prepared of MU factors normalized to one hr. based on available radiation effects data. The procedure required by the user of the MU factor listing is delineated. An example utilizing this procedure is discussed. It is intended to convey to the aircraft designer the necessary data required to evaluate various candidate materials and components in various nuclear radiation environments.

d. LOCKHEED AIRCRAFT CO.

Beltran, A. A. "Radiation Effects on Electronic Circuits." SRB-60-4 Lockheed Aircraft Corp. Missiles and Space Div., Sunnyvale, Calif. Aug. 31, 1960. 47p.

A bibliography on radiation effects on electronic circuits is presented. Reports and articles on designing for radiation environments, shielding, reliability, test procedures, and results are included. 73 references.

Bridges, W.L. "Radiation Effects Testing of Aircraft Sub-Systems and Components at Air Force Plant No. 67 for the ANP Program". NP-7365 (Vol. 1). Lockheed Nuclear Products, Marietta, GA. Paper 2 of Third Semi-Annual Radiation Effects Symposium, Atlanta, GA, October 28-30, 1958. Volume 1. General Session Papers. 12p.

A few of the features of Air Force Plant No. 67 are briefly reviewed as they contribute to a discussion of the philosophy of radiation effects testing of aircraft subsystems and components. The major functions of this facility will be to irradiate, test, and evaluate aircraft components and complete subsystems under dynamic environmental conditions.

Butz, J.S., Jr. "Tests Simulate Nuclear Test Environment". *Aviation Week*, June 1, 1959. PP. 88-9, 93, 95.

Describes the Georgia Nuclear Laboratory operated for the Air Force by the Georgia Div. of Lockheed Aircraft Corp. which will soon begin operations. Provides illustrations of the reactor building which has the capability to irradiation test six flatcar loads of full size aircraft components. Simultaneous environmental testing which simulates flight conditions can also be carried out during irradiation testing.

Cleveland, F.A. and Clarence L. Johnson. "Design of Air Frames for Nuclear Power". *Aeron. Eng. Rev.* 16 (June 1957):48.

The authors, both from Lockhead, stated that "It appears that the strategic bomber, by requiring both high speed and great endurance and because of the inherent low-altitude potential advantages over similar chemical planes, will be the first candidate for a nuclear power plant."

Gunson, D. 0. "Radiation effects on flight control subsystem design." Paper 25. Third Semi-Annual Radiation Effects Symposium. Atlanta. October 28-30, 1958, Volume 3. Aircraft Systems and Materials Papers. Lockheed Aircraft Corp., Marietta, Ga., NP-7365. 8p.

Successful application of nuclear propulsion to aircraft requires the development of a high-performance flight control subsystem that is not only more reliable, serviceable, and maintainable than the best flying today but is at least as efficient while operating in a radiation environment. The attainment of these aims demands close and continued cooperation between the radiation effects specialist and controls designer throughout the design, development, and testing of this subsystem. The basic problems considered are: the establishment of the important characteristics of a flight control subsystem, how radiation environment affects these characteristics, and the type of radiation effects data required by the controls designer.

Happ, W.W. and S.R. Hawkins. "A Critical Survey of Radiation Damage to Circuits. Paper 39. Third Semi-Annual Radiation Effects Symposium. Atlanta. October 29-30, 1958. Volume 4. Electronics and Semi-Conductors Papers". NP-7365 (Vol. 4). Lockheed Aircraft Corp., Missile Systems Div., Palo Alto, CA. 36p.

A critical survey was undertaken to investigate factors affecting circuit performance in the presence of damage producing radiations. Experimental work in progress consists of irradiating by gamma radiation with a 100-curie cobalt-60 source several types of circuits, such as multi-vibrators and blocking oscillators. Causes of failure of the circuits tested thus far were traced primarily to the deterioration of semiconductor devices. This preliminary work is being used as a basis for planning investigations of other selected circuits, both under gamma and neutron irradiation.

Hawkins, S.R. and W.W. Happ. "Radiation Stabilization of Transistor Circuits by Active Feedback. Paper 40. Third Semi-Annual Radiation Effects Symposium. Atlanta. October 28-30, 1958. Volume 4. Electronics and Semi-Conductors Papers. NP-7365. Lockheed Aircraft Corp. Missile Systems Div., Sunnyvale, CA. 26p.

The simultaneous deterioration of similar transistors due to radiation damage is employed to stabilize circuit characteristics by using one transistor as a feedback element. The relative merits of a number of circuit configurations are examined on the basis of over-all current and voltage amplification battery requirements. transistor symmetry and similar factors. The requirements of both stabilization and amplification are simultaneously satisfied for the common-emitter configuration using a transistor in the common-collector configuration as a feedback element. Design curves for this configuration are given for typical cases to illustrate the usefulness of this method of stabilization. Operating point stabilization is briefly discussed.

Osterman, J.A. "Pneumatics - a Tool for the Designer of Nuclear Powered Aircraft." Lockheed Aircraft Corp., Marietta, Ga., Paper 26. Third Semi-Annual Radiation Effects Symposium. Atlanta. October 28-30, 1958. NP-7365 (Vol. 3). Aircraft Systems and Materials Papers. 6 p.

Pneumatics has been demonstrated to have promise in the field of high temperature aircraft system operation. Air has greater resistance to nuclear radiation and is capable of operating over a wider range and higher temperatures than any available hydraulic fluid.

The essential results are given of a program of study of a high temperature pneumatic system which offers a promising tool to the nuclear aircraft system designer.

Simpson, K. M., C. C. Douglass and H. E. Stern. "Crew Shield Shaping." TID-6302 (Paper 12). Lockheed Aircraft Corp., Marietta, Ga. Seventh Semiannual Shielding Information Meeting, October 14-15, 1959. 8p.

A method for shaping the shielding on the sides of a cylindrical crew compartment is being developed. The shield is designed to achieve minimum weight subject to the requirement of a specified weighted average dose rate along the compartment center line. A machine program was written for a single component of radiation in which attenuation through a single shield material and angular distribution inside are incorporated in the form of general subroutines.

"Third Semi-Annual Radiation Effects Symposium, Atlanta, GA, October 28-30, 1958. Volume 3. Aircraft Systems and Materials Papers". NP-7365. Lockheed Nuclear Products, Marietta, GA. 177p.

Eleven papers are presented on aircraft systems and materials from the third session of the symposium. The classified papers from all the sessions were bound in volume six.

"Third Semi-Annual Radiation Effects Symposium [Held in Atlanta]. October 28-30, 1958. Volume 4. Electronics and Semi-conductors Papers". NP-7365 (Vol. 4). Lockheed Nuclear Products, Marietta, GA. 311p.

Thirteen papers are presented on the radiation effects in semiconductors and electronic equipment.

" Third Semi-Annual Radiation Effects Symposium [Held in Atlanta], October 28-30, 1958. Volume 1. General Session Papers." NP-7365 (Vol. 1). Lockheed Nuclear Products, Marietta, GA. 177p.
Ten papers on subjects of general interest in the ANP program are presented.

Thomas, Frank W. "Aircraft Radome Design Problems Associated With a Nuclear Environment". Lockheed Nuclear Products, Marietta, Ga. Paper 27 of the Third Semi-annual Radiation Effects Symposium. Atlanta. October 28-30, 1958. NP-7365 (Volume 3). Aircraft Systems and Materials Papers. 18p.

The effects of nuclear radiations in relation to microwave transmission through a dielectric lens, or radome, presents a number of design problems associated with nuclear-powered aircraft. A mathematical prediction technique was used to estimate the effect of radiation on multilayer dielectric flat panels. The results show how radiation effects data may be interpreted in the design of a radome test panel.

Thomson, R.A. , C. E. Vivian, and L. A. Williams. “The Georgia Nuclear Laboratories”. Lockheed Aircraft Corp., Marietta, GA. pp.97-108 in "Proceedings of the Seventh Hot Laboratories and Equipment Conference". No Date.

The Georgia Nuclear Laboratories presently being placed in operation by Lockheed for the Air Force will provide a capability to determine the needs for the development of nuclear aircraft. The primary objective is to experimentally conduct dynamic proof testing of nuclear aircraft subsystems and components under conditions of realistic flux and environment. The nuclear environment present in a nuclear powered manned aircraft places an additional burden on the initial design and maintenance phases of the aircraft. A conceptual view is presented of the Georgia Nuclear Laboratories which are currently under activation by Lockheed for the United States Air Force.

e. OAK RIDGE NATIONAL LABORATORY

Abbatiello, A.A. and F.R. McQuilkin. “ART Removal and Disassembly”. ORNL-2464. Oak Ridge National Lab., TN. Mar. 18, 1960. 126p.

A study of a high-level-activity hot cell for the major dissection of the ART was made. Such dissection was necessary to obtain metallurgical and design data on which future high-performance reactors might be based. The study included severing and removing the reactor from the test cell after operation, a procedure for a component removal sequence, and a proposed disassembly building facility. Evaluations of handling, measuring, and cutting techniques for remote work are presented. Although these are based on limited experimental work, progress is adequate to indicate their potential value for any high-level reactors which must be handled after irradiation. In many cases details of the work in the form of the original report have been included in the Appendix. With the termination Of the ART project in September 1957, the draft for what was to have been a status report was revised to become this termination report. Thus, the plans and experimental work are recorded for those who may find the information useful on similar problems.

Adamson, G. M. “Report on Third and Fourth ARE Cleaning Committee Meetings. CF-53-7-131.
Oak Ridge National Lab., TN. July 15, 1953. (Decl. July 5, 1957). 10p.

Problems are discussed pertinent to the post-operative cleaning and decontamination of the Aircraft Reactor Experiment.

“Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending June 30, 1957." ORNL-2340(Pts.1-5). Oak Ridge National Lab., Tenn. Sept. 12, 1957. 357 p.

Activities directed toward development of a circulating fuel type reactor are reported. The design, construction, and operation of the Aircraft Reactor Test (ART) are the major objectives which are discussed. This system includes a 60-MW circulating-fuel reflector-moderated reactor. Operation of the system will be for the purpose of determining feasibility and for studying problems associated with a high-power, circulating-fuel reflector-moderated aircraft reactor. Progress is reported on aircraft reactor engineering, chemistry, metallurgy, radiation damage, and reactor shielding.

“Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending December 31, 1956". ORNL-2221(Pts. 1-5). Oak Ridge National Lab., TN. Apr. 12, 1957. 377p.
The technical progress of research on circulating-fuel reactors and other ANP research is reported under the following headings: aircraft reactor engineering, chemistry, metallurgy, heat transfer and physical properties, radiation damage, fuel recovery and

reprocessing and reactor shielding.

"Aircraft Nuclear Propulsion Project Quarterly Progress Report for the Period Ending December 31, 1957". ORNL-2440. Oak Ridge National Lab., TN. Apr. 24, 1958 (Decl. with deletions Nov. 4, 1959). 222p.

Aircraft Reactor Engineering: A summary of the status of the ART-ETU program at the time it was cancelled is presented. Operation of the fuel pump endurance test was resumed. Operation of the primary NaK pump loop No. 1 at elevated temperatures was resumed in order to observe the effects of the lower seal area of operating without a purge flow down the shaft annulus. The Inconel thermal barrier that was designed to protect the bearing-housing region of the ART sodium pumps from thermal and radiation damage was subjected to tests. The test of the ART control rod drive system was terminated after successful operation. Operation of a 1-inch turbine flowmeter installed in a forced-circulation gas-fired Inconel loop containing a fused salt fuel is described. Additional tests were made of strain-gage pressure transmitters designed for use at high temperatures. A comparison of Russian and ORNL investigations of the NaF-ThF_4 system is given.

"Aircraft Nuclear Propulsion Project Semiannual Progress Report for Period Ending September 30, 1958". ORNL-2599. Oak Ridge National Lab., TN. Feb. 5, 1959. 220p.

Melting, purification, and fabrication of niobium were studied, and conclusions are drawn. Studies were conducted to determine the solubility, of lithium nitride and lithium oxide in lithium. Static corrosion tests of niobium tubing were conducted. A series of furnace tests of various systems is described. Static corrosion tests of Be in Li showed Be to be quite resistant to attack by static Li in all Be systems. A survey of phase diagrams of refractory-metal base binary systems revealed several promising brazing alloys. Equipment was developed for tensile and creep tests of materials in controlled environments at temperatures up to 2500°F. Creep and rupture properties, of Inconel were investigated in tubes with both internal pressure and axial stress. Dynamic load tests on Inconel rods and tubes are described. Small batches of zirconium boride were synthesized for incorporation into BeO bodies. Several additives were tested as means for increasing the density of BeO. Tests were run to determine the oxidation resistance of various borides when added to high-density BeO. Non-destructive testing techniques are discussed. A semicircular heat exchanger was examined metallographically to determine the location and effects of leaks that caused termination of operation. Experimental information was obtained regarding a tentative procedure for purifying lithium metal by extracting oxide, nitride and carbide impurities with a eutectic mixture of lithium halide salts. The method for the determination of oxygen in fluoride salts with $KBrF_4$ was successfully applied. A cryostat for studying radiation effects on semiconductors was constructed with a temperature range of -200 to 350°C. Radiation effects on a grown-junction silicon diode were determined. Attempts were made to alloy indium and germanium at low temperatures. Pump testing is described. Experimental studies of the effect of thermal-stress cycling on structural materials were conducted with the pulse-pump system. Analyses of data obtained from a mercury system in the study of heat transfer in a liquid metal with internal heat generation were completed. A survey was made of various types of auxiliary power units suitable for use in satellites. A calculation was performed to obtain predicted pulse-height spectra of capture and in-elastic scattering gamma rays. The Oracle Monte Carlo code was used to calculate the primary gamma heating in a slab shield. Neutron dose-rate distributions beyond water slabs were calculated for plane monodirectional, monoenergetic sources incident on the slabs at angles of 0, 30. 60, and 75°. Shielding studies and measurements in the Lid Tank Shielding Facility, Bulk Shielding Facility, and Tower Shielding Facility are reported. The latest design of the TSR-11 and several studies supporting the design are presented.

“Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending March 10, 1956". ORNL-2061 (Pts, I, II, and III). Oak Ridge National Lab., TN. June 13, 1956 (Decl. with deletions Nov. 10, 1959). 225 p.

Recent calculations have indicated that the heat flux through the core shells of the ART will be higher than previously estimated. Studies of flow in a full-scale plastic model of the core were continued. Flow diagrams and instrumentation lists were prepared for the Engineering Test Unit (ETU), which is a non-nuclear mockup of the ART. Three separate calculations of the activity that will be produced in the NaK in the fuel-to-NaK heat exchangers of the ART were normalized to the current ART design. An estimate was made of the activity to be expected in the ART radiators because of the deposition of Inconel that will become activated in the heat exchangers and will be carried to the radiators in the NaK stream. A calculation of the self-absorption of decay gamma rays in the ART fuel dump tank indicated a value of 90% and therefore cooling must be provided to remove almost all the decay heat. Disassembly and sectioning of in-pile loop No. 3 which operated in the MTR were completed. Synthetic lubricants in the UCON LB series were investigated to determine their stability as pump lubricating fluids in the ART. Difficulties were encountered in high-temperature tests of the fuel pump with NaK. Additional phase equilibrium studies were carried out in several fluoride systems in order to gain a better understanding of the structure and to aid in devising improved fuels.

“Aircraft Nuclear Propulsion Project Semiannual Progress Report for Period Ending March 31, 1959. ORNL-2711". Oak Ridge National Lab., TN. May 5. 1959. 162p.

Developmental studies on a pilot plant scale of methods for the production, of high-purity yttrium metal were continued. Numerous alloys of niobium with small amounts of Zr, Be, and rare earth metals were prepared to test the effects of these additions in stabilizing dissolved oxygen in the niobium. The reaction rates of oxygen with niobium at low pressures and at temperatures of 850 and 1000°C were investigated. Extrusion billets of niobium clad with type 446 stainless steel and Nb and Mo clad with aluminum bronze were prepared. Corrosion studies on Nb, 316 stainless steel, and TiC base cermets in lithium are reported. The solubility of lithium oxide in lithium was determined for the temperature range 250 to 400°C. Welding of Nb sheet and plate was studied. Techniques were developed for tensile tests of Nb in the temperature range 1800 to 2000°F in an inert atmosphere. A method for obtaining pure BeO by calcining beryllium oxalate was tested. A phase diagram for the LiF-YF_3 system was constructed. Studies were made of the process for obtaining oxygen-free LiF-MgF_2-YF_3 mixtures for reduction to Y-Mg alloys. An apparatus was set up for lithium metal purification. Methods of analysis were developed for samples from the steps in the production of yttrium. Tube burst tests of Inconel in air in the MTR and the ORR at a temperature of 1500°F indicate that irradiation reduced the time to rupture. Advanced power plant design studies are summarized.

"Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending June 10, 1954". ORNL-1729. Oak Ridge National Lab., TN. July 29, 1954 (Decl. with deletions Nov. 12, 1959). 114p.

The experimental reactor engineering program has included the development of components for in-pile loops, the design of forced-circulation corrosion-testing loops, and the construction of a unit for testing the mass-transfer characteristics of a sodium-beryllium Inconel system. Further tests of bearing and shaft-seal materials were also made. Components of the proposed 60-MW Circulating Fuel Reactor Experiment are being designed and constructed and are to be tested to determine operational characteristics. The intensive studies of the fluoride systems of interest as reactor fuels were continued with particular emphasis on systems in which the uranium-bearing component is the less corrosive UF_3 or a mixture of UF_3 and UF_4 rather than UF_4 alone. The metallurgical research effort was devoted to studies of the mechanical properties of Inconel in contact with fluoride mixtures, to investigations of materials suitable for high-thermal conductivity fins, to searches for container materials other than Inconel for fluoride mixtures, and to development of fabrication techniques. High-temperature oxidation tests of several brazing alloys have shown that the majority of the nickel-chromium-base alloys are suitable for service in oxidizing atmosphere at 1500°F. The following were reported for the ANP reactor theory and design activities. The main pump for the fuel system of the ARE was installed. The main sodium pump was also installed and the stand-by fuel and sodium pumps will be installed later. The fuel-to-helium and sodium-to-helium heat exchangers that had faulty welds were refabricated and reinstalled. The experimental reactor engineering program has included the development of components for in-pile loops, the design of forced circulation corrosion testing loops, and the construction of a unit for testing the mass transfer characteristics of a sodium-beryllium-Inconel system. Further tests of bearing and shaft seal materials were also made. Components of the proposed 60-MW Circulating Fuel Reactor Experiment are being designed and constructed and are to be tested to determine operational characteristics. The intensive studies of the fluoride systems of interest as reactor fuels were continued with particular emphasis on systems in which the uranium-bearing component is the less corrosive UF_3 or a mixture of UF_3 and UF_4 rather than UF_4 alone.

"Aircraft Nuclear Propulsion Project Semiannual Progress Report for Period Ending October 31, 1960". ORNL-3029. Oak Ridge National Lab., TN. Dec. 22, 1960. 125p.

The reactions of Nb and Nb alloys with low-pressure gases at high temperatures were investigated, and the compatibility of Nb-Zr alloys with UO2 was tested. The effects of oxygen contamination and Li on the tensile properties of Nb and Nb-Zr alloy were studied, as was the corrosion of oxygen-contaminated Nb and Ta by Li. Mass transfer of carbon and nitrogen from stainless steel to Nb and Nb-Zr alloy in NaK was also investigated; and tests were performed on the corrosion of Haynes alloy 15, 316 stainless steel, and Inconel by boiling potassium. Studies were continued on the effects of small amounts of surface contamination on the aging behavior of Nb-Zr alloys. The effects of hydrogen, nitrogen, and oxygen on the mechanical properties of Nb were investigated. Exceptionally pure Nb-Zr alloys were prepared by electron-beam melting; and the purification of Mo, Ta, W, and V by electron-beam melting was demonstrated. It was also demonstrated that electron-beam welding maintains the purity of Nb-Zr alloy, and an electron-beam furnace was modified for the melting of large ingots. Methods for the production and purification of BeO were studied, as well as radiation effects on BeO. A method was developed for determining He in irradiated BeO. The effects of neutron bombardment on the times to rupture of Inconel and 304 stainless steel were investigated, as were phase relations in BeO-metal oxide systems. The fabrication of components for the boiling-potassium heat transfer system continued, and the thermal conductivity of pure Li and of a Li-Ag alloy was measured. Computer programs for shielding calculations were developed, and the angular distributions of neutrons emerging from hydrogenous slabs and lead slabs were measured. Shielding calculations for space vehicles were also considered. Additionally, the gamma and neutron dose rates in the crew compartment of a nuclear aircraft were analyzed; and gamma and neutron attenuation in lithium hydride-uranium shielding was studied experimentally, together with secondary gamma production in the shielding.

"Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending September 30, 1957". ORNL-2387. Oak Ridge National Lab., TN. Feb, 19, 1958 (Decl. with deletions Oct, 28, 1959). 281p.

Progress is reported on reactor and facility construction, component development and testing, instrument and controls development, engineering design studies, design physics, materials and components inspection, heat transfer studies, phase equilibrium studies, chemical reactions in molten salts, physical properties of molten materials, development studies of Ni-Mo alloys and Inconel, welding and brazing, corrosion and mass transfer, materials fabrication, metallographic examinations of engineering test components after service, nondestructive testing and radiation damage.

"Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending December 31, 1956. ORNL-2221(Pts. 1-5). Oak Ridge National Lab., TN. Apr. 12. 1957. 377p.

The technical progress of research on circulating-fuel reactors and other ANP research is reported under the following headings: aircraft reactor engineering, chemistry, metallurgy, heat transfer and physical properties, radiation damage, fuel recovery and reprocessing and reactor shielding.

"Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending September 10, 1956". ORNL-2157 (Pts. 1-5). Oak Ridge National Lab., TN. Dec. 13, 1956 (Decl. with deletions Oct. 28, 1959). 265p.

The following activities in support of the Aircraft Reactor Engineering are reported. Most of the detail drawings of the reactor-core, heat exchanger, pump, and pressure-shell assembly for the ART have been completed, and design work on the reactor shield and the interior of the reactor cell is proceeding. Tests of a fuel pump in a high-temperature test rig have indicated that the cavitation limit is somewhat lower than anticipated. The preliminary design of the fuel-recovery tank was completed. Studies of the reactor support structure were completed. A series of low-frequency thermal-cycling tests of the core shells is under way. Additional core flow studies were made on the full-scale model of the ART core. The results of the experiments performed to determine the rate of gamma heating in various target materials near the BSF reactor were compared with results calculated by methods used for determining similar ART gamma heating rates. The ART stimulator was used for a study of temperature control of the reflector-moderator cooling system. Tests were continued on a helium bubbler type of level indicator for the fuel expansion tank. Evaluation tests of several types of high temperature pressure transmitters were continued. Evaluation studies of lubricating and cooling fluids for pumps were continued. Development test work on the fuel pump impeller continued. Liquid-metal-vapor condensers are being developed for use in helium purge systems in the ART sodium and NaK circuits and the NaK dump tanks.

"Aircraft Reactor Experiment". A set of articles in *Nucl. Sci.* and Eng.. 2, 6 (1957): 797-853, as follows: "Molten Fluorides as Power Reactor Fuels", R. C. Briant and A. M. Weinberg, pp. 797-803; Design and Construction", E. S. Bettis, R. W. Schroeder, G. A. Cristy, H. W. Savage, R. G. Affel and L. F. Hemphill, pp. 804-25; "Physics", W. K. Ergen, A. D. Callihan, C. B. Mills, and D. Scott, pp.826-40; "Operation", E. S. Bettis, W. B. Cottrell, E. R. Mann, J. L. Meem, and G. D. Whitman, pp.841-53.

"Atomic Shielding to be Oak Ridge Symposium Topic". *The News Sentinel*, Oak Ridge, TN. September 24, 1948.

Reports on the first symposium on radiation shielding which was held September 27-30, 1948. Attendees included individuals prominent in both the NEPA and Naval Reactors Projects (including Captain H.G. Rickover).

Bengston, Joel. "Interpretation of Fission Distribution in ARE Critical Experiment". CF-53-7-190. Oak Ridge National Lab., TN. July 20, 1953 (Decl. July 18, 1957). 16p.

Data on fission distribution in a fuel tube from the ARE critical experiment are fitted with analytic representations suggested by heterogeneous pile theory and by transport theory. Comparison with the thermal flux calculated from the composition of the materials indicates that transport theory must be used to obtain qualitative agreement with experiment.

Bertim, H. W., C. M. Copenhaver, A. M. Perry, and R. B. Stevenson. "Basic Gamma-Ray Data for Art Heat Deposition Calculations". ORNL-2113 Oak Ridge National Lab., Tenn. (1956. Decl. 1959) 76 p.

Heat deposition rates from gamma rays in the ART were required for thermal stress calculations. The basic physical data necessary in determining these rates are reported. U-235 prompt gamma rays, capture and decay gammas in the fuel and reflector, and gamma rays from inelastic scattering of neutrons are included. Buildup factors and absorption coefficients are considered. The multigroup intervals used for determining neutron fluxes for capture and inelastic scattering calculations are given.

Bertini, H.W. "The Amount of Na^{22} in the Na Coolant of the ARE after Operation at 2 MW for Two Days". CF-54-12-12. Oak Ridge National Lab., TN. Dec. 23, 1954 (Decl. July 6, 1957). 3p.

Bertini, H.W., C.M. Copenhaver, A.M. Perry, and R.B. Stevenson. "Basic Gamma-Ray Data for ART Heat Deposition Calculations". ORNL-2113. Oak Ridge National Lab., TN. Oct. 3. 1956 (Decl. Oct. 9, 1959). 76p.

Heat deposition rates from gamma rays in the ART were required for thermal stress calculations. The basic physical data necessary in determining these rates are reported. U^{235} prompt gamma rays, capture and decay gammas in the fuel reflector, and gamma rays from inelastic scattering of neutrons are included. Buildup factors and absorption coefficients are considered. The multigroup intervals used for determining neutron fluxes for capture and inelastic scattering calculations are given.

Bettis, E.S., R.W. Schroeder, G.A. Cristy, H.W. Savage, R.G. Affel, and L.F. Hemphill. "The Aircraft Reactor Experiment. Design and Construction". For Oak Ridge National Lab., TN. *Nuclear Sci. and Eng*. 2 (Nov. 1957): 804-25.

The Aircraft Reactor Experiment was designed for operation at temperatures in the region of 1500°F at a power of 1 to 3 MW with a fluoride-salt fuel circulating in a heterogeneous core. The moderator was hot-pressed BeO blocks cooled by circulating sodium. The heat produced was dissipated in water through hot liquid-to-helium-to-water heat exchange systems. All sodium and fuel circuit components were made of Inconel fabricated by inert-gas (Heliarc) welding. The system was heated to design temperature by means of electrical heating units applied over all parts of the system. Instrumentation and control of the experiment were fairly conventional. For the most part, standard instruments were modified slightly for the high-temperature application. The reactor system was constructed and operated in a building specifically provided for the purpose.

Blizard, E. P. "Shield Optimization." ORNL-1471. Oak Ridge National Lab., Tenn. Mar. 17, 1953. (Decl. Sept. 2, 1960). 20p.

A theoretical treatment of shield optimization in nuclear powered aircraft is given. An expression is developed for the ratio of neutron to gamma dose rates in an optimized spherically symmetric shield. The general method for shield optimization in which a finite number of parameters is adequate is outlined, and the optimization of a box-shaped shield as an example of this method is considered.

Blizard, E. P. "The Time Variation for Injury from Radiation". CF-54-9-119. Oak Ridge National Lab., Tenn. (1954 Decl. 1958) 15 p.

Effects of dose fractionation on radiation injuries are reviewed, and a formulation is presented for relating exposure time to dosage in determination of the maximum safe time for individual members of the crew of nuclear-propelled aircraft.

Blizard, E.P. "Minimum Shield Weight Penalty for Air Ducts". CF-53-9-16. Oak Ridge National Lab., TN. Sept. 2. 1953. (Decl. Feb. 20, 1957). 6p.

Shielding weight penalties for cooling-air voids within a spherical reactor and spherical shield are plotted against values of outer shield radii for a solid shield. Separate curves are given for several air-duct geometries.

Boch, A.L., E.S. Bettis, and W.B. McDonald. "The Molten-Salt Reactor Experiment". For Oak Ridge National Lab., TN. p.247-92 of "Power Reactor Experiments". Vol. I. International Atomic Energy Agency, Vienna, 1962.

The 10-MW(t) Molten Salt Reactor Experiment has a graphite-moderated core approximating a right cylinder 54 in. in diameter and 66 in. high. A molten-salt fuel (composition LiF-BeF_2-ZrF_4-ThF_4-UF_4, 70-23-5-1-1 mole %) is circulated through channels in the graphite, then is pumped through the shell side of a heat exchanger at a maximum temperature and pressure of 1225°F and 50 psi, respectively, and returned to the core to complete the circuit. Heat is exchanged to a coolant salt, which is pumped through the tubes of the heat exchanger, and through a salt-to-air radiation where the heat is discharged to the atmosphere. All portions of the reactor in contact with the salts are fabricated from INOR-8, a nickel-base alloy containing 17 wt % molybdenum, 7 wt %-chromium and 5 wt % iron; this alloy was developed specifically to contain molten salts. Replacement of major components will be accomplished by means of remotely-operated cranes, manipulators, and miscellaneous tools all controlled from a shielded cubicle with direct viewing possible and indirect viewing accomplished by means of TV equipment. The development programs for the reactor components, materials of construction, and remote maintenance facilities are discussed.

Burnett, T.H.J. "Induced Activity in Cooling Water-ARE." CF-52-3-172. Oak Ridge National Lab., TN. Mar. 24, 1952. 2p.

Conservative and upper limit approximations and estimates were used to calculate the amount of radioactivity induced in the mineral content of once-through untreated cooling process water. No significant hazard is seen to be probable except for the possibilities associated with scale formation. This cooling water in passing through a heat exchanger is in a neutron flux due to delayed neutrons arising in nearby circulating reactor fuel.

Burtnette, C.S., M.E. LaVerne, C.B. Mills. "Reflector-Moderated Reactor Design Parameter Study. Part I. Effect of Reactor Proportions." CF-54-7-5. Oak Ridge National Lab., TN. Nov. 8, 1954 (Decl. Mar. 22, 1961). 39p.

Geometrical effects on the criticality of the RM-CF (Fireball) reactor are calculated by a multiregion, multigroup method developed for solution by UNIVAC. Physical quantities such as U concentration in the fuel mixture, critical mass, etc., were calculated as a function of core radius, fuel thickness, and reflector thickness. (The "Fireball Reactor" was a modification of the ANP reactor design).

Cathers, G.I. and D.E. Ferguson. "Aircraft Nuclear Propulsion Chemical Processing". Quarterly Report for February 10, 1953 to May 10, 1953. CF-53-5-210. Oak Ridge National Lab., TN. May 27, 1953 (Decl. 1957). 13p.

An aqueous solution of ARE UF_4-NaF-ZrF_4 fuel, suitable for solvent extraction, may be obtained by reaction with dilute $Al(NO_3)_3$-HNO_3 solution under reflux conditions. Optimum proportions are five parts of $Al(NO_3)_3$ monohydrate, seven parts acid, and eleven parts of water to one part ARE fuel by weight. The resultant U concentration is 4.3 g per liter, if the fuel is undiluted with any flush material. Batch countercurrent runs have shown the feasibility of recovering and decontaminating U from the ARE fuel by solvent extraction. U losses of less than 0.01% in the fission product stream and decontamination factors of over 10^4 were obtained using a 5% solution of TBP in Amsco as the solvent. Tests have shown that dissolution of the ARE fuel at boiling temperature will cause considerable corrosion to either type 309 or type 347 stainless steel. The corrosion rate may be tolerable, however, on a non-routine basis in vessels which have already ben exposed to corrosive HNO_3. Discussions have resulted in the conclusion that processing of ARE fuel (70 kg U^{235} per batch) is possible in the present ORNL Metal Recovery Plant without major equipment additions.

"Chemical Technology Division Monthly Progress Report for December 1957". ORNL-2468. Oak Ridge National Lab., Tenn. (1958 decl. 1959) 43 p.

The Fused Salt-Fluoride Volatility Process pilot plant was modified to permit processing of the ARE fuel.

Cohen, G.H., A.P. Fraas, and M.E. LaVerne. "Heat Transfer and Pressure Loss in Tube Bundles for High Performance Heat Exchangers And Fuel Elements". ORNL-1215. Oak Ridge National Lab., TN. Aug. 12, 1952 (Decl. Oct. 9,1959). 75p.

A promising type of construction for both heat exchangers and fuel elements involves parallel flow through bundles of closely spaced tubes. This report discusses problems encountered in spacing long slender tubes and in handling the cross-flow regions at the ends. A series of model tests, planned to give the more important pressure drop and heat transfer information required for ANP design work, are reported. Two heat exchanger models and three ARE-type fuel element bundles were flow tested with water and air, and the heat transfer characteristics of one heat exchanger model were determined with NaK. Appendixes include the following: cooling effectiveness and overall heat-transfer coefficient; friction factor and Renyolds' number for air-flow and water-flow tests; correlation of flow through individual tubes with tube length and diameter; and metallographic examination of heat exchanger after 300 hr operation in NaK.

Cohen, S.I. and T.N. Jones. "Measurement of the Friction Characteristics for Flow in the ART Fuel-to-NaK Heat Exchanger". CF-57-3-95S. Oak Ridge National Lab., TN. Mar. 19, 1957 (Decl. Sept. 15, 1959). 11 p.

The friction characteristics of a full-scale straight-tube model of the ART fuel-to-NaK heat exchanger were determined. The presence of the spacers resulted in a transition to semi-turbulent flow at Reynolds modulus of 350. The semi-turbulent flow persisted up to a Reynolds modulus of 5,000. The circumferential spacers were found to contribute slightly more than the radial spacers to the pressure loss in the heat exchanger.

Coobs, J. H. and E. S. Bomar. "Methods of Fabrication of Control and Safety Element Components for the Aircraft and Homogeneous Reactor Experiments". ORNL-1463. Oak Ridge National Lab., Tenn. (1956 Decl. 1957) 17 p.

The method evolved for preparation of cylindrical inserts for the ARE control and safety rods required the hot-pressing of mixtures of B_4C with alumina and with Fe. A technique for fabrication of control plates for the ARE was devised to minimize defects found in earlier sets of plates. The method involved closely packing pressed-powder compacts in a frame and then hot-rolling to bond protective cladding sheets to the core.

Cottrell, W. B., T. E. Crabtree, A. L. Davis and W. G. Piper. "Disassembly and Postoperative Examination of the Aircraft Reactor Experiment". ORNL-1868. Oak Ridge National Lab., Tenn.(1958 Decl. 1959).
50 p.

A detailed account is given of ARE disassembly operations and the radiation levels encountered. Samples taken from various parts of the reactor are listed, and completed examinations are reported. Samples examined include those taken from the moderator, fuel and coolant lines, pumps, valves, structural material and coolant.

Cottrell, W.B., ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending June 10, 1953". ORNL-1556. Oak Ridge National Lab., TN. July 24, 1953 (Decl. with deletions Oct, 28, 1959). 106p.

The technical progress of the research on the circulating fuel reactor and other ANP research at ORNL is recorded. the effort on circulating fuel reactors is centered upon the Aircraft Reactor Experiment, a 3-MW high-temperature prototype of a circulating fuel reactor for the propulsion of aircraft. The experiment is being assembled, and its status is summarized. Other research areas reported on include experimental reactor engineering, reactor physics, reflector-moderated reactor critical experiments, chemistry of high-temperature liquids, corrosion research, metallurgy and ceramics, heat transfer and physical properties, radiation damage analytical studies of reactor materials, fluoride fuel reprocessing, Lid Tank Facility, and Tower Shielding Facility.

Cottrell, W.B., ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending December 10, 1952." ORNL-1439. Oak Ridge National Lab., TN. (Decl. with deletions Nov. 16, 1959). 156p.

The most significant ARE modification was the completion of the off-gas system design. Progress is reported on valves, pumps, instrumentation, and other components of the fluoride-fuel and reflector-coolant circuits. A rotameter-type flowmeter and the modified Moore Nullmatic pressure transmitter were tested. The heat-transfer coefficient of the sodium-to-air radiator was increased by 20%. General design studies include a performance study on a Sapphire turbojet engine. Reactor physics studies include those of oscillations in a circulating fuel reactor, a technique for reactor calculations, and the temperature-dependence of a cross section exhibiting a resonance. Measurements in several critical tests are reported. The research on fused-fluoride systems led to selection of the fuel and charging technique for ARE. Continued study of the corrosion characteristics of ZrF_4 bearing mixtures, hydroxides, and liquid metals is reported. Metallurgy and ceramics research includes work on development of spherical solid fuel elements, creep rupture tests of structural metal, welding and brazing techniques and cermets and ceramic coatings. Heat transfer and physical properties of several fluoride fuel samples, in-pile sodium-loop measurements, and in-pile creep measurements were made. Chemical and spectrographic identification of various impurities, corrosion products and reduction products are reported.

Cottrell, W.B., H.E. Hungerford, J.K. Leslie and J.L. Meem. "Operation of the Aircraft Reactor Experiment." ORNL-1854. Oak Ridge National Lab., Tenn. (1955). 238 p.

Cottrell, W.B., ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending June 10, 1952". ORNL-1294. Oak Ridge National Lab., TN. Aug. 5, 1952 (Decl. with deletions Oct. 23, 1959). 127p.

The technical progress of the research on the circulating fuel reactor and all other ANP research of the Lab is recorded. Topics covered include circulating fuel aircraft reactors, Circulating Fuel Aircraft Reactor Experiment, experimental reactor engineering, reactor physics, critical experiments, chemistry of high-temperature liquids, corrosion research, metallurgy and ceramics, heat transfer and physical properties research, radiation damage, and analytical chemistry.

Cottrell, W. B. "ARE Design Data". Oak Ridge National Lab., Tenn. (1953, Decl. 1959). 34 p.

Design data on the Aircraft Reactor Experiment (ARE) are summarized as of Dec. 1, 1953. The reactor is of the circulating fuel solid moderator type with a power rating of 1.5 MW. A nominal fuel composition of 53.5 mole % NaF-40.0 mole % Zr4-6.5 mole % UF4 is assumed. The moderator-reflector is of BeO cooled by sodium.

Cottrell, W.B., ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending December 10, 1951". ORNL-1170. Oak Ridge National Lab., TN. Mar. 6, 1952 (Oct. 27, 1959). 141p.

The technical progress on the ORNL ANP Project is summarized. Topics covered include Circulating Fuel Aircraft Reactor, Liquid Metal Cooled Aircraft Reactor Experiment, reactor physics, critical experiments, nuclear measurements, experimental reactor engineering, chemistry of high temperature liquids, corrosion research, heat transfer research and physical properties, metallurgy and ceramics, radiation damage, supercritical water reactor, and analytical chemistry.

Cottrell, W.B., ed. “Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending March 10, 1951". ANP-60. Oak Ridge National Lab., TN. June 19, 1951 (Decl. with deletions Jan. 7, 1960). 262 p.

Progress is reported on the design of the 200 MW Aircraft Reactor, design of the Aircraft Reactor Experiment, reactor physics, critical experiments, nuclear measurements, chemistry of liquid fuels, corrosion experimentation, liquid metal and heat transfer research, components of liquid metal systems, metallurgical processes, radiation damage, homogeneous circulating-fuel and circulating moderator reactors, vapor-cycle and helium-cycle systems, supercritical-water cycle, and supersonic tug-tow system.

Cottrell, William B. “Components of Fluoride Systems”. CF-53-1-276. Oak Ridge National Lab., TN. Jan. 27, 1953 (Decl. Feb. 17, 1959). 17p.

A summary is presented of the present status of knowledge of plumbing for a molten fluoride-salt mixture as obtained in the ANP program during the last year and one-half. Valves, pumps, level indicators and controllers, flowmeters, pressure meters, and vapor traps as components of the fluoride system are discussed. It is emphasized that while these components have been devised which are suitable for laboratory systems, considerable work remains to be done before the desired reliability can be attained for larger-scale systems.

Cottrell, W.B., W. K. Ergen, A. P. Fraas, F. R. McQuilkin, and J. L. Meem. "Aircraft Reactor Test Hazards Summary Report". ORNL-1835. Oak Ridge National Lab., Tenn., (1955, Decl. 1959) 156 p.

The ART is to be a 60-MW reflector-moderated circulating-fuel type whose basic design is suitable for use in aircraft. The new principle of design introduced in the ART consists of circulating the fuel through the reactor in a single, thick, annular passage and achieving the major portion of the moderation with a Be reflector which will also serve as an important portion of the shield. Descriptions are given of the reactor, reactor cell, test site, reactor controls, and operating plan. Three major categories of hazards are considered: accidents with an appreciable probability of occurring, accidents causing rupture of the pressure shell, and accidents causing rupture of the reactor cell.

Cottrell, W.B., H.E. Hungerford, J.K. Leslie, and J.L. Meem. “Operation of the Aircraft Reactor Experiment”. ORNL-1845. Oak Ridge National Lab., TN. Sept. 6, 1955 (Decl. Feb. 12, 1959). 245p.

The Aircraft Reactor Experiment (ARE) was operated successfully and without untoward difficulty in November 1954, The reactor became critical with a mass of 32.8 lb of U^{235}, which gave a concentration of 23.9 lb of U^{235} per cubic foot of fluoride fuel, For operation at power, the U^{235} content of the fuel mixture was increased to 26.0 lb/cu. ft., and thus the final composition of the fuel mixture was 53.09 mole% NaF, 40.73 mole% ZrF_4, and 6.18 mole% UF_4. The maximum power level for sustained operation was 2.5 MW, with a temperature gradient of 355°F; the maximum fuel temperature at this level was 1580°F. Temperatures as high as 1620°F were recorded during transients. From the time the reactor first went critical until the final shutdown, 221 hr had elapsed, and for the final 74 hr the power was in the megawatt range (0.1 to 2.5 MW), The total integrated power was about 96 MW-hr. While at power the reactor exhibited excellent stability and it was easily controlled because of its high negative temperature coefficient of reactivity, which made the reactor a slave to the load placed upon it. The fuel temperature coefficient was -9.8×10^{-5} (DELTA k/k)°F, and the over-all coefficient for the reactor was -6.1×10^{-5}. Practically all the gaseous fission products and probably some of the other volatile fission products were removed from the circulating fuel. In a 25-hr run at 2.12 MW the upper limit of the reactor poisoning due to xenon was 0.01% DELTA k/k. No more than 5% of the xenon stayed in the molten fluoride fuel. The total time of operation at high temperature (1000 to 1600°F) for the sodium circuit was 635 hr, and, for the fluoride fuel system, 462 hr. During most of the operating period the sodium was circulated at 150 gpm and the fuel at 46 gpm, The fabricability and compatibility of the materials system, i.e., fluoride fuel, system coolant, and Inconel structure, were demonstrated, at least for the operating times, temperatures, and flux levels present, All components and, with few exceptions, all instrumentation performed according to design specifications. The performance of the pumps was particularly gratifying, and the low incidence of instrumentation failure was remarkable in view of the quantity and complexity of the instruments used.

Cottrell, W.B., T.E. Crabtree, A.L. Davis, and W.G. Piper. “Disassembly and Postoperative Examination of the Aircraft Reactor Experiment”. ORNL-1868. Oak Ridge National Lab., TN. Apr. 15, 1958 (Decl. July 16, 1959). 50p.

A detailed account of ARE disassembly operations and the radiation levels encountered is given. Samples taken from various parts of the reactor are listed, and completed examinations are reported. Samples examined include those taken from the moderator, fuel and coolant lines, pumps, valves, structural material, and coolant.

Cottrell, W.B. (Ed.) "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending March 10, 1952." Oak Ridge National Lab., Tenn. May 7, 1952. 207 p.

Analysis of the circulating fuel aircraft reactor was extended to systems incorporating intermediate heat exchangers, various secondary coolants, liquid moderators and core. Progress is reported in the design of the reactor, fluid circuits, the reactor building and associated equipment. Development of plumbing for high-temperature fluoride mixtures is reported. Techniques of preparation, purification and handling fluoride mixtures were investigated. Techniques of pumping, sealing, and controlling fluoride coolants were developed along with lubrication methods. Criticality studies for the ARE, the ANP, and the simulated General Electric direct-cycle reactor are reported. Angular and energy-dependent radiation measurements on the mockup of the divided shield are discussed. Research on ducts included detailed measurement of the effect of duct geometry on neutron transmission, and confirmation of a neutron transmission theory for ducts. Design details of the Tower Shielding Facility are presented. Research on high-temperature liquids for use as a fuel-coolant for the circulating-fuel reactor is discussed. Tests of fluoride, hydroxide and liquid metal corrosion are reported. The effect of various additives on fluoride and hydroxide corrosion is being evaluated. Investigation of metallurgical processes involved in the construction and assembly of a high temperature reactor core is reported. Data on the heat transfer of boiling Hg is included.

Cottrell, W.B., ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending June 10, 1953". ORNL-1556. Oak Ridge National Lab., TN. July 24, 1953 (Decl. with deletions Oct. 28, 1959). 106p.

The technical progress of the research on the circulating fuel reactor and other ANP research at ORNL is recorded. The effort on circulating fuel reactors is centered upon the Aircraft Reactor Experiment, a 3-MW high-temperature prototype of a circulating fuel reactor for the propulsion of aircraft. The experiment to being assembled, and its status is summarized. Other research areas reported on include experimental reactor engineering, reactor physics, reflector-moderated reactor critical experiments, chemistry of high temperature liquids, corrosion research, metallurgy and ceramics, heat transfer and physical properties. radiation damage, analytical studies of reactor materials, fluoride fuel reprocessing, Lid Tank Facility, and Tower Shielding Facility.

Cottrell, Wiiliam B. "ARE Design Data". CF-53-12-9. Oak Ridge National Lab., TN. Dec. 1, 1953 (Decl. Oct. 9, 1969). 34p.

Design data on the Aircraft Reactor Experiment are summarized as of Dec. 1, 1953. The reactor is of the circulating fuel solid moderator type with a power rating of 1.5 MW. A nominal fuel composition of 53.5 mole % NaF- 40.0 mole % ZrF_4 - 6.5 mole % UF_4 is assumed. The moderator-reflector is of BeO cooled by sodium.

Cottrell, W.B. ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending March 10, 1953." ORNL-1515. Oak Ridge National Lab., TN. Apr. 16, 1953. 179p.

The Aircraft Reactor Experiment No. 1 is described and discussed. Tests of valves, seals, pumps, etc., are described. Preliminary results with an ARE fuel circuit mockup are reported. Air scattering experiments in the Bulk Shielding Reactor are described. The status of the Tower Shielding Facility are discussed. Control and safety rod inserts for the GE Reactor and Tower Shielding Facility are described.

Cottrell, W.B., W.K. Ergen, A.P. Fraas, F.R. McQuilkin, and J.L. Meem. "Aircraft Reactor Test Hazards Summary Report". ORNL-1835. Oak Ridge National Lab., TN. Jan. 19, 1955 (Decl. Oct. 9, 1959). 156p.

The ART is to be a 60-MW reflector-moderated circulating-fuel type whose basic design is suitable for use in aircraft. The new principle of design introduced in the ART consists of circulating the fuel through the reactor in a single, thick, annular passage and achieving the major portion of the moderation with a Be reflector which will also serve as an important portion of the shield. Descriptions are given of the reactor, reactor cell, test site, reactor controls, and operating plan. Three major categories of hazards are considered: accidents with an appreciable probability of occurring, accidents causing rupture of the pressure shell, and accidents causing rupture of the reactor cell.

Cottrell, W.B., ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending June 10, 1952". ORNL-1294. Oak Ridge National Lab., TN. Aug. 5, 1952 (Decl. with deletions Oct. 23, 1959). 127p.

The technical progress of the research on the circulating fuel reactor and all other ANP research of the Lab is reported. Topics covered include circulating fuel aircraft reactors, Circulating Fuel Aircraft Reactor Experiment, experimental reactor engineering, reactor physics, critical experiments, chemistry of high-temperature liquids, metallurgy and ceramics, heat transfer and physical properties research, radiation damage, and analytical chemistry. Investigating intermediate heat exchangers has led to the use of a spherical-shell type of hanger and shield arrangement; a diagram of such a heat-exchanger arrangement is shown. A design study was undertaken of a circulating fluoride-fuel reactor core in which a thick reflector replaces the moderator. Minor modifications were made in the design of the aircraft reactor experiment to be constructed at ORNL. Tests showed that small additions of Na, K, Mn, and Ca are beneficial in minimizing fluoride corrosion. Various fluoride mixtures were circulated in thermal convection loops. Stainless steel loops generally plug after short periods whereas Inconel loops consistently operate up to 1000 hours.

Cottrell, W.B., ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending September 10, 1952". ORNL-1375. Oak Ridge National Lab., TN. Nov. 19, 1965 (Decl. with deletions Nov. 16, 1959). 146p.

Progress is reported on the following studies: circulating fuel aircraft reactor experiment (fluid circuit, reflector coolant, pressure-shell stress analysis, off-gas system); experimental reactor engineering (pumps, valves, heat exchangers, instrumentation, fluid dynamics, technology of fluoride handling); reactor physics (oscillations in the circulating fuel reactor, effect of gas on reactivity); critical experiments (direct-cycle reactor, ARE critical assembly); nuclear measurements (fission cross section of U^{234} and U^{236}, a total cross section of N^{14}); chemistry of high-temperature liquids (fuel mixtures containing UF_4 and UF_3, alkali fluoborate systems, differential temperature curve of $NaF\text{-}ZrF_4\text{-}UF_4$, x-ray studies of complex fluoride systems, simulated fuel mixture of cold critical experiment, coolant development, hydrolysis and oxidation of fuel mixtures, reaction of fuels with alkali metals); corrosion research (parametric studies of fluoride corrosion, fluoride corrosion in thermal-convection loops, compatibility of BeO with fluoride mixtures, hydroxide corrosion, liquid-metal corrosion, fundamental corrosion research); metallurgy and ceramics (viscosity of fuel mixtures, heat capacity of LiOH, thermal conductivity of fluoride salt mixtures, vapor pressure of fuel constituents, convective heat transfer in liquid NaOH, boiling heat transfer in Hg); radiation damage (radiation of fused materials, creep under radiation); and analytical chemistry (analytical studies of components of fluoride mixtures, analytical studies of impurities in fluoride mixtures, determination of C in ZrF_4 and Zr-NaF-C mixtures).

Cottrell, W.B., ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending March 10, 1952." ORNL-1227. Oak Ridge National Lab., TN. May 7, 1952. 207p.

Analysis of the circulating fuel aircraft reactor was extended to systems incorporating intermediate heat exchangers, various secondary coolants, liquid moderators and heavier reactor shielding. Design of the ARE reactor core is discussed. Progress is reported in the design of the reactor, fluid circuits, the reactor building, and associated equipment. Development of plumbing for high-temperature fluoride mixtures is reported. Techniques of preparation, purification, and handling fluoride mixtures were investigated. Techniques of pumping, sealing, and controlling fluoride coolants were developed along with lubrication methods. Criticality studies for the ARE, the ANP, and the simulated General Electric direct-cycle reactor are reported. Angular and energy-dependent radiation measurements on the mockup of the divided shield are discussed. Research on ducts included detailed measurement of the effect of duct geometry on neutron transmission, and confirmation of a neutron transmission theory for ducts. Design details of the Tower Shielding Facility are presented. Measurements of the total cross section of Fe were made at 0.7 to 3.6 Mev. Research on high-temperature liquids for use as a fuel-coolant for the circulating-fuel reactor is discussed. Several fluoride systems are being investigated. Tests of fluoride, hydroxide, and liquid metal corrosion are reported. The effect of various additives on fluoride and hydroxide corrosion is being evaluated. Investigation of metallurgical processes involved in the construction and assembly of a high-temperature reactor core is reported. Information on fabrication of control rods, welding and brazing of core structure, and creep and stress-rupture of metals is presented along with data on viscosity, thermal conductivity, heat capacity, and vapor pressure of fluoride mixtures. Results of a theoretical analysis of heat transfer in circulating-fuel reactors were used to establish the design parameters for the core fuel circuit. Mathematical expressions for natural convection associated with liquid fuels were developed for the case of turbulent flow. Data on the heat transfer of boiling Hg is included. Radiation damage studies included those on fuel capsules, inpile liquid loops, and creep and thermal conductivity in metals. A summary of findings from a survey of the supercritical water reactor is included.

Cottrell, W.B., H.N. Culver, J.L. Scott, and M.M. Yarosh. “Fission-Product Release from UO_2". ORNL-2935. Oak Ridge National Lab., TN. Sept. 13, 1960. 140p.

The information available, as of the fall of 1959, on the release of fission products from UO_2 was studied and correlated in order to present a comprehensive and consistent Interpretation of the experimental data. A discussion of the mechanism for fission-gas release, the analytical model for predicting release, the model limitations. and the parameters affecting release are included. These considerations are necessary for the prediction of the total pressure buildup in a clad $U0_3$ fuel element and the prediction of the activity release from a defective or unclad $U0_2$ fuel element. The fuel-irradiation program of the Oak Ridge National laboratory is reviewed, and a number of parametric studies bearing on the performance of the fuel element for the Experimental Gas-Cooled Reactor are described. For this report the emphasis was placed on fuel elements operated at higher surface temperatures and lower external pressures than those for pressurized-water systems. Most of the experimental data were obtained for pressurized water systems, however, and the analytical extrapolations of these data to other conditions remain to be verified experimentally.

Cottrell, W.B. ed. “Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending March 10, 1953". Oak Ridge National Lab., TN. Apr. 16, 1953 (Decl. with deletions Dec. 14, 1959). 147p.

The present status of the Aircraft Reactor Experiment No. 1 is discussed and illustrated by photos. Tests of valves, seals, pumps are described. Preliminary results with an ARE fuel-circuit mock-up are reported. The following studies on the Aircraft Reactor Experiment No. 2 (reflector moderated, circulating-fuel reactor) are reported: static physics of the reactor, including the effect on the reactor of core size and the use of various materials in the core and reflector; results of critical experiments; and mechanical design envisioned and developmental work initiated to provide a basis for the detailed design of a full-scale reactor. Research on fused-fluoride systems concerned with purifying and preparing ARE fuel and fuel carrier is reported. Corrosion characteristics of various fluoride mixtures are discussed. Metallurgy and ceramics research reported includes the fabrication of various reactor components for use at high temperatures; creep rupture tests of structural metals; development of special alloys, cermets, and ceramic coatings; and tests of welding and brazing alloys. The fabrication of control and safety rods are described. Physical property measurements of various fluoride mixtures and heat-transfer studies of experimental systems as well as aircraft components are presented. Chemical, petrographic, and x-ray-diffraction studies of impurities, corrosion products, and constituents of reactor fuels are reported.

Cottrell, W.B., W.K. Ergen, A.P. Fraas, F.R. McQuilkin, and J.L. Meem. "Aircraft Reactor Test Hazards Summary Report". ORNL-1835. Oak Ridge National Lab., TN. Jan. 19, 1955 (Decl. Oct. 9, 1959). 156p.

The ART in to be a 60-MW reflector-moderated circulating-fuel type whose basic design is suitable for use in aircraft. The new principle of design introduced in the ART consists of circulating the fuel through the reactor in a single, thick annular passage and achieving the major portion of the moderation with a Be reflector which will also serve as an important portion of the shield. Descriptions are given of the reactor, reactor cell, test site, reactor controls, and operating plan. Three major categories of hazards are considered: accidents with an appreciable probability of occurring, accidents causing rupture of the pressure shell, and accidents causing rupture of the reactor cell.

Cottrell, W.B., ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending September 10**,** 1953". ORNL-1609. Oak Ridge National Lab., TN. Nov. 3, 1953 (Decl. with deletions Nov. 12 1959). 124p.

A higher value was obtained for the critical mass for the Aircraft Reactor Experiment. The exact value of the critical mass was not determined, but it is expected that the reactor will be able to "go critical." Structural poisons were removed from the core. The increase in the critical mass reduced the heat removal capacity by one-half. Coincident with these changes, both the fuel and sodium systems were revised to operate with only one pump. Vertical-shaft, sump type, gas-sealed centrifugal pumps are to be employed in both systems. Pump seals with packings of graphite, graphite with Woods metal. Beryllium fluoride and various vitreous and frozen seals were tested for use in continuous remote operation. No seals for such an operation were found suitable; however, several seals operated in excess of 1000 hr with leakage rates of less than 10 cm^3 per day. Suitable instrumentation to indicate leaks in the sodium and the fluoride systems was developed. Reliable fluid-low measurements were made by using two Moore pressure transmitters across a venturi. Several series of reactor and shield designs were made to determine the effects of reactor power, reactor core diameter, and division of the shield on aircraft performance. The activation of various secondary coolants, including Na and K**,** was measured. Sodium was found superior to K on the basis of total weight of the system, although the activity of the K was about 2 to 5% that of the Na. An analysis of a power plant system external to a reactor was made for a 200,000-lb aircraft with a 100- or a 200-MW reflector-moderated reactor and two or four Wright turbo-jet engines. The analysis revealed that the off-design, as well as the normal performance and control of these subsonic planes, is satisfactory when four engines are employed with chemical augmentation.

Cottrell, W.B., ed. “Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending December 10, 1951". ORNL-1170. Oak Ridge National Lab,, TN. Mar. 6, 1952 (Decl. with deletions Oct. 27, 1959). 141p.

The technical progress on the ORNL ANP Project is summarized. Topics covered include the Circulating Fuel Aircraft Reactor, Liquid Metal Cooled Aircraft Reactor Experiment, reactor physics, critical experiments, nuclear measurements, experimental reactor engineering, chemistry of high temperature liquids, corrosion research, heat transfer research and physical properties, metallurgy and ceramics, radiation damage, supercritical water reactor, and analytical chemistry.

Ellis, C.B. and W.B. Cottrell. “Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending December 10, 1950". ORNL-919. Oak Ridge National Lab., TN. Feb. 27, 1951 (Decl. with deletions Nov. 10, 1959). 160p.

Design of the Aircraft Reactor Experiment (ARE) is continuing, with particular emphasis on shielding, control, and fuel material. The most promising fuel mixture for the ARE is a solution of UF_4 in NaF, with possible admixtures of other fluorides to lower the melting point to a convenient range. Extensive computations of criticality and thermal xenon coefficients were made for both bare reactors and reflected reactors. Graphs of the spectra of several solid fuel reactors are included. A preliminary analysis of the fuel kinetics of the NaF-UF_4 reactor shows the existence of oscillation in the reactor following a change in reactivity, which arises from the coupling between fuel displacement and neutron flux. A resonance at approximately 49 ev was found from the preliminary neutron cross-section measurements on Mo. Theoretical analyses of heat transfer were completed on three situations which approximate the entrance conditions involved in current ARE core designs. Equipment was designed for the measurement of thermal conductivity, specific heat, and other high-temperature properties of various liquid metals and molten salts. The specific heat of Li between 550 and 900°C was measured as 1.0 plus or minus 10%. Both 316 and 347 stainless steel convection harps containing liquid Na have operated almost 800 hr at 1500°F without failure. Substances so far found to have good resistance to Na at 1800°F include types 316 and 347 stainless steel and Ni. Fair resistance under these conditions is shown by Mo, Ta, alloy N-155, Inconel, and Inconel X. The equilibrium diagram of the molten salt system LiF-UF_4 has been established, and the study of such systems as NaF-UF_4 is underway. Preliminary corrosion studies of numerous metals in NaF-UF_4 at 1300°F for 160 hr. show Hastelloy C, Inconel, and Mo to be the least attacked.

Ellis, C.B. and W.E. Thompson, eds. “The Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending August 31, 1950". ORNL-858. Oak Ridge National

Lab,, TN. Dec. 4, 1950 (Decl. with deletions Oct. 1959). 64p.

Stainless steel harps were operated both under thermal connection and with an electromagnetic pump using Na and NaK. Experimental equipment for measuring molten metal heat transfer coefficients was essentially completed. Equipment for measuring the heat transfer to boiling liquids is being designed. Plans were made to irradiate Cu and 316 stainless steel in the 20 Mev proton beam of the Y-12 cyclotron. The possibility of extending earlier thermal xenon cross sections vs. energy measurements to higher neutron energies is being considered.

Ergen, V.K., A.D. Callihan, C.B. Mills, and Dunlap Scott. "The Aircraft Reactor Experiment Physics". For Oak Ridge National Lab., TN. *Nuclear Sci. and Eng.* (Nov. 1957): 826-40.

The fluoride of a fissionable material dissolved in molten fluorides of other cations can serve as the fuel of a circuiting-fuel nuclear reactor. These fluorides have a slowing--down power about one-half or one-fourth of the slowing-down power of dense graphite. The resonance escape probability depends strongly on the cation but is always less than that of carbon. The consequences of these properties for various reactor applications are discussed. Techniques for critical experiments for molten fluoride reactors have been developed, and the physics aspects of operation of the ARE have been analyzed. Operation of the ARE demonstrated that molten- fluoride reactors have strong negative temperature coefficients, mainly as a result of fuel expansion. The ARE has shown to be very stable and to be a slave to the power load. No Xe^{135} poisoning was found in the ARE, and the radioactivity of the fuel after removal from the reactor was less than it would have been if all fission fragments had been retained. The loss of delayed neutrons by fuel circulation modified the inhour equation but not the stability of the ARE.

Farmer, W. S. "Minimum Weight Analysis for an Air Radiator-Laminar Flow". CF-53-3-176. Oak Ridge National Lab. (1953) 37 p.

The net thrust of a nuclear-powered turbojet engine is maximized with respect to minimum weight and pressure drop for a given power output. Component orientation is chosen so as to allow a laminar flow analysis. Heat transfer by a plain-plate, fin-type radiator is considered

Farris, E. S. comp. "Summary of High Temperature Liquid Metal, Fused Salt Pump Development Work in the ORNL ANP Project for the Period July 1950-January 1954". CF-54-8-234. Oak Ridge School of Reactor Technology, Tenn. (1954 Decl. 1957) 98 p.

All of the information available on high-temperature pumps originally reported in the ANP quarterly reports is summarized. The development program was more of a seal development than a specific pump program. Frozen seals of various kinds were tried and for many commercial applications would be perfectly satisfactory. For application in a system such as the ARE, operation of the frozen seal pump is questionable. A gas-sealed pump was developed and is expected to be entirely adequate for a system like the ARE.

Faulkner, J.E. "Visible Light Produced in Air Around Reactors". CF-54-8-99. Oak Ridge National Lab., TN. Aug. 30, 1954 (Decl. Sept. 26, 1958). 17p.

An estimate is presented of the amount of visible light produced by gamma-ray ionization in air such as might exist around a reactor or as might be observed in an accident. An examination is made of the conditions under which a shielded aircraft reactor would produce enough visible light to be seen. A comparison is made with an 18-curie polonium source which produces enough light to be just on the visible threshold.

Fraas, A.P. and A.W. Savolainen. "Design Report on the Aircraft Reactor Test". ORNL-2095. Oak Ridge National Lab., TN. May 1956 (Decl. with deletions Oct. 19, 1959). 163p.

The design of the Aircraft Reactor Test is presented, comprising a fairly detailed picture as it approaches completion. Changes based on information derived from component test experience, further analytical work, or fabricating developments are anticipated.

Fraas, A.P. "Design Precepts for High-Temperature Heat Exchangers". For Oak Ridge National Lab., TN. *Nuclear Sci. and Eng.* 8 (July 1960): 21-31.

While it is evident that weight and volume are vitally important in aircraft power plants, there is also a strong incentive in stationary and marine power plants to reduce both weight and volume because of such considerations a shielding, remote handling, liquid inventory, reactor hazards, control response rates, costs, etc. Analysis disclosed that the tube diameter should be as small as possible consistent with limitations imposed by deposits on the tube walls. Test experience demonstrated the practicality of tube diameters from 1/4 to 1/8 in. OD. It was found that thermal stresses imposed the most important single set of fundamental limitations on the heat exchanger design, and that thermal strain cycling associated with changes from low to high power was the most important failure mechanism. This, coupled with leak tightness requirements, made it essential that a ductile material be employed. The metal also had to be well suited to both welding and brazing because the only thoroughly satisfactory tube-to-header joints tested were first welded and then back-brazed. A series of heat exchangers designed according to these precepts was built and endurance tested at power densities as high as 10 MW/ft^3 (350 kw/liter). Many of the units were endurance tested for over 1000 hr at temperatures up to 1500°F.

Hamill, C.W., J.P. Rudd, and Blackett, F.E. "Inspection of "A" Test Sector After Thermal Cycling". Y-B-65-278. Oak Ridge Y-12 Plant, TN. April 21, 1959 (Decl. Nov. 12,

1974). 43p.

The “A” Test Sector is a 45° segment of the side shield for the General Electric Company's nuclear aircraft reactor (XMA-1). The all-metal shell was fabricated by the Budd Company of Philadelphia, Pennsylvania and shipped to the Y-12 plant at Oak Ridge, Tenn., with one side open. The Y-1-2 Plant fabricated and installed the lithium hydride shapes, closed the open side, and outgassed the sector at 800°F for 42 hours. After leak checking, the sector was shipped to Wright Air Development Center for thermal cycling tests. Upon completion of these tests, the sector was returned to Y-12 for disassembly and inspection. This consisted of making various measurements of the outside hull, the salt cavities. and the salt itself, and comparing these measurements with measurements made prior to testing.

Hanauer, S.H., E.R. Mann and J.J. Stone. “An On-Off Servo for the ARE.” CF-52-11-228. Oak Ridge National Lab., Tenn. (1952, Decl. 1957) 14 p.

Fuel temperature is used to govern the servomechanism which operates the ARE control rod. The mechanism circuitry is given and its operation is described.

Holland, L.B., V.R. Cain, et al. “Tower Shielding Reactor II Operation and Calibration”. ORNL-3193. Oak Ridge National Lab., TN. pp 9-21.

The Tower Shielding Reactor II (TSR-II), including control systems and cooling systems, is operated at powers to 100 KW (thermal) on a 24 hr per day basis. The reactor is used with no shield external to the pressure vessel, with an asymmetric shield, and with two nesting, lead-water shields designed to provide spectrum changes. During the operation of the reactor, power linearity is improved, a comparison technique is developed to in measure absolute reactor power, and studies leading to improved coolant circulation are carried out.

Ingersoll, D.T., ORNL and J.K. Ingersoll, Tec-Com, Inc.
Compilers. "Early Test Facilities and Analytic Methods for Radiation Shielding". ORNL/RSIC-55. American Nuclear Society Meeting. Chicago, IL. Nov. 15-20, 1992. p.90.

In a compilation of eight papers presented at the ANS meeting commemorating the fiftieth anniversary of the first controlled nuclear chain reaction, the history of some of the key advances in nuclear radiation shielding are reviewed. Included are papers relevant to the ANP Project, as follows:

"The Origin of Radiation Shielding Research", Lorraine S. Abbott, Tec-Com Inc., Oak

Ridge TN. Discusses how measurements made inside the ORNL Lid Tank Shielding Facility were used both for the Navy's nuclear submarine program and the ANP Project.

"Aircraft Shielding Experiments at General Dynamics Fort Worth, 1950-1962", Norman M. Schaeffer, Schaeffer Associates, Fort Worth, TX. (See separate listing, Section 3.c.).

"Where have the Neutrons Gone -- A History of the Tower Shielding Facility". F.J. Muckenthaler, ORNL, TN. (See separate listing, this Section).

"A Very Personal View of the Development of Radiation Shielding Theory". Herbert Goldstein, Columbia University, NY. Author states that the ANP Project provided the shielding designer with some of the most intellectually demanding problems ever encountered in this field. He indicates that exotic materials such as lithium hydride were considered for neutron shielding and specific, separated isotopes of tungsten were considered for gamma shielding.

Johnson, E.B. "Fuel Activation Method for Power Determination of the ARE". CF-54-7-11. Oak Ridge National Lab., TN. July 31, 1954. (Decl. July 5, 1957). 10 p.

Joseph, E.F, F.L. Daley, B.A. Hannaford, and E.L. Youngblood. "Aircraft Nuclear Propulsion: Fluoride Fuel Preparation Facility". CF-54-6-126. Oak Ridge National Lab., TN. June 1, 1954 (Decl. Sept. 26, 1958). 41p.

A description of the Fluoride Fuel Preparation Facility for the production of 250-pound units of $NaFZrF_4$-UF_4, NaF-ZrF_4 and NaF-UF_4 is presented, The facility consists of an arrangement of three cubicles. Cubicle No. 1 contains equipment for weighing and mixing. Cubicles 2 and 3 contain a reactor where the mixture is treated, and a receiver to which the purified melt is transferred for storage. The flow diagram of the system is given.

Lubersky, Bernard and B.L. Greenstreet. "Thermodynamic and Heat Transfer Analysis of the Aircraft Reactor Experiment". ORNL-1535. Oak Ridge National Lab., TN. Aug. 27, 1953 (Decl. July 14, 1959). 131p.

The Aircraft Reactor Experiment utilizes the circulating fluoride fuel as the primary reactor coolant. It is necessary, however, to employ an additional coolant whose primary function is to cool the reflector and pressure shell. Although liquid sodium will be used as the reflector coolant, the use of NaK had been assumed during the preceding year. Consequently, a considerable amount of consistent, detailed data on the performance characteristics for the reactor system using NaK as the reflector coolant has been assembled. These data are presented. A sufficient number of calculations based upon the use of sodium was made to assure that the performance with sodium will not deviate significantly from that calculated for NaK. Sodium is being used in preference to NaK because it can be more easily sealed at the pump shaft.

MacPherson, R.E., J.C. Amos, and H.W. Savage. "Development Testing of Liquid Metal and Molten Salt Heat Exchangers". For Oak Ridge National Lab., TN. *Nuclear Sci. and Eng.* 8 (July 1960): 14-20.

In order to investigate the design and fabrication problems inherent in compact, high-performance heat exchangers for aircraft nuclear propulsion applications, extensive development testing was done on bifluid molten salt-NaK heat exchangers and on liquid metal (NaK-air) radiators. These test units were prototypes of the heat transfer equipment which was to be used in the Aircraft Reactor Test (ART) at ORNL. Five bifluid test loops and one liquid metal test loop were used for performance and endurance testing of these components at simulated reactor operating conditions, The molten salt used was a ternary mixture of composition NaF-50 mole%, ZrF_4-46 mole%, UF_4-4 mole%. The NaK used was 56 wt% Na and 44 wt% K. A total of 47,000 hr of operation at 1200 to 1700°F was accumulated on 18 heat exchangers and 20 radiators. The program demonstrated that the compact heat exchanger geometries tested possessed the performance capabilities and mechanical integrity to meet ART design requirements.

MacPherson, H.G. "The Molten Salt Reactor Adventure." ORNL. *Nuc. Sci. and Eng.* 90 (1985):374-380.

A personal history of the development of molten salt reactors in the United States is presented. The initial goal was an aircraft propulsion reactor, and a molten fluoride-fueled Aircraft Reactor Experiment was operated at Oak Ridge National Laboratory in 1954. In 1956, the objective shifted to civilian nuclear power, and reactor concepts were developed using a circulating UF_4-ThF, fuel, graphite moderator, and Hastelloy N pressure boundary. The program culminated in the successful operation of the Molten Salt Reactor Experiment in 1965 to 1969. By then the Atomic Energy Commission's goals had shifted to breeder development; the molten salt program supported on-site reprocessing development and study of various reactor arrangements that had potential to breed. Some commercial and foreign interest contributed to the program which, however, was terminated by the government in 1976. The current status of the technology and prospects for revived interest are summarized.

MacPherson, R.E. and M.M. Yarosh. "Development Testing and Performance Evaluation of Liquid Metal and Molten Salt Heat Exchangers". CF-60-3-164. Oak Ridge National Lab., TN. Apr. 17, 1960. 43p.

Development testing was done on prototype, bifluid (molten salt-NaK) salt exchangers and on liquid-metal radiators in support of the ANP program. The molten salt was a Na-Zr-UF_4 mixture, and the NaK was 56 wt.% Na and 44 wt.% K. Performance tests were conducted on prototypes of the main heat exchangers for the Aircraft Reactor Test. The flow range on the molten-salt side of the exchanger varied from Reynolds numbers of 1000 to 6000, and NaK-flow operating range varied from Reynolds numbers of 15,000 to 200,000. Data were taken on 20-, 25-, and 100-tube bundles at start-up and after 500 and 1000 hr of operation. No deterioration of the salt coefficient occurred with time of operation. In general, the data were found to lie ~40% below the Dittus-Boelter line in the Reynolds range of interest. The effects of tube spacer arrangements on the unit performance were investigated. Pressure-drop data are presented for 1.75- and 0.5-MW Aircraft Reactor Test prototype radiator units.

Manson, S.V. "Temperature Drops in Are Reflector and Pressure Shell Due to γ-Heating". Y-F8-20. Oak Ridge National Lab., Y-12 Area, TN. Apr. 3, 1951 (Decl. July 5, 1957). 7p.

On the basis of heat generations most recently estimated by M. C. Edlund, the calculated maximum temperature drops are: in a pressure-shell dome two inches thick, 9.5°F, in a (shell + flange) thickness of four in., 26°F, and in the reflector 54°F. The total heat generated in the shell was roughly estimated to be 44 KW, about 1.5% of the currently envisaged ARE power .

"Metallurgy Division Semiannual Progress Report for Period Ending October 10, 1956". ORNL-2217. Oak Ridge National Lab., TN. Decl. with deletions Nov. 9, 1959. 231p.

Progress is reported in corrosion studies of stainless steels, Nb, Zr, Al-Fe-Mo, Mo, Ni alloys, and Al-Ni by various materials including Na, Na-K, Li, Rb, and fused salts. Corrosion studies in pump loops of various materials by fused salts and liquid metals are reported. Fuel elements and shielding materials for ART are being developed. General studies in welding and brazing, non-destructive testing, fabrication, and inspection are described. Developments in high-temperature metals and ceramics, metallographic techniques, ceramic materials, and Zr alloys are reported.

Mills, C.B. "The Spherical Reactor with a B_4C Layer Between Core and Reflector". Y-FIO-59. Oak Ridge National Lab, Y-12 Area, TN. July 6, 1951 (Decl. with deletions 1957). 15p.

A set of equations and constants is derived for a spherical homogeneous reactor with a layer of B_4C between core and reflector. The B_4C "curtain" is considered to define a boundary at which the nuclear reaction stops. In the derivations the B_4C curtain is considered to be infinitely thin.

"Molten-Salt Reactor Program Quarterly Progress Report for Period Ending June 30, 1958". ORNL-2551. Oak Ridge National Lab., TN. Sept. 24, 1958. 115p.

Reactor Design Studies: A conceptual design of a two-region. fluid-fuel power reactor, 640 Mwh and 260 Mwe, was prepared and evaluated for fabricabitlity. Design for the reactor fuel pump was completed. Nuclear calculations were continued with studies of Pu^{239} and U^{233} fuels. Studies of various cover gases indicate only argon and helium are suitable. Test rigs were designed for experimental studies of hearings for molten salt applications. Some preliminary results are given on both bearings and lubricants. Test of mechanical joints for remote separation of fused salt system components were continued. None of the joints tested gave evidence of leakage. Data from heat transfer coefficient tests on BF_2-LiF-UF_4 and BeF_2-NaF-UF_4 systems. A conceptual design was prepared of a 5 MW experimental reactor in which molten salt fuel would be circulated by thermal convection. The heat exchanger equipment required for gas cooling a molten-salt reactor was studied. Materials Studies: Metallurgical examinations and corrosive evaluations were made of specimens of several Inconel and INOR-8 thermal-convection loops in which various fluoride mixtures had been circulated. Specimens of Inconel and INOR-8 exposed to a sodium-graphite system were examined for carburization effects to their physical properties. Brazing alloys with high gold and silver contents show promising corrosion resistance to molten salts. Additional tests indicate that the weldability of INOR-8 is satisfactory. INOR-8 and Inconel capsules were fabricated for testing the stability of graphite in contact with molten-salt fuels. Phase equilibrium studies of BeF_2-LiF systems containing UF_4 and/or ThF_4 were continued. Data were obtained on the solubility of PuF_3, NiF_3, noble gases, and various fission products in alkali fluoride-beryllium fluoride systems. The chemical reactions of BeO with fluoride melts were investigated. Data are also presented on Cr diffusion in Ni-base alloys and CrF-BeF_2 vapor pressures.

Mott, J.E. "Radiation and Temperature Tests of Miniature Transistor Amplifiers". APEX-477. General Electric Co., Aircraft Nuclear Propulsion Dept., Cincinnati, OH. May 1959. 32p.

The results of radiation and temperature tests run on two different types of miniature transistor amplifiers are presented. Performance curves are shown, and an analysis of the results leading to a possible method of failure prediction is given. One of the amplifier types was successfully tested to a temperature of 150°C, gamma irradiation of 4.7×10^7 roentgens, and a fast neutron dosage of 7.0×10^{13} nvt (epi-cadmium). These results place the use of such an amplifier within the realm of feasibility as an airframe-mounted control component.

Muckenthaler, F.J. "Where Have the Neutrons Gone: A History of the Tower Shielding

Facility." ORNL. *Trans. Am. Nuc. Soc.* 66 (Nov. 15-20, 1992). 1992 International Conference on Fifty Years of Controlled Nuclear Chain Reaction: Past, Present, Future. Chicago. pp. 427-8.

Reviews the shielding work done at ORNL in support of the ANP Program. Also provides some background of the NEPA Project, stating that it was moved to ORNL in 1951, after the AEC designated ORNL in Sept. 1949 as the agency for continuing AEC's share of the joint NEPA Project. Work focused initially on a single shield around the reactor, but by 1952 this concept was gradually replaced by the divided shield approach in which both the reactor and crew compartment would be separately shielded. Since the weight and distribution of the shield substantially affected the shape and size of the aircraft, and calculations were uncertain, a full-scale testing facility was built at ORNL, the Tower Shielding Facility (TSF). Construction of the four 315 ft. towers began in March 1953 and the TSF was operational in June 1954. The TSF was built on schedule, at a cost of $1,997,613.72, under the $2M budgeted. The TSF-I reactor (100kW, later raised to 500kw) was used to irradiate crew compartments and a J-57 jet engine operating at full power. Only one ANP experiment was conducted with the spherical TSR-II reactor as an isotropic source, just prior to cancellation of the ANP Project. The TSF continued to operate for civil defense and space nuclear programs.

Muckenthaler, F.J. and L.B. Holland. "In-Air Measurements Of Radiation From the Tower Shielding Reactor II (TSR-II)". ORNL-3153. Oak Ridge National Lab., TN. pp. 22-25.

The γ and neutron dose rates from TSR-II are measured as a function of reactor height and reactor-detector range from 0 to 3500 ft. The measurements are taken using a shield designated as Cool-1.

Muller,G. L., J. 0. Bradfute and F. E. Lynch. "Investigation of Fluid Flow in the Art and Other Reflector-Moderated Reactor Cores". ORNL-2199. Oak Ridge National Lab., Tenn. (1958 Decl. 1959) 148 p.

The turbulent flow of liquid through ART reflector-moderated reactor cores of annular cross section was studied because of the need to obtain a steady flow exclusive of the normal unsteadiness of turbulent flow in ducts. Studies were made of water flowing through quarter-scale transparent plastic models of the cores so that flow visualization techniques could be used in the work. An extensive series of tests of many core systems was made over a range of Reynolds moduli based on core midplane dimensions and axial flow rates up to about 90,000. Analysis were made of velocity and static pressure data obtained on a full-size ART core model with several different entrance conditions.

Nielsen, M.J. and J. W. Webster. "Solution of Kinetic Equations of Cylindrical Liquid Fuel Reactor". AECD-4249. Oak Ridge National Lab., TN. Sept. 18, 1951 (Decl. with

deletions Feb. 20, 1957). 33p.

A method is presented for solving the non-linear equations which attempt to predict the kinetic behavior of the liquid-fuel Aircraft Reactor Experiment. Equations describing the flux and temperature of components are given. Problems considered response to a sudden control rod motion, response to a sudden change of inlet coolant temperature, and response to a sudden change of inlet coolant temperature when the control rod is activated by a certain function of the inlet and outlet coolant temperatures.

“Nuclear Propulsion Project Quarterly Progress Report for Period Ending March 31, 1957." ORNL-2274(Pts.1-5). Oak Ridge National Lab., Tenn. July 11, 1957. 327 p.

Activities in a program directed toward the design, construction, an operation of the Aircraft Reactor Test (ART) are reported. Progress is reported in the areas of aircraft reactor engineering, chemistry, metallurgy, radiation damage, fuel reprocessing, critical experiments, and reactor shielding.

Plains, D.L. “Thermal Stress Analysis of the Art Heat Exchanger Channels and Header Pipes”. ORNL-2442. Oak Ridge National Lab., TN. Apr. 2, 1958 (Decl. Oct. 9, 1959). 38p.

Thermal stresses, deflections, and the forces and moments acting on the Aircraft Reactor Test heat exchanger channels and header pipes due to relative thermal expansion between the channels and pressure shell at full power operation are summarized.

Platas, D.L. “Thermal Stress Analysis of the ART Heat Exchanger Channels and Header Pipes”. ORNL-2442. Oak Ridge National Lab., TN. Apr. 2, 1958 (Decl. Oct. 9, 1959). 38p.

The stresses, deflections, and the forces and moments acting on the Aircraft Reactor Test heat exchanger channels and header pipes due to relative thermal expansion between the channels and pressure shell at full power operation are summarized.

Platus, D. L., D.M. Miller and R.V. Meghreblian. “ART Reflector Temperature Distribution”. ORNL-2425. Oak Ridge National Lab., TN. Mar. 5, 1958 (Decl. Jan. 5, 1960). 43p.

A summary is presented of the application of the relaxation method to the determination of the steady state temperature distribution in the ART reflector beryllium during full power operation.

Platus, D. L. “Thermal Stress Analysis of the ART Heat Exchanger Channels and Header Pipes”. ORNL-2442. Oak Ridge National Lab., Tenn. (1958 Decl. 1959) 38 p.
The stresses, deflections, and the forces and moments acting on the Aircraft Reactor Test heat exchanger channels and header pipes due to relative thermal expansion between the channels and pressure shell at full power operation are summarized.

Poppendiek, H.F., N.D. Greene, L.D. Palmer, G.L. Muller, and G.M. Winn. “Analytical and Experimental Studies of the Temperature Structure Within the ART Core”. ORNL-2198. Oak Ridge National Lab., TN. Feb. 19, 1957 (Decl. Nov. 24, 1959). 106p.

The temperature structure within the core of the ART was studied for several different entrance flow conditions. Both analytical and experimental techniques of analysis are used in the investigation. Mean and transient temperature fields are predicted an the basis of the mathematical behavior of idealized cores. These results are compared with experimental temperature measurements obtained in a half-scale model of the ART core, within which the volume heat sources are generated electrically. The heat transfer studies revealed the following facts about the ART core: (1) Unless the core shell walls are cooled, maximum wall temperatures ranging from 1750 to 1850 deg.F. (depending upon the type of entrance flow) will exist near the core exit and necessitate removal of ~3% of the heat generated within the core to accomplish the cooling task. (2) Unless the sodium coolant flows through the cooling annuli in a uniform fashion, hot and cold spots will exist in the core shells. (3) Peak fuel temperature at the core exit, under wall cooling conditions, will be from 100 to 170°F higher than the mixed mean fuel temperature (depending on the type of entrance flow). (4) The temperature structure within the core is significantly asymmetric with respect to peripheral position when one pump is not in operation. (5) The core shell interface and fuel temperatures are transient in nature (frequency spectrum ranges from about ½ to 4 cycles per second). Some of the general principles upon which circulating-fuel reactors should be designed from the standpoint of heat transfer and fluid flow are discussed. Several reactor cores other than the ART are reviewed.

Rockwell, T., III and V. L. McKinney. “Thermal Neutron Shield and Method for Making Same”. Patent for U. S. Atomic Energy Commission. U. S. Patent 2,727,996. December 20, 1955.

An improved thermal neutron reactor shield of low weight and bulk, suitable for use aboard planes, ships and the like has been developed. The shield comprises a continuous matrix of a malleable metal such as Al or Zr, dispersed in which is a refractory material, boron oxide or boron carbide, in powder or pellet form, and a sheathing of Al or stainless steel bonded thereto. The matrix is sandwiched between the sheathing in a high temperature rolling process. The B content of the matrix may vary between 35 and 50%. A shield as described 1/4 in. thick will attenuate a neutron of .025 ev energy. [Researcher Note: This is the widely used Boral shielding material].

Rockwell, Theodore, III. and Arnold S. Kitzes. "Theoretical and Practical Aspects of Shielding." ORNL-710. Reactor Technology Division, ORNL. Sept. 29, 1950.

(Decl. Sept. 5, 1956). 334p.

When originally published as a classified report, this represented the most current status of work in the entire field of radiation shielding. Papers are updated versions of those presented at the first symposium held on radiation shielding at ORNL, September 27-30, 1948. Includes the following papers related to the ANP Project:

"Shields for Aircraft Reactors", A. Kalitinsky, NEPA Division, Fairchild Engine and Aircraft Corp.

"Tolerance Determination", Karl Z. Morgan, ORNL.

"Nuclear Data", S. Podger, Fairchild Engine and Aircraft Corp. (This paper mentions that the NEPA Project had a contract with the Univ. of Kentucky for measurements of some basic nuclear properties of materials of interest.)

"Geometrical Considerations in Shielding", Gunnar Thornton, Fairchild Engine and Aircraft Corp.

"Shielding Materials", V.P.Calkins and W.J. Koshuba, Fairchild Engine and Aircraft Corp.

Rockwell, Theodore III. "Putting Wings on the Atom". Unpublished manuscript intended for the *Saturday Evening Post.* April, 1947. 22 p. To be accessioned in the Air Force History Archives at the Air Force Historical Research Agency, Maxwell AFB, AL.

Rockwell prepared this article for the lay public to achieve some understanding of the NEPA Project. However, he was never able to obtain clearance to declassify the article, even though he claimed to have obtained all the information from unclassified sources, since he was not a member of the NEPA Project team. He outlines the difficult problems the project must overcome and discusses the potential benefits of nuclear powered flight. Includes photographs of: the thermal diffusion plant site used for the first location for the nuclear aircraft project, Gordon Simmons, Jr., originator and Technical Director of the NEPA Project; Andrew Kalitinsky, Chief Engineer of the NEPA Project; and Maj. Donald J. Grant, Contracting Officer for NEPA.

Savage, H. W., G. D. Whitman, W. B. McDonald, and W. G. Cob. “Components of the Fused-Salt and Sodium Circuits of the Aircraft Reactor Experiment”. ORNL-2348 Oak Ridge National Lab., Tenn., (1958). 43 p.

The Aircraft Reactor Experiment (ARE) successfully demonstrated the feasibility of generating heat by fission removed from the reactor by the fused fluoride at 1580 deg.F. Sodium at 1350 deg.F. was used to cool the BeO moderator. With minor exceptions all

the components proved to be adequate. The development of components and fabrication techniques for this reactor consumed a four-year period, during which time the technology for handling high-temperature fluids was extended to equipment operable above 1500 deg.F. The methods used for determining compatibility of materials under static and dynamic conditions, standards for materials, and techniques for welding, fabrication, and assembly and the design criteria for pumps, seals, valves, heat exchangers, cold traps, expansion tanks, instrumentation, preheating devices, insulation are described.

Savolainen, A.W. (ed.) "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending June 10, 1956." ORNL-2106 Pts.1-5. Oak Ridge National Lab., Tenn. Sept. 4, 1956. 285 p.

Activities in a program of research on circulating fuel reactors and other ANP projects are reported. Information and data are included on aircraft reactor engineering, chemistry, metallurgy, heat transfer, properties of reactor materials, radiation damage, fuel processing, critical experiments and reactor shielding. The specific objectives of the program include design, construction, and operation of the Aircraft Reactor Test (ART). The ART is a 60 MW circulating-fuel reflector-moderated reactor with adequate means for heat disposal.

Savolainen, A.W., ed. “Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending June 10, 1955". ORNL-1896. Oak Ridge National Lab., TN. July 28, 1955 (Decl. with deletions Nov. 13, 1959). 179p.

Progress is reported on the reflector-moderated reactor, experimental reactor engineering, critical experiments, chemistry of reactor materials, corrosion research, metallurgy and ceramics, heat transfer and physical properties, radiation damage, analytical chemistry of reactor materials, and recovery and reprocessing of reactor fuel.

Savolainen, A.W., ed. “Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending December 10, 1955". ORNL-2012 (Pts. I, II, III). Oak Ridge National Lab., TN. Mar. 12, 1956 (Decl. with deletions Oct. 22, 1959). 206p.

Construction work is under way on the Aircraft Reactor Test facility. System flowsheets and instrumentation lists were prepared in initial attempt to define the entire ART. The fuel-to-NaK heat exchanger design was modified to overcome interfaces at the headers and to provide additional space in the region of the headers for the Be support struts. The problem of cooling the fuel fill and drain tank was studied. Core flow studies were made on both the full-scale AL and plastic core models. An equipment layout was prepared for the Engineering Test Unit (ETU). Tests of an ART fuel pump are under way with high-temperature (1400°F) NaK as the pumped fluid. Operation of intermediate heat exchanger test A was continued, and test stand B was placed in operation. A test assembly for use in the development and testing of cold traps and plugging indicators is being fabricated.

Savolainen, A.W., ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending September 10, 1954". ORNL-1771. Oak Ridge National Lab., TN. Oct. 29, 1954 (Decl. with deletions Dec. 2, 1959). 152p.

Progress is reported on the circulating-fuel Aircraft Reactor Experiment, reflector-moderated reactor, experimental reactor engineering, critical experiments**,** chemistry of molten materials, corrosion research, metallurgy, heat transfer and physical properties, radiation damage, and analytical studies of reactor materials.

Savolainen, A.W., ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending June 10, 1956". ORNL-2106 (Pts.1-5). Oak Ridge National Lab., TN. Sept. 4, 1956 (Decl. with deletions Dec. 2, 1959). 257p.

Activities in a program of research on circulating fuel reactors and ANP projects are reported. Information and data are included on aircraft reactor engineering, chemistry, metallurgy, heat transfer, properties of reactor materials, radiation damage. fuel processing, critical experiments and reactor shielding. The specific objectives of the program include design construction and operation of the Aircraft Reactor Test (ART). The ART is a 60 Mw circulating-fuel reflector-moderated reactor. Progress is reported on the Aircraft Reactor Test (ART) design; ART physics; ART instruments and controls; component development and testing; ART, ETU, and in-pile loop operations; phase equilibrium studies; chemical reactions in molten salts; physical properties of molten materials; production of fuels; compatibility of materials at high temperatures; analytical chemistry; dynamic corrosion studies; general-corrosion studies; fabrication research; welding and brazing investigations; mechanical properties studies; ceramic research; nondestructive testing studies; heat transfer and physical properties; radiation damage; fuel recovery and processing; and critical experiments.

Savolainen, A.W., ed. "Aircraft Nuclear Propulsion Project Quarterly Progress Report for Period Ending September 10, 1955". ORNL-1947. Oak Ridge National Lab., TN. Nov, 10, 1955 (Decl. with deletions Oct. 22, 1959). 175 p.

The technical process of the research on circulating fuel reactors and other ANP research at ORNL is summarized. The design construction, and operation of the 60 MW Aircraft Reactor Test are the specific objectives of the project. Operation of the system will be for the purpose of determining the feasibility, and the problems associated with the design, construction, and operation, of a high-power, circulating-fuel, reflector-moderated air-moderated reactor, experimental reactor engineering, critical experiments, chemistry of reactor materials, corrosion research, metallurgy and ceramics, heat transfer and physical properties, radiation damage, analytic chemistry of reactor materials and recover and reprocessing of reactor fuels.

Semple, E. L. and W. C. Cooley. "Direct Cycle Nuclear Turbojet Power Plants". *Aero. Space Eng.* 17, 8 (1958): 30-5.

An attempt was made to estimate effects of more important design parameters flight performance of power plants, under consideration by General Electric Aircraft Nuclear Propulsion Dept. It is shown that two of the most significant factors affecting power plant thrust/weight ratio and, therefore, aircraft capabilities are turbine inlet temperature and reactor free flow fraction.

Slaughter, G.M. and P. Patriarca. "Welding and Razing of High-Temperature Radiators and Heat Exchangers." ORNL-TM-147. Oak Ridge National Lab., Tenn. Feb. 20, 1962. 25 p.

Procedures were developed for fabricating high performance radiators and heat exchangers for the Aircraft Nuclear Propulsion Program. These components, which contain multitudes of tube-to-tube sheet and tube-to-fin joints, are similar in design to those under consideration for a variety of space vehicle applications. In order to ensure reliability of the tube-to-tube sheet joints, techniques producing welds of extremely high quality were used and back brazing of the welds with a suitable alloy was incorporated. High-temperature brazing was also incorporated to attach high-conductivity fins to Inconel tubes in the radiators. The selection of a suitable brazing alloy for these applications was dependent upon several factors, including corrosion and oxidation resistance, flow point, and mechanical properties. A Ni- Si-B alloy was found to be adequate from all these considerations. Special brazing procedures were developed to obtain satisfactory flowability of this brazing alloy on tube-to-fin joints. The suitability of these fabrication procedures for the very stringent service conditions to which the radiators and heat exchangers were subjected was demonstrated by testing full-size components under operating conditions.

Stern, H.E. and F.B.K. Kam. "Design of a Reactor Shield". ORNL-3016. Oak Ridge National Lab., TN. (No Date). 233 p.

A study of some of the problems inherent in the design of reactor shields for nuclear powered aircraft was initiated. Calculational methods for obtaining optimum configurations are being explored. Initial attention was focused on gamma rays born in a core and utilized a simple model for some approximate calculations.

Thompson, W.E. , compiler. "History of the Oak Ridge National Laboratory, 1943-1963". ORNL 63-8-75. First Rough Draft, Aug. 23, 1963. PP. 89-100.

Marked as a "First Rough Draft", apparently no later version of this history was ever completed. One chapter reviews the history of the ANP work conducted primarily at

ORNL from the NEPA Project starting in 1946 and the Lexington Project review. After numerous conferences with AEC, ORNL, on Sept. 1, 1949 was instructed by AEC to establish an ANP Project. One of the first steps was the setting up of a Technical Advisory Board (TAB) of outstanding scientists who met at ORNL over the summer of 1950 to evaluate designs under consideration and to establish basic design points from which an aircraft reactor could be developed. The TAB issued an optimistic report on the prospects for ANP and recommended that the liquid fuel (molten salt) reactor ARE be built at ORNL. . ORNL proceeded to design the molten fuel, 2.5 MW Aircraft Reactor Experiment (ARE), with operation commencing in Oct. 1954. The ARE operated for 100 hours at the full design power of 1 MW, as planned. Plans were then initiated for a 60 MW prototype molten salt fueled reactor, the Aircraft Reactor Test (ART). Early in 1958, the ANP Program came under fire from both the President and the Congress. After the President ordered a review of the current status, reevaluation of the military need, and an assessment of the time and cost to meet objectives, major cutbacks were ordered, including elimination of the ORNL molten salt phase entirely. Upon cancellation, the main ORNL effort on ANP was in support of the GE and Pratt & Whitney work. Eventually, ORNL's R&D efforts shifted to the space program and high temperature research.

Waldrop, F. B. "Photographs of the "A" Test Sector and Components After Thermal Cycling". Y-B-65-257. Oak Ridge Y-12 Plant, TN. Feb. 9, 1959 (Decl. Nov. 12, 1974). 42p.

Photographs taken during inspection of a test segment of the General Electric aircraft reactor (XMA-1) side shield are presented.

Webster, J. W. and 0. A. Schulze. "Some Results of Criticality Calculations on BeO and Be Moderated Reactors". ANP-66. Oak Ridge National Lab., Y-12 Area, TN. Oct. 15, 1951 (Decl. Oct 9, 1959). 98p.

Results of criticality calculations are given for an intermediate energy BeO moderated reactor of 2.69-ft core diameter and for numerous variations of its parameters. The subjects quantitatively studied are: effect of core composition and core size, effect of xenon and uranium lumping, effect of reflector, and effect of iteration of the source term. Graphs are given for normalized fissioning spectrum, spatial power distribution, and leakage spectrum on each reactor assembly where significant. Also included is a graph showing the effect of reflector thickness on reactivity and a graph showing the convergence of the fission distribution with its iteration as the source distribution. The method of calculation is a 31-group numerical multigroup technique essentially that used by KAPL with modifications to adapt it to IBM computation.

Weinberg, Alvin M. "Some Aspects of Fluid Fuel Reactor Development". For Oak Ridge National Lab.,TN. *Nuclear Science and Engineering* 8 (Oct. 1960): 346-60.

Fluid fuel reactor development is reviewed and the advantages and disadvantages of this type of reactor are given. The technology of the Aqueous Homogeneous Reactor, the Aqueous Homogeneous Reactor Experiments, Molten Salt Reactors, and the Aircraft Reactor Experiment are discussed.

Weinberg, Alvin M. "First Report on 1,500 Deg. F. Aircraft Experimental Nuclear Reactor". *Chem. Eng. Progr*. 53, 6 (June 1957): 6, 10. Oak Ridge National Lab., TN.

Experiments at ORNL with the high-temperature, circulating-fluoride-fueled ARE are briefly described. The advantages of this reactor system which may make it useful as a power producer are outlined.

Whitman, Merrill J., and Don L. Stockton. "Boiling Rubidium as a Reactor Coolant. Preparation of Rubidium Metal, Physical and Thermodynamic Properties and Compatibility with Inconel". CF-55-6-49 (Pt.l). Oak Ridge School of Reactor Technology, TN. Aug. 1954 (Decl. July 1, 1960). 144p.

Rubidium metal was investigated as a possible heat transfer medium for an aircraft reactor. The separation of rubidium from other alkali metals by ion exchange was demonstrated. Data are presented on the physical and thermodynamic properties of rubidium and corrosive effect on Inconel at elevated temperatures. It was concluded on basis of empirical formulas that more heat can be transferred in a boiling rubidium system than in a comparable boiling water system.

Whitmarsh, C. L. "Reprocessing of ARE Fuel, Volatility Pilot Plant Runs E-3 Through E-6". CF-59-8-73. Oak Ridge National Lab., Tenn. (1959) 39 p.

Reprocessing of the ARE fuel was resumed after extensive leak testing in the pilot plant. This was considered necessary to assure no recurrence of gaseous UF-6 leaks as experienced in Run E-2. In the four additional runs required to complete the program, about 641 kg of fluoride salt containing 40.64 kg of fully enriched uranium was reprocessed. Recovery as UF-6 product represented 97.97% of the feed, with 0.01% measured losses. An additional 2.14% was reclaimed from NaF beds. The product was of sufficient purity to meet specifications for material designated for reduction to uranium metal. Decontamination from fission products was essentially complete. Calculations based on the entire ARE program indicated 96.38% product recovery, with 0.06% measured losses. An additional 2.50% was reclaimed from NaF beds and equipment washes.

Whitmarsh, C.L. "Equipment Checkout Prior to ARE Processing, Volatility Pilot Plant Run B-1". CF-58-5-112. Oak Ridge National Lab., TN. May 29, 1958. 14p.

The head-end system for the ARE salt was tested with barren salt and shown to be operable. Transfer of the final batch of salt by gravity flow from the hold tank was shown to be feasible with a redesigned feed salt freeze valve. The trap was also redesigned but the remote dumping mechanism did not function properly.

Whitmarsh, C.L. “Reprocessing of ARE Fuel Volatility Pilot Plant Runs E-1 and E-2". CF-59-5-108. Oak Ridge National Lab., TN. May 11, 1959. 42p.

After two batches (~340 kg) of fluoride salt from the ARE were reprocessed, pilot plant operations were terminated because of a leak through which an estimated 780 g of uranium (as UF_6) escaped. Of the 21 kg of highly enriched uranium in the feed, 93.12% was collected as UF_6 product, 0.13% represented measured losses, and 3.72% was unaccounted for (leak). An additional 3.03% was reclaimed from NaF beds and equipment washes. The product met both chemical purity and activity specifications for product level UF_6. Decontamination from fission products was essentially complete. A gross γ decontamination factor was apparently limited by the low activity of the feed salt.

Whitmarsh, C.L. “Reprocessing of ARE Fuel, Volatility Pilot Plant Runs E-3 Through E-6". CF-59-8-73. Oak Ridge National Lab., TN. Aug. 26, 1959. 39p.

Reprocessing of the ARE fuel was resumed after extensive leak testing in the pilot plant. This was considered necessary to assure no recurrence of gaseous UF_6 leaks as experienced in Run E-2. In the four additional runs required to complete the program, about 641 kg of fluoride salt containing 40.64 kg of fully enriched uranium was reprocessed. Recovery as UF_6 product represented 97.97% of the feed, with 0.01% measured losses. An additional 2.14% was reclaimed from NaF beds. The product was of sufficient purity to meet specifications for material designated for reduction to uranium metal. Decontamination from fission products was essentially complete. Calculations based on the entire ARE program indicated 96.38% product recovery, with 0.06% measured losses.

Wilson, J.C., J.C. Zukas, and W.W. Davis. “Creep of Inconel and Stainless Steel under Irradiation. Radiation Damage Conference, March 23-24, 1953". CF-53-3-276, Pt.II. Oak Ridge National Lab., TN.
p. 268-78.

The purpose of the creep-study program is to determine whether neutron irradiation will affect the creep strength of the metals proposed for use in the Aircraft Nuclear Propulsion Project. In-pile tests of type 347 stainless steel at temperatures from 1200 to 1500°F were carried out, and Inconel was tested at temperatures of 1500 to 1700°F in the ORNL Graphite Reactor and in the LID Test Reactor (LITR) where the fast fluxes were 4×10^{10} and 1×10^{12} neutrons/cm^2/sec, respectively, The stresses, ranging from 1500 to 8000 psi, were chosen to produce total elongations of about 0.2% for 250 to 1000 hr tests at the chosen test temperatures.

Yarosh, M.M. "Evaluation of the Performance of Liquid Metal and Molten Salt Heat Exchangers". For Oak Ridge National Lab., TN. *Nuclear Sci. and Eng*. 8 (July 1960): 32-43.

Heat transfer and pressure drop test data were obtained on liquid metal-to-molten salt heat exchangers and on liquid metal-to-air radiators. The data were correlated to permit predictions of the heat transfer and pressure drop performance of heat exchange equipment to be used on the Aircraft Reactor Test. The test results agreed well with analytical predictions using the Dittus-Boelter and Kaufman-Lubarsky equations except that in the transition region from laminar to turbulent flow marked differences were found in the heat transfer coefficients for flow through round tubes and axial flow between tubes. These differences appeared to stem in part from the irregular geometry of the flow passage between tubes and from the tube spacers employed.

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f. OTHER SOURCES

Adams, R.K., G.H. Burger, C.A. Pfretzschner, and S.T. Schy. "Interim Report to Oak Ridge National Laboratory Relating to a Digital Data Acquisition System for Use with the Homogeneous Reactor Test Facility". CF-60-3-159. Thompson Ramo Wooldridge Products Co., Beverly Hills, CA. Mar. 29, 1960. 146p.

A description is given of the findings of a survey of the HRE-III, which was conducted to define the functions which could be performed by an on-line computer system.

Addoms, James N.; McAdams, W. B. "Heat Transfer to Water Flowing Normal to Cylinders". NEPA 599-MIT-20 Mass. Inst. of Technology, Cambridge, MA. April 1948. P.56.

Studies were undertaken to employ Reynolds numbers from 1000 to 10,000 in order to secure densities of heat flux far higher than hitherto obtained with flow of liquid normal to a tube. Data were obtained for non-boiling conditions with water at 650 and 147O deg.F. and velocities from 3 to 10 ft. per sec. Flux densities as high as 1M Btu per hour per sq ft were obtained at 10 ft per sec without local boiling. With higher delta T, local boiling ensued and flux densities of 2.6M were achieved without vapor blanketing. In contrast, with saturated water at 212 deg. F., the peak density was 1.3M at 10 ft. per sec. and 700,000 at 3 ft. per sec.

"Airborne Reactors". *Electr. Times* 133, 3459 (1958): 331.

Reported on progress to date in the development of the ANP Program.

"Aircraft Alloys for Thermal Flight up to 1200° F". *Metal Progress* 71, 6 (June 1957): 97-110.

A discussion is presented of the problems involved in the fabrication of alloys for thermal flights up to 1200° F.

Arndt, R.J. and C.W. Terrell. "Irradiation Testing of Operating Electronic Equipment by Fast Neutrons and Gammas". NP-7189. Illinois Inst. of Tech., Chicago (Armour Research

Foundation). Apr. 30, 1958. 42p.

A study of the radiation effects of fast neutrons (0.5 ev to about 15 Mev) and gamma rays (fission spectrum) on various pieces of aircraft instrumentation is reported. Components studied were: fuel gage vacuum tube amplifier and indicator, transistorized (germanium and silicon) servo amplifier system, and 4-in. diam. gyro. The fuel gage was subjected to a total neutron flux of about 6 x 10^5 nvt and about 5 x 10^8 r gamma with no adverse electrical effect. Physical damage was evident. Four transistorized amplifiers were irradiated in a fast flux of about 1.0 x 10^{10} n/cm^2/sec. Rapid loss in gain, rapid increase in d-c current drain, and complete failure occurred when the integrated flux reached about 10^{13} n/cm^2/sec. The silicon diodes were unaffected by the same flux. Studies on the gyro were inconclusive due to equipment failure.

Artamkin, V. "On an Atomic Airplane". T-10620. Rand Corp. Santa Monica, CA. Oct 14, 1958. P.10.

A review of the non-Soviet literature concerning nuclear powered aircraft design efforts.

Aschenbrenner, F. A. "Shielding for Aircraft Nuclear Power Plants". Presented at Nuclear Engineering and Science Conference, held at Chicago, March 17 to 21**,** 1958. Preprint 120, Session 36. New York, American Institute of Chemical Engineers (1958) 12 p.

The main function of an airborne aircraft nuclear shield system can be briefly summarized as those of protecting the operating crew from biological radiation damage and protecting aircraft components from excessive activation and material damage. The airborne shield system can also serve a secondary function as part of the shield system necessary for protecting ground handling and maintenance crews. Thus, the shield system must be designed subject to the radiation level constraints which may apply to either the operating conditions, after shutdown conditions, or both. Any shield system used would be expected to constitute the heaviest single item aboard a nuclear powered aircraft. Therefore, power plant performance is quite sensitive to the specific nuclear shield design. Accurate and efficient design procedures must be developed which can be used to calculate optimum shield thicknesses efficiently. Some of the most important problems which must be faced in the design of high performance aircraft shield systems are described.

"Atomic Power for Aircraft and Missiles". A Bibliography. *Missiles and Rockets 11*, 6 (1957): 136,138,140.

Some articles on ANP are listed and all have been included in this bibliography.

"Atomic Powered Aircraft". *Flight Aircraft Eng.* 60 (1951) 780.

Reviewed progress on the ANP Program.

Aukerman, L.K. and R.K. Willardson. "Radiation Effects in Compound Semiconductors". Paper 38 of the Third Semi-Annual Radiation Effects Symposium. Atlanta. October 28-30, 1958. Volume 4. Electronics and Semi-Conductors Papers. NP-7365. Battelle Memorial Inst., Columbus, OH. 20p.

The properties of semiconductor devices depend strongly on minority-carrier lifetime, carrier concentration and mobility. These parameters are strongly affected by nuclear irradiation. For the design of a device relatively insensitive to radiation damage, semiconductors composed of heavy atoms and having a high minority-carrier mobility and a large energy gap are desirable. The properties of several compound semi-conductors. including AlSb. InP, GaAs, CdTe, and InSb, are compared with respect to the above criteria. Investigations of the effects of fast-neutron irradiation of these compounds are reported. Annealing and heat-treatment studies before and after irradiation are discussed.

Barad, M. L., D. A. Haugen and J.A Fuquay. "Diffusion-Deposition Model for in-Flight Release of Fission Fragments." AFCRC-TN-60-400. Air Force Cambridge Research Center. Geophysics Research Directorate, Mass. *Air Force Surveys in Geophysics* No. 123. Apr. 13, 1960. 32p.

A diffusion-deposition model is developed for use in estimating dosage levels due to in-flight release of fission fragments from a nuclear-powered aircraft. The model is based on the work of Sutton for diffusion and the work of Chamberlain for deposition. The model considers an elevated instantaneous point source and an elevated instantaneous line source oriented at an arbitrary angle to the mean wind direction. Suggested values of the various deposition, rain-out, and diffusion parameters to be used with the model are presented along with a qualitative discussion of the uncertainties of the model and the suggested parameters.

Baxter, E.F, Jr, and J.F. Black. "The Effect of Radiation on Petroleum and Its Products". ESSO-MA-l. Esso Research and Engineering Co., Products Research Div., Linden, NJ. Aug. 1, 1959. 19p.

The radiation chemistry of pure hydrocarbons was reviewed to illustrate the reactions of the various hydrocarbon types found in petroleum and petroleum products. These studies show that unsaturated compounds are more reactive than saturated, and aromatic compounds are the most stable of all. The radiation resistance of polynuclear aromatic compounds extends to high temperatures, which makes these materials interesting as moderator-coolants for nuclear reactors. Irradiation experiments with multi-component systems indicate that data on individual organic compounds cannot predict the radiolysis behavior of complex mixtures of the type found in petroleum. A review of the available data on the radiolytic behavior of petroleum fractions reveals that they can usually be exposed to radiation dosages in the range of 10^6 to 10^8 rads without serious damage to properties affecting their end use. With jet fuels, for example, doses in the neighborhood of 10^7 rads have been observed to produce threshold damage effects. Petroleum-based lubricants can generally withstand several times this amount of radiation. Literature data on diesel fuel, gasoline, and other petroleum fractions are meager, but it appears that they should be as stable as jet fuel unless they contain radiation-sensitive additives such as tetraethyl lead. Crude oil apparently is more radiation resistant than any of the products prepared from it. The available data on the evolution of gas from irradiated hydrocarbons show that the range of gas yields is 1 to 5 milliliters of gas/milliliter of liquid per 10^8 rads dosage. A consideration of the possibility that gamma rays and fast neutrons may differ in their effectiveness for causing radiation damage has led to the conclusion that in most cases serious errors will not be introduced by assuming equal damage from equal energy input.

Bicknell, J.E. "Reactors for Propulsion of Manned Aircraft And Missiles". For U.S. Atomic Energy Commission, Washington, DC. *Texas Engineering Experimental Station Misc. Publications* E 72-60 (Apr. 1960): 19-28.

The four programs of the Atomic Energy Commission concerned with aerospace application of nuclear energy are discussed. Three are concerned with reactors for propulsion and one is concerned with the application of nuclear energy to generate Auxiliary electrical power. Two aeronautically oriented propulsion reactor programs are the manned nuclear-powered aircraft and the nuclear-powered ram-jet (Project PLUTO). A resume of radiological safety considerations inherently associated with aerospace applications of nuclear energy is included.

Bohannon,J. R. Jr. and W. E. Baker. "Simulating Nuclear Blast Effects". *Nucleonics* 16, 3 (1958): 75-9.

A summary of blast effects testing of a one-quarter scale model of the Air Force Nuclear Engineering Test Reactor is presented. An analysis of the test results indicates that the full-scale design can safely contain nuclear energy releases exceeding that in the maximum credible accident. The validity of assumptions made in the analysis is discussed in the article.

Bond, F., Jr., R. Mould, A. Preston. "Aircraft Power Plant Analysis". TID-5079. Flader (Fredric) Inc., North Tonawanda, NY. Oct. 20, 1950. 64p.

The power plant includes two separate and distinct cycles which are nevertheless closely interdependent in operation. The first of these is a closed vapor cycle whose useful output is shaft power from a steam turbine and whose heat sink is an air-cooled condenser. The second is an open, air cycle in the form of a jet engine. The reactor cooling system utilizes water as a coolant and the vapor cycle to drive the air compressor. The condensers contribute a major part as the heat sink function in the vapor cycle, and supply heat to the air in the jet engine cycle. The maximum coolant temperature was limited to 980°F and the pressure was established at 5,000 psi. The coolant is plain water deaerated and distilled to remove impurities. The coolant circulates directly through the reactor core and functions as the primary moderator. Control is effected by varying flow through the reactor.

Born , J. W. "Radiation Resistant Aircraft Tires." NP-9333 (Vol.III). B.F.Goodrich Co. Research Center, Brecksville, Ohio. Paper 5 of Fourth Radiation Effects Symposium, September 15-16, 1959, Cincinnati, Ohio. General Session Papers. 60p.

Radiation effects tests were conducted on aircraft tires, half of which contained antirad protective compounds. The tires received nominal exposures of 8.39 x 10^9 ergs per gram. The conventional tire retained an average 15% of the normal test life. The antirad-protected tires retained 25% of the normal test life after receiving a 16% higher radiation exposure than the conventional tire.

Borst, L. B. "Reactor Development". AECD-2172. Brookhaven National Laboratory. Oct. 1948. P.3.

Studies have shown that power generation and breeding efficiencies will be sacrificed to achieve compact and mobile units for the propulsion of ships, locomotives, and aircraft. Present research for study of various scientific problems will be supplemented by the Brookhaven reactor and the Oak Ridge high flux pile.

Brady, J.F. "Nuclear Powered Aircraft." Soc. Automotive Engrs., Paper 92A for meeting Sept. 29-Oct. 4, (1958) 8 p.

Data on different types of problems encountered and types of aircraft considered. With regard to proposed power plants and proposed propulsion cycles, two possible programs can be pursued. The fastest, easiest program would be a subsonic turboprop aircraft using existing components and technology. The turbojet power plant under development needs advances in technology over turboprop, which in part can be obtained from development of turboprop.

Bruner, Fred W. "The Application of Nuclear Power to Aircraft and Rocket Propulsion". ATI-47066. Purdue University. Nov. 1948. P.27.

The elementary principles of nuclear power production are reviewed, and some of the problems of application to aircraft and rocket missiles are discussed. Superficially, it would appear that a propellant capable of producing 23,000 kw-hr, or 31,000 hp-hr, of

energy per gram of propellant is ideal for any application requiring that weight be kept to a minimum. In reality, the conditions are not so encouraging
from the weight viewpoint as might be expected became of necessities of shielding and cooling. Components of a nuclear power plant are discussed, as well as control, cooling, and power systems, heat transfer aspects and materials. Propellent requirements for two years of aircraft operation are estimated and matters of economics and logistics are analyzed.

Buhler, Rolf D. and Peter J. Gingo. "Potential Aircraft Applications of Closed Gas Cycle Nuclear Power Plants". "In Advanced Propulsion Systems". Plasmadyne Corp., Santa Ana, CA. Pergamon Press, New York: 1959. p.117-34.

Closed gas-cycle nuclear power plants for aircraft applications are discussed in view of recent advances in refractory metals and ceramic fuel element technology. With high-pressure helium as the primary loop working fluid, the chief advantages of the closed-cycle gas-cooled system are its compact reactor, high cycle efficiency, freedom from corrosion, and high physical and nuclear stability of the working fluid. Heat exchanger sizes, weights, and tightness, together with the possibility of fission product leakage into the helium, are considered the most severe problems. Neither the size, weight, nor performance of the helium turbo-machinery should pose serious difficulties. The performance of a subsonic cruise-supersonic dash airplane, with chemical fuel augmentation, is calculated using material temperatures compatible with present technology. Two other airplanes, which were all-supersonic and which used a nuclear power plant system during their entire mission, are studied.

Buhler, R.D. "Escher Wys Closed Cycle Aircraft Power-Plant Study. Part 1. Summary and Valuation of Phase I". PRC-258; AFOSR-TR-57-36; AD-12. Propulsion Research Corp., Santa Monica, CA. May 8, 1957. 65p.

Various ducted fans driven by closed cycle gas turbines were studied. For chemical fuels, two arrangements were considered for the combustion chamber containing the closed cycle gas heater: (a) as part of a separate turbojet engine (external heat source), and (b) as in afterburner in the ducted fan air flow (self-contained closed cycle engines). For nuclear fuels the high-temperature gas-cooled reactor was considered the most likely heat source (single loop system). One closed cycle powerplant with external gas heater was fairly completely designed, The component weights of this engine were used as a basis for weight estimates of the other engines. Two other closed cycle applications were briefly investigated: a high altitude secondary powerplant, and a boundary layer suction fan drive system. The closed cycle ducted fans using chemical fuels were found to be too heavy and complicated to be competitive with open cycle engines. The gas-cycle nuclear engine looked promising for subsonic and possibly for low supersonic propulsion. Further work on this was initiated. As secondary powerplants for future high altitude flight vehicles, closed cycle turbines promise to have a definite field of application.

Cannon, R.D., B. E. Paiii, K. L. Rohde, and M. W. Roberts, Ed. "Laboratory Studies for HTRE Fuel Reprocessing". IDO-14523. Phillips Petroleum Co. Atomic Energy Div., Idaho Falls, ID. June 23, 1961. 8lp.

Uranium may be recovered from Heat Transfer Reactor Experiment nichrome fuels by a process involving: dissolution of fuel in mixed nitric and hydrochloric acids, removal of chloride from dissolution product by volatilization, and extraction of uranium from the chloride-free product into dilute tributyl phosphate. Laboratory studies served to define a batch process, furnished alternative operations, and provide data required for full-scale development.

Corey, Calvin H. "Boral for Neutron Shielding." Technical Sales Brochure of Brooks and Perkins Inc., Detroit, MI. Probably printed in 1956. 3p.

Brooks and Perkins was the first commercial manufacturer of Boral, an engineered shielding material developed at ORNL by Theodore Rockwell, III. and patented by the AEC. The brochure includes current applications of this material in the ANP Project.

Credit, L.W. "Single Reactor All Nuclear System Favored for Nuclear Aircraft." *Soc. Auto. Eng.* 68 (May 1960):34.

Three alternatives for achieving nuclear flight reliability were considered: single reactor, dual reactor and combination reactor and chemical fueled. Conclusion reached was that the single reactor would be more reliable.

Culp, A.W., Jr., E. M. Page, and J. W. Stephenson, Jr. "Static Control Characteristics of Fast Reactors". APEX-603. Astra Inc., Raleigh, NC for General Electric Co., Flight Propulsion Lab. Dept., Cincinnati, OH. Oct. 15, 1959. 158p.

The static control analysis of two shaft-through-fast reactors (A-132-A and A-133-A systems) for possible use in the open cycle ANP program. The work consists of an evaluation of the critical masses of the systems including shield effects, determination of the control requirements of each system for an extended mission application, and investigation of the effects of different control systems. The critical masses of the systems range between 350 to 550 lbs of plutonium and 550 to 700 lbs of uranium. The control requirements for a thousand hour mission at full power ranged from 4.5 to 6.0 percent in reactivity. These requirements include startup reactivity requirements (bringing the system to temperature) and operating requirements. The operating requirements amount to approximately two percent in reactivity, this includes fission product poisoning, fuel depletion due to burnup, and the positive effect of conversion of thorium to uranium-233. A number of proposed control systems appear to be more than capable of meeting the control requirements of these systems. One of the most effective systems consists of a sliding absorber sleeve between the shaft and the core with a moderating plug inside the shaft a neutron trap. One such system permitted a control of l4.7 percent in reactivity (Δk). Three poison materials were investigated for use in these systems; europium, gadolinium, and boron-10. Of the three materials, europium appeared to be most effective, followed by boron-10. An analysis of the effect of Doppler broadening is also presented or these systems. Because of the extremely high-operating temperatures, it was found that this effect was negligible compared to expansion effects.

Das, Y. C. and C. C. Hslao. "Effect of Strain Rate on Tensile Strength of Irradiated and Non-Irradiated Drawn and Undrawn Nylon." TID-5804. Technical Report No. 5. Minnesota. Univ., Minneapolis. July 1959. 15p.

Simple tension stress-strain properties for irradiated and non-irradiated drawn and undrawn nylon samples were experimentally determined for several different rates of straining. Within the range of strain rate studied, the tensile strength was found to be linearly related with the logarithm of strain rate.

Dayton, R.W. “Heat Exchange and Fluid Flow In Porous Materials, Relating to the Nuclear Propulsion of Aircraft and Rockets”. Battelle, Columbus, 0. Jan. 1948. P.53.

The porous heat exchanger reactor, as a nuclear power source for aircraft propulsion, has been studied with regards to heat transfer, fluid-flow and mechanical design characteristics. These studies indicated that porous heat exchangers have characteristics that are desirable for nuclear aircraft power plants. The advantages are high energy density, low frictional
pressure drop in the gas under conditions theoretically required for aircraft power plants, temperature gradients, even under conditions of extremely high energy density, and ease of fabrication with adequate strength and control of dimensions.

DeCelles, P. C., F. I, Jenkins, and J. B. Weddell. “Aircraft Structure and Component Scattering and Activation”. ER-9427. Martin Co., Baltimore. Feb. 1958. 39p.

An analytical model was developed so that the crew compartment dose rate in a nuclear powered aircraft due to structural and component scattering and activation could be calculated. The airframe and other aircraft components were represented by a series of coaxial cylindrical shells extending along the longitudinal axis of the fuselage. Each shell was assumed to be of a homogeneous composite material, the which was based upon the mass distribution of chemical elements in the aircraft. Mathematical expressions for quite general conditions applicable to the reactor emission and the structural materials, were derived for calculating dose components. These components are due to gamma ray and neutron scattering, and gamma rays emitted by activated materials. Attenuation and scattering of the radiation by air were also considered. Only single scattering was included in the shell model for the structure and components.

Dicker, Gordon K., Roy L. Shipp, and Carl L. Oakes, Jr. "Standard Instrumentation Techniques for Nuclear Environmental Testing". WADC-TN-56-190. Wright Air Development Center, Wright-Patterson AFB, Ohio. Apr. 20, 1956. 12p.

Techniques for measurement of parameters in radiation environments of nuclear propelled aircraft are outlined. These proposed standard methods are the simplest, least expensive, most adaptable ones presently available.

"Digital Start-Up Control for Aircraft Reactors". NYO-8586. Ford Instrument Co., Long Island City, NY. Mar. 12, 1958. 27p.

An aircraft reactor start-up channel was selected for investigation to indicate the potential advantages of digitalizing a complete aircraft reactor control system. A start-up channel is described which retains present analog sensing techniques and replaces relays and vacuum tubes by digital transistor logic. It is concluded that this instrumentation will result in considerable reduction in size and weight and increased reliability.

Dotson, C. L. and J. R. Kattus. "Tensile Properties of Aircraft Structural Metals at Various Rates of Loading after Rapid Heating". Period Covered: January 1953 to January 1955. Project Title: "Material Analysis and Evaluation Techniques". Task Title: "Design and Evaluation Data for Structural Metals". WADC-TR-55-199 (Part 1) Southern Research Inst., Birmingham, Ala. (1955) 174 p.

The effects of the following variables on the tensile properties of seven aircraft-structural sheet metals after they had been heated within 10 sec. to temperatures up to 1200 deg.F. are described: strain rates from 0.00005 in./in./sec to 1.0 in./in./sec; holding times at test temperature from 10 sec. to 30 min. Special testing apparatus for heating and controlling the temperature of the test specimens, loading the test specimens, and recording load-strain curves was developed. The test results showed that the tensile properties of the structurally stable test alloys, Type 321 stainless steel, RC-70 A titanium and RC-130 A titanium alloy, were not appreciably affected by changes in holding time. Because of the structural changes which occurred, the tensile properties of the precipitation hardening test alloys, Alclad aluminum alloys 2014-T6, 2024-T3, and 7075-T6, and hard rolled AZ-31 magnesium alloy changed as the holding time was varied at certain temperatures. With the exception of the results at one particular test condition, the strength properties of each alloy increased with increasing strain rates. The exception occurred in Alclad 2024-T3 alloy at 4500 F, at which temperature a strongly mitigating structural change occurred. Percent elongation in the different test alloys varied inconsistently with increasing strain rates dependent upon the alloy, temperature, and holding time.

Douglas Aircraft Company, Inc., "Integrated Space Studies Summary Briefing ", (July 1960)

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Call Number K146.01-15p
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Includes discussion of Nuclear Propulsion for Aircraft.

Dowben, Robert M., Daniel B. Williams, Edward M. Miller, and John E. Pickering. “Aircraft Nuclear Propulsion Biomedical Research Program- Report No. 4. Radio-Biologic Problems of ANP”. NP-6763. School of Aviation Medicine, Randolph AFB, TX. Oct. 1955. 11p.

The biological effects of exposure to low radiation dose rates over a long period of time are discussed. Problems in the quantitative determination of the differences in biological response to physically equivalent doses of various radiations are reviewed. Factors to be considered In establishing permissible radiation levels for the crews of nuclear aircraft are discussed.

Dunworth, J.V. “Nuclear Propulsion of Aircraft. *Atom* 12 (1957): 6-10.

Article discussed progress in ANP development.

Durgin, C. T., Jr. “Nuclear Power and the Seaplane.” *U.S. Nav. Inst. Proc.* 82,1 (1956): 18-23.

Reviewed Navy’s approach for ANP.

Earhart, W.H. and N. R. Thielke. “Refractory Materials for Use in High Temperature Areas of Aircraft Bi-monthly Progress Report. Memo Report No. 17". AD-15955. Pennsylvania State College School of Mineral Industries. Feb. 16, 1953. 38p.

The method of differential thermal analysis was applied to a study of oxidation of powdered carbides and metals. Exothermic heat effects of variable magnitude were noted in all cases. Several indices of stability, which were computed, demonstrated generally that TiC, among others, is relatively easily oxidized, whereas Cr and Si carbides are much more resistant in this respect. Similarly, Cr and Si are more stable than Mo or Ni. The relationship between oxidation resistance of sintered compacts and differential thermal analysis of powders was investigated by studying selected commercial cermet compositions. The data were insufficient to establish the correlation between weight-gain measurements and heat effect observed by differential thermal analysis procedures.

Edwards, William E. and John MacDonald. "Reactor Shield Penetration Calculations". Presented at Nuclear Engineering and Science Conference, Chicago, IL. March 17 to 21, 1958. Preprint 119, Session 36, American Institute of Chemical Engineers, New York. 1958. 13p.

Application of point-to-point attenuation functions to the calculation of fast neutron and gamma ray dose and energy absorption rates in and around reactor shields is described. A description is presented of IBM-704 programs capable of evaluating attenuation functions along source-receiver paths in complex shields and performing a final integration over a source region.

Estoque, M. A. "Venting of Hot Gases Through Temperature Inversions". AFCRC-TN-58-623. GRD Research Notes No. 3. Air Force Cambridge Research Center. Geophysics Research Directorate, Mass. (1958) 17 p.

The penetration of temperature inversions in the lower atmosphere by plumes of hot air is investigated as part of a safety analysis in the nuclear aircraft program. This problem is studied with the aid of existing theoretical as well as experimental work. A nomogram showing the relationship between the maximum height attained by a hot plume of a given heat source intensity and the temperature gradient of the environment is presented. The limitations of existing knowledge on the problem are pointed out and some recommendations for future research are made.

Etherington, Harold, editor. "Nuclear Engineering Handbook". McGraw Hill Book Co., New York. 1958. P. 12.53.

Dr. Miles C. Leverett, Manager, Development Laboratories, GE Aircraft Nuclear Propulsion Dept., is listed as a contributor to this handbook. Table 26 in Section 12.1 lists the engineering characteristics of the ANP test reactor, including maximum fuel temperature of 1800 deg. F. Limitations of the design are listed as low heat transfer coefficients, induced radioactivity in cooling air requiring operation of a "hot" turbine. The table includes the note that the design is unproven and successful operation has not yet been achieved.

"Experimental Equipment for Nuclear Powered Aircraft Engines". USA. *Interavia Air Letter* 4060 (1958) 4.

Discussed ANP testing program.

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Fischer, D. J., R. G. Chaffee and Vernon Flegel. "Radiation Resistent Polysiloxane Elastomers".

NP-9333(Vol.III.). Dow Corning Corp. Midland, Mich. Paper 6 of Fourth Radiation Effects Symposium, September 15-16, 1959, Cincinnati, Ohio. General Session Papers. 13p.

The effects of high temperature and radiation environments on polysiloxane elastomers were studied at temperatures up to 200 deg. C.

Fraas, A. P. "Aircraft Design Considerations Associated with Shielding For Aircraft Nuclear Power Plants". Preprint *Inst. Aeronaut. Sci.* 644 (1956) 11 p.

Article covered shielding design problems for the ANP Program.

Fraas, A.P. “Nuclear Aircraft Shielding.” *Aeronaut. Engng. Rev.* 15, 9 (1956): 39-43.

Types of radiation from nuclear reactors and their effects were discussed in relation to shielding materials and configurations for aircraft applications.

Fries, R. C. “Radiation-Resistant Motors for Nuclear Aircraft Controls”. *Nucleonics* 16**,** 7 (1958): 103-4.

Reviewed progress to date in hardening. or otherwise modifying, electric motors to be radiation resistant.

Glasstone, Samuel and Alexander Sesonske. “Nuclear Reactor Engineering.” Van Nostrand, Pub., Princeton, NJ. 1963. P. 734.

A brief description of the HTRE series of tests for the ANP Program is provided. Technical details given include the moderators (water or zirconium hydride), maximum power levels (32.4 MW), compressed air as coolant, with the maximum gas exit temperature of 1640 deg. F., and fuel materials (fully enriched uranium dioxide, in a matrix of 80% nickel and 20% chromium and clad in a niobium-stabilized form of the same Ni-Cr alloy).

Goertzel, Gerald, Mathew M. Shapiro, and Harry Soodak. “Dynamics of the Supercritical Water Reactor”. ORNL-1178. Nuclear Development Associates, Inc., White Plains, NY (For Oak Ridge National Lab.). Feb. 1, 1953 (Decl. July 2, 1959). 92p.

The background work on the dynamics and control of the Supercritical Water Reactor is summarized with emphasis on the determination of the inherent stability of the machine. Variations in water density are found to provide a substantial amount of self-regulation, and the reactor appears quite amenable to control under steady conditions. The use of a fluid which undergoes a six-fold expansion in passing through the reactor for both moderating and cooling makes necessary a more elaborate treatment of the hydrodynamic

behavior of this fluid than is usual. The equations of motion of the system are derived and simplified by linearization thus limiting the validity of the results to the case of small departures from equilibrium. The resulting partial differential equations are then transformed by a variational procedure into a system of first order, ordinary differential equations. The time responses to some disturbances of interest are then determined. Eight major reactor periods, all stable, have been found.

Gordon, S.A. “The Selection of Materials for High-temperature Applications in Airframes.” TML-13. Battelle Memorial Institute Titanium Metallurgical Lab, Columbus, Ohio. Aug. 5, 1955. 38p.

It is intended that this report be considered as a supplement to TML-5A. The airframe industry was surveyed to determine the methods used in the selection of material for application in airframes to determine the relative position of Ti with competing materials. The factors, strength/density ratio, fabricability, availability, dependability, time-temperature effect, and cost are found to be critical. A comparison at Ti and some commonly used airframe metals is made.

Gorker, G. E. “Control Problem Areas in the Design of Nuclear Aircraft Power Plants”. Presented at Nuclear Engineering and Science Conference, held at Chicago, March 17 to 21, 1958, Preprint 111, Session 25.
New York, American Institute of Chemical Engineers (1958) 26 p.

Some of the control problem areas associated with aircraft reactor power plants, some of which are common knowledge and others which are less familiar, are presented. The behavior of a reactor is compared to the more familiar chemical burner so that the reader may notice some of the differences between the two heat sources. Nuclear instrumentation and control system concepts are discussed to some extent so that more detailed problem areas become apparent. This information may prove to be of some value as a guide to the development of control components intended for reactor applications.

Greenwald, W. E and G. P. Kerr. “Impact Deformation Test No. I with Simplified Aircraft Model.” TID-6641. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. July 31, 1960. 29 p.

To evaluate an analytical approach to the impact deformation of a simplified aircraft structure in which the crew compartment, reactor. and fuselage form a double spring mass system, a high velocity impact test was performed on a physical model. The model, consisting of cylindrical 4 and 6 lb. masses separated from each other and from the 50 lb. projectile by thin-walled aluminum cylinders, was instrumented with strain gages at various locations, an accelerometer in each of the two masses, and marked with reference lines for photographic measurement of the collapse and motion. The displacement and accelerations measured confirmed theoretical predictions in most cases. A notable exception was the apparent dynamic critical buckling strengths, which were considerably larger than those predicted.

Gregson, T.C. and S.D. Gehman. "Radiation Damage of Airplane Tire Materials". NP-7365 (Vol. 3) (Paper 24). Goodyear Tire and Rubber Co., Akron, OH. Paper 24 of Third Semi-Annual Radiation Effects Symposium (Held in Atlanta, October 28-30, 1958). Volume 3. Aircraft Systems and Materials Papers. 25p.

Damage to tire components typical of present production was studied with Co^{60} gamma radiation. The influence of various environmental factors was also investigated. Tire fabric and fabric-rubber adhesion are far more susceptible to radiation damage than are the rubber compounds in general use. Cord fatigue and dynamic adhesion are the most serious aspects of radiation damage to tires. Various types of nylon tire cords possess significant differences in their ability to withstand irradiation. Several nitrogen inflated tires were exposed to a dose of 10^7 rad, a level above the damage threshold for nylon cords when irradiated in air. Their performance in laboratory tests confirmed the protective benefits of nitrogen inflation.

Guarnieri, G.J. and J. Salvaggi. "Limiting High Temperature Creep and Rupture Stresses of Sheet Alloys for Jet Applications". (Project Squid). CAL-39 Cornell Aeronautical Lab., Inc., Buffalo, NY. Sept. 28, 1951. 51p.

The high-temperature creep and fracture stresses have been determined for 24 alloys in sheet form over the range of service temperatures and times of interest to designers of jet aircraft parts. Included are steels representative of the low alloy ferritic and austenitic stainless types, Co base alloys, Inconel X, 24S- T3 Alclad Al and Fe-Mg. While the data presented were obtained from a single heat for each material, they provide a design basis for efficient utilization of sheet alloys in high temperature service.

Hale, James C. and Edward A. Douglas. "Investigation Directed Toward the Development of Ceramic Coatings with High Reflectivities and Emissivities for Use In the Aircraft Power Plants". AD-52428. Quarterly Report No. 3 of the Bettinger Corp., Waltham, MA. Jan. 15, 1955. 38p.

Tests were made on the oxidation resistance of various metals, and the effects of oxide diffusion through emissive coatings were considered. Tests were also made to check possible emissivity changes which might occur between a durable enamel and one which had been oxidized. The emissivity data on emissive coatings are discussed. The method of re-calibrating the emissivity machine was also given in detail. Data are given on the development of oxidation resistant coatings. Reflective oxide emissivities and the effect of glass on emissivity of pure oxides are also studied.

Hammitt, F. G. and H. A. Ohlgren. “Nuclear-powered Gas Turbines for Light Weight Power Plants.” *Advances in Nuclear. Engineering*, vol. 2 (1957): 2-25. Proceedings of the Second Nuclear. Eng. & Sci. Conf. held at Philadelphia (1957 Nuclear. Congr. Vol. 1 and 2). New York, Pergamon Press (1957). Vol. 1: 523 p.; Vol. 2: 581 p.

“Handbook of Nuclear Radiation Effects. Part 2". AD-105663. Motorola Inc., Riverside Research Lab., Riverside, CA. Apr. 1956. 78p.

A brief examination of radiation effects on the materials and electronic processes involved in the design and operation of electronic equipment is presented. The radiation intensity used as a reference was 10^6 n/cm^2 sec, applied in 40-hour increments for a total irradiation time of 5000 hours. The data were compiled for use in designing electronic equipment for use in a nuclear powered aircraft.

Hartert, G. “Summarizing Technical Report for Research and Development Task Part 4A (Task No. 4. Additives Investigation. Part 4A. Halo Contamination. Final Report. May 1-September 30, 1963.)”. Coors Porcelain Co., Golden, CO. Oct. 15, 1963 (Decl. Nov. 26, 1973). 18p.

The findings of an extensive investigation into the identity and source of the contaminant which causes "halo” defects in fired fueled tubes are presented. Results reported previously are reviewed briefly and the results of recent experiments are included in detail. In addition, specific recommendations aimed at elimination or alleviation of the "halo” contamination problem are included.

Hawthorne, E.P. “Nuclear Propulsion for Aircraft.” *Aeroplane* 91, 2358 (1956): 686-87.

Design of possible liquid metal cooled reactor for aircraft use, of approximately 9 ft width and 13 ft height; various factors and uncertainties of shielding problem suggest that minimum aircraft size is likely to be of order of 150,000 lb and may well be twice as great; problem of takeoff power; possibility for subsonic aircraft.

Hendrickson, J.R., Sr. “Nuclear Shielding Materials for Electronic Circuit.” *Electr. Manuf.* 60, 5 (1957): 130-35.

Standard enclosures for circuits fail to provide effective shielding against nuclear radiation; equipment operating in nuclear powered aircraft and in other nuclear environments have to be designed with adequate protective shielding; mechanism of nuclear radiation effects; pertinent properties of shielding materials; specific shield design considerations.

Hess, Raymond E. and R. F. Badertscher. “The Effect of Nuclear Radiation on the Performance

of a Hydraulic Flight-Control System". REIC-Memo-18. Battelle Memorial Inst., Radiation Effects Information Center, Columbus, OH. June 15, 1959. 15p.

Hydraulic flight-control-system components are subject to radiation-induced failures. For nuclear-powered aircraft, the components of the flight-control system will probably be located in a high radiation flux. This high level of radiation coupled with continuous operation can result in failure or control degradation. By proper design during the early stages of the aircraft development, certain components of the utility hydraulic system could be planned as stand-by units to take over the function of a failed component. Definite answers to the problem of providing a suitable hydraulic flight-control system for nuclear-proved aircraft will only result from detailed design studies.

Hider, P.K., M. E. Ward, A. D. Silcox, and R. H. Willsey. "Electrical Control System Components for Starting Aircraft Propulsion Reactors". Presented at Nuclear Engineering and Science Conference, April 6-9, 1959, Cleveland, Ohio. Preprint V 47. New York, Engineers Joint Council (1959) 30 p.

Components for an aircraft reactor startup control system are described. Major design considerations for the electrical circuitry and the mechanical configuration are outlined and briefly discussed. The system described includes both vacuum tube and magnetic amplifier circuits.

Hiser, P.K., M. E. Ward, A.D. Silcox, R.H. Willsey. "Electrical Control System Components for Starting Aircraft Propulsion Reactors". Presented at Nuclear Engineering and Science Conference, April 6-9, 1959, Cleveland, OH. Preprint V-47. New York, Engineers Joint Council, 1959. 30p.

Components for an aircraft reactor startup control described. Major design considerations for the electrical circuitry and the mechanical configuration are outlined and briefly discussed. The system described included both vacuum tube and magnetic amplifier circuits.

Hogerton, John F. "The Atomic Energy Deskbook". Reinhold Pub., New York. 1963. PP. 15-20.

This reference deskbook was sponsored by the AEC, and contains a summary of the ANP Program from its inception as the NEPA Project in 1946 until its cancellation in 1961. Discusses the major technical difficulties, which were identified as: (a) development of compact reactors with extremely high power-to-weight ratios, capable of operating for 100 hours; (b) design of minimum weight and optimum weight shielding; (c) airframes designed to take extremely high landing loads and weight distributions; (d) radiation effects on materials; (e) development of facilities and techniques for ground handling with remote maintenance; and (e) operational safety questions. Activities of all organizations are discussed. Article outlines the sequence of changing requirements starting with the "X-6 flying test bed" (1952) and cancelled in 1953; subsonic cruise and supersonic attack set in 1955 and cancelled in 1956; the CAMAL objective set in early 1960 and cancelled along with the entire project in 1961. The outgoing Eisenhower Administration's budget recommended cancellation of one of the two primary approaches for the ANP engine. Pres. Kennedy's special defense message in March, 1961 cancelled the entire project.

"Huge Hangar Being Built for Testing Atomic Planes". *Pac. Build. and Eng.* 64, 8 (1958): 94-6.

Structural details of flight engine test facility at National Reactor Test Station near Idaho Falls are described. The hangar type building will be used to test nuclear aircraft engines in conjunction with airframes, typical crew compartments and aircraft control systems. The structure will be built entirely of concrete and steel, with a 320 ft. continuous arch.

Hunter, Edwin T. "The Use of Plastic Shields to Reduce Permanent Nuclear Radiation Damage." USASRDL-TR-2123. Army Signal Research and Development Lab., Fort Monmouth, N. J. June 15, 1960. 15p.

Permanent alterations in d-c electrical characteristics of germanium homogeneous-base power transistors was determined as a function of the thickness of epoxy type shielding material surrounding the device. Exposures were made on the Godiva reactor. Results indicate that most of the permanent damage is caused by fast neutrons, with a smaller part of the damage being caused by some other component of the radiation, and that the epoxy shields thermalize any of the fast neutrons, thereby reducing the permanent damage suffered by the transistors. The subsequent increase in thermal neutrons and gamma rays inside the shields will probably have an effect on the transient electrical characteristics of the devices, but this facet of the investigation was not studied.

"Improvement in Aircraft Propulsion". *Nuclear Power* 3 (1958) 462.

The propulsion unit comprises a multi-stage, axial-flow compressor delivering air through the channels of a reactor, a number of combustion chambers, and the nozzles and rotor blades of a turbine, finally discharging it through an ejection nozzle. When the aircraft is on or near the ground the reactor is shut down, the air passes through it without heating and the combustion chambers are fed with hydrocarbon fuel so that the unit becomes a conventional turbojet.

"Intermittent Stressing and Heating Tests of Aircraft Structural Metals". Period Covered: April 5, 1950 to August 31, 1952. WADC-TR-53-24 (P. 1). Cornell Aeronautical Lab., Inc., Buffalo. (1954) 78 p.

Methods for testing and data evaluation capable of defining the creep-rupture properties of aircraft alloys subjected to intermittent heating and loading were developed. Creep-rupture test equipment was developed and constructed capable of testing sheet specimens under various conditions of constant or intermittent temperature and load. 24 S-T 3 Alclad Al has been studied in the 300 to 600 deg.F. temperature range at stresses capable of producing various amounts of deformation and rupture in time periods extending from several hours to at least several hundred hours. In addition to establishment of the reference constant temperature-constant load creep-rupture data, comparable results were obtained under conditions of constant temperature-cyclic load, constant load-cyclic temperature, and combined cyclic load-cyclic temperature.

Jackson, L.R. "Material Properties for Design of Airframe Structures to Operate at High Temperatures". TML-38. Battelle Memorial Institute Titanium Metallurgical Lab., Columbus, Ohio. Mar. 23, 1956. 64p.

Mechanical and physical properties of structural materials are discussed with the idea of re-evaluating their usefulness for high-temperature design. The extent of available data on typical metallic materials is also discussed.

Jackson, L. R. "The Use of Titanium Alloy Sheet in Airframe Component". TML-5A. Battellle Memorial Institute Titanium Metallurgical Lab, Columbus, Ohio. July 29, 1955. 22p.

This report presents quantitatively significant strength/weight criteria for Ti sheet alloys against a background of similar criteria for alternative sheet material, in order to provide a realistic basis for judging the circumstances under which it may be used in airframe components. Results of tests of tensile strength, yield strength, compression strength, elastic modulus, and buckling are included.

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Jackson, L. R. "Formability Tests of Titanium Alloy Sheet." TML-12. Battelle Memorial Institute Titanium Metallurgical Lab, Columbus, Ohio. July 20, 1955. 24p.

A discussion of the properties of Ti alloy sheet and their effect on formability is presented.

Johnson, C. L., and F. A. Cleveland. "Design of Air Frames for Nuclear Power". *Aeron. Eng.. Rev.* 16, 6 (1957): 48-57. See also: *Am. Soc. Nav. Engrs. J.* 70,1 (1958): 110-20.

Discusses: problems which must be surmounted before the atom can be packaged aloft; basic power plant characteristics; highly concentrated weight in reactor; powerful radiation field from reactor; and no consequential flight endurance limitations by power plant fuel; divided shield concept of crew compartment design; material radiation damage may prove significant; electronic equipment may suffer serious effects; cooling apparatus design.

Jung, R.J., J.N. Anno, and J.W. Chastain. "Radiation Damage Study of Electronic Components". NP-7855. Battelle Memorial Inst., Columbus, OH. Mar. 5, 1959. 38p.

The effects of radiation on several electronic components used in aircraft instrumentation were studied. The components were airspeed and altitude transmitters, synchrotel data transmitters, control transformers, resolvers, linear generators, and thermistors. Each component was irradiated to an integrated total fast-neutron flux of 10^{16} n/cm^2 with an associated total gamma dose of 10^8 rep. The operation of the components was monitored before, during, and after irradiation. The postirradiation studies were performed for a 100-hr period immediately after irradiation and then for an additional 50 hr following a 2-week rest period. The operation of the altitude transmitters, resolvers, linear generators, and thermistors showed no effects of damage. The remaining components suffered slight to moderate damage. The damage generally resulted in binding or insulation breakdown.

Kalitinsky, A. "Atomic-Powered Plane Hurls Challenge at Engineers". *Soc. Automot. Engrs. J.* 57 (1959): 44-7.

Discussed the advantages of using atomic energy to power a plane are noted and some of the engineering problems this would involve. Showed the basic types of power plants which might be suitable for adaptation to atomic energy usage. They were:(1) steam turbine, (2) turbojet, (3) ramjet and (4) rocket. Discussed the problem of high temperatures which are necessary for high performance. It was suggested that the components of a nuclear engine would be an engine, reactor, and shielding, which would correspond to the conventional power plant proper, fuel, and fuel tanks, respectively. Noted some of the possible means of reducing the shielding weight.

Kattus, J. R. and J. D. Morrison. "Tensile Properties of Aircraft Structural Metals at Various Rates of Loading after Rapid Heating". Period Covered: November 1954 to April 1956. Project Title: "Material Analysis and Evaluation Techniques". Task Title: "Design and Evaluation Data for Structural Metals". WADC-TR-55-199 (Part 2). Southern Research Inst., Birmingham, Ala. (1956) 201 p.

The effects of variations in strain rate and holding time on the tensile properties of several aircraft-structural-metals after they had been heated within 10 sec. to test temperatures up to 1200 deg.F. are determined. The work was primarily directed toward determining these effects on the yield and ultimate strength. Other properties such as modulus of elasticity, proportional limit and total elongation were also determined but only as byproducts and for the purpose of establishing trends. These properties should be used only after careful consideration of the complex conditions under which they were obtained. This investigation covered strain rates from 0.00005 in./in./sec to 1.0 in./in./sec, holding times at test temperature from 10 sec. to 30 min, and the following materials; sheet metals: annealed Stellite-25, precipitation-hardened Inconel-X, half-hard and full-hard Type 301 stainless steel, 17-7 PH stainless steel in both the annealed and the unannealed conditions, AISI-4130 steel in both the normalized and the quenched and tempered conditions, hot-rolled SAE-1020 steel, and A 110-AT and Ti-140 A Ti alloys; and cast metals: ZrH-62T5 Mg alloy and 356T6 Al alloy. With a few exceptions, the strength properties of the test metals increased appreciably with increasing strain rates.

Keeler, J.R. and A.W. Hare. "The Fabrication of Subassemblies for the Supercritical-Water Reactor". BMI-919. Battelle Memorial Inst., Columbus, OH. Aug. 16, 1954 (Decl. Aug. 10, 1959). 30p.

In studies of the fabrication of fuel subassemblies for the supercritical-water reactor, the limited ductility of stainless steel- UO_2 fuel sheet made the fabrication of corrugated-flat-plate-type subassemblies impractical. A fabricable MTR-type assembly was developed. Methods for edge cladding fuel sheet were developed and a brazing alloy, GE-75, was found to be corrosion resistant in supercritical water.

Kircher, J.F. "Format for Reporting Radiation-Effects Data". REIC-Memo-10. Battelle Memorial Inst., Radiation Effects Information Center, Columbus, OH. May 15, 1959. 14p.

The format used by the Radiation Effects Information Center (REIC) in reporting radiation-effects data is given. From the discussion, it is apparent that there is no simple way of reporting radiation-effects data that is applicable to all situations, nor is there any one unit that can be used to cover all situations. It is felt, however, that the methods and terminology outlined in this memorandum are the best available today that are generally applicable to nuclear-propulsion development programs. Recommendations for neutron and gamma-ray dosimetry techniques are given. The terminology used by the REIC is presented. Since there is not complete agreement among those working with radiation as to the best way of reporting or correlating data, the usage must be somewhat arbitrary. It is hoped that, by consistent usage of terms, the task of interpreting data from REIC Reports and Memoranda will be simplified.

Klein, C.A. and W.D. Straub. "On the Energy Levels in Neutron-Irradiated P-Type Silicon". NP-7365 (Vol. 3) (Paper 30). Raytheon Mfg. Co., Waltham, MA. Paper 30 of the Third Semi-annual Radiation Effects Symposium Held in Atlanta, October 28-30, 1958. Volume 5. Aircraft Systems and Materials Papers. 29p.

High-resistivity p-type silicon samples were irradiated in the Brookhaven pile for short periods of time resulting in integrated fast neutron fluxes of the order of a few 10^{14} n/cm^2. Hall coefficient and conductivity measurements were then performed over extended temperature ranges. A detailed analytical investigation of these data is provided.

Koshuba, W. J. "Metallurgical Considerations in the Application of Nuclear Energy for the Propulsion of Aircraft". *Metal Progr.* (1959):635-40.

The author discusses the problems involved in the application of nuclear power to aircraft propulsion. They are as follows: (1) the choice of the type of aircraft propulsion plant will influence the selection of materials; (2) the engineering and physical and chemical properties of materials above the range of temperatures in common use must be determined, studied, and correlated; (3) the selection of materials must satisfy the nuclear requirements for a given service application of the aircraft atomic plant; and (4) the weight of the complete power plant must be sufficiently low to permit its use in a practical aircraft.

Kotanchik, Joseph N. "Experimental Research on Aircraft Structures at Elevated Temperatures". NP-6065. Langley Aeronautical Lab., Langley Field, VA. May 1956. 36p.

The equipment and methods used at the Langley Laboratory of the NACA in experimental research on aircraft structures at elevated temperatures are reviewed. The equipment ranges from conventional steady-state furnaces for stress-strain tests to transient radiant-heating apparatus and aerodynamic heating and loading in a supersonic air jet.

Kovacik, V.P. and D.P. Ross. "Performance of Nuclear Electric Propulsion Systems." Preprint in IAS 27th Annual Meeting, New York, Jan. 26-29, 1959. Inst. of the Aeronautical Sciences, New York, N.Y.

Krasnow, M. E., 0. P. Reynolds, R. L. Thistlethwaite, E. J. Vilter, H.G.R. White and H. A. Mitchell. "Determination of Testing Schemes for ANP Weapon System Material". WADC-TN-57-185. Inland Testing Labs., Morton Grove, Ill. (1957). 114p.

In order to build a nuclear powered vehicle, it is necessary to build systems that will operate satisfactorily in conjunction with a nuclear environment. Before design and development testing can begin, it is necessary to determine which environments are interactive with radiation, and therefore, which environments need be to combined for irradiation testing. Those environments which additive and those which are interactive with a radiation environment are defined.

Lane, James A., H.G. MacPherson, and Frank Maslan, eds. "Fluid Fuel Reactor". Addison-Wesley Publishing Company, Inc., Reading, MA. 1958. 999p.

A summary of the work done in the United States on fluid fuel reactors is presented. The first part deals with the aqueous homogeneous reactor; most of this work was done at ORNL with some phases of the work on slurries done at Westinghouse Atomic Power Division and some work on phosphate solutions at Los Alamos Scientific Laboratory. The second part deals with the fused salt system, which was investigated primarily at ORNL. The third part deals with the bismuth-uranium system, investigated at Brookhaven National Laboratory. The development of aqueous homogeneous reactors is discussed. The nuclear characteristics of one and two region homogeneous reactors are summarized. The properties and technology of aqueous fuel solutions are treated. and the integrity of metals in homogeneous reactor media is reviewed, Core and blanket chemical processing is summarized. Design, construction, and costs are discussed. Under molten-salt reactors chemical aspects of fuel, construction materials, nuclear characteristics, heat-transfer systems, and conceptual designs are considered. The aircraft reactor experiment is summarized. Reactor physics for liquid metal reactor design are reviewed. The composition, properties, and chemical processes of liquid metal fuels are discussed. The metallurgy and construction of materials is discussed.

Lee, J.F. "Atoms in Action" *Consult. Eng.(USA)* 11,1 (1958): 74, 76, 78, 80.

Article included a discussion of the ANP Program.

Leverett, J.K.,and C.H. Beasley. "An Investigation of Lens Opacity on Personnel Operating a Portable Nuclear Reactor". *Am. Ind. Hyg. Assoc. J.* 21 (1960): 84-6.

Results are reported from investigations of lens opacity in personnel exposed to many types and intensities of radiation while operating a portable polonium beryllium neutron source, the Ground Test Reactor, and the Aircraft Shield Test Reactor. Yearly examinations were made on employees subject to neutron radiation exposures. None of the people examined had received excessive radiation exposure. Lens opacities were found in 24 of 655 examinations. Fifteen were of the congenital variety and 9 were developmental.

Levin, Harry. "Inhalation Dose from Aircraft in Flight." NP-9623. Marquardt Corp., Van Nuys, Calif. Nov. 17, 1959. 28p.

In the application of air-cooled nuclear power plants for aircraft, it to important to evaluate inhalation dose on the ground resulting from various flight conditions. Methods of radiation inhalation dose calculation for three principal conditions of flight are presented. These conditions are flight in the crosswind direction flight, in the wind direction, and orbital flight. The methods deal with emission of fission products by recoil mechanisms only from unclad fuel elements.

Loening, G. "Economics of Large Aircraft". Society of Automotive Engineering Paper for Meeting Jan. 4, 1956, 9 p. See also: *Soc. Automot. Engrs. J.* (1956): 20-3; *Aeron. Eng.. Rev.* 15, 4 (1956): 48-55.

Prediction is made that water-based aircraft will be lighter and cheaper than land-based aircraft, because of total elimination of landing gear. Discusses feasibility of flying aircraft carrier that could cruise at 40,000 ft. at 400 to 500 mph. Design envisaged for giant cargo flying boat with turbojet or nuclear energy jet driven power plant.

Maloney, F. J. "Use of Sandia Corporation Analog Computer in Sled Design". AECU-3490. Sandia Corp., Albuquerque, N. Mex. (1957) 23 p.

Formulas were developed on an analog computer for the rocket thrust, the inertia forces (which are continually changing because of decreasing rocket propellant weight), aerodynamic drag, and rail friction for a sled designed to reach a velocity of 1600 ft/sec without exceeding 6 g's of acceleration or deceleration, and for a single-stage sled designed to reach 3000 ft/sec in shortest possible distance. Data and formulas are presented for the case when the sled is stopped by a water brake.

McGarvey, J. W. "Antirads for nitrile rubber." NP-9615 (RIA-60-2856). Rock Island Arsenal Lab., Ill. Sept. 22, 1960. 31p.

The mechanisms of radiation damage and protection in organic materials were investigated and a total of 118 different nitrile vulcanizates containing potential antirads was evaluated in a screening program. Several antirads were found which Imparted a significant degree of protection to nitrile rubber exposed to Co-60 gamma radiation. A good antirad such as 1,1-diphenyl-2-picrylhydrazine imparted approximately the same degree of radiation resistance to nitrile rubber as is inherent in natural rubber. This investigation also demonstrated the existence of certain structural correlations by which it may be possible to select or synthesize new and even more efficient antirads.

McNabb, J.W. and P.P. Sondeen. "Airborne Electronics for Nuclear Powered Vehicles". NP-9333 Vol. IV. For Bendix Aviation Corp. Bendix Systems Div., Ann Arbor, MI. Paper 2 of Fourth Radiation Effects Symposium, September 15-16, 1959, Cincinnati, OH. General Session Papers. 20p.

Problems in fabrication, testing, and evaluation of electronic components for nuclear powered aircraft are discussed. An evaluation of the program of designing and selecting electronic components for the mission and traffic control subsystem is made.

Middlewood, R.W. and R. B. Ormsby, Jr. "Application of Nuclear Power to Logistic Aircraft Systems". Soc. Automotive Engrs. Paper No. 206 for Meeting Sept. 30-Oct. 5, 1957 16 p.

Article reviewed ANP progress to date.

Miller, H. "Testing an Aircraft Nuclear Propulsion System". *SAE J.* 56,11 (1958): 26-8.

Discussed ANP experimental work and future plans.

Miller, M. M. and A. M. Liebschutz. "Radiation Effects Testing of Aircraft Systems". Society of Automotive Engineers. Paper No. 92 C for Meeting Sept. 29-Oct. 4 (1958) 7 p.

To evaluate performance of systems in nuclear powered aircraft, tests of operating system must be conducted under conditions simulating those expected to exist during flight.

Miller, A. B. and E.A. Platt. "Analysis of Side Support Pressure Requirement for Nuclear Reactors Subject to Maneuver Loads". UCRL-12282. California Univ., Livermore, (USA). Lawrence Livermore Lab. Apr. 12, 1965 (Decl. Nov. 27, 1973). 63p.

Certain design criteria are analyzed for the structure providing side support within a cylindrical duct for an air-cooled reactor core constructed of a large bundle of small tubes. The structure performs two related functions: (1) it supplies clamping pressure to stabilize the tube array, (2) it transmits transverse loads between the reactor duct and core. Various instabilities which could occur with insufficient bundle pressurization are described for an array of hexagonal tubes. Brief mention is made of: (1) effect of side support flexibility on a coupled inertia-neutronic excursion mode, (2) weight optimization of side support springs in accommodating core thermal expansion and differential duct thermal and pressure expansion, and (3) some novel support schemes that have been proposed.

Nance, J.C. and L. W. Perry."Aircraft Shield Test Reactor". *Nucleonics* 16,1 (1958): 58-61.

Design, cooling system, ground and flight testing, and handling and operation of the Aircraft Shield Test Reactor are described.

Nayler, J. L. "Nuclear Power for Aircraft". *Handbook Aircraft Industry,* London, George Newnes, Ltd. (1958): 208-10.

Nelson, H.R., Dayton, R.W. “Fuels and Materials Progress Report October 1953”. BMI-885. Battelle Memorial Inst., Columbus, OH. Nov. 1, 1953. (Decl. June 25, 1982). 66p.

Progress in the following areas are reported: ceramic fuel elements, general ceramics, uranium and its alloys, zirconium metallurgy and fuel elements, materials for aircraft reactors, miscellaneous studies of materials, and liquid coolants and fuels.

Newcomb, Philip P. “Means and Methods of Assembly of a Nuclear Aircraft Engine”. U. S. Patent 3,235,205. Feb. 15. 1966.

A nuclear gas-turbine engine-driven aircraft is so designed that the major mounts supporting the engine on the airframe are located on the radiator section with any component parts that may need to be removed for periodic inspection mounted in such a way that they may be easily removed. The easily demountable parts may include the engine turbine section, the engine compressor section, the engine shaft, and the engine bearings. The radiator with its fluid connections to the reactor is a relatively permanent part of the aircraft structure.

“Nuclear Power for Aircraft.” *Time Rev. Ind.* 9, 107 (1955): 48.

Provided a general review of the objectives of the ANP Program.

“Nuclear Aircraft Reactor and Configuration Aired". *West Aviation*. 37, 6 (1957) 24.

Article discussed ANP concepts for the reactor.

“Nuclear Energy Power Plants.” *Aeroplane* 90, 2321 (1956): 48-9.

Considered the likely configuration and type of aeronautical power plant, and where possible advantage may be taken of their special characteristics. Discussed normal reactor processes.

Ohlinger, L.A. “Nuclear Power in Air of Tomorrow.” Soc. Automotive Engrs. - Paper No. 729 for meeting Apr. 9-12, 1956. 7 p.

For reasons of security, remarks are confined to data and facts from unclassified sources including: “when and why” of nuclear powered flight; major problems are high temperature materials of construction and radiation shielding; among operating problems are control of power plant, long runways required, possible radioactive contamination of field, hazards of crash landing, and difficulties of maintenance and repair.

Ormsby, R. B. "Airborne Nuclear Propulsion System - Design Considerations". *Jr. Aeron. Eng.*.

Rev. 17, 1 (1958): 20-3.

Gross weight variations of ANP aircraft are examined to point out basic underlying reasons why they are inherently large and to determine how to make them smaller. Discusses: reactor shield requirements and design; how reactor power density promises improvement; and calculations determining effect of increasing power density.

Perkins, J.E.B. "The Gas Turbine in Atomic Energy". *Nuclear Power* 1 (July 1956): 108-13.

The efficiency of the simple gas-turbine cycle, being highly temperature-dependent, limits the selection of reactor to those in which a temperature of at least 500°C can be maintained for continuous operation. With more complex cycles the choice is wider. Possible reactor-turbine systems are discussed and tentative evaluations made of the various combinations of thermal and fast reactors with open- and closed-cycle turbines. Of the possible gases considered, air is considered the best. An attempt Is made to visualize how the gas turbine might be used for land, sea and air application.

Pfaff, E.R. "Evaluation and Development of Mil-C-14157 Capacitors for Nuclear Radiation Environment." NP-9523. Scientific Report No. 5. Admiral Corp., Chicago. 1960. 43p.

All capacitor units impregnated with uninhibited FS-5 and silicone gel dielectric impregnated and the capacitors with FC-43 dielectric fluid constituting the gamma group failed in less than 63 hr. Irradiated units with Etherm "A" dielectric fluid and 4% tertiary butyl anthraquinone exhibited a slight improvement in the 75% failure point over the irradiated standard 1% inhibited units. The control group units with additional inhibitor had an appreciable improvement in the 75% failure point over the 1% inhibited units.

Pfaff, E.R., and R.D. Shelton. "The Effects of Radiation on Various Resistor Types. Paper 37. Third Semi-annual Radiation Effects Symposium. Atlanta. October 28-30, 1958. Volume 4. Electronics and Semi-conductors Papers". NP-7365. Admiral Corp., Chicago, IL. 16p.

A study of the effect of nuclear radiation on various types of resistors revealed interesting trends and several possible damage mechanisms, most of which seem to be associated with the boron content in the components. Film-type resistors consisting of a glass core containing boron and a conducting film with no boron showed greater damage when the film was thin. It is probable that in this case the (n, α) reaction in boron removed some of the atoms from the thin conducting film. Resistors having a core with no boron but with a borocarbon conducting film showed greater damage when the film was thick. It is conjectured that since, in this case, all of the boron is in the conducting film, there is more recoil energy deposited in the conducting layer having the thicker film. Wire-wound resistors having a vitreous enamel coating had resistance changes greater than could be attributed to temperature coefficient or a change from a disordered to ordered arrangement in the wire. There is some evidence that the vitreous coating, sometimes containing a large amount of boron, changes density sufficiently to distort the wire and increase the resistance of the unit by as much as 6 percent.

Porter, W. H. L. "Nuclear Power for Aircraft". *Atomics* 8 (Jan. 1957): 7-14.

Considerations determining the design of an aircraft propelled by nuclear power are reviewed. Factors influencing reactor design, heat transfer systems, coolants, reactor stability, and shielding are discussed. Crash hazards are considered. It is concluded that the liquid metal cooled reactor is the only possibility for aircraft propulsion.

"Proceedings - Nucleonics in Flight Symposium." American Nuclear Society, North Texas Section. March 28-29, 1961. P.199.

This symposium started on the same day that Pres. Kennedy cancelled the ANP Program and the keynote speech, scheduled to be given by Mr. William Weitzen, Deputy for Development to the Assistant Secretary of the Air Force for Research and Development, was never delivered. Although the speech is not included in the proceedings, the title was to be "Nuclear Power and the Future". Papers were presented on the following ANP subjects: Reactors for flight propulsion -- physics. control, fuels, materials, heat transfer, fluid flow; shielding; radiation damage; and reactor safety. Papers were authored by all contractors and laboratories involved in the ANP Program.

"Program for the Development of Extruded Beryllium Shapes". NOR-60-14. Northrop Aircraft, Inc., Hawthorne, CA. Interim Engineering Report No. 6. September 1, 1959 through November 30, 1959. 20p.

A portion of the total effort of the Beryllium Extrusion Development Program, Phase 1, is summarized. The work reported is part of an extension to Phase I in which the major problems of beryllium extrusions are being thoroughly investigated. Feasibility of unclad beryllium extrusion was demonstrated; however, additional work was considered necessary to perfect extrusion methods. Twenty linear foot lengths of extruded shapes are desired. Ten to twelve foot lengths have now been realized, and efforts are now being directed toward method development for the twenty-foot long Phase I channel shaped extrusions.

"Proposal Program". CNLM-2398. Westinghouse Electric Corp., Lima, OH. Mar. 18, 1960 (Decl. Jan. 9, 1976). 117p.

Research and development program budget data are presented for AEC contract AT (11-1)-229 involving airplane propulsion reactors. Fiscal years 1960, 1961, 1962 are included.

Richey, Neil F. "Results of a Survey on the Use of Boral in Shielding." Presented at the AEC Conference on Radiation Shielding. Knolls Atomic Power Laboratory, Schenectady, NY. May 13-14, 1954. 3p.

Ritchey is listed as the Atomic Energy Advisor for the Reynolds Metals Co., Louisville, KY. He describes the fabrication of Boral, which is an engineered shielding material mixture of boron carbide and aluminum clad with pure aluminum. This material was developed at ORNL by Theodore Rockwell, III. and is patented by the AEC. Ritchey has surveyed the industrial uses of Boral and reports that it is being considered for the ANP Project to shield both the reactor and easily activated components, particularly the engine.

Rimer, John P. "Nuclear Fission and its Application to Jet Propulsion Engines". Rensselaer Polytechnic Inst., Troy, NY. June 1947. P.55.

A review Of nuclear fission process and its application in nuclear reactors is given. At the present time, the atomic pile is the most significant of reactors and is covered on basis of limited known theory. Having investigated how power is produced from the nucleus, application is made to various probable types of jet engines -- especially those intended for use in guided missiles. Nuclear fission does not present good prospects for utilization in guided missiles; application to large aircraft seems more likely.

Rodgers, S.J. and J.W. Mausteller. “Fission Product Release During Melt-down of ANP Indirect Cycle Fuel Elements”. CONF-39-31. MSA Research Corp., Callery, PA. From American Nuclear Society Meeting, Salt Lake City, UT. June 1963. 11p.

Meltdown tests were performed to determine the degree of fission-product release from indirect-cycle aircraft nuclear propulsion fuel pins. Techniques were developed for the induction heating and melting of the pins and for containing the molten fuel for times as long as twenty minutes in atmospheres of helium and air-alkali metal vapor. Fission product release from fuel pins irradiated to an integrated thermal flux of approximately 7 x 10^{15} was determined for 2 and 20 minutes melts at the fuel melting point and at 5500°F. The release of Xe^{133}, I^{131}, Te^{132}, Cs^{137}, Y^{91}, Ce^{141}, beryllium, and uranium was measured quantitatively, and the size distribution of released particles was determined. Fission product release in air- alkali metal vapor over the temperature range of investigation varied from 50 to 100% of the volatiles (Xe^{133}/, I131, Te^{132}, Cs^{137}) and 0.2 to 10% of the nonvolatiles (Sr^{90}, Ba^{140}, Y^{91}, Ce^{141}, uranium, and beryllium).

Russell, J. A., S. F. Hemmenway, J. L. Scharf and P. C. Sharr. “Magnetic Automatic Power-Range Control for an Aircraft Nuclear Reactor”. Presented at Nuclear Engineering and Science Conference, April 6-9, 1959, Cleveland, Ohio. Preprint V-46. New York, Engineers Joint Council (1959) 31 p.

Control system philosophy for an aircraft nuclear power plant is discussed briefly. Advantages are presented for a power-range magnetic control system with a minimum number of moving parts. Control system elements and computing devices are discussed in detail. Performance of a bread-board version of the control system is evaluated.

Schaeffer, N.M. "Nucleonics in Flight". *Nuclear Engineering* 6, 60 (May 1961), 199-201.

Nuclear-propelled aircraft, rockets, ramjets, and space nuclear auxiliary power are discussed in a general manner. Data are given on the Tory rocket reactors and the ANP High Temperature Reactor Experiment. Such topics as shielding, radiation damage, and reactor safety are also covered.

Schaeffer, N. M. and R. L. French. "Shielding Experiments for Nuclear Aircraft Are Conducted: High-Up on Towers, in the Air, on the Ground". *SAE J.* 67**,** 2 (1959): 32-7.

Reviewed shielding development work at the TSF and the NTA.

Schmitt, R.A. and R.A. Sharp. "Measurement of the Range of Recoil Atoms". NP-7365. General Atomic Div., General Dynamics Corp., San Diego, CA. Paper 32 of the Third Semi-annual Radiation Effects Symposium. Atlanta. October 28-30,1958. Volume 3. Aircraft Systems and Materials Papers. 9p.

An important problem in the interpretation of radiation damage and sputtering phenomena is the evaluation of the range of an atom which moves through a lattice after having received an initial energy of 10 to 100 kev. An experiment is described in which atoms with initial energies in this range were produced by irradiating suitable targets with high-energy bremsstrahlung gamma rays, and the products of photonuclear reactions, such as photoneutron (γ, n) transmutations, were observed. The photon spectrum of the gamma rays was continuous from 0 to 24 Mev. The energy spectra of evaporated neutrons were centered at about 1.5 Mev.

Scott, Dunlap and Dixon Callihan. "Preliminary Critical Assembly for the Molten Fluoride Reactor Experiment". ORNL-1634. Oak Ridge National Laboratory, TN. Nov. 18, 1953. (Decl. July 2, 1957). 59p.

A zero power mockup of the Molten Fluoride Reactor Experiment was constructed in the ORNL Critical Facility. The assembly was BeO moderated and reflected and used a powder of Zr, Na and enriched U, simulating the reactor fuel, packed in stainless steel tubes.

Selengut, D.S. "The Nuclear Design of Aircraft Reactors". Presented at Nuclear Engineering and Science Conference, Chicago, IL, March 17 to 21, 1958. Preprint 97, Session 13.

American Institute of Chemical Engineers, New York. 1958. 19p.

Nuclear design can be defined in terms of the requirements for criticality, control, and desired power distribution--subject to the limits imposed by air flow, thermodynamics, structural, and materials requirements. Difficulties arise from the large number of constraints and the strong interaction of the design variables. Meeting these requirements entails a closely integrated program of analysis and experiment, in which the main tools are flexible and mockup critical assemblies, and large scale digital computers.

Seren, L. “Safety Hazards of Nuclear Propulsion II”. *Space/Aero*naut. 30, 6 (1958): 48-52.

Reviewed questions regarding the safety of nuclear-powered propulsion.

“Seventeenth Quarterly Progress Report on ANP Development for Period Ending March 31, 1960". SCNC-308. Sylvania-Corning Nuclear Corp., Bayside, NY. May 1960. 61p.

Reported on ANP work by Sylvania-Corning.

“Site Survey Monitoring of ANP-IET Operations, April 19 Through July 2, 1956". ICF-1000. Idaho Operations Office, AEC. Decl. Apr. 27, 1959. 12p.

The AEC Idaho Operations Office Health and Safety Division monitored all areas beyond G.E. jurisdiction which could possibly be affected by Initial Engine Test operations over the test period. All releases of activity were detected in the month of June. Various locations were monitored by G-M counters, fall-out plates, film badges, CFM filters, and sky scanners. No significant releases were detected.

Smith, L. W. and F. J. Gillig. "Evaluation of Titanium Aircraft Parts and Semi-Finished Products". CAL-KB-868-M-5. Bimonthly Progress Report No. 5. October 16, 1953 to December 15, 1953. Cornell Aeronautical Lab., Inc., Buffalo, NY. 77 p.

Stathoplos, A. “Engineering Design of 10 MWe SDR, Status Report as of April 30, 1958". NDA-84-8. Nuclear Development Corp. of America, White Plains, NY. July 31, 1958. 33 p.

Preliminary design of a 10 MWe sodium deuterium reactor (SDR) is presently in progress at NDA. Design features of the reactor, which is sodium cooled and D_2O moderated, are described, and the results of several experimental testing programs designed to establish the feasibility of sodium-heavy water separation are summarized.

Struble, A. D., Jr. “Men, Materials, and Maintenance for the Nuclear-Powered Seaplane”. *SEA J.* 65, 10 (1957): 64-6.

Discussed the Navy's ANP development work.

Sullivan, R.J. "Feasibility Study of Powered Flying Crane Helicopters". TID-21987. Hughes Tool Co., Aircraft Div., Culver City, CA. Oct. 23, 1958 (Decl. Oct. 21, 1971). 81p.

Preliminary studies were conducted on the feasibility of nuclear powered flying crane helicopters based on the direct cycle reactor system. Rotor tip jet drives of the hot, cold, and mixed cycle systems were investigated. The feasibility of a nuclear geared turbine helicopter and of the use of a combination petroleum-nuclear powerplant was examined. Results of the studies and recommendations for further work are presented.

Szekely, T. "Direct Cycle Reactors for Aircraft Nuclear Propulsion". Nuclear Engineering and Science Conference, March 17-21, 1958, Chicago Preprint No. 93, New York, American Institute of Chemical Engineers (1958).

"The Selection of Materials for High-temperature Applications in Aircraft Gas Turbines". TML-50. Illinois Inst. of Tech., Chicago, Armour Research Foundation for Battelle Memorial Inst.
Titanium Metallurgical Lab, Colombus, Ohio. Aug. 17, 1956. 34p.

A survey was made of the major gas-turbine manufacturers to determine the applicability of Ti in gas turbines and the criteria whereby gas turbine materials are selected. The ultimate tensile strength, yield strength, stress-rupture properties and fatigue strength of three commercial Ti alloys and one experimental alloy are compared on a strength/density basis with similar properties for other metals. Other properties considered are modulus of elasticity, damping capacity, creep strength, corrosion resistance, weldability, thermal stability, and notch sensitivity. The temperature range for superior performance of titanium over other metals is identified. A discussion is given on the current applications of Ti in gas turbines and possible influence of future trends in gas-turbine development.

"The Supercritical Water Reactor". ORNL-1177. Nuclear Development Associates, Inc., White Plains, NY. A Report to Oak Ridge National Lab., TN. Feb. 1, 1952 (Decl. with deletions Sept. 21, 1959). 129p.

A study on the Supercritical Water Reactor and shield is presented. The reactor consists of a structure of stainless steel plates immersed in a vessel of water which is above the critical pressure. The plates contain the fuel and provide a heat transfer surface. The water serves as coolant, moderator, reflector, shield, and some reactivity control. The heat output 400 MW appears attainable with a reactor having a modest size core 2.5 ft^2 cylinder) and a reasonable fuel inventory (20 kg).

Thompson, L.N. "Nuclear-energy Propulsion." *Flight* 60, 2235 (1951): 656--58.

Theoretical investigation into application of nuclear energy to reaction propulsion in general, rocket propulsion in particular being logical subsequent step to turbo-nuclear application.

Udy, Murray C. and Francis W. Boulger. "Survey of Materials for Supercritical-Water Reactor". BPE-890. Battelle Memorial Inst., Columbus, OH. Nov. 27, 1953 (Decl. Aug. 10, 1959). 52p.

A survey was conducted in the search for materials potentially useful in the supercritical-water reactor. Tensile strength, 0.2% offset yield strength 1000 hr. rupture strength, endurance strength, tensile elongation, Young's modulus, coefficient of thermal expansion, and coefficient of thermal conductivity are presented as a function of temperature. Nominal compositions, usual heat treatment, density, and thermal-neutron-absorption cross sections are tabulated. Materials covered include SAE 4340, Timken 17-22-A, 17-22-A S, and 17-22-A V, Types 310, 347, 410, and Crucible, 422 stainless steels, Jessop H46, Rex 448, Armco 17-4 PH and 17-7 PH, Stainless W, Allegheny A-286, Tinidiur, Discaloy, Nimonic 75, 80, and 80A, Hastelloys C and X, Inconel X, Copper Alloy V2B, and titanium alloys RC 130B, RC A110AT, Ti155AX, and Ti-3 Mn complex.

von Zborowski, H. P. G. A. "Thermal Nuclear Reactor, in Particular for Aircraft Propulsion". *Nuclear*. *Engng.* 1 (1956) 316 p.

The system has a reserve of fissionable material with at least two wall portions opposite each other between which a moderator fluid can pass. The whole mass of fissionable material is chosen so than it is 1.01 to 1.1 times the "slow" critical mass (0.01 of the fast critical mass.) The moderator is supplied under pressure and the rate of flow so chosen than the moderator leaves the passage in gaseous form and the multiplication factor is equal to 1 under normal running conditions. The nuclear generator then automatically has a stable output.

von Zborowski, H. "Improvements in Thermal Nuclear Reactors, in Particular for Aircraft Propulsion". *Nuclear Power* 2 (1957): 121-22.

A thermal reactor is described which consists of a tube of fission material with a mass slightly over critical. The moderator is D_20, H_20, hydrocarbons, or a water-alcohol mixture. Control is achieved by regulating the mass flow of the moderator.

Woll, Edward. "Power from Nuclear Fuel". Rensselaer Polytechnic Institute, Troy, N.Y. Mar. 1946. P.16.

A brief history is presented of the field of nuclear physics resulting in speculation on development of the atomic bomb, and ultimately leading to possible applications of nuclear energy as fuel. Modified plutonium or uranium piles designed specifically to produce heat are suggested. In one type, plutonium is used to charge an enriched uranium pile; another type uses ordinary enriched uranium metal; an uranium oxide pile is also suggested as a source of U-235. Nuclear fuel has special applications to stationary power plants and engines for large aircraft, naval vessels, and guided missiles.

Wright, Theron E., Richard J. Statany and C. E. Lapple. "High Velocity Air Filters". WADC-TR-55-457. Donaldson Co., Inc., St. Paul, MN. July 1957. 277p.

A study was made of the performance of fibrous filters with the specific objective of obtaining design information for high-velocity air filters. Experimental data on pressure drop, collection efficiency. and life for fibrous filters were obtained with two supercooled liquid aerosols (0.3 and 1.4 microns diameter) and one solid aerosol (1.2 micron diameter). Filter fiber size ranged from 3 to 30 microns, filter pad density from 0.01 to 0.10 cu.ft. fiber per cu.ft. pad, and filter velocity from 0.3 to 100 ft/sec. The data on the collection of liquid aerosols agreed well with theoretical predictions. Collection efficiencies with the solid aerosol particles were very much lower, however, at filtration velocities over 1 ft/sec, apparently due to failure of all colliding particles to adhere to the fibers. The density of degree compaction of the aerosol deposit was a controlling factor in determining the manner in which aerosol loading of the filter affected the pressure drop and collection efficiency. The degree of compaction was, in turn, dependent on both the characteristics of the aerosol particles and on the operating conditions. In the case of the solid aerosol, vibration of the filter produces major effects only at frequencies over 1200 cycles/sec, which was beyond the designed capacity of the vibration equipment. High filter velocities, however, resulted in marked dislodgement and internal re-disposition and compaction of previously collected solid aerosol. Data are also presented on the pressure drop and collection efficiency for pad-supporting screens, on the mechanical compressibility of fibers, and on two novel arrangements for particle size analysis.

Zizza, M. "Seaplane Hull Bottom Neutron Activation Study". NP-6691. Bi-Monthly Progress Report No. 3. Grumman Aircraft Engineering Corp., Bethpage, N. Y.(1958) 13 p.

The period since the release of the second progress report on the Neutron Activation Study of Seaplane Hull Bottom Materials has been spent in carrying out experimental work at Brookhaven and in analysis of the data collected. A series of specimen irradiations were made and the specific radioisotopes that led to the total activity of a specimen were identified as aluminum-28, sodium-24, manganese-56, magnesium-27, nickel-65, and zinc-69. The specimens prepared for irradiation were typical of the structural materials used in the hull bottoms of modern seaplanes. Aluminum alloy 2014 was used as the base material with a number of surfacing substances such as paints, primers, tapes, sealants, and sea water residue added as modifications. A gamma ray spectrometer was used for detecting and identifying the radioisotopes in the irradiated specimens. Procedures were established for arriving at the counting efficiency of the spectrometer as a function of the incident gamma ray. For this purpose samples of manganese-56, gold-198, and cobalt-60 were used as calibration standards. As a result of the specimen irradiations and data reductions now completed several conclusions become apparent: (1) the surfacing materials associated with the hull bottom, such as paints, primers, sea water residue, etc., contribute very little to the total activity of the specimens themselves; (2) the relative quantities of activities resulting from (n, p) and (n, alpha) reactions are appreciable when a predominantly fast neutron flux is employed for activation purposes; and (3) the effect of increased irradiation time on specimen activity is not pronounced.

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CHAPTER 4
U.S. GOVERNMENT AGENCIES

a. ATOMIC ENERGY COMMISSION

"Acceleration of Third Aircraft Reactor Project". Minutes of the 100th AEC-MLC Meeting. Sept. 15, 1955. RG 326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

In a meeting of the AEC Commissioners and the Military Liaison Committee, Comm. Libby stated that it might be necessary for the third type of reactor, another heterogeneous reactor, be accelerated for the ANP Program. He was supported by Comm. Von Neumann, who recognized the concern of Gen. Thatcher that there could be a conflict with the other ANP projects, but felt that the third approach "...appears to be relatively straightforward". Gen. Thatcher believed that the Air Force would prefer acceleration of the current two approaches rather than have a third concept in competition with them.

"AEC and DOD Joint Press Release. Jan. 19, 1959. RG128, Box 462, JCAE General Correspondence, Folder - Nuclear Propulsion Aircraft, Vol. 2: National Archives, Washington, D.C.

Announces the establishment of the Life Sciences Working Group for ANP. The purpose of this group is to define the human factors problems nuclear aircraft and missiles. The group was chaired by Maj. Charles M. Barnes, USAF, ANPO.

"AEC Adopts New Research Program for High Temperature Materials and High Performance Reactors". Atomic Energy Commission Press Release. Apr. 15, 1961. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

AEC announced use of some of the ANP Program facilities and contractors for a new high temperature materials R&D and high performance reactor program. Approximately $19.9M will be expended in FY62 for this new program at GE and Pratt & Whitney. The press release details the allocation to contractors and indicates $13.2 M would go to Pratt & Whitney for development of a high performance reactor experiment. About 375 GE and 1450 Pratt & Whitney employees would remain on these projects.

"AEC Acting General Manager. Letter to James T. Ramey, Executive Director, JCAE. April 25, 1957. JCAE #5183. RG 128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

AEC provided expenditure rates prior to and subsequent to the 1953 cutback of the ANP Program, along with respective statements of program objectives. Also provide a chronology of key events from the fall of 1944 to January 1956.

"AEC Terminates Development Work for Nuclear-Powered Aircraft Engine". AEC Press Release, No. D-73. March 30, 1961. RG359, Box 21, Executive Office of the President, OSTP Folder-ANP T.F. 1961: National Archives II, Washington, D.C.

Following a decision by Pres. Kennedy to cancel the development program for nuclear military aircraft, the AEC has notified its prime contractors in the ANP Program (GE and Pratt & Whitney) that the program is being terminated. AEC will be discussing with its contractors their possible participation in a new research program in high temperature materials.

"Aircraft Nuclear Propulsion Citations." Reynolds Electrical & Engineering Co., Coordination and Information Center (CIC), Las Vegas, NV. August 8, 1995.

This is a computer printout of 171 documents with ANP citations found at the CIC, operated for the Dept. of Energy (DOE). This printout lists titles and authors of documents, which are currently being held (in microfilm format) by DOE and not being made available. These documents are AEC correspondence, Commission Staff Papers, and meeting minutes and general correspondence of the AEC's General Advisory Committee. When available, these documents should be reviewed for applicability.

"Aircraft Nuclear Propulsion Program". AEC Staff Paper 17/90. September 2, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

In a report to the General Manager from the Director Div. of Reactor Development, the solid fuel liquid metal cooled reactor(LMCR) is discussed as a back-up to the circulating fuel reactor (CFR) program. The Division of Reactor Development is arranging for Pratt & Whitney to undertake this work. Studies by NDA have shown that the LMCR could be substituted for the CFR with no significant changes in the propulsion system. The LMCR work planned is consistent with recent recommendations of the GAC. Pratt & Whitney will have subcontracts with NDA, Sylvania Electric Products, Inc. and Nuclear Metals, Inc. Estimated funding levels are given by the staff.

"Aircraft Reactor Project and Navy ANP Requirements". AEC Staff Paper 17/110. March 7, 1956. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

The AEC staff proposed responses to DOD letters of Nov. 28, 1955. In the first, AEC dropped consideration of third nuclear plant project until it is determined if the Navy's requirements can be met from the current ANP projects, without affecting the strategic bomber plant development efforts. A "modest effort" is being expended on the Pratt & Whitney sodium cooled, heterogeneous reactor, as a backup to the CFR, (referred to as the "fireball" reactor in the Air Force correspondence). In the other response, the AEC discusses steps taken to establish the cooperative AEC/Navy ANP project. This includes assignment of four Naval officers to the AEC and funding in the FY57 AEC budget for R&D in support of the Navy's ANP requirements. These requirements were provided in one of the Nov. 28 DOD letters, and are less stringent that the Air Force ANP requirements. AEC has arranged for the eight Navy contractors to have access to ANP Program information and Glenn L. Martin and Convair (San Diego) have engineers at ORNL. The AEC staff provided additional background information to the Commissioners in the accompanying staff Paper.

"ANP Program". AEC Commission Staff Paper 17/37. Feb. 8, 1952. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.1 ending June 20, 1952: National Archives II, Washington, D.C.

AEC staff paper discusses the decisions necessary to implement the joint AEC-USAF program for nuclear propulsion. USAF was to brief Commission on Feb. 12, 1952 regarding Air Force objectives of an R&D program to develop ANP. USAF position was anticipated to be development of the GE gas turbine, open cycle reactor system as the main ANP Program reactor development effort, with Consolidated Vultee Aircraft Co. of Fort Worth, TX. Goal is for experimental flight in a modified B-36, not for military use. Also discusses construction of facilities at the NRTS, ID, based on an engineering study of that site and Edwards AFB. The Air Force is also expected to support continued research on liquid-cooled indirect and supercritical water reactor cycles. An Air Force budget of $230M is anticipated, half of which is to support the experimental flight and 10% of which is to support R&D on the backup reactors. . The AEC staff recommends Commission agreement with the anticipated USAF proposals. They recommend continuation of the liquid-cooled reactor work at ORNL, with work on the supercritical water concept to be initiated at an unspecified contractor.

"ANP Program". AEC Commission Staff Paper 17/41. May 27, 1952. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.1 ending June 20, 1952: National Archives II, Washington, D.C.

The Director of Reactor Development recommended to the AEC Commissioners that they formally agree with the Air Force's proposals for the cooperative program for development of ANP. As of this date the Commission had not acted on the Air Force letter of April 8, 1952, except approval of the Air Force's use of part of the NRTS. On May 20, the Commission had asked for more information on the GE program. The Air Force had revised downward the estimate for their R&D effort from $230 to $170M. The staff asked for approval the objectives of the ANP Program as outlined in the Air Force letter, which were to continue the GE direct cycle effort as the "...initial main development effort", at a cost to AEC of about $75M over the next several years to support the USAF in the development of an experimental flight test aircraft. The staff also asked for approval of the test facilities at NRTS and support for R&D on the liquid-cooled and supercritical water reactors, as backup efforts. Budget estimates are provided by FY from 1953 through 1957.

"ANPO Funding Estimate". Feb. 6, 1957. JCAE #5090. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

The AEC ANPO provided an estimate, as of June 1956, of the funds required for the originally planned Weapons System WS-125A being operational in 1964.

"Atomic Energy Commission Report". Thirteenth Semi-Annual Report. December, 1952. As reported in *Scientific American,* March, 1953.

A large materials testing reactor went into service in Idaho, to provide information for the ANP Program, as well as other reactor development activities. At Oak Ridge National Laboratory the first homogeneous (circulating fuel) reactor began operations. Design of a ground facility to test nuclear power plants for aircraft was started and investigations on ANP yielded promising results.

Bowen, E.N., ARB, AEC. "Mr. Cook's Request for ANP Review Information, Dated 3/9/56". Letter to Mr. Delmar Morris (affiliation not given). Mar. 12, 1956. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Responded to questions regarding the last GAC review of the ANP Program, any special reviews since the previous July and official DOD statements of requirements. [Researcher Note: These responses provide a convenient list of interactions between the ANP Project and outside reviewing organizations.]

Boyer, M.W., AEC General Manager. Letter to William L. Borden, JCAE Executive Director. Dec. 30, 1952. JCAE #3173. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Provided details on the planned ANP test facility at NRTS.

Brinner, C.R., and C.W. Hammond. "Heat Exchanger". For U. S. Atomic Energy Commission. U.S. Patent 3,139,927. July 7, 1964.

A heat exchanger is described in which liquid metal heated by a reactor supplies additional heat to heated air passing from an air compressor to a jet engine. The annular beat exchanger surrounds a drive shaft extending between the compressor and the jet engine and built in semicircular sections to facilitate assembly about the drive shaft.

Davis, W. Kenneth, Director, DRD, AEC. "Additional (Navy) ANP Program." Memorandum to K.E. Fields, General Manager, AEC. Mar. 16. 1956.
Davis reports on his participation in a meeting on March 14-5, 1956 with the TAB on Aeronautics to the Assistant Secretary of Defense, R&D. The purpose of the meeting was to review the proposed Navy ANP Program, in particular the "Compact Core Reactor"(CCR) proposed by NDA and Allison Division of General Motors. The cost of the R&D for the project was estimated at $900M. Davis summarizes the points he made, speaking for DRD. He questioned if a third project was the best use of the money and technical manpower. He recognized the value of bringing the engineering capabilities of General Motors, but pointed out it would take about two years to bring them up to speed. He also compared the CCR with other reactors and emphasized the much more difficult requirements for the CCR.

Davis, Kenneth W., Director AEC Division of Reactor Development. Memorandum to K.E. Fields, General Manager, AEC. "Navy Participation in the ANP Program". July 12, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Davis reports that the CNO has issued to the Navy's Chief of the Bureau of Aeronautics a development characteristic for a subsonic nuclear-powered patrol-attack seaplane system. Correspondence will be sent by the CNO to the AEC requesting naval personal be added to Gen. Keirn's staff.

Dean, Gordon. "Report on the Atom". Knopf, Pub., New York. 1957. pp. 157-8, 221, 311-13.

Dean, Chairman of the AEC 1950-53, includes a brief description of the ANP Program and his views on the prospects for success. He discusses the advantages of a nuclear airplane , but does not minimize the technical difficulties However, he concludes that these technical problems will be solved and a nuclear propelled aircraft will be flying several years after the first nuclear submarine is operational, but at a cost of "considerably more money". He also states that achieving nuclear-powered flight "depends almost solely on how much money the government is willing to spend...". He predicts that commercial nuclear flight will not be a possible in the next decade, but "... it is quite possible that this will become a reality later on". He also suggests that nuclear-powered dirigibles could, if funds were made available, be available for commercial use in fifteen or twenty years.

Dean, Gordon, AEC Chairman. Letter to Cong. Carl Durham, Chairman, Reactor Subcommittee, JCAE. July 1, 1952. JCAE #2911. RG128, Box 46, Folder -

Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Responding to Cong. Durham's letter of June 11, 1952 the AEC provided a summary of the actions taken by the AEC and DOD to establish the ANP Program. Chairman Dean also reviews the GE, Pratt & Whitney and ORNL ANP work scopes and funding. He also indicates that the organization to direct the Air Force and AEC ANP still must be arranged between the two organizations.

Dean, Gordon, Chairman, AEC. Letter to Sen. Brian McMahon, Chairman JCAE. Mar. 23, 1951. JCAE # 2016. RG128, Box 47, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

The AEC provided formal notification that they had authorized negotiation of the GE contract for construction of an aircraft test stand reactor . Funding was $500K in FY 51 and $3.7 M in FY52.

Dean, Gordon, AEC Chairman. Letter to Cong. W. Sterling Cole, JCAE Chairman. May 27, 1953. JCAE #3479. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Chairman Dean presented the AEC's assessment of the impact of proposed cuts in the ANP Program. The ground and flight testing of the ANP system would be postponed an indeterminate period. A major revision would be made in the GE part of the program, with the ORNL and Pratt & Whitney efforts essentially unaffected.

Dean, Gordon, Chairman, AEC. Letter to Thomas K. Finletter, Secretary of the Air Force. June 19, 1952. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.1 ending June 20, 1952: National Archives II, Washington, D.C.

The AEC Chairman responds to the April 8, 1952 letter of the Air Force and accepts "...with reservations the immediate objectives of the ANP Program". He states that on May 15 the Commission approved use of part of the NRTS by the Air Force and on June 12 approved the GE direct cycle reactor program, at a cost of about $16M for each of the next two years. He also noted that the AEC staff had been instructed not to increase the funding for alternative cycles beyond current levels, pending further discussions with DOD at policy levels to explore if the military could increase funding for development work, or even assume complete responsibility for ANP funding. Specific location of a runway at NRTS is left open for further discussion. The AEC General Manager, Mr. Boyer, is expected to initiate discussions shortly with USAF Gen. Craigie to establish the organization for accomplishing the ANP objectives.

Dean, Gordon, Chairman, AEC. Letter to Sen. Brian McMahon. Sept. 10, 1950. JCAE #1749. RG128, Box 47, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Dean advised the JCAE Chairman that 100 kg. of U-235 had been allocated to the ANP Program. The material was taken from retired weapons.

"Department of Energy. "OpenNet Internet Data Base". Address is: http://www.doe.gov/html/osti/opennet/opennet1.html

Using the key words ANP, or Nuclear Energy for Aircraft Propulsion, a search of the DOE OpenNet Data Base yielded 140 documents. The OpenNet provides only limited information for each entry, viz. title, author, addressee, originating organization, location of document, document type and date. No abstracts are available via OpenNet. The location of most of the articles is: DOE/NV CIC, P.O. Box 98521, Los Vegas, NV 89193; e-mail: cic@egg.nv.doe.gov. Other documents are located at: DOE OSTI, P.O. Box 62, Oak Ridge, TN 37831; e-mail: reports@adonis.osti.gov. Many of these documents are also found in other sources, such as the National Archives Record Groups 128 (JCAE), 326 (AEC) and 359 (OSPT), as well as DTIC. When found at these other sources, the documents have been abstracted and included in this bibliography.

Fields, K.E., AEC General Manager. Letter to Dr. Eugene Wigner, Member, GAC. Nov. 8, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Fields was responding to a query regarding the need for a special advisory board for the ANP Program. He relates how Brig. Gen. Keirn suggested earlier that a single advisory board be established with representatives from the GAC, the Air Force advisory group, the Air Force SAB, and appropriate panels under the Assistant Secretary of Defense for R&D. The purpose would be to reduce the number and frequency of briefings. However, the SAB and Assistant Secretary for R&D expressed reservations with a composite group carrying out advisory responsibilities for three different groups. The Chairman, SAB planned to establish a permanent reviewing group for ANP.

Fields, K.E., AEC General Manager. Letter to Robert McKinney, Chairman, Panel on the Impact of the Peaceful Uses of Atomic Energy, JCAE. Aug. 23, 1955. JCAE #4668.. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Fields provided a report by Brig. Gen. Donald Keirn on the commercial aspects of nuclear-powered aircraft. He also encloses a report on this subject by August C. Esenwein, Vice President, Convair Aircraft Corp.

Grebe, J.J. "Nuclear Reactor." (Communication to U. S. Atomic Energy Commission). U.S. Patent 2,917,443 (1959).

A reactor which is particularly adapted to serve as a heat source for a nuclear powered aircraft or rocket is described. The core of this reactor consists of a porous refractory moderator body which is impregnated with fissionable nuclei. The core is designed so that its surface forms tapered inlet and outlet ducts which are separated by the porous moderator body. In operation a gaseous working fluid is circulated through the inlet ducts to the surface of the moderator, enters and passes through the porous body, and is heated therein. The hot gas emerges into the outlet ducts and is available to provide thrust. The principal advantage is that tremendous quantities of gas can be quickly heated without suffering an excessive pressure drop.

Grebe, J.J. "Nuclear Reactor". U.S. Patent 2,917,443. Dec. 15, 1959.

A reactor which is particularly adapted to serve as a heat source for a nuclear powered aircraft or rocket is described. The core of this reactor consists of a porous refractory moderator body which is impregnated with fissionable nuclei. The core is designed so that its surface forms tapered inlet and outlet ducts which are separated by the porous moderator body. In operation a gaseous working fluid is circulated through the wet ducts to the surface of the moderator, enters and passes through the porous body, and is heated therein. The hot gas emerges into the outlet ducts and is available to provide thrust. The principal advantage is that tremendous quantities of gas can be quickly heated without suffering in excessive pressure drop.

Hafstad, Lawrence R. "Reactors". *Scientific American 185* (April 1951):43-50.

The author, Director of the AEC's Division of Reactor Development, reports on the status of the AEC's reactor development efforts. This article is interesting because it discusses all ongoing and planned reactor development projects, except it does not mention the ANP Project. By 1951, the ANP Project had been discussed in the press and other public sources, including in speeches by Hafstad. Its omission from this otherwise comprehensive article (which includes description of two Naval Reactor projects) is unexplained.

Hewlett, Richard G. and Francis Duncan. "Nuclear Navy, 1946-62." The University of Chicago Press, Chicago. 1974. 466 p.

Only limited mention is made of the ANP Project, but this book provides information to compare that project with the Naval Nuclear Power Program. Provides listings and terms of AEC Commissioners, Chairman of the JCAE, key AEC staff positions, as well as DoD Secretaries and staffs. Discussion is provided on ANP (p. 198-9) regarding the budget cuts imposed by the new Eisenhower Administration in early 1953. At a National

Security Council meeting on March 31, 1953, Lewis Strauss, then Eisenhower's special assistant on atomic energy, suggested eliminating the ANP Program. ANP survived, but at a much reduced budget.

Hewlett, Richard G. and Jack M. Holl. "Atoms for Peace and War, 1953-1961, Eisenhower and the Atomic Energy Commission". University of California Press, Berkeley, CA. 1989. 696 p.

This is Volume III. in the series of histories of the AEC and covers the period when the ANP Project peaked and then was cancelled. Includes discussion of the ANP cutbacks (and near cancellation) that occurred in 1953, and frequently changing requirements throughout this period. Discusses actions by the JCAE to accelerate the ANP Program, especially after the successful launch of *Sputnik* by the U.S.S.R. in 1957. This book provides only limited insight into the cancellation of the ANP Project by President Kennedy in 1961. Appendices provide information on AEC Organization and personnel, budgets, and makeup of the JCAE. Overall, this book provides a good overview for the ANP Program, in the context of the other major AEC development programs.

Hewlett, Richard G. and Oscar E. Anderson, Jr. "The New World, 1939-1946. Vol. I., A History of the United States Atomic Energy Commission". The Pennsylvania State University Press, University Park, PA. 1962. 766 p.

Covering the earliest work on atomic research and focusing on the Manhattan Project, this work provides a good background for the subsequent efforts on nuclear propulsion for aircraft. No specific mention is made of the NEPA Project, which was just getting started at point that this history concludes.

Hewlett, Richard G. and Francis Duncan. "Atomic Shield, 1947-52, Vol. II. A History of the United States Atomic Energy Commission.". The Pennsylvania State University Press, University Park, PA. 1969. 718 p.

Provides significant general information on the ANP Program, including the origins in the NEPA Project. This book, written as a history of the AEC, provides a perspective on the ANP Project primarily from the AEC viewpoint. Discusses work by all contractors, national laboratories, the AEC, Air Force, Navy and NACA. Provides a summary of the origins of a nuclear aircraft project as the Manhattan Project wartime activities wound down. Records objections by prominent scientists who questioned the feasibility of nuclear propulsion of aircraft at the project's beginnings. Provides discussion of the Lexington Project's review of the NEPA Project. Interactions among the AEC, JCAE, and the DOD regarding ANP are covered in some detail.

Ink, Dwight, Assistant General Manager, AEC. Letter to James T. Ramey, Executive Director, JCAE. Mar. 30, 1961. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

AEC informed JCAE that an announcement was being made and AEC contractors were being notified to terminate all ANP work. The contractors were GE and Pratt & Whitney. Copies of messages and a Press Release were attached. Termination of all ANP work, except basic high temperature R&D, was carried out to implement the decision of President Kennedy on March 28. 1961.

Keirn, Gen. D.J., Chief, ANPO. "ANP Program Briefing". Minutes of Sept. 13, 1955 AEC Commission Meeting. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

The purpose of the meeting was for Gen. Keirn to review the factors leading to the conclusion that 1959, rather than 1958 was the appropriate planning date for final test of the ANP system. The present schedule was reviewed by Gen. Keirn. He also reviewed the requirements, which were: (a) Chemical fuel for high speed and high altitude dash, (b) Nuclear power for 11,000 mile cruising radius (22,000 mile round trip) at 30,000 ft., or more, (c) Penetration radius of 60,000 ft. and (d) Dash radius of 1000 miles at the highest possible supersonic speed. With regard to crew exposures, he said that five years training is contemplated, after which crews would have 80 REM reserve for military missions. Recent plans envisaged speeds of Mach 2.5-3.0 and stainless steel or titanium aircraft, instead of aluminum. Gen. Keirn said that if requirements were relaxed to meet a production date earlier than 1961, the aircraft might not be militarily useful. Questions were raised on the status of the Atlas ICBM, and Keirn said they would probably be available in 1961. He also stated that he thought nuclear-powered aircraft would have a commercial application. Further discussions were held the impacts of having a third reactor concept and the Air Force's views, and other strategies to accelerate the program.

Kelehan, J.L., AEC Assistant General Manager for Administration. Letter to Herbert I. Miller, Executive Director, Panel on the Impact of the Peaceful Uses of Atomic Energy, JCAE. Jan. 10, 1956. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Provides a report requested entitled "Commercial Application of Nuclear Powered Aircraft", prepared by the ARB, DRD and signed by Maj. Gen. D.J. Keirn. Qualitative cost comparisons are provided between conventional and nuclear-powered commercial airplanes. Shielding requirements will probably reduce the passenger payload to uneconomic low levels until possibly the second or third generation designs. Safety aspects, in particular radioactive releases under accident conditions pose significant risks to the public, but the details of the problem are not yet well defined.

La Plante, Bryan F., Special Assistant to General Manager (Congressional). Letter to James Ramey (Attn: B.W.O. Dickinson). Apr. 18, 1957. JCAE #5174. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Provided Pratt & Whitney presentation materials from a recent briefing by B. Schmickrath. This gave data for two options, the CFR and the solid fuel reactor (SFR), for the WS-125A powerplant. The requirements for this aircraft are for a Mach 0.9 cruise and a Mach 2.75 dash.

Leudecke, A.R., AEC General Manager. Letter to James Ramey, Executive Director, JCAE. Jan. 21, 1959. JCAE #5829. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Provided financial history of the nuclear aircraft program from inception in FY46 through FY58.

Libby, Willard, Acting AEC Chairman. Letter to Sen. Clinton Anderson, JCAE Chairman. Jan. 27, 1956. JCAE #4781. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

JCAE informed that AEC has transferred 4.171 kg of SNM for ANP. AEC has also authorized continued possession and use of the GTR and ASTR for the ANP Program.

Luedecke, Alvin R., Maj. Gen., USAF (Ret.). Interview by Dr. James C. Hasdorff. July 1987.

Iris Number 1095093
Call Number K239.0512-1759 C. 1
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Maj. Gen. Alvin R. Luedecke, USAF (Ret.) served as General Manager of the Atomic Energy during the beginning of the ANP Project. Interview, conducted by Dr. James C. Hasdorff, USAF Historical Research Center, in Bryan TX from July 7-8, 1987, should be reviewed for ANP information.

Luedecke, A.R., General Manager, AEC. Letter to Dr. James R. Killian, Jr., Special Assistant to the President for Science and Technology. No Date. RG359, Box 22, Executive Office of the President, OSTP Folder-ANP 1959: National Archives II, Washington, D.C.

Luedecke forwards the May 5, 1959 GAC Report on ANP in advance of his May 15, 1959 with Dr. Killian. The report is from the GAC, Reactor Subcommittee consisting of Dr. Manson Benedict and E.V. Murphee. Dr. Eugene Wigner was a consultant. All visited GE and Pratt & Whitney in mid-April. At GE they felt the ANP had been advanced by the Air Force's definition of CAMAL in the form of a requirement and design progress for the XMA-1a power plant with Ni-Cr fuel and Zr-H moderator. The committee saw the XMA-1a at 153 MW as a logical step toward the XMA-1c as a full-sized power plant of

220 MW, to be operational by 1962. GE indicated the need for a runway at NRTS for flight testing. At Pratt & Whitney the committee thought that their work had progressed to the point that an lithium cooled, ceramic fueled experimental reactor should be built. The committee questioned the Navy's request that a sodium cooled reactor be developed for the Princess flying boat. The committee also believed that ANP had made progress with the selection of Convair to design the airframe for CAMAL. Finally the committee "feels that (CAMAL) may well have military value".

Luedecke, A.R., AEC General Manager. Letter to Cong. Clinton P. Anderson, JCAE Chairman. Oct. 8, 1959. JCAE #6131. RG128, Box 46, Folder Vol. III. - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

AEC informed that the future orientation of the ANP Program had been changed. AEC deleted the ground test of the XMA-1 scheduled for spring 1961 and phased out all work on nichrome fuel elements. Emphasis will be on ceramic fuel elements, with an advanced reactor test with the X-211 turbomachinery planned for late 1961 to early 1962. The GE program remains the primary ANP effort. The current objective of a low power experimental reactor test of the Pratt & Whitney high temperature lithium cooled system is still planned for 1963. A higher powered reactor test of several hundred megawatts is under consideration by Pratt & Whitney. A joint AEC/DOD press release was attached which made no mention of the estimated 1000 job cutback at GE.

Murray, Thomas E., Commissioner, AEC. Memorandum to AEC Chairman Lewis Strauss. "Proposed Joint Memorandum to the NSC on the Aircraft Nuclear Propulsion Program". June 1, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Commissioner Murray comments on a proposed joint memorandum to the NSC forwarded by DOD on April 29, 1955, recommending that the statement that recent progress indicates that ANP may be available for military use in the 1960's be made more explicit. He points out that, as written, this objective could be anywhere between 1960 and 1970. He also requests that the Commission discuss with the Chief, AEC Aircraft Reactors Branch, why the beginning of 1959 proposed as the date for initiation of full-scale tests of prototype aircraft nuclear plants cannot be advanced by one year.

Murray, Thomas E., Commissioner, AEC. Memorandum to AEC Chairman Lewis Strauss. "Joint Memorandum to the NSC on the Aircraft Nuclear Propulsion Program". July 25, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Responds to Strauss memorandum of July 15(not found), which stated that the memorandum to NSC had been sent after Murray had signed off with no comments. Murray complains that his comments were provided (and ignored), and the NSC memorandum should be revised to more explicitly state the date for ANP objectives. Apparently Strauss had argued that funding uncertainties pose difficulties in forecasting. Murray argues that "...JCAE has given every indication that we can continue to expect the strongest support of this project". Murray goes on to state that even though the NSC memorandum has been sent without his approval, he still wants a Commission meeting with the AEC staff to discuss why the time objective for full-scale testing of prototype aircraft nuclear power plants cannot be advanced from 1959 to 1958.

Murray, Thomas E., Commissioner. Memorandum for Chairman Lewis L. Strauss. "Proposed Joint Memorandum to the National Security Council on the Aircraft Nuclear Propulsion Program". June 27, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Questions what action Strauss has taken on Murray's memorandum of June 1, 1955 regarding the DOD proposed joint memorandum to the NSC. The memorandum was forwarded to Strauss by the Secretary of Defense on April 29, 1955.

Pittman, Frank K. "Nuclear Power Development in the United States". *Science* 133 (May 19, 1961): 1566-72.

Author was the Director of Reactor Development, AEC. This paper, which reports on the progress to achieve competitive nuclear power, is interesting because no mention is made of the spinoff benefits that were claimed elsewhere (reference GAO Report) when the ANP Project was canceled the month prior to publication of this paper.

"Press Service Story Concerning the ANP Program". Minutes of AEC Commissioner's Meeting. Dec. 13, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

The AEC General Manager, K. Fields advised that the International News Service planned to disseminate an account of the ANP Program derived from a classified film.

"Reactor Development". AEC Minutes of Commission Meeting. Oct. 25, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

The minutes record that Commissioner Murray raised a question to which Mr. Davis responded that a nuclear propelled aircraft was still scheduled for flight in 1961.

Roddis, Lewis H., Jr., AEC Deputy Dir. of Reactor Development. "ANP Program". Memorandum to K.E. Fields, AEC General Manager. Nov. 8?, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Roddis reports on a Nov. 2 meeting of the Coordinating Committee on Atomic Energy of the Office of the Assistant Secretary of Defense for R&D. Two reports were presented from the Winne Committee, the Ad Hoc group on ANP. Decisions were deferred until the next meeting, but if adopted the ANP objectives and schedules for both the Air Force and the Navy would be significantly affected. The committee approved the Navy letter to the AEC establishing Navy requirements for the ANP Program. No decision was made, but the Air Force, Navy and DOD representatives "...expressed alarm at the thought of a third major approach". This was to be discussed at the Nov. 17, AEC-MLC Conference.

Schmickrath, B.A., General Manager, Pratt & Whitney. Letter to Maj. Gen. Donald J. Keirn, ARB, DRD, AEC. June 11, 1957. JCAE #5315. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Referring to Jan 24 and Apr. 3, 1957 letters from Keirn, Pratt & Whitney provided recommendations for a revised ANP development program. He recommends that the ANP be directed toward the development of a supersonic aircraft, with a program that leads to a technical evaluation of the air-cooled (GE) and liquid-cooled nuclear power plant systems. This includes a redirection of the J-91 turbojet engine program to converting this engine to nuclear power, development and testing of a liquid metal cooled solid fuel experimental reactor, and research and engineering efforts for future improved systems. A schedule and list of milestones was provided. Schmickrath's understanding was that both the CFR and solid fueled liquid metal cooled reactors could not be supported with available funding, and he recommends termination of the Pratt & Whitney CFR work, which was considered to have less potential than the solid fueled reactor.

Seaborg, Glenn T., AEC Chairman. Letter to Robert McNamara, Secretary of Defense. Mar. 2, 1961. JCAE #6613. RG128, Box 46, Folder Vol. III. - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

The AEC Chairman addressed his response to the Feb 28, 1961 DOD letters from Roswell Gilpatric (Deputy Secretary of Defense) to Robert McNamara, Secretary of Defense. Seaborg stated that the Commission had considered the DOD proposal for AEC to assume full responsibility for the complete ANP power plant development and "...believes it has merit". However, Seaborg believes that implications of a cycle decision is of sufficient importance to the national security and the national economy, that it must be recognized by the BOB and the President. Therefore the Commission would not accept the DOD suggested division of responsibility with assurances that the program is approved by the President. Seaborg suggests that they arrange a meeting with the President.

Shugg, Carlton, Deputy General Manager, AEC. Letter to William L. Borden, Executive Director, JCAE. Jan. 8, 1951. JCAE #1838. RG128, Box 47, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Provides brief history of the ANP Project that was requested by the JCAE Subcommittee on Reactor Development when they visited Oak Ridge on May 1, 1950, in connection with JCAE Hearings held there. The ANP history was prepared by the AEC's Oak Ridge Operations Office and includes a discussion of the establishment of a Technical Advisory Board (TAB) of scientists that met during the summer of 1950 under the direction of Dr. F.W. Loomis. This TAB evaluated the designs under consideration and attempted to establish basic design points from which an aircraft reactor could be developed. The TAB members are listed in an appendix to the report. Shugg also provided copies an approximate schedule for development of a nuclear-powered aircraft, and technical performance data for aircraft.

Snapp, R.B. "Organization for Aircraft Nuclear Propulsion". Office of the Secretary, AEC. Nov. 18, 1952. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol. 4:National Archives II, Washington, D.C.

This is a note by the Secretary of the AEC to USAF Secretary Thomas K. Finletter reporting on the agreement reached on July 11, 1952 in a meeting between Marion W. Boyer (AEC- General Manager) and Gen. Lawrence C. Craige(USAF). The agreement was to establish a central, combined program authority for the ANP Program. Gen. Keirn has been assigned as the Chief, Aircraft Reactors Branch in the AEC's Div. of Reactor Devel. The AF has formulated an AF regulation to implement the AF organization. Enclosure is a letter from AEC Chairman Gordon E. Dean to T.K. Finletter responding to a draft of this AF regulation.

"Status of Current Developments of the ANP Program". AEC Commission Staff Paper 17/36. Jan. 4, 1952. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.1 ending June 20, 1952: National Archives II, Washington, D.C.

The AEC Director of Reactor Development recommended that the main ANP Program for FY 52 and 53 should be with the GE reactor for the direct air-cooled cycle engine This is recommended because of the Air Force's stated need for an experimental flight test aircraft by 1956. Reference is made to AEC 17/33. The liquid metal cooled and super-critical water reactors are considered as "insurance efforts". The critical technical problems for the GE reactor are stated to be accurate determination of the U-235 required, control of the reactor and heat transfer as related to fuel temperatures. The Director reports on a meeting with the Air Force, Wright Air Development Center on Nov. 20, 1951 where agreement was reached to: (a) proceed with the X-6 (modified B-60, the swept wing version of the B-36), (b) the Air Force proceed with the Lockland and Fort Worth facilities, (c) each would finance facilities on their own property, and (d) the Air Force will require significant funding beyond the normal R&D allotment to Wright Air Development Center.

Strauss, Lewis, AEC Chairman. Letter to Cong. W. Sterling Cole. Nov. 2, 1953. JCAE #3714. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

AEC notified the transfer of SNM to Consolidated Vultee Aircraft Co. as an Air Force contractor in the ANP Program. The transfer was approved by President Eisenhower.

Strauss, Lewis, AEC Chairman. Letter to Carl T. Durham, Chairman JCAE. Feb. 5, 1957. JCAE #5085. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

AEC Chairman advised on current ANP planning with reorientation of the program requirements by the DOD. Both GE and Pratt & Whitney contracts will be retained, but greater emphasis will be placed on GE. The planned FY57 &58 funding for operations and facilities are provided.

Strauss, Lewis, AEC Chairman. Letter to W. Sterling Cole, JCAE Chairman. Aug. 16, 1954. JCAE #4133. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

AEC responded to Cole's May 14 letter (presumably to the President) to expand the ANP Program. Strauss discusses the changes to expand the ANP Program in support of the cruise-type, dual power system. After studies sponsored by the Air Force initiated in the spring 1953, the Pratt & Whitney supercritical water concept was terminated and all their efforts placed on the CFR, providing engineering support to ORNL. ORNL has the lead for CFR development, including the soon to be operated ARE. This placed the same emphasis on the CFR as had been on the GE direct cycle approach, since the ducted fan jet engine required by the direct cycle does not lend itself to chemical operation. An additional $5M is being allocated to the ANP Program by the Air Force and AEC for FY55, to be applied to the CFR effort. The objective of this effort will be to provide a firm engineering base for the design of the CFRE, targeted to operate in 1958. At an appropriate time, based on technological progress, Pratt & Whitney will design a ground prototype aircraft propulsion system, with the support of ORNL. In a letter dated July 23, 1954, the Secretary of Defense, Charles Wilson supported this buildup of the ANP Program. Strauss also noted that the NSC has approved this expanded ANP effort.

Strauss, Lewis L. , AEC Chairman. Letter to W. Sterling Cole, JCAE Chairman. Dec. 9, 1954. JCAE #4256. RG128, Box 46, Folder - Declassified Records from the Classified JCAE

Subject File:National Archives, Washington, D.C.

AEC reported that the ARE successfully completed a continuous 200 hour run at a maximum power of 2.5 MW during the period Nov. 3-Nov. 12, 1954. Including the pre-critical and post-critical phases, the reactor operated for approximately 600 hours at high temperature. This CFR was fueled with a molten mixture of sodium, uranium and zirconium fluorides, operating in the range of 1300-1580 deg.F. This experiment represented the first known power production from a reactor at temperatures required by a jet engine. Strauss closes with the statement: "As such the results represents an important achievement in the development of nuclear propulsion systems for aircraft. The Commission intends to review progress in the aircraft reactor program to determine whether present development schedules can be accelerated."

Strauss, Lewis L., Chairman, AEC. Letter to Gen. Loper, Chairman, MLC. Sept. 29, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Strauss requested that the October AEC-MLC Conference include a discussion of the greater emphasis should be given to the ANP Program by starting development of a third reactor concept. AEC had already established dual projects at both GE and Pratt & Whitney to improve the chances for success. The GE direct air cycle has both liquid and solid moderated reactor designs, with research on various fuel element designs. At Pratt & Whitney the liquid metal cooled reactor project was recently expanded to include work on a solid-fuel reactor as a backup to the CFR. The goal was stated to have an operational power plant for a nuclear-powered strategic bomber by 1964. Recent objectives for a nuclear-powered seaplane have imposed additional power plant needs, but AEC had not received a stated requirement yet for a seaplane.

Strauss, Lewis L. Chairman, AEC. Letter to Charles E. Wilson, Secretary of Defense. June 23, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Chairman Strauss concurs in the proposed joint memorandum to the NSC provided by DOD on April 29, 1955, with no comments regarding its contents. The memorandum concerns the AEC/DOD plans to accelerate and expand that ANP Program. [Researcher Note: The April 29 letter remains classified.]

Strauss, Lewis L., AEC Chairman. Letter to Dr. C.C. Furnas, Assistant Secretary of Defense (R&D). May 29, 1956. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Chairman Strauss responded to Dr. Furnas April 18. 1956 letter which requested that the

AEC increase Pratt & Whitney's effort on the solid fuel, liquid metal cooled reactor (LMCR). Strauss reviews the history of Pratt & Whitney's work on both the CFR and the LMCR, with the latter being initiated in FY56. FY57 funding for the LMCR will be double that of FY56. Consideration of further increases were planned to be based on Pratt & Whitney's ability to properly utilize increased funds and the technical progress on the LMCR.

Strauss, Lewis L. , AEC Chairman. Letter to Cong. Carl T. Durham, JCAE Chairman. Oct. 28, 1957. JCAE #5367. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Advised JCAE that the CFR reactor concept was being dropped and replaced with the solid fuel reactor, because funding available will not support both concepts. The GE direct cycle work remains the top priority of the ANP Program. After a six months evaluation period, it was determined that the SFR was the preferred approach, based, in part, on the extension of the startup date for the ART from 1957 to 1960 and at a total cost of some $21M. The development of the SFR has the potential to utilize a lithium-cooled reactor as a high performance reactor for later applications as an all nuclear-powered supersonic aircraft. This potential cannot be predicted for the CFR. All R&D at ORNL and Pratt & Whitney on circulating fuel reactors for ANP has been terminated, including the ART.

Strauss, Lewis, AEC Chairman. Letter to Sen. W. Sterling Cole, JCAE Chairman. August 16, 1954. JCAE #4132. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

AEC responded to a JCAE Subcommittee Report and also advised on ANP Program development efforts.

Strauss, Lewis, Chairman, AEC. Letter to Gen. Herbert B. Loper, Chairman, Military Liaison Committee, DOD. Feb. 1, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Chairman Strauss notes that progress with the AEC's direct cycle ANP Program at GE has exceeded expectations, allowing advancement of the HTRE operations to the last quarter of 1955. The AEC is authorizing an additional $1.875M to be spent during FY55 to support this effort.

Summary of Report on the HTRE Operation at NRTS". AEC Staff Paper 17/112. April 9, 1956. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

The staff reviewed the operations of the HTRE from Feb. 11 to 24, 1956. During this period, operation at a significant power level occurred for nearly 18 hours. For seven days, radioactivity was released to the environment, totaling 3111 curies. Limited examinations showed three or four failed fuel elements of the nine that have been removed from the core.

Szekely, T. “Nuclear Propulsion Apparatus with Alternate Reactor Elements.” Patent No. US 4147590. Filed Sept. 1, 1965. Issued April 3, 1979. 12p.

This patent, filed four years after ANP Program cancellation, is assigned to the U.S. Dept. of Energy.

Thomson, W.B. and A. Corbin, Jr. “Neutronic Reactor Core”. Patent No.: US 2992981. (Assignee: U.S. Atomic Energy Commission). July 18, 1961.
An improved core for a gas-cooled power reactor which admits gas coolant at high temperatures while affording strong integral supporting structure and efficient moderation of neutrons is described. The multiplicities of fuel elements constituting the critical amassment of fissionable material are supported and confined by a matrix of metallic structure which is interspersed therebetween. Thermal insulation is interposed between substantially all of the metallic matrix and the fuel elements; the insulation then defines the principal conduit system for conducting the coolant gas in heat-transfer relationship with the fuel elements. The metallic matrix itself comprises a system of ducts through which an externally-cooled hydrogenous liquid, such as water, is circulated to serve as the principal neutron moderator for the core and conjointly as the principal coolant for the insulated metallic structure. In this way, use of substantially neutron transparent metals, such as aluminum, becomes possible for the supporting structure, despite the high temperatures of the proximate gas, The Aircraft Nuclear Propulsion program's "R-1" reactor design is a preferred embodiment.

Von Neumann, John, Acting Chairman, AEC. Letter to Cong. Melvin Price, Chairman, JCAE Subcommittee on Research and Development. Aug. 9, 1955, JCAE #4656. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

The AEC responded to a July 12, 1955 letter from Cong. Price requesting information on advanced ANP concepts. The effort to date is described as “modest”. Most of the work has been done by NDA, with cumulative costs of $400K through May 1955. This effort is a backup to the CFR and consists of a sodium cooled, solid fuel reactor which could be substituted for the CFR. This solid fuel alternative to the CFR was anticipated to receive increased funding to $2M in FY56, with the work being done at Pratt & Whitney, and on subcontract to NDA.

Von Neumann, John, Acting Chairman, AEC. Letter to the Secretary of the Air Force. Sept. 8, 1955. RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

AEC reviewed the proposal by Consolidated Vultee Aircraft Corp. to fly an airplane at 10,000-35,000 ft carrying the ASTR. They concluded that flying with the AFTR operating at power levels up to 1 MW, could pose a serious hazard to the public, from either a crash or jettisoning of the reactor in advance of an impending crash. Burning of jet fuel and the decay heat from the reactor might cause the reactor to melt down and release fission products. Von Neumann notes that the airplane will fly under limited weather conditions and over a selected flight pattern this may reduce the probability of harm to the public, but not eliminate the risk. He states that in spite of these precautions, "...there can be no assurance that there will be no crash...without harm to the public". The September 22, 1953 memorandum of understand between the Air Force and the AEC specifies that the Air Force assumes all responsibility for the safety of this operation. Von Neumann states that he assumes the Air Force has determined that the purpose of this flying test cannot be satisfied by ground testing. [Researcher Note: Portions of this letter remain classified].

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b. AIR FORCE and DEPARTMENT of DEFENSE

Air Force Plant Representative Office, General Electric Company, Cincinnati. “Annual Report”. (1/7-12/31/59).

Iris Number 00476615
Call Number K208-31
Reel 14840 Beg Frame 508 End Frame 527 Old Reel Number K2279

Discusses major efforts which included J-79 series of aircraft jet engines and aircraft nuclear propulsion.

(Some pages difficult to read).

Air Research and Development Command. “Quarterly Report (1/1/54-6/30/54)”, Vol. I. of II

Iris Number 00449603
Call Number K243.01 V.1
Reel 15389 Beg Frame 1204 End Frame 1693 Old Reel Number K2837

Reports on plans underway to provide necessary facilities for development of Aircraft Nuclear Propulsion.

“Air Force Nuclear Propulsion". Air University, Quarterly Review, Vol. XI, Numbers 3 and 4. Fall and Winter, 1959. 207 p.

Iris Number 00482248
Call Number K239.309 V,12-3,4 C.1
Reel 15263 Beg Frame 2424 End Frame 2635 Old Reel Number K2711

Includes articles entitled:

"Nuclear Propulsion and Aerospace Power", Gen. Thomas D. White.
"Payoff in Nuclear Propulsion", Lt. Gen. Roscoe C. Wilson.
"United States Nuclear Propulsion Programs", Maj. Donald J. Keirn.
"Manned Aircraft Nuclear Propulsion Program", Col. William A. Tesch.
"Nuclear, Missile, Rocket, and Auxiliary Power Programs", Col. Jack L. Armstrong.
"Power Reactor Fundamentals", Capt. Thomas L. Jackson.
"Thrust and Power Production from Nuclear Energy", Capt. John P. Witt.
"Heat Transfer and Coolant Systems", Capt. John P. Witty.
"Reactor Materials", Lt. Commander John J. Connelly, Jr.

Includes information on the need for nuclear radiation shields, direct-cycle nuclear propulsion, indirect-cycle nuclear propulsion, nuclear reactors for ramjet propulsion, design of a nuclear ramjet, nuclear rocket propulsion, radioscopic power sources, nuclear reactors as auxiliary power sources, testing radiation effects on aircraft systems, radiological aspects of nuclear aircraft and human factors of nuclear powered aircraft, ground support for nuclear aircraft, and public hazards from nuclear aircraft. Contains many graphs, charts, diagrams, and photos. Also contains a glossary of terms relating to aerospace nuclear propulsion. The public hazards of nuclear aircraft are discussed. This very useful reference gives a comprehensive review of the ANP Project in mid-1959. (Also published as "Nuclear Flight - The United States Air Force Programs for Atomic Jets, Misses, and Rockets", Edited by Kenneth F. Gantz, Lt. Col., USAF, Duell, Sloan and Pearce, Pub., New York. 1960).

Air Corps. "Aircraft Accident Report". Aug. 12, 1930.

Iris Number 138305
Call Number 200.3912-1 (Keirn)
Reel 3789 Beg Frame 781 End Frame 787 Old Reel Number A2022

Aircraft accident report regarding Lt. Donald J. Keirn, Kelly Field, TX, LB-5A Aircraft Serial No. 28-3. [Researcher Note: Included as possible background information on the future Director of the joint AEC and USAF ANP Program].

Air Force Plant Representative Office, Jan. 1, 1950-Feb. 28, 1951. NEPA Division, Fairchild Engine and Airplane Corporation, Oak Ridge, TN

Iris Number 00476337
Call Number K208-3c
Reel 14828 Beg Frame 1463 End Frame 1523 Old Reel Number K2277

Office Established July 29, 1949 and Functioned Continuously Until Feb. 28, 1951. Mission Was to Administer NEPA Programs Under Contract W33-038 Ac-14801 with

Fairchild Engine and Airplane Corporation. NEPA Program Was Air Force participation in Aircraft Nuclear Propulsion Program, joint endeavor of Air Force, Atomic Energy Commission, and National Advisory Committee for Aeronautics.

Air Research and Development Command, Biographies and Other Materials, .

Iris Number 484773
Call Number K243.01 V.1
Reel 15390 Beg Frame 557 End Frame 1065 Old Reel Number K2838

Includes biographical information on Brig. Gen. Donald J. Keirn and Brig. Gen. Marvin C. Demler. Both individuals played key roles in the USAF ANP Program.

Aircraft Nuclear Propulsion Office, Air Force Contract with University of Minnesota AF 29(601)-2 , (12/18/58-10/12/60).

Iris Number 01080364
Call Number Micfilm 40876
Reel 40876 Beg Frame 195 End Frame 279 Old Reel Number

Contains Letter of Transmittal to Air Force Special Weapons Center and 16 attachments concerning contract with University of Minnesota College of Veterinary Medicine for research services and materials for determining effects of irradiation on large animals simulating man.

(Available on Microfilm Only. Part of Air Force Special Weapons Center Contract File Collection, Call Number K242.86).

Aircraft Nuclear Propulsion Biomedical Research Program. Report No. 5. Contract Research on Radiobiologic Problems of ANP". NP-6764. School of Aviation Medicine, Randolph AFB, TX. 1958. 18p.

Long term research studies on the acute and chronic biological effects of mixed neutron and gamma radiation on experimental animals are outlined. Emphasis is placed on studies aimed at defining permissible exposure levels for nuclear aircraft personnel. Other problems of interest include: the biologic and physiologic effects, mechanisms, and kinetics of radiation injury; the development of prophylactic and therapeutic treatments for radiation injuries; and the development of standardized dosimetry for the expression of tolerance doses.

Anderson, R.B., Acting Secretary of Defense. Letter to Cong. W. Sterling Cole, JCAE Chairman . May 20, 1954. JCAE #4065. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Acknowledged receipt of May 14, 1954 report of the JCAE R&D Subcommittee. DOD and AEC had under discussion a reorganization and perhaps an acceleration of the ANP Program to take full advantage of the new concepts outlined to the JCAE by Gen. Keirn. Anderson promised to keep the JCAE informed.

Arnold, Henry H. “Transcript of Oral History Interview with Maj. Gen. Donald J. Keirn, USAF, (Ret.)”. Sept. 25, 1970.

Iris Number 1103143
Call Number Microfilm 43823
Reel 43823 Beg Frame 75 End Frame 82 Old Reel Number (N.A.)
Call Number 168.7326-205.

Maj. Gen. Donald J. Keirn, USAF, (Ret.), was the Director of the joint Atomic Energy Commission and USAF Office of Nuclear Propulsion. Keirn retired in October 1959, about one and a half years prior to the cancellation of the project. He died in 1980. Part of a collection of documents which were microfilmed. Collection includes correspondence, biographical sketch and interview material.

Aviation Week. November 24, 1958. p. 27.

Reported that Maj. Gen. Donald Keirn stated that the ANP Project was “re-oriented because the technical risk of success was considered too severe to justify the high cost.”

Bell, James B. Evaluation of an Aircraft Tire Irradiated Systems Panel Test Number 2". WADC-TN-58-86. Wright Air Development Center, Aircraft Lab., Wright-Patterson AFB, OH. Mar. 27, 1959. 15p.

The purpose of the tests was to evaluate the suitability of an aircraft tire and inner tube irradiated in Systems Panel Test No.2. The aircraft tire and inner tube performed satisfactorily in dynamometer flywheel tests. A burst test of the irradiated tire showed a small decrease in the burst strength, but the tire still satisfied the specification minimum burst strength requirements. The evaluation of the materials in the irradiated tire revealed a small decrease in the tensile strength of the nylon cords used In the tire carcass. This decrease in cord tensile strength was largely due to the radiation. No change was detected in the rubber materials of the tire. Present aircraft tires could provide from one to five actual landings when subjected to radiation of the level of this test.

Benoit, John W. and Clinton R. Foulk. “COP II, A Multigroup-Multiregion Reactor Program”. WADC-TN-58-91. Wright Air Development Center. Propulsion Lab., Wright-Patterson AFB. Ohio and Wright Air Development Center. Aeronautical Research Lab., Wright-Patterson AFB, Ohio. Oct. 21, 1957. 138p.

A program is given which is designed to make static diffusion theory computations of thermal and intermediate spherical reactors. The program is coded for the ERA 1103 with line printer. The Selengut-Goertzel slowing down model has been used for hydrogen. Inelastic scattering has not been included. The program will accommodate two to thirty regions inclusive with U^{235} fuel in any or all regions.

Boston Air Procurement District, (July-December 1955).

Iris Number 00474479
Call Number K204.22-12
Reel 14612 Beg Frame 547 End Frame 636 Old Reel Number K2062

Discuses how the Aircraft Nuclear Propulsion Program, assigned to Pratt and Whitney Division, and sponsored by Air Force and Atomic Energy Commission, grew during period.

Connor, Joseph A., Jr. “Space Nuclear Power Safety Considerations”. For USAF. *Aero/Space Eng.* 20, 5 (May 1961): 26-7; 58-61.

Safety considerations in uses of nuclear power plants in space missions are detailed. The biological effects, probable amounts, dispersions, and locations of released radioactivity are considered. Engineering problems examined include personnel protection, site and range selections, and launching, pre-orbital, and random reentry failures of vehicles. Aspects of manned nuclear aircraft are discussed.

Demler, Marvin C., Folder T-3.18: "Army Air Forces Early Jet Engines". 1944.

Iris Number 1094081
Call Number 168.7265-115
Reel 42659 Beg Frame 337 End Frame 376 Old Reel Number (N.A.)

Contains a report made by Col. D.J. Keirn for the President, dated Jan. 15, 1944. [Researcher Note: Included as possible background information on the future Director of the joint AEC and USAF ANP Program].

Demler, Marvin C., Folder T-6.4: ANP(Airborne Nuclear Program), Wassel Papers, (1/67-6/1/71)

Iris Number 01094107
Call Number 168.7265-141

Reel 42662 Beg Frame 208 End Frame 248 Old Reel Number

Contains Correspondence with and Papers of Brig. Gen. Ralph L. Wassel: "An Important Application of Nuclear Power(Utility of Nuclear Propulsion in Enhancing Nuclear Deterrence Capabilities of the United States)", Jan 67; "On The Impact of Applying Nuclear Power to the Airplane", (Apparently Also Sent by Maj. Gen. Marvin C. Demler to Grant L. Hansen and Lt. Gen. John Carpenter), Feb 70; Memorandum For Gen. Demler Dated 12 Mar 70 by Lt. Col. Earl C. Cranford, Comments on Gen. Wassel's Paper, "The Impact of Applying Nuclear Power to the Airplane", Feb 70; Letter from Gen. Wassel to Lt. Gen. John O'Neill Dated 9 Feb 70 Regarding Effects of Declining Department of Defense Budgets; Letter From Gen. Demler to Gen. Wassel Dated 18 Mar 70 Concerning Transmission of Gen. Wassel's Feb 70 Paper to Gen. Carpenter, Mr. Hansen and to Maj. Gen. John S. Samuel; 24 Mar 70 Letter From Gen. Wassel Answering Gen. Demler's Letter of 18 Mar 70; 4 May 70 Letter from Gen. Wassel to Gen. Demler "Problems With and Importance of Nuclear Powered Aircraft Development "(With Enclosures, "New Nuclear Strategy for America?" From *US News and World Report,* 13 Apr 70, and "New Strategy Likely As Leadership of Joint Chiefs Shifts to Navy" by William J. Lanouette), Includes Memoranda and Comments of 11 May 70 of Lt. Col. Cranford; Includes handwritten transcription of notice from *Aviation Week*, 1 Jun 70, of "Proposal of Nuclear Powered, Seaplane Version of C5A Aircraft"; Newspaper article by Michael Getler, "Air Force Seeks 10 New Sky Headquarters (Airborne Command Post)", from *Washington Post,* 20 Dec 70; 19 Feb 70 Letter from Gen. Wassel to Maj. Gen. D.V. Miller with Copy of Letter to Gen. Bruce K. Holloway; and 1 Jun 70 Note to Gen. Demler and His Wife.

Demler, Marvin C., Maj. Gen., USAF, (Ret.), Official Biography, Oct. 9, 1923- Nov. 71.

Iris Number 1093967
Call Number 168.7265-1
Reel 4264 Beg Frame 12 End Frame 22 Old Reel Number (N.A.)

In 1944, Maj. Gen. Marvin C. Demler, along with Col. R.C. Wilson, were the first Air Corps officers to visit Los Alamos Laboratories of the Manhattan Project and obtain detailed information on atomic bomb development. In late 1946, Demler was assigned as Chief, Propulsion Section, Research and Engineering Division. In this capacity he prepared directives for development in jet engines, rocket propulsion, ramjet engines, and nuclear powered aircraft program.

Demler, Marvin C. Folder T-6.1: “NEPA (Nuclear Energy for Propulsion of Aircraft) Project". November, 1945-51.

Iris Number 01094103
Call Number 168.7265-137

Reel 42661 Beg Frame 714 End Frame 825 Old Reel Number

Contains: Newspaper clipping describing nuclear energy for propulsion of aircraft , B-36 Aircraft; report on NEPA (Perhaps by Maj Gen Marvin C. Demler), 4 Apr 49; reprint of articles on nuclear physics by E. U. Condon, W. E. Shoupp, Frederick Seitz, Jr., C. F. Wagner, J. A. Hutcheson, Hugh Odeshaw, and J. W. Cottman (undated); presentation on NEPA to Scientific Advisory Board Group (Perhaps by Gen. Demler), 13 Jul 49; "Atomic Power and Aircraft Propulsion" by Andrew Kalitinsky from *Society of Automotive Engineers Quarterly Transactions*, Jan 49; and Apr 60 Issue of *Airpower Historian* which includes "NEPA, 1946 to 1951", by Lt. Col. Francis X. Kane.

Demler, Marvin C., Folder T-6.2: “ANP (Airborne Nuclear Program)”. (1945-71).

Iris Number 01094104
Call Number 168.7265-138
Reel 42661 Beg Frame 826 End Frame 1141

Contains: Translation (From Russian), "Application of Atomic Engines in Aviation"" (Primeneniye Atomnykh Dvigateley V Aviatsii) by G. N. Nesterenko, A. I. Sobolev and Yu. N. Sushkov, Military Press of the Ministry of Defense of the Union of Soviet Socialist Republics, Moscow, 1957; "Soviet A-Plane by '60 Forecast" by John G. Norris from Kansas City (KS) Star, 11 Apr 58; "(Gordon) Dean (Chairman of the Atomic Energy Commission) Predicts Atomic Planes 'Within Decade'", Associated Press, 8 Oct 51; "Address to NEPA (Nuclear Energy For Propulsion of Aircraft) Member Companies" by Col Marvin C. Demler, 23 Apr 51; "Aeronautical Engineering, the Atom, Power for Flight", by David A. Anderton from *Aviation Week*, 21 and 28 May, 4 and 11 Jun 51; "Aircraft Nuclear Propulsion" By M. C. Leverett from *Aeronautical Engineering Review*, Jan 52; "Nuclear Powered Aircraft Are Not Far Off " by Walter A. Kilrain from *American Aviation*, 27 Sep 54;" Nuclear Planes Will Add Force" from Kansas City Times, 25 Apr 58; "Applications of Nuclear Energy for Aircraft" by Leonard F. Harmon, 5 Jan 59; Editorial, "The Case for Nuclear Powered Aircraft" by Robert Hotz, *Missile Engineering*; "Lack of Engineering Data Delays Nuclear Ramjet" by J. S. Butz, Jr., from *Aviation Week*, 2 Mar 59; "General Electric Official (John W. Darley, Jr.) Details Nuclear Plane Need" from *Aviation Week*, 16 Mar 59; Editorial, " Spotlight on Nuclear Plane Program", by Robert Hotz from *Aviation Week*, 3 Aug, 59; Publications of General Electric Aircraft Nuclear Propulsion Department (Circa 1957 to 1959); " Disputes Cloud Nuclear Plane Effort in Critical Period" from *Aviation Week*, 19 Dec 59; "Direct/Indirect Nuclear Engine Awaits Test Data" from *Aviation Week*, 26 Dec 60; "Aeronautical Engineering, Gains Promise Supersonic Nuclear Flight", from *Aviation Week*, 2 Jan 61; “Management, Reorientations Hamper ANP Program" by Katherine Johnsen from *Aviation Week and Space Technology*, 1 Apr 63; and Handwritten Notes on History of NEPA and ANP (Airborne Nuclear Program) Programs (Presumably by Gen. Demler), 17 Apr 81.

Dicker, G. K., R. L. Shipp and C. L. Oakes, Jr. "Standard Instrumentation Techniques for Nuclear Environmental Testing". WADC-TN-56-190. Wright Air Development Center, Wright-Patterson AFB, Ohio (1956) 12 p.

Techniques for measurement of parameters in radiation environments of nu-clear-propelled aircraft are outlined. These proposed standard methods are the simplest, least expensive, most adaptable ones presently available.

Douglas, James H., Office of the Secretary of the Air Force. Letter to Cong. Melvin Price, Chairman, R&D Subcommittee, JCAE. June 28, 1957. JCAE #5261. JCAE #5402. RG128, Box 46, Folder Vol. III. - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Douglas reports on a realignment of the AF-ANP organization. On mar. 29, 1957 a new office in the Air Staff was formed. This office was the Assistant Deputy Chief of Staff, Development for Nuclear Systems which encompasses their ANP Program (along with the nuclear rocket programs, Pluto, Rover and Pied Piper). The Chief of this office is also Chief of the Aircraft Reactors Branch, AEC, Donald Keirn. The new organization was effective on June 4, 1957. Douglas also discussed AEC/AF funding levels. He reiterates Deputy Secretary Quarles Apr. 4, 1957 letter which provided a statement of ANP objective of "...the achievement of an initial, operational capability with nuclear-powered strategic bombers during the period 1966-69." No specific performance requirements could be specified, however early flight testing was an important part of the program. The direct cycle showed the greatest promise in the near term, but liquid metal cycles had greater growth potential. Therefore both cycles should be pursued.

Dowben, R.M., D.B. Williams, E.M. Miller, J.E. Pickering. "Aircraft Nuclear Propulsion Biomedical Research Program. Report No. 4. Radiobiologic Problems of ANP". NP-6763. School of Aviation Medicine, Randolph AFB, TX. Oct. 1955. 11p.

The biological effects of exposure to low radiation dose rates over a long period of time are discussed. Problems in the quantitative determination of the differences in biological response to physically equivalent doses of various radiations are reviewed. Factors to be considered in establishing permissible radiation levels for the crews of nuclear aircraft are discussed.

Estoque, Mariano A. "Venting of Hot Gases Through Temperature Inversions". AFCRC-TN-58-623. Air Force Cambridge Research Center. Geophysics Research Directorate, MA. Dec. 1958. 17p.

The penetration of temperature inversions in the lower atmosphere by plumes of hot air is

investigated part of a safety analysis in the nuclear aircraft program is studied with the aid of existing theoretical as well as experimental work. A nomogram showing the relationship between the maximum height attained by a hot plume of a given heat source intensity and the temperature gradient of the environment is presented. The limitations of existing knowledge on the problem are pointed out and some recommendations for future research are made.

Gantz, Kenneth, ed. Nuclear Flight. The United States Air Force Programs for Atomic Jets, Missiles, and Rockets. Duell, Sloan and Pearce, New York: 1960.

A description is given of the developments in the nuclear propulsion of aircraft, missiles and space rockets. These developments are a basic step toward future aerospace forces capable of extreme duration of flight, large payload, and flexible maneuver. Power reactors, reactor materials, heat transfer and coolant systems, and power production from nuclear energy are discussed. The development of direct-cycle and indirect-cycle propulsion, ramjet reactors, radioisotope power sources, and radiation effects is considered. (Same as Air University Quarterly Review, Vol. II., Nos. 3-4. 1959).

Gasser, Clyde D., "Brief History of the Air Force Aircraft Nuclear Propulsion Program and its Future Implications". September, 1962.

Iris Number 00126294
Call Number 168.7017-68
Reel 3323 Beg Frame 4 End Frame 28 Old Reel Number A1867

Narrative describes history of Air Force Aircraft Nuclear Propulsion Program and Nuclear Energy Propulsion for Aircraft programs as undertaken by several contractors and Air Force. Narrative concludes with arguments and suggestions for future application of aircraft nuclear propulsion technologies.

Gilpatric, Roswell L., Deputy Secretary of Defense. Two Letters to Glennn T. Seaborg, Chairman, AEC. Feb. 28, 1961. JCAE #6613. RG128, Box 46, Folder Vol. III. - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Two letters were sent this date from Gilpatric to Seaborg. In the longer of the two, he amplified DOD objectives that had been outlined to the AEC General Manager by Dr. Herbert York in a Feb.27, 1960 letter. Gilpatric emphasized that nuclear power plants possess growth potential beyond the minimum objectives established as initial goals. DOD believes early flight is important to explore problems associated with nuclear flight, but does not consider early flight an important end itself. Gilpatric gives short and long term requirements, as follows. Short term: Mach 0.8, 35,000 ft., 100 hours of reactor life. Long term: all short term requirements, at least 1000 hours of reactor life, reliability

essentially the same as current high performance chemical power plants, low enough fission product release to permit take-off and landing from regular military airfields without producing a public hazard, unitary (not divided) shielding. Regarding the split shield, Gilpatric stated that having only restricted areas of low radiation was unacceptable for a militarily useful aircraft. A capability for supersonic flight is desired, but not required. Although the decision should be made by the AEC, Gilpatric believed that the indirect cycle was the most promising approach.
The second letter Gilpatric proposes that the AEC assume full responsibility for the complete power plant development and selecting the cycle to meet the Air Force requirements. The Air Force would reduce its ANP role to only development of the airframe and providing flight test facilities. Air Force funding would decrease from $35M to $10M in FY62, with an appropriate increase in AEC funding.

Gilpatric, R.L., Acting Secretary of the Air Force. Letter to Gordon Dean, Chairman, AEC. Apr. 8, 1952. JCAE #2094. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

The Air Force submitted a proposed plan for initiation of the joint AEC/Air Force ANP Program This plan was derived from the JCS determination on March 12, 1951 that a military requirement existed for a nuclear-powered aircraft. Prior to that the RDB recommended in Dec. 1950 that the first ANP objective be development of a nuclear propulsion system for installation in a subsonic aircraft by 1956-7. The planned R&D program is in accordance with the above, plus it is consistent with work of the NEPA Project, AEC laboratories, AEC's TAB and industrial contractors. A primary objective was, by 1956-7 , flight test a nuclear propulsion system in a flying test bed. GE was to be supported by both AEC and AF to develop an nuclear power plant with a target date of 1956 for flight qualification tests. Consolidated Vultee will continue under AF support to provide the X-6 aircraft for flight testing the GE power plant. AEC will continue support of the alternative reactor concepts. This letter provides enclosures which detail the proposed joint project.

Gilpatric, Rosewell, Deputy Secretary of Defense. Letter to Cong. Melvin Price, JCAE Chairman, R&D Subcommittee. Mar. 29, 1961. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Gilpatric comments that the suggestions in Price's March 18, 1961 letter to him should now be addressed to the AEC, "...to the extent that they are still relevant", considering the President's March 28 decision on ANP. The previous day Kennedy had stated in a special message on the Defense budget that the entire ANP Program would be transferred to the AEC, and that both approaches to the nuclear power plant be terminated.

Gorn, Michael H. "Harnessing the Genie: Science and Technology Forecasting for the Air

Force, 1944-86". Office of Air Force History, Washington, D.C. 1988. PP. 30, 54.

In his report summarizing the existing state of aeronautical knowledge in 1945, "Where We Stand", Theodore von Karman included recommendations for aircraft propulsion by nuclear power. Gorn references von Karman's great faith in atomic power for aircraft propulsion and his recommendation that the AF bring to bear its best engineering minds on the problems of nuclear flight. Von Karman notes that should atomic propulsion become feasible, the AF would command the air with no range limitations whatever.

Gorn, Michael H., Editor. "Prophecy Fulfilled: 'Toward New Horizons' and Its Legacy." Air Force History and Museums Program, Washington, D.C. 1994. PP. 3, 59-61, 188.

Limited reference is made to nuclear powered flight in Theodore von Karman's seminal study for the post-World War II. Air Force,"Where We Stand". Von Karman completed his report on August 22, 1945 and included a short chapter on the potential benefits of nuclear power for aircraft. He stated that "...no hope for spectacular improvements in range and speed performance of aircraft can be derived from conventional fuels. Use of atomic energy as fuel, however, will radically change this situation". He states further: "It seems to me that there are possibilities in the development of nuclear energy for jet propulsion which deserve immediate attention of the Air Forces. ... It is my feeling that the Air Force should, as soon as possible, take the lead in investigating the possibilities of using nuclear energy for jet propulsion". One of the supplements to the report is entitled "Aircraft Fuels and Propellants" includes in Part V.a section entitled "Possibility of Atomic Fuels for Aircraft Propulsion of Power Plants" by H.S. Tsien.

"History of Air Force Plant Representative Office, General Dynamics, Central Contract Management Region". Air Research and Development Command, Air Force Periodical 80-1: Research and Development Quarterly Review, (7/1-9/30/58).

Iris Number 00486409
Call Number K243.0709-1
Reel 15528 Beg Frame 2096 End Frame 2288 Old Reel Number K2976

Discusses portion of nuclear contract covering design and development of an aircraft suitable for nuclear propulsion terminated.

Howard, F. E. Jr., Staff Engineer, Technical Planning Group, Eglin AFB, FL, "Task 3-7, Weapons and Target Systems Space Simulation Requirement", Air Proving Ground Center, (10/26/59).

Iris Number 01048453
Call Number K242.056. Micfilm 36493
Reel 0000036493 Beg Frame 000302 End Frame 000000 Old Reel Number NA

Contains data on: Nuclear Propulsion or Power Development.

Jackson, Howard W. D. “Aerothermodynamic Test of 2000°F Thermal Insulation”. TN-60-175. Wright Air Development Div., Propulsion Lab., Wright-Patterson AFB, OH. June 6, 1960. 20p.

Thermal insulation for the ANP Engine Development Program was tested to determine its structural reliability thermal effectiveness in a gas stream of 2000°F. and mach 0.6. Of 98 fasteners in the test sample, 24 failed during the 104.25 hours of testing. The insulation system remained intact throughout the test. A temperature drop of 1100°F and 718°F measured across the 0.60 inch-wall with and without cooling respectively.

Keirn, Donald. “Biography”. Department of the Air Force. Feb. 24, 1905- July 4, 1957.

Iris Number 893657
Call Number Microfilm 23237
Reel 23237 Beg Frame 1004 End Frame (N.A.) Old Reel Number (N.A.)

Biography of D. J. Keirn, Director of the joint AEC and USAF ANP Program, who retired in October 1959, approximately one and a half years prior to cancellation of the project.

“Keirn Details Nuclear Aircraft Plans". *Aviation Week.* February 2, 1959.

Maj.Gen. Donald J. Keirn is reported to state that the first nuclear powered aircraft will have engines with the thrust comparable to current B-52 and B-58's. ANP plans are for a high subsonic speed prototype capable of serving both as an engine test-bed and a vehicle for studying operational and tactical doctrines. Although Keirn had previously stated that the ANP Program had been delayed by limited funding (*Aviation Week*, Nov. 24, 1958, P.27), he did not believe the program was "dangerously slow". He did state that he thought the Russians would be flying a nuclear aircraft soon. Keirn spoke at a luncheon during the Institute of Aeronautical Sciences 27th. Meeting in New York City, saying that the recent progress in integrated shielding design will allow extended periods of flight with each crew flying for 1000 hours annually, with missions well over 100 hours each. He also noted that extensive studies of the hazards of nuclear flight have been conducted.

Keirn, Donald John. “Biography, July 25 1925-Sept. 1951.” Department of Defense.

Iris Number 481910
Call Number K239.293 (Keirn)
Reel 15259 Beg Frame 141 End Frame 142 Old Reel Number K2702

Part of the biographical collection including personnel transferred from the Air University or retired from active military service. Information compiled by the Air University, Office of Information.

Kelly, Joe W., Brig. Gen., USAF, Director Legislative Liaison. Letter to Cong. Dewey Short, Chairman, Committee on the Armed Services. June 22, 1954. JCAE #4100. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Provided a description of the Pratt & Whitney facilities at the Hartford Research Laboratory used for ANP R&D.

LeBaron, Robert, Chairman MLC. Letter to Cong. Carl Durham. June 30, 1952. JCAE #DCXXXVIII. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Responding to a June 11 request from Cong. Durham, LeBaron provided a synopsis of the reviews of the ANP Program conducted by DOD and AEC. DOD had recently completed a complete re-evaluation under the direction of Under Secretary of the Air Force, R.L. Gilpatric. LeBaron expressed concern about current budget cuts causing major delays in the program. Attached to this letter are: a resume of the ANP Program status; the April 8, 1952 letter from Acting Secretary of the AF, R.L. Gilpatric (JCAE #2094); the June 19, 1952 letter from AEC Chairman Gordon Dean.

LeMay, Gen. Curtis E., USAF, Vice Chief of Staff. Letter to Dr. George B. Kistiakowsky, Special Assistant to the President for Science and Technology. July 29,1960. Enclosing a copy of the SAB ANP Ad Hoc Committee Report, July 1960. RG359, Box 4, Executive Office of the President, OSTP Folder-ANP 1960: National Archives II, Washington, D.C.

Provides a copy of the SAB ANP Ad Hoc Committee Report, July 1960, indicating that it is preliminary and does not necessarily represent the views of the Air Force. As background to the report, LeMay offers a presentation on the ANP Program by Brig. Gen. Irvin L. Branch, Assistant Deputy Chief for Nuclear Systems (Donald Keirn's successor). The SAB Ad Hoc Committee was chaired by Dr. Ernst H. Pleaset and their report considers three possible courses of action, viz. Earliest nuclear flight possibly with chemical assist; development of a sustained high subsonic flight on nuclear alone, meeting DOD requirements; and development of a more advanced nuclear plane technology with a significant improvement over the DOD requirements, with deferred flight. They recommended the GE direct cycle to meet the first alternative, with the Pratt & Whitney indirect cycle best able to meet the other two alternatives.

LaPierre, C.W. General Electric Co. Letter to Roswell L. Gilpatric, Deputy Secretary of Defense. Feb. 16, 1961. Available in NASA, Hq. Office of History.

GE executive providing a letter to DOD Deputy Secretary Roswell Gilpatric (addressing him as “Dear Ros”), which encloses a letter to Secretary of Defense Robert S. McNamara. Letter to McNamara states that originally in 1951 GE minimum estimate to develop a aircraft nuclear power plant was five years, but frequent re-directions of the program has resulted in no flight objective remaining in place long enough to be attained. LaPierre states that now a flight powered with the direct cycle ANP could be achieved within three years. In his opinion the basic cause of program re-directions has been a disagreement over the choice of direct (GE) vs. indirect (Pratt and Whitney) reactor concepts.

LeMay, Gen. Curtis E., USAF, Vice Chief of Staff. “SAB ANP Ad Hoc Committee Report, July 1960". Aug. 23, 1960. RG359, Box 4, Executive Office of the President, OSTP Folder-ANP 1960: National Archives II, Washington, D.C.

Gen LeMay provides comments on the SAB report and discusses three alternatives defined by the committee. LeMay dismisses two alternatives and comments only the plane based on current guidance (given by Dr. York, Director of Defense, Research and Engineering in his letter of Feb. 27, 1960) should be pursued. LeMay also feels that the committee’s report on the GE work is too pessimistic and on the Pratt & Whitney work is too optimistic. He states that it is believed that both cycles can meet the performance requirements specified by Dr. York. LeMay agrees that the committee’s recommendation that modification of an existing plane might be a costly dead end.

Loper, Gen. H.B. “Outline for ANP Program Presentation to Dr. J.R. Killian”. May 15, 1959. RG359, Box 22, Executive Office of the President, OSTP Folder-ANP 1959: National Archives II, Washington, D.C.

Presentation reviews current ANP objectives and discusses new objectives, including plan to flight test commencing in early 1964. Provides a review of the bases for the proposed expansion of the program.

Loper, Herbert B., Assistant to the Secretary of Defense (Atomic Energy). Letter to Carl Durham, Chairman JCAE. Feb. 1, 1957. JCAE #5079. JCAE #5085. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Advised that reorientation of the WS-125A had reduced the FY57 & 58 budget required. He indicated that the requirement for a long subsonic cruise and supersonic dash for 600-1000 miles would have required a very expensive development and procurement program to meet a 1964 operational date. The reoriented program will emphasize the GE concept, with Pratt & Whitney a delayed, second generation approach.

Loper, Herbert. Letter to Sen. Clinton Anderson, Chairman JCAE. July 19, 1955. JCAE #4627. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject

File:National Archives, Washington, D.C.

Loper provided an outline of work that will be done at the proposed Pratt & Whitney facility near East Hartford, CT.

Loper, Herbert. Letter to Sen. Clinton Anderson, Chairman JCAE. August 2, 1955. JCAE #4651. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Loper forwarded description of the Pratt & Whitney CANEL facility, along with information on the Pratt & Whitney ANP Program.

Muscrave, Maj. Gen. Thomas C., Jr., USAF, Director of Legislative Services. Letter to Cong. Chet Hollifield, JCAE Chairman. Mar. 30, 1961. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Musgrave notified the JCAE that in accordance with President Kennedy's decision to terminate ANP, the Air Force was taking immediate actions to cancel contracts with GE, Pratt & Whitney, Convair and Lockheed. The President's March 28 message estimated a savings of $35M in the FY62 Defense budget below the figure previously reduced in January. At least $1B will be avoided in future expenditure for achieving the fist experimental flight of a nuclear-powered aircraft. A total of 2715 contractor employees were currently working on the ANP Program. He provides a breakdown of this total by contractor. He closes by saying a release of this information will be made shortly after delivery of this letter to Holifield.

Neufeld, Jacob. "Ballistic Missiles in the United States Air Force: 1945-1960". Office of Air Force History, Washington, D.C. 1990. P. 144.

Reference is made to the "Killian Report", which includes a brief recommendation on nuclear powered aircraft. The report of the Killian Committee, in February 1955, provided recommendations for development of missiles to counter the threat from the USSR. However, the report also recommended that high priority be placed on the development of nuclear power for aircraft propulsion. (See also James R. Killian, "Report to the National Security Council").

"Nuclear Propulsion, Aviation Report Supplement Number 13". Aviation Studies International, Limited, (November 1956)
Iris Number 43000020
Call Number K148.163-3
Reel (N.A.) Beg Frame (N.A.) End Frame (N.A.) Old Reel Number (N.A.)

Contains information on nuclear powered aircraft. Includes Atomic Energy Commission testimony which plots the transition from theory to hardware engineering.

"Nuclear Tactics". *Aviation Week*. April, 20, 1959.

In a letter to the editor, an unidentified Air Force officer comments on an editorial in the March 2, 1959 issue of *Aviation Week* that discussed nuclear propelled aircraft. He expands on the editorial by claiming that a few nuclear-powered aircraft would create havoc within the air defense system of the Soviets, soon exhausting the their defense fighter force.

Price, Cong. Melvin. Letter to Donald Quarles, Deputy Secretary of Defense. Feb. 27, 1957. JCAE #5098. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Air Force comments were requested on ANP, including establishment of definitive objectives, and administrative improvements to expedite the program. Price requested effective action for early achievement of a ground test prototype reactor and flying prototype.

"Report of the Air Force Space Study Committee". Air Research and Development Command. March 21,1961.
Iris Number 01028467
Call Number Ts-Hoa-78-179
Reel 0000033526 Beg Frame 001155 End Frame (N.A.) Old Reel Number (N.A.)

Reviews current Air Research and Development Command Space Development objectives and resources and recommended a program which would enable AF to effectively meet its development responsibilities in space during 1960 to 1970. Includes discussion of ANP.

(Document in Hard Copy Only).

"Safety Study Nuclear Propulsion (12/16/71-6/12/75)". Special Weapons Center.

Iris Number 01052124
Call Number Micfilm 37121
Reel 0000037121 Beg Frame 000883 End Frame Old Reel Number
Call No.K242.85-128.

Nuclear safety impact tests are discussed.

(Available on Microfilm Only).

Smart, Maj. Gen. Jacob E. , Assistant Vice Chief of Staff, USAF. "Nuclear Powered Aircraft Policy". Memorandum for Air Force Deputy Chiefs of Staff. Feb. 6, 1957. JCAE #5206. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

A statement of Air Force policy on ANP was announced to insure that strategic capability does not suffer through wasteful competitive ANP development practices nor through improper allocation of ANP for various service missions. Development will continue with the AEC as directed by the JCS on March 12, 1951. This will include both high and low altitude applications over a broad spectrum of speeds. The Air Force will retain responsibility for the program funded by DOD. Cooperation will continue with the Navy, but first priority must be accorded to the strategic air capability.

Smith, Willard W., Brig. Gen., USAF, Deputy Director of Operational Requirements. "Cancellation Notice for Specific Operational Requirement". S.O.R. No. 81. Nov. 10, 1960.

This is the official notice of cancellation for the Piloted Nuclear Powered Intercontinental Strategic Bombardment Weapon System. The original requirement was issued Mar.22, 1955 and amended Sept. 16, 1955.

Smith, Willard W., Brig. Gen., USAF, Deputy Director of Operational Requirements. "Cancellation Notice for Specific Operational Requirement". S.O.R. No. 172. Nov. 10, 1960.

This is the official notice of cancellation for the CAMAL (Continuously Airborne Missile-Launcher and Low Level Weapon System) ANP Project. The original requirement was issued on Oct. 28, 1958.

Space Miscellaneous Correspondence. 11/22/57-10/31/58. Department of the Air Force

Iris Number 01029962
Call Number K168.8636-25
Reel 33714 Beg Frame 788 End Frame (N.A.) Old Reel Number (N.A.)

Miscellaneous correspondence concerning space technology. Includes brief outline of the organizational history of the Aircraft Nuclear Propulsion Program from Fall, 1944 to March 18, 1957.

United States Air Force Aerospace Medical Center, Brooks Air Force Base Texas, (10/159-6/30/60)

Iris Number 00478976
Call Number K237.01
Reel 15040 Beg Frame 813 End Frame 915 Old Reel Number K2489

Includes brief overview history of attempts to establish aeromedical center in USAF beginning in 1946. Includes discussion of primary research mission within USAF for medical aspects of aircraft nuclear propulsion and defense against atomic warfare.

Williams, Clanton W,. Col., "A History of the Air Force Atomic Energy Program", Study Seven, Vol. V., (1943-55).

Iris Number 00470345
Call Number K V. 5, Pt. 3
Reel 11840 Beg Frame 120 End Frame 416 Old Reel Number K1141

Documents bound in this volume were originally prepared to support history of ANP Program through 1958 published separately by Wright Air Development Center as the "Development of Nuclear Propulsion for USAF, 1945 through 1945". Includes documents designated 1 through 71a.

Wilson, Charles W., Secretary of Defense. Letter to Cong. W. Sterling Cole, JCAE Chairman. July 23, 1954. JCAE #4132. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

DOD responded to a JCAE Subcommittee Report and also advised on ANP Program development efforts.

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c. NACA/NASA

[Note: All Documents referenced in this section are available in the NASA, Hq. - Office of History, Washington, D.C.]

"Atomic Power for Planes." *New York Times*. Sept. 25, 1955.

Reports that NACA has selected a site for a laboratory at Sandusky, Ohio to study nuclear powered aircraft. The article states that this commitment of $4.5M for the NACA Laboratory was an indication of the government's confidence in the nuclear powered aircraft concept. [Researcher's Note: This became the site for the Plum Brook nuclear reactor.]

Belcher, F.H. Acting Chief, Clinton Laboratories Division, AEC. "Materials Procurement for NACA." Letter to Dr. Harold E. Etherington, Monsanto Chemical Co., Clinton Laboratories, Oak Ridge, TN. Jan. 22, 1948.

Belcher refers to a Dec. 30, 1947 request from NACA-Cleveland for beryllium oxide material for research work. In this letter he establishes administrative procedures for transfer of materials from the Clinton Laboratories to NACA-Cleveland.

Bogart, Donald D., and Michael F. Valerino. "The Sodium Hydroxide Reactor: Effect of

Reactor Variables on Criticality and Fuel-Element Temperature Requirements for Subsonic and Supersonic Aircraft Nuclear Propulsion". NASA-RM-E52I19. NASA, Lewis Flight Propulsion Laboratory, Cleveland, Ohio. February 1953. 86p.

Collins, John H. , Chief, Engine Performance and Materials Division, NACA-Cleveland. Memorandum for Chief of Research, NACA-Cleveland. January 3, 1947.

Research program in progress in the High Temperature Materials Section on nuclear energy problems is described. Work includes nuclear radiation effects on material properties and investigation of ultra-high temperature materials, some of this work is sub-contracted to the NBS(ceramics) and the University of Notre Dame (metal alloys).

Condon, E.G., Director, NBS. Letter to Dr. Jerome Hunsaker, Chairman, NACA. April 16, 1947.

Dr. Condon responds to a request made by NACA that he consider the suggestion made by Adm. Stevens on Jan. 10, 1947, that NACA establish a committee on the application of nuclear power to aircraft. Dr. Condon provides a summary of the current situation on the subject of nuclear aircraft propulsion, as follows: AEC is facing uncertainties and has not planned any work in this area; preliminary studies have been made by Dr. Harvey Hall, technical aid to Adm. Stevens(Navy Bureau of Aeronautics), and by Dr. Arthur Ruark (Johns Hopkins Applied Physics Lab); NACA Cleveland has started general thermodynamic and heat transfer studies; the AAF has established the NEPA Project (with input from NACA Cleveland). Condon quotes from the March 4, 1947 letter from Maj. Gen LeMay and makes the suggestion that NACA set up a broader based committee, under NACA chairmanship with War Dept., Navy, AEC and academic representatives. Condon lists names of potential members.

Dawson, Virginia. "Interview with Ben Pinkel". NASA Oral History Program. Interview conducted August 4, 1985. pp. 5-11.

Pinkel, an early developer of jet engines, discusses the origins of the NEPA effort and the contribution of the NACA. He states that Dr. Hugh Dryden was on a committee that followed the aircraft nuclear propulsion work for NACA and that Pinkel was on an ad hoc committee that reported to the Dryden Committee. Pinkel states that he advocated a research effort be supported to provide the necessary technology, while the Air Force was more eager to acquire a nuclear powered aircraft as soon as possible. Pinkel makes reference to Frank Rom (see references) who was in charge of the NASA work when the Air Force tried to revive the ANP Project in the mid-1960's.

Dietrich, J.R., "Atomic-power Aircraft Engines." August 7, 1945.

Upon announcement by President Truman on the previous day that atomic power has been harnessed with the dropping of the first bomb on Hiroshima, Dietrich proposes immediate development of this energy source for aircraft propulsion. He provides a review of the physics and nuclear reactions for a self-sustaining atomic reaction, based only on information available before the war. He correctly identifies U^{235} as the fuel, the need for an adequate amount (i.e. a critical mass), and the need to thermalize neutrons in a hydrogen based compound. He also discusses the amount of energy released per fission. He then surmises that the released nuclear energy can be converted to thermal energy and supplied to an aircraft engine of a conventional form. He concludes that, "thorough analysis is needed of the many possibilities for aircraft propulsion afforded by atomic fuels...to use them to their full advantage." [Researcher Note: This one of four memoranda forwarded both Rothrock's August 10?, 1945 memorandum to NACA-Hq.]

Dietrich, J.R., Head Ignition Research Section, NACA-Cleveland. Memorandum for Executive Engineer, NACA-Cleveland. "Conference at AERL on August 7, 1945 to Discuss Nuclear Power for Aircraft Propulsion." August 8, 1945.

The conference among NACA-Cleveland staff, the day after the first atomic bomb was dropped, was called to discuss the role of AERL in developing the means to utilize nuclear energy for aircraft propulsion. It was acknowledged that only very limited information was available, but that nuclear power applications to aircraft were within the scope of AERL research. Rapid development was considered necessary to maintain the current U.S. lead in nuclear technology. Recommendations were made that NACA send representatives to the New Mexico nuclear energy laboratory to get information as the starting point for AERL research. The conclusion of the meeting was that the matter should be taken up with Dr. Vannevar Bush who would know best where NACA fits into the picture.
[Researcher Note: This is one of the four memoranda forwarded by Rothrock's August 10?, 1945 memorandum to NACA-Hq.]

Doyle, R.B. "Calculated Condenser Performance for a Mercury-Turbine Power Plant for Aircraft". RM E8C23. NACA Flight Propulsion Research Laboratory, Cleveland, Mar. 1948. 22 p.
An analysis was made to determine the effect of several operating conditions on the performance of condensers for a nuclear energy mercury-turbine power plant. The analysis covered a range of turbine inlet and outlet pressures, condenser cooling-air pressure drops, flight and altitudes. At turbine inlet and outlet pressures of 500 and 10 lb/sq. in. abs., respectively, the minimum specific condenser weight was 0.225 lb/net thrust hp, and the minimum specific condenser frontal area was 0.005 sq ft/net thrust hp. These values occurred at a flight speed of 300 Mph and an altitude of 30,000 ft.

Evvard, John C., Head, Small-Scale Engine Section, NACA-Cleveland. Memorandum for Acting Executive Engineer, NACA-Cleveland. "Points Which Might be of Interest to You for your Washington Discussions." August 9, 1945.

Evvard reviews some basic knowledge about nuclear fission and states, that without considering the economics of the situation, the use of atomic energy appears feasible for power plants. First application would for stationary use ("due to the dangers of gamma radiation"), but eventually for rockets and turbo jet engines. He suggests that Dr. Lewis contact Dr. Vannevar Bush to see if some NACA scientists can join the New Mexico Laboratory of the Manhattan Project to deuterium how the AERL can apply nuclear energy to aircraft propulsion.
[Researcher Note: This is one of the four memoranda forwarded by Rothrock's August 10?, 1945 memorandum to NACA-Hq.]

Evvard, John, NACA-Cleveland. Memorandum to NACA Chief of Research. "Possible Utilization of Nuclear Energy in Aircraft." March 15, 1946.

Committee work at NACA-Cleveland, headed by John Evvard, concluded that further consideration should be given to applications of nuclear energy to the propulsion of aircraft.

Finger, Harold E. "Proposed Nuclear Powered Aircraft Study." Memorandum for the NASA Associate Administrator for Advanced Research and Technology. June 28, 1965.

The Director, Nuclear Systems and Space Power, H. Finger, raises the issue that NASA Lewis Research Center has started to re-examine the ANP concept without any Hq. approval and he recommends this decision be reviewed by NASA top management, including the addressee, Dr. Seamans and possibly Dr. Dryden. He is unsure if this NASA and AF initiative has support of the DOD and is concerned that the aftermath of the 1961 ANP Project cancellation has allowed enough time for the "...many old wounds (which) remain in Congress, the various Government agencies involved and in industry have not yet healed sufficiently well to permit ... a resurrection of the ANP program with anything less than a violent frothing at the mouth."

Hicks, Bruce L. and Sidney L. Simon, NACA-Cleveland staff physicist and chemist, respectively. Memorandum for Acting Executive Director, NACA-Cleveland. "Nature of AERL Research on Nuclear Energy Fuels." June 11, 1945.

Hicks and Simon, apparently writing without the benefit of any information from the Manhattan Project, discuss the pre-war knowledge about nuclear energy. They discuss the enormous potential energy release in the fission process, the possibility of a continuous chain reaction, the need for control of the energy release and the possibility that this energy could be used for aircraft propulsion. They correctly identify the need to concentrate some of the uranium isotopes that are fissionable and state that, "At the beginning of the present world war, a considerable amount of work had been done of the problem of making the reaction self-sustaining, but with the war publications ceased to appear. It is a matter of common belief among physicists that every major power in the world has been devoting a tremendous amount of effort to the solution of this and similar problems." The authors advocate that NACA get involved in the nuclear physics research they assume is underway so that applications for aircraft propulsion can be explored.

Hilberry, Norman. Associate Director, Argonne National Laboratory, Chicago. Letter to Dr. J.W. Crowley, Acting Director of Aeronautical Research, NACA, Washington. January 27, 1947. Available in the NASA, Hq. Office of History.

Discusses the one year assignment of a metallurgist (Howard Kittel) from the NACA-Cleveland Laboratory to the Argonne Laboratory operated for the AEC. Question is raised about the high temperature work of interest to NACA. Hilberry states that the Argonne work is directed at lower operating temperatures, whereas the Clinton Lab Daniels Pile (reactor) is directed at much higher temperature work with ceramics. Hilberry also raises the issue of the need for NACA to reach an agreement with the AEC regarding a general policy of cooperation between the two organizations.

Humble, L.V., W.W. Wachtl, and R.B. Doyle. "Preliminary Analysis of Three Cycles for Nuclear Propulsion of Aircraft". NASA-RM-E50H24. NASA, Lewis Flight Propulsion Laboratory, Cleveland, Ohio. October 1950. 26p.

A preliminary study was made of the feasibility of three cycles for nuclear propulsion of aircraft: a direct-air-turbojet, a binary liquid-metal turbojet, and a helium compressor jet. All three cycles appeared feasible for flight at a Mach number of 0.9 and altitudes up to 50,000 feet; the liquid-metal cycle appeared feasible for flight at a Mach number of 1.5. The air and helium cycles resulted in heavier aircraft than did the liquid-metal cycle, particularly at a Mach number of 1.5. The relative advantage of the liquid-metal cycle became greater as the flight speed and altitude increased, and as the reactor wall temperature decreased.

Johnson, Paul G., James W. Miser, and Roger L. Smith. "Nuclear Logistic Carrier". NASA, Lewis Flight Propulsion Laboratory, Cleveland, OH. November 1957. 12p.

This discussion of air-breathing nuclear propulsion systems is limited to their use in large, medium-altitude aircraft. Specifically, the study involves turbojet aircraft of 500,000-pound gross weight designed for flight at 35,000-feet altitude in the Mach number range from 0.9 to 2.5. Three types of nuclear-propulsion systems are presented for comparison: (1) a direct air system, (2) a liquid-metal system using lithium 7 as the reactor coolant, and a helium system. All shields are "unit shields." schematic diagrams of the three propulsion systems and some of their advantages and disadvantages are given.

Karp, Irving M. "An Analysis of a Nuclear Powered Supercritical Water Cycle for Aircraft

Propulsion". NACA-TM-X-61622. Volume 2. Flight Propulsion Conference (1957). Held at NASA, Lewis Flight Propulsion Laboratory, Cleveland, Ohio. 1953. 77p.

Reviewed studies of this unique concept, the supercritical water nuclear reactor, for application to the propulsion of aircraft.

Kemper, Carlton, Executive Engineer, (signed by Addison M. Rothrock) NACA-Cleveland. Memorandum for NACA-Hq. "Applications Concerning the Application of Nuclear Energy to Aircraft Power Plants." May 24, 1946.

Reference is made to a March 15, 1946 recommendation that NACA-Cleveland staff be cleared with the Manhattan Project to have access to information that can be used to evaluate the application of nuclear energy to aircraft propulsion. Kemper again asks that this be done so that NACA is not left behind in this field. He now recommends that instead of a committee being formed on the applications of nuclear energy, a panel be formed for preliminary discussions. Members suggested include Dr. Farrington Daniels, Head of the Metallurgical Lab at Chicago Univ., Dr. J. Robert Oppenheimer, Dr. H.D. Smyth, et. al.

Klein, Milton, Mgr. Space Nuclear Systems Office, (SNSO) NASA. "Briefing Paper on Aircraft Nuclear Propulsion." Feb. 18, 1971.

Paper submitted at the request of George M. Low, Acing Administrator, NASA was based on the recollection and archives of several SNSO staff formally associated with the ANP Program. He emphasizes that SNSO had no responsibility for the ANP Program. Klein states further that the nuclear rocket program under his direction has demonstrated a sound technological basis for development of a useful space propulsion system, whereas ANP Program "never did develop a reactor that would meet the requirements of a useful nuclear airplane as defined by the DoD prior to the cancellation of the project. This is not to say that a nuclear airplane could not have been built and flown at subsonic speeds." He also points out that the issue of requirements vs. technology will be controversial with those who supported ANP around the time of its cancellation. NASA Lewis initiated new nuclear airplane studies in 1965, under Dr. Silverstein. These were: applications, reactor design analyses, fuels and safety studies.

Kotanchik, J. N."Experimental Research on Aircraft Structures at Elevated Temperatures". NP-6065. Langley Aeronautical Lab., Langley Field, Va. 1956) 36p.

The equipment and methods used at the Langley Laboratory of the NACA in experimental research on aircraft structures at elevated temperatures are reviewed. The equipment ranges from conventional steady-state furnaces for stress-strain tests to transient radiant-heating apparatus and aerodynamic heating and loading in a supersonic air jet.

LeMay, Curtiss, Maj. Gen. U.S. Army, Deputy Chief of Air Staff for R&D. Letter to Dr. Edward U. Condon, Director, National Bureau of Standards. March 4, 1947.

Maj. Gen. LeMay responds to Dr. Condon's recent discussions with Dr. R.P. Johnson of LeMay's Office regarding NACA's participation in the nuclear aircraft project. LeMay states that the NEPA Project is AAF sponsored along with the (Naval?) Bureau of Aeronautics. He states further that the NEPA Project was undertaken by the AAF with the approval of the Manhattan Engineer District (now the AEC) and thus the AAF has the sole authority to pursue R&D where classified information and/or facilities of the AEC are utilized. LeMay goes on to explain the NEPA organization and lists the NACA participants, and states that any NACA committee on nuclear energy is unnecessary because of this involvement.

Lewis, G. W. Director of Aeronautical Research, NACA. Letter to Dr. C. Rogers McCullogh, Director Power Pile Division, Monsanto Chemical Co., Clinton Laboratories. July 26, 1946.

Discusses assignment of Dr. Sidney L. Simon from NACA-Cleveland to the Monsanto Co. for training. Also discusses assistance from NACA to the high temperature pile (reactor) work for aircraft propulsion. List of assistance areas includes lubrication, materials, airflow, heat exchangers, compressors, turbines and thermodynamics.

Lewis, G.W., Director of Aeronautical Research, NACA-Hq. Memorandum for NACA-Cleveland. "Nuclear Fuels and their Utilization." August 1, 1945.

Responds to Addison Rothrock's June 22, 1945 memorandum submitting a memorandum of Messrs. Hicks and Simon on the nature of the research which NACA-Cleveland should undertake to investigate use of nuclear power for aircraft. Lewis stated that NACA should not engage in any research in this field because "a great deal of effort was now being expended on this subject, which is considered a secret project."

"Lewis Flight Propulsion Conference (1957). Volume 2". Held at Lewis Flight Propulsion Lab., Cleveland, OH on 21-22 November 1957. 79p.

Papers included present information on nuclear, satellite and space propulsion systems.

Maxwell, W.A.. "Preliminary Investigation of Plate-Type Molybdenum Disilicide Fuel Elements for an Air-Cycle Nuclear Reactor". NACA-RM-E52L18. NASA, Lewis Flight Propulsion Laboratory, Cleveland, OH. March 1953. 13p.

Flat, plate-type elements, 3.5 by 0.5 by 0.070 inches in size and containing 10 percent elemental natural uranium, were produced by hot pressing. The elements were acid-treated to remove surface uranium and then coated with an alumina glaze. Such an element remained stable and did not lose detectable quantities of fission fragments in a 400-hour treatment at 1800°F in a flux of 5 X 10^{11} neutrons per square centimeter per second. Such elements are conveniently produced and, dependent on design and on the successful resolution of problems such as thermal shock, offer a possible method of increasing air-cycle element temperatures and related performance.

Meals, E. O. Col. USAF, Deputy Chief, Aircraft Reactors Branch, Div. of Reactor Devel., AEC. Letter to Mr. Benjamin Pinkel, NACA Lewis Flight Propulsion Laboratory, Cleveland. March , 1956. Available in NASA, Hq. Office of History.

Agrees with the NACA support of the ANP Program in two areas: (1) direct support of existing ANP efforts, and (2) advanced development efforts. Suggests frequent meetings among NACA, ANP contractor and Air Force-AEC personnel.

"NACA Executive Committee Minutes". June 17, 1954. Available in the NASA, Hq. Office of History.

Reports on discussion held on the appropriate role for NACA in the development of the nuclear powered aircraft. The Chairman stated that it would be necessary for NACA to make a major policy decision in the near future whether to request funds for a nuclear aircraft research facility. The Director reported that NACA had been spending about $1M a year on research having a bearing on nuclear propulsion, principally heat transfer and materials work. He also said that Dr. Lawrence R. Hafstad, Director of Reactor Development, AEC is in agreement with NACA entry into the nuclear engine research field and that installation of a reactor in the Cleveland area appeared feasible. The Chairman stated that he recently discussed this matter with the AEC Chairman, Adm. Lewis Strauss.

"NACA Minutes of Regular Meeting of the Executive Committee." Sept. 13, 1945. p.8.

The Chairman reported a suggestion from Sir A.A. Roy Fedayeen, of the British Ministry of Aircraft Production, that a study be made of the possibilities of applying atomic energy to propel aircraft. Dr. Bush stated that the President was preparing a message to Congress that was relevant and anything the Committee might do now was premature. Adm. Mitscher stated that there was a general directive that nothing regarding development atomic energy be given out except from the White House.

"NACA Minutes of Regular Meeting of Executive Committee". August 11, 1947.

The Committee discussed the Proposed Special Committee on Application of Nuclear Energy to Aircraft Propulsion. Dr. Condon reported that he and Dr. Hunsker had conferred with Carroll Wilson, AEC, on the Navy proposal that NACA establish this special committee. Gen. LeMay reviewed the difficulties of the NEPA Project. It was agreed that further discussions would be held with the AEC.

"NACA Minutes of Semiannual Meeting." May 1, 1952. pp.9-10.

Dr. Doolittle questioned whether NACA should undertake research requested by the AEC. (AEC had requested wind tunnel work for ANP be done by NACA). The NACA Director stated that a major policy decision was necessary to establish the amount of nuclear energy research NACA should undertake. He stated that this decision will be dependent upon the nuclear propulsion for aircraft program adopted by the AF. The Director further said that a small amount of heat transfer and materials work was being done by the NACA - Lewis staff, that he believed it advisable that a few Lewis people be familiar with the field of nuclear energy and that all this work should be funded by NACA, not AEC. The Director also stated that the current level of NACA work had not changed for the past two or three years.

"NACA Minutes of Annual Meeting and Minutes of Special (Organization) Meeting of Executive Committee". Oct. 23, 1947.

The Chairman reported on meetings he and Dr. Condon had with AEC Officials regarding cooperation between NACA and AEC. The question of whether the NEPA Project was proceeding was raised and Dr. Bush observed that it is under discussion between the AEC, the AF and the industry and that a plan will probably emerge shortly. Dr. Condon suggested that if NACA is going to have a committee on nuclear power for aircraft, it should proceed with it and advise the AEC, since NACA had been waiting more than six months for AEC and NACA should take definite action. Dr. Bush said that the three groups were drafting a reasonable plan, although NACA was inadvertently not included in the planning.

"NACA Minutes of Regular Meeting of Executive Committee". Dec. 16, 1948. p. 15.

The Director stated that at the request of the R&D Board that the AEC has accepted responsibility for unifying the program for nuclear energy for the propulsion of aircraft, with the participation of other agencies. AEC had established the Lexington Project under contract with MIT. Professor Walter Whitman is the Chairman of the Lexington Project and Addison M. Rothrock of NACA is a project member. NACA also has three men at Argonne Laboratory and one at Oak Ridge. NACA Lewis has 30 or 40 related projects in the fields of heat transfer and materials at high temperature and large temperature gradients. Work is also underway on nuclear power plant cycles, radiation effects on materials and shielding. Arrangements have been made for exchange of information with AEC and NEPA.

"NACA Minutes of Semiannual Meeting". April 19, 1948.

The Chairman stated that he and Dr. Condon had meet with Carroll L. Wilson, General Manager and subsequently with David Lilienthal, Chairman of the AEC to discuss liaison and cooperation between NACA and AEC. The NEPA Project was discussed and the Chairman reported that AEC had asked MIT to evaluate the project. The MIT review group was chaired by Dr. Walter Whitman of MIT, a chemical engineer who was wartime Chairman of the NACA Subcommittee on Aircraft Fuels and Lubricants. The Chairman reported that Addison M. Rothrock, NACA Assistant Director for Aeronautical Research, would loaned to the AEC for 9 months or a year. Dr. Dryden that Rothrock would remain on the NACA payroll but would serve as part of the AEC staff. Dr. Dryden also said that Dr. Sidney Simon, NACA Lewis, was serving at Argonne; Dr. Diedrich, Lewis was moving from Oak Ridge to Argonne and several others from NACA would be detailed to AEC.

"NACA Minutes of Regular Meeting of the Executive Committee". March 27, 1947.

Dr. Condon reported on his study of the Proposed Special NACA Committee on Application of Nuclear Energy to Aircraft Propulsion. Because of the delay of the confirmation of the members of AEC, he would need more time before making a recommendation. [Researcher's Note: Dr. Edward U. Condon was Director of the National Bureau of Standards.]

"NACA Minutes of Semiannual Meeting". April 17, 1947

The Proposed Special Committee on Application of Nuclear Energy to Aircraft Propulsion was discussed. Dr. Condon read his April 16 report on this subject and quoted from Gen Curtis LeMay that the proposed committee's function is essentially now in hand with the participation of the NACA group in the NEPA Project. Dr. Condon still recommended establishing the special NACA committee. The stabs of application of nuclear energy to aircraft was discussed and of the policies of the recently confirmed AEC. It was agreed that the Chairman and Dr. Condon would confer with the AEC Chairman Lilienthal and Carroll Wilson to have AEC recognize NACA's interest in this area.

"NACA Executive Committee Minutes". Date uncertain, probably July or August 1954.

Records discussion on research in support of nuclear propulsion for aircraft. About 80 NACA reports were identified having a bearing on nuclear propulsion; NACA work was largely due to requests from the AF, Navy and the AEC. Dr. Doolittle reported that a design of a proposed NACA research facility to study ANP components under conditions of pressure, temperature and radiation to be located at or near Lewis Flight Propulsion Lab, Cleveland, would cost about $5M. Conditions under which this project should go forward, included ensuring flexibility, getting AEC approval and the military services agreement that the data was needed, and ensuring no duplication of activities with AEC.

The Committee Minutes concludes that: “A public relations job will be required to obtain acceptance of the facility by the public in the Cleveland area”.

Neill, T.T., Chief, Tech. Pub. Br.,Office of Adv. Research and Technology, NASA. Memorandum to Dir., Lewis Research Center. April 26, 1968.

This memorandum withholds approval for publication of a proposed Technical Memorandum (E-3914) by Frank E. Rom, entitled: “Subsonic Nuclear Aircraft Study.” This action is based on Dr. Foelsche of Langley taking exception to this report using 5 REM, in lieu of 0.5 REM as an acceptable annual radiation dose for passengers. The Executive Director of the Federal Radiation Council has advised that the 5 REM figure is too high by at least a factor of 10 for individual civilian exposures, but that DoD has the authority to use 5 REM for military personnel under their jurisdiction.

Neill, T.T., Chief, Tech. Pub. Br.,Office of Adv. Research and Technology, NASA. Memorandum to Lewis Research Center. Jan. 16, 1968.

Disapproves abstract of paper, entitled: “Safety Outlook for Nuclear Aircraft”, because the inadequate consideration has been given to all aspects of impact accidents.

Pinkel, Benjamin, Chief, Fuels and Thermodynamics Research Division, NACA-Cleveland. Memorandum for Chief of Research, NACA-Cleveland. January 3, 1947.

Discusses proposed program of thermodynamic research for nuclear energy application. Engine cycle studies will include: (a) closed cycles - condensing (steam or other vapors) and noncondensing (air, helium or other gases); (b) open turbojet and propeller turbine cycles; (c) ram jets; and (d) rockets. Reactor analyses and heat transfer investigations will also be carried out.

Pinkel, Benjamin. “Formation of Special Committee on Aircraft Propulsion by Nuclear Energy.” Memorandum for Chief of Research, NACA Lewis Flight Propulsion Laboratory. Cleveland. Feb. 29, 1952.

Pinkel, Chief, Materials and Thermodynamics Div., recommended to Abe Silverstein, Chief of Research, Lewis, that NACA establish a committee to coordinate research between Lewis and the AEC/Air Force nuclear powered aircraft program. Silverstein forwarded this memorandum to NACA Hq. on Feb. 29, 1952, with no recommendation.

Pinkel, Benjamin, NACA-Lewis, Cleveland. Letter to Col. E.O. Meals, USAF, AEC. March 5, 1956.

Discusses the need for closer integration of NACA work and ANP Project. Current NACA work described as: (1) research in close support of specific prototype developments, and (2) advanced research which may lead to improved propulsion systems. He understands the Air Force would increased NACA support, but improved communications are necessary.

Rom, F.E. "Advanced Reactor Concepts for Nuclear Propulsion". *Astronautics* 4, 10 (1959): 20-2.

The potential of nuclear energy in reactor concepts for rockets is discussed. The limitations of ceramics, graphite, hafnium, tantalum, and tungsten for use in high-temperature solid-fuel-element reactors are described.

Rom, Frank E. "The Nuclear Powered Airplane". Technology Review (MIT) 72, 2(Dec.1969):49-56.

Rom reviews the incentives for nuclear powered flight and argues that such aircraft can be designed to operate safely and practically. He presents a conceptual design for an aircraft engine that can be powered either by nuclear or chemical fuels. He also includes a concept for an impact resistant containment vessel that has provisions for sealing off all coolant lines to prevent external leakage. This work has been conducted at the NASA Lewis Research Center.

Rothrock, Addison M. Chief of Research, NACA-Cleveland. Memorandum for NACA Director of Aeronautical Research. "Cooperation with the Monsanto Chemical Co., Clinton Laboratories. July 9. 1946.

Discusses the assignment of Dr. Sidney L. Simon and Dr. J.R. Dietrich from NACA-Cleveland to the high temperature pile (reactor) development project underway at the Clinton Laboratories. This project is considered a forerunner of a nuclear power plant for aircraft. Assistance to the NEPA Project is recommended to be offered in the fields of high temperature materials and components.

Rothrock, Addison M., Acting Executive Engineer, NACA-Cleveland. Memorandum for the Director of Aeronautical Research, NACA-Hq. "Nuclear Energy Fuels and their Utilization." June 22, 1945.

Provides for information a paper by Drs. Hicks and Simon, NACA-Cleveland staff, which discusses atomic energy. Rothrock does not recommend any action at this time, but suggests that NACA should be thinking about applying atomic energy to aircraft propulsion.

Rothrock, Addison M., Acting Executive Engineer, NACA-Cleveland. Memorandum to NACA-Hq. "Nuclear Energy Fuels and their Utilization." August 10?, 1945.

Forwards four memos written on August 7-9,1945 by J.R. Dietrich, Robert F. Selden and John C. Evvard which discuss the potential applications of nuclear power. [Researcher Note: The first atomic bomb was dropped on Hiroshima on August 6, 1945, the day before the first of these memos were written]. Rothrock requests that NACA-Hq. determine if information can be made available to NACA-Cleveland regarding the extent to which nuclear energy release can be controlled. He asks if discussions could be held with Manhattan Project scientists on the possibility and methods by which nuclear energy might become a source of power.

Rothrock, Addison M. Chief of Research, NACA-Cleveland. Memorandum for Director of Aeronautical Research, NACA-Hq. April 2, 1947.

Discusses the current assignments of NACA physicists Dr. S.L. Simon and Dr. J.R. Dietrich to the Clinton Laboratories, Oak Ridge, TN. Both have been assigned to work in the high temperature pile group at Clinton for a one year assignment commencing, respectively, in July and September 1946. The question is raised whether their continued assignment for another year should become full time in the high temperature group, or they should continue taking an advanced class in nuclear energy half time.

Rothrock, Addison M. Assistant Director for Aeronautical Research, NACA. "Cooperation between the NACA and AEC." Washington, D.C. July 15, 1948.

In this "Memorandum for Records", Rothrock documents the agreement signed by NACA with the Chicago Director of Operations, AEC, and the Argonne National Laboratory which assigns NACA men to Argonne. These men are working in the field of nuclear physics, and are not just liaison between NACA and the AEC Laboratories. The purpose is to provide nuclear physics information to the NACA work being conducted in heat transfer, power plant analysis and high temperature materials. The NACA work is being guided by the needs of the nuclear powered aircraft program.

Scharp, Edward R., Director, NACA-Lewis, Cleveland. "Training of Personnel for Research using the Cyclotron." Memorandum to NACA-Hq. Nov. 3, 1948. 2p.

Requests assignment of a research scientist to the Radiation Laboratory of Dr. E.O. Lawrence at Berkley, CA to learn the cyclotron techniques of the North American Aviation Co. for investigating the effects of radiation on solid materials. Request is being made because NACA-Lewis is to install a General Electric Co. built cyclotron in Sept 1949.

Selden, Robert F., Assistant to the Chief of Research, NACA-Cleveland. Memorandum for Chief of Research, NACA-Cleveland. "Immediate Problems with Respect to NACA Participation in Nuclear Energy Work." October 29, 1946.

Selden recommends that NACA actively support research on aircraft pile (reactor) designs and continue related research on compressors, turbines and heat exchangers. He recognized the need to reduce shield weight for the success of the nuclear powered aircraft and recommended university contracts to work on this fundamental problem. He states that an early decision is necessary to acquire and train NACA staff. He argues that, “If the NACA does not see fit to commit itself (to nuclear energy work) at this time, I am quite sure that there are other agencies who will undertake to do so. If this happens, then the NACA is automatically relegated to a secondary position in the field of nuclear propulsion for aircraft.”

Selden, Robert F., Assistant Chief, Fuels and Lubricants Division, NACA-Cleveland. Memorandum for Acting Executive Engineer, NACA-Cleveland. “Power Possibilities Using Atomic Energy.” August 9. 1945.

Selden discusses the implications of atomic energy relative to propulsive devices for aircraft and missiles. He feels that the possibility of getting any information on atomic fission at this time is extremely remote. However, he believes that some work can be done in anticipation of getting this information. He describes possible nuclear powered aircraft and rocket engine cycles and lists probable characteristics, including high temperature material requirements. [Researcher Note: This is one of four memorandum forwarded by Rothrock’s August 10?, 1945 memorandum to NACA-Hq.]

Selden, Robert F., Assistant to Chief of Research, NACA-Cleveland. Memorandum for Manager, NACA-Cleveland. “Comments on Nuclear Energy Aircraft Propulsion Laboratory.” September 21, 1946.

Selden believes that nuclear energy can be applied to either very large of fast aircraft in the next 10-20 years and proposes that a Nuclear Energy Propulsion Laboratory (NEAP) be established at NACA-Cleveland as a logical choice of the agency to undertake this work. The initial purpose of the lab would be to develop a relatively small light-weight, but high power reactor. He also discusses the need for training of NACA personnel. A detailed cost proposal is provided for the NEAP.

Sessions, Robert. Acting Director, NACA-Cleveland. “Procurement of Uranium.” Memorandum to NACA-Hq. Cleveland. April 30, 1948.

Requesting approximately 4 lbs. of pure uranium be provided from Monsanto Chemical Co., Clinton Laboratories, Oak Ridge, TN to NACA-Cleveland to allow investigation of ceramic-uranium materials for high temperature applications. Sessions states that the Cleveland Laboratory has a source material license from the AEC and is cognizant of the ingestion toxicity hazard of uranium and is prepared to handle it safely.

Sharp, Edward R., Director, NACA-Cleveland. Memorandum to NACA-Hq. May 27, 1948.

Requests that AEC be asked to accept Mr. Ben Kalmon for training for a year in Health Physics and radiation instrumentation at the Clinton Laboratory, Oak Ridge, TN. Reference is made to a September 26, 1947 agreement in which NACA agreed to conduct research in the fields off heat transfer and ceramics which are of interest to the AEC. Sharp also states that NACA- Cleveland expects to have a cyclotron within the next two years for materials testing and they need some NACA staff familiar with Health Physics.

Sharp, Edward R., Manager, NACA-Cleveland. Memorandum for Director of Aeronautical Research, NACA-Hq. "NACA Work on Nuclear Energy Power Plants for Aircraft." October 29, 1946.

Makes reference to NACA-Cleveland proposed work, including facilities for experimental research on nuclear energy applications for aircraft. This proposal shows a construction program costing about $54M by 1957. Details of this proposal are given in a memorandum from Robert F. Selden for the Manager, NACA-Cleveland, September 21, 1946. The proposed program was discussed with Dr. Farrington Daniels, Clinton Laboratories in October 1946, and he gave his endorsement.

Silverstein, A. "Heat: Key to A-Powered Aircraft". *Aviation Week* 60**,** 21 (1954): 28-30,34.

Investigations at NACA's Lewis Flight Propulsion Laboratory, Cleveland show more difficult scientific and engineering problems encountered in nuclear project are result of quest for higher operating temperatures. Material selection and mass transfer are being investigated because of their importance in cooling cycle. Presented as a paper before the Institute of Aeronautical Sciences.

Victory, J.F. "Excerpt from NACA Minutes of Meeting Held January 24, 1947." Letter to E.G. Condon, Director NBS. January 30, 1947.

J.F. Victory, Executive Secretary, NACA, quotes from a letter from Adm. Stevens dated Jan. 10, 1947, that NACA should establish a subcommittee for the aviation application of nuclear power. Adm. Stevens, U.S. NAVY, Bureau of Aeronautics, states that the NACA, "as a matter of inherent responsibility" should be evaluating data becoming available as the result of AAF and Navy contracts such as the NEPA Project and Princeton's Project Squid. The NACA Chairman suggested a special committee be set up under the chairmanship of Dr. Condon. Dr. Condon agreed to look into the matter and advise the Committee.

Victory, J.F., Executive Secretary, NACA-Hq. Memorandum for NACA-Cleveland. "Utilization of Atomic Energy." December 10, 1945.

This is the NACA-HQ. response to the August 20, 1945 request of NACA-Cleveland for information on nuclear energy for possible application to aircraft propulsion. Victory indicates that in an October 25, 1945 meeting of the NACA, Dr. Vannevar Bush indicated that utilization of atomic energy for, power will come first in large size units, perhaps weighing 50 tons. The Committee agreed to submit appropriate questions to the new AEC when established by Congress. At that time the Cleveland Laboratory will be advised further.

Wachtl, William W., and Frank E. Rom. "Analysis of the Liquid Turbojet Cycle for Propulsion of Nuclear Powered Aircraft." NASA-RM-E51D30. NASA, Lewis Flight Propulsion Lab., Cleveland, OH. November 1951. 86p.

An analysis of the nuclear powered liquid-metal turbojet cycle is presented for a wide range of engine operating conditions at flight. Mach numbers of 0.9 and 1.5, and at altitudes of 30,000 and 50,000. Airplane gross weight and reactor heat release is presented for typical values of airplane lift-drag ratio, structure to gross weight ratio, and sum of reactor, shield, payload, and auxiliary weights. The effect of varying these assumptions and of including nacelle drag is shown along with the effect of flight conditions.

Wachtl, William W. and Frank E. Rom. "Analysis of a Liquid-Metal Turbine-Propeller Cycle for Propulsion of Low-Speed Nuclear-Powered Aircraft." NASA-RM-E52D02. NASA, Lewis Flight Propulsion Laboratory, Cleveland, Ohio. 1952. 31p.

The potential application of nuclear energy for the propulsion of low-speed turbine-propeller with a liquid metal cycle is discussed.

d. NAVY

Burke, Adm. Arleigh L., Chief of Naval Operations. Testimony to Congress. Mar. 11, 1957. JCAE #5166. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

On Apr. 13, 1955 the CNO issued the military requirement for an ANP attack seaplane. This was followed by a SecNAV instruction 9890.1 of May 14, 1955 which stated that "A vigorous program shall be developed and pursued for nuclear propulsion of naval aircraft". Study contracts were placed with Glennn L. Martin Co. and Convair, also Parsons Co. for study of a seaplane base. The testimony provides a good summary of the Navy ANP program, and included the possibility that nuclear seaplanes could be serviced at sea by nuclear-powered submarines!

"Naval Nuclear Propulsion Program". Naval Propulsion Division, Bureau of Aeronautics, Navy Dept, Washington, D.C. Nov. 15, 1958. JCAE #5804. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File, Vol. III.:National Archives, Washington, D.C.

Cost estimates for the "Princess" Flying Boat Program were provided. An outline of the proposed program was given, which included acquisition of three Princess airframes from England, after modification for nuclear power by the manufacturer, Saunder-Roe, Ltd. Further flight testing would occur in the U.S., after which the nuclear power plant would be installed. The development of the nuclear power plant would undertaken jointly by the Navy and the AEC. The program would take five years at a maximum cost to the Navy of $188M and a total cost of $255M.

Richardson, Capt. N.R., USN. Letter to Wade O. Dickinson, III., JCAE Staff. Apr. 10, 1957. JCAE #5166. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

This letter provided a summary of the Navy's ANP seaplane program in the form of a statement by Adm. Arleigh Burke, CNO. After tracing the early ANP history, Adm. Burke indicated that on Apr. 13, 1955 the CNO issued a Navy requirement for an attack seaplane propelled by nuclear power. This was followed by Instructions issued by the Secretary of the Navy on May 19, 1955, and in June, study contracts were placed with Convair and the Glennn L. Martin Companies. A contract was also placed with the Parsons Co. to determine requirements for a nuclear seaplane base. After initially considering a third major ANP reactor contractor (Allision Div. of General Motors), it was decided that the Navy requirement should be met by the Pratt & Whitney projects. During the period June -October 1956 the Navy ANP efforts were reduced by about one-half because the ultimate success of the systems could not be guaranteed. Further reductions were made because of the Navy's doubts that current Air Force designs will be militarily practical. On November 29, 1956 the Deputy CNO (Air) writing to the Assistant Secretary of Defense outlined the Navy's ANP Program. He reaffirmed the Navy's belief that safety and practicality make it inevitable that the first application of ANP will be in a seaplane. Burke states that the Navy will be prepared to take advantage of any technological breakthrough in the AEC's ANP efforts. He said the Navy plans to use nuclear-powered aircraft for ASW, early warning, reconnaissance, attack and mining and logistical support. He envisioned nuclear aircraft being serviced by nuclear-powered submarines at sea.

Rockwell, Theodore, III. "The Rickover Effect, How One Man Made a Difference". Naval Institute Press, Annapolis , MD. 1992. frontispiece, 92 p.

Brief, but significant mention is made of the ANP Program in this book. Rockwell noted that on March 31, 1953, Lewis Strauss (Pres. Eisenhower's Assistant on Atomic Energy) recommended "killing" the nuclear-powered airplane project, along with the nuclear-powered aircraft carrier project. Rockwell also pointed out a basic difference in approach in building the aircraft nuclear propulsion prototype and the nuclear submarine prototype. Rickover insisted that the Nuclear Navy's prototype built in the Idaho desert be a duplicate of the submarine propulsion plant, including building it into a full-sized submarine hull. In this way, all of the problems of building and operating a compact nuclear power plant inside a hull would be experienced on the prototype and would be directly applicable to solving the same problems on the submarine. According to Rockwell, when the ANP Program prototype was built it was made simpler by making it different from the final design for an aircraft. He stated that this led to numerous problems unique to the prototype, the solution of which did not contribute to the actual aircraft.

Salkovitz, E.I., A.I. Schindler, and G.S. Ansell. "The Effects of Nuclear Irradiation on Metallic and Nonmetallic Magnetic Materials. Paper 33. Third Semi-Annual Radiation Effects Symposium. Atlanta. October 28-30, 1958. Volume 3. Aircraft Systems and Materials Papers." NP-7365. Naval Research Lab., Washington, DC. 23p.

Extensive investigations of the effects of nuclear environments upon magnetic materials were undertaken. A major aim of the program was to obtain basic information concerning the mechanisms producing the observed effects. More than 100 samples were irradiated in the Brookhaven graphite reactor at an integrated flux of 10^{17} NVT. The materials studied were in the form of toroids or rods and consisted mainly of various ferrites and square loop and high permeability alloys. In addition, discs of permanent-magnet type ferrites and portions of magnetic devices were irradiated.

Struble, A. D. "Toward a Nuclear-Powered Seaplane". *U.S. Nav. Inst. Proc.* 83,11 (1957): 1168-173.

Reviewed progress made in the development of a seaplane for the Navy that would be powered by nuclear energy.

Taylor, John W., Elizabeth Reeves and Emma Fessenden. "The Health Hazards of Radioactivated Materials in Nuclear Powered Seaplanes". MA-6039. Naval Air Development Center, Aviation Medical Acceleration Lab., Johnsville, PA. Dec. 31, 1960. 24p.

The general health hazards of a nuclear powered aircraft are discussed. Emphasis is placed on the problem of ingesting particulate material. Dust samples were collected from operational P5M seaplanes and results extrapolated to an assumed nuclear aircraft. The dusts were studied using microscopy to determine gross particulate nature, x-ray diffraction to determine molecular constituents and particle size below one micron, and activation analysis to determine individual nuclides that become radioactive under neutron bombardment. These results indicate that no special problem exists in connection with the occupied areas of a seaplane. Sodium was not found to be a major constituent and little additional hazard results from operation in salt water environments.

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e. OTHERS

Kroll, Wilhelmina D. “Aerodynamic Heating and Fatigue”. NASA-M-6-4-59W. National Bureau of Standards, Washington, DC. June 1959. 30p.

A review of the physical conditions under which future airplanes will operate has been made and the necessity for considering fatigue in the design has been established. A survey of the literature shows what phases of elevated-temperature fatigue have been investigated. Other studies that would yield data of particular interest to the designer of aircraft structures are indicated. Report made reference to ANP.

Penner, S.S., ed. “Advanced Propulsion Techniques.” Proceedings of a Technical Meeting Sponsored by the AGARD Combustion and Propulsion Panel. Pasadena, CA. August 24-26, 1960. Pergamon Press. 1961. p.ix.

This AGARD (Advisory Group for the Aeronautical Research and Development - North Atlantic Treaty Organization) Panel meeting was concerned with aircraft nuclear propulsion and other advanced propulsion approaches. Lt. Gen. (Ret.) D.L. Putt was the opening speaker at this meeting, which had the active support of the Dr. Theodore von Karman, Chairman of AGARD. Includes numerous, general articles on the U.S. ANP Program

Precision Steel Castings for Aircraft Use." National Research Council. Materials Advisory Board, MAB-106-M (1956) 59 p.

Present activities are insufficient and uncoordinated in the wider use of precision steel castings in aircraft. Basic investigations in foundry controls, mold materials and techniques, alloy casting and quality standards should be continued. Report made reference to ANP.

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CHAPTER 5.
POLITICAL CONSIDERATIONS

a. U.S. CONGRESS

[Note: The Joint Committee on Atomic Energy (JCAE) was a single Congressional Committee with members from both the U.S. Senate and House of Representatives.]

"AEC Authorizing Legislation - Fiscal Year 1963". Hearings before the Subcommittee on Legislation of the JCAE. April 5, 6, May 16-18, 21, 29, 1962. p. 32.

AEC testimony by Chairman Seaborg and Gen. Mgr. Luedecke discusses use of some ANP Project facilities for other AEC reactor development projects.

"AEC Authorizing Legislation - Fiscal Year 1962". Hearings before the Subcommittee on Legislation of the JCAE. May 1-4, 10, 17-19 and June 6, 1961. P. 156.

Testimony by AEC Gen. Mgr. Luedeke responding to questions regarding future utilization of AEC facilities from the ANP Program in Idaho being utilized for other projects. Luedeke was also questioned about the use of experienced GE engineers that were being laid off in Idaho.

"Aircraft Nuclear Propulsion Program, Hearing Before the Subcommittee on Research and Development of the Joint Committee on Atomic Energy, Congress of the United States, Eighty-Sixth Congress, First Session on the Aircraft Nuclear Propulsion Program, July 23, 1959". Joint Committee on Atomic Energy: 1959. 421p.

The first public hearings on the ANP Program were held on July 23, 1959 by the JCAE Subcommittee on R&D. After an introduction by Congressman Melvin Price, Chairman of this JCAE Subcommittee, testimony was given by: John Mc Cone, AEC Chairman; Thomas Gates, Dep. Sec. of Defense; Maj. Gen. Donald Keirn, ANP Project Director; Herbert York, Director of Defense Research and Engineering; D.R. Shoults, Gen. Mgr., General Electric ANP Dept.; B.A. Schmickrath, Pratt and Whitney ANP Project Manager, et.al. Additional material supplied for the record includes a report by Maj. Gen. Keirn and the JCAE Press Release announcing the hearing. Appendices to the report of the hearing include: (a) A chronology of the ANP Program from 1946-July, 1959; (b) A summary of funding by year from 1946-60 (estimated);
(c) A series of Press Releases and correspondence from the JCAE, individual Committee Members, Dept. of Defense, President Eisenhower and the Atomic Energy Commission; (d) Speeches and technical articles, including articles on the Russian ANP Program; (e) A

bibliography on nuclear powered aircraft and rockets; and (f) A Sept. 1959 JCAE Report on the ANP Program. This a very useful reference which provides a comprehensive overview of the ANP Project and also highlights the differences between the Congress and the Eisenhower Administration over the priorities for the program. The possible threat that the USSR may achieve successful nuclear powered flight before the U.S. overshadows these JCAE Hearings.

"ANPP Status". Presentation to JCAE by GE. July 23, 1959. JCAE #6086.RG128, Box 46, Folder Vol. III. - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

GE presented the characteristics of what would be a useful nuclear-powered airplane and discussed problems to be solved, courses of action, current technological state-of-the-art, schedule and funding required.

Aviation Week. Dec. 8, 1958. p. 28.

Reports that Rep. Melvin Price, Chairman of the Research and Development Subcommittee of the JCAE, upon hearing of the Russian ANP Program success, stated that: "We have reached a critical stage in our nuclear aircraft program. Either we push forward rigorously to a successful conclusion of our efforts or we forfeit, once again, our technological leadership." Sen. Dennis Chavez, Chairman of the Senate Aviation Subcommittee, is quoted as saying that Congress would provide "all the money they want" to achieve a flying nuclear powered aircraft. Sen. J. William Fulbright, a member of the Senate Foreign Relations Committee, criticized the Administrations "weak, apathetic leadership" in failing to advance the ANP Project.

Bacher, Robert F., Prof. of Physics, Cal. Inst. of Tech., letter to Donald A. Quarles, Deputy Secretary of Defense. Jan. 29, 1959. RG359, Box 22, Executive Office of the President, OSTP Folder-ANP 1958 (Unclassified Portion): National Archives II, Washington, D.C.

Dr. Bacher forwards a copy of his Jan. 28, 1958 letter to Cong. Melvin Price. He states that since the formal request from Cong. Price for a review of ANP by the Ad Hoc Committee, chaired by Dr. Bacher, was actually received after the April 26, 1958 meeting with the ANP contractors, he felt it was a good idea to review the events of last spring. Since a report and transcript were made available to Cong. Price, Bacher did not think there is anything useful that the committee can do at this late date.

Bauser, Edward J. "ANP Program". Memorandum to File, Feb. 25, 1960. JCAE #6240. RG128, Box 46, Folder Vol. III. - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Bauser recorded information from an informal meeting among Cong. Price, James

Ramey, Gen. Branch, Col. Tresch and Col. Anderson. Regarding release of fission products from fuel in the direct cycle, operational studies showed that releases cannot exceed 0.1 to 0.15 percent. In recent limited testing of ceramic fuel, release rates start out at 0.01 % and increases with operating time. Maximum test temperatures were 2500 deg.F. for 300 hours. Also, HTRE-3 testing with nichrome fuel was run during the first part of the year. Starting March 1, 1960, an AEC-Air Force group is evaluating which of the following two option should be followed, proceeding with a ceramic core test or proceeding with an integrated power plant test. Pratt & Whitney is continuing with a lithium-niobium primary system and a NaK-stainless steel secondary system. A 10 MW lithium-niobium reactor experiment is planned for NRTS the latter part of 1962.

Bergman, Harold, JCAE Staff. Memorandum to File. Aug. 26, 1952. JCAE #2963. RG128, Box 47, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Bergman reported that Dr. Chauncy Starr, North American Aircraft Co., had serious doubts about the success of the NEPA Program. Starr pointed out that no plane or missile has yet flown more than five minutes at supersonic speeds.

Borden, Bill. Memorandum for the Files. Mar. 6, 1951. JCAE #1973. RG128, Box 47, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

As instructed by the JCAE Chairman’s instructions, Borden advised Mr. LeBaron of the MLC that unless the Joint Chiefs of Staff makes a firm decision on the ANP Program within seven days, the JCAE desirers the Joint Chiefs to appear and testify on the eighth day. LeBaron advised that the MLC just reached a unanimous decision to recommend that project go forward. The issue was now up to the Joint Chiefs.

Borden, William, Executive Director, JCAE. Memorandum to J. Edgar Hoover, Director, F.B.I. November 7, 1953. As quoted in “J. Robert Oppenheimer, Shatterer of Worlds”, (p. 223) by Peter Goodchild. Fromm International Pub., New York. 1985.

The subject of this memorandum is J. Robert Oppenheimer. Borden includes in his listing of charges against Oppenheimer’s loyalty (which resulted in a hearing that removed Oppenheimer’s security clearance) that “... he used his potent influence against every post-war effort directed toward atomic power development, including the nuclear-powered submarine and aircraft programs...”.

Borden, Bill. Memorandum for the Files. Mar. 13, 1951. JCAE #CCCVII. RG128, Box 47, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

On this date the Joint Chiefs of Staff established the requirement to build a nuclear powered aircraft, subject to a priority less then the reactors designed to produce fissionable material. This decision was made known to the AEC Commissioners this date, and they are expected to authorize the GE contract in a week. Borden goes on to say that, "Thus the great decision has at last been made--unanimously, I believe--and now it is up to the Air Force to do the building if they can. Those who delayed this decision so long are principally four in number: Admiral Hill, Dr. Oppenheimer, Dr. Conant, and General Nichols."

Borden, Bill. "Nuclear-Powered Aircraft Project at Cincinnati, Ohio". Memorandum to Rep. Elston. Sept. 11, 1951. JCAE #2343. RG128, Box 47, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Borden reviewed recent activities related to GE work on ANP Project. On March 24, 1951 the AEC announced that it was negotiating with GE for aircraft reactor development. The AF had previously announced GE negotiations for associated propulsion devices. The AEC announcement followed a decision by the Joint Chiefs of Staff in Dec. 1950 to proceed with design and construction of a nuclear-powered aircraft. At a meeting on Aug. 28, GE proposed an air-cooled direct cycle reactor mounted amidships powering four jet engines in a swept-wing B-36 being designed by Consolidated Vultee Aircraft Corp. Conventional engines would power the aircraft for take-off and landing. The GE project is located in a converted aluminum foundry in the Lockland area and is headed by David Roy Shoults under the direction of C.W. LaPierre, General Manager of the Aircraft Gas Turbine Dept.

Brown, Ted. "Cut in Pratt & Whitney Participation in the ANP program". Memorandum to Files. Aug. 14, 1957. JCAE #5316. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

DOD had advised that Pratt & Whitney is informing its stockholders that their ANP project may be drastically reduced, or even eliminated. The *Wall Street Journal* will report this. AEC and DOD representatives briefed JCAE this date, stating that the CFR work will be terminated at Pratt & Whitney and drastically reduced at ORNL. Funds have also been eliminated for the Pratt & Whitney jet engine development work, but some funds will be available for their solid fuel reactor effort, although not all of the CANEL facility will be needed and part will be closed down. No final funding figures have yet been established by the Bureau of the Budget.

Brown, Ted. "Reported Cutback in ANP Program". JCAE Internal Memorandum to James Ramey, Executive Director. Nov. 5, 1956. JCAE #5021. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

DOD made a policy decision three weeks ago to cutback the ANP Program and contractors had already been advised. The JCAE was not informed. The new policy is to stretch out the ANP Program and cancel the airframe project until on of the reactor concepts was proven. Some thought is being given to waiting until a freeze can be put on the design for one reactor and aircraft type. Brown states that "...by that time we will have abetter picture of progress in the missile field."

Brown, Ted and N.R. Nelson. "Trip Report --ANP Project--G.E. Plant at Evendale, OH, 8 March 1958". Memorandum to James T. Ramey, Executive Director. Mar. 15, 1958. JCAE #5508. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Brown and Nelson met with JCAE members, GE and AEC personnel to review technical status of the GE ANP work, and proposed plans to overcome obstacles to achieving early flight testing by the winter of 1961-62. The most likely reactor to meet this goal would use uranium oxide fuel clad with nickel-chromium alloy, (nichrome). This fuel is expected to provide 1400 deg.F. air to the turbine without exceeding 1900 deg.F. in the fuel, or 1200 deg.F. in the moderator. In 1956 this fuel was tested in HTRE-1 for 40 hours at 1900 deg.F. A chronology of the HTRE-1, 2, 3 testing is provided. Brown and Nelson noted that the Killian Committee investigators could have misunderstood the failure of a zirconium hydride moderator that failed in a HTRE test, since it was not explained that it was anticipated that this failure would occur. It was also noted that GE had translated part of an unclassified Russian report on the Russian ANP Project and the concepts and problems are similar to the those of the U.S. program. They further note that latest Russian advances obviously would not be given in an unclassified report.

Brown, Ted. "ANP Program". Memorandum to James Ramey, Executive Director. Dec. 4, 1958. JCAE #5787. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Brown reports on his understanding of meetings that had taken place recently at high levels between representatives of DOD, AEC, BOB and the Killian Office to establish the ANP Program funding for FY60. The President's "hold the line" policy on the Defense budget may have serious impacts on ANP. Defense officials met with President Eisenhower in Augusta the last week in November 1958, at which time the possibility of a cutback in ANP was first discussed. Although the FY60 is not final, the portion of the ANP Program directed toward first flight is being delayed, along with ground testing. The accident at HTRE-3 may have been a factor.

Brown, Ted. "Proposed New ANP Program". Memorandum to James Ramey, Executive Director. Oct. 20, 1958. JCAE #5756. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Brown reported that he had recently learned from Jack Armstrong of the ARB, AEC that a new ANP Program had been approved by the AEC and Air Force. This would be the missile carrying CAMAL, Mach 0.9 aircraft. The new program includes ground testing the XMA-1 prototype by late 1960 in Idaho, and first flight with a militarily useful aircraft in 1962. This is different from the flying test bed approach proposed last November in which a KC-135 jet tanker would be modified to be an experimental carrier for the XMA-1. Brown comments that this is the first time, to his knowledge, that agreement has been reached on specific objectives and target dates. The Air Force is said to have established definite requirements for the CAMAL and has full support of Gen. Power and SAC. Final approval of the new program was anticipated on Oct. 29, 1958 when the Air Force and Navy Secretaries meet with Deputy Secretary of Defense Quarles.

Brown, G.E. (Ted). "Present Status of the ANP Project". Memorandum to Files. Sept. 18, 1959. JCAE #6133. RG128, Box 46, Folder Vol. III. - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Brown reported on a meeting with Irving Delson, GE Washington Office, in which the present status of the GE ANP Program was discussed. GE has proposed a FY60 budget of $89M, $2M below the FY59 budget. This would require a cut from 3550 people to 3200. AEC and the Air Force budgeting is less than what GE proposed, requiring that a shield test facility be deferred, delay in ordering materials for the Advanced Core Test and a cutback in the X-211 engine development work. Personnel would be cut to about 2500 with the AEC and Air Force budgets. By Feb. 1960, a decision on a Mach 0.9 propulsion system is planned from among the three options: (a) Single XMA with two X-211 jet engines, (b) a smaller single reactor/engine combination which requires two for flight or (c)a direct shaft connection through the center of the reactor. Testing plans are for HTRE-3 to modified to house a ceramic core of clad BeO capable of 1800 deg.F. turbine inlet temperatures. Advanced fuels work will include barylides which GE believes the Russians are also working on their ANP Program. Another committee has been established to review the ANP Program, which includes Gen. Branch who has been picked by AEC General Manager Luedecke to replace Gen. Keirn. This committee, chaired by Dr. Joseph Charyk, will review the GE proposal and also the Navy proposals for a turboprop engine utilizing the Pratt & Whitney indirect cycle.

Brown, Ted, JCAE Staff. Memorandum to Melvin Price. Dec.23, 1957. JCAE #5402. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Reported that Gen. Loper recommended to Deputy Defense Secretary that an expedited ANP project be established for nuclear flight as soon as possible. The objective was for flight in 1960-61 time period with two modified KC-135 jet tankers (similar to the Boeing 707), weighing 250,000 lbs., speed 5-600 mph. A GE reactor would power four engines. This would not be a fully operational aircraft, but more than a flying test bed. Separately, the Navy proposed the British “Princess” flying boat with six turboprop engines which have never before been considered for nuclear power. Brown questioned whether the Navy could fly by 1960-1. He also provides the FY59 budget.

Brown, Ted. “Further Information on the ANP Program”. Memorandum to File. Sept. 29, 1959. JCAE #6133. RG128, Box 46, Folder Vol. III. - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Reporting on further discussions with Delson of GE, Brown noted that the Charyk Committee had approved the ANPO recommended $39.3M program, not the GE proposed $48M. The ACRS will be reviewing the safety of the proposed testing of GE’s ceramic fuel elements at Idaho. Although the Killian Committee is enthusiastic about the ceramic fuel, GE admits that there may be a serious problem of release of fission products from the unclad BeO fuel. Brown notes that it is ironic that DOD’s York has directed that GE drop other materials development and concentrate on BeO. Delson stated that Wright-Patterson intelligence people now believe that there is an excellent chance that the Russians will be flying a nuclear plane by the end of 1959.

Brown, Ted. “Further on Reported Cutbacks in ANP Program”. JCAE Internal Memorandum to James Ramey, Executive Director. Nov. 13, 1956. JCAE #5025. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Brown reported that the ANP cutbacks are part of a larger holdup of all R&D funds ordered “...because of the world crisis...Funds are being set aside for operational contingencies.”

“Congress Told A-Plane Is Still 5 Years Away.” *Evening Star (Washington, D.C.).* May 25, 1959.

Reports on testimony before the House Appropriations Subcommittee by Lt. Gen. R.C. Wilson, Deputy Chief of Staff for Development, who stated that a nuclear powered aircraft could be flying in five years “if we had the money to do it”. The program was said to cost $990M from 1946 through the estimated spending of next year. Gen. Wilson is reported to have said that Deputy Secretary of Defense, Donald A. Quarles, before he died May 8, had decided to ask Pres. Eisenhower’s permission to step up the plane’s development. Subsequently, DoD denied the matter had been raised with the President. The article states that Rear Adm. J.T. Hayward, Chief of Naval R&D, told the Subcommittee that the Navy had proposed a $200M program to get a seaplane into the air by 1962 or 63.

Durham, Cong. Carl T., Chairman, JCAE and Cong. Melvin Price. Joint statement On ANP Program. March 6, 1958. RG359, Box 22, Executive Office of the President, OSTP

Folder-ANP 1958 (Unclassified Portion): National Archives II, Washington, D.C.

They criticize the Administration's decision to abandon the goal of early nuclear flight. This allows the Russians to have the first nuclear-powered flight, which after *Sputnik*, "...could well prove disastrous to world confidence in America's scientific abilities". They criticize the "cursory review of the(ANP)program" by an advisory group set up by Dr. Killian. This group was then reconstituted as an advisory group to the Pentagon. All of this has served to slow down, not expedite the ANP Program.

Durham, Carl, JCAE Reactor Subcommittee Chairman. Separate letter to Gordon Dean, AEC Chairman and Robert LeBaron, Chairman MLC, DOD. June 11, 1952. JCAE #2867. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Requested status reports on their ANP Programs.

Eastman, Ford. "Soviet Nuclear Plane Possibility Conceded". *Aviation Week*, January 19, 1959 p. 29.

Reports on a briefing of the R&D Subcommittee of the JCAE in an executive session by the intelligence community and the AEC. After the briefing, Rep. Melvin Price (D-IL) said that a new type of Soviet aircraft had been sighted in Russia that appeared suitable for nuclear propulsion, but he would not say that nuclear engines had in fact been installed. The subcommittee briefing had been called to determine the authenticity of the reported Soviet nuclear bomber that had been reported six weeks earlier in *Aviation Week* (Dec.1, 1958, p.27). Rep. Price stated that the Russians would have publicly announced a successful nuclear powered flight, so he remained somewhat skeptical that they had done so. He did believe that the Russians would make the first nuclear flight this year, and they are three to five years ahead of the U.S. Defense Secretary Neil H. McElroy was highly skeptical of the Russian flight reported six weeks ago, but admitted they might have a "slight lead" over the U.S. Rep. Price, along with most JCAE members have ben long-time advocates of early nuclear powered flight and critics of the program's slow, methodical R&D efforts, coupled with indecision and lack of leadership.

Green, Harold P. and Alan Rosenthal. "Government of the Atom - The Integration of Powers". Atherton Press, Division of Prentice Hall, New York. 1963. 281 p.

Green and Rosenthal described how the Joint Committee on Atomic Energy (JCAE), since its inception in 1946 has played an unusually influential role in the conduct of the nation's atomic energy activities. The JCAE's unique structure as the only joint Congressional Committee with legislative powers had a major influence on the ANP Program. The authors trace the membership and leadership of the Research and Development Subcommittee which, starting in 1948, continually emphasized the need for the ANP Program, and especially urged the Air Force and the AEC to fly a nuclear-powered aircraft as soon as possible, even if it would be of questionable military value. The book also focused on the balance of power between the JCAE and the Executive Branch.

Hamilton, Walter A. “ANPP Organization”. Memorandum to File. Sept. 4, 1952. JCAE #2993. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton reported on an interview with Brig. Gen. Donald Keirn and Col. Ralph Wassell on Sept. 2, 1952. Keirn had reentered the ANP Program two weeks ago, having previously been with AFOAT I. He now has the following three positions: (a) Assistant to the Deputy Chief of Air Staff for R&D, Maj. Gen. Craige, (b) Assistant to the Deputy commanding General, ARDC, Brig. Gen. McCormack, and (c) Director, ARB, RDD, AEC, and Assistant to Dr. L.R. Hafstad. In the first position Keirn was responsible for the formulation of policy on the development of nuclear-powered aircraft. The second position he was responsible for coordination and direction of the Air Force Program for development of a nuclear propulsion system and aircraft. The third position made Keirn responsible for both policy and direction of the AEC ANP Program. Hamilton notes that for the first time there is one man who wears all three hats. Hamilton also notes that Gen. Keirn has come a long way in his career since he was originally in charge of the NEPA Program. He said that Keirn is regarded by the Air Force as one of its tougher command officers, and if that it so, his reputation belies his soft-spoken manner.

Hamilton, W.A., JCAE Staff. " ANP Oak Ridge". Memorandum to File. Dec. 6, 1951. JCAE # 2499. RG128, Box 47, Folder I.- Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Reports on interview of Dr. Alvin Weinberg, Director, ORNL regarding status of ANP work at ORNL. He reports that GE and NACA rejected sodium coolant in Sept., 1951, and ORNL switched to molten fluoride salt as liquid fuel. ORNL believes that GE direct cycle is "dead ended". LaPierre, a senior GE manager has been quoted as saying that he will make a nuclear plane fly even if only for five minutes, five ft. off the ground. He said he will then have discharged his contract responsibility. Hamilton concludes that ORNL should be encouraged in their work.

Hamilton, Walter A. “Summary--Aircraft Nuclear Propulsion Status Report”. Memorandum to Carl Durham. July 2, 1952. JCAE #DXLII. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

The DOD RDB recommended, in Dec. 1950, the development of subsonic nuclear-powered aircraft by 1956 or 57. The JCS established a military requirement pursuant to this recommendation. However, at the beginning of 1952, the Committee on Atomic Energy of the RDB recommended a complete re-evaluation of the complete ANP

Program. Upon completing this re-evaluation, the Air Force transmitted a program proposal to the AEC on Apr. 8, 1952. This was accepted by the AEC on June 19, 1952. The objective of the current program is to complete a flying laboratory by 1956-57, at a cost of $300M, evenly split between the AEC and Air Force. This would be a chemically powered B-36 or B-69 modified to carry a nuclear reactor propulsion system for testing. Both AEC and the Air Force hope that the first militarily useful aircraft, probably a subsonic heavy bomber with round-the-world flight characteristics, can be operational by 1958-60.

Hamilton, Walter A. Memorandum to File. “ANP Program”. May 10, 1955. JCAE #4510. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton gave past and projected funding, as provided by Gen. Keirn and Dr. Davidson, AEC on May 10, 1955. A total of $820M was budgeted through flight testing.

Hamilton, Walter A. Memorandum to Bill Borden. May 27, 1952. JCAE #2860. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton reported that the Atomic Energy Committee of the RDB of which Robert Oppenheimer, Robert Bacher and Hans Bethe are members decided to press for an acceleration of the ANP Program. This was a reversal of the RDB position in their review of the FY53 research budget. Hamilton also discussed impacts of the reduction in the FY53 budget, which eliminated $10M from the initial engine test at Idaho for the ANP Program.

Hamilton, Walter A. “Nuclear Powered Aircraft Status Report”. Memorandum to Files. Mar. 18, 1952. JCAE #2723. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Col. Ralph Wassell provided information on the probable joint Air Force and AEC organization for the ANP Program. Air Force Secretary Thomas Finletter and AEC Chairman Dean are expected to meet soon and agree to establish a joint task force, headed by Gen. McCormack. If McCormack does head the program, Wassell thought the program would be expedited because McCormack has access to individuals most concerned at the policy level and he has their confidence. Hamilton described the three part ANP Program: GE and Consolidate Vultee, Pratt & Whitney and Boeing and Oak Ridge. Possible budget cuts by the Air Force are discussed that are anticipated to affect the schedule.

Hamilton, Walter. "Nuclear-powered Aircraft" Memorandum to Bill Borden. Dec. 4, 1950. JCAE #1781. RG128, Box 47, Folder - Declassified Records from the Classified JCAE

Subject File:National Archives, Washington, D.C.

Hamilton reviewed the WSEG evaluation of the nuclear aircraft which concluded that there was little, if any, advantage over a chemical-fueled strategic bomber. Dr. Hafstad, Chief of Reactor Development, AEC and Gen. Donald Putt, Director of AF R&D, have concluded that the WSEG Report is flawed. Hamilton reviewed the AEC and AF plans to initiate work at GE and Consolidated Vultee (although Boeing is still in the running). He suggested that the JCAE should determine whether or not the U.S. can afford a nuclear-powered aircraft in view of other major commitments which will draw upon the national economy in the next few years.

Hamilton, W.A. "Satellite Platforms and Fission Product Powered Aircraft". Memorandum to the Files. Oct. 9, 1952. JCAE #3068. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton reported on his meetings with Dr. Chauncy Starr, North American Aviation Co. on Sept. 29, 1952 and with Dr. Gore from the Rand Corp. the following day. Dr. Starr had done a one week conceptual study for the Air Force on a polonium-fueled power plant for small, single person reconnaissance aircraft. Dr. Gore thinks this concept is not reasonable, but believe earth satellites could provide reconnaissance.

Hamilton, Walter. "Aircraft Nuclear Propulsion Program". Memorandum to File. Oct. 11, 1954. JCAE #4198. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton reported on his trip to ORNL on Oct.6-7, 1954. He indicated that ORNL work on the CFR, called the "Fireball", looked very promising based on the technical progress to date. ORNL and Pratt & Whitney worked together on this parallel effort to the GE work. ORNL will build and test the reactor, while Pratt & Whitney will develop and test an integrated ground-based propulsion system. The next important step is to operate the ARE for its design lifetime of 200 hours to demonstrate extremely high temperature operations. The ARE was operated previously for 1000 hours at 1200 deg. C, in a non-critical (i.e. non-nuclear) mode. This was the highest temperature any reactor system had ever been operated.

Hamilton, Walter. "ANPP - GE Air Cycle". Memorandum to File. Oct. 21, 1954. JCAE #4209. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton reported on his trip to the GE ANP facility in Evandale, OH. He indicated that the HTRE test is scheduled for the Spring, 1956. He also reported on an experiment in which four J-47 jet aircraft engines were being operated from a single heat source, simulating a reactor power source. From his discussions with Roy Shoults, Hamilton reported that GE management was frustrated with the statements that the project should be accelerated, but no response is received to GE proposals to increase activities which would speed up the work.

Hamilton, Walter. "Inspection Visit to Convair Division, General Dynamics Corp., Ft. Worth, Texas". Memorandum to File. Oct. 21, 1954. JCAE #4211. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton reviewed the Convair ANP work which included shielding experiments, instrumentation development, preparation for testing a small reactor in a B-36 for shielding studies. Flight testing of the B-36 was scheduled for the spring of 1955. Hamilton discusses Convair studies for the Air Force to determine the best replacement for the B-52 for SAC in about 1963. Conventional, nuclear and conventional aircraft convertible to nuclear power were under consideration.

Hamilton, Walter. "Nuclear Development Associates Inspection". Oct. 22, 1954. JCAE #4210. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton reports on the trip he and George Norris took to NDA in White Plains, NY on Oct. 15, 1954. NDA was a small organization of about 65 engineers and scientists built around a core of men who worked on the Manhattan Project at Oak Ridge during the war. NDA worked as a subcontractor to Pratt & Whitney and had come up with alternatives to the "fireball" reactor concept. NDA also had done some preliminary studies for the Navy ANP effort.

Hamilton, W.A., JCAE Staff. Memorandum for the Record. June 5, 1948. "Conference with Col. Marvin Demler, Chief, Propulsion Branch, R&D Div., AAF on May 28 and June 1, 1948.JCAE #1691. RG128, Box 47, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Conference also included Mr. Hoagland and Mr. Heller. Discussions were also held with Gen. Craige, Chief of R&D Div.,AAF. The purpose of the Demler meeting was to discuss the NEPA Project. Demler outlined the history of the project, which was directed by the AAF. On July 30, 1947 the Atomic Energy Committee of the JDRB, which included members of the MLC and the GAC (Conant, Seaborg, and Oppenheimer recommended that NEPA be terminated and the AEC be given the responsibility for further R&D. Demler said that the AAF objected to this recommendation, because they felt that the reactor and airplane work should be managed by the same organization. In April, 1948 AEC agreed to cooperate on this project. The week of this conference, Demler said that Drs. Oppenheimer, Bacher and Fisk were meeting with Drs. Zacharias and Whitman of MIT to initiate an evaluation of the NEPA Program by MIT. Gen.

Craigie believed the development of a prototype reactor for aircraft propulsion would take five to seven years, with the objective of having an operational plane in another five years. Col. Demler stated that the AAF considered the nuclear plane to have high priority, but that the soon-to-be-available B-52's would be the alternate approach to delivering atomic bombs.

Hamilton, Walter. "Aircraft Nuclear Propulsion Review - Pratt and Whitney and Oak Ridge". Memorandum to File. May 10, 1955. JCAE #4509. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton reports on his and Rep. Hinshaw's attendance in CT at a review of the Pratt & Whitney and ORNL ANP projects by the Reactor Subcommittee of the GAC on April 29, 1955. The ORNL reactor development work includes construction and testing of a 60 MW CFR scheduled for early 1957. Pratt & Whitney is responsible for developing the airborne power plant, including a prototype for ground testing in Idaho, scheduled for 1960. A flight test should be ready in 1961 or 62. The major technical problems are corrosion in the primary loops and metallurgic problems in the radiator incorporated in the engine. This entire effort is approximately 12-18 months behind GE. A third reactor development effort, the Compact Core Reactor, is underway at NDA. Hamilton records his discussion with Edgar Murphee, GAC Chairman, who mentioned that he (Murphee) would seek GAC attention to the application of nuclear power to military aircraft, other that SAC bombers, such as seaplanes, airborne radar platforms and aerial in-flight refueling tankers.

Hamilton, Walter. "Aircraft Nuclear Propulsion Program". Memorandum to Members of the Research and Development Subcommittee. May 12, 1955. JCAE #4538. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton reports on the May 11, 1955 meeting of the SAB to the Air Force reviewing the ANP Program. He notes that much of the SAB membership overlaps with the AEC GAC. Maj. Gen Price, who was in charge of Air Force weapons planning at WADC described the ANP objective to permit a shift by 1963 so that one-third of the SAC fleet was airborne at all times, within striking distance of the Soviet Union. Price also said that achieving this airborne alert patrol earlier than 1963 was desirable at almost any price. Price hoped that nuclear-powered bombers would be on patrol for up to 10 days at a time. Hamilton noted that Price's statements were in direct conflict with the requirements given to the ANP Program to date. Hamilton also reported on discussions he had with Dr. Edward Teller, who supported the JCAE's attempts to accelerate the ANP Program. Teller agreed that a low subsonic, low altitude aircraft capable of a 7-10 cruise period and a short, high speed strike capability was the bets requirement for early nuclear flight. Teller also suggested a low-speed, very large nuclear aircraft would be valuable as a troop transport. Such planes would not have a supersonic requirement and could avoid operation over populated areas. Teller expressed serious reservations about operation over friendly populated areas, since with a large number of nuclear-powered planes a crash is inevitable. In discussions between Teller and Brig. Gen. Estey, who wrote the present ANP requirements, Estey said that any program along the suggested lines of Teller's would slow down achievement of the SAC bomber.

Hamilton, W.A. Memorandum to File. Apr. 8, 1953. JCAE #3393. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton reported that the United Press release appearing in the *New York Times* about the ANP Program was erroneous. The *Times* reported that the Air Force planes to construct an airstrip at Edwards AFB for test flights of the first nuclear-powered airplane. Hamilton noted that the *Times* reported made an erroneous extrapolation and this was another example of a press release "SNAFU" that was under investigation by Secretary of Defense Wilson.

Hamilton, William A. "GE-ANPP Conference". Memorandum to William Borden. Aug. 31, 1951. JCAE #2357. RG128, Box 47, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.
Hamilton provides a good summary of the NEPA/ANP Program including the evaluations GE did to decide on the air-cooled direct cycle. In August 1951, 120 invited engineers and scientists attended a presentation by GE to the Ad Hoc Committee consisting of Dr. L.R. Hafstad, AEC Director of Reactor Development; Maj. Gen. Donald Putt, AF Chief of Staff for Development; Rear Adm. T.C. Lonnquest, Deputy Chief of the Navy Bureau of Aeronautics; Dr. Hugh Dryden, Director of the NACA. Among the guests were Dr. Eugene Wigner, Jimmy Doolittle, Maj. Gen Dent (CO of Wright Field) and Dr. Alvin Weinberg. Details of the design were reported, including the fact that about 10,000 curies of mostly radioactive nitrogen-16 (from activation of oxygen) would be released per day of aircraft operation. This activity will persist for about 30 seconds. This was recognized as a problem of enemy detection and possible missile homing on this trail. Wigner commented that the extreme requirements for heat removal far exceeded any present reactor system. Dr. Hafstad observed that the design temperature was at limits for 310 stainless steel, which has the highest know temperature limits. This implied that unless new fuel were developed the GE concept could not evolve to a higher speed design. David Roy Shoults, GE director of the project said that liquid metal cooled reactors were historically impossible to be kept sealed and the direct cycle was the preferred approach. GE was to make a proposal which will undergo AEC and AF review. Hamilton believed that the greatest danger was that the AF and the AEC would lose sight of the objective of achieving nuclear flight with a militarily useful aircraft, on a time scale integrated with other weapons development.

Hamilton, Walter A. Memorandum to File. "ANP Program". May 10, 1955. JCAE #4506.

RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton reported on his meeting with Jack Hurley, Chairman and President of Curtis-Wright. Hurley was not aware of any pressure brought by anyone in Curtis-Wright on the ANP Program or the Navy to establish a third development effort leading to a nuclear-powered seaplane for the Navy. (Hamilton noted that this was contrary to all previous reports he had seen). Hurley said they would not object to doing ANP work, but he still feels that Enrico Fermi's assessment of ANP made four years ago that "...this thing will never work" is still valid .

Hamilton, Walter A. "Conference with Gen. Putt and Dr. Hafstad RE: Aircraft Nuclear Propulsion Program". Memorandum to Bill Borden. JCAE #1681. RG128, Box 47, Folder -Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Records the opinion of both the AEC and AF that a nuclear-powered B-52 could be flying within five years at a cost of $200-250M. Both Putt and Hafstad agreed that this specific objective was the only practical course, rather than the broad objectives of the ORNL Program. With the phaseout of Fairchild, ORNL will direct the reactor portion of the ANP Program, and the AF will assign Boeing the job of adapting the B-52 to a nuclear power unit, according to Putt and Hafstad. Both were of the opinion that the long-range view of the Lexington Report does not lend itself to any realistic military evaluation.

Hamilton, Walter. "Military Liaison Committee". Memorandum to File. Jan. 23, 1951. JCAE #1872. RG128, Box 47, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton records that the Joint Chiefs received recommendations from the WSEG for development of a supersonic nuclear-powered B-36. After some delay, the Joint Chiefs referred the recommendation (along with one for a nuclear-powered aircraft carrier) to the MLC for further consideration. The WSEG had indicated that the nuclear-powered aircraft was only useful only if available soon, i.e. a flying model operational by 1956. Meetings between the MLC and Dr. Hafstad, AEC had not resulted in a decision whether or not there should be an ANP Program. Despite this plans for the modified B-36 continued, with both the AF and AEC negotiating contracts with GE. Hamilton states that the JCAE needs to review the policy in this field.

Hamilton, Walter A. Memorandum to File. May 21, 1952. "Aircraft Nuclear Propulsion Program". JCAE #2821. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Hamilton reported on his trip to the Idaho Reactor Testing Station, May 2-7, 1952. The

Air Force and the AEC have agreed to build all ANP test facilities and to locate the ANP flight test runway at the Idaho facility. The Air Force has attempted to have the AEC expedite their part of the ANP Program, but the Air Force has yet to provide a firm definition of requirements, in spite of the decision in 1950 by the JCS to proceed with the ANP Program on a high priority. Also, Hamilton pointed out that there was virtually no funding support for the Air Force program.

Heller, Edward L. "Radiological Hazard to Crews in Operating Nuclear-Powered Aircraft". Memorandum to File. May 17, 1954. JCAE #4057. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Dr. Bugher and Dr. Dunham expressed concern if the crew were to receive greater than the international radiological standard dose of 15 REM per year, by receiving 5 REM per 20 hour bombing mission. They pointed out that 5 REM per mission was acceptable, but exceeding 15 REM per year would open up major legal issues for the government for the lifetime of those so exposed. Both saw the cruise concept as the first design that was acceptable from a radiological standpoint. They felt that in time required to design this concept, a suitable method of reducing the crew exposure could be developed to a risk level that would be insignificant compared to those normally faced in the military service.

Heller, Edward L. "Comments by Dr. Shields Warren on the Nuclear Propulsion Aircraft Program, and the Polygraph". Memorandum to File. Apr. 23, 1953. JCAE #3422. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Heller reported on his trip to meet with Dr. Warren on Apr. 22, 1953 in Boston where Dr. Warren was Director of the Deaconess Hospital Cancer Research Laboratory. Dr. Warren had been an advisor to the Air Force on the NEPA Program and felt that it was "...badly off base". Dr. Warren believed that the radiation exposure tolerances being used for shielding of the crew were ten times too high. With the typical time of 500 hours required to train a pilot and crew, based on experience with crews for the B-29 and B-50 aircraft, by the time the crew had completed their training they would have received a radiation dose which required them to be grounded. Dr. Warren also felt there was some question whether a crew would be able to carry out a military mission after this amount of radiation exposure. He said that reducing the exposures by a factor of ten would require a major re-study of the ANP Program. Dr. Warren said that the NEPA Program had, when serious scientific questions were raised, had responded with the comment, "We'll take care of that when we get to it." He believed the current ANP effort was treating the radiation exposure question with this same approach.

Loper, Herbert B., Assistant Secretary of Defense (Atomic Energy). Letter to Cong. Melvin Price. July 17, 1959. JCAE #6067. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Provided JCS memorandum on ANP, following presentation to JCS by Herbert York on June 17, 1959 and Donald Keirn on June 18, 1959. The Deputy Secretary of Defense requested the JCS to provide a military appraisal for the course to develop a militarily useful nuclear aircraft. The JCS believed there was considerable military potential, but precise application was not clear at that time. They did recommend a flight test vehicle capable of flight testing any of the nuclear-powered engines,

Loper, Herbert B., Assistant to the Secretary of Defense (Atomic Energy). Letter to Cong. Melvin Price, JCAE Chairman, Subcommittee on R&D. May 12, 1959. JCAE #5986. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Loper responded to JCAE requests for information on the ANP prototype testing and the public hearings planned by the JCAE Subcommittee. Loper states that ground tests of the XMA-1A was now scheduled to start in the spring of 1961. This will be a derated power plant suitable for the CAMAL-type aircraft, but not suitable for military missions. The XMA-1C is required for the first flight of the second nuclear aircraft in January 1965. Loper also discusses the problems of declassification of information for the planned public hearings.

Lunger, R.T. "Highlights of Verbal Presentation on ANP Program During Recent (April 1, 1959) Visit to NRTS". Memorandum to James Ramey, Executive Director. Apr. 8, 1959. JCAE #5927. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Lunger provided information from his trip to NRTS as background for a possible JCAE visit to GE-Evandale. He discussed the GE organization, HTRE developments to date, and other significant GE ANP Program accomplishments. He also discusses a concern of the AEC that in building a air strip facility at NRTS the Air Force could restrict future expansion of other AEC test facilities at NRTS, or even usurp NRTS as an operating base. An AEC organization chart is provided.

Mansfield, Ken. "The Joint Committee Report on the ANP Program". Memorandum to File. May 14, 1954. JCAE #4058. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

[Researcher Note: Presumably the Committee Report refers to the Report sent to the President by Cong. W. Sterling Cole, JCAE Chairman on May 14, 1954].
Mansfield reports on his conversation on May 13 with Gen. Taylor Drysdale of AFOAT, who usually represents SAC thinking. Drysdale downplayed the potential of the cruise-type dual powered ANP concept, stating that the ICBM would be the

thermonuclear weapon delivery system of the future.

McNamara, Robert S. Testimony at "Hearings Before the Senate Committee on Armed Services." April 11, 1961.

Robert S. McNamara's first testimony before the Senate Committee on Armed Forces as President Kennedy's Secretary of Defense, elaborates on the President's Special Message to Congress on March 28, 1961. He states that neither the direct or indirect cycle nuclear power concept holds any great promise as a practical propulsion unit for aircraft in the foreseeable future. He goes on to say that the powerplant has been specifically designed for early nuclear flight, with little, if any, potential to grow into something militarily useful. He states that defense projects should not be pursued only to provide the prestige that would result from having the first nuclear powered flight. The Joint Chiefs of Staff have, since 1959, taken the position that there is no specific military requirement for a nuclear powered aircraft. He therefore recommends that the project no longer be continued as a hardware development project by the DOD.

"Nuclear Science". GAO/RCED-88-138. General Accounting Office, Washington, D.C. Resources, Community and Economic Development Division, Gaithersburg, MD. 1988. 44p.

The joint Department of Energy and Air Force small reactor project was intended to develop a prototype reactor to assess the possibility of using nuclear power to meet the secure power needs of the Air Force. The project ran for a period of 4 years and cost about $3.75 million. Despite the time and money spent, it made little progress towards it intended goal, and the Air Force decided to terminate the project in May 1987. Several problems with DOE's and the Air Force's management of the project contributed to its termination, including (1) the feasibility of using nuclear power that was not clearly established and documented prior to the decision to proceed with the project, (2) disagreements between DOE and the Air Force that contributed to a shifting of responsibility for the project, and (4) an Air Force failure to coordinate its request for project funding with the appropriate congressional committees. The Air Force is now planning another study of energy technologies to identify a potential power source to meet its secure needs. Even today, the Air Force is unsure of the extent of its need. [Researcher Note*:* Reference is included as an example of a later joint AEC/AF nuclear power project that was considered to have management problems and unclear goals.]

"Pentagon Scored on Atomic Plane." *New York Times.* Sept. 23, 1959.
Article discussed JCAE report that criticized DOD for not providing concrete objectives for the ANP Project and suggested that the entire project be turned over to the AEC. JCAE was particularly critical of the recent DOD decision to defer any plans for the first flight test. DOD is stated to take this action because the engine under development has little potential of powering a militarily useful airplane and that no military requirement

had been established for a nuclear powered aircraft. It was reported that $2M has been spent so far on the ANP Project.

Price, Congressman Melvin, (D., IL), Chairman of the R&D Subcommittee of the JCAE. Letter to Dr. Robert Bacher, Prof. of Physics, Cal. Inst. of Tech. May 9, 1958. Attached to letter from Alice Horne, Secretary to the Director, Physics Lab., Cal. Tech. to Spurgeon Keeny, President's Science Advisory Comm. May 13, 1958. RG359, Box 22, Executive Office of the President, OSTP Folder-ANP 1958 (Unclassified Portion): National Archives II, Washington, D.C.

Cong. Price thanked Bacher Committee for appearing before the JCAE Subcommittee, but asked Bacher to send his views on the ANP Program regarding progress that has ben made since issuance of the Bacher Committee report. Price especially requested Bacher's current thinking on the question of early flight, including prerequisite tests and other information. Horne letter provided Price letter for Dr. Killian, Presidential Science Advisor.

Price, Congressman Melvin, (D., IL). "Opening remarks on ANP as Chairman of the R&D Subcommittee of the JCAE". April 25, 1958. RG359, Box 22, Executive Office of the President, OSTP Folder-ANP 1958 (Unclassified Portion): National Archives II, Washington, D.C.

The JCAE R&D Subcommittee meet with the Ad Hoc Advisory Committee to the Deputy Secretary of Defense on the ANP Program. This advisory committee was chaired by Dr. Robert Bacher and included Drs. Hans Bethe and Hugh Dryden, along with Gen. Jimmy Doolittle. Price restates the JCAE support for ANP the past 11 years and the need to expedite the program after the Soviet launch of *Sputnik* the previous fall. He cites his talks with Russian scientists who confirmed they are pursuing a vigorous ANP Program. Price reviews recent events, including the January, 1958 statement by Deputy Defense Secretary Quarles that consideration was being given to accelerating ANP to achieve early flight. However, before this course was recommended to the President, Dr. James Killian established aa advisory committee to review the ANP Program. JCAE was meeting with this advisory committee, which was reconstituted to provide advise to DOD, after completing their report to Killian. This report recommended against acceleration of the program, in conflict with the recommendations of the ANP contractors. [Researcher Note: This report to Killian has not been located.]

Price, Melvin. Letter to Donald A. Quarles, Deputy Secretary of Defense. Apr. 24, 1959. JCAE #5950. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

A recent JCAE trip to ANP-GE, Evendale showed considerable technical progress. Price urged going ahead with the prototype airframe which can take any one of the reactor types and could fly in early 1963. Price asked what additional DOD and AEC funding was required in FY60 to proceed with the flight program.

Price, Congressman Melvin, (D., IL). Statement on ANP as Chairman of the R&D Subcommittee of the JCAE. January 7, 1958. RG359, Box 22, Executive Office of the President, OSTP Folder-ANP 1958 (Unclassified Portion): National Archives II, Washington, D.C.

Cong. Price expressed his, and his colleagues', concerns about the indecision and lack of leadership on the ANP Program. He provided the text of an Oct. 24, 1957 letter to the President. This letter cited the recent launching of an earth satellite (*Sputnik)* by the Soviets in urging the development the of a flying capability for the nuclear-powered aircraft to satisfy the "long standing need" of the U.S. He stated that he and other JCAE members recently visited the Soviet Union and is convinced the Soviets are "placing considerable emphasis on their own program to develop a nuclear propelled aircraft". He stated further that "The Soviet Union is pressing ahead with the development of its own nuclear-powered airplane. I was told this personally by a leading Russian scientist during my visit to Moscow this past October...". Price was also concerned that the Navy had proposed to take over am large part of the responsibility for nuclear aircraft and engine development.

Price, Cong. Melvin. Letter to Roswell Gilpatric, Deputy Secretary of Defense. March 18, 1961. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Cong. Price enclosed a copy of his March 18 letter to the President and raised some questions from the recent JCAE hearings. He suggested that the fall, 1960 House Appropriations Committee staff report on ANP be reviewed. He also suggested that the technical basis for the Feb. 20 DOD criteria be re-examined in the light of expert testimony by Dr. Kalitinsky on shielding and airframe design. Price proposed that the new DOD Assistant Secretary for R&D, Harold Brown review the ANP Program.

Price, Cong. Melvin. "Aircraft Nuclear Propulsion". Excerpt from the *Congressional Record*. June 21, 1961. P.10155. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Cong. Price spoke about the death of the atomic powered airplane, "...assassinated by an unwise decision of the Department of Defense." He states that the only way to bring the program back would be for the Russians to successfully fly a nuclear-powered airplane. Price acknowledges the response of the press for their indication of the importance of the ANP Program to American prestige. Price inserts into the record an editorial from Belleville, IL *News-Democrat* which criticized the termination decision and praised Cong. Price.

Price, Cong. Melvin. "Aircraft Nuclear Propulsion Budget Cut Assailed by Congressman Melvin Price". Press Release. Jan. 17, 1961. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Cong. Price issued a statement critical of President Eisenhower's budget proposal of Jan. 16, 1961 which includes a reduction of the ANP Program funding by over 50%, from $73M to $33M. He also criticized Eisenhower's proposal to reduce the program to development of only one nuclear power plant concept, which was not specified. Price noted that this action, taken in the last week of the Eisenhower Administration, will embarrass the incoming Kennedy Administration. Price questioned how a decision on the best cycle was made, when as recently as Jan. 4, Courtland D. Perkins, Assistant Secretary of the Air Force for R&D stated that an additional period of experimentation and engineering will be required before a decision can be made between the direct and indirect cycles. Price attaches his recent correspondence on the ANP Project with DOD, including his criticism of the Air Force SAB Ad Hoc Committee's July 1960 report.

Price, Cong. Melvin. Letter to Robert McNamara, Secretary of Defense. Feb. 1, 1961. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Cong. Price urged the new Secretary of Defense to review and reconsider the actions taken by the outgoing administration to significantly reduce the ANP Program. Price enclosed copies of his Jan. 17, 1961 Press Release, the JCAE Report from the July 1959 public hearing on ANP. Price stated that many of the problems with the ANP Program were caused by a failure by the agencies involved to follow clear-cut lines of responsibility. He expressed the belief that the AEC should be primarily responsible for development of the nuclear engine, with the Air Force, as the customer, specifying the basic performance characteristics. He further stated that the DOD Office of the Director of Defense R&D interfered with the AEC, resulting in many starts and stops of the ANP work. He cited as an example the recent announcement of another major program change by the outgoing Eisenhower administration.

Price, Cong. Melvin. Letter to President Kennedy. Feb. 28, 1961. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Cong. Price, following up to a meeting between the President and JCAE Chairman Chet Holified, requested a meeting with Kennedy to discuss the ANP Program. Price states that "...the present nebulous state of the project justifies the immediate attention of the Administration to this program." Price briefly outlines recent events and encloses his Feb. 1 letter to Secretary McNamara, his Jan.17 Press Release and the Jan. 4 letter to him from the Air Force. He notes that although the Eisenhower Administration's Jan. 9 budget message announced only one of the two technical approach would be continued, no further action to make a selection has been forthcoming and the ANP Program is "...again in an indeterminable state."

Price, Cong. Melvin. Letter to President Kennedy. Mar. 18, 1961. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Price referred to his Feb. 28 letter to the President and repeats his desire to meet with Kennedy to discuss the ANP Program. Price notes that two executive session hearings have been held recently on March 8 and 15 and information received substantiate his concerns. He claims that the cutback ordered by the Eisenhower Administration originated in a hasty commitment by former Defense Secretary Gates to the House Appropriations Committee that a cycle decision could be made in the fall of 1960. In the recent hearings Deputy Defense Secretary Gilpatric was reported to have no technical basis for continuing with the Gates commitment. According to Price, Gilpatric relied upon Dr. Herbert York, outgoing DOD Director of R&D, who chose not to participate in these recent hearings. A staff member of Dr. York's Office, John Early Jackson testified that he assembled the information on which the decisions were reached. Price states that Jackson's "...hostility to the ANP project is well-known...". Price also criticizes the superficial reviews given this project by various inter-locking boards, specifically mentioning the Air Force SAB. He "reminds" Kennedy that the JCAE was primarily responsible for supporting both the nuclear Navy program and the H-bomb development, while the Executive Branch and many scientists were opposed. Price closes with the suggestion that the President examine the possibility the Soviets will fly the first atomic airplane and this would have adverse effects on U.S. prestige. Conversely, the benefits to U.S. prestige if we were to have the first such operational airplane should also be considered.

Price, Cong. Melvin. "Statement on Cutback in Aircraft Nuclear Propulsion Project". Press Release. Mar. 28, 1961. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Cong. Price responded to the March 28, 1961 Presidential Message that the ANP Program to develop a military nuclear-powered aircraft was being terminated. Price said that he regrets and questions this decision and hopes this will not set a precedent for other atomic energy projects. He noted that he had pointed out many times that we could have had a nuclear airplane flying if it had not been for the mismanagement of the DOD and its scientific advisors. Price stated that he can understand the President's decision from a fiscal standpoint, but cannot agree with his scientific and defense advisors' approach to development projects.

Price, Melvin. Separate letters to Donald Quarles, Secretary of the Air Force and C.C. Furnas, Assistant Secretary of Defense-R&D. Feb. 1, 1957. JCAE #5078. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Notified DOD that the JCAE R&D Subcommittee wanted to meet on Feb. 6, to review ANP developments. Price stated that they were particularly concerned about reported funding cutbacks.

Ramey, James T.,Executive Director, JCAE. "Termination of Aircraft Nuclear Propulsion Work by General Electric, Pratt & Whitney and Oak Ridge". Memorandum to All JCAE Members. Mar. 31, 1961. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Ramey summarized the March 30 AEC announcement to its contractors to terminate ANP work, except for some basic high temperature materials efforts. ORNL was also told to discontinue ANP shielding work, but not discharge any employees pending a complete review of ORNL programs. The AEC has requested $25M for FY62 support of the high temperature materials efforts, and possible continuation of the 10MW Pratt & Whitney reactor experiment. A table of the manpower and funding levels for FY61, prior to termination, is provided.

Ramey, James T.,Executive Director, JCAE. "Termination of Air Force Sponsored ANP Work". Memorandum to All JCAE Members. Apr. 4, 1961. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

Ramey summarizes the ANP termination actions by the Air Force and attaches the March 30, 1961 letter from Maj. Gen. Musgrave to JCAE Chairman Holifield. He also provides the manpower and funding for Air Force sponsored ANP projects, prior to the termination.

"Review of Manned Aircraft Nuclear Propulsion Program of the AEC and DOD". Comptroller General of the U.S. GAO. February, 1963. 191p.

GAO presents a comprehensive critique of the entire ANP Program, along with a summary of the Program's history. They point out that the program was characterized by frequent changes in emphasis and objectives, varying from a R&D program to an accelerated weapons development program for the Air Force, and at the time the program was cancelled in 1961, no nuclear-powered aircraft had been flown nor had any prototype plane been built. In addition, GAO noted that benefits accruing to the government from the $1B spent are dependent upon the future use of the facilities and the technology gained. (AEC is reported to have stated that the ANP facilities and technology have become the basis of much of the R&D for the space reactor programs). Furthermore, GAO commented on deficiencies they noted in the administration of the ANP Program, including DOD not furnishing sufficient and timely guidance, incurrence of costs for facility designs that were not used because of frequent program reorientations, and ineffectiveness of recurrent program reviews by temporary groups.

"Suggested Questions on Aircraft Propulsion". Prepared by JCAE Staff. Mar. 11, 1953. JCAE #3311. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

[Researcher Note: Although not specified, it appears that these questions were prepared for a hearing by the JCAE Subcommittee on R&D].
Question included: military mission, performance requirements and schedule for ANP; mission and funding for each contractor; decision point for selecting the best concept; has the decision two years ago to give priority to GE system proven valid; are potential competitors to present contractors being discriminated against. Also, the question is raised regarding advice received in 1951 from Dr. Eugene Wigner that the scale-up of the ANP Program should not proceed so quickly, since the technology was not yet ready to support the development. Dr. Wigner recommended waiting at least another three years before starting a scale-up.

Thomas, Morgan in collaboration with Robert M. Northrop. "Atomic Energy and Congress." The University of Michigan Press, Ann Arbor, MI. 1956. PP. 180-1.

Discusses the strong support provided to the ANP Program by the JCAE, including continuing insistence that a flight test be planned as a top priority. In particular the emphasis on early flight by Rep. Melvin Price is mentioned in his capacity as chairman of the Research and Development Subcommittee. Appendices provide a list of AEC Commissioner's and JCAE member's dates of service, and AEC budgets for Fiscal Years 1947-55.

"Statement on Cutback in ANP". Press Release. March 28, 1961. Accompanied by pg. 4329 of the *Congressional Record - House*, March, 1961. All attached to White House note from Spurgeon (Keeny) to Jerry(No last name used). RG359, Box 21, Executive Office of the President, OSTP Folder-ANP T.F.1961: National Archives II, Washington, D.C.

Keeny's note forwards Cong. Price's statement with the comment that "In addition to his statement, he did manage to get in a few interesting thrusts at the evil scientists in the Congressional Record (attached)." Price criticizes the President and DOD for using the criterion of a "militarily useful aircraft in the foreseeable future" as the basis for ANP cancellation. He argues that his and the JCAE's position on ANP has been that the military uses of an atomic powered engine cannot be foreseen until an experimental engine is in operation. He states that “When something is demonstrated our military people see a great many uses”. He further states that “I have pointed out many times we could have had nuclear aircraft in flight today if it had not been for the ‘on again, off again’ system of mismanagement by the Defense Department and its scientific advisors”. The *Federal Register* excerpt includes statements by Price and JCAE Chairman Cong. Chet Hollifield urging increased development in nuclear power, including ANP. Hollifield called for a fixed flight date for nuclear-powered airplane.

b. OFFICE OF THE PRESIDENT

Cole, Sterling, JCAE Chairman. Letter to the President. May 14, 1954. JCAE #DCCXCVI. RG128, Box 46, Folder - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

JCAE provided a report on the ANP Program from their R&D Subcommittee. The report points out that the deterrent value of the U.S. atomic weapons is directly related to the ability to deliver these weapons. As the enemy's defense and interception capabilities increase, U.S. delivery capability is less probable. This requires the development of a unique delivery system, arguing for an emphasis on the ANP Program "...with as much vigor as has been devoted to achievement of the weapon stockpile itself". Cong. Cole described the recent radical change in the ANP Program with the concept of using nuclear power for subsonic cruising and a chemically-powered supersonic sprint to the target. He went on to explain that all efforts over the past eight years directed toward a supersonic nuclear-powered aircraft engine have failed, in spite of spending $100M, because of the inability to achieve extremely high temperatures in a small enough reactor to fit into a practical airframe. The new concept may be possible because of the existence of an jet engine that can utilize both nuclear and chemical power, the J-75 manufactured by Pratt & Whitney. This system would not be available until after 1960, perhaps as late as 1965. However, given a "crash" priority, [Researcher Note: The unfortunate choice of the word "crash" is Cong. Cole's], proof testing could be advance to 1957. The letter states that Gen. Keirn indicated that Gen. Curtiss LeMay regards the nuclear-powered aircraft as potentially the most significant advance in U.S. strategic air capability since the advent of nuclear weapons. Cole also argues that ANP will provide a more effective delivery system than ICBM's currently under "crash" development. This letter was provided to DOD and AEC.

Keeny, S.M. , Jr. Memorandum to Dr. James Killian, Presidential Science Advisor. "WSEG Report on ANP." May 15, 1959. RG359, Box 4, Executive Office of the President, OSTP Folder-ANP Panel 1959: National Archives II, Washington, D.C.

Summarizes the results of a study of the military worth of the ANP, in advance of Killian's meeting with Dr. York, Gen. Loper and Gen. Luedecke. Conclusions of study are anticipated to be: (a) Requirement exists for a subsonic, low-altitude bomber in 1968-75 period and ANP has advantage over convention power, (b) For AEW and ASW conventional power has the advantage, and (c) ANP cannot compete for logistics missions during wartime in 1968-75 period.

Keeny, S.M. , Jr. Memorandum to Dr. James Killian, Presidential Science Advisor. "Meeting on ANP with Dr. York. May 15, 1959. RG359, Box 4, Executive Office of the President, OSTP Folder-ANP Panel 1959: National Archives II, Washington, D.C.

Provides questions to be raised at Killian's meeting this date with . Killian's concurrence will be sought for recommendation to the President that a special aircraft be built by Convair to test GE reactor.

Keeny, S.M. Memorandum to Dr. James Killian, Presidential Science Advisor. "Alternative ANP Programs." May 18, 1959. RG359, Box 4, Executive Office of the President, OSTP Folder-ANP Panel 1959: National Archives II, Washington, D.C.

Questions the Air Force proposed FY60 changes to the ANP Program to construct two test aircraft for flight testing the GE reactor in 1964. Also they propose to construct an experimental lithium-cooled indirect cycle reactor. Keeny states that there have been no technical developments by GE to justify this proposal, while he favors proceeding with the indirect cycle reactor experiment at Pratt & Whitney. Keeny suggests that the current GE work be terminated and reoriented to nuclear ramjet or rocket work. Suggestion is based on lack of demonstration of GE fuel at even the minimum temperatures required for flight. Keeney expresses concern about retaining the same GE management for a reoriented program because they would be the same group "...who attempted to build a weapon system empire in their work on the direct air cycle".

Eisenhower, President Dwight D. "Press Conference". *Keesing's Contemporary Archives.* 1958. p. 1183.

In a Dec. 10, 1958 press conference, President Dwight D. Eisenhower responded to a question about the ANP Project, as follows: "There is no usefulness that anyone could possibly see from such a plane. There is no use of going into a field where the whole purpose would be to get a plane a few hundred feet off the ground. There is absolutely no intelligence that Russia is flight testing an atomic powered airplane."

Kennedy John F. "Special Message to the Congress on the Defense Budget. March 28, 1961". Contained in "Public Papers of the Presidents of the United States". Jan.20-Dec. 31, 1961. U.S. Government Printing Office. 1962. p. 239.

President Kennedy, states that after nearly 15 years and about $1 billion, that the possibility of achieving a militarily useful nuclear powered aircraft is "still very remote". He proposes to "terminate development effort on both approaches on the nuclear powerplant, comprising reactor and engine, and on the airframe; but to carry forward scientific research and development in the fields of high temperature materials and high performance reactors...".

Killian, James R., Jr. "Report to the National Security Council by the Technological Capabilities Panel of the Science Advisory Committee". Feb. 14, 1955. pp. 198-200.

This report is frequently referred to as the "TCP Report or the Killian Report". James Killian was at that time the President of MIT. The panel recommended the high-priority development of nuclear propulsion for aircraft. This recommendation was made in the context of a comprehensive evaluation of weapons and intelligence technology ways of avoiding a surprise attack by the Soviet Union on the U.S. The evaluation was requested by President Eisenhower.

“Meeting of the ANP Panel of the Science Advisory Committee”. Jan. 21, 1958. RG359, Box 4, Executive Office of the President, OSTP Folder-ANP Panel 1959: National Archives II, Washington, D.C.

In a meeting held at in Washington, D.C., attended by the panel of Dr. Robert F. Bacher (Presiding), Dr. Hans Bethe, Dr. Hugh P. Dryden, Dr. Kenneth W. Davis, Gen. Loper and Joe C. Jones (AEC-ANPO), Gen. Keirn and others made statements regarding the acceleration of the ANP effort. The incentive for acceleration came from the U.S.S.R. launch of *Sputnik* in October 1957. Keirn provides a summary of the program’s history, including a good discussion of the changing Air Force requirements and the strategic uses of a nuclear-powered aircraft. He also discusses the Navy’s ANP needs. Although portions of the transcript remain classified, it is apparent that considerable discussion took place on Russian ANP capabilities. Keirn believes that “...a great deal of information from the Lexington Report was leaked”. He also cites an article in *Pravda* which discusses the technical problems for ANP.

Smith, Dr. Cyril Stanley. Memorandum to Dr. James Killian, Presidential Science Advisor. “Notes on a Visit to GE ANP Facilities, May 28-June 2, 1959". June 10, 1959. RG359, Box 4, Executive Office of the President, OSTP Folder-ANP Panel 1959: National Archives II, Washington, D.C.

Describes trip to GE with Dr. Herbert York and his party. After discussing status of high temperature fuel R&D, Smith concludes that the XMA-1 is an inadequate nuclear-powered engine with the design capability to just fly at 10,000 ft. at Mach 0.5 to 0.6 for a distance of only 750 miles. He also concludes the next stage, XMA-1c is more questionable with untried materials. Even if successful, Smith believes these materials will not operate at the highest temperatures desired in the ANP Program.

Strauss, Lewis, Chairman, AEC. Letter to the President. Dec. 22, 1955. (Portions still classified.) RG326, Box 51, AEC Secretariat Files, Folder - Military Research and Application, Aircraft Propulsion, Vol.4: National Archives II, Washington, D.C.

Chairman Strauss requested authority to transfer additional special nuclear material (i.e. fissionable uranium) to the DOD for use by Consolidated Vultee Aircraft Corp. for use in a replacement nuclear core for the GTR.

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CHAPTER 6.
FOREIGN ANP-RELATED ACTIVITY

"A-Project Atomic Aircraft". *(*In German*). Schweiz. Techn. Z.* 54 (1957): 1021-2.

Article reviewed the U.S. ANP Program.

Alder, K.F. "Growth of Beryllium under Irradiation". AAEC/E-6. Atomic Energy Commission Research Establishment, Lucas Heights, New South Wales, Australia. Feb. 1956. 10p.

The results of a calculation estimating the rate of swelling of beryllium metal by the formation of bubbles of helium gas due to irradiation are reported.

Artamkin, V. "On an Atomic Airplane". T-106 (RAND). Translated by C. M. Weber, Jr. from *Atomnaya Energ.* 4, 389-91(1958): 9p.

A discussion concerning aspects of atomic airplane design is presented. Crew protection and associated weight factors are examined, and engine design features are covered. A review of general activities along this line in the U.S., England, and France is included.

Artamkin, V. "The Atomic Aircraft". (In German). *Kernenergie* 2 (1959): 86-8.

Discussed the U.S. ANP Program progress to date.

"Atomic Energy in Search of a Market". Interavia (Switzerland), Vol. X, No.11, 1955. pp. 847-52.

Reports on the first "Atoms for Peace" Conference held by the United Nations in Geneva, Switzerland, August 8-20, 1955. This article emphasizes nuclear powered flight from information provided at the conference. A brief history of the NEPA and ANP Projects is provided. Included in this history are statements that both the Canadians and British had started ANP Programs and that Martin Co. and Curtiss-Wright are both involved in the U.S. program. The article also states that the most likely type of reactor for aircraft propulsion is the fast breeder reactor. Use of a reactor for propeller driven aircraft such as the B-36 bomber or the Saro Princess flying boat is said to require an 80 ton powerplant.

"Atomic power for aircraft". (In German). *Universum* 11, 8 (1956): 242.

Reviewed the ANP Program in the U.S.

"Atomic aircraft". (In Russian). *Kryl'ja Rodiny* 6 (1958): 21.

One of several Russian articles on ANP that appeared around this time.

"Atomic Power for Aircraft". Research by British manufacturer. *Capital* 136**,** 3397 (1956) 270.

Aviation Week. Oct. 10, 1955. P. 54.

Gave one of the first speculative reports that suggested that the Soviets had a nuclear powered aircraft program. Included an illustration of a Soviet artist's conception of what such an aircraft would look like. Drawing was apparently taken from a popular youth monthly, *Mechanics Youth*. Six months later, *Newsweek* (April 23, 1956), p.35. reprinted the same picture, without identifying the source.

Aviation Week. January 12, 1959. p. 26.

Reported that Soviet publications stated that 1959 "will see first trials of atomic engines for civil aviation". Article indicated that Soviet scientists had been working for some time on atomic engines for civilian applications and successful results were the basis for this announcement.

Balrabanov, E. "The Possibilities of Using Atomic Energy in Aviation." *(In Russian). Gratdanskaja Aviacija* 12, 4 (1955):30-2.

One of the earliest Russian articles openly published on ANP.

Baxter, A.D. and G.E. Preece. "Nuclear Power in Aviation." *Aeroplane* 94, 2423 (1958): 171-73. Extracted from article in *de Havilland, Gaz.* Feb. 1958.

Based on theoretical considerations, it was concluded that use of nuclear propulsion appeared to be technically feasible but a vast program of research and testing would be required to produce a reactor of acceptable weight and standard of reliability. There remained the problem of ensuring that no excessive radiation hazard will exist in event of accident.

Bosnac, T. *Nuklearna Propulzija*. Belgrade, Novinsko-izdava_ko Preduze_e Export Press. [no date] 86p.

Discussed the application of nuclear energy to propulsion and presented the basic principles involved in the operation of reactors, followed by descriptions of applications for propulsion in the ice-breaker Lenin and the N.S. Savannah. The state of the art of nuclear ship propulsion was reviewed for the important maritime countries. The principles of nuclear rocket propulsion were also considered, with special attention to ion propulsion. Finally, the author mentioned the application of nuclear power for propelling aircraft and surface vehicles, such as locomotives.

Bunata, O. "Use of Atomic Energy in Aviation". (Translated from Czech). *Wings of the Fatherland*, 8(Apr. 19, 1954):178-9. RG128, Box 463, Folder - ANP Vol. 4, Jan.61 - Declassified Records from the Classified JCAE Subject File:National Archives, Washington, D.C.

This is a verbatim translation by Air Intelligence of the article, along with 3 schematic drawings. The article elaborateed on the possibility of nuclear- powered aircraft and discussed various types of engines. The article acknowledged that the utilization of nuclear power for aircraft in the USSR will be considerably more difficult than for other applications. Discussed both direct air and indirect liquid metal cooled cycles.

Burgdorfer, A., R. Tognoni, and W. Spillmann."Application of the Closed-Cycle Principle to Aircraft Propulsion Systems". Volume VIII, Chapters 1 to 9. "Sizing of the Components of a Closed-Cycle He-NAP System". AFOSRTR-58-32. Escher Wyss GmbH, Zurich. (1957) 50 p.

Described work on sizing of axial compressor, turbines, fans, recuperator, cooler, ducting, and auxiliaries for a helium closed-cycle nuclear aircraft propulsion (NAP) system.

Butz, J.S., Jr. "Soviets Study Nuclear Plane Concepts". *Aviation Week* 71, 2 (July 13, 1959): 65, 67.

Article discussed the various proposals the Russians supposedly have under consideration for nuclear-powered aircraft.

Chang Pin-Chuan. "Energy Sources in Aircraft Engines". (Trans. from Chinese). FTD-HT-23-584-6820. Foreign Technology Div. Wright-Patterson AFB. Oct. 9, 1968. 7 p.

Author reviewed the properties and limitations of chemical fuels such as gasoline, solid fuel and hydrogen fuel, and discussed the possibilities of ionic fuel and nuclear fuel, and their existing problems of application to aviation. It was stressed that with scientific progress and requirements, these pending problems may soon be solved.

“Characteristics of nuclear-powered aircraft”. (In German). *Luftfahrttechn.* 3 (1957): 1.

Briefly explained the basic requirements for a nuclear-powered airplane.

Cherkasov,B. A. “Automation and Control of Jet Engines”. (Trans. from Russian). FTD-MT-24-237-6820. Foreign Technology Div. Wright-Patterson AFB. Sept. 27, 1968. 496 p.

Discusses principles of control of gas-turbine and ramjet aviation engines. Includes a general idea of the control of nuclear jet engines, principles of external control of an aircraft power plant and the application of statistical calculation methods, allowing consideration of the effect of random influences on control systems.

Driessen, A. ed. “Power Units for Future Aircraft”. *Ingenieur ('s-Gravenhage)* 65 (1953):7-15.

Included discussion of nuclear-powered aircraft.

Ermakov, A. P. and A.G. Syramai. “Atomic Energy and Aviation”. (Trans. from Russian). FTD-MT-64-41520. Foreign Technology Div. Wright-Patterson AFB. Feb 12, 1965. 19 p.

Presented a general discussion of aviation technology as a preface to a more specific discussion on aircraft nuclear propulsion. Subtopics included aircraft reactors, aircraft nuclear power plants, nuclear open cycle turbines, ramjet atomic engine and closed cycle systems.

First things first”. *Verkehr (Oesterr.)* 12, 32 (1956) 1051. See also: *Atoms for Peace Digest* 2, 12 (1956) 6.

Reviewed development programs for the U.S. ANP effort.

Florio, F. “The Nuclear-Propelled Aeroplane”. (In Italian). *Polit. Trasp.* 7**,** 3 (1957): 147-53.

Discussed the U.S. ANP Program.

French Atomic Developments”. *Atomics* 8 (Jan. 1957): 15-19.

Described the French atomic power program, including existing facilities and those planned for the immediate future.

[*Researcher Note:* May indicate early French interest in ANP].

Grzegorzewski, J. translated by J. Woroncow. "Application of Nuclear Propulsion in Aviation." XDC 60-10-151. GE ANP Dept., Cincinnati. September 22, 1960. 13p.

This is a translation of a Polish technical article from *Wojskowy Przaglad Lotniczy, (Polish Airforce Review)* Warsaw. 13, 3 (March 1960):24-32. In this study are discussed various aspects of atomic aircraft engines. Presented basic information on nuclear turbojet, turboprop and ramjet engines. Discussed possible application of atomic energy in rockets in the section., "Nuclear Rocket Engine" and in the section "Aircraft with Nuclear Propulsion" where the author compared chemical fuel with nuclear fuel. Reviewed in general the shielding problem, safety, materials, ground service, landing and vertical take-off.

Gun Czjan'. "Aircraft Nuclear Propulsion". (In Russian). *Hangkong Zhishi* 2 (1959): 4-6.

One of a series of Russian articles on ANP published in this time period.

Hinz, E. R. "Stability and Control Characteristics of the Vertical Attitude VTOL Aircraft". *Canada Aeronaut. J.* 4, 2 (1958): 52-62.

Included some consideration of a nuclear-powered VTOL aircraft.

Hotz, Robert. "The Soviet Nuclear Powered Bomber" and "Soviets Flight Testing a Nuclear Bomber". *Aviation Week.* December 1, 1958. p.1, 26-29.

Reported (erroneously) that the Soviets had been flying a nuclear-powered bomber for at least two months in the Moscow area. The article stated that the aircraft was powered by two direct cycle nuclear power plants producing 70,000 lbs. of thrust, supplemented by two conventional jet engines of 35,000 lbs. thrust each. It was reported that this aircraft was the result of a Soviet high-priority program for nearly the past 8 years. Article made reference to brief reports in the Soviet technical press, about a year ago, of successful ground testing of atomic aircraft powerplants. The article concluded with the following statement: "Recent speculative stories in the Soviet popular press suggest conditioning the Russian people to an announcement of a spectacular achievement by an atomic powered aircraft in the near future, probably a nonstop, nonfueled flight around the world." [Researcher Note: This article appears to be calculated to fuel the "bomber gap."]

"Improvement in Aircraft Propulsion". British Patent 798,617. *Nuclear Power* 3 (1958): 462.

The propulsion unit comprises a multi-stage, axial-flow compressor delivering air through the channels of a reactor, a number of combustion chambers, and the nozzles and rotor blades of a turbine, finally discharging it through an ejection nozzle. When the aircraft is on or near the ground the reactor is shut down, the air passes through it without heating and the combustion chambers are fed with hydrocarbon fuel so that the unit becomes a conventional turbo-jet. There is a pressure loss between the compressor and combustion chambers prevented by a modification of the idea in which those units are parallel.

"Is the nuclear-powered aircraft on the way?". (In German). *Flieger 31*, 1 (1957) 12-4; 2 (1957) 54-6; 3 (1957) 75-6.
Reviewed the ANP Program of the U.S. and future prospects.

Jaeger, Th. "Shielding of nuclear aircraft power units". (In German) *Techn.* 12, 11 (1957): 762-63.

Discussed the problems of shielding in the ANP Program.

Jefferson, S., ed. "Handbook of the Atomic Energy Industry". George Newnes Limited, London: 1958. 256p.
Information is presented on the atomic energy industry throughout the world, including nuclear power for aircraft.

Kackley, P. "Nuclear Power for Aircraft." *Canad. Aviat.* 30, 3 (1957): 32-84.

Reviewed the prospects for nuclear-powered flight.

Kaeppeler, H. J. "Use of Nuclear Energy for Storage Jet-Propulsion Units". (In German). *Astronaut*. *Acta* (Wien) 2 (1956): 48-52.

Discussed the U.S. ANP Program.

Kopalin, S. "Birth of Atomic Aviation". AEC-tr-3178. Translated from *Krasnaja Zvezda* 232 (1956) 4 p.

Discussed the possibilities of the application of nuclear energy to the powering of aircraft are discussed. A nuclear aircraft is described, including the design difficulties with respect to weight and personnel protection from radiation.

Krieger, F. J. "The Russian Atomic Airplane of the Future". T-55 (RAND). RAND Corp., Santa Monica, CA. Jan. 26, 1956. Includes translation of article by G. I. Pokrovskti (Pokrovsky) from *Tekh. Molodezhi* (Aug. 1955): 7p.

Presented an idea for design of a nuclear powered airplane based on fission in uranium dust in a graphite moderated area.

Kulesca, A. "Atomic Horses." NP-tr-658 Translated from *Horyzonty Tech*., No. 2, 63-8 (1960). 16p.

Reviewed the advantages and problems of using atomic energy for aircraft and rocket propulsion. The possible engine types which may be used with a nuclear reactor are outlined, and discussed the research programs being conducted in this field by U.S.A. and U.S.S.R.

Kurchatov, I., et al. "Atomic Energy in Aviation and Rocket Technology". (Atomnaya Energlya v Aviatsii i Raketnol Tekhnike). NP-tr-344. Translated from a publication of the Military Publishing House of the Ministry of Defense, Moscow, 1959. 547p.

Presented a description of the possibilities and prospects of the utilization of nuclear energy in aviation and in the development of aviation and rocketry.

Les Perspectives Prochaines D'une Aviation a Propulsion Atomique." *Techn. et applic. petrole* 13, 151-152 (1958): 5997, 5999, 6001.

Discussed the prospects for a successful ANP Program.

Malodorskii, Ya. Yu. and E.V. Rovinskii . "Aircraft Nuclear Power Plants". (Atomnye Aviatsionnye Dvigateli). NP-tr-661. Translated from Chap. 1, p. 29-32 of "Osnovy Termodinamiki i Gazovoi Dinamiki," Moscow. 1960. 5p.

Described the series of structural, technological, and operations difficulties which occur during the utilization of a nuclear reactor in aircraft engines. Discussed the nuclear turbojet engine and its differences from the ordinary turbojet.. Reviewed the weight and size of the nuclear aircraft engines and methods of reducing them.

Medici, M. "Nuclear Engineering Aspect of Present Trends in Nuclear Fueled Aircraft Research". (In Italian). . *Aerotecn.* 37 5 (1957): 273-77.

Included discussion of the nuclear-powered aircraft.

Mikhailov, V.A. ed. "The Application of Atomic Engines in Aviation". Military Publishing House of the Department of Defense: 1957. 167p. In Russian.

Gave a compilation of published data on applications of nuclear power plants in aviation and in rockets in popular form. Described various aspects of nuclear reactors including their performance, the fuels used and their prospective applications in aviation and in interplanetary flight. Analyzed the flight of aircraft propelled by chemical and nuclear

energy and the complications involved in construction of nuclear aircraft reactors. Designs of aviation nuclear power plants are shown, including rocket engines, air-cooled engines, turbojets, turboprops, etc. Discussed radiation hazards and protection involved in nuclear powered aircraft and servicing problems in flight as well as the nuclear aircraft take-off and landing characteristics.

“More about Nuclear-Powered Aircraft" *Aeroplane* 90, 2322 (1956):92-3.

Reviewed work being done in United States including a diagram of a hypothetical nuclear power plant using pressurized water type of reactor which, it was suggested, will be incorporated in first American nuclear aircraft. Made reference to British nuclear engines.

“Moscow Claims to be Building an Atomic Plane". *Missiles and Rockets*. 2,6(June 1957):54.

Reported that the USSR has announced the building of an atomic powered airplane in Moscow that will encircle the earth at 1800 mph, and fly non-stop to a new Soviet base in Antarctica from Moscow. Prof. G. Pokrovsy, reported as the chief Soviet authority on atomic planes, is quoted as saying that regular air travel to Antarctica is necessary. The Soviets are said to be in the first preliminary phase of experimentation, but are confident that a plane will be flying soon. Another Russian physicist-mathematician, Y. Balabanov, stated that the most serious problem is the 100 ton weight of the protective concrete shielding. The high temperature materials problems will be solved by the Russians, according to Prof. Pokrovsky. He also stated that the future atomic aircraft will have jet engines that rotate from vertical (for take off) to horizontal (for flight).

Munzinger, Friedrich. “Atomic Power - The Stationary Structure and the Movable Atomic Drive and their Technical and Industrial Problems - A Critical Introduction for Engineers, Political Economists, and Politicians” (In German). Springer-Veriag: Berlin: 1960. 316p.

A survey of world-wide power reactor development for electric power and propulsion is presented in five parts. In a theoretical part, basic atomic physics is reviewed and sections on reactor cooling systems and on structural and fuel materials are given. The technical part has an extensive section on reactor structure which discusses fuel elements, the different reactor systems, thermal and biological shielding, control of reactors, accident hazards, removal of atomic waste, and heat exchangers and circulating pumps. Other technical sections are devoted to power-removal machinery for reactors, fuel material and structural material requirements of reactors, and the structure of the whole atomic power plant. The industrial part has sections on competitiveness of atomic power plants, German atomic power plant construction, and the atomic industry. The fourth part discusses atomic power and the second industrial revolution. Part five, Atomic Drives for Propulsion Installations, includes reactors for ships, airplanes, rockets, locomotives, and power trucks.

Nesterenko, G.N., A. I. Sobolev, and Yu. N. Suskov. “Application of Atomic Engines in Aviation”. NP-tr-81. Publication of the Military Press of the Ministry of Defense of the USSR, Moscow (1957) 187 p. Available from NTIS.

The scattered data in the literature on the utilization of atomic power plants in aviation and rocket engineering were systematized and reviewed in popular form. Discussed the range of aircraft using chemical and nuclear fuels, the two major methods of obtaining nuclear energy, a comparison of the world resources of chemical and nuclear fuels, and the first concept of atomic aircraft engines. The principles of reactor engineering and the various types of reactors were dealt with in an elementary manner. The possible types of nuclear aircraft power plants were divided into three major groups: rocket engines; three types of ramjet engines; turbocompressor engines and motordriven compressors; and turboprop engines. Discussed the most typical designs of nuclear aircraft power plants are reviewed and the possibilities of their application.

‘Nuclear Research in French Aviation.” *Eng.* 205 (1958): 868.

Discussed consideration of nuclear powered for aircraft by the French.

“Nuclear Powered Aircraft”. (In German). *VDI-Nachr. 10*, 2 (1956) 2.

Discussed the U.S. ANP Program.

“Nuclear Energy for Propulsion of Aircraft”. (In German). *Interavia* 6, (1951):246-7.

Reviewed the prospects for nuclear-powered airplanes.

“Nuclear-powered aircraft”. (In German). *Europa Technic-Masch. u.* Werkzeuge 19, 57 (1956): 38,40.

Discussed the possibility of nuclear aircraft.

Perelman, Ropman G. “Soviet Nuclear Propulsion”. Triumph Pub. Co., Washington. 1960. 31p.

Described a Russian nuclear propelled flying boat project proposed in 1950 with a flying weight of 1000 tons. The plan was to provide four atomic powered turbo-prop engines of greater than one-half million horsepower. With a wing span of more than 130 meters, the aircraft was to carry 1000 passengers and 100 tons of load at a speed of 1000 km/hr.

Pokrovskii, G. I. “The Russian Atomic Airplane of the Future”. T-5520. Rand Corp. Santa

Monica, CA. Jan. 26, 1956. 10 p.

Discussed the possible design of a future Russian nuclear powered aircraft, including the reactor and shield.

Pokrovskii, G. "Red Star Series on the Problems of Utilizing Atomic Energy. Pt. V. The Nuclear Fuel Engine". (In Russian). No date. 10 p.

This article was concerned with the application of atomic engines to submarines, aircraft, guided missiles and automobiles. Although not yet used in aircraft, atomic engines are reported to have great significance for pilotless aviation, e. g., guided missiles, long-range rockets, and cargo- and passenger-towing aircraft, since there is no need for extremely heavy shielding around the nuclear power plant.

Pokrovskii, G.I. "The Way to an Atomic Aircraft". AEC-tr-3537. Translated from *Sovet. Aviatsiya*, 152 (June 1957): 2-5.

A discussion of the design of a nuclear-powered aircraft is presented. Crew protection is most important, and a design is presented to place the crew as far as possible from the reactor and to locate mass, such as normal aircraft mechanisms, between crew and reactor instead of a shield to serve solely as crew protection. Other methods of separation of people from the reactor vicinity are discussed, such as teleguided glider tow aircraft and the use of remotely controlled freight planes.

Preston-Thomas, H. "Nuclear Electric Propulsion System". *Brit. Interplan. Soc. J.* 16,9 (1958): 208-17.

In paper by R. W. Bussard an expression for maximum overall specific impulse of ion rocket is derived. It is shown that insufficient account is taken of variables involved and the expression is incorrect. Solutions valid for various design parameters are given and overall specific impulse is replaced by characteristic velocity.

"Prospective Atomic Aircraft". *Rodiny, Kryl'ya* 8 (1957): 25p. In Russian.

A brief review was given of prospective aircraft using atomic power. The types of aircraft mentioned were the atomic electrically driven aircraft, the nuclear turbojet, the ion-flux rocket, and the thermonuclear rocket missile.

Reis, T. Economic Aspects of the Industrial Applications of Nuclear Energy . In French. *Dunod.* 1958. 383 p.

The economic evaluation of nuclear energy is a function of a large number of variables and hypotheses to which no absolute values may be assigned. However a large number of technical-economic studies have been made, especially in the United States, An attempt is made to assemble these studies so as to find a unity in the methods of calculating these

variables and to apply these methods to specific cases. The utilization of nuclear reactors for the production of electrical energy and fissionable materials is, at present, the most important application. Reactors, therefore, are discussed in great detail, and the technical factors influencing the cost/kw are considered. The utilization of nuclear reactors for propulsion of ships, planes, and land vehicles is then discussed. 238 references.

Reynolds, C.A. "Some Observations on the Propulsion of Aircraft by Atomic Energy". (In German) *Atomkernenergie* (1956): 351.

Discusses concepts for nuclear-powered flight.

"Rolls-Royce on Nuclear Propulsion". *Aeroplane* 91**,** 2363 (1956): 905-7; 2364 (1956): 938.

Review of three papers by senior engineers of Rolls-Royce Nuclear Engineering Section: "Atomic Energy for Aircraft Propulsion", J. E. B. Perkins; "Safety Considerations of Nuclear Power Reactors", C. D. Boadle; and "Atomic Energy for Aircraft Propulsion", S. G. Bauer.

"Russians Review Aircraft-Reactor-Performance Goals. *Nucleonics* 17,1 (1959): 84.

Reported on a recent Russian publication (see Nesterenko, G.N., A.J. Sobolev, et. al.) which reviews the requirements for a nuclear-powered aircraft. *Nucleonics* did not indicate the Russians have an active development program, but rather they were describing approaches which reflect the U.S. program. *Nucleonics* also reported on the recent *Aviation Week* article that stated that a Russian nuclear-powered aircraft was already flying. (See Holz, Robert. *Aviation Week* (Dec. 1, 1958):1, 26-29).

Samaras, D.G. "Nuclear Propulsion and Engineering for Engineers." Athens, The Technical Chamber of Greece (1955). 720 p.

The fundamentals of nuclear physics and engineering from the aviation point of view are discussed. The existing information on nuclear reactors and their ramification for use in aviation is analyzed. A knowledge of the theory of differential equations and elementary statistics is assumed in the reader. The book is expected to cater to the needs of both undergraduate and graduate students and to professional engineers in different areas of theological endeavor.

Samaras, D.G. "Nuclear Propulsion, Aviation's Future." *Can. Aeronaut. J.* 1, 6 (1955): 163-68. Future aviation is subdivided into terrestrial, interplanetary or solar, and intragalactic aviation. Terrestrial aviation was achieved in 1903 and interplanetary aviation may be attained by use of nuclear propulsion system. Intragalactic aviation seems unlikely by known methods of propulsion, however, more advanced methods, such as field interaction propulsion may give satisfactory results.

Schulz, R. W. "Work on Development of Nuclear Power Plant for Aircraft". (In German). *Luftfahrttechv* 3 (1957): 22-6.

Discussed current efforts on ANP.

Schulz, R. W. "Ways to Nuclear-Powered Aircraft Power-Units". *Luftfahrttechn.* 2 (1956)**:** 33-4.

Reviewed approaches for nuclear-powered flight.

Sedov, A. "The Problems of Safeguards Against Radiation on Atomic Aircraft". AEC-tr-3489. Translated from Russian. *Sovet. Aviatsiya* (Oct. 25, 1957): 5p.

Reviewed information on the subject contained in the foreign press. The discussion included radiation characteristics and means of protection. Also included was a diagram of the shielding in a projected aircraft. Underscored the probable vulnerability of the atomic aircraft.

Shevyakov, A.A. "Automation of Aircraft and Rocket Power Plants". (Trans. from Russian). Foreign Technology Div. Wright-Patterson AFB. Feb. 5, 1969. P.436.

First published in 1960, this second-edition, revised and enlarged, textbook was intended for aeronautical schools of higher education, and may also have been useful to engineers and scientific workers. The book, based partly on the author's own work, dealt with automatic regulation and control of aircraft and rocket power plants, discussed control systems used in turbojet, turboprop, ramjet, and liquid-rocket engines and nuclear and other power plants. Special attention was given to safety requirements. There were 38 References; 28 Soviet (Translations), 9 in English, and 1 German.

Shortall, J.W. "Atomic Energy Plants for Aircraft". *Atomkernnergie* 3 (1958):150-54, 397-401.

Reviewed the use of nuclear reactors as power sources for aircraft included consideration of the shielding problems. Discussed the research program in the United States for the development of nuclear aircraft, including the power plant, radiation protection and shielding.

Sorger,M. "Vers Une Aviation Atomique". *Nature* 3266 (1957): 228-32.

Provided a French review of ANP.

"Soviet Scientific and Technical Literature Volume I. Selected Bibliography." XDC-60-4-2.

General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. 346 p.

A selected bibliography was presented of Soviet scientific and technical literature. Subject, publication and translation data were presented for 90 periodicals and 598 monographs. The references were listed in alphabetical order by title of periodical or by last name of first author of monograph.

"Soviet Scientific and Technical Literature Volume II. Selected Bibliography." XDC-60-4-61. General Electric Co. Aircraft Nuclear Propulsion Dept., Cincinnati. 277 p.

The bibliography included references on aircraft design, aircraft nuclear propulsion, apparatus and testing methods, automatic and remote control, gas turbines, high temperature materials, heat transfer, hoisting equipment, manufacturing technology, nuclear fuel, nuclear radiation environment, pumps, and tires. About 3500 references.

"Soviet Nuclear Plane". *Aviation Week.* December 22, 1958.

Published three letters to the editor commenting on the Soviet nuclear powered airplane article in the December 1, 1958 issue of *Aviation Week.* All letters expressed serious concern that the U.S. national security may be threatened by the Soviet strategic advantage and that the U.S. ANP Program needed to be accelerated. Two of the letters were from Air Force officers and the third was from a civilian engineer.

Spillmann, W. and B. Speckert. "Application of the Closed- Cycle Principle to Aircraft Propulsion Systems. Volume VII, Chapters 1 to 4. Gaseous Working Media for Closed Cycle Power Plants. (Cover Carries Title: "Closed Cycle Aircraft Propulsion Systems)". AFOSR-TR-58-31. Escher Wyss GmbH, Zurich. July 21, 1957. 32p.

At the present state of the art, helium, nitrogen and carbon dioxide are considered feasible as working media in nuclear power plants. Particularly for a nuclear aircraft plant, helium seems to be the best suited gas with respect to radiation stability and resulting plant size. A great advantage is the excellent heat transfer properties of helium. They are of prime importance for the size of the heat transfer equipment, which naturally should be kept as small as possible for use in aircraft. In the cycles under consideration gaseous mixtures might also be used as working media.

Spincourt, J. ."Etat Actual et Avenir De La Propulsion Atomique Des Avions". (In French). *Ingrs. et Technicians* 112 (1958): 45, 47.

Discussed nuclear propulsion of aircraft.

Suskov, Yu. N. "Atomic Energy in Aviation". (In Russian). All-Union Society for the Dissemination of Political and Scientific Knowledge. Series IV, Science and

Engineering 4, 22 (1958): 1-30.

On of a series of Russian documents on ANP published in this time period.

"The Use of Nuclear Power for Aircraft Propulsion". (In German). *Flugwehr. u. Techn*. 19, 12 (1957): 338.

Discusses nuclear-powered aircraft development efforts in the U.S.

Thompson, M. W. "Radiation Damage." NP-9340 (Vol. I.)(Sect. III). United Kingdom Atomic Energy Authority Research Group. Atomic Energy Research Establishment, Harwell, Berko, England. Section of Advanced Course on Fuel Elements for Water Cooled Power Reactors. 33p.

Reviewed recent advances in solid-state research that provided a general picture of the mechanisms of a damage model for the observed effects. Considered fast neutrons, beta radiation, gamma radiation, and slow neutrons and the damage each produces.. The structural processes of damage. Outlined effects in nonfissile materials, metallic fuels, and ceramic fuels.

Thring, M.W., ed. "Nuclear Propulsion". Butterworth & Co. Ltd. London: 1960. 303p.

Studied aspects of nuclear marine, aircraft, and spacecraft propulsion. Discussed design, metallurgical, and heat transfer problems associated with propulsion systems reactor. Examined nuclear and reactor physics, jet and rocket propulsion thermodynamics, and medical and biological aspects of sealed environments. Attention was devoted to the following: reactor control and instrumentation; uses of ceramics in reactors; problems encountered in handling working fluids; and uses of the nuclear closed-cycle gas turbine.

Tognoni, R. "Application of the Closed Cycle Principle to Aircraft Auxiliary Power Plants. Volume IX. Comparison Between Direct and Indirect Heat Addition from an Atomic Reactor to a Closed Gas Turbine Cycle". (Cover Carries Title: "Direct and Indirect Addition of Heat and Pumping Power"). AFOSR-TR-58-33. Escher Wyss GmbH., Zurich. Technical Note No. 5. July 2l, 1957. 61p.

Discussed how heat can be added to a gas turbine cycle either by a heat source in the cycle itself, or through a heat exchanger in connection with an external heat source. The penalties for this second configuration were investigated and its efficiency compared to the "simple" cycle.

Truelle, J. "La Propulsion Nucleaire Des Avions." I-11. "Les Problemes Techniques Particuliers Poses Par La Propulsion Nucleaire." (In French). *Forces Aeriennes Franc.* 142 (1958) 653-76; 143 (1958) 967-99.

Discussed the problems that must be solved before ANP will be successful.

Vasiljevic, N. “Atomic Aircraft Engines”. (Yugoslavia). FTD-TT-65-1180. Foreign Technology Div. Wright-Patterson AFB. May 23, 1966. P.12.

Discussed the advantages and disadvantages found in nuclear aircraft engines.. The advantages of atomic aircraft engines over conventional are many. Some are of extreme importance to further growth in aircraft developments. Nuclear power plants offer advantages in the following areas: Hugh quantities of nuclear fuel; great concentration of energy in nuclear fuels; possibility of simultaneous increase in range and speed; greater power output by using one reactor for more than one engine; convenient variance in power; possibility of adapting vertical takeoffs to heavy aircraft. The preeminence of conventional aircraft engines will not be infringed upon any time soon because of the many short-comings inherent in nuclear engines.

von Zborowski, H.P.G.A.R. “Thermal Nuclear Reactor, in Particular for Aircraft Propulsion”. *Nuclear Engineer* 1 (Oct. 1956): 316. British Patent # 754,559.

The system has a reserve of fissionable material with at least two wall portions opposite each other between which a moderator fluid can pass. The whole mass of fissionable material, is chosen so that it is 1.01 to 1.1 times the "slow” critical mass (0.01 of the fast critical mass). The moderator is supplied under pressure and the rate of flow so chosen that the moderator leaves the passage in gaseous form and the multiplication factor is equal to 1 in normal running conditions. The nuclear generator then has automatically a stable output.

Voronkov,B. S. “The Nuclear Reactor as an Object of Control”. (Trans. from Russian). FSTC-HT-23-162-7320. Army Foreign Science and Technology Center. Charlottesville, VA. Oct 23, 1973. P.41.

This article deals with the dynamic analysis of a Nuclear reactor used in aircraft. In the case of small deviations from the equilibrium position, the nonlinear equation of the reactor can be linearized. The linear equation is then analyzed for stability of the system. The effect of various perturbations on stability and quality of the system is also discussed.

Wolczek, O. “Nuclear Propulsion for Aircraft and Rocket” NP-tr-183. Part V, of “Newest Aviation Designs, Collection of Articles”. Translated from Polish. Warsaw, Poland. 1957. pp. 102-55.

Nuclear reactors are reviewed for possible applications to aircraft and rockets. Thermonuclear research in the various countries is summarized. The different types of propulsion systems for aircraft and at systems are described and the contributions of the various countries are discussed.

CHAPTER 7.
TERMINATION REPORTS

"Aerothermodynamics." APEX-919. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 109p.

This volume summarized the methods and techniques developed for use in the thermal design of nuclear reactors associated with that program. Information and references were given on the analytical and experimental work required to design and evaluate the proposed high performance air cooled-fuel elements. Methods of optimizing the thermal designs, particularly by the use of high speed electronic digital computing equipment, were discussed. The computer programs developed to provide accurate performance predictions, were identified and described. Details of the computing programs may be found in the referenced material. Discussed means for matching the coolant-flow to the predicted internal heat generation rates in the non-fueled components. Test methods and results were indicated and significant equipment and instrumentation information provided. The relationships of reactor pressure losses and of localized perturbances to power plant performance were indicated, and the detailed analyses which were required to identify and predict these effects were discussed.

"Aircraft Nuclear Propulsion Application Studies". APEX-910. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 158p.

Provided a description of the studies of advanced applications of nuclear reactors that were performed, including various types of aircraft, missiles, space vehicles, ships, and portable power plants. In part, the studies were based on the advanced power plants described in APEX-909, "Aircraft Nuclear Propulsion Systems Studies." Although most of the work was concerned with open-cycle, gas-cooled systems, other systems were also investigated, such as closed gas cycle, indirect liquid metal cycle, gas fission, and liquid circulating fuel systems. Air, helium, hydrogen, and neon were considered as coolants for the gas cooled systems. Except for a portable nuclear system for power generation, all the studies were concerned with propulsion applications. The application studies showed the feasibility both of using reactors developed during the ANP program in advanced vehicles, and of the use of advanced reactors in various types of systems. Performance data, configurations, development program elements and schedules, and estimated costs were included in this summary of the results of the studies.

“Aircraft Nuclear Propulsion Systems Studies”. APEX-909. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 191p.

This volume described the advanced systems which were studied and identified those from which hardware -oriented programs were derived. In the earlier periods, the objectives of the advanced system studies were the exploration of the numerous possible performance and design parameters in order to determine the most promising design approaches. The parameters investigated included flight speed and altitude, number of engines per reactor, number of reactors per propulsion system, core configuration, and materials and shapes of core components. Later, the objectives of the advanced system studies were to incorporate the technology advances in nucleonics, materials, and engineering into new system designs in order to obtain increased performance or new mission capability. An additional purpose was to identify the developmental data required to further a particular reactor or propulsion system concept to the final design phase.

“Applied Mechanics.” APEX-920. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 101p.

This report contained brief descriptions of the methods and techniques that were used by General Electric's Aircraft Nuclear Propulsion Department to achieve structural integrity in developmental nuclear flight powerplants. Vibrational and impact methods were used to evaluate ceramic-core structural mockups under several conditions of mounting. Experimental and theoretical stress-analysis technology was used to extend existing information in high temperature environments and in complicated stress fields. IBM programs were set up for computing thermal stresses. Progress was made in photoelasticity through the use of the techniques of photostress and photo-thermoelasticity. The state of the art of high-temperature strain gages was advanced by raising the temperature limits and by developing and manufacturing a precision device for fabricating strain gages. Standard procedures for installation of strain gages were developed, evaluated, and published. Reactor control elements were developed to regulate reactor power output. Relaxation characteristics of high-temperature alloys under stress were evaluated at elevated temperatures. The results of stress tests performed at elevated temperatures on molybdenum clad with protective coatings are reported. Investigational work was done on material friction and wear at elevated temperatures. Several different designs of heat and airflow sources are presented for use in reactor component testing. Test data of the properties of several thermal-insulating materials are presented. Several configurations of metallic fuel elements were structurally evaluated under conditions of reactor temperatures and gas flow rates.

"Ceramic Reactor Materials." APEX-914. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 283p.

Report summarized the R&D and manufacture of ceramic core components for use in an annular, beryllium moderated, air cooled reactor. Discussed feasibility studies on silicon carbide and molybdenum disilicide as fuel-bearing media. Described fabrication techniques and properties of the various ceramic materials used in fuel elements, reflectors, shaft-housing shields, radial arches and transition pieces. Discussed the technology of the preparation, fabrication and properties of beryllium intermetallics which were undertaken to develop core components for advanced reactor concepts. Summarized in-pile materials tests.

"Controls and Instrumentation." APEX-912. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 133p.

This volume was a compilation of reports on the more worthwhile technology and hardware development efforts for the control system of an aircraft nuclear power plant. The major part of this volume was devoted to the development efforts applied to the reactor control rather than to the turbomachinery control. This volume omitted those developments that were applied to specific power plants and their associated controls, since they were covered in individual volumes of the APEX 901-921 series. The information presented was divided into four sections: Control System Technology - This section covered the philosophy of control, analysis and simulation techniques, and some of the systems that were proposed and investigated. Power plant simulation was included in this section, although it was used as a design and analysis tool for three power plants.
Mechanical Components - This section described the various actuator designs that were considered as possible solutions to such problems as high temperature, poison rods located behind the turbomachinery compressor, and backup safety actuators.
Electrical Components - This section covered all of the control hardware except for the actuators and sensors. Much of the electrical component effort was directed toward obtaining equipment capable of operating in the nuclear and temperature environment of a supersonic aircraft while meeting established reliability, size, and weight requirements.
Instrumentation - This section described the efforts on the sensors, primarily for measurement of temperature and neutron power level, that were necessary for the control of the reactor.

"Heat Transfer Reactor Experiment No.3". APEX-906. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 201p.

This volume described Heat Transfer Reactor Experiment No. 3 (HTRE No. 3), a solid-moderated nuclear power plant with a horizontal reactor. The objectives and accomplishments of the program were presented in addition to nuclear, thermodynamic, and control system design data. Described the power plant and components, including the reactor, shield, turbomachinery, controls and test support equipment, and the low-power and operational tests are discussed. Manufacturing techniques, component testing, and materials developments were also presented. The objective of the HTRE No. 3 program was to provide the technical information needed for the design of a ground test prototype power plant and to test methods of design analysis and performance prediction.

"Heat Transfer Reactor Experiment No. 2". APEX-905. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 82p.

This volume described Heat Transfer Experiment No. 2, a test reactor used to evaluate ANP fuel elements and solid moderator materials. The reactor, a modification of Heat Transfer Reactor Experiment No. 1, had the seven center cells of the core removed, providing a hexagonal hole for test inserts. The reactor and the inserts tested were described and the results of the various tests presented.

"Heat Transfer Reactor Experiment No. 1". APEX-904. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 197p.

This report described Heat Transfer Reactor Experiment No. 1, believed to be the first successful operation of a turbojet engine on nuclear power. Design data were presented, including a general description of the test assembly, the nuclear characteristics of the reactor, fuel element thermodynamic characteristics, and the control system. The three series of test runs were also described and the test results summarized. The general objectives of Heat Transfer Reactor Experiment No. I were to demonstrate the feasibility of the direct air cycle system by operating a turbojet engine on nuclear power, to demonstrate the adequacy of reactor design features and to evaluate aerothermodynamic and nuclear characteristics of the reactor for use in the design of militarily useful aircraft power plants.

"Metallic Fuel Element Materials". APEX-913. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 165p.

This report described work on Metallic Fuel Element Materials. Information was presented on properties, fabrication procedures, test data, and technical developments in high temperature gas-cooled metallic nuclear fuel element technology. Nuclear fuel element materials suitable for gas-cooled reactors with gas exit temperatures of from 1200 deg.F. to somewhat higher than 2000 deg.F. were discussed and test results summarized. The general objective of the fuel element materials development program was to provide materials for the design of reactors for militarily useful aircraft power plants. Service lives from a few hours to a thousand hours were considered, depending upon the mission contemplated. The report included discussions and data on nuclear fuel elements containing dispersed uranium dioxide with a matrix and cladding of stainless steel, nickel-chromium alloy, iron-chromium-yttrium alloy, iron-chromium-aluminum alloy, niobium alloy, or chromium alloys.

“Moderator Materials.” APEX-916. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 43p.

Summarized the development of high-temperature, highly efficient moderator materials, which included oxides, metals, metal hydrides, and intermetallics. Operating temperatures generally varied from maximums of 1200 deg. to 2700 deg.F. but some extended to 5000 deg.F. and higher. Discussed fabrication methods, physical properties, and sources of additional materials information. Described the development of zirconium hydride, yttrium hydride, and other moderator materials.

“Nuclear Safety.” APEX-921. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 93p.

Presented the highlights of the technical effort to evaluate, understand, and ameliorate aircraft reactor hazards. The program included unique field-release studies, safety-fuse studies, experiments to measure fission-product release from molten fuel, analytical and experimental methods for estimating the consequences of a reactor runaway, criticality safety, and predicted consequences of a nuclear powered -aircraft crash. Also included was an account of several analytical and experimental developments pertaining to reactor hazards which were employed during the course of the aircraft nuclear propulsion work at the General Electric Company.

“Organic, Structural and Control Materials.” APEX-917. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. p. 61.

This report discussed the radiation effects on organic materials used in accessories and controls for the nuclear power plant. Also discussed high-temperature control rod development, radiation effects on high-temperature structural material, and thermocouple development.

"P-1 Nuclear Turbojet". APEX-902. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 67p.

This was the summary report prepared as a close out of the GE ANP Program effort which had been cancelled in April 1961. APEX-902 was one the volumes prepared by GE to summarize all the technical results of their ANP work. This portion described the design of the reactor for the first direct-air- cycle nuclear power plant undertaken in this Program. Presented the bases for selection of the moderator, fuel element material and shape, basic reactor configuration, design point selection, and turbomachinery selection. Included details of the methods used to flatten power radially and longitudinally, verify nuclear design (critical mockup and shield mockup), and fabricate fuel elements. The control system and its components were described, including the control console and instrumentation. Discussed the design of the shield and moderator cooling systems. The modifications of the conventional turbomachinery included: in-line combustors, ducting and duct arrangement, valving, and the turbomachinery controls. Also described the Propulsion Unit Test, for chemically simulating reactor operation.

"Reactor Core Test Facility". APEX-903. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 141p.

This volume presented a summary description of the Core Test Facility (CTF) that was used in the first two Heat Transfer Reactor Experiments (HTRE No. 1 and No. 2), which were conducted at the Idaho Test Station. The CTF consisted of shielding, an air supply, and other necessary auxiliaries and services, which were combined into assemblies in order to test a succession of direct-cycle cores, fuel elements, controls, and other components.

"Reactor and Shield Physics." APEX-918. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 205p.

This volume described the experimental and theoretical work accomplished in the areas of reactor and shield physics. The reactor physics technology for all ANP reactor types was presented in its most advanced stage; i.e., no attempt was made to present chronologically the development of the technology. The use of automated techniques for power-mapping critical experiments in the reactor physics program were discussed, with particular attention to the use of high speed computer programs employing the IBM 704 and IBM 7090 computing systems. In the nuclear shielding program, efforts were concentrated in two main areas: (1) the optimum placement of shield materials to reduce radiation levels, and (2) the calculation of specific nuclear data, such as nuclear heating and activation, which were important to the design of an efficient, safe power plant. Methods were developed for determining, at any position in the reactor-shield assembly, the total flux and the angle and energy distribution of neutron and gamma rays, as well as the response of any detector used to measure radiation effects. Important shielding computer codes described were the point kernel and single scattering codes and the more recently developed Monte Carlo codes.

"Remote Handling." APEX-911. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. p. 68.

This volume described the remote handling tools and techniques developed in the course of the GE-ANP Program.

"Shield Materials." APEX-915. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 200p.

Provided a discussion of shielding materials development, which was begun in 1956. Specialized materials, which would provide the most efficient neutron and gamma shielding per unit of weight and would be capable of high temperature (900 deg. to 1600 deg.F.) operation under the thermo-mechano-nuclear environment associated with the direct-cycle reactor power plant, were presented. Primary development effort was focused on three neutron shielding materials: (1) beryllia plus boron, (2) beryllium plus boron, and (3) lithium hydride. In addition, stainless steel plus boron and tungsten-base alloys with boron additions were evaluated as combined gamma-neutron shielding materials. Fabrication technologies that were developed, physical and mechanical properties that were determined, and the environmental testing programs, including radiation stability studies used to prove the usefulness of the materials under simulated operating conditions, were discussed in their respective sections.

Thornton, G. and A.J. Rothstein. "Comprehensive Technical Report. General Electric Direct-Air-Cycle Aircraft Nuclear Propulsion Program. Program Summary and References". APEX-901. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 303p.

This was the summary report prepared as a close out of the GE ANP Program effort which had been cancelled in April 1961. APEX-901 was one the volumes prepared by GE to summarize all the technical results of their ANP work. This volume discussed the background to the GE Program and summarized the various direct-air-cycle nuclear test assemblies and power plants that were developed. Because of the requirements of high performance, low weight and small size, vast improvements in existing technology were required to meet the flight objectives. Summarized the technological progress achieved in the program. Also provided GE-ANPD expenditures and personnel levels by fiscal year, along with numerous illustrations.

"XMA-1 Nuclear Turbojet." APEX-907. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 257p.

This report described the XMA-l which was the first developmental model of a power plant designed for operational applications. The XMA-I was designed to be a nuclear powered turbojet aircraft power plant consisting of a direct air cycle reactor, nuclear shielding, two parallel sets of X-211 turbomachinery, and the required ducting, interconnecting structure and controls. Provisions were made for operation on either nuclear or chemical heat source. Initially, the XMA-1 was to satisfy the requirements which included (1) cruise at Mach 0.9, 20,000 feet altitude; (2) low level attack at Mach 0.9, 500 feet altitude; and (3) sprint at Mach 2.5, 55,000 to 60,000 feet altitude. These were later changed to (1) cruise at 30,000 feet altitude at Mach 0.9 and (2) flight at Mach 0.9 at sea level. The power plant proposed for first flight test was designated XMA-IA. The objective of the first power plant was a system that would represent as closely as possible the requirements and characteristics identified for the operational version. The operational version was designated XMA-lC. This report presented a description of the XMA-1A design, design requirements, design data, and major test results, as well as the results of the studies directed toward selection of a reactor for the XMA-IC.

"XNJ 140E Nuclear Turbojet." APEX-908. GE Nuclear Materials and Propulsion Operation (Formally ANP Dept.), Flight Propulsion Laboratory Dept., Cincinnati. June 28, 1962. 1090p.

This was a comprehensive technical report of the design and development activities of the XNJ140E Project. Included a presentation of the design objectives and requirements, an engineering description of the XNJ140E-1 nuclear turbojet engine, supporting analytical design data and methods of calculation, and a brief review of three design studies preceding, and directly applicable to the XNJ140E program. Beginning early in 1960, a major phase of the national effort leading to the achievement of nuclear powered flight was the design and development of the XNJ140E-1 nuclear turbojet engine to be utilized in an Advanced Core Test program. This program was to demonstrate the capabilities of a ceramic reactor coupled with the appropriate associated components of a direct-air-cycle nuclear turbojet engine. Descriptive material contained in this report was based upon the status of the XNJI40E Project at the time of contract termination. The XNJ140E-1 engine was designed with a reactor of sufficient capability to provide engine performance equivalent to that specified in Department of Defense guidance, which required a speed of Mach 0.8 at an altitude of approximately 35,000 feet in a Convair Model NX-2 aircraft, or equivalent, and an engine life potential of 1000 hours. During this flight condition, the estimated minimum net thrust of the engine was 8120 pounds. The engine contained a reactor-shield assembly coupled with a single set of X-211 turbomachinery and arranged in an integral, in-line configuration. The compressor and turbine were separated, but connected by a long coupling shaft. An annular combustor system, using JP-4 jet fuel, was placed in-line between the reactor rear shield and the turbine inlet, and was arranged concentrically around the coupling shaft.

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CHAPTER 8.
APPLICATION TO OTHER TECHNOLOGIES

"630A Maritime Nuclear Steam Generator Scoping Study." GEMP-107. Summary Report. General Electric Co. Flight Propulsion Lab. Dept., Cincinnati. Mar. 5, 1962 41 p.

A summary was presented of the results of a study of a nuclear steam generator which uses reactor technology developed during the aircraft nuclear propulsion program to produce superheated steam for marine propulsion. This system was first proposed to the Atomic Energy Commission in June 1961, and was one of the results of an effort initiated in April 1961, following the cancellation of the ANP program, to investigate other applications of the technology developed. Reviews with members of the Atomic Energy Commission and the Department of Defense Agencies established directions of interest for these studies.

"630A Maritime Nuclear Steam Generator Scoping Study." GEMP-108. General Electric Co. Flight Propulsion Lab. Dept., Cincinnati Dec. 15, 1961. 222 p.

Results of a study were presented of a nuclear steam generator which would be developed using the reactor technology developed during the aircraft nuclear propulsion program. The reactor could be used to produce superheated steam for marine propulsion. The generator for which a design is presented is designated 630A. It consisted of a water-moderated air-cooled reactor, a boiler, shielding, and accessory equipment. The coolant air was contained throughout a closed cycle in the fully shielded reactor pressure vessel.

"630A Maritime Nuclear Steam Generator". GEMP-231. General Electric Co., Advanced Technology Services, Cincinnati, OH. Sept. 12, 1963. 284p.

The current status of the 630A Nuclear Steam Generator was reported. The 630A Nuclear Steam Generator consisted of an air-cooled, water-moderated reactor using

metallic fuel elements, a once-through water tube boiler, two axial-flow blowers, lead and water shielding, controls, and necessary auxiliary equipment. The design, safety features, overall configuration, and operating cycle for a 27,300-SHP version of the 630A were summarized. Information was included on the design and characteristics of the reactor shield plug assembly, boiler, pressure vessel, shield containment vessel, shield, nuclear steam generator accessories, handling and service equipment, fuel elements, control systems, control rods, cooling systems, critical experiments, power cycles, and blower systems. A discussion was included on the need for a maritime fleet and the technology which led to the decision to develop the 630A system. A summary was included for capital and operating costs, safety hazards, ANP reactors, alternate configurations, computer programs. specifications, operating conditions and future development.

"710 High-Temperature Reactor Program Summary Report. Element Drawings and Manufacturing Specifications". GEMP-600 (Vol-6). General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Nd (Decl. Sept. 4, 1973). 262p.

Presented drawings and process specifications for the fabrication of W-Re-Mo-clad fuel elements developed under the 710 High-Temperature Gas Reactor Program. Also included a description of the facilities and equipment used for fabricating the fuel elements.

"710 Reactor Program, Progress Report No. 13". GEMP-349. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Mar. 31, 1965 (Decl. Sept. 4, 1973). 63p.

Information on the development of the 710 Reactor was presented concerning the performance testing of refractory-metal fuel elements, critical experiment mockup of the 710 Reactor, reactor component design and development, and test facilities and pilot loop design.

"710 Reactor Program,.Progress Report No. 12". GEMP-333. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Jan. 28, 1965 (Decl. Sept. 4, 1973). 76p.

Presented further information on the development of the 710 Reactor.

Anderson, J.L. and P.M. Finnegan. "Creating New Cities Through the Large Air-Cushion Vehicle". *Astronautics and Aeronautics* 10 (Jan. 1972): 46-54.

This air stated that the air-cushion vehicle (ACV) (with nuclear propulsion as a potential option) can travel over concrete roads, grass, sand, mud, swamp, snow, ice, and water. This mobility made possible a totally new geographical freedom in choosing transportation routes, locating ports, and laying out a city. The authors predicted that by the 1980's fleets of large ACV freighters could begin carrying ocean-going cargo. The mobility of an ACV fleet would allow placing hoverports away from areas now crowded. New cities could rise along shallow or reef-bound seacoasts and rivers, just as cities once rose around deep-water seaports.

Banach, H. J. “Preliminary Design of the 2 MWt Reactor and Shield (PWAR-20) for the SNAP-50/SPUR Powerplant”. PWAC-445. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Dec. 30, 1964 (Decl. Sept. 6, 1973). 51p.

The SNAP-50/SPUR powerplant development program concentrated on a system designed for unattended operation in space for 10,000 hours, and which produced a net electrical output of 300 KW(e). The reactor and shield for this powerplant had been designated the PWAR-20. The powerplant weight goal for the 2-MW(t) reactor was 1800 pounds, exclusive of shielding. A target weight for shielding, the design of which is mission oriented, had not been specified because mission requirements have not been clarified to date. The preliminary design of the PWAR-20 was presented. The major problem areas which exist were described.

Bigelow, C.C. “TID-7653-P2(P1 and 2). Design and Testing Columbium-1 Zirconium Reactor Pressure Vessels”. United Aircraft Corp., Middletown, CT. 1962.

Paper presented in proceedings of a nuclear propulsion conference. Outlined conservative design criteria for low-weight (Nb-l% Zr) reactor pressure vessel, and tests for validating these criteria.

Bower, J.R., ed. “Chemical Processing Technology”. IDO-14646. Phillips Petroleum Co., Atomic Energy Div., Idaho Falls, ID. Jan. 1965. 38p.

The modified ICPP zirconium processing facilities were prepared for cold start-up testing, and the flowsheet was presented for the new process. In aluminum fuel processing studies, the potential usefulness of dissolved cadmium (nitrate) as a nuclear poison in nitric acid dissolver solutions was demonstrated. Sample ATR fuel plates and Type 6061-TO aluminum were shown to resist corrosion in the fuel storage basin water. Electrolytic dissolution of kilogram quantities of actual HTRE-3 fuel elements were successfully demonstrated in the Model 2 pilot plant dissolver. The operation of the dissolver is described. Laboratory studies characterized the sludge produced during electrolytic dissolution as consisting of grains dropped from the dissolving surface and silica produced by polymerization following dissolution. The ICPP Waste Calcining Facility has operated very smoothly; only 55 hours of down time have been experienced since starting radioactive operation in December 1963. The successful calcination of zirconium-aluminum-fluoride wastes from the ICPP hydrofluoric acid process for zir-conium-based fuels was demonstrated in WCF pilot plant equipment. Additional waste

management studies indicate that alumina calcine deposits yield to nitric acid decontamination and that phosphate glasses prepared from calcined alumina were blackened, but otherwise unaffected, by gamma irradiation to 10^{10} R.

“Conceptual Design Study of *a* Power Plant for a Deep Operating Submersible”. CNLM-5671. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. July 2, 1964 (Decl. Sept. 5, 1973). 288p.

The Advanced Sea Based Deterrent Committee had expressed an interest in power plants of 1400 to 25,000 hp rating for potential use in submersible vehicles with 8000 feet or greater operating depth. The conceptual design of a power plant for such a deep operating submersible (DOS) at the upper end of the power range of interest was presented in detail. The design was based on CANEL's lithium-columbium ANP reactor technology and Pratt & Whitney Aircraft's proven gas turbine technology. Weight and performance data for similar power plants covering the entire power range were also presented. Cost and reliability forecasts for the large power plant are presented to assist an evaluation of its cost effectiveness. Discussed potential improvements in the power plant concept which should be investigated in a continuing design study.

“Engineering Investigation and Tests Which Further Substantiate System Feasibility and Provide Data Relative to the Development of a Nuclear Low Altitude Supersonic Vehicle. Part II. Technical Information. Volume 10. Nuclear Radiation Effects. Test No. 18.”. Ling-Temco-Vought Inc. Dallas TX. Dec. 1964. P.211.

This document presented the test results of nuclear radiation effects tests which were a dynamic credibility demonstration conducted in the Air Force Ground Test Reactor (GTR) during the time period of 29 July through 5 August 1964. The GTR was originally used in the ANP Program. This work was performed in support of the Air Force. This work provided specific test data on subsystems, components, and materials representative of those which would be used in a nuclear powered ramjet missile.

Hodge, Webster. “Beryllium for Structural Applications. A Review of the Unclassified Literature”. DMIC-106. Battelle Memorial Inst., Defense Metals Information Center, Columbus, OH. Aug. 15, 1958. 181p.

Presented a summary of available information on beryllium including recent data which may aid in evaluating its usefulness as a structural material in airframe and missile applications. The literature references included data on sources of ore and the production, fabrication, properties, and applications of the metal. The problems in industrial hygiene encountered in working with beryllium and its compounds are reviewed briefly. Included applications of beryllium in the ANP Program.

“Irradiation Test, Preliminary Report”. GTR-14. General Dynamics/Fort Worth, TX. July

23, 1964. 94p.

A series of tests was performed at the Nuclear Aerospace Research Facility (NARF) of General Dynamics/Fort Worth to determine the effects of nuclear radiation on components proposed for inclusion in the NERVA engine. This was the facility originally developed for the ANP Program. Aerojet-General Corporation, Azusa, California, had prime responsibility for development of the NERVA engine; the incorporated nuclear reactor was being developed by Westinghouse Astronuclear Laboratory, Large, Pennsylvania.

"Irradiation Test, Preliminary Report". GTR-11. General Dynamics/Fort Worth, TX. Feb. 11, 1964. 93p.

An experiment was performed utilizing the NARF Ground Test Reactor to determine the effects of combined reactor radiation and cryogenic (LN_2) temperatures on linear motion displacement transducers, strain gages, development strain gages, dome end support ring sections, and cork board insulation. These components were of the type proposed for the NERVA engine. The experimental design encompassed three prime objectives: (1) to determine radiation rate (transient) effects on the electrical characteristics of the test items. (2) to determine the effects of total radiation exposure on these characteristics, and (3) to determine abilities to recover these electrical characteristics after removal from the radiation field. This facility was originally built for the ANP Program.

Knudsen, L.K., R.P. Lamers, B.R. Lucas, D.V. Manfredi, and H.P. Odom. "Design Summary Report of LCRE Primary Coolant Pumps and Sump". PWAC-383. Pratt and Whitney Aircraft Div., United Aircraft Corp., Connecticut Aircraft Nuclear Engine Lab., Middletown, CT. Nov. 22, 1963. 54p.

A design summary report was presented on a lithium pump and sump unit designed by Pratt & Whitney Aircraft. This report covered all work accomplished in the design phase, including analytical design studies. The subject pump (designated LP-1) was designed during the Aircraft Nuclear Propulsion development program as a ground test reactor coolant pump to circulate lithium at 1600 deg.F. for 1000 hours. The LP-1 pump incorporated the design features of a flight type reactor coolant pump for a nuclear aircraft powerplant. After cancellation of the ANP Program, the LP-1 pump and sump unit was designated for use in the Lithium Cooled Reactor Experiment (LCRE) to operate at a reduced temperature of 1000 deg F for 10,000 hours without maintenance. The LP-1 pump design was based on current state-of-the-art concepts and was guided by experience gained in earlier, high temperature liquid metal pump design and development efforts. All components in contact with lithium were fabricated of Nb-l Zr alloy, whereas the remaining components are predominantly type 316 stainless steel.

"Lithium-Cooled Reactor Experiment Reactor Operations Final Report". PWAC-408. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. Jan. 30, 1964 (Decl. Sept. 5, 1973). 112p.

The Lithium-Cooled Reactor Experiment (LCRE) Reactor Operations Group was organized in the Fall of 1962 and given the responsibility for the safe, efficient operation of the LCRE. Since many, often subtle, aspects of the design of a complex, experimental system such as the LCRE strongly influenced the ease, if not the actual feasibility, of its operation, the Reactor Operations Group from the beginning assisted in the design of the LCRE and its auxiliary and support systems. The status of the work accomplished by this group at the time the CANEL SNAP-50 program was reoriented was described. The first drafts of the Fuel Loading Experiment Procedures and the Operator Training Manual, as well as the preliminary outline of the Plant Operating Manual, were included as appendices.

"NARF Final Progress Report, October 1, 1962 Through September 30, 1963". NARF-63-9p. General Dynamics/Fort Worth. Div. of General Dynamics Corp., Fort Worth, TX. 250p.

Development and fabrication of an exhaust-gas sampler for the TORY-IIC were completed except for tests of tip durability in the exhaust jet. Further durability tests were recommended. Discussed radiation considerations in design of Orion-type vehicles. Radio-induced vehicle and fuel healing was examined along with radiation streaming in ducts. Fabrication of thermal transducers, an argon monitor, a TV system for reactor operations, and shielding instrumentation was reported. Discusses aspects of installation and use of an acoustic facility in the Ground Shield Test Reactor (GTR). Data were tabulated on radiation damage in Si and Ge transistors according to base material and typical use to which each may be put. Results of constant temperature irradiation of three thermistor types were reported. The tests were conducted to determine the effects of total dose at constant temperature. Reported the effects of light, gamma irradiation and temperature on the electric conductivity of polyethylene. Radiation effects data were included on fluid and solid lubricants. Other radiation effects data were included on elastomeric and plastic materials such as polyethylene, acetal resins, polyvinyl carbazole, and polycarbonate. Radioinduced reactions of polyethylenes were studied, and data were presented on gas liberation, temperature dependence of trans-vinylene absorbance, and chain scission and linking. Included information obtained in studies of resonances in free-radical intermediates of gamma-irradiated hydrocarbons and thermoluminascence of 1-dodecyne.. In the study of low-energy subexcitation electrons in hydrocarbon gases, improvement of detection capabilities was reported along with data accumulation in this area. Data were included on He, methane, ethane, and propane excitation by energetic electrons. Gave data and conclusions resulting from an evaluation of a proposal for improving the accuracy of neutron spectral measurements using foils. Included response data on several neutron detectors. Discussed developmental work on In and U foils, and radiation effects on N_20 at liquid N_2 temperature. Work on control rod optimization resulted in development of a suitable alloy for use in the GTR. Discussed results of analytical studies directed toward shielding properties of active and passive materials. Modification of the Aerospace Shield Test Reactor (ASTR) for 10-MW operation was reported along with GTR modification and maintenance. Included a list of reports issued under the NARF-63 statement of work.

Nash, E.G. “Feasibility Study of Application of a Yttria -Urania Fuel Element Reactor to the Ramjet Mode of an Aerospace Plane”. TM-62-6-15. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Jan. 16, 1962 (Decl. Aug. 31, 1973). 27p.

A study was conducted to determine the feasibility of using an yttria-urania fueled reactor as a heat source for propulsion of an aerospace plane. It was found that use of an yttrium-urania fuel element reactor for the ramjet mode of operation of an aerospace plane does not appear practicable because of the limitations on operating temperatures of about 3500°R for this type of fuel element. In addition, values of specific impulse during the ramjet mode, because of this same limitation, would be considerably lower than the values obtained utilizing a hydrogen-fueled air-breathing type of ramjet. It is concluded that any further studies should be directed towards the two-mode form of propulsion in which airbreathing hydrogen-fueled turbomachinery conceivably may be utilized up to Mach 4.5. However, the specific impulses obtained by a nuclear reactor would again be lower than the hydrogen-fueled turbo-accelerator system because of the lower allowable operating temperatures inherent with the nuclear reactor. Therefore, the application of nuclear power appears to be confined solely to the rocket mode of operation, which is from Mach 8 to 26 for the three-mode system, and Mach 4.5 to 26 for the two-mode system.

“Presentation of 710 Reactor Technology Development Program to the U.S. Air Force, June 9, 1964". GEMP-302. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. No Date. (Decl. Sept. 21, 1973). 41p.

Information on the 710 Reactor development program was presented concerning design characteristics of the reactor, reactor applications, and component fabrication.

Project NOBSKA - The Implications of Advanced Design on Undersea Warfare". National Academy of Sciences - National Research Council. NRC-CUW-0233- Vol.I. December 1, 1956. 51p

The Committee on Undersea Warfare of the National Academy of Sciences was asked by the Chief of Naval Operations, Adm. Arleigh Burke to undertake a study of anti-submarine warfare. Included among the recommendations of this group was to study the adaptation of an ANP Project reactor concept, the "Fireball Reactor", for use as a high performance propulsion system for submarines.

Reid, R.E., E.L. Semple, J.D. Simpson. “Selection of 710 Reference Reactor”. GEMP-514. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. May 1967 (Decl. Sept. 5, 1973). 17p.

A reactor configuration and operating conditions were selected for a 200 KW(e) Brayton cycle space power system as a reference point for the 710 Reactor fuel systems development program and for studies of the effects of the reactor and space power system designs on the 710 Reactor fuel system.

Seamans, Robert C., Jr., Associate Administrator, NASA. Letter to Dr. Frank K. Pitman, Dir. Div. of Reactor Devel., AEC. June 27, 1961. Available in the NASA, HQ. Office of History.

Dr. Seamans requested a compilation by the AEC of the ANP radiation shielding research work that could be applicable to design of nuclear powered space vehicles.

“Second Generation Portable Nuclear Powerplant. Volume V. Contractor Qualification and Management Data. Proposal". CNLM-5325 (Vol. 5). Pratt and Whitney Aircraft, Middletown, CT. No Date. 130p.

The qualifications of the several organizations which would participate in this proposed Second Generation Portable Nuclear Powerplant Program were outlined and the Management Approach described. The prime contractor would be Pratt & Whitney Aircraft-CANEL, Middletown, Connecticut, a Division of the United Aircraft Corporation. It was proposed to perform the work at the Connecticut Advanced Nuclear Engineering Laboratory (CANEL), Middletown, Connecticut. Associated Nucleonics, Inc., a Subsidiary of Stone & Webster Engineering Corporation, was proposed as a major subcontractor responsible for providing architect-engineering services to Pratt & Whitney Aircraft. Modification of an existing gas turbine engine, the FT-12, for this application would be undertaken by Pratt & Whitney Aircraft, East Hartford, Connecticut.

“Study of Adapting the SNAP-50 Space Powerplant to a Lunar Base”. PWAC-406. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. July 26, 1963 (Sept. 5, 1973). 60p.

Discussed the adaptation of the SNAP-50 reactor to an electrical generating system for a lunar base is discussed. Described the required modifications to the powerplant and special problems peculiar to operation in the lunar environment.

“Study of Brayton Cycle Space Power Systems”. GE-NMP-62-17. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. July 9, 1962 (Decl. Nov.

28, 1973). 12p.

A program for the development of a fast-spectrum refractory metal reactor was recently initiated at GE-NMP0 by the Atomic Energy Commission. The development and test of an experimental reactor of this type was planned. The reactor was a compact, high power density reactor which offered the capability of providing gas at temperatures in excess of 3000°F for extended periods of time. The reactor would also permit multiple restarts and rapid power charges. The specific operating life of the reactor varied inversely with gas temperature. Many applications of this reactor were contemplated. Preliminary studies were made of its use in a nuclear rocket and in a compact, closed-cycle power pack for marine propulsion or for a power supply in isolated areas. Other potential applications such as space power, compact mobile, energy supply, etc., were given brief consideration. At the request of the Atomic Energy Commission, a study was made, during a two-week period, of the application of the fast-spectrum, refractory metal reactor to a Brayton cycle space power system. The basic study contemplated a system with a one-megawatt electrical power output. A single extrapolation was made to the level of 100 kilowatts. Because of the short time available, maximum effort was applied to a semi-optimization of the radiator which was the heaviest item. No attempt was made at optimization of the other components or of the total system.

Szekely, T. "A-136 Nuclear Turbo-Ram Powerplant (Invention Disclosures). APEX-727. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Apr. 10, 1961 (Decl. Sept. 12, 1973). 102p.

Described a new concept of a nuclear direct-cycle turbo-ram power plant, the A-136. Information was presented on the power plant cycle, arrangement of components, mechanical design, reactor materials, thermal and nuclear design, reactor kinetics and shield design, and estimated preliminary performance. The cycle of the A-136 was designed to exploit the high-temperature capabilities of promising new reactor materials without increasing the temperature demands for turbine operation. The cycle and high-temperature reactor were mutually employed to broaden the all-nuclear atmospheric flight spectrum. Also, the A-136 was the first to develop for direct cycle atmospheric propulsion a reactor that may be used for ram-rocket propulsion in more advanced nuclear space plane systems.

Thomson, W.B. "Folded Flow Ramjet Proposal". DC-60-8-15. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Aug. 3, 1960 (Decl. May 12, 1970). 11 p.

Preliminary calculations on a folded flow ramjet reactor had been made. This reactor was of the P122 type with Nichrome wire fuel elements and zirconium hydride moderator.

At Mach 2.8 and an altitude of 1000 feet the thrust is 51,000 pounds, the overall power plant diameter is 50 inches and the maximum average wire temperature is 1975°F. For the SLAM application, this folded flow reactor was competitive with the high temperature ceramic reactors usually associated with ramjets.

Thornton, Gunnar, Mgr, Engineering. Letter to W.H. Long, Mgr. Nuclear Materials and Propulsion Operation. General Electric Co., Nuclear Materials and Operation, Cincinnati, Ohio. January 19, 1965.

Gunnar Thornton proposed to prepare, with V.P. Calkins, an article (about four years after ANP cancellation) which would discuss the spinoff from ANP technology with particular emphasis on non-nuclear applications. Letter enclosed a detailed listing of 133 different ANP Project technological contributions for specified spinoff applications. Thornton stated that "Publication will be sought in a prestige-type journal...", but it never was completed.

Williams, R. F. and S.E. Ingels. "Fabrication of Beryllium. Vol. IV. Surface Treatments for Beryllium Alloys". NASA-TM-X-53453(Vol.4). National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, AL. July 1966. l6p.

Documented the surface treatment techniques developed for use in the fabrication of Be aerospace vehicle structures. Reported on proven techniques for the removal of surface contaminants resulting from in-process shop handling and specific pre-cleaning and activation procedures for the preparation of the surface for subsequent operations such as plating and brazing. Beryllium fabrication techniques were developed in the ANP Program.

Williams, R.F. and S.E. Ingalls. "Fabrication Of Beryllium. Volume V. Thermal Treatments For Beryllium Alloys". NASA-TM-X-53453(Vol.5). National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, AL. July 1966. 55p.

The thermal treatment techniques investigated and evaluated for possible application in the fabrication of Be aerospace vehicle structures were documented. Evaluated the effects of time and temperature on the removal of residual stresses, induced by prior work. Investigated the physical, mechanical, and dimensional changes resulting from rates of rapid cooling are reported; and the effects prolonged exposures at high temperatures on the mechanical properties of Be sheets. Beryllium fabrication techniques were developed in the ANP Program.

Williams, R.F. and S.E. Ingalls. "The Fabrication of Beryllium Alloys. Volume II. Forming

Techniques for Beryllium Alloys". NASA-TM-X-53453 (Vol.2). National Aeronautics and Space Administration, George C. Marshall Flight Center, Huntsville, AL. July 1966. 84p.

Described the forming techniques investigated and the fabrication of Be aerospace vehicle structures. Time-temperature relations were established for the forming of straight bends, compound curved channels, and hemispherical segments. The flow of the material was determined, and the resulting dimensions are measured. The feasibility of the extreme forming of cross-rolled Be sheet material was demonstrated. Beryllium fabrication techniques were developed in the ANP Program.

Yaffee, Michael. "USAF Tests Synthetic Hydraulic Fluids". *Aviation Week* 70, 1 (Jan. 5, 1959): 71, 73, 75, 77, 79, 81-3, 85.

Presented information on the development of high-temperature hydraulic fluids for advanced aircraft and space-craft. The need for these fluids was being met by the development of synthetic chemical compounds for operation in the 400 to 1000°F range. Discussions were included on: high-temperature problems, the application of cooling devices, radiation-resistant fluids for nuclear-powered aircraft, and the properties of polyphenyl ethers and other materials for use at temperatures above 700°F.

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CHAPTER 9.
EVALUATIONS OF ANP

Albrecht, Ulrich. "The Nuclear-Propelled Bomber - A Faked Arms Race Between the US and the USSR". Chapter 6 in: Brauch, Hans Gunther, ed. "Military Technology, Armaments Dynamics and Disarmament". St. Martin's Press, New York. 1989. pp.127-164.

A critical review of the ANP Program from inception to cancellation in which the argument was made that a major incentive for the project came from an unjustified concern that the Soviets would be successful before the U.S. Author implied that the Russian ANP effort was a minor effort that may have been exaggerated by the Army Air Forces and U.S. intelligence community to enhance support for the U.S. program. Included a good discussion of the policy decisions made and traces the history of the project, with emphasis on the personalities involved. Provided useful insights into the early years of ANP. Included alarmist statements regarding radiation exposures to crew of NB-36B, with references to the Chernobyl accident exposures. Author appeared to have limited technical expertise in his description of the activities of the major participants in the project. Author attributed cancellation of project to actions initiated by Eisenhower Administration in 1959. Included a list of useful references.

Bikowicz, Brian B. "The Decay of the Atomic Powered Aircraft Program". Student Paper in Partial Fulfillment of the Requirements of the Humanities Sufficiency Program. Worcester Polytechnic Institute, Worcester, MA. Available in the Wooster Polytechnic Institute Engineering Library.

Provided a brief review of the history of the ANP Project, including descriptions of the design options considered. Pointed out major problems with shielding and radiation release to the environment. Asserted that airframe design received relatively little attention, compared to engine designs. Contrasted degree of success of the GE work in achieving operational test reactors compared to that by Pratt and Whitney. Author summarized many re-direction of program by the Air Force and the large, expensive facilities that were built, but never operated. Assertion was made that the technology was available for a successful project, but that ANP was cancelled for political reasons.

Cortright, Vincent. "Dream of Atomic-Powered Flight". *Aviation History* (March 1995):30-36,69.

Author traced the history of the nuclear powered flight from the 1946 NEPA Project through ANP Project cancellation in 1961. He states that J. Robert Oppenheimer and Edward Teller, along with other noted scientists, opposed the concept from the beginning. The NB-36H flights with an operating nuclear reactor on board are discussed and illustrations provided. The major technical problems are outlined and the lack of success emphasized. Discussed attempts by the Eisenhower administration to single out the ANP Project for funding cuts and the opposing support provided by the JCAE. Article included discussion of the potential harmful effects of radiation from this project. Provided a review of the changing ANP Project objectives, and pointed out the contrast with the success of the Naval Nuclear Propulsion Program. Provided insight into the politics of ANP Project cancellation.

Grey, J. "Nuclear Propulsion: An Epilogue". For American Institute of Aeronautics and Aeronautics, Inc., New York. *AIAA Stud. J.* 11 (Dec. 1973): 4-7.

A review was presented of NASA efforts concerned with the development of propulsion systems based on nuclear fission. Work regarding such systems began in 1945 and was discontinued on January 9, 1973. The U.S. spent about 3 billion dollars for the various programs connected with this work. Almost half of the funds were used for research and development on nuclear rockets. The bulk of the remainder was spent on projects related to nuclear propulsion of aircraft. Other projects were concerned with nuclear ramjet engines, high-speed airbreathing missiles, and the generation of electric power for spacecraft propulsion. The various programs involved are examined, giving attention to the reasons which led to the discontinuation of the projects before final success was attained. Results connected with the work have found applications in various fields or might provide the basis for future technological advances.

"Review of the Naval Reactor Program and Admiral Rickover Award". Hearings before the JCAE. April 11 and 15, 1959.

These hearings provided an interesting contrast between the Naval Reactors Program and the ANP Project. The Naval Program showed definitive progress toward having a nuclear powered fleet of submarines fully operational while the ANP Project was still being developed, amid serious questions about the wisdom of proceeding further. The JCAE Hearing on April 11 was held aboard the *U.S.S. Skipjack*, SSN-585 in the Atlantic Ocean while it set records for speed and depth. The *Seawolf* was at about the same location off the coast as the U.S.S. *Nautilus* was over 4 years ago when the JCAE held a similar hearing undersea. Success of the Naval Reactors Program is measured by the fact that *Skipjack*, the first of the S5W Class of attack submarines was fully operational 32 days after sea trials, and she was the fifth nuclear submarine to become operational in the past four years. Adm. Rickover's testimony emphasized that these nuclear submarines can remain submerged and self-sufficient for at least two months and made all other submarines obsolete.

Tierney, John. "Take the A-Plane - The $1,000,000,000 Nuclear Bird that Never Flew." *Science*. January/February 1982. pp. 46-54.

Traced the history of the ANP Project from its NEPA beginnings to cancellation. Author cited early, prominent critics Robert Oppenheimer and Edward Teller who were ignored in the enthusiasm over having an airplane aloft indefinitely. He also stated that the rivalry between the Navy and the Air Force contributed to the Air Force's insistence in proceeding with their nuclear program. The NEPA Project assessment by the Lexington group was discussed in the context of limitations placed on their review. The author quoted from the 1954 hearings at which Robert Oppenheimer was labeled as a security risk and Air Force Gen. Roscoe Wilson questioned Oppenheimer's loyalty because he opposed the NEPA Project. The possible Russian ANP Program was also discussed as an unjustified rationale for continuing the U.S. program. The program cancellation was described, just as a two day symposium on ANP was starting in Dallas on March 28, 1961. [Researcher Note: By coincidence, the accident at the Three Mile Island nuclear power plant, that many believe was the end of new U.S. nuclear power plants, also occurred on March 28, 1979, exactly 18 years after the announced cancellation of the ANP Project.]

Weinberg, Alvin M., "The First Nuclear Era - The Life and Times of a Technological Fixer". American Institute of Physics Press. 1994. 271 p.

This was a recent autobiography and overview of nuclear development work by the retired Director of the Oak Ridge National Laboratory. Dr. Weinberg was instrumental in initiating the ANP work at ORNL and Chapter Five provided a useful overview of the project from initiation to cancellation. Emphasis was given to ORNL work leading up to, and including, the Aircraft Reactor Experiment. However, work by other organizations, including Fairchild, Pratt and Whitney and GE, was also discussed. Dr. Weinberg attributed the original concept of the nuclear-powered aircraft to Gordon Simmons, an engineer at the gaseous diffusion plant, who brought the idea to J. Carlton Ward, President of the Fairchild Aircraft Co. Weinberg traced development and "selling" of the concept, and was critical of the politics that promised success, when the technology was unproven. He acknowledged that ORNL participated in ANP, in spite of his misgivings, because at that time the project was the only avenue for the laboratory to continue in any nuclear reactor development efforts.

"What Ever Happened to ... The Nuclear Aircraft Project of the United States' Air Force." *The Nuclear Engineer 22,1 (Jan/Feb 1981):2-5.* Journal of the Institution of Nuclear Engineers (London, England).

Issue was devoted to projects that did not come to fruition, including the ANP Project which was stated to have been "spectacularly successful... the nuclear aircraft project achieved ... every one of its targets within the originally estimated limits of time and cost." Article reviewed the ANP Project history starting six months before the first atomic explosion at Alamogordo, with an approach by Army Air Force officers to Vannevar Bush, (Director of the Office of Scientific Research and Development) for government support for a nuclear-powered aircraft project. This was stated to be five years after the start of the U.S. Navy's nuclear submarine program. No diversion of Manhattan Project efforts was ever allowed for the nuclear aircraft concept. The subsequent NEPA, the Lexington Report and the ANP Project organization efforts are summarized. It was claimed that the shielding problem was solved with the divided shield. Safety studies at ANPO starting in 1955 predicted a chance of one in 10^4 of a severe accident and one in 10^6 chance that a town would be affected. These estimates were based on restricting takeoffs and landings to daylight hours in favorable weather only, with flight paths over sea or sparsely-populated areas. These restrictions in practice would limit flexibility originally used to justify the project. Provided costs of the ANP Project, and a comparison with the Navy Nuclear Program.

Whittemore, Gilbert. "A Crystal Ball in the Shadows of Nuremberg and Hiroshima: Ethical Debate over Human Experimentation in the Development of the Nuclear Powered Bomber, 1946-1951". Paper delivered at the "Science, Technology and the Military", Sociology of the Sciences Yearbook Conference, January 8-10, 1987. Harvard University, Cambridge, MA. Also published in "Science, Technology and the Military". Vol. XII/2. Edited by Everett Mendelson, Merritt Roe Smith and Perter Weingart. Kluwer Academic Publishers, Norwell, MA. 1988. pp.431-457.

Provided a good early history of the NEPA Project, in particular the influence of J. Carlton Ward, Chairman of the Board of Fairchild Engine and Airplane Co. Author was concerned primarily about the radiation effects on the health of project participants and the ethical question of such exposures. In particular, he presented a case study concerning the ethical debate surrounding human experiments with radiation that were proposed as part of the development of the nuclear powered bomber program. He stated that because of the ethical issue, these proposed experiments were abandoned. He also claimed that the NEPA Project, created to develop a better bomber, served the further objectives of: (a) supporting an aircraft industry collapsing from post-war cutbacks, and (b) enhancing the Air Force's stature vis-a-vis the other services.

CHAPTER 10.
POSSIBLE FUTURE FLIGHT APPLICATIONS

"A Review of Precious Resources and their Effect on Air Transport; Proceedings of the Spring Convention, London, England, May 15, 16, 1974". 1974. 282p.

Papers on air transport resources were given, including nuclear contribution to future energy supplies were also considered.

"Air Force Studying A-Powered Plane." *Washington Star*. April 1, 1975. p. A-4.

Associated Press reported that the Air Force was studying the feasibility of a nuclear powered plane twice the size of a C5 according to Dr. Lawrence Noggle, program director for ANP at Wright-Patterson Air Force Base. Noggle said the study was motivated by the current fuel crisis. The plane would use conventionally powered engines for takeoff and landings.

"Air Force's Long-Standing Interest in Nuclear Powered Aircraft." *Aviation Week*, Sept. 1, 1969. p.5.

In a brief news article, *Aviation Week* claimed that the Air Force has increased its interest in nuclear powered flight because of advances in reactor technology. They were exploring a multi-mission aircraft approximately twice the weight of a Lockheed C-5A. Lockheed was also investigating a C-5A powered by a reactor inside its center fuselage.

"Airports Evolution and Qualification." Convegno Internazionale dell Comunicazioni, 21st, Genoa, Italy, Paper. In Italian. Oct. 8-13, 1973. 27 p.

According to the authors, the 1950's and 1960's which mark the beginning of the air transportation industry, were decisive for airport structure through the realization of suitable flight and operational infrastructure capable of assuming practicability and receptivity. The 1970's with jumbo jets had new problems of dimensions and qualification for large airports together with problems of accessibility and ecology. Thus it was necessary to consider if the way followed until now, which leads to the super airport, does not have to be reexamined for a different solution to the problem of qualified airport systems. According to the authors, in the 1980's and thereafter, in addition to use of atomic energy in air transportation, a new and unforeseeable leap will be made with commercial aircraft.

Amos, M.W., J.S. Butt, D.L. Campbell, R.G. Diehl, and W.J. Fanning, Jr. "Nuclear Aircraft Feasibility Study (Executive Summary). Report for 1 Mar 74--7 Feb 75". AD-B-008941; GSE/SE-75-1-Summ. Air Force Inst. of Tech., School of Engineering, Wright-Patterson AFB, OH. Mar. 1975. 37 p.

The objective of this study was to assess the feasibility of applying nuclear propulsion to aircraft in performance of the Air Force Mission. This was accomplished by using a systems approach with the system divided into six areas: (1) Mission Selection, (2) Required Mission Avionics, (3) Aircraft Design, (4) Propulsion System Design, (5) Public Safety, and (6) Cost. The overriding constraint of the study was the assumption that technology would limit an aircraft gross weight to 2,000,000 lbs in the 1990's. At this gross weight, an aircraft built using conventional construction methods and powered by a liquid metal cooled nuclear reactor, but using only chemical fuel for takeoff, would have a negative payload of 120,000 lbs. If the aircraft were constructed using advanced composites and a liquid metal cooled reactor with chemical augmentation for takeoff, the payload would be 470,000 lbs. By switching the liquid metal reactor for a similarly constructed helium cooled reactor, the payload would drop from 470,000 lbs to 210,000 lbs. For each individual in the U. S., the risk of being killed by the radioactive particles associated with one of the airborne 574 MW reactors, would be 9.34 X 10^{8} per year, which is less risk than that of being struck by lightning. The 52,000 hr. airframe life cycle cost was estimated to be $26.4 billion for 60 aircraft.

Amos, Michael W.; Butt, James S.; Campbell, Bruce L.; Diehl, Richard G.; Fanning, William J. "Nuclear Aircraft Feasibility Study, Volume I.". Air Force Inst. of Tech. Wright-Patterson AFB, OH School of Engineering. Mar. 1975. 415 p.

From several missions requiring a long endurance aircraft, the antisubmarine warfare mission was selected for the purpose of establishing point design parameters. Since the mission avionics package was required to be relatively large, the weight was minimized using a constraint of 0.95 reliability for a 14 day mission. The aircraft was designed utilizing standard aerodynamic design techniques, considering mission constraints but optimizing to require minimum thrust. From the several aircraft configurations analyzed. A canard configuration was chosen for final design consideration. The propulsion system, consisting of the reactor, the heat transfer system and the engines were analyzed for various configurations, including liquid metal and gas cooled reactors and indirect and direct cycle engines. A probabilistic risk analysis was performed to determine the hazard to society in terms of deaths caused by radiological exposure. Several cost modeling techniques were coupled with expert opinion to form a probabilistic assessment of the life cycle cost of the point design aircraft.

Amos, Michael W.; Butt, James S.; Campbell, Bruce L.; Diehl, Richard G.; Fanning, William J. "Nuclear Aircraft Feasibility Study. Volume II." Appendices. GEE/SE/75-1-VOL-220. Air Force Inst of Tech Wright-Patterson AFB, School of Engineering. March 1975. 87 p.

Report included: sample calculations; computer program logic charts; airfoil characteristics; engines; heat transfer; safety analysis; release probability data; reactor

safety study validation; computer logic diagrams; and life cycle cost for nuclear powered aircraft.

Anderson, J. L. and F.E. Rom. "Assessment of Lightweight Mobile Nuclear Power Systems." NASA, Lewis Research Center, Cleveland, Ohio. American Nuclear Society, Winter Meeting, San Francisco, Calif., Nov. 11-15, 1973, Paper, 34 p.

After nearly two decades of study, analysis, and experiments relating to lightweight mobile nuclear power systems (LMNPS),the status was reported and some options assessed for the future of this technology. This report: (1) reviewed the technical feasibility studies of LMNPS and airborne vehicles; (2) identified what remains to be done to demonstrate technical feasibility of LMNPS; (3) reviewed missions studies and identifies particular missions that could justify renewed support for such technology; and (4) identified some of the nontechnical. conditions that will be required for the development and eventual use of LMNPS.

Anderson, J. L. "Nuclear Powerplants for Mobile Applications." NASA, Lewis Research Center, Cleveland, Ohio. American Institute of Aeronautics and Astronautics, and the Society of Automotive Engineers, Eighth Joint Propulsion Specialist Conference. New Orleans, LA. Nov. 29- Dec. 1, 1972. 34 p.

Included technical and economic analysis of nuclear power reactors application for international cargo ship and air transportation, noting feasibility study of airborne power plants. Mobile nuclear powerplants, for applications other than large ships and submarines required compact, lightweight reactors with especially stringent impact-safety design. This paper examined the technical and economic feasibility that the broadening role of civilian nuclear power, in general, (land-based nuclear electric generating plants and nuclear ships) can extend to lightweight, safe mobile nuclear powerplants, The paper discussed technical experience, identified potential sources of technology for advanced concepts, cited the results of economic studies of mobile nuclear powerplants, and surveyed future technical capabilities needed by examining the current use and projected needs for vehicles, machines, and habitats that could effectively use mobile nuclear reactor powerplants.

Andrews, D. and S. Zakanycz, et. al. “Comparison of Nuclear versus Hydrogen Fueled Aircraft.” American Institute of Chem Eng. Conference. “Proceedings on Energy and the Environment.” College Corner, OH. Nov. 13, 1974. pp. 45-48.

Provided results of a comparative analysis of the nuclear and hydrogen powered aircraft engines.

Anzine, A. M. “The Atom Engine“. (Trans. from Russian). Translation-2125. Department of the Navy. Washington, DC. 1966. 69 p.

This brochure described atomic engines of electric stations, submarines, surface ships, aircraft and rockets. It discussed the fields in which atomic energy plants were currently being used and the prospects for their application.

Arata, W.H., Jr. "Very Large Vehicles - to Be or --- Aircraft Design Concepts." Northrop Corp., Los Angeles, Calif., 17 *Astronautics and Aeronautics* (April 1979):20-25, 33.

Some of the concepts being studied for large aircraft were briefly discussed. Reviewed concepts for conventional takeoff and landing aircraft, distributed-load aircraft, wing-in-ground effect aircraft, multiple fuselages, the laminar-flow-control aircraft,, nuclear powered tug, air-cushion-landing-system aircraft, blimp-helicopter combination, and surface-effect ships.

"Are Nuclear Planes Next?" *U.S. News and World Report*, March 4, 1978.

Provided an interview with Dr. Ronald Smelt, a Vice President and Chief Scientist at Lockheed Aircraft Co. who stated that the C-5A Galaxy, for the first time, provided an airframe large enough to allow a practical nuclear powered aircraft. Smelt indicated that in the ANP Program the aircraft limitation of about 400,000 lbs. the reactor and shielding limited the payload to an impractical small amount. He estimated that a nuclear-powered aircraft could be developed for $1-2B and take 10-12 years. He also indicated that more adequate shielding would be provided to meet regulatory standards, whereas the ANP Program "solution attempted ...was not to shield adequately but to leave some radiation spraying out from the aircraft". Smelt suggested that a small runway might be built on top of the nuclear aircraft to allow crew changes while remaining aloft for extended periods.

"Background Information for Nuclear Aircraft Safety Analysis Program". FZM-25-022. Convair, Forth Worth, TX. Nov. 22,1957. 127p.

A summary was presented of the status in 1957 of studies on the hazards associated with nuclear-powered aircraft. Postulated the nuclear consequences of a typical and an extreme reactor accident. A statistical prediction was made of the probable average number of bystanders affected by the postulated aircraft accidents. Analyzed the effect of the worst credible accident. A discussion was included of what would have happened if the B-47 bombers had been nuclear-powered between 1952 and 1955.

Bedwell, Don. "Space Shuttles, Nuclear Flying Wings Predicted in Decade." *Miami Herald*, Nov. 29, 1970. p.13.

Reported that Roy A. Lange, a Lockheed-Georgia advanced concepts specialist predicted that Lockheed's conceptual flying wing can utilize improved nuclear reactors and shielding to provide a 219,000 lb. payload aircraft cruising at Mach 0.75.

Bockrath, T.A.. "The Preliminary Design of a Very Large Pressure Airship for Civilian and Military Applications". AIAA PAPER 83-2005. In "Lighter-Than-Air Systems Conference, Anaheim,, CA, July 25-27, 1983, Collection of Technical, Papers". 1983. p.176-184.

The present pressurized semirigid airship, for which nuclear power was considered as a propulsion system option, was 2000 ft. in length, 500 ft. in diameter, and designed for a cruise speed of 200 mph at an altitude of 2000 ft., over a 12, 000-mile range. The airship could withstand wind shears of over 150 ft/sec at cruise speed, and could withstand a gauge pressure of 6 psi, as a result of the extensive use of Kevlar cable and fabric in its construction. Civilian applications of this vehicle included the transport of cargo in standard, 40-foot containers, and of natural gas in internal membranes. Military uses ranged from the transport of either an entire infantry division and up to 50 tanks, to the highly mobile deployment of 24 MX ICBMs housed internally in 300-foot long vertical launch tubes.

Brewer, G.D. "The Potential of Large Aircraft." For Lockheed-California Co., Burbank, CA. Presented at the American Institute of Aeronautics and Astronautics, International Very Large Vehicles Conference, Washington, DC. May 17-18, 1982. 6p.

The present investigation was concerned with two designs of unconventional aircraft, both very much larger than existing equipment. One of the two designs, implemented by the Surface Effect Aircraft (SEA), took advantage of the increase in lift/drag (L/D) which results from flying very close to the surface. In connection with their size, the vehicles were designed to operate as flying boats. It was recognized that their principal operational mode would be in transocean service, providing "125 knot sea lift". At a takeoff gross weight of 1.8 million pounds one of the considered SEA was capable of carrying 810,000 pounds of payload a distance of 3450 nautical miles. Attention was also given to a study regarding the largest aircraft anyone might conceivably build, taking into account the conceptual design of a nuclear-powered aircraft which weighed nearly 12 million pounds. A military situation was conceived in which such aircraft might be used.

Bussard, R.W. and R.D. DeLauer. "Fundamentals of Nuclear Flight." Mc Graw Hill Book Co., New York. 1965. 445 p.

This textbook was primarily directed to nuclear power applications for space vehicles, not manned aircraft. However, it did discuss basic technology which was applicable to ANP, including heat transfer, shielding, fluid flow, reactor physics and materials.

Callaghan, Richard L., NASA Asst. Administrator for Legislative Affairs. Letter to Senator Warren G. Magnuson. May 5, 1967. Available at NASA, HQ. Office of History.

Responded to Sen. Magnuson's letters on behalf of a constituent, William Clendenon, Jr. who proposed an atomic powered aero-space plane to the Inventions and Contributions Board of NASA. NASA concluded that all the technology necessary to implement this suggestion is not now in existence and his ideas do not qualify for a monetary award.

Clements, E. W., E.J. O'Hara. "The Navy Rigid Airship". NRL-MR-246320. Naval Research Lab. Washington, DC. July 1972. P. 42.

Lighter-than-air craft were used with great success by the navy for some fifty years. Consideration of the unique capabilities of these craft, particularly rigid airships, suggests that they would be well suited to some present-day navy missions. This memorandum presented a resume of past experience with rigid airships and outlines their performance characteristics. The most prominent of these included the ability to remain airborne for great lengths of time carrying large payloads, the ability to land and take off vertically and hover, and their apparent compatibility with nuclear propulsion. In view of the considerable technical potential, a mission-oriented systems analysis of updated rigid airship designs was recommended.

Clyman, Milton, Sheldon J. Einhorn, Richard Shultz. "Compilation of Energy Efficient Concepts in Advanced Aircraft Design and Operations". Volumes I. and II. Information Spectrum Inc., Warminster, PA. Nov. 1980. p. 434.

Contained a data base arranged into areas of research and development effort including synthetic and liquid hydrogen fuels; gas turbine, and nuclear propulsion.

Decher, R., A.W. Strawa, M.R. Fiske, B.L. Lohmueller, V. Schmidt, M.C. Joshi, J.S. LeGath, M. Polites, P. Dugge and J. Hodkinson. "Aerospace '92 - The Year in Review". *Aerospace America* 30, 12 (Dec. 1992): 10-25, 28-39, 41-48.

Included discussion of advancements in airship design, liquid and solid rocket propulsion and nuclear thermal propulsion.

Demler, Marvin C., Folder T-6.3: Nuclear Powered Aircraft, Reassessment, (5/8/61-11/83)

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Contains " Mr. McNamara's misinformation on Aircraft Nuclear Propulsion", an Editorial by Robert Hotz from *Aviation Week,* 8 May 61; "Prospects for High Thrust Nuclear Propulsion", by Ralph S. Cooper, *Astronautics and Aeronautics*, (AA) Jan 66; "Atomic

Plane Able to Remain Aloft for Months Is Again under Study", Newspaper Article by George C. Wilson (Circa 1967); "Possible Nuclear Aircraft Roles Analyzed", from *Aviation Week and Space Technology* , 30 Oct 67; "Will Nuclear Powered Aircraft Be Safe?" By Frank E. Rom and Patrick M. Finnegan and "Nuclear Propulsion for Aircraft" by John M. Wild from (AA), Mar 68; Comment, "C-5 Aircraft and the Future", from *Lockheed Reports*, Mar 68; Handwritten Notes Regarding ANP Studies by Rand Circa Mar Through May 69); the "Nuclear Powered Airplane" (Discussed Safety of Nuclear Powered Aircraft) from the "Nuclear Powered Airplane", *Technology Review*, 1969; on the " Impact of Applying Nuclear Power to the Airplane" by Frank L. Wassel, Feb 70; "Nuclear Powered, Seaplane Version of Lockheed C5A Aircraft Has Been Proposed to the Navy" from *Aviation Week and Space Technology*, 1 Jun 70; "Evaluation of Technology for Low Specific Weight Reactors in the Union of Soviet Socialist Republics" (Bears Handwritten Notations, Received 25 Feb 71 from W. L. Budge, W. E. Astronuclear Laboratory), 19 Jan 71; "(Nobel Prize) Winners Plumbed Inner World of the Atom" from *New York Times*, 31 Oct 69; Newspaper Clipping, "Global Airliner, Atomic Powered, Seen for Year 2000", 20 Apr 70;" What's Holding Nuclear Propulsion Back?" (Proceedings of a *Joint AIAA (American Institute of Aeronautics and Astronautics)/SAE (Society of Automotive Engineers*) Joint Specialist Propulsion Conference Including Frank E. Rom, Russel C. Drew, David G. Gabriel, William Budge and Donald G. Brennan) from *AA*, Jan 72;" What Can Nuclear Energy Do for Society?" by Frank E. Rom from *Astronautics and Aeronautics*, Jan 72; and" Will Atoms Take Off?" From *Popular Mechanics*, Nov 83.

Ehlbauer, J.C. “Very Large Aircraft with Alternate Fuels - LH2 Most Promising.” Lockheed-Georgia Co., Marietta, GA, American Institute of Aeronautics and Astronautics, Second International Very Large Vehicles Conference Washington, DC, May 17-18, 1982.

Reported on optimum designs of cargo aircraft using alternate fuels and carrying large payloads roundtrip over transoceanic distances without refueling that were developed and compared. Considered synthetic jet propulsion (JP) fuel, liquid hydrogen (LH2) fuel, and nuclear power. In relation to the JP aircraft, the LH2 aircraft was found to have lower ramp weights (by 25%) and lower trip costs (by 15%). The ramp weights and trip costs of the nuclear aircraft were, respectively, approximately 5 and 20% higher than those for the JP aircraft. With JP aircraft trip costs the most sensitive to fuel price it was believed. that rising prices in the future will make LH2 and nuclear power increasingly attractive.

“Ferguson Cites Feasibility of Nuclear Aircraft.” *Space Daily*, April 29, 1970. p. 282.

The Commander of the Air Force Systems Command stated that C5-A and larger aircraft to follow will make nuclear propulsion “eminently feasible”. He justified the effort based on the “dynamic nature of the threat we face...(means) we have no real choice... but to push constantly on the state of the art.”

Finnegan, M. Patrick, Richard L. Puthoff, and James. W. Turnbow. "Preliminary Impact Speed and Angle Criteria for Design of a Nuclear Airplane Fission Product Containment Vessel". N-71-25411. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH. May 1971. 37p.

Studied reports and photographs of 96 major accidents occurring before 1965 and involving multi-engine jet aircraft. Impact speed and angle were presented for landing and takeoff accidents, cruise accidents without in-flight structural failure, and in-flight structural failure accidents. The landing and takeoff accidents had an average impact velocity of 200 ft/sec from any direction and a maximum impact velocity of 300 ft/sec with a 10 deg solid angle about the roll axis. The cruise accident without structural failure had an average impact velocity 400 ft/sec and a maximum possibility as high as 1000 ft/sec (305 m/sec), both within a 10 deg solid angle about the roll axis. The in-flight structural failure accident had an average impact velocity of 400 ft/sec from any direction and a maximum possibly as high as 1000 ft/sec within a 10 deg solid angle about the roll axis. The in-flight structural failure accident determined the most severe impact speed for all impact angles.

Fishbach, L. H., and W.C. Strack. “Performance Characteristics of Nuclear Powered VTOL Aircraft”. NASA-TM-X-52524 . National Aeronautics and Space Administration, Lewis Research Center, Cleveland OH.

Discussed the application of nuclear power to VTOL Aircraft.

Fishback, Lawrence H. "Steam Cycle for Aircraft Propulsion". N-69-40060. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH. Oct 1969. 21p.

Presented a preliminary cycle of a steam-driven, nuclear-powered turbofan engine. It was found that maximum efficiency and minimum thrust per unit airflow both occur for a bypass ratio of zero. This corresponded with minimum heat-exchanger-outlet air temperature. Parametric numerical results were presented which can be used for selecting the proper engine operating conditions for a given airplane.

Gaffin, W.O., and P.I. Perry. “Nuclear Turboprop Powerplant Preliminary Performance and Installation Data”. PWAC-405. Pratt and Whitney Aircraft, Connecticut Advanced Nuclear Engineering Lab., Middletown, CT. June 25, 1963 (Decl. Sept. 5, 1973). 22p.

Preliminary estimates were presented of the performance, weight, dimensions and handling requirements of a nuclear powered turboprop powerplant for use in a large, low speed, long endurance airplane. Because of a shortage of time and the lack of definition of airplane requirements, the powerplant had not been completely optimized for the mission. However, the estimates should prove adequate for preliminary feasibility studies.

Goodger, E. and E. Vere. "Aviation Fuels Technology". Macmillan Publishers Ltd, Basingstoke, England. 1985. 278 p.

Analyzed the fuel characteristics within aircraft fuel systems and fuel combustion performance. Described the fuels for ultra-high performance aircraft and rocket propulsion. The application of electric, nuclear, or inertial propulsion, and biofuels to aircraft propulsion systems was proposed.

Greenwood, Stuart William. "The Nuclear Powered Aircraft as an Airborne Laboratory." *Astronautics & Aeronautics*, July 1968. pp.40-41.

The author, a Professor at the University of Manitoba, proposed use of nuclear powered aircraft for long flight duration for continuous observation of space objects and the atmosphere. He cites articles in recent issues of *Astronautics & Aeronautics* for nuclear aircraft information. (See Wild, J.M. "Nuclear Propulsion for Aircraft". *Astronautics & Aeronautics,* March 1968. pp. 24-30. and Rom, F.E. and Finnegan, P.M. "Will Nuclear Powered Aircraft be Safe?" *Astronautics & Aeronautics,* March 1968. pp. 32-40).

Grey, J. and C. Simpson. "Future Engines and Fuels". *Exxon Air World* 27, 4 (1975): 91-95.

The variable-cycle engine and the supersonic-combustion ramjet (for hypersonic aircraft) were discussed, with emphasis on the first topic. The use of hydrogen as a fuel and the need for rejuvenation of the nuclear aviation power development effort were also discussed.

Grey, Jerry. "Nuclear Aircraft Propulsion: Time for a Second Look". Greyrad Corp., Princeton, NJ. *Ann. N. Y. Acad. Sci*. 163 (Sept. 4, 1969): 310-19.

It was suggested that the Aircraft Nuclear Propulsion program, cancelled in 1961, should be reconsidered. Such reconsideration would be based on the acceptability of aircraft having higher gross weight than the rather arbitrary 500,000 lb. limit set for the ANP vehicle. Removal of this simple limitation, together with elimination of the requirement for supersonic "dash" capability, now makes the nuclear-powered cargo airplane not only possible, but competitive, both economically and operationally, with conventional chemically fueled aircraft. The principal advantage offered by a nuclear engine, which needs no refueling, was unlimited range. Missions whose key requirement is payload-carrying over long distances were examined. The military usefulness of a fleet of such airplanes was commented on, and several critical requirements referred to. In addition to the operational need for aircraft that are economical, operationally practical, and able to utilize existing runways, it was necessary that safety be a prime factor. This called for a unit shield around the reactor rather than the ANP's divided shield, so that not only the crew but all ground-handling personnel and passengers were protected. Also, the shield must be crash proof to avoid escape of radiation sources from the reactor in the event of an aircraft accident. Further, from a safety point of view as well as to minimize reactor power demand and, therefore, shield weight, it was advisable to utilize chemical fuel in the engines for takeoff and landing. Conversion of the C-5A aircraft to nuclear power and some aspects of engine design were also considered.

Gumto, K.H. and R.L. Puthoff. "Parametric Study of a Frangible-Tube Energy- Absorption System for Protection of a Nuclear Aircraft Reactor." NASA-TN-D-5730 E-4991. National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

Provided analysis of frangible-tube energy absorption system for protection of nuclear aircraft reactor.

Holton, Ronald L. "Impact Tests of Simulated Nuclear Containment Vessels". AFWL-TR-72-6920. Air Force Weapons Lab. Kirtland AFB, NM. June 1972. P.33.

Four impact test runs have been completed using the Holloman AFB test tracks. The tests were designed to evaluate selected reactor core and containment vessel concepts having possible application to airborne reactor propulsion systems. Tests were run with the test models impacting against concrete targets at velocities of 640, 914, 1055, and 1080 ft/sec. Two of the four test models survived the impact without rupture or leakage.

Hyland, R.E., and C.J. Lennon. "Criticality Study of Meltdown Configurations for Nuclear Aircraft Reactors". NASA-TM-X-2068 E-4973. National Aeronautics and Space Administration, Lewis Research Center, Cleveland OH. August 1970. 20p.

Discussed the results of studies of criticality meltdown configurations for nuclear aircraft reactors.

Jones, Andrew R. and Robert E. Thompson. "A Nuclear System Suitable for Aircraft Propulsion." Westinghouse Astronuclear Laboratory, Pittsburgh. *Trans. Am. Nuc. Soc.* 18 (June 1974):3-4.
Utilizing the technology developed in the nuclear rocket program, which included testing at performance levels several times that requires for aircraft propulsion, a nuclear aircraft engine appeared possible. The engine would use NERVA nuclear rocket technology as a helium cooled graphite moderated design in a two loop cycle.

Kascak, A. F. and F.E. Rom. “The Potential of Nuclear Power for High-Speed Ocean-Going Air-Cushion Vehicles." NASA-TM-X-1871. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH. 34 p.

Reviewed the utilization of nuclear power plants for nuclear aircraft technology to power ocean-going air cushion vehicles.

Kascak, A.F. and F.E. Rom. "The Potential of Nuclear Power for High-Speed Ocean-Going Air-Cushion Vehicles". For NASA, Lewis Research Center, Cleveland, OH. American Inst, of Aeronautics and Astronautics, Second Advanced Marine Vehicles and Propulsion Meeting, Seattle, WA, May 21-23, 1969, New York, NY.

Covered performance potential of high speed ocean-going air cushion vehicles with aircraft nuclear power plants.

Kascak, Albert F. "Parametric Study of Large Nuclear Surface Effects Machines". N-69-36757. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH. Sept. 1969. 41p.

Described some performance estimates of a high speed peripheral jet nuclear powered surface effects machine. The calculations incorporated a recently proposed nuclear airplane reactor concept. This high temperature reactor reduces shield weight and eliminated a need for a heavy preheater. Payload fraction and reactor power were calculated for vehicle gross weights from 1000 to 5000 tons, forward velocities from 0 to 250 knots, and clearance heights from 10 to 50 ft. For these ranges, the payload varied from 0 to 60% of the gross weight, and the total reactor power varied from 400 to 10,000 MW.

Layton, J.P. “Advanced Nuclear Systems for Large Aircraft". AIAA PAPER 79-0852. Very Large Vehicle Conference, Arlington, VA, April 26-27, 1979; Technical Papers, American Institute of Aeronautics and Astronautics, New York. 55p.

Recent advances in nuclear power and propulsion systems as well as aircraft technology have resulted in large military aircraft concepts that promise practical operational aircraft. Outlined an approach to the interdependent definition of future military missions and credible nuclear aircraft based on a carefully conceived program of analysis, research, and technology. Particular consideration was given to advanced nuclear aircraft concepts, including heavier-than-air and lighter-than-air. Emphasized aspects of operational safety .

Lehman, L.O., D. Woll, and C. Lampart. “Aircraft Design for Fuel Efficiency”. In “International Council of the Aeronautical, Sciences, Congress, 13th and AIAA Aircraft, Systems and Technology Conference, Seattle, WA, August 22-27, 1982, Proceedings. Volume 2". 1982. pp. 969-979.

U.S. Navy Aircraft Energy Conservation Research, Development, Test and Evaluation Program recommendations to date were presented, with emphasis on those aircraft design approaches which promise the greatest fuel savings for a given level of investment. The study results covered fighter, attack and patrol aircraft, and includes recommendations for such year 2000 air vehicles as nuclear aircraft and advanced lighter-than-air vehicles.

Lennon, Conrad J. and Robert E. Hyland. "Criticality Study of Meltdown Configurations for Nuclear Aircraft Reactors". N-70-36660. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH. Aug. 1970. 20p.

As part of a containment system study for the nuclear aircraft reactors, a description of the meltdown problem was presented along with curves of reactivity for reflected and unreflected slabs, spheres, and cylinders as a function of UO_2 fuel loading, composition and size. These were presented to help the early design concepts avoid configurations that would cause excursions in the event of a core meltdown and thereby obtain a feasible containment system. Results were presented which indicates that masses that have melted down from reactors can be kept subcritical provided certain geometrical dimensions for specific dilutions of fuel were not exceeded within the containment system.

Lockheed Envisions 10 Million Pound Nuclear Aircraft." *Space Daily*, July 24, 1970. p. 106.

Lockheed stated that nuclear technology had advanced to the point where a nuclear engine with enough power for cruising can fit into a C5-A. Reference was also made to the initiation in June 1970 of ANP studies by the Air Force and the advantages of a nuclear plane cited by the commander of the Air Force Systems Command, Gen. James Ferguson on April 29, 1970.

Lockheed Horizons. AIAA PAPER 79-1793. Spring 1980. pp. 32-39.

Some new technologies were surveyed that offer the possibility of making obsolete the present concept of a jet transport. Attention was given to such areas as laminar flow control, all-wing concepts, super large aircraft, advanced turboprops, air cargo, avionics, hydrogen, VTOL and V/STOL. Also covered were a nuclear-powered airplane and a supersonic transport. It was concluded that new developments will be of an evolutionary manner rather than a sudden jump to a new generation of aircraft, as in the past.

Lutz, O. "Gas Turbines in Aeronautics". In "Gas Turbines- Problems and Applications. Part 4 - Constructed Movable Plants". VDI-Verlag GMBH, Germany. No Date. pp.461-99. In German.

Covered gas turbines in aeronautics, discussing auxiliary systems, nuclear and V/STOL aircraft turbine engines.

Martinez, J.S. and R.K. Plebuch. "Nuclear Propulsion Applications". For TRW Systems Group, Redondo Beach, CA. Presented to New York Academy of Sciences, Second Conference on Planetology and Space Mission Planning, New York, NY, Oct. 26-27, 1967. In *New York Academy of Sciences Annals* 163: 358-379.

Discussed nuclear propulsion systems types, including relative capabilities and future roles in aerospace applications.

Mikolowsky, W. T. "An Evaluation of Very Large Airplanes and Alternative Fuels: Executive Summary". R-1889/1-AF20. Rand Corp. Santa Monica, CA. Dec. 1976. P. 40.

Candidate applications of very large airplanes included: Strategic airlifter, tanker, missile launcher, tactical battle platform, maritime air cruiser, and C-3 platform. This report summarized previous work which explored the military utility of very large airplanes (over 1 million pounds gross weight) and examined several alternative fuels that could be used by such airplanes, including nuclear power.

Mikolowsky, W.T., L.W. Noggle, and W.L. Stanley. "The Military Utility of Very Large Airplanes and Alternative Fuels". *Astronautics and Aeronautics* 15 (Sept. 1977): 46-56.

This paper described a study with the objectives of evaluating very large airplanes in the context of existing and possible future Air Force missions and determining the most attractive alternative fuel for these airplanes. The chemical fuel alternatives considered were liquid hydrogen, liquid methane, and synthetic JP, each of which can be readily synthesized from coal. The nuclear-fueled aircraft was a fourth candidate aircraft. The cost and energy effectiveness of these basic aircraft-fuel combinations in typical range, radius, and station-keeping missions was estimated. It was concluded that overall, a conventional hydrocarbon jet fuel remains the most attractive fuel for military aircraft. Nuclear propulsion was attractive only for station-keeping missions requiring large station radii. Very large aircraft were especially attractive if the capability to airlift U.S. forces world-wide without reliance on overseas bases is a major requirement.

Mikolowsky, W.T., L.W. Noggle and W.L. Stanley. "An Evaluation of Very Large Airplanes and Alternative Fuels". Presented at American Institute of Aeronautics and, Astronautics, Aircraft Systems and Technology, Meeting, Dallas, TX, Sept. 27-29, 1976. September 1976. 13 p.

This paper examined the potential of very large airplanes in the context of existing and possible future Air Force missions, and determined the most attractive fuel for airplanes of this type. The description of alternative conceptual designs included the desired aircraft characteristics, results of a screening analysis which identified the most promising candidate fuels, and some characteristics of the alternative projects, such as life-cycle cost and energy consumption. Synthetic jet fuel, liquid methane, liquid hydrogen, and nuclear propulsion were the fuel alternatives selected for detailed analysis. The effectiveness of the alternative airplanes was analyzed in strategic airlift and station-keeping missions. It was shown that for most military applications, aircraft with gross weight exceeding one million pounds promise to be superior to contemporary vehicles in terms of cost and energy effectiveness. The conventional jet fuel (made from coal, oil shale or crude oil) appeared to be the most effective at least up to year 2000. Nuclear propulsion was attractive only for station-keeping missions requiring larger station radii (greater than about 4000 nautical miles).

Miller, M.M. "Nuclear Airplane Now!". For Lockheed-Georgia Co., Marietta, GA. *Ind. Res.* 12, 3 (March 1970): 48-50.

Described advances in the technology of nuclear reactors, heat transport systems, shielding and containment materials, and engine efficiency, including the potential for successful development of nuclear airplanes.

Mills, K. Louis, III. “Aircraft Nuclear Propulsion: A New Look In 1971". Univ. of Virginia, Charlottesville, VA. 1972. 275 p. Thesis. Avaliable in the University of Virginia Library.

The design of a nuclear propulsion system for large aircraft was presented. Primary interest was on achieving an accurate description of the reactor core and reflector. Power tailoring was used to reduce the radial peak-to-average ratio to 1.1 or less throughout the core. Basic heat transfer equations were used to obtain axial and radial temperature distributions in a fuel pin. Shield configurations and weights were based on AEC standards for occupational exposure because the aircraft design is military rather than commercial. Reactor power requirements were based on energy equivalents: the thermal energy from the core equals the energy input from jet fuel at the flight design conditions. The consequences of a major aircraft accident were considered and the penalties to reduce or prevent them were determined. Full containment of fission products seemed possible for most conceivable accidents. The overall system was analyzed and compared to other proposed systems. All calculations for shielding and safety were designed to give conservative answers and to provide a margin of safety.

Mills, K. Louis, III. and J. L. Meem. “Nuclear Power for the C-5 Transport Aircraft”. University of VA. *Trans. Am. Nuc. Soc.* (June 18-22, 1972):5.

Citing the “well-known” advantages of nuclear aircraft, authors argued that the NERVA/KIWI nuclear rocket propulsion reactor could be used as a closed cycle helium cooled heat source for a jet engine. They projected a 3000 hr. core lifetime for the helium cooled NERVA reactor due to reduced temperatures over the rocket application. An axially laminated lithium-hydride and tungsten shield would be utilized.

Morse, F., G.J. O’Hara, J.G. Vaeth, V.H. Pavlecka, and K.R. Stehliong. “Dirigibles - Aerospace Opportunities for the '70s and '80s”. *Astronautics and Aeronautics* 10 (Nov. 1972): 32-40.

According to the authors, the dirigible or rigid airship, a versatile and potentially ecologically 'clean' STOL with exceptional payload capability, endurance, range, flight stability, and onboard roominess, deserved renewed consideration as a useful vehicle in tomorrow's scheme of things. It was pointed out that great improvements can now be made in the structure of the rigid airship because computers and modern structural dynamics permit the analysis of the ship's structure as a whole. The history of dirigibles was reviewed and new advances for future airships were considered. An exciting picture emerged when nuclear power propels a lighter-than-air craft. Onboard radar would help avoid obstacles and detect other aircraft. It would examine the ground for accurate navigation, provide weather surveillance, and assist mast-approach control in poor visibility.

Morse, F.B.. “Airships - The Next Generation and Beyond”. *AIAA Student Journal 16* (Summer 1978): 20-25.

Developments currently in the design stage for lighter than air vehicles are reviewed with reference to a 12 million cu. ft. rigid airship. The ship would be inflated with helium, have a skin of aluminized Kevlar fabric, a gross lift of 800,000 lbs. (equal to that of a Boeing 747), and be used for both short and long range passenger and freight applications. Attention is given to LH_2 and nuclear fuel as propulsion material.

Muehlbauer, J.C., D.N. Byrne, E.P. Craven, C.C. Randall, and S.G. Thompson. “Innovative Aircraft Design Study. Task II. Nuclear Aircraft Concepts. Final Report, 24 June 1976--15 April 1977". AD-B-017795; LG-77ER0008. Lockheed-Georgia Co., Marietta, GA. Apr. 1977. 254 p.

Parametric analyses and design refinement studies were performed for conventional, canard, and spanloader aircraft configurations to determine the lightest ramp weight configuration with a nuclear propulsion system. Mission requirements for these analyses were: 400,000 and 600,000-lb payloads, 0.75 cruise Mach number, 1000 n.m. emergency chemically-fueled range, and a 9000-ft field length. The canard configuration was between one and ten percent lighter in ramp weight than the other candidates at both payloads. Comparison were made of the reference, (Brayton nuclear propulsion cycle and canard wing configuration) and alternate nuclear aircraft with JP-fueled aircraft to determine that design range value which will result in JP-fueled aircraft with the same ramp weights or life-cycle costs as the nuclear aircraft. The results showed, the equal ramp weight cross-over ranges to be 9200 and 7850 n.m. relative to the reference and alternate nuclear aircraft, respectively. For mission ranges exceeding these values, the nuclear aircraft will be lighter in weight. The converse is true for shorter ranges. Similarly, the life-cycle cost ranges were 11,950 and 11,100 n.m., respectively. However, a 300-percent fuel price increase reduced these ranges to 6100 and 4700 n.m., respectively. Thus, as the severity of the energy shortage increases fuel prices, the future prospects for airborne nuclear propulsion will improve.

Muehlbauer, J.C., and R.E. Thompson. "Nuclear Aircraft Innovations and Applications". AIAA PAPER 79-0846. Presented at American Institute of Aeronautics and, Astronautics, Very Large Vehicle Conference, Arlington, VA, Apr. 26-27, 1979. May 1979. 15p.

Determination of the minimum weight nuclear propulsion cycle and aircraft configuration, identification of technologies and innovations for enhancing mission accomplishment, and evaluation of alternate mission applications in the framework of the Innovative Aircraft Design Study program are discussed. Parametric studies of four aircraft configurations showed the minimum weight configuration to be one which carries the payload and reactor in the fuselage and uses a canard surface for horizontal control. A Bi-Brayton propulsion cycle with a gas cooled reactor and dual mode engines offers the potential for the lightest weight nuclear aircraft. While sea control, cruise missile carrier, tanker, and airborne command post are prospective alternate mission applications, the nuclear powered cruise missile carrier aircraft concept provides unique strategic capabilities.

Muehlbauer, John C.; Byrne, David N.; Craven, Eugene P.; Randall, Charles C.; Thompson, Sterling G. "Innovative Aircraft Design Study. Task Ii. Nuclear Aircraft Concepts". LG-77-ER0008. Lockheed-Georgia Co Marietta. April 1977. p. 254.

Parametric analyses and design refinement studies were performed for conventional, canard, and spanloader aircraft configurations to determine the lightest ramp weight configuration. With a nuclear propulsion system mission requirements for these analyses were: 400,000 and 600,000-lb payloads, 0.75 cruise mach number, 1000 n.m. Emergency chemically-fueled range, and a 9000-ft field length. The canard configuration was between one and ten percent lighter in ramp weight than the other candidates at both payloads. Comparison were made of the reference, (Brayton nuclear propulsion cycle and canard wing configuration) and alternate nuclear aircraft with jp-fueled aircraft to determine that design range value which will result in jp-fueled aircraft with the same ramp weights or life-cycle costs as the nuclear aircraft. The results showed the equal ramp weight cross-over ranges to be 9200 and 7850 n.m. relative to the reference and alternate nuclear aircraft, respectively. For mission ranges exceeding these values, the nuclear aircraft will be lighter in weight. The converse is true for shorter ranges.

Nagel, A. L. "Studies of Advanced Transport Aircraft". NASA-TM-78697 L-12276. National Aeronautics and Space Administration, Langley Research Center, Hampton, VA. Presented at Transport Technology Conference Hampton, VA. Feb. 28-Mar. 3, 1978. Published in NASA-CP-2036. 35p.

Concepts for possible future airplanes were studied that included all-wing distributed-load airplanes, multi-body airplanes, a long-range laminar flow control airplane, a nuclear powered airplane designed for towing conventionally powered airplanes during long range cruise, and an aerial transportation system comprised of continuously flying liner airplanes operated in conjunction with short range feeder airplanes. Results indicated that each of these concepts has the potential for important performance and economic advantages, provided certain suggested research tasks are successfully accomplished. Indicated research areas included nuclear aircraft engines.

Noggle, L. W.; C. E. Jobe. " Large-Vehicle Concepts - Aircraft Design." USAF, Aeronautical. Systems Div, Wright-Patterson AFB, Ohio; USAF, Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, *Astronautics and Aeronautics*, vol. 17, Apr. 1979, pp. 26-32.

The paper briefly surveyed most of the very large vehicle concepts examined by Air Force, Navy, NASA, and industry in recent study efforts, Some of these included a conventional aircraft capable of carrying a 400,000-lb load over a range of 6200 n. mi. a laminar flow control. aircraft, where slotted wing and tail surfaces provide laminar flow to 70% chord to conserve fuel, nuclear-powered aircraft with active-controls technology, swept-wing space-distributed load aircraft capable of carrying a million pounds of payload, wing-in-ground-effect vehicles, a power-augmented-ram/wing-in-ground.-effect vehicle, and the heavy-lift airship.

"Nuclear Aircraft Study Opened." *Space Daily*, Feb. 18, 1971. p. 220.

The Air Force Aeronautical Systems Division was soliciting proposals to define, analyze, and compare nuclear power plants for aircraft propulsion. Two conceptualized systems were to be selected for more thorough analysis and adaptation to an aircraft configuration.

"Nuclear Aircraft/Aerodynamic Vehicle Studies Initiated." *Space Daily*, June 24, 1970.

Competition was opened for two studies of nuclear powered aircraft. The first study was to define, analyze and compare nuclear power systems. The second study was planned to define applications where unique missions can be accomplished.

“Nuclear Airliner Foreseen as Aerospace Breakthrough in 30 Years.” *The Hunstsville (AL) Times.”* May 3, 1970. p. 7.

Reported Lockheed vision that an 850,000 lb. nuclear powered aircraft, with a 199 ft. wingspan and 130,000 payload could be carrying 600 passengers nonstop to any city in the world by 2000. Included an artist concept illustration.

Orazio, F.D., Sr., and J.E. Werle. "Reactor for Nuclear Extended Range Aircraft". For USAF, Aeronautical Systems Div., Wright-Patterson AFB, OH and Westinghouse Astronuclear Lab., Pittsburgh, PA. In American Nuclear Society, National Topical Meeting on Aerospace Nuclear Applications, Huntsville, AL, Apr. 28-30, 1970. pp. 242-273.

Discussed high temperature liquid metal cooled nuclear reactor for military aircraft with long flight endurance and range.

Peterson, John. “Cranking Up Old Plan for Atom-Powered Plane.” *National Observer*. Oct. 28, 1968.

Briefly discussed the history of the ANP Project and reported that after cancellation further consideration of the concept was given by the Air Force and NASA after conducting studies in 1963. In 1966, the AF held a conference in Ingelwood, CA to look beyond the horizons to the 1980's. After that both the AF and NASA let contracts to several companies, including: Lockheed, Westinghouse, General Electric, Aerojet, Goodyear, General Nucleonics, and Allison Div. of General Motors. Advances in technology and the production of very large aircraft, such as the C5-A transport large enough to carry the reactors and shielding necessary, were providing incentive for further investigations. Frank Rom, Chief of Advanced Program Concepts at NASA-Lewis in Cleveland predicted that nuclear propulsion could be economical for commercial aircraft in the 1980's. Lockheed’s aerospace division manager, M. Miller stated that the technology was already available, and that “I would appear that all we need now is the decision - and the money - to build it.”

Pierce, B.L. “Nuclear Bi-Brayton System for Aircraft Propulsion”. ASME Paper 79-GT-119. Westinghouse Electric Corp., Advanced Energy Systems Div., Pittsburgh, PA. Presented at American Society of Mechanical Engineers, Gas Turbine Conference and Exhibit and Solar Energy Conference, San Diego, CA, March 12-15, 1979. 10p.

Recent studies have identified and shown the desirability of a new system concept for nuclear aircraft propulsion utilizing a modification of a closed-cycle gas turbine. This system concept, the Bi-Brayton system concept, permitted coupling of a gas cooled reactor to the power transmission and conversion system in a manner such as to fulfill the safety criteria while eliminating the need for a high temperature intermediate heat exchanger or shaft penetrations of the containment vessel. This system has been shown to minimize the component development required and to allow reduction in total propulsion system weight. This technical paper presented a description of the system concept and the results of the definition and evaluation studies to date. The technical paper discussed the application of this new closed cycle gas turbine system to aircraft propulsion.

"Possible Nuclear Aircraft Roles Analyzed." *Aviation Week*, Oct. 30, 1967. pp. 11-12.

The Air Force had nuclear powered aircraft mission studies underway at the Rand Corp. These studies was to utilize data from the cancelled ANP Program and more recent information to investigate applications for 1-1.5 million pound subsonic aircraft, including use as transports, airborne warning and control centers, patrol, tankers, strategic missile launchers, tugs for conventional aircraft and VTOL aircraft. Rand's work was expected to be completed by the end of 1967. NASA had about 9-10 people working under Frank Rom, Chief of the Advanced Nuclear Propulsion Concepts Branch at the Lewis Laboratory. The Air Force had six people working part time at Wright-Patterson AFB on nuclear propulsion under the direction of Fred D. Orazio, Sr. Chief of the Advanced Systems Analysis Divisions. The NASA and Air Force work was coordinated through a technology working group headed by Rom and Orazio. Industrial firms that had done recent nuclear powered aircraft work included Lockheed, General Electric. Allison Div. of General Motors, Westinghouse Electric, Astronuclear Div., Aerojet-General and General Dynamics. Each of these company's efforts were $55,000-$99,000 projects.

Poznanski, W. "Application of Atomic Energy to Jet Engines". FTD-HT-23-1562-6720. Foreign Technology Div., Wright-Patterson AFB. Feb 16, 1968.

Discussed general aspects of the use of atomic energy for jet and rocket propulsion. It was noted that the development of atomic engines was being carried out in three stages. The first stage was the introduction of atomic energy for electric power generation, and then came the atomic engines for marine propulsion. The present stage consisted of developing an atomic aviation engine. Work on such an engine had long been proposed. Research in this field has been conducted in the Soviet Union and in the West for several years. It appeared that the day is near when the nuclear powered aircraft will be flown. Such an aircraft will greatly surpass the performance of present aircraft.

Puthoff, R.L. and C. C. Silverstein. "Application of Heat Pipes to a Nuclear Aircraft Propulsion System". For NASA, Lewis Research Center, Cleveland, OH. American Institute of Aeronautics and Astronautics, Sixth Propulsion Joint Specialist Conference, San Diego, CA, June 15-19, 1970, New York, NY.

Report covered heat pipes in nuclear aircraft propulsion system, describing core, heat exchangers, and reactor to jet engine heat transport system.

Puthoff, R.L., W.G. Parker, and L.E. Vanbibber. "Post Impact Behavior of Mobile Reactor Core Containment Systems". NASA-TM-X-68176 L-6283. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH. Presented at the Annual Meeting of the American Nuclear Society, Las Vegas, NV, June 18-22, 1972. 31p.

Analyzed the reactor core containment vessel temperatures after impact, and the design variables that affect the post impact survival of the system. The heat transfer analysis included conduction, radiation, and convection in addition to the core material heats of fusion and vaporization under partially burial conditions, Also, included was the fact that fission products vaporize and transport radial outward and condense outward and condense on cooler surfaces, resulting in a moving heat source. A computer program entitled Executive Subroutines for Afterheat Temperature Analysis (ESATA) was written to consider this complex heat transfer analysis. Seven cases were calculated of a reactor power system capable of delivering up to 300 MW of thermal power to a nuclear airplane.

Puthoff, Richard L. "Neutronic Design of a Reactor Core Containing Heat Pipes for Application to a Nuclear Airplane". N-70-23226. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH. 1969. 21p.

A study was conducted to perform the neutronic calculation on the proposed heat pipe reactor. The study revealed that utilizing heat pipes for a nuclear airplane, reactor application appeared promising when heat pipe performance was applied to the limit of heat pipe technology. The design parameters calculated are number of heat pipes, radial heat flux, core diameter, core L/D, heat pipe vapor temperature, fuel enrichment, fuel loading, clad temperature, clad stress and power.

Raymond, A. E. "Over the Horizon in Air Transportation". P-3396,20. Rand Corp. Santa Monica, CA. Aug. 1966. 17 p. (Also published in *Astronautics and Aeronautics*, Sept. 1966).

The article was an attempt at a broad forecast of the types of air transport vehicles that will follow the C-5A/747 subsonic jets and first-generation supersonic jets. The period covered was roughly 1980-2000. Both civilian and military aircraft was considered. Included nuclear powered aircraft. General aviation was not included.

Robson, F.L., and G.T. Peters. "Engine Technology for Large Subsonic Nuclear Powered Aircraft". AIAA PAPER 72-1062. Presented at American Institute of Aeronautics and, Astronautics and Society of Automotive Engineers, 8th Joint Propulsion Specialist Conference, New Orleans, LA, Nov. 29-Dec. 1, 1972. November 1972. 9p.

Presented results of a technology review of the propulsion system of a large subsonic nuclear-powered aircraft. Low to moderate bypass ratio turbofan engines of 60,000 lb static thrust utilizing technology currently available in the JT9/CF6 jumbo-jet engines were the most suitable for use in a large subsonic aircraft. Such engines could be used with either gas-cooled or liquid-metal-cooled nuclear reactors. The analysis leading to selection of this type of engine was described, and conceptual design layouts of two engines were presented.

Rom, F.E. "What Can Nuclear Energy Do for Society?" NASA-TM-X-67963 E-6674. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH. Presented at the Second Uranium Plasma Symposium, Atlanta, Nov. 15-17, 1971; Sponsored by American Institute of Aeronautics and Astronautics. November 1971. 24p.

Discussed the utilization of nuclear energy and the predicted impact of future uses of nuclear energy. Reviewed areas of application in electric power production and transportation methods. It was concluded that the need for many forms of nuclear energy will become critical as the requirements for power to supply an increasing population are met.

Rom, F.E. "Airbreathing Nuclear Propulsion - a New Look". NASA, Lewis Research Center, Cleveland, OH. US Air Force Office of Scientific Research, Sixth Symposium on Advanced Fission Concepts, Niagara Falls, NY. May 4-6, 1971.

Discussed air breathing nuclear propulsion, considering reactor safety in air cushion vehicles and aircraft.

Rom, F.E. and C. Masser. “Large Nuclear-powered Subsonic Aircraft or Transoceanic Commerce”. NASA-TM-X-2386 E-6271. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH. November 1971. 47p.

Reviewed performance and costs of nuclear aircraft used in transoceanic commerce.

Rom, F.E. and P.M. Finnegan. “Will the Nuclear-Powered Aircraft Be Safe?”. *Astronautics and Aeronautics* 6,3 (March 1968):32-40.

The incentive for nuclear powered flight was higher payload, at lower cost than chemical powered aircraft. However, the issue of safety and public acceptance must also be resolved. This article addressed the safety issue while specifically not addressing the public acceptance issue. A conceptual design was presented that provided a complete reactor shield that keeps the flight crew, ground crew and passenger doses within acceptable limits for normal operations. The concept also provided containment for accident situations. Results of accident analyses were given for release of radioactive fission products to the environment.

Rom, F.E. "Status of the Nuclear Powered Airplane". AIAA PAPER 69-554. NASA, Lewis Research Center, Cleveland, OH. Presented at American Institute of Aeronautics and Astronautics, Fifth Propulsion Joint Specialist Conference, U.S. Air Force Academy, Colorado Springs, CO, June 9-13 1969. 13p.

Covered the nuclear aircraft power plant, discussing safety, economy and obstacles.

Rom, F.E. "What Can Nuclear Energy Do For Society?". For NASA, Lewis Research Center, Advanced Nuclear Propulsion Concepts Branch, Cleveland, OH. *Astronautics and Aeronautics* 10 (Jan. 1972): 56-61.

It was pointed out that the earth's crust holds 30,000 times as much energy in the form of fissionable atoms as fossil fuel. Moreover, nuclear fuel costs less per unit of energy than fossil fuel. Capital equipment used to release nuclear energy, on the other hand, is expensive. For commercial electric-power production and marine propulsion, advantages of nuclear power have outweighed disadvantages. As to nuclear submarines, applications other than military may prove feasible. The industry has proposed cargo submarines to haul oil from the Alaskan North Slope beneath the Arctic ice. Other possible applications for nuclear power were in air-cushion-vehicles, aircraft, and rockets.

Rom, F.E. "Status of the Nuclear Powered Airplane". For NASA Lewis Research Center, Cleveland, OH. U.S. Air Force Office of Scientific Research, Sixth Symposium on Advanced Concepts Niagara Falls, NY. May 4-6, 1971. 8p.

Discussed nuclear powered long distance aircraft engines, including high burnup fuel, weight factors and safety problems.

Rom, F.E. "Airbreathing Nuclear Propulsion - A New Look". For NASA, Lewis Research Center, Cleveland, OH. USAF Office of Scientific Research, Symposium on Advanced Propulsion Concepts, May 4-6, 1971, Niagara Falls, NY. May 1971, pp.23.

Reviewed air breathing nuclear propulsion, considering reactor safety in air cushion vehicles and aircraft.

Rom, F.E. "Status of the Nuclear Powered Airplane". For NASA, Lewis Research Center, Cleveland, OH. American Institute of Aeronautics and Astronautics, Fifth Propulsion Joint Specialist Conference, U.S. Air Force Academy, Colorado Springs, Co, June 9-13, 1969, New York, NY, American Institute of Aeronautics and Astronautics.

Discussed nuclear aircraft power plant, including safety, economy and obstacles.

Rom, F.E.. "Nuclear Power for Surface Effect Vehicle and Aircraft Propulsion". Presented at Amer. Inst. of Aeronautics and Astronautics 7th Annual Meeting, Houston, TX, Oct.

19-22, 1970. October 1970.

Included information on nuclear propelled aircraft.

Rom, Frank E. "Airbreathing Nuclear Propulsion - A New Look." NASA TM X-67837. NASA Lewis Research Center, Cleveland. Technical Paper proposed for presentation at the Sixth Symposium on Advanced Propulsion Concepts. Niagara, NY. May 4-5, 1971. 23p. (Also published in *Nuclear News*, Oct. 1971, pp. 79-87).

This NASA Technical Memorandum was for the Air Force Office of Scientific Research sponsored symposium. The author claimed that the major obstacle to achieving nuclear powered flight has been that aircraft have not been large enough to carry the required heavy power plant. He stated that this size limitation and the desire to have supersonic dash capability were the basic reasons for cancellation of the ANP Program. Rom indicated that fuel costs favor nuclear powered aircraft. The results of NASA reassessment of ANP since 1964, with some AF involvement, have focused on safety considerations, including high speed impacts, reactor containment failure and long-lived nuclear fuel. Described both analytical and experimental efforts.

Rom, Frank E., and Charles E. Masser. "Large Nuclear-Powered Subsonic Aircraft for Transoceanic Commerce". N-71-38277. National Aeronautics and Space Administration, Cleveland, OH (Lewis Research Center). Nov. 1971. 47p.

Large subsonic aircraft, greater than 905 metric tons (1000 tons) gross weight, have the potential for hauling transoceanic cargo at rates in the range of $ 0.006 to $ 0.036 per metric ton-kilometer ($ 0. 01 to $10.06/ton-n mi) at speeds of 740 to 925 kilometers per hour (400 to 500 knots). It theoretically would take a fleet of 500 such aircraft to handle 1 percent of the forecast world ocean trade in 1980. For gross weights of 3620 metric ton (4000 tons) the cargo rate would be reduced to less than $0.012 per metric ton-kilometer ($0.02/ton mi). It theoretically would take a fleet of over 1000 such aircraft to carry 8 percent of the world's transoceanic trade projected for 1980 or 4 percent of the projected rate in 1995. Aircraft with a gross weight of 3620 metric tons (4000 tons) using compact lightweight nuclear reactors show better performance than chemical aircraft for ranges greater than 5565 kilometers (3000 n mi). Nuclear aircraft performance is less sensitive than that of chemical aircraft to the operating and cost assumptions used. Relatively large variations in any of the important assumptions have a relatively small effect on nuclear aircraft performance.

Rom, Frank E. "Status of the Nuclear Powered Airplane." Proposed article for *Journal of Aircraft.* NASA Lewis Research Center. Cleveland. Oct. 30, 1969. 39 p.

NASA had been carrying out a low level effort to determine and solve the problems facing practical, safe and economical nuclear aircraft. The key problem was safety. The prevention of fission product release after a major accident on land was difficult. Studies indicated in principle that fission products can be contained; however, much work needed to be done to demonstrate the proposed techniques. Over-water flight minimized the safety problem. This suggested the possibility of restricting early nuclear aircraft for over-water flights to gain experience and confidence. The use of thermal reactors appeared to simplify the problem of containment because they make possible the avoidance of nuclear excursions in accidents by minimizing the fuel inventory. Low fuel inventory and the desirability of long reactor life required reactor fuel with very high burnup capability. A fuel concept existed which had promise for meeting this requirement.

Rom, Frank E. "Nuclear-Powered Airplane". *Technol. Rev.* 72 (Dec. 1969): 48-56.

Some technical considerations were reviewed that indicate that it may be possible to make a large, long-range nuclear-powered aircraft which was economically competitive. Considerations of safety lead to some new concepts for reactor design and control. The basic concept of a nuclear power plant for aircraft use was described. The reactor's heat energy traveled, in a good heat-transfer fluid such as high-pressure helium or liquid metal, to an exchanger, which heated the air flowing through a conventional turbofan engine. This heat exchanger was placed immediately in front of the normal combustor. The engine could then run on conventional fuel, or nuclear energy, or both. To be practical, safe, and publicly acceptable, a nuclear aircraft must meet certain requirements, which were outlined. The payload anticipated for a nuclear aircraft with a gross weight of 1.75 million lb. is shown. The payload (cargo and chemical fuel) was plotted as a function of flight Mach number. Chemical fuel was provided for takeoff and landing and for 1 hr. flying time at design flight conditions. The payload was approximately 500,000 lb. for Mach numbers of 0.5 to 0.75. The fuel load was about 120,000 lb. in this range, so that the cargo capacity was about 400,000 lb. This amounts to >20% of the gross weight.

Rosendahl, C.E.. "Where Do We Go From Here". In "Interagency Workshop on Lighter than Air, Vehicles, Monterey, Calif., September 9-13, 1974, Proceedings". MIT Flight Transportation Laboratory, Cambridge, MA: 1975. p.XIII-XVII.

Recent comments on new potential uses of lighter than air aircraft, particularly rigid airships, and on proposed improvements of them, were criticized because of their lack of realism. The buoyant hybrid was discussed, as well as various suggested structures and propulsion systems for the craft. The utility of rigid airships in intermediate-density cargo transport was pointed out. Limitations to the use of metal hulls, nuclear power, aggregate hulls, and overland travel were considered. Some misconceptions about the history of lighter than air aircraft were dispelled.

Scott, W.F. "Feasibility Study on Fast-Acting Valves for Airborne Nuclear Containment Systems". SLA-73-221. Sandia National Labs., Albuquerque, NM. No Date. 33 p.

Studied the feasibility of developing fast-acting valves to seal the coolant lines emanating from a reactor used to power aircraft. The valves must be made integral with the wall of a hardened containment sphere in such a way that the structural integrity of the sphere was unimpaired in the event of a crash.

Shevell, R.S.. "Advanced Subsonic Aircraft - The Technological Response to Future Air Transportation Needs". In The Future of Aeronautical Transportation;, Proceedings of the Princeton University, Conference, Princeton, NJ, November 10-11, 1975. Princeton University Press, Princeton, NJ: 1976. p.5-1 to 5-26. 26p.

The history of transport aircraft was reviewed as were technological advances - drag reduction, weight reduction, improvement in lift coefficient, etc. Some developments in air transportation which raised great expectations, but have failed to have a significant impact were reviewed: laminar flow control, nuclear powered aircraft, STOL and the supersonic transport.

Silverstein, C.C. "A Study of Heat Pipe Applications in Nuclear Aircraft Propulsion Systems. (Final Report)". NASA-CR-72 610 SIL-104. CCS Associates, Baltimore, MD. Nd. 110p.

Discussed the use of heat pipes for nuclear aircraft propulsion systems.

Silverstein, Calvin C. "Final Report - Study of Heat Pipe Applications in Nuclear Aircraft Propulsion Systems." NASA CR-72610,SIL-104. Prepared for NASA Lewis Research Center, Cleveland. Dec. 1, 1969. 4 p.

Described preliminary studies of heat pipe systems for reactor-to-jet engine heat transport and for emergency distribution of reactor afterheat over the surface of the reactor containment vessel. The reactor-to-jet engine heat transport system included 5480 small-diameter reactor heat pipes, four large diameter adiabatic heat transport pipes, and 8300 small-diameter heat pipes in each of the four engine heat exchangers. The total system weight was about 47,000 lb. The emergency afterheat distribution system included 4280 heat pipes 1 in. in diameter and 11.7 in. long, whose total weight was 3400 lb.

Silverstein, Calvin C. "A Survey of Advanced Energy Conversion Systems and Their Applicability to Army Aircraft Propulsion Requirements". SIL-10320. Baltimore MD. Oct. 1969. 177 p.

A survey of advanced energy conversion methods and an evaluation of their applicability to army aircraft propulsion requirements were carried out. Systems surveyed included: closed Brayton cycle, Rankine cycle, intercool-reheat cycle, fuel cells, MHD converters, thermionic converters, thermoelectric converters, radioisotope heat sources, and nuclear reactor heat sources.

Silverstein, Calvin C. "A Study of Heat Pipe Applications in Nuclear Aircraft Propulsion Systems." N-70-12923. National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH. Dec. 1, 1969. 110p.

Described preliminary studies of heat pipe systems for reactor-to-jet engine heat transport and for emergency distribution of reactor afterheat over the surface of the reactor containment vessel are described. The reactor-to-jet engine heat transport system included 5480 small-diameter reactor heat pipes, four large-diameter adiabatic heat transport pipes, and 9300 small-diameter heat pipes in each of the four engine heat exchangers. The total system weight was about 47,000 lb. The emergency afterheat distribution system included 4280 heat pipes 1 in. in diameter and 11.7 in. long, whose total weight was 3400 lb.

Sindir, Munir M. "Some Comments on Turbulence Modeling from an Industrial Perspective". Rockwell International Corp., Rocketdyne Division Canoga Park, CA. In NASA, Lewis Research Center, Workshop on Engineering Turbulence Modeling. No Date. pp. 351-358.

In propulsion industry, computational techniques (namely computational fluid dynamics) are gradually becoming engineering design and analysis tools, especially in the case of high performance aircraft engines, high speed air breathing propulsion, rocket propulsion, and advanced nuclear propulsion and electric propulsion.

Stanford, Neal. "A-Powered Plane Makes Comeback." *Christian Science Monitor*, April 15, 1968.

Reported that technology advances since cancellation of the ANP Project has "put the nuclear plane back in the budget." The AEC, NASA and the Air Force were showing new interest, with NASA including $250,000 in its 1969 budget. Air Force funding was classified, but said to be considerable. The Air Force was considering aircraft large enough to have an airstrip built on top to allow ferrying crews and supplies. The major problems for nuclear aircraft development were size, shielding and crash survivability. Estimates were given that several billion dollars and about 15 years are needed.

Strack, William C. "Effect of Two Types of Helium Circulators on the Performance of a Subsonic Nuclear-Powered Airplane". National Aeronautics and Space Administration, Cleveland, OH (Lewis Research Center). Mar 1971. 29p.

Two types of helium circulators were analytically compared on the bases of their influence on airplane payload and on propulsion system variables. One type of circulator was driven by the turboengines with power takeoff shafting while the other, a turbo-circulator was powered by a turbine placed in the helium loop between the nuclear reactor and the helium-to-air heat exchangers inside the engines. Optimum engine and heat exchanger temperatures and pressures were significantly lower in the turbocirculator case compared with engine-driven circulator scheme.

"The Selection of Reactive Metals for Aircraft Nuclear Power Plants". General Electric Co., Cincinnati, OH. p.379-86. In "Reactive Metals - Proceedings of the Third Annual Conference, Buffalo, New York, May 27-29, 1958," W. R. Clough, ed. Metallurgical Society Conferences, Volume 2.Interscience Publishers, New York. 1959.
The general systems available for aircraft nuclear propulsion and the major components of the direct cycle system were reviewed and described. For best performance, all components of the system were required to operate in air at relatively high temperatures. To take full advantage of "reactive" metals for these components, improved methods of providing high-temperature oxidation resistance must be developed.

Thompson, R. E., B.L. Pierce, R. Calvo, J.A. Christenson, H.D. Coe. "Nuclear Bi-Brayton System for Aircraft Propulsion Study". WAES-TNR-23420. Westinghouse Electric Corp. Advanced Energy Systems. Pittsburgh, PA. March 1978. 107 p.

Parametric and reference system definition studies were performed with respect to a new concept for a nuclear aircraft propulsion system. Also studied was a possible method for increasing the payload of a nuclear powered aircraft during wartime. The Bi-Brayton system concept for nuclear propulsion of aircraft had been examined and found to be feasible. The system had been shown to be one which minimizes the component developments required and one which can make effective use of reactor technologies that already exist. Cycle variants and component characteristics were parametrically evaluated and a reference system defined. Weight estimates indicated that with optimized reactor and shielding, the total powerplant and fuel weight for the innovative aircraft design reference aircraft could be reduced from that predicted for a liquid metal cooled reactor system coupled to an open Brayton cycle turbofan engine. The Bi-Brayton system combined with a compact gas-cooled (NERVA-derivative) reactor was found to be a desirable system for nuclear aircraft propulsion and is recommended for consideration in any further studies of nuclear propelled aircraft.

Thompson, R.E., B.L. Pierce, R. Calvo, J.A. Christenson, and H.D. Coe. "Nuclear Bi-Brayton System for Aircraft Propulsion Study. Final Report, July 1,1977 - January 31,1978". AD-A-054672; WAES-TNR-234. Advanced Energy Systems Div., Westinghouse Electric Corp., Pittsburgh, PA. March 1978 107 p.

Parametric and reference system definition studies were performed with respect to a new concept for a nuclear aircraft propulsion system. Also studied was a possible method for increasing the payload of a nuclear powered aircraft during wartime. The Bi-Brayton system concept for nuclear propulsion of aircraft has been examined and found to be feasible. The system has been shown to be one which minimizes the component developments required and one which can make effective use of reactor technologies that already exist. Cycle variants and component characteristics were evaluated and a reference system defined. Weight estimates indicate that with optimized reactor and shielding, the total power plant and fuel weight for the Innovative Aircraft Design Study Task II reference aircraft could be reduced from that predicted for a NERVA liquid metal cooled reactor system coupled to an open Brayton cycle turbofan engine. The Bi-Brayton system combined with a compact gas-cooled,(NERVA derivative) reactor was found to be a desirable system for nuclear aircraft propulsion and is recommended for consideration in any further studies of nuclear propelled aircraft.

Thompson, R.E., B.L. Pierce, R. Calvo, J.A. Christenson, and E. Coe. “Nuclear Bi-Brayton System for Aircraft Propulsion Study”. AD-AO54672 WAES-TNR-23. Westinghouse Electric Corp., Advanced Energy Systems Div., Pittsburgh, PA. July 1977 - Jan. 31, 1978.

Parametric and reference system definition studies were performed with respect to a new concept for a nuclear aircraft propulsion system. Also studied was a possible method for increasing the payload of a nuclear powered aircraft during wartime, The Bi-Brayton system concept for nuclear propulsion of aircraft has been examined and found to be feasible, The system has been shown to be one which minimizes the component developments required and one which can make effective use of reactor technologies that already exist. Cycle variants and component characteristics were evaluated and a reference system defined. The Bi-Brayton system combined with a compact gas-cooled (NERVA derivative) reactor was found to be a desirable system for nuclear aircraft propulsion and is recommended for consideration in any further studies of nuclear propelled aircraft.

Thornton, Gunnar. “Introduction to Nuclear Propulsion. Lecture 1. Introduction and Background”. GEMP-190A. General Electric Co., Nuclear Materials and Propulsion Operation, Cincinnati, OH. Feb. 1963. 80 p.

Consideration of the performance, weight, operational and other factors will favor the choice of nuclear propulsion systems for some applications and chemical systems for others. In some cases combinations of chemical and nuclear propulsion will be desirable. The application of a nuclear reactor to rocket propulsion is limited by the supply of rocket propellant that must be carried, even though the consumption of nuclear fuel is negligible. Nevertheless, since the propellent can consist entirely of a substance of low molecular weight, such as hydrogen a heat transfer nuclear rocket has a potential advantage of a factor of approximately 2 in specific impulse. In other words, a given thrust level can be sustained twice as long by a nuclear rocket as compared with a chemical rocket the same weight of propellant. Alternately, the given thrust level may be sustained for the same period of time but with a much lower mass of stored propellant and consequently lower overall weight. Since this weight must be accelerated, a much higher velocity can be attained with the nuclear system when the thrust is applied over a fixed period. This provides a decided performance advantage for the nuclear system for a number of potential space missions. In air-breathing nuclear systems, such as turbojets and ramjets, a given thrust level can be sustained virtually indefinitely because the supply of propellant (air) is unlimited. However, since most air-breathing missions do not require acceleration to extremely high velocities, the fuel consumption during acceleration is usually not prohibitively large. Furthermore. most air-breathing missions operate within reach of additional fuel supplies. Consequently, the advantage of nuclear power for rockets appears to be a more critical one that is the case for air-breathing systems.

Ulsamer, Edgar E. "Rebirth of Aviation's Top Challenge: The Nuclear Powered Airplane." *Air Force/Space Digest*. August 1967. (Inserted in the *Congressional Record*, Extension of Remarks by Cong. Melvin Price. Oct. 23, 1967.)

This article by the Associate Editor of the *Air Force/Space Digest,* discussed the renewed interest in the nuclear powered aircraft. Quoting a government scientist as saying: "ANP had two strikes against it when the mission parameters were set. Holding the weight to 500,000 lbs. was one principal mistake and requiring the plane to fly supersonically was another." Lockheed was said to be the leading industry proponent and the Air Force is increasing its interest.

Vaeth, J. G. "The Airship Can Meet the Energy Challenge." NOAA, National Environmental Satellite Service, Washington, D.C. *12 Astronautics and Aeronautics* (Feb. 1974):25-27.

It was suggested that lighter-than-air craft, in the form of very large airships, can be developed using nuclear propulsion. Such an airship can be designed to move cargo pieces weighing a million pounds and more into difficult-to-reach places at energy expenditures matching available resources. Inherent environmental cleanliness and quiet would be important fringe benefits.

Van Der Sluis, J.C. "The Nuclear Propelled Aircraft", in *Nederlandse Vereniging voor Luchtvaarttechniek, Yearbook 1974,* A75-41951 21-03, Amsterdam, Netherlands. Vereniging voor aarttechniek 1975, pp. 4-1 to 4-19.

The major design, safety and economic problems in the realization of nuclear powered aircraft are discussed on the basis of a propulsion model in which the turbofan engines of the aircraft obtain heat for expanding the air passing through them from circulating helium heated by a central nuclear fission reactor, one of the main technological problems remains the development of heat-exchanger creep-resistant -materials. The main safety criteria were complete freedom of movement in and around the aircraft, no release of radioactivity during normal operation and no release of radioactivity in case of a major accident. The third criterion represented the most formidable challenge. The reactor shield assembly must withstand the shock of impact without rupture, melt-through of the containment vessel must be prevented, and the possibility of accidental critical mass must be eliminated. It was shown that nuclear aircraft become economically more attractive as aircraft gross weight increases.

VanSant, S.A.. "Aeroenergy - A New Frontier". AIAA PAPER 66-671. Amer. Inst. of Aeronautics Astronautics, 2nd Propulsion Joint Specialist Conference, Colorado Springs, CO, Jun. 13-17, 1966, Paper 66-671". June 1966. 14 p.

Included discussion of future applications of nuclear energy to aircraft propulsion.

"Very Large Vehicle Conference", Arlington, VA, April 26-27, 1979, Technical Papers. 1979. 133 p.

Papers were presented on the demand for large freighter aircraft as projected by NASA cargo/logistics airlift system studies, large wing-in-ground effect transport aircraft, and nuclear aircraft innovations and applications. Consideration was also given to large lighter-than-air vehicles, the concept of a large multi-mission amphibian aircraft, and strategic airlift vehicle concepts.

Volz, Joseph. "AF Runs N-Plane Scheme Up Flagpole." *New York News*, Dec. 11, 1983. 12 p.

Dr. Robert Cooper, Director of the Advanced Research Projects Agency, DOD, testified before a House Science Subcommittee that it now feasible to install nuclear engines in aircraft. He stated that "the endurance of weeks could be achieved in the early part of the next century."

Von Veress, E. "Project of a Nuclear-Powered Dirigible - New Paths in Aeronautics". *Flugwelt* 19 (Jun. 1967): 412-415. In German.

Discussed the potential of using nuclear power for a dirigible.

Wild, J.M. "Nuclear Propulsion for Aircraft". *Astronautics and Aeronautics* 6,3(March 1968):24-30. 7 p.

Author argued that ANP deserves renewed attention because of the evolutionary advances in a number of relevant technical areas, including larger aircraft and improved materials. At a range of 10,00 mi., the nuclear aircraft had greater payload capacity than a conventional aircraft. Crash containment remains the biggest problem. Included photographs of: a concept for aircraft reactor containment, the NTA in flight with an accompanying B-50 equipped to measure radiation fields, the ASTR mounted in the NTA, measurements at the TSF, a design concept for a twin reactor, four engine 1.5 million lb. aircraft.

Wiler, C.D and D.P. Raymer. "Manned strategic system concepts 1990-2000." Rockwell International Corp, North American Aircraft Group, Los Angeles, Calif., American Institute of Aeronautics and Astronautics, Aircraft Systems and Technology Meeting, New York, N.Y. August 20-22, 1979, 15 p.

Manned strategic system concept designs were discussed, requiring the development of new technologies in the areas of aerodynamics, propulsion (including nuclear), structures, controls, and stealth. A total of 34 innovative concepts were prepared using the advanced technologies, Concepts were designed to a strategic 'high-low-low-flight missions, with several exceptions, and can be grouped into four major categories: (1) low-cost simplistic, (2) minimum weight, (3) supersonic penetration, (4) laser defended. The concepts were qualitatively rated to select the best two or three concept in each category. These remaining candidate concepts were then subjected to a preliminary sizing exercise to select one baseline per category. The baselines were sized, configured, analyzed, and reconfigured.

Wilkinson, K.G.. "Air Transport in the 21st Century". *Aerospace* (UK) 9 (Jan. 1982): 18-23.

Trends in aircraft design into the 21st century were discussed, based on the driving need for higher fuel efficiency and alternative fuels. Noting that fuel presently accounted for 30% of air transportation, results of an international study on the world energy supply and growth were used to present several scenarios of future aerospace operations. Global energy was projected to be provided from renewables and nuclear, coal and gas, and oil, each group producing 1/3 of the world energy demands, with aerospace consuming 3% of the total oil consumed. Advances in aerodynamics from NASA studies, in lightweight synthetic materials, in active controls, and in propulsion systems were outlined, with mention made of the CO_2 contribution to a global rise in temperature. The development of nuclear technology and the availability of nuclear fuels was contrasted against the environmental costs of using hydrocarbon fuels, and the necessity of developing a hydrogen-based fuel economy.

"Will Atoms Take Off?" *Popular Mechanics*. November 1983. p. 140.

Reported that a source at the Air Force Institute of Technology predicted that a nuclear powered aircraft could be flying for the military or commercially by the 1990's. The plane would be used primarily for submarine surveillance. It would be a canard-type design to maximize distance from the reactor to the crew and conventional engines would be used for takeoff.

Wilson, George C. "Atomic Plane Able to Remain Aloft for Months is Again Under Study."

Washington Post, Jan. 18, 1967. p.1.

Charles W. Harper, Director of NASA's Aeronautical Division, was reported to have said that the large size of the C-5A and future aircraft make the nuclear power option attractive. Conventional engines would be used for takeoff and landing, with nuclear power used for cruising. Harper said that they were investigating nuclear engines that could operate for 3800 hours so an aircraft could stay aloft for about a year. The first of the conventionally powered C-5A's was scheduled for completion in February 1968.

"Nederlandse Vereniging voor Luchtvaarttechniek, 1975". In Dutch and English. Amsterdam. 143 p.

Some selected topics in recent developments in the design of new aeronautical systems were discussed, including the development of rapid transit over water, considerations in the design of very large aircraft, nuclear-propelled aircraft and flight characteristics of very large subsonic transport aircraft in landing.

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CHAPTER 11.
ILLUSTRATIONS

General Dynamics Corp. Photograph. *Air Force / Space Digest* (Sept. 1967):25.

Provided photograph of the 1960 artist's concept of the General Dynamics design for a atomic powered aircraft. Showed two nuclear engines in the tail and two conventional engines mounted under the wings. Reference was made to Theodore von Karman's 1945 report, "Toward New Horizons" in which he saw the nuclear powered aircraft in the distant future and said the problem should "be attacked urgently."

Lehman, D.C. and G. Thornton. "Remote Handling of Mobile Nuclear Systems". GE-ANPD. TID-21719. 1966.

Provided photographs of the HTRE experiments and diagrams of alternate arrangements of reactor engines.

"Lockheed Policy Committee Sees Nuclear Aircraft Cockpit Mockup." *Aviation Week*. Feb. 3, 1958. p.90.

Two photographs showed a mockup of the ANP crew compartment and monitoring equipment at Lockheed's Georgia Division, Marietta, GA.

Photographs (color). General Electric Nuclear Turbojet. Undated, but probably about 1961.

These four 8 in. x 10 in. photographs showed a wooden model (not to scale) of the XNJ140E Nuclear Turbojet being developed by the GE-ANP Division, Evendale, Ohio. The photographs included fully assembled and sequential disassembly views of the engine which shows the internal components that make up the nuclear reactor.

Photographs (black and white). XMA1 Nuclear Engine Mockups. ANP Division, GE. Undated.

Five photographs of the XMA1 Dual Reactor Engine full-scale wooden mockups being shipped to Wright-Patterson Air Force Base museum. Original glossy photographs available from Gunnar Thornton, 1017 Onondaga Road, Schenectady, NY 12309.

"Special Progress Report on the Power Plant Test Program at the U.S. AEC NRTS." DC-56-7-3. GE-ANP Dept., Cincinnati. 1956. 35 p.
This document was prepared at the request of Adm. Lewis L. Strauss, Chairman, U.S. AEC for the purpose of depicting highlights of the nuclear power plant test program being conducted at the National Reactor Test Station, Idaho by the GE-ANP Dept. Included photographs and drawings of the NRTS facilities and the HTRE-1.

CHAPTER 12.
ABANDONED ANP FACILITY ENVIRONMENTAL EFFECTS

Fauver, D.N., M.F. Webber, T.C. Johnson, and J.D. Kinneman. "Site Decommissioning Management Plan". NUREG-1444, Supplement 1. U.S. Nuclear Regulatory Commission. Nov. 1995.

The CANEL Site, Middletown, CT. was finally decontaminated and decommissioned approximately 45 years after the site was used by Pratt and Whitney for the ANP Program.

McCusker, T.K. "Decontamination and Decommissioning of Heat Transfer Reactor Experiment Test Assemblies HTRE-2 and HTRE-3". EGG-2575. EG & G Idaho, Inc., Idaho Falls, ID. Sept. 1989. 51p.

The purposes of this report were to describe the decontamination and decommissioning (D&D) of Heat Transfer Reactor Experiment (HTRE) Test assemblies HTRE-2 and HTRE-3 at the Idaho National Engineering Laboratory during 1987, 1988, and 1989, and the conditions existing after completion of D&D activities. The primary objectives of the D&D Project were to remove all accessible radioactive and hazardous contamination from the assemblies, to seal all system openings, and to relocate the assemblies from the Test Area North to the Experimental Breeder Reactor-I area in a safe configuration for permanent public display.

"Radiological Characterization of the TAN-IET Facility". RE-P-82-053. EG& G Idaho, Inc., Idaho Falls, ID. June 1982. 72p.

The Initial Engine Test (IET) facility was located on the Idaho National Engineering Test Laboratory (INEL) site at the north end of Test Area North (TAN). The facility was constructed and used for the Aircraft Nuclear Propulsion Program during the 1950's and was later used for two other programs: the Space Nuclear Auxiliary Power Transient and the Helium Decontamination and Decommissioning Project. The facility was no longer in use, therefore, a complete radiological characterization was conducted at the IET site. The characterization included measurements of beta-gamma dose rates; beta-gamma and alpha surface contamination; concentrations of selected radionuclides in subsurface storage tanks, surface soil, the exhaust duct, stack and test pad; and a walk-over surface survey of the entire facility. The information contained in this report will be useful as the IET facility goes through the decommissioning and decontamination process.

Stoll, F.E. "Decontamination and Decommissioning of the Initial Engine Test Facility and the IET Two-Inch Hot-Waste Line". EGG-2468. Idaho National Engineering Lab., Idaho Falls, ID. Apr. 1987. 32 p.

The Initial Engine Test Decommissioning Project is described in this report. The Initial

Engine Test facility was constructed and operated at the National Reactor Testing Station, now known as the Idaho National Engineering Laboratory, to support the Aircraft Nuclear Propulsion Program and the Systems for Nuclear Auxiliary Power Transient test program, circa 1950 through 1960's. Due to the severe nature of these nuclear test programs, a significant amount of radioactive contamination was deposited in various portions of the Initial Engine Test Facility. Characterizations, decision analyses, and plans for decontamination and decommissioning were prepared from 1982 through 1985. Decontamination and decommissioning activities were performed in such a way that no radiological health or safety hazard to the public or to personnel at the Idaho National Engineering Laboratory remains. These decontamination and decommissioning activities began in 1985 and were completed in 1987.

Stoll, F.E., H.A. Bohrer and C.M. Voldness. “Decontamination and Decommissioning of the Initial Engine Test Facility.” INEL. 1987 International Decommissioning Symposium Proceedings. CONF-871018-Vol. 1 (DE87012821). Pittsburgh. Oct. 4-8, 1987. pp. III-237 to III-253.

The Initial Engine Test (IET) facility was constructed and operated at the National Reactor Testing Station, now known as the Idaho National Engineering Laboratory (INEL), to support the Aircraft Nuclear Propulsion Program and the Systems for Nuclear Auxiliary Power Transient test program, circa 1950 through the 1960's. Due to the severe nature of these nuclear test programs, a significant amount of radioactive contamination was deposited in various portions of the IET facility. Characterizations, decision analyses, and plans for decontamination and decommissioning were prepared from 1982 through 1985. Decontamination and decommissioning activities were performed in such a way that no radiological health or safety hazard to the public or to personnel at the INEL remains. These decontamination and decommissioning activities began in 1985 and were completed in 1987.

“Superfund Record of Decision (EPA Region 10): US DOE Idaho National Engineering Laboratory, Operable Unit 2, ID. (Third Remedial Action) September 1992.” PB-93-964615/XAB and EPA/ROD/R-10-92/045. Environmental Protection Agency, Washington, DC. Office of Emergency and Remedial Response. Sept. 28, 1992. 49p.

The 890-square mile Idaho National Engineering Laboratory (INEL) is located 32 miles west of Idaho Falls, Idaho. The site, established in 1949, is operated as a nuclear reactor technology development and waste management facility by the U.S. Department of Energy. Land use in the area is predominantly industrial and mixed use. The site overlies a sole source Class I aquifer, the Snake River Plain Aquifer. A 10-mile-square area within the INEL complex, referred to as Test Area North (TAN), was built in the 1950's to support the Aircraft Nuclear Propulsion Program sponsored by the U.S. Air Force and Atomic Energy Commission. The selected remedial action for the site

includes pumping the contaminated ground water from the injection well and treating the ground water onsite using filtration to remove suspended solids, followed by air stripping and carbon adsorption to remove organics, and ion exchange to remove inorganics and radionuclides; modifying the existing TAN onsite disposal pond to receive treated ground water and ensure that it does not exceed discharge limits; transporting any spent carbon offsite to a permitted facility for regeneration; installing two additional ground water monitoring wells within the contaminant plume; monitoring air emissions; and implementing administrative and institutional controls, including ground water use restrictions.

Wald, Matthew L. "Uranium Leak at Tennessee Laboratory Brings Fears of an Accidental Chain Reaction." *New York Times*. November 25, 1994.

Uranium leaking from the shutdown MSRE has lodged in a pipe outside the containment of the reactor building, and concerns were expressed about an accidental nuclear chain reaction, or criticality. The MSRE, which ran from 1965-69, was built by the AEC as one approach to develop nuclear propulsion for aircraft. About 68 lbs. of U^{233} remains in the facility, mostly contained in drainage tanks. However, about 4.4 lbs. has moved to 6 in. diameter pipe requiring the evacuation of a nearby office building.

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CHAPTER 13.
ANP ORAL HISTORY INTERVIEWS

Bethe, Dr. Hans A. Oral History Interview conducted by Dr. Bernard J. Snyder. "Nuclear Propulsion of Aircraft". Dec. 28, 1995.

Dr. Bethe, 1967 Nobel Laureate In Physics and Professor of Physics at Cornell University since 1935 was interviewed on his role in the ANP Program. After completing work on the Manhattan Project as Director of the Theoretical Physics Division at Los Alamos, Dr. Bethe returned to Cornell. Dr. Bethe provided consulting services to the NEPA program, primarily assisting in the analysis of the shielding requirements. In about 1958 he served with Dr. Robert Bacher, Gen. Jimmy Doolittle and Dr. Hugh Dryden on a Presidential Advisory Committee to review the ANP Program. They concluded that the project would not be successful. He also believed that the Russians never had an ANP Program.

Bigelow, Chester and John Semko. Oral History Interview conducted by Dr. Bernard J. Snyder. "Aircraft Nuclear Propulsion Project at Pratt & Whitney". Jan. 18, 1996.

Both Bigelow and Semko worked together at the Pratt & Whitney CANEL Facility on the ANP Program and afterward on some of the subsequent high temperature materials and high performance reactor development efforts. Bigelow was involved in some of the earliest evaluations of the NEPA Project, serving on the TAB at ORNL in the summer of 1950. Subsequently he was a manager in materials development at Pratt & Whitney, starting there in September 1952, after the ANP Program was initiated there. Semko joined Pratt & Whitney after Bigelow. Both talked about the changing requirements for the reactor being developed by Pratt & Whitney. The relationship between Pratt & Whitney and NDA was explained, and also how they worked with ORNL. The series of many different ANP reactors that Pratt & Whitney worked on were explained and clarified, with insights into the particular technical problems.

Cosby, J. T. "Convair Division of General Dynamics (1940-73)".

Iris Number 00904831
Call Number K239.0512-693
Reel 0000024668 Beg Frame 000080 End Frame Old Reel Number
Transcript of Tapes: Iris Nos. 01000066 Through 01000069. Tapes Time 05:00.

Oral History Interview of Mr. J. T. Cosby conducted by Lt.Col. Robert G. Zimmerman at Fort Worth TX. Part of the United States Air Force Oral History Program. Includes information on Airborne Nuclear Propulsion.

Leverett, Dr. Miles C. Oral History Interview conducted by Dr. Bernard J. Snyder. "Aircraft Nuclear Propulsion". Jan. 8, 1996.

Dr. Leverett was involved in senior technical management positions with the ANP Program for essentially the entire life of the program. He worked on the Manhattan Project at Oak Ridge (Clinton Laboratory) until the end of the war. He was part of the Lexington Project which evaluated the NEPA Project in 1948. Subsequently Leverett was asked to join the NEPA Project as the Technical Director. He explained the relationship to the ORNL, how GE replaced Fairchild when the ANP Program evolved from the NEPA Project. Dr. Leverett became the GE Technical Director for the ANP Program, continuing in that position until the project was cancelled in 1961. He discusses the entire GE program and changing AEC and Air Force requirements. Dr. Leverett also was convinced that there was a Russian ANP Program, working on some of the same concepts the U.S.

Rockwell, Theodore III. Oral History Interview conducted by Dr. Bernard J. Snyder. "Aircraft Nuclear Propulsion". Jan. 11, 1996.

Rockwell worked on the Manhattan Project at Oak Ridge (Tennessee Eastman) until the end of the war. After the war he became interested in shielding work and soon became Head of the Shield Engineering Group at ORNL. In this capacity he worked on basic engineering that was applicable to shielding designs for both the ANP and Navy Nuclear Programs. Rockwell never worked directly in the ANP Program (he joined Adm. Rickover's organization in Nov. 1949, becoming Technical Director of the Naval Nuclear Reactor Program in 1954 and remaining in that position for ten years). However, he was familiar with much of the early NEPA and ANP work, and even wrote a popular article on ANP that was intended for the *Saturday Evening Post,* but was never cleared for publication because of security concerns. Rockwell provides unique insights into the differences between the Navy and Air Force nuclear programs, including anecdotes about Rickover's interactions with ANP and Gen. Keirn.

Thornton, Gunnar. Oral History Interview conducted by Dr. Bernard J. Snyder. "Aircraft Nuclear Propulsion Project at GE". Dec. 26, 1995.

Thornton worked on the Manhattan Project, helping to assemble the second atomic bomb dropped on Nagasaki. After returning to college in the post-war period, he joined the GE ANP Project. He eventually became the Engineering Manager of the project. He worked for GE throughout the project duration and continued after cancellation in 1961, directing the phase-out of the project. He was responsible for the GE report series 901-921 which document most of the technical information GE developed on the ANP program from its inception in 1951 to cancellation in 1961. In this interview Thornton discusses the major elements of the GE work, including the testing activities of GE, the HTRE-1, 2, 3 tests run in Idaho at the NRTS. All of these tests of nuclear reactors with jet engines were his responsibility.

END

AIRCRAFT NUCLEAR PROPULSION:

AN ANNOTATED BIBLIOGRAPHY

[ANNEX OF CLASSIFIED DOCUMENTS]

Prepared for the

UNITED STATES AIR FORCE

HISTORY SUPPORT OFFICE

BOLLING AIR FORCE BASE

WASHINGTON, DC

Bernard J. Snyder, Ph.D.

MAY 3, 1996

Note: All documents are available in the IRIS Data Base.

"Annual Report, Secretary of the Air Force". Office of the Secretary of the Air Force, (7/1/59-6/30/60).

Iris Number 472282
Call Number K168.02
Reel 11945 Beg Frame 23 End Frame 573 Old Reel Number K1246

Document Security: Secret

Detailed report of the Secretary of the Air Force includes progress on the ANP Program.

Air Force Academy Construction Agency (ACS)/Installations, Vol 6 of 8 (4), (1/1-6/30/55)

Iris Number 00470391
Call Number K V.6
Reel 1143 Beg Frame 1617 End Frame 1725 Old Reel Number 11842

Document Security: Secret, Nuclear Information

History of Air Force Academy Construction Agency, Construction Directorate. Discusses award of contract for design of Aircraft Nuclear Propulsion Facilities.

Air Force Periodical 80-1: "Research and Development Quarterly Review (1/4/59-6/30/59)". Air Research and Development Command. 1959

Iris Number 00486692
Call Number K
Reel 15541 Beg Frame 1662 End Frame 1759 Old Reel Number K

Document Security: Secret, Restricted Data, No Foreign

Includes progress report on Nuclear Propulsion Continuously Airborne Missile Launcher and Low Level Weapon System (CAMALS).

Air Force Regulation 20-44 ". Department of the Air Force. Dec. 5, 1952.

Iris Number 01040390
Call Number 168.7171-243
Reel 0000035274 Beg Frame 000158 End Frame 000000 Old Reel Number NA

Title of this Regulation is: "Air Force Aircraft Nuclear Propulsion Program".

Air Research and Development Command, Vol. 1 of 3, (1/1-6/30/55)

Iris Number 00484776
Call Number K V.1
Reel 15391 Beg Frame 27 End Frame 581 Old Reel Number K

Document Security: Secret, Restricted Data, No Foreign

Contents includes information on aircraft nuclear propulsion.

Air Force Special Weapons Center. "Nuclear Propulsion Safety Program". (1957-60).

Iris Number 01079599
Call Number Micfilm 40793
Reel 40793 Beg Frame 771 End Frame 999
Call Number K

Document Security:Secret, Restricted Data

Weapons Center Contract File Collection, includes ANP information.

"Air Force Systems Command Foreign Technology Bulletin". FTD-TA-64-27. Foreign Technology Division, Air Force Systems Command, Wright-Patterson AFB, OH. July 10, 1964.

Iris Number 00899822
Call Number K243.015-320
Reel 23512 Beg Frame 689 End Frame 718 Old Reel Number NA

Document Security: Secret, Restricted Data

Includes information on Soviet research related to Aircraft Nuclear Propulsion. Russian scientist, Yu. I. Dantlov, who in 1960 wrote a general review article on ANP, has performed basic work on materials and heat transfer that is applicable to an ANP Project. However, there is nothing to suggest that the Soviets have a current capability to produce a successful nuclear-powered aircraft.

"Military Liaison Committee, Minutes, (5/19/48-11/29/48)". Atomic Energy Commission.
Iris Number 01044353 Document Type
Call Number 143.5191

Reel 35954 Beg Frame 1297

Document Security: Secret

Minutes of Atomic Energy Commission-Military Liaison Committee-Conferences. Includes discussion of status of program for Nuclear Propulsion of Aircraft.

"Minutes of Military Liaison Committee Meeting, August 18, 1957". Department of Defense Military Liaison Committee to Atomic Energy Commission.

Iris Number 00470936
Call Number K143.5191
Reel 11872 Beg Frame 316 End Frame 463 Old Reel Number K1173

Document Security: Secret, Restricted Data

Contains Draft of Minutes of meeting held. Also contains memoranda pertaining to subject matters discussed at meetings. Includes the presentation to Military Liaison Committee at Idaho Test Station entitled: "The Aircraft Nuclear Propulsion Department and Summarized Reports".

Perry, R. L., "Atomic Weapon Delivery Systems, The USAF Aircraft Nuclear Propulsion Program," 1944-1958, Vol 5 Part 2. Included in Bowen, Lee and Robert D. Little, "The History of Air Force Participation in the Atomic Energy Program, 1943-1953." Office of Air Force History, Washington, D.C. 1959.

Iris Number 01036336
Call Number K V.5 Pt.2
Reel 34628 Beg Frame 000572 End Frame 000000

Document Security: Secret, Restricted Data

Includes the history of the effort to design and build a nuclear-powered aircraft for the Air Force and specifically discusses: bureaucratic planning; military's relationship with the Atomic Energy Commission; Lexington Project and Report; role of Gens. D. L. Putt and Donald M. Keirn; the X-6 Test Aircraft (Converted B-36); creation and operation of the Nuclear Energy for the Propulsion of Aircraft (NEPA) Program; role of Oak Ridge National Laboratories, General Electric Company, Convair Aircraft Corporation, Lockheed Aircraft Corporation, and R. M. Parsons Company; the Boeing Bomber Study MX-2145; Weapon System 125A; Arco, Idaho research facilities; Blackjack, "Tug-Tow" Nuclear Weapons System; Littlewood Committee; Canterbury Report; Mills Board Report; and Project Pluto (Nuclear Ramjet). This Volume

Contains Study 7. Atomic Weapon Delivery Systems.

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Special Weapons Center, "Physics Division Digest". Jan. 2, 1961.

Iris Number 01046903
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Document Security: Secret, Restricted Data, No Foreign

Includes information on Aircraft Nuclear Propulsion.

Williams, Clanton W., Col., United States Air Force Historical Division, Folder on Aircraft Nuclear Propulsion Program History, Vol V. (Pt. 2) of V. , (1943-55).

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Call Number K V.5, Pt.2 working Papers
Reel 11840 Beg Frame 27 End Frame 119 Old Reel Number K1141

Document Security: Secret, Restricted Data

Contains Draft of study, correspondence and documents.

Wright Air Development Center, Vol. II of IV, (7/1-12/31/55)

Iris Number 00484889
Call Number K243.011 V.2
Reel 15412 Beg Frame 613 End Frame 988 Old Reel Number K2860

Document Security: Secret, Restricted Data

Contents include list of illustrations, aircraft nuclear propulsion, glossary of abbreviations, index, and supporting documents.

(Print Is Very Difficult to Read).