UNITED STATES OF AMERICA

NATIONAL TRANSPORTATION SAFETY BOARD

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Investigation of: *
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LOSS OF THE SUBMARINE *TITAN* *
IN THE NORTH ATLANTIC OCEAN * Accident No.: DCA23FM036
ON JUNE 18, 2023 *
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Interview of: [redacted] Co-designer/Pilot
*Deepsea Challenger*

via Microsoft Teams

Friday,
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I N T E R V I E W

LCDR [redacted]: Mr. [redacted] let's go ahead and move forward into the interview, more so about -- I'd kind of like to run the interview as like a conversation, but I will pose some questions. Feel free to expound as much you want on something.

MR. [redacted] Okay.

LCDR [redacted]: You know, we're here to hear your expertise and your guidance really.

INTERVIEW OF [redacted]

BY LCDR [redacted]:

Q. So how did you get yourself started into submersible operations?

A. Well, I'm sure you're familiar with my film *Titanic*. When I set down the path to make that film, the first thing that I did was arrange to be introduced to the head of the submersible program at the P.P. Shirshov Institute in Moscow, a guy named Professor [redacted]. I did that through a mutual friend of ours, a guy named [redacted], who is one of the preeminent underwater cinematographers in the world. And [redacted] had been on a submersible expedition out to *Titanic* the previous year with the Russians. And that was organized by a Canadian company that was doing an IMAX film which was released under the title *Titanica*.

When I found out that it was possible to essentially hire or charter the Russian submersible system, I wanted to meet them. So, you know, I arranged for a visa. I went to Moscow. I met with Dr. [redacted] and we discussed the possibility of chartering his two submersibles that he co-designed, and he ran that program for the Russian Academy of Sciences. So essentially we made a deal with the Russian Academy of Sciences to charter their ship, the mothership for those two subs and -- those two very capable subs, to subsequently do an expedition to the *Titanic* wreck site, which we wound up doing in August and September of 1995, where we made 11 dives to the *Titanic* wreck and explored it and photographed it for the film. We also operated an ROV of our own construction at the wreck site at that time. We used camera systems and lighting systems of our own construction. As well, my brother [redacted], was a very accomplished engineer, originally from aerospace, but he was working in marine systems at the time.

To put backstory to that, I had been an avid diver since I was in my teens and I made a film called *The Abyss* in 1988 which was released in 1989, and I -- and as my research for that project, I got in touch of the lot of the leading lights in US and Canada on deep marine systems and a number of them worked with me on that film. So at that point, in '88 and '89, I had become very familiar with submersible operations, ROV operations, deep camera systems, deep lighting systems, and so on. Except that all of what we did for that film was all done shallow. So we used deep systems, for photographic purposes we shot them in a tank that was about 20 meters deep. So I was familiar with the hardware, I was familiar with all the personnel, but I hadn't actually operated deep until our 1995 *Titanic* expedition.

So then I learned a lot from the Russian submersible pilots and engineers and so on about how these subs are built, how they're operated, how their tracking systems work, how their sonar systems work, how their ballast systems work and so on, because I'm engineering oriented and pretty curious. And on that expedition I went from being a sole passenger with a crew of two Russians, one of whom was an engineer and one of whom was the pilot, to essentially stepping into the shoes of the engineer and allowing us to have two pax on board with a solo pilot. Because I took over all the comms, navigation, and -- not all comms -- some comms, navigation, and sonar, as well as the lighting and imaging.

So I was getting essentially a crash course in deep submersibles in the *Mir* system. They were called *Mir* subs. I'm sure you're familiar with them. Very capable submersible, 6,000 meter rating, three passengers -- or three occupants including pilot. Internal sphere diameter for the pilot sphere was about 2 meters, so they're fairly roomy, about a -- I think it's 18 ton, 18.5 ton vehicle; dedicated mothership, dedicated handling system to get it in and out of the water. So, you know, that was my trial by fire, if you will, my crash course in submersible operations.

We had 11 safe dives. I subsequently made, I think, somewhere on the order of 50, 5-0, *Mir* submersible dives including those 11 dives, in all sorts of places, including *Titanic* on two subsequent expeditions, and then also hydrothermal vents all sort of in the 3- to 4,000 meter depth range and so on. And, you know, I became an informal pilot of the *Mir* submersibles, learning, you know, from their pilots. And then we -- if I'm going into too much detail, stop me.

Q. No. No, sir. It's great.

A. In 2002, I had the opportunity to buy the *Deep Rover*. The sub is called the *Deep Rover 2*. There were two of them available. They had been operated by a group that were working for Canal+, the big media company in France. I had an opportunity to buy them as a kind of a job lot, essentially, when they closed that whole operation down. So I bought the submersibles with a partner, an Australian named [redacted], who had done a lot of *Titanic* and deep hydrothermal site tourist dives. So he had been working with the *Mirs*. I knew him through that connection. He had done a very large number, I want to say in the 20 or 30 or so number of deep submersible dives with paying tourists using the *Mirs*. He and I went in as partners on the *Deep Rover 2* submersible system and we bought the entire thing, all of the support and, you know, the compressors and the diving gear and all the support infrastructure, the trailers, you know, the containers that would be transshipped and welded down onto whatever ship of opportunity we would operate those subs from.

And then we -- subsequently, I worked with a guy named [redacted], whose name I'm sure you're familiar with. He runs the company Triton submersibles, and they are the largest and best of the commercial submersible suppliers and operators. He and I tore the subs apart down to every nut and bolt, reassembled them, made some electronics improvements, had them classed in the Bahamas in 2003 with ABS, and then we successfully operated those subs at numerous sites in the Atlantic and Pacific that year and the following year.

Then I made additional dives with the *Mir* submersibles on a later expedition to *Titanic* in 2005. Then after that, I started design and construction of my own submersible from scratch, which became the *Deepsea Challenger*, which was a 11,000 meter rated submersible. I was the co-designer of that with an Australian engineer named [redacted], and we built that sub in Sydney, Australia. It took us 7 years to build and then we operated it successfully in 2012. I made 10 dives in the submersible and -- anyway, you can jump off from that. That's the basic sort of chronology and timeline of my expertise around submersible diving.

Q. I greatly appreciate it. That (indiscernible). It's very deep. I want to just back up a little bit.

A. Yeah.

Q. I just want to ask a few questions down along the line. So we discussed initially the Russian *Mir* subs. While we know a good amount about the Russian *Mir* subs, did the Russian *Mir* subs, were they -- what were they constructed of and do they have their own classification system that they would utilize? And were they owned and operated by Russia or who are they owned and operated by?

A. It's interesting. They were developed -- [redacted] was one of the co-designers. He came from the Pisces system, which was an American submersible system. The Russians had bought one or two of them. [redacted] worked with a Finnish company. The name escapes me right now, but the subs were built in Finland. They were classed through German Lloyd's.

Q. Okay.

A. So they weren't completely -- they weren't designed and operated in Russia. They were built externally. They were classed externally, and I believe they continued to be classed right up until their retirement, through German Lloyd's.

Q. Great. Thank you. And then you had mentioned about the *Deep Rover 2*. And the *Deep Rover 2*, you said -- did you say that that was previously a tourist sub, submersible?

A. It was designed for exploration and for imaging essentially for media. I believe it was commissioned by the Canal+ team. They were -- that team was run by a name you'll be very familiar with, P.H. Nargeolet, and came from the *Nautile* sub system, submersible system. As you know, he worked with IFREMER for many years and then subsequently with RMS *Titanic* using the *Nautile*, the IFREMER sub. So P.H. Nargeolet operated the *Deep Rover 2* subs before I acquired them. I had known, you know, P.H. for many years at that point, or for several years.

So they were not designed specifically as a tourist sub. They were designed, I would say, as an exploration class sub to be professionally operated, and that was pretty much their history. I don't believe they ever worked as a tourist sub. They were an acrylic hull, two-seat vehicle, a design that's very typical now, but they were quite radical in their time. They were the first of the kind of transparent bubble subs. They were designed by [redacted], a name that you may be familiar with. And so they were considered fairly radical in their day.

A fairly simple design actually, and that design has been taken and used by let's say Triton -- or at least emulated, I should say, by Triton Subs. Most of their tourist and exploration subs follow that same acrylic bubble design; big battery system down below; strong riding moment, a very stiff boat that stays quite strongly vertical in the water. The arrangement of the thrusters is very similar in the Triton subs to the *Deep Rover 2*'s.

Q. Thanks. I want to talk a little bit -- before I get off of the subject of the construction, so what type of construction subs have you owned and/or operated in? And by construction I mean the hull, the pressure hull. So you mentioned acrylic. What other types of constructions have you been involved with?

A. Okay. So the *Mirs* had a steel hull. They used a high nickel maraging steel. They -- it was formed in two hemispheres which were, I believe, bolted together as opposed to welded. And that was the Finnish -- from Finland. It was -- you know, they were built in Finland, at a yard in Finland. Obviously the acrylic subs, the -- with the [redacted] design, which were two acrylic hemispheres that were just joined by acrylic bonding, which is almost like welding because it's the same material.

The *Deepsea Challenger*, we looked at a lot of different potential pressure sphere materials. We looked at titanium. We eventually settled on -- we even looked at glass for a while. I know the Navy had done some work with glass under extreme pressure, but there were still too many variables on that. We went with a high ductile, high nickel steel called EN26, that was developed in the UK in the second world war for gun breech, you know, big guns, naval guns, design. And we did that primarily because of our timetable. Titanium would have set us back about a year to get the input slabs that we needed, so we went ahead with the EN26. And then we forged our own hemispheres and figured out how to, you know, weld them together and all that sort of thing. I mean, we were working with some pretty high level metallurgists and experts on that sort of thing in Australian.

I remember we had about a 6-month setback where our finite element analysis showed that the weld material that was proposed by Apollo Forge, the people that were actually doing the forging and construction, would have been in yield at our service depth. So we had to start over and figure out a different weld material that would have worked and, you know, we went through very, very extensive stress field analysis in FEA to get the sphere very finely tuned to what it needed to be. We worked with a company in Tasmania called Finite Elements. A gentleman -- run by a guy named [redacted], who did all the computer sims.

We spent about 3 years on the sphere design before we actually built it. And we built the sphere first and then we pressure tested the sphere first before we went ahead with the rest of the construction of the sub because we knew it's all about the pressure boundary, as I'm sure you're learning about these vehicles. All of the -- all the externalities, all peripheral systems, you know, buoyancy, communications, all those things, are all secondary to, you know, having a safe -- a high, you know, what do you call it, margin of safety with that pressure boundary.

Q. Can you tell me a little bit more about the EN26 and the pressure tests that you put it through and what type of tests, you know -- what type of tests you used, if you did, you know, unmanned dives or whether you did pressure boundary testing or -- you know, it can be ocean test facility and those types of things.

A. Yeah. The important thing to remember on the pressure boundary is that it doesn't consist just of the hull. It consists also of the penetrators, the hatch, and the viewports. So you have to think of it all as a system, anyplace that the pressure can be problematic. Implosion is the obvious problem. The thing that dumbfounds me about this, about this whole thing is implosion should never be on your mind when you're in a sub. It should have -- that should have been eliminated as even the most remote possibility very early on in the engineering phase. Leakage at a penetrator could always become a problem. Hatch seating, viewport seating, if you're using an acrylic viewport as we did. You know, it has creep due to, you know, cold flow deformation and all those things have to be thought through.

So when we completed the sphere -- and by complete I mean the penetrators were installed and the acrylic viewport was installed so it was ready for actual pressure boundary testing, we shipped it to Penn State and we tested it in their 16,000 psi chamber at Penn State. Which means that it wasn't overpressure testing. The only place to do overpressure testing was in Russia, and I'd had enough dealings with the Russians to not want to send my sphere to Russia. Just there's a lot of payola and there's a lot of things involved that I didn't want to deal with.

So because we were not able to overpressure test the sphere, we came up with two protocols. One was that we covered it with 28 strain gauges and we looked at the performance curves that we were able to achieve down to -- the 16,000 psi gets us to our service depth. It doesn't get us to an overpressure test. But we worked with the metallurgist and said, if you're curves agree all the way down to your test depth, then you can extrapolate those curves within the known -- because it's an isotropic material. You know, we're not dealing with a composite where you have to actually eliminate failure. And the other thing we did was an unpiloted dive at full ocean depth. So when we finally got out to the Challenger Deep, we basically dropped the sub to the [redacted] on an [redacted] program, treated it essentially as an autonomous vehicle. And so we, you know, we got all the data that we needed from that as well.

The other thing is I have to point out with the *Deepsea Challenger* because classification is a big issue around this. The sub itself in its all-up configuration was not classified. It was considered an experimental vehicle. Myself and my co-designer were the only two people that were ever meant to pilot the vehicle. So we never had paying passengers. It was a solo, it was a solo -- a one-seater anyway. So, you know, we decided that we would use that as a pilot program and later we would ideally build a second sub that was a two-seater, at which point we'd go through full classification once we had proof of concept. So I'm very familiar with the classification process and we're very familiar with like why we didn't do it on that particular vehicle.

That said, we had a group called Bureau Veritas, who are -- you probably know them --

Q. Yeah.

A. -- in Australia. Bureau Veritas were with us every step of the way in the design and qualification of the sphere. So we have a signed essentially classification of the sphere itself. What we don't have is classification of the all-up vehicle with all its peripheral systems.

Q. Understood. And the overpressure test, do you know what percentage that would be of your rated dive depth?

A. It was 100 percent.

Q. 100 percent?

A. So 16,000 psi is essentially the pressure at full ocean depth.

Q. Um-hum.

A. And that's what the Penn State chamber could do.

Q. Okay. But the question -- so what would be considered the overpressure test? Would that be 125 percent or anything above --

A. Yeah. Yeah, you -- there's a -- overpressure testing is a bit controversial. I have my own opinions about it. I think it's a good thing to do up to but not including a yield threshold of the material itself. So if you're on a safety factor as we were of 1.65 or 1.7, then 125 percent would have been about the right number. You could go higher if you want -- I mean, I would say with any outboard implodable volumes on a vehicle, I would go to 150 or 200 percent. I'd want to be absolutely certain that none of the small components around the vehicle could implode. Because obviously there's the danger of a sympathetic implosion, you know, and we've seen accidents like that happen on deep unpiloted vehicles.

LCDR [redacted] Mr. [redacted] if we can we take just one second real quick.

Mr. [redacted] we've been going for about 27 minutes now. Do you want to introduce yourself, sir? I apologize.

MR. [redacted] No, I apologize for being late.

Mr. [redacted] my name is [redacted] I'm the chair of the Coast Guard Marine Board of Investigation. And I appreciate your time and apologize for coming in -- arriving late this afternoon. Or morning for you. So thank you.

MR. [redacted] Yeah. Well, thank you. Yeah, it's morning where I am anyway. Yeah, well, we've used the time productively and obviously there's a recording, so anything that came out of it will be available.

MR. [redacted] Yes, sir. Thank you.

BY LCDR [redacted]

Q. Mr. [redacted] I'm going to continue on with the basic testing and creation of your vessel. So did you determine how many cycles you could take it to that depth or was there -- was it one cycle, two cycles?

A. The sphere, we believed, was good for many, many cycles, in the 500 range, something like that. Cycling was not our problem. It was corrosion, right, because the particular seal that we used was subject to saltwater corrosion. So it would've required complete disassembly and inspection and reassembly. We figured somewhere on the order of 20 to 25 dives would've been about our limit on that. We had an upper boundary condition on the acrylic viewport because of the extreme pressure that it was seeing and the cold flow characteristics of the acrylic material. We put an upper boundary of 10 dives per viewport. We felt that the theoretical limit was somewhere around 100 cycles, but we just made extra viewports and brought them with us and we were prepared to change them out every 10 dives.

Q. And the viewport was rated to the max depth --

A. Yes. Correct.

Q. -- of the vehicle?

A. But again, the acrylic material is very interesting. It behaves different than almost anything else. It does have a, a kind of a cold flow characteristic within the conic thrust and seat of the dome port.

I forgot to mention that we did high pressure testing of the acrylic ports, where we tested them to essentially failure. And they failed at about about 2X of the operating pressure. We built a -- because they were small, we could put them into a smaller chamber that could go up to I think 35,000 psi or 30,000 psi, something like that. So we put two viewports back to back in a common titanium seat or steel seat, and then we externally pressured those until we started to see fracturing. And so, you know, they were extensively tested.

They were our own design. We worked with [redacted]. That's probably a name you've run across. [redacted] wrote a book about this thick. He was the Navy's primary consultant on acrylic viewports for human-occupied vehicles. And he was consulting with us up until his death, unfortunately, in the middle of our program. But he had already signed off on our design.

Q. And to build your -- I was going to call it a vehicle, if that's a proper terminology to call it.

A. Sure.

Q. So in creating and building and testing your vehicle, could you estimate the -- you gave us the time, but can you determine how much does it cost to actually go through all the proper testing to get a vehicle to that depth with that amount of cycles?

A. I'm not sure we ever broke it out as a separate sort of budget line item. It was so integrated into our day-to-day process. We had a 20,000 psi chamber. We had a 30,000 psi chamber. We had a number of chambers at our facility that we built ourselves. My colleague [redacted] was very good at designing and building pressure test pressure chambers. So we tested every component multiple times, every circuit board, every pressure vessel, the thrusters, everything. They were constantly, constantly running on chambers runs. It was an integrated part of our process. So we never broke it out and it wasn't really done by an external testing body. It was integrated into our in-house operations.

So I should loop back. We -- early on, we had an engineering sort of brainstorming session with the Woods Hole team, and I'm very close with them. You probably know [redacted], who runs their engineering group. They were about to start building their *Nereus* vehicle, which was an unmanned ROV/AUV, hybrid mode vehicle for full ocean depth, at the same time we were starting our vehicle. So we kind of had a little symposium where we said, look, there may be components that can be shared in common, why don't we, you know, spend the non-recurring engineering costs jointly and then just make a number of units that can go on each vehicle. And we actually found out that we were too divergent in our engineering cultures.

They were going to use ceramic spheres for floatation and ceramic pressure vessels with airspaces inside and 1 atmosphere electronics. I said I'm not comfortable with that for a human-occupied vehicle when I'm the human because of the danger of sympathetic implosive failure of relatively small implodable volume outside the main crew pressure boundary could cause that crew sphere to fail if it implodes. We were very, very aware of this problem. There had been a lot of -- there's a lot in the literature around it. So they were determined to go their way. I said we're not going to do that, so we used a completely different system, which you -- I'm sure you've heard the term PBOF, pressure balanced oil filled. Our batteries, all of our electronics, all of our outboard systems were all at ambient pressure, meaning the electronics had to be vetted to be able to see that pressure of 16,500 psi, which was the sort of design depth of -- full ocean depth in the Challenger Deep.

So we were pressure testing all day, every day. Every component that would populate a circuit board had to go through validation, multiple, multiple cycles, make sure it didn't fail, before we could even design a circuit board. And then I think there were over 1200 circuit boards on the vehicle, because there was a circuit board in every module of the -- or every small unit of the battery system. We called them battery boxes, and the boxes were grouped in modules, and the modules were on separate redundant buses. The whole vehicle was designed to be not failure proof but small outboard failures would not take down the overall operational capability of the vehicle. It was a high multiple redundancy system: multiple thrusters, multiple battery buses, etc., etc. So that's why we never really broke it out as a line item, that kind of testing.

Q. Understood. So thank you for that. I kind of want to back up -- not back up, but I want to discuss you working with class with a -- I don't want to call it a novel product with a pressure vessel, but a new type of construction, a new, using a new -- how did that work and how was it working with class? And I know you have a lot of experience with class. And you said it was BV you used?

A. Yeah, Bureau Veritas Australia.

Q. Yeah.

A. They were great. There was one person from BV that worked with us, I want to say for about 2 years; reviewed our FEAs, made recommendations. He knew his pressure vessels. He knew internal pressure vessels and external pressure vessels. You know, pressure going two direction -- or in different directions is a whole different animal. I'm trying to remember his name. Right now it's escaping me. We worked with him, you know, 14, 15 years ago. He was with us, as I recall, for about 3 years. Through the final all-up testing, he flew with us to Penn State. That was in -- that would have been in September of '09 we did that testing. The sub didn't make its dives, its sea trials and its deep dives until February or March of 2012, but he was with us throughout the earlier stage of getting the sphere finished. And then they -- I don't have the certification with me, but they did certify the sphere.

I found it to be a good experience. I found his input welcome. I found it comforting, you know, as the person not only paying for the vehicle but the one that would be piloting, you know, to full ocean depth. We worked very, very closely together. He worked very, very closely with [redacted], obviously, because they're both Australian. But he made it -- I felt like he made it a project of personal interest, you know. And he brought a tremendous amount of experience in metallurgy and pressure vessel design to the situation.

And he alerted us to a problem that was a potential problem, which is that we used a material called 300M for the hatch, which had a microscopically different bulk modulus than the EN26 that we used for the rest of the sphere.

Q. Yeah.

A. And he said there is a possibility that you might not be able to get the hatch open after -- you know, that the way that the two would interface under pressurization, that there could be a binding problem. And so we looked at ways that we could solve that by slightly changing the conic angle of the hatch. And he brought in the documentation for scenarios where he had seen that problem before. We incorporated it into our design, etc. etc.

So when we actually did our pressure testing, I think we did three pressurizations to 16,000 psi and we had no problems with anything with the penetrators or the viewport or the hatch itself, the functionality of the hatch. And we never had any problems with any of those things in operation.

Q. And did you -- I know you said that you used strain gauges throughout your testing. Did you use them throughout operation as well?

A. No. No.

Q. No. Okay. Have you ever used --

A. That's actually not a bad idea. It just -- it never occurred to us. We felt we were beyond that stage once we had the sphere certified. But it wouldn't have been a bad idea.

Q. Yeah. Understood. I appreciate that.

A. Just, you know, additional complexity. These vehicles get quite complex quite quickly in terms of all the electronics for the instrumentation. Our vehicle's very, very different than something like the OceanGate vehicle. I mean, we had a lot of lights and very, very high capability in the battery system. We had a -- it was a 100 kilowatt design, which is quite a large battery for a relatively small sub, and, you know, lighting, camera, so many overlaid electronic systems, and comms, navigation. We had full redundancy in comms. We had backup beacons. We had all kinds of things on the sub. So there were many, many layers of electronics to the sub. I guess we figured the -- the strain gauge question never came up. That's -- I'm going to put that -- I'm going to write that one down.

Q. Okay. So, and then -- discussing that, so you had mentioned encyclic testing. Have you maintained the *Deepsea Challenger* to actually redo testing of the pressure hull and the systems?

A. The sub was donated after the expedition to Woods Hole, with the agreement that they wouldn't operate the sub but they would completely deconstruct it and they would incorporate the technology into some of their future programs, which they have done, and that any components that they could use from it, like cameras and lights and things like that, that they would cannibalize into their other vehicles.

Woods Hole had the same problem of it being a solo pilot, so they couldn't take a science observer. I mean, when I dove the sub, I was the pilot and the science observer and the imaging guy and all of that, all at one. It was like a, you know, one-man band. And so it didn't fit the way they organized their program, so the donation was made so that they would publish the technology and incorporate the technology into their future programs.

So no, the sub has not been maintained in that way. There is the possibility that we could take the sub out of it -- it's basically intact, it's just dormant. It's been reassembled and not tested but switched on, so we know that it works. It's currently going to be in a touring exhibit. We could bring the sub back to life at some point and use it programmatically, at which point I think it would be a good thing to class it just to have done that. You know, once again, solo pilot, but at a certain point we want to train other pilots so that we got more capability out of the vehicle. We just never got that far with it.

What we found was that there -- we were expecting some program money from, you know, from science and academia to go to what I always called Phase 2. Phase 2 we go sort of operational on a multi-year basis. It turns out there's not a lot of interest in academia for human-occupied vehicles at those depths, at hadal depths. They get more bang for their buck with robotic vehicles and AUVs and things like that. There's not much money in --

Q. You had mentioned --

A. There's not much money in it in general. That's the problem for deep ocean research.

Q. You had mentioned pilot training. And you kind of got your pilot training through the Russian *Mir* subs. Is there --

A. Informal, yeah. Yeah.

Q. Informal, yeah.

A. We did a very, very carefully worked out pilot training program for the *Deepsea Challenger* where we built a 100 percent mock-up of the vehicle with all internal electronics, life support and everything. And we did actual lock-in dives in a freezer, where -- you know, just like kind of a NASA plugs-out test, you know. You'd sit in the vehicle and you'd make a simulated 12-hour dive. You'd cold soak. You'd change your, you know, clothing, etc., according to the checklist. You'd run through all systems over and over. They'd throw simulated emergencies at you from a control room. I mean, we did it exactly the way NASA would do it. I don't know how many other sub operators do it that way, but we did it that way because we felt it was important. And I wanted the very best training that I could have to operate the vehicle.

So we -- you know, we had a manual this thick. It was developed by a guy named [redacted] in Australia. He was a cave diving instructor, so he knew -- he basically knew rebreather systems intimately. We built our own -- we designed and built our own life support system. Basically we were kind of arrogant, which is we didn't like the standards for a lot of what's out there so we kind of set our own higher bar in a lot of areas. Because, you know, personally what scared me in a sub was not implosion, we had designed against that, it was fire. You're in a very small volume. You've got a lot of electronics packed in there. If you have a fire, it can contaminate your breathable air very, very rapidly. So we had a 100 percent redundant backup system that we could go on with a full-face breathing mask, very much like you do -- you know, an SCBA-type mask. And we could literally switch over to a fully redundant system. No other sub, to my knowledge, has that. They usually have a BIB system, built-in breathing system, but nothing like what we designed.

Q. And with that manual, the operations manual, would you guys run your own types of -- we call them like BECCEs in the Coast Guard. So would you run like engineering casualty control drills and have those --

A. Absolutely.

Q. -- things that you would set up and kind of run through them?

A. Absolutely.

Q. And how would that work?

A. [redacted], who designed the systema and designed the training mock-up and the, you know, the cold soak room and the control room for it, he ran vigorous tests. He actually did a lot of the pilot runs himself. His maximum run, I think, was 18 hours, which was kind of a -- the sub was not designed to dive for 18 hours, but that was -- if you had a contingency scenario where you were stuck on the [redacted] and you are waiting for a redundant weight-drop system to time out. Because ultimately if you -- the way we designed the vehicle was we had a -- we had manual ballast drop. If that failed because of some communications error from the inside to the outside of the vehicle, then there was a timer-based system, and then there was even a simple corrodible link system that would fail chemically. And the outside time from the time of the start of the dive in saltwater was somewhere between 18 and 22 hours. So he did a -- like a worst-case contingency dive, where, you know, he basically locked in for 18 hours. I didn't have to do that. My longest training dive was 12 hours. But he was just exploring the outer boundary essentially of what our contingency protocols were. And he and I sat and brainstormed this stuff, but he was the one that actually designed it and wrote it all up, created the training protocols.

And another thing that was unusual about our operation is everybody who designed and built the sub went with the sub to sea for the sea trials, even though some of these engineers had never been a ship before. I think the most dangerous part of our whole operation was these young software engineers puking over the railing in a high sea. But I wanted them with me because I knew as an experimental vehicle we would be finding little flaws and ways to improve it and so on as we went along. We wanted to emerge out of that sea trial program with a fully vetted and refined vehicle before it went into Phase 2. We never went into Phase 2, but that was our game plan.

Q. You mentioned the drop weights. So did you guys utilize a motorized system as well as a hydraulic release or was it just the hydraulic release and then the squibs or the sacrificial anodes that would dissolve to therefore drop the weights?

A. So there was a, there was sort of a series that -- so the prime system was based on a simple breakable electric circuit. And I said, guys, I don't want this going through the computer. Because we had a PAC, a P-A-C, on board, programmable controller for all the subsystems so that we could limit the number of conductors going through the penetrator. We had an electronic penetrator -- an electrical penetrator and we had a fiber optic penetrator. The fiber optic penetrator was its own dedicated thing. We only had a limited number of conductors on the electrical penetrator.

And they said, well, we don't want a dedicated circuit for the weight drop because it'll limit how much we can MUX over the -- you know, multiplex over the other conductors. I said I don't care; we're not going through the PAC. The PAC can latch up, the PAC can glitch, the PAC can go down, and then I lose control of my ballast system. I said I want it medieval. I want it dead simple: I throw a switch, breaks a circuit, a magnet releases, an electromagnet that had its own dedicated battery releases. So the sort of hierarchy was commandable release, I break the circuit with a toggle switch, just dead simple. Everything else was very sophisticated electronically on the vehicle. I said I wanted that medieval. So I throw the switch, the electromagnet releases, and through a kind of mechanical advantage it then releases the weights.

There were two separate drop weights on two separate slides on either side of the vehicle. They were tested over and over and over, like hundreds of cycles in a pressure chamber at temperature. I said this is the one thing that absolutely electromechanically cannot fail on the vehicle. So I had 100 percent -- I actually helped design the mechanical interface with the guys who built that. They were an outside contractor that we got in, people that I had worked with for 30 years. I knew them very well. And they were more paranoid than I was. But paranoia is a healthy thing when you're designing a submersible vehicle.

So that was the first step in the hierarchy. If that failed for whatever reason -- we couldn't imagine a reason why it would fail -- then the dedicated electromagnet battery would just run down. And we did a lot of testing to know like how long it would take to run down. And we always set it at somewhere around 14, 15 hours so that it wouldn't suddenly interrupt us in the middle of an operation at hour 11 or 12 on a dive, which could be dangerous in and of itself.

And then if that failed for whatever reason we couldn't imagine, there were -- like let's say there was a mechanical failure, something fouled the mechanism, something got into the mechanism and fouled it or something broke and fouled it, the entire weight drop slide unit itself, the actual -- the base unit, so that the weights would slide off, the base unit was attached to the sub by two frangibolts. And so the frangibolts would then -- could then be commanded. So if I commanded the weight to drop and it didn't drop, I'd then go to the frangibolt. It takes them a minute or so to heat up and then break the bolts, and then at that point we lose the entire system, but that's preferable to -- so there was no hydraulic amputation. We used the frangibolts as the amputation system. Because when we were originally designing the vehicle, we didn't really want hydraulics. It was a layer of -- we eventually wound up with a hydraulic manipulator and a few other hydraulic functions on the sub, but initially we tried to do everything with kind of solid state electrical solutions.

If you got past the frangibolts and that didn't work, then there was the sacrificial anode, you know, corrodible link which would fail. So, you know, I guess that's quadruple redundancy, something like that.

Q. Yes.

A. Yeah. So -- and, you know, we had the same frangibolt system on the manipulator as well. So if -- you know, obviously manipulator fouling is always a risk with submersibles. To my knowledge it's never actually happened in a way that required outside interdiction, but I know there are stories across the last 50 years of sub ops where people had to drop their manips.

Q. Um-hum. Now did you also have a variable ballast system for external -- for ballasting, for like external high pressure air to be able to put it into, say, like an umbrella type system or whatnot to use air for ascent?

A. Yeah. We didn't begin the -- we used essentially an external ballast system where we had a lift bag, and then we'd physically release the lift bag to start the descent. So we started the dive negative. We didn't have space inside the vehicle for a variable ballast system. But what we did do is we had a passive variable ballast system that would deploy on a set. So basically it would pressurize at -- a very large bright orange lift bag would emerge at about 1,000 feet. And that way, if we were -- if we had some sort of compromised buoyancy, some piece of syntactic had crushed or broken off or, you know, anything that compromised our ability to surface, we had an additional, I think it was, 8- or 900 pounds of buoyancy at that point, and a very high visibility flotation, you know, system.

So typically we would surface about 300 or 400 pounds buoyant just innately in the structure of the sub, and then we had an additional 8- or 900 pounds of gas, so variable buoyancy. But it was a passive system. It armed on the way down due to pressure and it released on the way up due to pressure. It was a fairly clever design, I think actually. Because the problem is what's your gas source? Any gas cylinder that you put on the vehicle becomes an implodable volume at full ocean depth. Even if it's pressurized at 10,000 psi, it's still 6,000 psi additional external overpressure on top of that. So there was no gas bottle in the world that could do that.

So we designed a gas-over-oil system so that the gas went into solution in an oil that came into the cylinder and then came back out of solution and pushed the oil out and then continued to expand into the lift bag. It was a very clever system. I don't know anybody else that ever did something like that, but -- that's part of what we turned over to Woods Hole, if they ever found a purpose for any of these things. Because there were -- I would say there were about 15 or 16 highly innovative things on our vehicle that were kind of unprecedented.

Q. Absolutely. I'm just going to ask you about a few more things before I take it over to Mr. [redacted] and Mr. [redacted] real quickly. So I believe when you were talking about the *Rover 2*, it had a dedicated support vessel. Was that with (indiscernible)? I apologize (indiscernible) --

A. No. It was *Mirs*. The *Mirs* had a dedicated support vessel, a dedicated handling system. The *Deep Rovers*, when we got them, we didn't get a vessel, we just got -- we got all of the support systems, but not the ship.

Q. Understood.

A. And so we would use a ship of opportunity.

Q. What did you use for the *Deepsea Challenger*?

A. *Deepsea Challenger*, we used a -- it was a, basically an oil company or an oil support ship that was a wet deck, a wet deck ship, like a typical pipeline inspection or oil rig support ship. It was called the *Mermaid Sapphire*. It was operated by Sapphire

Marine out of Singapore. And they did a lot of work in southeast Asia and the western Pacific in -- for, you know, oil contracts.

Q. And with the vessel, what was your expectation of the vessel as like a support ship? What did you look for? I mean, I'm going to guess that you were part of the contracting and setting up.

A. Sure.

Q. What were some of your requirements for the vessel?

A. We wanted DP2. We wanted sub tracking. We wanted an onboard ROV so that we had safety backup and support down to whatever depth. Theirs was only good to 1500 meters, but we knew as long as we were diving in less than 1500 meters in our trials, we had a backup vehicle.

And just as an aside in case I forget to say it later, I think one of the recommendations you should strongly consider is the idea that anybody operating a human-occupied vehicle for deep exploration should have an ROV, at least an observer class ROV if not a work class ROV, on board that can make the depth. Because if you think about the tens, hundreds of millions of dollars spent by people to go determine what we all already knew, which is that it was lying at its -- that the *Titan* was lying at its last known position on the [redacted] and it wasn't a rescue, it was a recovery, you know, that -- I think the capability to determine that a rescue is required should be innate on the vehicle. If you can afford a human-occupied sub and a support ship of that class, which is going to cost you a million bucks a week, you can afford a small fiber-spooling ROV that can make the depth and get eyes on. That's just my recommendation.

Q. Thank you, sir, for that. Appreciate that.

A. But anyway, in terms of support vessel, we wanted DP2, we wanted an onboard ROV, we wanted -- so that we had some backup down to -- we knew we were going to be going far beyond the ROV's depth and that I'd, you know, I'd be solo beyond that, but -- and my requirements were both for safety and for imaging. We could image from the ROV, we could image the ROV from us, but we interested in imaging our sub in operation so we could study its performance. So we were -- you know, we wanted a crew that seemed capable of doing things that they weren't used to.

And so we spent a lot of time with the Sapphire company figuring out who they were going to populate their key, their top crew members with, the captain and so on. Had they done sub ops, had they done -- obviously they've got an onboard ROV, they've done a lot of ROV ops. They had sub following, so they had they tracking capability to follow their own vehicle. They had -- we were able to get onto their frequency with our transponders so that they could track our vehicle as well.

Now if you know sub ops, DP2 and UQC comms are not very compatible. When you're operating the DP thrusters, they often contaminate the water with too much sound and make your voice communications difficult. So we had to have somebody that could operate in DP but switch out of DP for comms and have a pretty disciplined protocol around that. I mean, we learned how -- the Russians do it without DP. What they do is they motor up weather and then they drift down across the dive site for an hour so that they have clear comms. Then they switch comms to a small boat and they motor back up weather and they hand off and so they have an unbroken comm cycle. And we adopted that same methodology, except when we were doing joint ops with the ROV, in which case we had to have a more of a compromised system. But we brought that to the *Mermaid Sapphire* captain, said this is how we'd like to operate so that we have an unbroken comm cycle. And it worked very well. You know, we know had one comms transducer on a 10-meter rib and we had another one hanging from the ship. And so they'd just hand off.

Q. And by comms, you're not talking verbal communications, more as --

A. Oh, yeah. Sure.

Q. -- (indiscernible)

A. Oh, we had voice comms all the way down. We had voice comms at 7 miles down. Yeah. I talked to my wife.

Q. Like what (indiscernible) --

A. When I reached depth --

Q. -- system?

A. When I reached depth, I reported in. I gave the -- you know, I gave the depth. I said I'm on the [redacted] depth is, you know, whatever. And there was a long pause and then the next voice -- I heard "copy" from the comms guy, and then the next voice I heard was my wife saying, honey, congratulations, you know.

Q. Well, that's -- I didn't know that was even possible. That's fantastic. I know a lot of the new systems are using like the acoustic telemetry modem to send up texts back and forth, but I didn't know actually verbal was a possibility.

A. Yeah. We had a text backup. You know, there was obviously lower bandwidth. If we failed in voice, then we'd switch to text. But I never had to. I mean, we spent a lot of time at sea doing at sea test operations in the Tasmin Sea off Sydney getting all of our launch recovery and our deep comms and so on worked out before we even went off on our sea trials.

Q. And did you ever lose communications or tracking at all throughout your process?

A. Our system was not designed to have accurate tracking beyond a certain depth. They could only get us to, I think, 4,000 meters with their system on board the ship. And then beyond that, we had to do old-fashioned plotting. Right? So we basically used multiple transducer positions and we'd take readings and then a very, very capable guy named [redacted] would literally plot it on a -- like, you know, with a pencil. But they were pretty accurate.

Q. Just one more question. So your -- the *Deepsea Challenger*, when it was on the aft portion of the vessel, for it to get into the water was it an A frame, was it a davit lift in? Like how were you then put into the water?

A. We used a less than optimal system. I had designed a dedicated system that would have gone on the -- would have welded onto the back of the ship, but we ran out of time to build it. We were assured by the Sapphire guys that they could do it with their crane. Turned out they were kind of full of shit. So we -- when we were in Sydney, what I did was I built a mock-up of the sub that was the full weight and exact configuration and we did repeated trials at sea in parallel with finishing the build of the sub to launch and recover what we called the mock-up sub or the dummy sub. And what we wound up with was something that we had used with the *Deep Rovers*.

When you have a pendulous load under a crane, if you don't -- if you have a snubbing system like the Russians did or like we'd used on other ships, then you can snub the sub, have control of it, put it in the water, and then release it. We didn't have that, so it was essentially a pendulous mass on a cable, which is not desirable with an 11-ton sub. So what we did, we set up a lateral, a side bridle on it, which was a wide bridle, was made out of Dyneema, you know, straps sort of this big. It had -- I don't know, it was like a 10X safety factor or something. And we had a dedicated winch on deck that would laterally load the sub. And so the crane would swing outboard always farther than the sub. So the sub was essentially locked to the ship by gravity at an angle and the crane would swing out and then we'd lower the sub and pay out the side loading winch. And we got pretty good with that by using the dummy sub.

So I went out and supervised the launch/recovery operations for about 2 months to get us dialed in on how to operate this. And then we operated it successfully. Because I knew that was going to be ultimately the dummy in the real sub and, frankly, launch/recovery operations always scare me more than the actual at-depth operations.

Q. Wow. Thank you, sir.

LCDR [redacted] I'm going to pause my questions for now.

Mr. [redacted] I can defer to you for any questions. You're muted, sir.

MR. [redacted] Yeah, why don't go to the NTSB?

[redacted] do you have any questions?

BY MR. [redacted]

Q. I really just have one. And I heard you say earlier that you didn't like the standards and I think -- at the time I think you were referring to back when you first started with *Mir*. So the thing I'm struggling with is, you know, are the standards adequate and people are just following them in our case or do we need to revisit the standards and, if so, which ones? Do you have a favorite class? You mentioned GL, DNV, ABS.

A. Yeah. I want to qualify that as specifically around the idea of diving to full ocean depth --

Q. Okay.

A. -- and that particular exotic regime. I think the standards that are in place now -- now I want to say upfront for transparency, I'm a minor equity owner in Triton. So I know -- I've known [redacted] for 25 years. I'm a very small -- I think I've got like 5 percent of the company, something like that. So I'm very familiar with their operations, their standards, their safety manuals and all that sort of thing, and I've reviewed everything with them.

I think the actual standards that are applied to exploration vehicles in the less than 6,000 meter depth, right -- so you're talking 97 percent of the ocean floor and obviously all the tourist subs, I think the safety standards are very high both in terms of construction, classing, and operationally. And speaking for -- as a representative of Triton, there have been no incidents that required external assistance. And we never had an incident that required external assistance with the *Mir* program or with our own *Deep Rover* program or with our *Deepsea Challenger* program.

I think the standards are good. I think there's nobody really enforcing the standards, I think may be an issue. I mean, Triton knows that its ability to operate commercially is based on its safety record, which is 100 percent right now. It can't fall below 100 percent. It's just not allowable. So it's a mentality.

What I was talking about with respect to *Deepsea Challenger* was that, you know, some of the ways that things were done we felt that the specific challenge of what we were doing, the specific mass constraints that we had and the specific operational challenge of a solo operation, that we needed to go beyond. We had to have a mentality of going beyond. Okay. That's what everybody -- that's worked for everybody else, we want to go beyond. That was just a, a kind of a mantra.

Q. Okay. How about for the surface tender or the mothership? Is there -- the standards you mentioned like they should have ROVs, what -- I know what you're looking for, but there's no requirements that I know of. I think the British have some for their flag ships, but that's about it. Is there something, is there -- are those standards adequate?

A. Well, I've never -- I mean, look, I always find that the ABS standards when I've been on various ships and we're brought in and we're given the safety brief and the lifeboat drills and the fire drills and all that, I've always found that to be adequate, but I'm definitely not an expert in that. And, you know, I've never been involved in having paying passengers going on any of our deep submergence vehicles. So this is an area where if you haven't talked to [redacted], I strongly recommend it. He's the -- he has designed more subs and, by a factor of at least 10, more humans have spent time in his subs than any other provider. He reckons that somewhere around 1.2 million human submerged hours in his vehicles. Now that includes your kind of 40-place, big, you know, 100-foot depth tourist buses, which is, you know, probably the larger part of that number.

Q. Sure. Sure.

A. But that's still an impressive figure, with 100 percent safety, no injuries or casualties. So I would strongly recommend -- he can talk about classing and operational safety standards and engineering safety standards a lot more than I can.

Q. Okay. How about safety management systems? So some of those vessels you're using have -- are required to have safety management systems, others don't, like the research vessels, so --

A. Right.

Q. Did you merge your safety system with theirs or were they just -- the ship's crew just a separate entity, just, you know, hands on deck helping you?

A. I think there was a -- if you think of it as a Venn diagram, you know, there was definitely an intersection set where we had to work together to create safe operating protocols. So I brought to that and other members of my team brought to that their experience working on different ships, some dedicated, some ships of opportunity. And this particular ship, the *Mermaid Sapphire*, had no prior experience with a human-occupied vehicle, plenty of experience with a remotely operated vehicle. So they -- so we had to create a set of operational procedures that everybody was comfortable with.

Q. Okay.

A. And of course, we have to defer to the captain always, you know, as the master. And if the captain ever saw anything he felt was unsafe on his ship, we deferred to that. So we came to it by consensus, I would say. On a dedicated ship like when I was working with the Russians, that was just -- it was a work of art to behold how they did it.

Q. Okay.

A. And so, you know, and that -- but they had worked together as a group for 20 years, same ship, same submersibles, same handling system. So, you know, there was an awful lot to be learned there.

Q. Okay. Well, thank you for that. And my last question -- I've asked this of everybody without -- it's a different topic really. Do you know where [redacted] carbon-fiber submarine is?

A. [redacted] deep sub, the --

Q. He started building --

A. Are you asking where --

Q. -- a carbon fiber. Nobody seems to know where it is.

A. I don't know, I don't know where it is. I mean, it was -- there was a time when we were sort of in a friendly competition to get to the Challenger Deep first with -- [redacted] was dead by that point and it was now being funded by [redacted] and run by another guy. I never liked the [redacted] sub. I told [redacted] he was going to die in it if he dove it to the Challenger Deep. I told the -- I'm going up on his name right now -- the fellow that was going to dive it. I said it's a wound carbon-fiber cylinder, it's not going to work.

Now I never talked to Stockton Rush about that. He never asked me. I knew him socially, but I never got into the details. But I never liked the wound carbon-fiber concept. It's an amazing material for aerospace; in compression, bad idea.

Q. No, no, our understanding is (indiscernible) --

A. I'm sure going to -- you'll --

Q. -- originally, but --

A. -- you'll come to your conclusions around that, but we -- I mean, there's a, you know, group of people in the deep submergence community that sort of knew when they heard the news what had happened.

MR. [redacted] Okay. All right. Well, thank you for your time, sir. I appreciate that.

MR. [redacted] Yeah. Thanks for your question.

MR. [redacted] [redacted]

MR. [redacted] Yes, sir.

BY MR. [redacted]

Q. Thanks again, Mr. [redacted] I just had a couple follow-up questions. I'd like to know more about that *Mir* operation. I haven't -- don't know, you know, a lot of details, but first -- what was the occupancy of that -- of those submersibles in that time?

A. I'm sorry. The speed?

Q. Oh, I'm sorry, the max human occupancy? Was it up to (indiscernible) --

A. Oh, sorry. Three people. Right? So the typical -- I first worked with the *Mir* team in '95 and then subsequently in 2001, and then in 2005 -- sorry, 2003 and 2005. We had programs in each one of those years. And I think you weren't on the call yet, but I've made over 50 dives in that vehicle.

When we first came to it, their standard operational procedure was they had a pilot and an engineer and an observer, typically a scientist, marine biologist or marine geologist. We convinced them to go with two observers, and then that became their standard operating procedure after that. And I convinced them to do that by taking over certain of the engineer's duties around ballast control and sonar navigation just because it seemed like a fun thing to do. And they were fine. I mean, the Russians were simultaneously incredibly disciplined and also flexible thinkers. So we found them actually very easy to work with and we approached engineering problems together.

So they had a dedicated ship called the *Akademik Mstislav Keldysh*, is actually the name of the ship. And it was about 420 feet overall. It had -- it operated the subs out of the starboard side. It was a dedicated hangar bay, two large clamshell hangars that opened like that. There was a central crane that could pivot and pick up *Mir 2*, pivot the other way and pick up *Mir 1*. It was a snubbing system where they pull it up into a capture mechanism. They'd turn the sub outboard, and then they -- there was a rack and pinion or like a crown gear that would rotate it and put the sub in the water in the right configuration. So it was an excellent system. And then it released at the surface of the water. So you weren't hanging, you know, pendulously on a cable the way you would be even with an A frame.

Everybody thinks the A frame is best, but it's not. Any kind of a snubbing system is much better. Which is not to say that it's not still challenging getting the sub back into that system when you're at a high sea state. I think the highest sea state I saw them recover in was 20 feet. That's no fun. Made a nice shot in the film, but it was no fun.

Once again, they were -- this was operating back in the mid '90s, so the weather forecasting wasn't as good then as it is now. There's no excuse to get into that kind of sea state now. You just don't go. You just don't launch if you see a front or winds or whatever. There's really no excuse for any kind of accident now. I mean, we -- collectively, the community knows enough. And the community knew that OceanGate were breaking a lot of rules.

You know, I'd just like to contextualize something. I described the *Deepsea Challenger* as an experimental vehicle, which it is. Where we didn't play fast and loose with innovation was that pressure hull. That pressure hull was tried and true old school technology. We used all the existing literature to, you know, set our safety -- decide on our material, design it, inputs to the FEA. And, you know, the end result and the whole testing regime were all entirely conventional, which is why were able to class the sphere. There are a lot of radical things about the configuration of the sub and a lot of the outboard systems, but none of those were really life threatening. They would only have impacted our operational capability and required us to abort the dive and make repairs. So we were really conventional when it came to the pressure boundary and we were -- we let all of our innovation be in other areas.

Q. Yes, sir. Do you happen to remember was the vessel that you mentioned, the (indiscernible) the vessel, is that Russian flagged? Do you know?

A. Is it Russian flagged? I believe it is, yeah. It's owned by -- I think it's not even being used for submersible operations anymore. They're using it, I think, in oil and gas. I've sort of lost track of it. But it was -- I'm pretty sure it was Russian flagged, yeah. It was owned by the Russian Academy of Sciences. I think at one point it was a spy ship, honestly, before it was converted to submersible operations. Because there was a big electronics bay down on deck 2 that we took over and turned into a TV station. It had a lot of old stuff in it that we couldn't even figure out what it was. That's pretty common knowledge. I don't think I'm spilling any beans here.

Q. Do you happen to know if those submersibles ever operated independently of the vessel or were they kind of part of the vessel itself?

A. It did. In the subs later years, the Academy of Sciences had to -- they basically ran out of money. So the *Mir* team transshipped and they took the subs by truck to Lake Baikal and they dived them off a barge in Lake Baikal for a couple of years, which is a really interesting science subject, but they never went to sea again after that. So that's the only time I know of that those subs were not operated from the *Keldysh*. Because that whole thing was conceived as one integrated system.

Q. Yes. I was just curious if those submersibles were independently registered or flagged. You probably wouldn't remember that part.

A. I think that there was a discussion at one point about us chartering the subs on a long-term charter from the Academy of Sciences and putting them on a different ship and training up an international crew or a US-based crew to operate the *Mir*s. That sounded like it would have been possible to do, at least in the climate at that time, and this is going back 15 years or so. We just never did it. We were never able to get the funding to do that.

Q. Okay. Thank you. I think you already mentioned it, but all the times you were down, you know, on the *Mir*s, on your *Deepsea Challenger*, you never had a near miss even during like recovery operations or, you know, aloft in the (indiscernible) system even in a sea state potentially? I'm just trying to --

A. Yeah. Sure. So in terms of safety, we did a lot of operations around hydrothermal vents and we did a lot of operations around deep ship wrecks, including the *Bismarck* at 16,000 feet, *Titanic* at 12,500 feet. And you obviously have a lot of fouling hazards. I found that having two submersibles on station at the same time was a great comfort and a great redundancy. We never actually had an entrapment where we had to have the other submersible intervene. I recall having one scenario where we weren't sure if we were stuck or not and the other sub came over, took a look, and said, no, you're fine, just do this. That was a big help, you know, when you're 12,000 feet down.

I strongly recommend two vehicle systems where that's possible. Most people can't afford it. It was standard for the Russians. If I were going to develop a human-occupied vehicle system from scratch for myself to use, two subs.

Q. Yes, sir.

A. Then your rescue capability is innately right there.

Q. Yeah. Yes, sir. That's kind of why I asked the question. I appreciate the -- you know, recalling that, at least where you thought it might have been entrapment. It sounds like --

A. Yeah.

Q. -- because you thought it (indiscernible) --

A. I would think the descending of order of desirability would be, the highest sort of Cadillac level is you've got two equally capable subs. They're either on station at the same time or one has had to go back early, and then your worst-case scenario is you're trapped for the length of time it takes them to recharge and come back down, which is not a big problem. Right?

Your next tier is you've got a human-occupied vehicle and a remotely operated vehicle operating from the same ship at the same time and if you need eyes on or you need some kind of assistance, the ROV can be deployed. I think your third tier, which would be the absolute minimum I would go with in the future is you've got your human-occupied vehicle and you've got an observer ROV, which can be quite a bit smaller, maybe a spooling fiber vehicle that can just be sent down to assess the situation and make recommendations and call for external assistance if necessary. I would not go below that tertiary level in the future personally.

Q. Yes, sir. Excellent. I only have a couple more questions. One thing I was wondering is during all your excursions to the [redacted] to the *Titanic*, was it always -- or even a thermal vent, was it always that case that you would charter the entire submersible? Was there ever a situation where you have other passengers or other I guess in this case observers who were paying separately?

A. Yeah. In my first expedition we chartered the whole *Mir* operations, the *Keldysh* and everything, we did it ourselves directly. Subsequently -- and then after that, a gentleman that I had mentioned before you joined the call named [redacted] out of Australia, he did a long-term charter agreement with the Academy of Sciences and he ran tourist dives to *Titanic* and hydrothermal vents very successfully for a number of years. He and I were friends. We ultimately went in as partners on the *Deep Rover 2* submersible system and bought them, although I never was involved with any tourist dives on those. He did that himself.

But at that point it became more convenient for me for my subsequent building operations at *Titanic* and at the hydrothermal vents to essentially sub-charter from him. So he had the primary relationship and then I would just buy time from him. Whenever I was using the system, which might be for 4 weeks, 6 weeks, something like that, I would have members of my team diving in the subs. They were technically not paying tourists. They were basically paid employees of the film who were along because they were historical experts or they were marine forensic experts on the wreck site. Or in one case we had a marine biologist who was studying the rustical formations or we even had some jet propulsion laboratory people who came to run a laser spectrometer in the hydrothermal fields as part of a search for life kind of, you know, Earth analog program. We had astronauts. We had -- I mean, and not as a gimmick. I mean, we were doing a NASA -- a joint project with NASA for Earth analog studies of, you know, essentially human factors in -- you know, so they were all sanctioned science observers essentially. I never messed with paid tourists. But my colleague that I kind of subleased from, he did that very successfully for a number of years and completely safely.

Q. And just to clarify, sir, was that the *Mir* subs or was that other platforms with the tourists?

A. Both the *Mir* subs and the *Deep Rover* platform. Because he would -- when I wasn't using it for filming, he'd operate it for his tourist operations.

Q. Thank you. I appreciate the answers and the time on that.

MR. [redacted] All right. Mr. [redacted] any further questions from your side?

LCDR [redacted] I do have a few more, sir, if you can bear with us for just a little bit longer.

MR. [redacted] Yeah. No problem.

BY LCDR [redacted]

Q. I kind of wanted to do some questions specific -- first -- I want to get to some OceanGate specific questions. I know that you had already stated and your representative had basically told me, you know, you didn't really -- you didn't know Stockton Rush well and you didn't deal much with OceanGate. But before I get into that, I want to talk really quickly about maintenance of your submersible in storage. Obviously you've talked about safety and you being the sole occupant of the *Deepsea Challenger*. You want -- everything's about safety. How did you handle it? How did you store it? How did you move it around the US? How did you get it to where you needed to get it? Like talk to me about those types of logistics.

A. Well, curiously enough, the sub was being moved by a truck once and the brakes on the truck trailer caught fire and then burned the sub, burned part of outer ferry of the sub. So we had to repair the sub thanks to a failure of, you know, some trucking company to have good brake maintenance. No, you know, the sub would be trucked around as needed. We didn't -- we never flew it anywhere. Or it would be moved on a ship as freight.

In terms of maintenance, there was a whole DMOB on a protocol. We had to take the batteries out. We had to safe the whole battery system. We had to open it up so that all of our corrosion inspections could be done, done with a borescope and so on. There were different levels of disassembly that you'd want to do to inspect it. Not necessarily go for -- because, you know, we weren't in class so we couldn't really get out of class and we only dove it for the one series of dives. But even to preserve future capability, we basically did a, pretty much a full disassembly and inspected everything more as sort of a post-mission analysis, you know, to look at how the -- if the penetrators were showing any signs of corrosion; they weren't, fortunately. If the hull was, if the hatch was, etc. We took the whole thing apart, every nut and bolt, at Woods Hole with their engineering team and my engineering team working together for about a week. Took it all apart, put it all back together. And that was more in the nature of a technology transfer. However, if we had intended to dive the sub again and/or go for classification on that experimental vehicle, we would have done pretty much the same thing in any case.

And I would recommend a full disassembly of any experimental vehicle after an operation, after any -- you know, if you're at sea for a month or 2 months or something like that, there should be definitely certain inspection points. At the very least, you'd have a protocol where you take out the viewport and you inspect the seat and then you reinstall it. You'd have a kind of a maintenance protocol like you would on an aircraft, like on a helicopter, you know, mean time to failure, number of cycles, all of those things for every part on board.

And we basically had that in the abstract. We just never got to the point where we were going to go operational again. That hasn't happened yet. And I say yet because we might still put that thing back in the water someday. But right now I've got a year and a half of finishing *Avatar 3* ahead of me, so it's not going to happen in the next year and a half.

Q. I understand, sir. And I'm going to guess this is needless to say, but storage of the vehicle should be in an environmentally controlled or -- in an environmentally controlled location?

A. Absolutely. Yeah, yeah. Look, I know where you're going with this because they left the thing outside in Newfoundland for the winter. And I think that that might have been a contributing factor to failure. I mean, it's my strong hypothesis that water ingress at a molecular level invaded and followed the fibers of the carbon fiber. It's very hard to imagine what's happening with water molecules at that kind of pressure, but they can go anywhere. And I believe that they migrated along the pathways of the fibers and created a delamination problem. And if there was water ingress from a previous season of diving and the sub was left outside in subfreezing temperatures and that water was able to expand, that could have created additional delamination. I mean, rocks weather because of water in the rocks freezing and they break. You know, if you can break rocks, you can break a pressure hull. So that may have been a factor.

I think the other places you guys should be looking is at the end mating seat between the raw end of the carbon-fiber cylinder and the titanium end flange. Because that's -- they just basically glued it on, and that's not how pressure seals work. And they also did like a Rhino coat around the outside of the entire cylinder, which is -- that's great for your pickup truck bed, not so good for a pressure hull. To me, that's right where I would go.

I don't mean to say too much here, but when I heard -- I went and pulled the emails from the morning -- it was actually the morning after the incident because I had been at sea the entire previous day and so I first heard about it at around 9 a.m. the Monday morning. And the first thing I heard was that they had lost comms and tracking. It's like, oh, they imploded. I literally, that -- okay, they imploded. Just because you don't lose comms and tracking at the same time. They're independent systems and the only way to lose them both is to have a catastrophic failure. So, you know -- and it took me two phone calls to confirm that they Navy heard a bang at that location. So it's like, okay. So I just sent out an email blast to all my tight circle of people and said we've lost our friends, hoist a glass tonight in their honor. That was on Monday. It was Monday at 9:30 a.m. So to me there was never a doubt that it was sitting in pieces at the last known position, which is why I strongly advocate for having an ROV available like at the ship.

Q. Yes, sir.

A. Or nearby at the worst-case scenario, you know --

Q. Yes, sir.

A. -- to either assist or confirm.

Q. Appreciate that. Just a few more questions. So just to kind of -- obviously the reason why we're here is kind of just as part of the investigation for OceanGate and *Titan*. Did you ever have any interactions with Stockton Rush with regards to the *Titan* submersible?

A. He invited me to come out and make a dive and which I declined. Two reasons: one, I was too busy; and two, I didn't like the design.

Q. What didn't you like about the design?

A. I don't like cylinders. I like spheres. Cylinders can be used down to a certain depth, but not a depth class -- or like the 4,000 meter depth class, I would say. Just in general, it's a bad idea. Specifically, I didn't like the carbon fiber. I had already -- I knew very well the design specs for [redacted] submersible, which I think he called -- I can't remember what he called -- *Deep Flight 2*, I think it was, *Deep Flight 2*. And, you know, it had an end flange and it had a sapphire dome and it had a carbon-fiber cylinder and a titanium hemispherical end cap on the other end. So it was basically a big get cap, very much like the *Titan* sub. And I hated the idea of wound carbon fiber as a pressure vessel for extreme depth. I mean, maybe you can get away with it for a couple thousand meters, something like that, but it's just not the right material for the job. It's a non-isotropic material. I'm sure you're hearing this from everybody.

I never specifically told Stockton it was a bad idea. I did specifically tell [redacted] that it was a bad idea and he was going to die if he dove that thing -- and he never did, which I think is interesting -- or he dove it deep. I think ultimately his sub dove to a depth of about 1,000 meters, you know, a couple times. It never really, it never really did what it was supposed to do, which go to 11,000 meters -- or 10,900, which is really about the deepest spot.

I didn't like the dissimilar materials mated, you know, at the place where the cylinder interfaces with the end flange just because your differential bulk modulus, when you start dealing with extreme pressures, they compress at a slightly different value, which introduces shear forces at that place of, you know, maximum interface pressure. You're introducing shear forces, which essentially on a microscopic level creates tension failure, things pull apart. When you start pulling apart a wound carbon-fiber material you start creating a pathway for water ingress. You know, there's just a lot of problems with that concept.

And they did it to save weight, but there are no shortcuts when you're dealing with pressure. You need -- your hull needs to be spherical and it needs to be an isotropic material, whether that's titanium, steel, glass, acrylic, whatever it is. It's an isotropic material so it behaves the way -- it can be predicated in an FEA. Then you test, obviously you test. But you can't predict the behavior of a, you know, a material made up of different things, you know, the bonding epoxy and the carbon fiber and how they interact with each other. You know, if you've got steel, if you've got acrylic, you know the number of cycles that it can withstand safely and it's usually in the hundreds if not thousands. And carbon fiber you have no idea. And you add to that the fact that they didn't have inspection protocols with ultrasound or, you know, some other sort of radiography or any kind of diagnostics operationally, that's just a recipe for disaster.

Q. And you had stated earlier that you had a very good relationship with P.H.

A. P.H., yeah.

Q. Did you ever discuss his interactions with OceanGate and

Mr. Rush?

A. No. I had sort of lost track of what they were doing, to be perfectly honest. I didn't even know until I got the roster of people involved in the incident that P.H. was on board. I knew him from way back in the day from my first expeditions at *Titanic*. And we'd compare notes, and he's the only other person in the world that's piloted a remotely operated vehicle inside the *Titanic* wreck. So we'd get together and we'd look at each other's footage and we'd talk about what we thought was happening inside the wreck, the marine forensics of it. You know, and there was a little bit of a friendly competition because, you know, I think he had 37 *Titanic* dives and I had 33, and so, you know -- but we were pals, you know.

Q. Yeah.

A. Plus he's French, so we'd get together and, you know, drink wine and talk about our adventures. You know, I don't want to say as a matter of public record what I think about P.H. being involved with this. The only thing I'll say is he wasn't an engineer. You know, he believed the assurances. That wasn't his thing. He was a pilot.

Q. Understood. Thank you. I appreciate that.

I was going to ask you earlier how important the modulus is in the submersible, but I think you just covered that there with that one.

A. Dissimilar materials at a mating, at a high-pressure mating seat are not a good idea unless you really know what you're doing. So an acrylic port going into a steel or titanium conic frustum, you've got to understand what's happening at that boundary, at that pressure interface. And we came to understand that very well. We even -- sometimes we'd use a lubricating material so that it could cold flow within the seat in a predicable way. We even did something that was pretty radical that even [redacted] hadn't thought of, which is that we slightly radiused our cone, our acrylic cone so that it actually had about -- I think it was less than a millimeter, maybe a millimeter or two, at the [redacted] it wasn't fully seated at the [redacted] It was only seated on the outside part of cone so that under pressure as it cold flowed, it expanded into the rigid, relatively rigid seat. And that reduced the stress riser that showed up at above 10,000 psi. So we were seeing a stress riser, we were seeing spalling -- not spalling, it was actually a concoidal fracture. We said, well, we can't have a concoidal fracture in our dome plate, that's probably bad form. So I actually figured out the idea that we could gently relieve it by machining the cone and then the cone would seat.

But you've got to get into the dynamic, you got -- I mean, my engineering partner, [redacted], is much better at this than I am, but he can literally think at a molecular level of what's happening. And when you have a differential bulk modulus at a mating seat, you've got to really understand what's going on there. And I don't think they did. And they obviously -- it's a matter of public record that they didn't even believe their own chief engineer and fired him and sued him and, you know, all that crap, so -- you know.

I think what you've got is cultural failure, you know, is not putting safety first, not putting safety as the highest priority. [redacted] You've got to be paranoid about everything that can go wrong. You sit and you think about it and you dream about it and you wake up in the middle of the night thinking about what can go wrong, and then you engineer against it. And you spend years thinking about what can go wrong and then you engineer against it. And then operationally you think about everything that can go wrong and you build your operational protocols. You know, it's the same thing as in aerospace or in space. You know, you never want to be dealing with the thing you predicted. You only want to be dealing with the thing that your imagination couldn't have predicted.

Q. Thank you, sir.

A. And it's just a philosophy. So, you know, I think that, you know, as you talk to people I'm sure you're getting a sense of moral outrage that these guys didn't have that. But it's definitely a failure of culture of that operational group.

Q. Understood. Mr. [redacted] I don't have any further questions.
LCDR [redacted] Mr. [redacted] do you have any further questions?
MR. [redacted] You know, if I might, just one follow-up from your line of questioning.
BY MR. [redacted]
Q. In all of your dives to *Titanic*, did you interact at all with Transport Canada from ship safety point of view?
A. I didn't personally. I'm not sure -- I couldn't say if somebody in my organization did or not. You know, we had to deal -- I mean, we had Coast Guard, we had Canadian -- well, the first time we went out with the Russians in waters that were international but adjacent to Canada and operating out of a Canadian port, we had -- you know we had Orions going around us dropping sonar buoys to keep an eye on what we're doing.
Q. Okay. Yeah.
A. You know, so there was a high level of scrutiny, let me put it that way. No sonar buoys showed up on our second expedition in 2001. In terms of interfacing with the Canadian Safety Board, no. I didn't have any direct communication with them.
MR. [redacted] Okay. Thank you again for your time today.
MR. [redacted] Yeah.
BY LCDR [redacted]
Q. All right. Mr. [redacted] I had one question I forgot to ask. From an egress standpoint, in all the submersibles that you've -- you know, you're familiar, was it always like a single egress

point available?

A. Yes. Every sub I've been involved with, deep sub, has a single egress point. You may have multiple protocols for how to get people safety out of the sub, but it's all about that hatch.

Q. Okay. And then a follow-up to that, sir. Was there ever a situation that you're aware of in any of those submersibles where you would have to have an outside extract, you know, take off the hatch, where you are essentially bolted in or --

A. In my sub, I was bolted in. I could not, I could not get out. But we talked about this for 2 years, about the various scenarios. And ultimately, we came on the side of it being actually safer that way, and to -- you pile your chips in different areas. You can have self-egress, but where does that put you? It puts you with a sub that's now open to the sea and flooding and sinking versus making sure that you have a safe capture environment for the vehicle, either that it's being held at the surface or whatever and a controlled egress. So, you know, there's different schools of thought on that. Because being -- sitting outside the sub with a ham sandwich, sitting on top of a sub that's that big at the top, in an open sea state nowhere near you're other people is also not a very desirable situation, especially if it sinks because you opened the hatch. So, you know, you're faced with some hard choices on an experimental vehicle.

On a tourist sub I think you have to have multiple protocols.

The Russians did. They had -- they could get out of the sub. The sub had very little freeboard. You open the hatch, sub's going to sink. Wave will go in, it'll get negative, and then it'll be a self-propagating reaction. And that happened to *Alvin* back in the '60s before they put a sail on *Alvin* to prevent that from happening in the future. The Russians has an inflatable sail, which is an interesting concept, that would accordion up. So there was a gas feed, I don't know, probably just nitrogen, dry nitrogen in a bottle, and it would inflate and it would sit about a meter because the sub had very low freeboard. And so then they could actually egress on their own and get outside the sub.

With the *Deep Rover 2*, the way it worked, because it functioned like an air bell, the hatch swung down. So the air captured in it, the sub stayed, the hatch swung down. Because [redacted] said, if we have a low freeboard vehicle and you open the hatch at the surface and the water can ship in, you're going negative and you're going to lose the vehicle and you might not get everybody out. So he said, I'm going to do the reverse. And this was actually embraced for a while as a concept in the submersible design community. But now you're opening -- you have to equalize pressure, it's about 7 -- 6 or 7 psi, and then you can open the hatch and it'll drop open.

We did a lot of safety training around how to do that. We always had a -- we always contemplated having a support diver there, but you could have done it on your own if you had to. You could even theoretically do it if you were grounded on the [redacted] in less than, you know, 100 feet of water. You could theoretically get out of the vehicle on the [redacted] That was abandoned by the community and everybody went to top hatch scenarios. And that's kind of where it sits today, that you get out the top.

Q. Okay.

A. And I wasn't involved in any of those analyses in that egress space. We had our own egress protocols for the *Deepsea Challenger* if we couldn't recover it. Because that was -- that would've been a bad day. If you can't get the sub out of the water and the egress point is submerged, how do you get out? Well, we had a protocol for that, but it required support divers.

Q. Okay. Thank you, sir. I appreciate those explanations. And then did you ever see a hatch that was not a top hatch, like the *Titan* design, where it was front dome that --

A. *Titan* was basically kind of a clamshell design. There were a couple of subs historically where the entire -- they would -- two hemispheres would part and be mated before the dive. And I actually think that the original *Deep Rover 1* worked that way, and there are some other subs that work that way. I think the *Deep Worker* sub basically is a cylinder with a dome on top, an acrylic dome on top that opens that functions as a hatch for a single occupant vehicle. So that's not that uncommon an idea. That's even an idea that I explored for the *Deepsea Challenger* at one point, which is that your joining of your two halves of your pressure vessel is also your hatch seat essentially. In any kind of hatch, whatever it is, if it's a high pressure mating seat, which it is, you have to inspect very carefully because even the finest piece of grit causes a slight separation in that immediate region between and you need -- it's a steel-to-steel seat. I'm sure you've had this explained. But there's an O-ring seal that does virtually nothing below 30 or 40 feet. Once external pressure has seated the hatch, once you've started your dive, that O-ring is irrelevant. That O-ring only really works in the top few feet of water before the pressure is really acted. After that, it's a steel-to-steel or whatever your material is seat that's driven by pressure. So you ask the ocean's pressure to work to keep the water out, and that's how all these ideas work.

So the idea that you could do it at that scale, I guess it's probably, what, a 2-meter diameter interface? It's -- you know, it wouldn't be my first choice, let me put it that way. Because now you've got a much larger mating seat that you have to carefully inspect and make sure it's joined and aligned properly and all that. It wouldn't daunt me as an engineering problem if you decided to do it that way. And I don't think that that's where their failure mode lay at all. I also don't think it was the acrylic port. I think the acrylic port just got knocked out by the internal in-rush of water at hypersonic speed, just blew it out the front, broke all the retaining bolts. That's my hypothesis, because I know it came up without it. And at first it was like, oh, might have been the port. But I don't think it was the port. But you guys will suss that all out. I look forward to reading the report. Let me put it that way.

LCDR [redacted] Sir, no, thank you very much. That is the last question I had. I really appreciate your time.

MR. [redacted] Yeah.

LCDR [redacted] I look -- we look forward to providing a report to the people and, obviously, after we move forward with our marine board hearing, which will hopefully be soon, so --

MR. [redacted] Okay.

LCDR [redacted] But, Mr. [redacted] I want to thank you for your time. Thank you for allowing us to speak to you and kind of run through your history and all your expertise. We greatly appreciate it. If there's anything else that comes up that you can think about or something that comes to light that maybe you wanted to touch on, I've been in contact with [redacted].

MR. [redacted] Yeah. Yeah.

LCDR [redacted] She has my email. And if you need anything, feel free to reach to me and then we can get back in touch.

MR. [redacted] Okay. Yeah, I'll look. I think this has been pretty thorough going, guys. I appreciate it. I would strongly recommend talking to [redacted] if you haven't already. He's far more expert than I am on the day-to-day operations of tourist class vehicles. That's his main business. And he wrote most of the protocols that are currently used by -- you know, are accepted by the community and so on, and he can speak to it nuts and bolts at a level that I can't.

LCDR [redacted] Yeah. I've spoken with [redacted], and we're looking at speaking with him at great length as we move more into the future of the process here. But absolutely.

MR. [redacted] Yeah. Yeah. No, he'd be a great resource.

LCDR [redacted] Thank you, sir. And with that --

MR. [redacted] Thank you, Lieutenant Commander. Thank you, gentlemen. It was great talking to you and I wish you luck in your pursuit of the truth.

LCDR [redacted] Thank you, sir. Good luck.

MR. [redacted] Thanks. All right. Bye now.

LCDR [redacted] Bye.

(Whereupon, the interview was concluded.)

CERTIFICATE

This is to certify that the attached proceeding before the

NATIONAL TRANSPORTATION SAFETY BOARD

IN THE MATTER OF: LOSS OF THE SUBMARINE *TITAN* IN THE NORTH ATLANTIC OCEAN ON JUNE 18, 2023
Interview of [redacted]

ACCIDENT NO.: DCA23FM036

PLACE: via Microsoft Teams

DATE: July 26, 2024

was held according to the record, and that this is the original, complete, true and accurate transcript which has been transcribed to the best of my skill and ability.

[redacted]
Transcriber