Speaker: Commander David T. Leighton

Topic: Naval Nuclear Power Program

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EMCEE: Our speaker tonight is Commander David T. Leighton, United States Navy, he's at the Mare Island Naval Shipyard. Commander Leighton has been the nuclear power superintendent of Mare Island Naval Shipyard since August of 1959, and during the preceding six years he was attached to the Naval Reactors Branch, division of Reactor Development, United States Atomic Energy Commission in the Nuclear Propulsion Division, Navy Bureau of Ships. During this period, he worked on the development and control of electrical systems for the sodium-cooled reactor plant in the USS *Seawolf*. For five years he was project officer for the development of the nuclear propulsion plant for the USS *Triton*. During the final two years of this period, he served also as project officer for the development of the nuclear propulsion plant for the first nuclear powered destroyer-leader, USS *Bainbridge*. My pleasure to introduce Commander Leighton.

Applause.

LEIGHTON: Can you hear me in the back of the room? OK. People in my office say I'm the only one in the office that talks to Washington without using a telephone **(laughter)**. I'm told there are more ladies present here this evening and somebody wondered why, apparently this group just doesn't understand the ways of a Sailor **(laughter).** Anyhow, I for one, am delighted to see the ladies here and I'm sure the rest of you gentlemen aren't **(laughter)**. Let's see if you know any more about Naval nuclear propulsion. I'm going to talk about Naval nuclear propulsion tonight, but before I start, I'd like to get some idea of what this audience already knows about it. Now, I'm gonna ask a few questions, and I'm gonna ask the ringers not to answer them because we got a number of people here from Mare Island tonight who know all about it. I see a couple people here who used to work in Admiral Rickover's group in Washington, and they know more about this than I do I think, so it's not fair for the ringers to answer the questions. But let me ask some of you people that have not been associated with the Naval Nuclear Reactor Program a few questions.

To get some idea of where we stand today. How many nuclear powered submarines has the United States Navy operated at sea to-date? Now would someone like to answer that who has not directly associated with this program, just to get an idea of what you know about this.

AUDIENCE: Six, murmuring, fifteen.

LEIGHTON: Six. Now how many of you would say. Let me ask it this way, how many here would say it's more than six? Well, then that means a lot of you say it's less than six, or it is six.

When the *Roosevelt* went to sea last month, and I assume some of you may have known that from your local newspapers, when *Roosevelt* went to sea from Mare Island, last month, she was the fifteenth nuclear powered submarine to go to sea. Within another month there will be, we hope, at least a couple more.

How many types of nuclear powered submarines has the United States Navy built?

AUDIENCE: Fifteen (laughter).

LEIGHTON: That sounds like a, that sounds like a former submariner because **(laughter)** it just so happens I don't think all during World War Two the United States Navy built two submarines identically the same **(laughter)**. But, there are four basic types of nuclear submarines that have been built to-date. Attack submarines, the predominant number, the attack submarine is a submarine which fires torpedoes. There are actually four different types of attack submarines that have been built. But basically we call the group, the lot of them, attack submarines. These are ones that fire torpedoes, these are ships that are built to fire at other ships. These are submarines or surface ships. The, another type that has been built is a missile submarine which can fire regular-size missiles. There is only one nuclear submarine of this category and will only be one. There, another type is a radar-picket submarine, there is only one of these, the *Triton*, and the chances are there will not be anymore, although this hasn't been finally determined. And the fourth type that has been built is of course the Polaris missile launching submarine, the *Roosevelt* falls in to that category, the *Theodore Roosevelt*. Now I'll say that to those that are Republicans and Democrats can divide up **(laughter)**. In any case it's the *Teddy Roosevelt*.

AUDIENCE: Murmuring and laughter.

LEGIHTON: How many ships builders are building nuclear submarines in this country today, what is the scope of this program in the country today and how many of these builders are located on the Pacific coast? Now who'd like to take a whack and the number of builders altogether?

AUDIENCE: Two, three, five, seven.

LEIGHTON: Well, I hear a wide, a wide run down. There are six nuclear boat builders, the most predominant one of course is the Electric Boat Division of the General Dynamics Corporation in Groton, Connecticut has built the largest number. The other yards which have built submarines which have operated at sea are the Portsmouth Naval Shipyard, which is a government installation, the Newport News Shipbuilding and Dry-dock Company at Newport News, Virginia, and the Mare Island Naval Shipyard which is the only west coast yard that has built a nuclear powered ship. The other yards that are building nuclear powered submarines are the New York Shipbuilding Corporation in Camden, New Jersey and the Ingalls Shipbuilding Corporation in Pascagoula, Mississippi. Did I get the six? Should have. I think I got six, now that's submarines only. The other yard that's building nuclear powered ships - suddenly I've got a Bethlehem representative in the crowd. The other yard that's building nuclear powered ships for the Navy is the Bethlehem Shipbuilding division of Bethlehem Steel Company at their Quincy yard in Massachusetts. They are building the first guided missile cruiser that is nuclear powered, and the first guided missile destroyer leader that is nuclear powered. By the way, in case any of you want to take notes, don't bother on this because I've got a handout that will be on the back table when you leave that lists all of the nuclear powered ships authorized by Congress to-date. And the yards that they're being built in. I got one more question in this regard, how many nuclear submarines have been authorized by the United States Congress to-date?

AUDIENCE: Thirty-five (murmuring).

LEIGHTON: Wow, pretty close on this one, forty-three that have been authorized by Congress to-date. Just to give you an idea on how that stands relative to the overall Navy, there are approximately one hundred conventional-type submarines on active duty in the United States Navy. Now you can see that as far as authorization is concerned, we're well on the road to converting the submarine service to nuclear propulsion and within a few years, within three years, all of those authorized to-date should have been completed. Now tonight I would like to point out some of the highlights in the development of Naval nuclear propulsion which may be of interest to you, and explain to you some of the problems we've had, and some of the lessons that we've learned. Now I will be glad to entertain questions as we go along because if you've got questions in your mind that indicates what you're interested in, and I'd much rather talk about what you're interested in than what may be here. So, please, I'll be very happy to answer questions, particularly if you feel they may be of general interest to the group. Within of course…

Audience member asks a question.

LEIGHTON: Pardon? **(repeats question)** How many types of reactors is the question that we've had here. I'll tell you what I'll try and do. I'll try and answer these questions in a direction that would have been some of the information covered here anyhow. The beginning of the Naval Nuclear Propulsion development saw the road being taken down two paths, pressurized water as a coolant for the reactor, and sodium. Now an evaluation of all the possible coolants for a reactor in the days following World War Two, led all the technical people concerned to propose that these two coolants offered the earliest opportunity for rapid development. Nobody knew of course whether either one would work. Following the close of World War Two it was obvious that you could build a reactor as far as the physics is concerned, but nobody knew if you could take this and put it in a weight and space and have the reliability necessary to produce power for running a ship. Now Admiral Rickover, as you all know, went down to Oak Ridge in '46 to '48 and he succeeded while he was there in convincing the people back in Washington that we should one- have a nuclear propulsion project, and two- that it should be on a submarine. Now I'll come back to reading for a submarine a little later. He succeeded in getting the Daniels Pile power pile group in Oak Ridge to work on pressurized water for submarines in lieu of the gas cooled reactors that were working for central station plants. Now, and if you know Admiral Rickover, realize that you don't just walk in and get people to change their minds, but he's pretty good at it **(laughter)**. This group, this group did change their mind and instead of working on a gas cooled reactor, ended up working on a design, conceptual design, of a pressurized water plant for naval application. Also at this period, the General Electric Company at Schenectady, New York already had contracts with the Bureau of Ships for investigation of sodium as a possible coolant for a reactor cycle and they were working on this along, the thinking of that time was along the development for a destroyer plant. Furthermore, the General Electric Company at the Knolls Atomic Power Laboratory had investigative contracts with the U. S. Atomic Energy Commission for the development of a sodium cooled power breeder type reactor. One that produces power and one that breeds fuel at the same time. So General Electric had already chosen the path of sodium as a possible reactor coolant. Admiral Rickover in his own inimitable fashion succeeded in one- getting the Atomic Energy Commission to accept as a secondary project at the Knolls Atomic Power Laboratory the development of a sodium cooled reactor for a submarine, and then by his own persuasive personality persuaded the US Atomic Energy Commission to drop the power breeder project and establish the submarine project as its primary project for that laboratory. I think that he was right. I want to make it very clear that Admiral Rickover is very persuasive, but he also has a habit of being quite right on important decisions, and I think history has shown that there is not any great advantage today in building a sodium cooled power breeder reactor, but there was a great advantage in developing a sodium cooled submarine reactor in the years, in the early '50s. Since at that time we needed nuclear power for the Navy and there was no assurance that either project would work. The, these were the two cycles that were picked out to start with. Many other cycles since that time have been looked at. We have looked at high temperature gas, liquid lead, lithium seven, fused salts, organics; if it'll flow and it won't absorb too many neutrons, it's been looked at as far as reactor design is concerned. People talk about pebble bed reactors, all sorts of things. But, in looking over the last decade and a half, and evaluating all of the cycles for naval nuclear propulsion, the one cycle that stands out, that has the most advantages for the Navy, for naval applications for a ship, one cycle that stands out is pressurized water. And today we are using all water cooled reactors and of all the cycles that have been suggested to-date, this is the only one that the Navy is currently developing.

Now you say, how many types of reactors. It's like asking a physicist how many kinds of cars do we have because they'll say that a 1901, or a 1905 Ford, or whatever Ford, when did they start? Anyhow, it's the same as a 1960 Cadillac because after all it has an internal combustion engine and it's somewhat the same when you talk about pressurized water reactors. There are many different pressurized water reactors and we are continually improving them. But they are pressurized water. Some people say, well they're all the same type. They're not all the same type, each one is different than the last one, it has improved features in it, but the Navy and the AEC and the Naval Nuclear Propulsion Program are trying to develop as much as possible, pressurized water reactor technology for naval propulsion. I'll say a little more later about some of the advantages of pressurized water to the Navy. One should be obvious, every reactor plant, every reactor cycle has a lot of auxiliary systems. There is one very nice auxiliary system in a pressurized water plant. That is, it uses water and you can make your own coolant. This should not be overlooked. If you have any reason why you want to dump the coolant, you can make some more. For a ship at sea, this is a very valuable thing since we normally make water aboard ship. And if we use up the water, we can make more. This is one very important reason why water is of real advantage to the Navy for their reactor plant. There are many more reasons.

Now, the development then started with, started with both of these approaches going on simultaneously, the sodium cooled reactor, actually the sodium cooled work was started before the pressurized water was. In order to carry this out, carry this development on, Oak Ridge started the conceptual design, then it was transferred to Argonne. Argonne developed the design further - and at this point Admiral Rickover being in both the Atomic Energy Commission, and in the Navy Bureau of ships - when the Atomic Energy Commission passed, got the AEC to authorize the fission uranium submarine project, and also got the Atomic Energy Commission to let a contract with the Westinghouse Electric Corporation, for the development of the reactor plant which eventually ended up in the *Nautilus*. Now at this point in history, this plant was not designated for the *Nautilus* and clear up in to 1950, it was not known which of these plants would go in to the first nuclear submarine. The first nuclear submarine, if you look back in the authorizing legislation, was appropriated for in order to have a nuclear powered submarine, there was no designation of what reactor would go in to it. The second nuclear submarine the same way, and even though both of these submarines were authorized, there was no commitment as to which reactor was going into which submarine. The two projects were both going along and both submarines were being developed. But there was no commitment to which plant was for which submarine when they were first authorized. As a matter of fact, there were a lot of people in 1950 who were very knowledgeable in this program who felt that the first one would be sodium, and there were a lot of people in those days that thought that would be a better plant. Today I don't think too many people feel that way.

The Bettis Plant of the Atomic Energy Commission was created for the purpose of developing the pressurized water reactor, Westinghouse staffed it, it was built on an airfield near Pittsburgh, Pennsylvania and the laboratory was built from the ground up for the purposes of developing the *Nautilus* plant. The, I think all of you know the history, in 1953 the first and last prototype of the *Nautilus* plant went in to operation in Arco, Idaho. Perhaps you don't know that clear back in 1953 the reactor design for the *Skate* class was already started and clear back in 1951, two years before, or, at this point a year and a half before the operation of the land prototype of the *Nautilus*, the beginning of the *Triton* project took place. Namely looking for an improved reactor design, looking for something going beyond either the sodium plant, or the pressurized water plant. And in those years, a tremendous amount of effort went in to investigating all kinds of coolant cycles. That's what my answer to your question, "How many kinds of reactors" is.

Virtually every kind of reactor was looked at, conceptual design, cartoon studies, whatever you want to call them, were made to determine the feasibility of the different coolants for naval reactors. The Knolls Atomic Power Laboratory which is one of the major laboratories today working with the Naval Nuclear Power Program, just as a matter of interest, was created at the end of World War Two under a contract between the Atomic Energy Commission and the General Electric Company. General Electric took over the operations of the Hanford Works from DuPont and part of their price for taking it over, or part of their reward for taking it over was the dollar a year for operating Hanford, plus the establishment of a research laboratory in atomic energy in Schenectady and the Knolls Atomic Power Laboratory was built by the Atomic Energy Commission, it is an Atomic Energy Commission laboratory, and then operated under contract by General Electric Company and this put GE, gives GE a place to do research work in atomic energy. It did start out with its major project being the power breeder and was then changed to submarine work. Today the Knolls Atomic Power Laboratory works full time on naval nuclear propulsion development, so does Bettis. Both of these plants. Bettis works in addition of course on the Shippingport plant which was the first central station nuclear power plant in this country. But that was a special project assigned to Admiral Rickover in order to get a central station plant into operation at the earliest possible time. Now, in the early days of this work, there were some problems that might be of interest to this group. In the development of the pressurized water plant, there were some very knotty metal problems. The first thing needed was a core structural material. Now, you had fission so you had to pick a fuel. It wasn't hard to pick a fuel, as we only had one, you had to pick uranium, and uranium 235 is what you needed. Now uranium 235 is very nice for fissioning, but from any other aspect in terms of structural application, it's a terrible material. It's pyrophoric, it burns in air, you can't machine it too readily, all the chips would come off and you would have a nice fire on your hands, you have to be very careful in how you handle it. It has no structural strength, it's heavy and that's about all you can say for it. It's a very nasty material to work with, when it comes to building a core.

Now, we need, for naval application, not just, well other people talk about a football or a baseball of uranium. I read these articles all the time, well, they just throw another tennis ball of uranium and run around the world a couple more times **(laughter)**. You just don't do that. We've got to have something that'll stand up, not just that you can put together and look at it, it's got to stand up, not only under the terrific radiation conditions of a high neutron power level, but it's got to stand up under high impact shock and vibration. We're gonna run this thing around in a ship. Furthermore, somebody someday might take a shot at it, and long about the time somebody drops a depth charge right next door, there's no time for the core to fall apart. So, you've got to have metals that will hold this thing together. Well, here was a very knotty problem, what to use for a structural material. Now, you can't just go pick any old thing as a structural material, you're in a new game now. You're in a radiation business. You got high neutron levels, and who knows what happens under radiation. I mean, who in 1946 knew what would happen under radiation? In 1948 you had some experience with the plutonium producing piles, but very little experience in terms of structural metals for building a reactor core. You need something not only that's strong, but you gotta have something that doesn't have a high neutron cross-section, something that won't take all the neutrons and stop the reaction from proceeding. You need something in the case here where you're gonna use water at fairly high temperature, at least it's high temperature as far as reactors were concerned at that time, not high temperatures as far as what we know today in a modern steam plant. But, high temperatures compared to the Hanford piles which run their water practically at ambient temperature, these were high temperatures in a reactor and you need a material that is corrosion resistant under these circumstances.

Well, I read with interest that a couple years ago in building your new headquarters in Metals Park in Ohio, that one of the materials that was used was zirconium and I think it's true that there is more zirconium in that building than existed in the whole country in 1948 when Admiral Rickover decided to use zirconium as the basic structural material for the *Nautilus* project. This was not an easy decision to make, and here you have a few pounds available, and you needed tons to build one reactor. Well, that's an interesting metallurgy story, we don't have time to go in to it here, but the whole story of the development of zirconium is a very interesting story, and in those years, then-Captain Rickover was known as Mr. Zirconium because this was a, at many times along the way, people wondered, "Was it gonna work?". The whole mining process in order to get large quantities at a reasonable price, all the processing, all the fabrication techniques et cetera had to be worked out and even today, of course, there is still a tremendous development in efforts going into zirconium and the improvement of zirconium and fuels in order to take care of things that we have to face today.

We're continually to try and get longer and longer lives in cores. You want to extend them so they last longer, you go around the world once submerged, let's go around five times submerged, well obviously we don't want to go around five times submerged, but we like to stay submerged for a whole war, come up to get supplies, but keep the ships on the line, run at high speeds for long periods of time, come in for supplies only, ammunition only, but keep the ships on the line and that means keepin' them running, don't have to refuel them. And the longer you go, the more corrosion resistant the material has to be, the more it has to take the neutron irradiation et cetera, so there is still a very large development effort going into improving this material and making it a better one.

There was another fundamental metals problem that was facing the group when they had to set up the basic parameters for this plant. You had to pick something to build the whole plant out of. What do you use, what do you use for the pipes to push this pressurized water through? What do you use for the pumps, what do you use for the heat exchangers, what do you use for the reactor vessel? You have to pick a material again that is corrosion resistant. Here you're interested in corrosion resistance for a couple of reasons. If you get very many corrosion products, they're gonna go into the reactor and what do you know, they get radioactive and now they can run around the system and deposit out, and pretty soon you'll build up such a high radiation level on all your components that if you ever want to go in and work on 'em, you can't do it. Now this, of course, is brought home tremendously by the situation out at Arco today where the reactor blew up and there, they're in a different situation, but there are people that I think are impressed by the fact you have an entry time of 65 seconds that somebody can afford to stay inside the building. Well, this is a different situation working on components, but it's still a serious one.

What if you wanna take one of these components out and work on it? You can't afford to have it that a mechanic that can only work on it for three minutes at a time, or you'll take every mechanic in the shipyard to make a minor repair. You can't afford to have a large amount of corrosion products for that reason. Another reason you can't afford is, if you get a lot of corrosion products and they go into the fuel and block off water passages, you'll starve the flow and melt the fuel, and that's just no way to run a reactor **(laughter)**. You can't do that. There are people in this room who have worked on this very problem and it sounds very simple, but it's not so simple. Now, so you had to pick a material to do this, that has the strength, that you can make an all welded system, et cetera, and the material that was chosen was of course stainless steel. Now, we all sit here and eat with stainless steel, I can't remember if we ate with stainless steel tonight or not, but a lot of us have eaten with stainless steel and everybody knows all about stainless steel. On the other hand, 1948, you'd be surprised how little was known about stainless steel. Every time you picked up some data on stainless steel you'd find out it wasn't true, it wasn't so, it didn't have these properties. It was not very much experience with stainless steel as a structural material in 1948. Very little experience with it. This was another major commitment. Even today the Naval Reactor Program is one of the largest single users of stainless steel in this country. The largest castings in this country that had ever been made were made in this program and an awful lot of development workforce had to go in to doing it.

I was talking to Mr. Swanson earlier this evening and he and I agreed, I think, that the foundries and the mills are very reluctant to try anything new, they are very reluctant to go off into developmental programs, maybe foundry and mill people here like to throw a rotten tomato at me at this point **(laughter)**. Well, it's so nevertheless. Across the board it's been my experience anyhow that you have a hard time getting, in that part of the industry, getting people to want to go in to development of new things and an awful lot of work had to be done to get these things developed so that you could fabricate whole plants out of this, so you could fabricate a pump out of stainless steel, a large pressure vessel, or steam generators, or cladding. Build a carbon steel vessel and then clad it with stainless steel so that all your surfaces would be stainless steel. This was a major metals problem. I mention this because I think some of you would be interested in the metallurgy aspects.

On the sodium side on the other hand, there were some very interesting metals problems too. The whole technology of liquid metals had to be entered in to in the *Seawolf* project. The, we were using liquid sodium, we were using NaK, sodium-potassium alloy. We were using liquid mercury. All these were used in the project in one place or another. An awful lot had to be learned about the properties of these liquid metals. The Knolls Atomic Power Laboratory wrote the liquid metals handbook which is still a reference in that field, a reference document in that field, even though we are not working in the liquid metal area today.

Now, stainless steel, to go back to it for just a moment, we're still learning a lot about. It's a very nice material, but it has one very nasty characteristic. It doesn't like chlorides, I think any of you work with stainless steel know, know about chloride stress corrosion. And we, unfortunately have to live in a sea water medium. Now, this still bothers us and that's why we're spending a considerable amount of money and time to develop other structural materials for pressurized water reactor plants. The problem here is that you use a highly purified water in the reactor system, but you are making it from sea water. You are always subject to the possibility of flooding of a compartment, and bringing the salt water against hot stainless steel pipe and getting yourself into trouble. We always have to worry about the plant being hot, flooding the compartment, filling up with sea water, now we've got the salt water soaked up in the insulation right up against stainless steel and then worry about getting chloride stress corrosion. Therefore, considerable effort is still going on trying to develop better materials. As a matter of fact, in some of the nickel materials, again the largest castings and forgings in this country today are being made in this program to try and find a material which may be more suitable than stainless steel. I think that you will find that the Naval Reactors Program in the next several years will make a significant contribution in the development of technology related to fabricating large parts out of some of the nickel alloys.

Now, I'd like to go back, go for a few moments through the development of the various nuclear submarines to give you some idea of what the Navy has built and where they came from. I mentioned that in 1953 the land prototype for the *Nautilus* was operated the first time. This was the first power producing, first reactor producing useful power, operated in the world. The, in the same year, the basic design for the next class of submarines was determined. And, at that time, there were a lot of people that didn't like the *Nautilus* and one reason they didn't like it was that it was too big. And you could get the kind of feeling from a lot of submariners that the *Nautilus* was too big and you, so you'd say, "Well, why is it too big?" "Well, it's too big" **(laughter)**. And, "Well, what do you mean it's too big?" "Well, it's bigger than any other submarine that we've built." Well, it's true that there was some feeling against large submarines. The French had built *Surcouf* which was never a successful submarine, the United States had built the *Argonaut* which was a large submarine, very cumbersome, and was never really a successful submarine, and then some people just didn't like big submarines. Of course they never had a nuclear powered submarine, and they didn't really know what that meant, but large submarines are just too big.

So there were people who make decisions on these things who wanted a nuclear submarine no larger than the boats being built at the end of World War Two. Now, you can go back in and find out how did they get that big, it's just the way they were so you shouldn't build them any bigger. Furthermore, there was no operational requirement for submarines much faster than those boats because they never had a submarine faster than those boats **(laughter)**. So why'd you need them any faster: they wouldn't know what to do with it **(laughter)**. I suppose I shouldn't say this sort of thing …

Mumbled question from audience member.

LEIGHTON: Pardon?

AUDIENCE MEMBER: How fast are those old boats?

LEIGHTON: Oh, how fast were those old boats? I've been asked a lot of questions about speed tonight and I'm not talkin'. The only thing I'll say about speed is, a nuclear submarine can go faster than 20 knots, that's all. No other comment that's unclassified, that's the only thing I can say. But, there were a lot of people who felt this way, and of course these nuclear boats were expensive and money's hard to come by too. Furthermore, there are people who didn't like nuclear submarines because there wasn't enough uranium around. You gotta go back in your minds, any of you in the nuclear programs today, uranium's plentiful. U235 heh… heck, we have ladies present, heck U235 you can get anywhere you want. You can probably buy it at the dime store if you have enough millions of dollars. Now **(laughter)**, but in those days it wasn't that way. There were so many kilograms of U235 and you argued with the weapons people who wanted to blow up some city versus one nuclear submarine. So, there was another reason for bringing power levels down.

Anyhow, the next class of submarine was born at that time, but remember this is almost two years prior to operating the *Nautilus* at sea, and the *Skate* class was originated. This is a submarine of the *Skate* class. There are four submarines in this class. The *Nautilus* and *Seawolf* are attack submarines, they fire torpedoes. This is the next class, the *Skate*. This is the *Sargo* here which was (I have to put a plug in for my alma mater up on the screen here) this was built by Mare Island. This is identical to the *Skate*. The *Skate* was built by Electric Boat, the *Sargo* was built by Mare Island, the *Seadragon* and the *Swordfish* which are the same class of submarine where built by the Portsmouth Naval Shipyard and those are the four ships of this class. *Skate* and *Sargo* have both been to the North Pole and back, so I think we can say they're pretty reliable ships. And very worthwhile ships. They're an outstanding submarine. You note the twin screws on this submarine, you note the general hull form. The hull form here is very close to the World War Two submarine. Very much like it. The *Nautilus* and *Seawolf* are also very close to World War Two submarine but expanded, larger in size. The *Sargo* on its, to get some idea of nuclear submarines, the *Sargo* on its shakedown cruise, which is the first cruise after a submarine goes through builder's trials and we go out to make sure it runs and then it's delivered to the fleet, it's commissioned then it goes on a shakedown cruise of some length of several months' period of time to get all the bugs out of it, it comes back. The *Sargo* for example, her shakedown cruise took a cruise of 19,000 miles, almost all of it entirely submerged. She submerged when she left and she came back up and that was about the extent of her surface operation.

The, in this same period, the *Nautilus*, excuse me, the *Triton* plant was being determined. The *Triton* originally was a two reactor submarine, that is one of the characteristics that has stayed with it throughout its history. There were several reasons for this. One- the Navy was looking for, in this case, a high-speed submarine, there were some people who wanted a high-speed submarine and so the thought was, "Well, let's take a look at something that will give us high speed". That means lots of power and in order to get that much power, we'll have to have two reactors. The other thing was to get extra reliability. Again, remember, the first reactor hadn't even been run yet, so how in 1953 somebody says to you, "How reliable are nuclear reactors? Naval nuclear reactors? How reliable are they? How long will they run?" When the Mark 1 prototype of the *Nautilus* started out in the desert, it had an expected life of several hundred hours plus or minus several hundred hours **(laughter)**.

There was actually an experiment in the Chalk River pile in Canada just preceding the prototype running out in the desert that gave an unidentified deposit, a very high corrosion product in the loop that was running in a reactor up at Chalk River and this loop, special loop went in to the reactor and back out again, the stainless steel system, and my gosh the samples came out and they were covered in an unidentified deposit. And, people shook their hands in horror and said my goodness gracious is this what happens when this stuff goes through the reactors? Is there something going on in the reactor that gives us this high corrosion rate? This was known as the Chalk River Unidentified Deposit which is Cee Are You Dee and is the standard term in the technology of pressurized water reactors. So CRUD **(laughter)**. And I mean that literally. Today when you talk about CRUD in the reactor system of a pressurized water reactor technology, it really means Chalk River Unidentified Deposit. To this day that particular experiment has never been explained. But, there was real worry when the land prototype was operated because there was not enough time to find out where this came from and whether it applied. I mention these things because people seem to think that, “Gee, pressurized water reactors, that was simple, they were on the shelf” and that just isn’t the way it was. They aren’t even on the shelf today. A little later I’m going to say a few things about the kind of metals and stuff people give us today and I sometimes wonder if we can ever make them run **(laughter)**.

AUDIENCE MEMBER: Oh come on now.

LEIGHTON: Mack, you gotta defend me, Mack I wanna give your people hell, and I’m gonna. Because we need help, we really do. We try and keep them runnin’ but, the question I’ll ask you is, you go, you give us the products for these things and now you’re gonna go ride this thing under the arctic ice and go up and say hello to the North Pole, and whether you come back depends on what you gave us. That’s gotta be reliable.

Triton on her shakedown cruise, she sailed out of New London and everybody said, “Goodbye, goodbye, goodbye” comes back a couple months later and, eighty something days later. Been around the world submerged, never came up. Except to transfer an injured man and throw some ashes over the side. That’s pretty good reliability I think for the maiden voyage of a ship. But, it’s got to be good, it’s just got to be good. You’re gonna have these things so they’ll run and run and run, otherwise what’s the use of nuclear power? If you substitute an oiler for a tender, what good is it?

Now, there’s this metal problems, I have a note in here. See, I’ve got something that says here, that says, “The gamut of metal problems which are encountered in reactor design appears to be endless”. It, sometimes I think it is endless. When you look at each one of the reactor technologies in itself, there are just endless metals problems. And even in pressurized water, all by itself where we’re specializing today, we have one metals problem after another.

Now, let me go on with these, with the ship development. In 1955, there was the concept, now this is the thing, the *Nautilus* hasn’t even gone to sea yet, in this time. It takes time, lead time is terrific, it takes seven years to do anything. It takes seven years from concept to finish of a project. We’ve now got it down to so you can do a nuclear plant in five years, it takes seven years to change a uniform in the Navy, but now we can get down to five years here. If you think that’s not true, look up the statistics on how long it takes to change the uniform in the Navy. That’s true in any business though, not just the Navy. Don’t you people misunderstand me. I’m not trying to tear down the Navy, I’m in the Navy and I’m all for the Navy, but it takes a long time to get anything done and developing a nuclear propulsion plant takes quite a while too.

So in 1955 there were some other classes being determined. The *Tullibee* is one. The *Tullibee* (I don’t have a representative here because we only have the Mare Island ships here) is a hunter-killer attack submarine, this was a smaller, even smaller size than the *Skate* class. Again, the thinking in those days was still towards getting smaller submarines and getting, it didn’t matter if they were perhaps slower, if they were quieter. Now you gotta recognize submariners worry about noise and we’re running a lot of propulsion machinery. High power means noise no matter which way you cut the cake, some percentage of some fraction of all your energy is going to go in to noise vibration and people worry about, say “Fine, I’m out there running around but they can hear me halfway around the world, they'll know where I am", so the *Tullibee* came in to being in concept. That is a so-called hunter-killer submarine. Its basic function is to shoot at other submarines, it is smaller than any of the others. It happens to have an electric propulsion as opposed to a steam turbine propulsion. Again, in an effort to get quieter.

The *Tullibee* is one other class, the reactor developed for the *Tullibee* was developed by Combustion Engineering at Windsor, Connecticut. They set up a laboratory in conjunction with the Atomic Energy Commission for developing this project. They did develop and build a land prototype of the *Tullibee* and the *Tullibee* started operating at sea last year. This class is still being evaluated, I think that the turn of events has superseded it. People now are interested in faster submarines and I doubt we'll build any more like the *Tullibee*. A lot of lessons were learned from it. Many lessons are learned from every one of these projects which are then factored in to future projects.

But, also in 1955 came the *Halibut* which was Mare Island's second nuclear powered submarine. This is a Regulus-firing guided missile submarine and is actually the first nuclear powered missile firing submarine built. The, the history of the *Halibut* is this ship was authorized by the Congress as a diesel-driven submarine. And was actually authorized, plans drawn and was set for construction. There were some people who had demonstrated that you could take the same kind of a propulsion plant that you had in *Skate* and *Sargo* and that you could put it in to this diesel-driven submarine in lieu of the diesel without changing the submarine design from one end to the other and make it nuclear propelled. Therefore, this ship was changed in the congress from a conventional submarine to a nuclear submarine and was built as a nuclear powered submarine. She went to sea in the fall of 1959 for the first time and is currently operating in the Pacific with the other Regulus-firing submarines that are diesel driven.

Now these ships are on the line and they can carry a hydrogen warhead. They don't have the range of a Polaris and you have to surface to fire them, still in all, it's a mighty big ocean, and a hydrogen warhead can blow up a city no matter what kind of missile it's carried in. So it's a very, very potent weapon. See this is old-style now, it only has more firepower than the entire United States Navy of World War Two. We're not building any more because now all the effort on the missile firing submarines is going in to Polaris. Now in '55 also, and again we're talking at the time that *Nautilus* first went to sea. You gotta think back on these things. You know sometimes it's hard to say, "Why did so-and-so do this?" and, "Why did they think that?". Well, it's the old Monday morning quarterbacking. It's an awful lot easier to say now what you would have done as opposed to what you did in those days.

But there were people, there were some people who felt that once they got the *Nautilus* to sea that the Navy would, that the people who made the decisions in the Navy, would change their mind and decide that they did want a fast submarine. And might even want one faster than the *Nautilus*. Well, events proved this to be the case. Now the Navy also in the non-nuclear area was working on the *Albacore* at this time. I think most of you probably heard of the *Albacore.* After fifty years of submarine design, or whatever it is, about fifty years at that time, people decided that the whale was a pretty good idea after all. And the whale happens to have a pretty good hydrodynamic hull form, and is very close in shape to what we're building as attack submarines these days. The *Albacore* approximated that. A teardrop sort of design. The *Albacore* was a diesel-driven, or is a diesel-driven submarine, and was built as an experiment in hydrodynamic hull forms. It was built to find out would it do what the Naval architects thought it would do? And it did, and performed very well to give high speed with a single screw. But, of course it was diesel-driven still.

Well, why do we want nuclear power anyhow? The reason we want nuclear powered submarines of course is to get away from the use of oxygen. The *Albacore* can dive and run very fast on a battery, and how long can you run on a battery? If you're running very fast you'll take a lot of power but you don't run for very long. And then if you want to run longer you have to come up to where you can get oxygen to run your diesels. Well, with nuclear power of course you can get oxygen-free power and that means you can dive and stay down and run for long periods of time. So, with the *Albacore*, with the work going on in hydrodynamic design, with the *Albacore* and then with the higher speeds available in the *Nautilus*, if you match the two, you come up with the *Skipjack* design which is the same as the *Scamp* that we're building at Mare Island.

That's a picture, that lower picture there, some of you may want to look at these afterwards. Here's the *Skipjack* on the surface. The *Skipjack* just likes to submerge, that particular picture is taken at high power on the surface and it is only about what, 5 percent of the ship that shows on the surface, and that's fully surfaced in that picture. When you're standing on the Bridge of the *Skipjack*, at full power and you look out in front of you, there's a nice long bow in front of you, and you can't see it. It's all underwater. You look straight down and there's the water. All that's above the surface when you're doing full power on the surface is this sail and a little bit of the superstructure aft here. The whole bow is underwater. You can, if you look down in clear water you can see it underneath, but it doesn't even come up to the surface. These boats go down and stay down.

Somebody asked me earlier don't they have a deck on here? Particularly on one of these other models, is there any deck? Well, why put a deck on a submarine submerged? It's kinda wet **(laughter)**. They're built that way. They're built to be submerged and with fairing surfaces to get the streamlining for submerged operations.

Now, with the *Albacore* you have a single screw, this again is to get this hull shape for higher speed and to get a higher propulsive coefficient with the propeller. A single screw submarine back here all by itself has a higher propulsive coefficient than the twin screw here where the wake from one interferes with the other and reduces the propulsive coefficient. Which means in this case that a higher percentage of power goes in to making wake et cetera than on this ship. Given power put in, more power goes in to moving the ship on the single screw design with this hull form. Well, again, the reactor design for this plant, which is different than the *Nautilus*, then the *Skate* class, then the *Skipjack* class. Those reactor designs were all under development before the *Nautilus* ever went to sea. And that was to try and out-guess them on what was going to be wanted. And to get a jump ahead. Otherwise, these ships would not have gone to sea when they did if you didn't have these things well under development by the time the ship was authorized you'd take longer to get to sea. It is really for that reason, that in the six years since the *Nautilus* went to sea, it's six years this month since the *Nautilus* went to sea, it's because of the lead time that's put into these plants before she ever went to sea that we're able to have as many nuclear submarines as we have today. Or as many different types, to gain the experience from them.

Now, we're building a lot of the *Skipjack* type or *Scamp.* This is *Scamp*, it was launched over at Mare Island last October. This particular one, as I said we only advertise our own product here. These are the Mare Island boats. But, this one will go to sea this year. God willing and if I stop giving talks and go back and go to work. There are some of my people here, what's their excuse **(laughter)**. Now this class was being built in '57 they were under construction, and the *Scamp* for example at Mare Island had been laid down, on the ways. There were five ships of this class already under construction in various yards around the country, two at Electric Boat, one at Portsmouth Naval Shipyard, one at Mare Island, and one at Newport News, when it was decided that the Polaris program could be speeded up, that the missile could be made ready sooner. This also was the time of Sputnik. What was Sputnik, October 1957 I think, was it not?, or was it end of '56? October the fourth, what was it? '56? '57? '57 I think, October 4th, 1957. Yeah, after Sputnik, there was of course the Polaris project was already underway as a missile project and one Polaris submarine was already in the mills for authorization to Congress. But the concept here was to have a ship by I think 1963, to have the first ship on the line, something like that. But, after Sputnik, there was a lot of flurry in Washington to try and get this out sooner. Furthermore, the initial stages of Polaris had been quite successful so that the five ships of the same class as *Scamp* that followed *Skipjack* were all changed to Polaris firing submarines.

In our case, what was laid down as *Scamp* was changed to *Theodore Roosevelt*. And the way this was done was to, you can see that it's a heavier submarine than the other one **(laughter)**. The way this was done was to separate the ship right here, at the tail end of the sail. We call this part the sail, these are the bow planes here, and the stern planes here, and the propeller of course, and rudder here. That the ship was separated at the tail end of the sail and moved forward and then it was, the after section was moved back here. Now here's the propulsion machinery and here's the torpedo firing and crew's living quarters et cetera. And a missile section was installed in between. Being capable of firing sixteen missiles and of course then all the missile control equipment et cetera had to be also built into the ship. This is a considerable design job, take the submarine and just pull it apart and design the part that went in between. Fortunately, at this point on all five of the ships, the state of construction was such that all you were moving was hull sections and machinery had not yet been installed in these, so you could physically separate them on the ways. You didn't have to cut a lot of wires and pipes et cetera to do it. And that is the beginning of the five Polaris submarines that are currently either operating at sea, or in the case of the fifth one, completing construction now.

There's the *George Washington*, *Patrick Henry* of Electric Boat construction, and the *Robert E. Lee* from Newport News and the *Theodore Roosevelt* from Mare Island and the *Abraham Lincoln* from Portsmouth Naval Shipyard which has not yet been to sea, but is pretty well along in construction. These ships truly do have more firepower. Actually in explosive power, you probably heard this a hundred thousand times, they have more explosive power than all of the ordnance of all the military structures of the world since the history of man started. And that's why these things are like saying the National Debt is umpteen billion dollars. You just can't comprehend it. It's a remarkable thing. Here is a ship that's staying submerged, can fire a missile which can, if it hits anywhere close to its target, obliterate a whole city. And we think, the Navy thinks, and apparently the Congress thinks that the taxpayer is getting something for his money because this gives you a retaliatory weapon that gives you time to think. You don't have to worry about the guy in the first thirty seconds of war obliterating all of your missile launching sites. Or, saboteurs building their own missiles inside your hangar so-to-speak. Got pretty good control over that, he doesn't know where your missile launching platform is, et cetera, et cetera, et cetera.

I'm sure you've read many articles on this subject. But, it is true. Two thirds of the world's surface is covered by water and these things can go anywhere with enough water. Including under the arctic ice and if things get, if they get good detection methods out there in the open sea, which nobody's ever gotten yet, then give them the problem of finding you under the arctic ice pack. Picture a hole in the surface, you can go twenty miles in any direction and find another hole. And surface and sit there, or don't surface, stay under a hole, shoot it out of the hole. Well, it gives the Russians an antisubmarine problem now, we're gettin' tired of the antisubmarine problem **(laughter)** with the Russian submarines. The got four hundred fifty submarines running around the ocean and it's a tremendous problem for the Navy. The Navy today has a couple very major problems. One of which of course, is to provide Polaris submarines as a deterrent weapons system and the other is to find some means of controlling Russian submarines. Now one of the means you get after that is of course the nuclear submarine. The nuclear submarine is one of the better antisubmarine warfare vessels. It's a very good anti-submarine warfare ship, actually, and of course that's one reason that we're building so many of them.

Now, going on from there, the last class that we're building right now at Mare Island is the *Permit* class. This, the forerunner of this class is being built at Portsmouth right now, the *Thresher* is nearing completion. We're building two like this, the *Permit* and the *Plunger*. These ships are an improvement in design over the *Scamp* or *Scorpion* or *Skipjack* class. But they are essentially the same, same thing. They are an attack submarine, a torpedo-firing submarine. Of course torpedoes these days are getting even more exotic you know. You can talk about putting nuclear warheads in torpedoes too. The Atomic Energy Commission has certainly done a fine job working with the military to develop nice compact destruction for the world, and you can put a nuclear warhead these days on, I guess on almost anything you want to.

Now, let's talk for just a minute about the surface ships. Naval surface ships. There are three Naval surface ships, the aircraft carrier *Enterprise* which has been launched and has had one reactor, one of its eight reactors go online. The guided missile cruiser *Long Beach*, as Ben may have mentioned, the *Bainbridge*. That's the *Bainbridge* up there, the one surface ship in the pictures. It's a guided missile destroyer leader, for those of you who are old destroyer men, you'd never recognize her, it's almost eight thousand tons which is larger than many former cruisers. But, you have to recognize today you're trying to put long-range missiles on ships, you're trying to get sustained high power, it takes large power plants and the ship comes out wherever it'll come out. You decide on what you want to put on it and don't expect to put everything on a sub-chaser. You want to get these modern weapons on it and get the modern electronic equipment on it and propulsion plant et cetera, you got to recognize it's going to take some weight and space.

I'll only touch for just a moment on the basic design factor in a Naval nuclear propulsion plant. By far the most important consideration is given in the design of a Naval nuclear propulsion plant is to the protection of the public from radioactivity. This is an overriding consideration. For the first time we're building ships which not only serve a war function, but do have the possibility of creating a real public hazard. Now, we can have a Naval ammunitions ship blow up in a city and get us in trouble, we can have any one of our ships blow up and knock out a few piers or something like that, but for the first time, of course, we have something like a pot full of radioactivity on a ship and we have to be very careful about that. And about all I can say here is that a tremendous amount of effort has gone in to designing these plants to make them safe and the whole design is predicated around that. The design is reviewed by the reactor Safeguards Committee in Washington, which is a statutory group set up by the Congress for the specific subject of reviewing reactor designs before they're allowed to operate. This committee reviews the reactor designs of all reactors before they're allowed to operate in populated communities in the United States. Including Naval reactors and that committee gets into the design of these things in intimate detail. I've been up before this committee and had them questioning individual valves and the design of individual valves and why they were placed where they were placed. To look at all the safeguards aspects of these reactors.

A second major consideration of design of a Naval nuclear propulsion plant is reliability and maintainability. If it isn't reliable and it isn't maintainable, it isn't much good to you in a Naval nuclear propulsion plant. We're not looking for something that says, "Here's nuclear power" we're looking for something that'll drive a ship through the water for sustained periods of time and will stand up in combat. Pressurized water plays a great deal in this part. One of the things that has caused many reactor coolants to be ruled out is their vulnerability. Their vulnerability to either vibration or shock, or the lack, just plain lack of reliability. They'd be fine as long as they'd run and then they wouldn't run any longer. You'd always have to worry about that. The *Seawolf* plant was an outstanding plant if we had not had pressurized water work, we'd just be delighted to have the *Seawolf* plant today. And we'd be building, if sodium had worked, and pressurized water hadn't, we'd be building all sodium-cooled reactors right and left. We'd still be building a nuclear powered Navy. Because having nuclear power versus not having nuclear power is very important to us, and sodium would give us nuclear power. The *Seawolf* operated successfully for several years at sea. You may remember Dick Laning staying submerged sixty continuous days on *Seawolf*. Why did he surface at the end of sixty days? Well, if you stay submerged for sixty days, how long do you want to stay submerged? And this is the longest anybody'd ever been submerged. But, they coulda stayed longer if they wanted to, but you reach the point of no return, why stay any longer? The *Seawolf* has performed very well. On the other hand, pressurized water plants for our purposes are even better. Well, then, why not build the kind that are better? The *Seawolf* today has a pressurized water plant in it. *Seawolf* was taken in to Electric Boat for reactor, sodium reactor was taken out at the end of the first core life, when the fuel is all used up, instead of refueling it, it was replaced with a pressurized water plant. Yes, sir?

Audience member asks a question.

LEIGHTON: Ah sodium, so the basic drawbacks of a sodium system. One, you cannot tolerate leaks of any size whatsoever. This is a serious drawback. You just can't afford to have any leaks. Now, you got to manufacture large components, large heat exchangers with many, many, many, many welds, and you've got to produce them on a production basis for a whole Navy and you gotta have 'em without leaks. Well, we worked very hard to make the *Seawolf* very carefully and we had leaks. And the first thing we had was a leak that leaked in to the superheated steam system and this was a sodium potassium alloy that was used as another fluid in the plant, leaked into the superheated steam system and caused caustic corrosion and just chomped its way through a stainless steel pipe in a matter of hours, and we had to isolated the superheaters from the system. We had other leaks in the sodium system. At West Milton we had leaks, both in to and out of the sodium systems. Small leaks on both plants once they would operate for any period of time, we had no further leaks so the chances are that these particular leaks were in the initial fabrication. But doggone it they'd be hydroed and re-hydroed and hydroed again and they'd been inspected to a fare-the-well on every weld and every place, but you're asking for a lot to ask for large components to be made leak-tight. There are other big drawbacks. Sodium has a fourteen point eight-hour half-life; it becomes highly radioactive. You want to dry-dock the ship, what are you gonna do? You gonna drain the sodium out of the system? If you want to dry-dock in a hurry, if you're willing to wait, you wait two weeks, but if you're not willing to wait, then you wait seven or eight days while you drain it out, flush it out et cetera to try and get this radioactivity down so that you can put the thing into a dry-dock and drain the seawater out around it. So the people can work in the dry-dock. You wanna go down not because of the power plant, you want to go down get a look at your sonar dome, you ran in to a whale last time you were out **(laughter)**. Well laugh, the *Seadragon* on initial sea trials chomped in to a whale: she chomped one of her screws in to a whale and limped home on the other shaft. They had to dry-dock it right away to look at the propeller and find out what was the matter with it. There are many reasons why you wanna dry-dock a ship, that's why we got dry-docks. We have four of them over at Mare Island and it's not at all uncommon to bring a ship in. *Howell* had gone out on a sea trial and she had a mine cutting cable cut loose, get caught in the propeller dragging it, dry-dock her, clear the propeller, send a diver down if you can, but if you can't, dry-dock the ship. We dry-dock them all the time. It's a matter of routine, but in a sodium plant, it's not a matter of routine to dry-dock your ship. This is a disadvantage to a ship.

Far away from theoretical advantages. You say, well it has fine theoretical advantages, one of the things people are always gonna say, yes but it gives you high temperature and that's not an advantage, high temperature's not an advantage. High temperature is a disadvantage. Now, if you get less weight and space, increased efficiency or some such thing, it's an advantage, but high temperature per se is not an advantage, high temperature per se is one of the darndest disadvantages you can get. One of the real disadvantages of a sodium-cooled plant is that it operates at high temperature and has a high delta T across the reactor. Which means that every time you go through a transient, you slug it with a thermal shock, that's a real disadvantage unless you get something for it. Well, we go something for it, we got a higher efficiency in the *Seawolf*. What's that mean? Higher efficiency, we can run around the world on the uranium anyhow. It has a higher thermal efficiency but be careful! In fact the overall efficiency is not higher, because it just so happens it has an intermediate spectrum and it just so happens that the ratio of neutrons captures to neutron fissions in uranium at the intermediate spectrum is higher for the neutron captures and therefore, the efficiency, the thermal efficiency was higher, but the efficiency in terms of kilowatt hours per gram of uranium burned was less because of the nuclear characteristics. So don't just talk high thermal efficiency, that doesn't mean anything if you're burning more uranium. You can design it maybe to get a thermal reactor. We also happen to have there a type of core, in order to use the structural material for this you had a stainless steel, and this has a higher neutron capture cross-section so it takes more uranium to make the thing critical in the first place, which means a bigger investment of uranium. But the net result was that for the same power between the *Nautilus* and *Seawolf*, the overall weight of the plant and size of the plant was about the same size and was a little heavier. The machinery was smaller in the engine room because you had better steam conditions, but you put it all back in, you put it all back in to the weight of the shield, to shield against the radiation of this sodium. Well, those are some of the disadvantages of sodium. It's a harder material to play with, it's just not as nice as water. It's a wonderful thing, it was a very marvelous plant. I don't want to in any way imply it was not a successful plant. We had problems with it and we had, I said cons are significant et cetera but the *Seawolf* operated successfully on a sodium plant for several years and ran a hundred, matter of fact, went a hundred thousand miles on her sodium plant. It was a very fine plant, but it wasn't as good as a pressurized water plant for our applications. That gets into reliability and maintainability, the very thing I'm talking about. It was not as reliable or not as maintainable in any case. She ran and she ran beautifully, the thing we never knew was whether it was going to conk out tomorrow, and if it did conk out tomorrow we couldn't do anything about it. We couldn't get in to the reactor compartment to look at it.

Now, we've had cases for example, in pressurized water plants where the foundation, some; you're always at the mercy of over mechanic, every welder, every electrician, every inspector in the country **(laughter)**. Now, some guy doesn't make a weld properly on a pin that's fastening a major component down in a reactor compartment see, and some inspector doesn't catch it, Joe Dolt, somebody. You can find out from a card who it was alright, but somebody didn't do it right. You gotta get down and inspect it once in a while. For two years we couldn't get in to the reactor compartment on the *Seawolf* because the radiation level was so high, and in order to do it, we were gonna dump all the sodium, we would have had to flush it and flush it and flush it et cetera. So, it was never worth putting the ship out of commission long enough to get down there to find out, and you never knew. Now, fortunately it was put together right and we didn't have to worry about it, but I've seen plants where you go down, you go look, you find some little thing wrong. Something that if you didn't catch it then, would lead to trouble tomorrow. We actually had a pin, we had on one ship, we had after her sea trials, she came back in and a weld hadn't been put properly on the end of the pin, the locking device, the locking device fell off, the pin supporting one of the main components was backing out. Now you go out for another half a dozen dives, the thing drops out and the component falls off the bulkhead, then you're in trouble. But, in a pressurized water plant we can get down and look at these things. We can, when the ship comes in, we can dry-dock it if we want we can shut down the plant and as fast as we get the thing open we can get in and look at it, any time we want to. These are operational advantages. These are not the things that you talk about with high temperatures and the theoretical advantages, but in this game also, in any new game, don't go by the old advantages. High temperature is better. I mean that's something, high temperature isn't better and even in high temperature steam we pay a price to get it, but we got something for it. If you get something for it, fine. If you don't get something for it, don't do it because it hurts. High temperature, you metals people, you must know that. High temperatures are harder to get. Of course it, somebody always says, "Yeah, but look at all the interesting problems" **(laughter)**. Well there are people that think that way, but we don't. We're looking for the simple way **(laughter)**.

Ok, another one, another major factor that's for reliability and maintainability, another major factor is cost. Cost is a real problem. We're expensive, we're in an expensive business. People think for some reason you ought to get nuclear power, they think it's fine, and they want it, but they want it cheaper than you had diesel power or something else. Well, it just doesn't come that way. All modern technical developments cost more money, it's a fact of something or other. I'm not an economist, it may be the fact of the economy, it may of metallurgy, I don't know what it's a fact of, but it's a fact. Modern developments cost more money, and you gotta face up to it. You've got to look to see what you get for it, and in our opinion, you get something for it of course and that's why the Navy's building nuclear powered ships even though they cost more than conventional ships. Although today, in nuclear powered submarines, it does not cost as much as twice the price of a conventional submarine, and boy they're worth more than two conventional submarines. So, that's why the Navy's building all nuclear powered submarines. In surface ships this is a big argument. A big argument. That's why the Navy's only building one of each type, and until they operate them at sea and they sit and evaluate them for several years, nobody is gonna want to build very more of them. There are differing opinions on the subject. I have my own, but we won't take time for that now.

Weight and space is another major factor considered in the design of any of these plants. It is something that you are continually fighting to bring down, the weight and space. At the same time we put higher on the list of the design the reliability and maintainability. And when you wanna talk increased ranges, increased operation, you can go full power for many, many years, so why not do it, and let's go. You are pushing machinery harder than it's ever been pushed before in a Naval vessel. At Arco, the land prototype of the *Nautilus*, at one point was operated at full power continuously for sixteen hundred hours. That is a long time to operate a machinery plant. The Navy and its normal certification of propulsion plants runs for four hours at full power, and then ships operate at full power every once in a while. Those of you've been in the Navy can count on your fingers the number of times that the ship you were on operated at full power. Even during the war, during the war you're always saving that fuel to get home, or get out, or run, or something **(laughter)**. And, you burn up your fuel too fast. You don't operate at full power very often. Your range at full power is very limited, so you don't go up there very often. So our machinery history in the Navy for just plain propulsion machinery is not based on operating at high power for long periods of time, and that doesn't make the stuff get lighter, it makes it get heavier. This is a constant fight, to bring down the weight and space, but we have to maintain the reliability. If we make it weigh half as much, but it will only operate occasionally, it isn't much good to you.

Well, in that regard, I'd like to take just a few minutes to discuss a point near and dear to my heart. And I'd like to take some of you to task for this, your society is devoted to the improvement of metals, and a great many of you here are in the education field and you've trained engineers, people coming along in this business, others of you are from fine American industry that produces a lot of this junk, and I mean junk, that we get **(laughter)**. By junk I define it this way, I don't care if it cost a hundred million dollars, if it doesn't work, it's junk. And I mean that. I've had people say, but it's so beautiful. Look at the technology that's gone in to it, everything else, but it doesn't work. No, then it's junk. I don't care how many PhDs or anybody else massaged it and design or anything else. If it doesn't work, it's junk **(laughter)**. I don't have a PhD so I'm not insulting myself **(laughter)**. But, it is so. Now…

Audience member asks a question.

LEIGHTON: I was asked a question to compare the weight of a nuclear plant to a diesel plant for the given horsepower. Actually, the pounds per shaft horsepower which is a term I don't wanna use because again, it's misleading. It's like high temperature. But, in a nuclear submarine, pounds per shaft horsepower-wise we have an advantage. The nuclear plant's lighter in pounds per shaft horsepower. The ship, however is larger and heavier because there's more horsepower. But, there is an advantage in submarines. Surface ships, where pounds per shaft horsepower has been really worked down in conventional surface ships, we're hard to compete. The pounds per shaft horsepower in a nuclear plant for the same horsepower is greater. And this is one of the reason we haven't been able to get the smaller surface ship. Because the, they're larger. Let me qualify that to one extent though. People are very much misled on that subject too. If you're gonna spend the price of nuclear power to build a surface ship, for crying out loud put something else on it besides a propulsion plant, and that makes the ship get expensive, it also makes it get large again. I mean, this works both ways. I don't know how much you know about Naval design, but actually in some of our conventional surface ships, if the ships were made bigger for the same propulsion plant, they would actually go faster. For the same propulsion plant. Because people have this idea, make it small, make it small, why do you want it small? "I don't know, but I like it small." And some of them are not optimized at all for maximum speed for given a power, actually making the ship longer, to some degree, for a given power you may make it go faster. And then you can actually put more into the same ship and have it go faster.

Well, let me get back to the subject that I wanna mention **(laughter)** and that is the question of detail in what you work on. To work on the details and don't get up in the office to go make big decisions, let's worry about that goes in to it, and the other is to make sure that all of it comes through right, not just one of it. Now, I got a table with a whole bunch of junk over there, you may wanna look at. Pieces of pipe for example, that come to us, fine reputable pipe manufacturers who send us stainless steel pipe to stick in a ship. We also, they've tested it, it's all fine, wonderful, high quality control, paid a huge price for it, we ultrasonic test it, find big gouges on the inside of it. Not frequently but I don't have to find it frequently. All I got to find it once and I'm in trouble. If I install a piece of pipe like that in a submarine system I can get in serious trouble. And the poor guy, he's there under the North Pole and he says goodbye cruel world, and that's a wonderful vendor, but one half of one percent of his pipe was no good, it ruptured, and here we are sinking gaily. It's no good. It's gotta be one hundred percent working, not ninety-nine point nine percent, one hundred percent. There are a couple pieces of pipe like that over there, there are all kinds of examples, on the table, might want to take a look at them. Maybe some of them were made by your companies, I don't know.

I'll just tell you a little story to try and bring this home. I was on sea trials with one particular submarine, on the first time we went out, and I won't mention the submarine, and I'll try to keep away from anything classified. But, let me show you the kind of things that can happen to you. We were making full power and fortunately we were on the surface. First time we'd been out to sea in this fine ship. Worked our way up to full power, everything is wonderful. We're all smiling feeling very proud of ourselves. The ship's Commanding Officer elected to blow a couple of the tanks dry. Well, he wasn't gonna blow them dry, he was just gonna blow them down to prove that you could blow water out the tank through this line, while he was underway and he was gonna leave a water seal on the bottom, and he watched the tank gauge, and when he gets down to this point in the gauge stop blowing and leaves water in there, no air coming out of the ship. First thing that was wrong, the tank gauges didn't work. He blew it and there was still water in the tank, according to the gauge. But there wasn't any water in the tank. The air blew all the water out and the air was blowing out of the ship. Well, alright, that's no great sin. Second problem, the designer of the ship had built bilge keels on the bottom of the ship. That would be as if you'd taken, this ship doesn't have that kind of a keel, but that's as if you'd put a keel on here for roll stabilization on the surface. A lot of you are familiar with that.

Alright, he put his bilge keel down here, he calculated it from a ships standpoint, and it was just fine, great. He ran it back in here, and from a naval architecture standpoint, that was swell. But this gets to another subject, find out what the other guy's doing. Don't just sit in your own corner, or don't allow your people, and those of you in education please teach this to your people. Tell them when they're working on anything in design, go find out where it's going and how it's going to be used. These particular bilge keels after we dry-docked the ship afterwards, we could see that it ended right next to the sea suction for the main turbine's condenser. Well, air coming out here, riding back, trapped by the bilge keel, and sucked into suction of the main pump for circulating water into the condenser. Grand. Pumps don't run on air, they run on water. Pumps are air bound, they don't pump water anymore so what happens? Condenser loses vacuum, condenser loses vacuum you can't run a turbine that way. That closes stop valves, and that shuts down the main turbines. Also shuts down the turbine generators. Well, these reactors require coolant, and to have coolant you gotta have pumps, and to have pumps, you gotta have electricity. Shut down the TG, sets the pumps stop. Pumps stop, reactor shuts down. Well, we'd just gotten up to full power on the surface and like that we weren't running anymore, just coasting to a stop, reactor shut down. All safe, mind you, nothing unsafe, but very disconcerting **(laughter)**. Thankfully while I was in charge of the propulsion plant, Admiral Rickover was driving the submarine **(laughter)**. I wasn't exaggerating, it was very, very disconcerting.

Member from audience: What did he say?

LEIGHTON: Oh, he's a very understanding gentleman **(laughter)**. You know what he says? He said, "That's happened before and I don't understand why these guys didn't know it" but that's another point **(laughter)**. Anyhow, that's just the start of our problem, when you notice one little old thing like a gauge in the tank, some designer worked on somewhere, it wasn't working right. Another guy who does here, and the real lesson here is, not lookin' to see where he's right on this thing. He's taking care of Naval architecture, but not worrying about where it ends. That we'll find out about later, at this point all we knew was we had shut down the reactor. Now, this is just the beginning of the story, do you mind if I take the last five minutes to finish the story? The next problem, you try to start the diesel generator, well that starts all right. We have an auxiliary source of power in these things just in case nuclear power doesn't work and of course the ship immediately went on to battery. That's automatic, but the battery doesn't have an awful lot in it so you start the diesel to get yourself some electric power back, some more electric power. We had, for the battery, you get a small amount of electric power, you can run the vital loads, but you can't run the ship on that for any length of time on a nuclear submarine. So, we start the diesel generator and that's all fine, but the diesel generator has to be cooled, as does any good piece of machinery, and to cool that you got to have seawater pumps to shove seawater through it, and we have also sea suctions for the auxiliary seawater pumps and they're right aft of the main suction and that's right next to the bilge keel again. So those pumps were air bound.

Now, here you are inside a massive steel hull, that's where you are you know, you try to figure out what this is all about, and the ship's force figured out what had happened, they knew they'd blown the tanks, the figured the air somehow had gotten back to these sea suctions, didn't know anything about this bilge keel problem at that point, but knew somehow this air had gotten carried back and figured that these pumps were air bound. But here's where we got ourselves in worse trouble. What we didn't know was that in the Napa River, see now I've already said it's Mare Island, let's say in the Yangtze River or whatever you want **(laughter)**. They had a peculiar form of animal life that particular year that was growing quite rapidly called hydroids. I don't know if you know what hydroids are or not. I'd never heard of them before, I have now. These things look like seaweed but they're actually living organisms and they just grow and grow and grow. And, in the river and that particular season, for some reason beyond all previous years, they had grown like mad. And these hydroids had grown inside the sea suction sea chest in the ship. We didn't find that out until we came back either and dry-docked the ship. They'd gown right up inside and made a very handy-dandy, handy-dandy filter. Then, as luck would have it, the ship when it came to a stop, came to a stop in a bed of jellyfish **(laughter)**. Now your design has gotta knock off these jellyfish or something, but I think you can't control that. But, anyhow **(laughter)**. There also were some shrimp because in the torpedo tube sight glass there was actually one shrimp living inside of the glass. We knew we'd come in to some marine life in that area **(laughter)**. It sounds funny now, but it sure wasn't funny then. The, what actually was happening to us, but unbeknownst to us, was that these jellyfish were getting sucked up against the sea suction and against this fine mesh of hydroids, and normally jellyfish will just get sucked right in to a sea suction and get chopped up in the pumps and out the other side, because the seawater pump is of that nature. Well, with this fine mesh, these things jammed up against it, and when we dry-docked later we could find these jellyfish hangin' on this thing. Well, we didn't know all about that and what was actually happening was these were blocking off all the sea suction, so while the crew was frantically trying to vent these pumps, to get the air out of them, they long since had gotten the air out that had come in by blowing air in, but they couldn't get any sea suction and didn't realize it. They thought their problem was that they were still air bound from the air that had blown in. Didn't know, and there was no way to know. Well, the subject came up of well let's blow out the sea chest just in case something else has gotten in there and clogged it up. But, of course, and I think at that point it appeared logical, no don't let's do that because we're already air bound. Blowing air down the chest isn't gonna help us any. We've already got air in it and the thing to do is to vent it out. Well, that was the problem and improper diagnosis you might say, if there are any doctors present.

Anyhow, things were not going so well though. The diesel was overheating and had no way to be cooled down. The reactor meanwhile had been put back on the line and we could get enough sea suction to get enough auxiliary cell water for spurts. Now a reactor, any reactor, has some kinds of control elements, and control elements imply motors, and without getting in to classification I think we can say there's some electrical equipment involved in control of a reactor, and any electrical equipment, the chances are requires some kind of cooling, and this particular one requires water to cool it. And the water was not seawater of course, but it was a, another kind of water and this kind of water though, has to be cool. On any ship, you end up cooling anything from the sea sooner or later. So, you had to have a source of auxiliary seawater for cooling this thing through some sort of a chain. Now, if you didn't keep 'em cool, then you're not allowed to operate the reactor. And the problem here was that, that a number of control elements indicated that they were going over temperature for lack of water, and therefore the book says, so many minutes of this and you gotta shut down. We were within three minutes of so many minutes. So, this gets very disconcerting because by this time the diesel had to be shut down for overheating due to lack of cooling water. And, there you are, you're on your first sea trials of a brand new nuclear powered submarine, and you have no diesel, you got the reactor runnin' but you got three minutes left to figure out your problem or you're out of business.

Well, I didn't want to tell Admiral Rickover we had to be towed into port for sea trials **(laughter)**. You laugh, I wasn't laughing. Neither was anybody else that was there, and I think there's some people in the room that were there besides me. Furthermore, I was very hot because by about this time point, to get minimal electrical load, you have to shut down all your air conditioning system and in a nuclear submarine, air conditioning is fundamental. Now the British had tried building one steam-driven submarine before this. People overlook this. Putting nuclear power in a submarine is new, but putting steam in a submarine is new also. The British had built one steam-driven submarine, it's been an abysmal failure because it just got too humid, and too hot, they didn't have good air conditioning in those days. That was long ago, and of course Admiral Rickover, and I keep mentioning his name, and I mention his name because he personally has made the decisions on these issues, and all the ones I mentioned tonight in particular were major decisions made by Admiral Rickover. Very often over a great deal of opposition by technical people on technical subjects, and air conditioning is one of them. It is a history of a fight in Washington that's strewn with blood, the subject of how much air conditioning to put in nuclear submarines. Well, he always insists that we not let an air conditioning set be the thing that makes a nuclear submarine come home, let's make it the nuclear reactor plant that requires us to go home, not just the air conditioning. And so we put a lot of air conditioning in. But, in this case we had to shut it all down in order to use the electrical motor. So things were getting pretty hot and humid, and you have a lot of electrical equipment and it won't keep running as long as it's humid. So we were getting in a nasty situation. Not safety, don't misunderstand me, we were on the surface, we hadn't dived at all, we were just sittin' there, nothing unsafe, but doggone awkward, and certainly no way to be doing this thing, and a similar situation in war time could be disastrous, that's the other thing.

I'm trying to get in some principles that do affect this though, of the interrelation of events that get you in trouble and you've got to worry about detail. I'll take the blame, we should have had divers check those sea chests before we got underway. As it turns out had they checked them, the chances are we wouldn't have seen it because the stuff was on the inside, not the outside, and the diver probably wouldn't have seen it. But believe you me, we don't send a submarine out of there that hasn't had a sea chest thoroughly cleaned before she gets underway these days, and we watch the hydroid growth in the Napa River right now **(laughter)**. I mean that literally, we know it grows in that river and we keep track of what grows in that river and when it grows. You can't, at least we try to learn our lessons.

Ok. So at this point the ship's force got smart and they figured out how to cross-connect some of their saltwater systems and they got enough water to cool off the control elements, get the reactor, keep the reactor on the line. We didn't have to shut it down, and finally blew the, we knew it was air, but we blew it anyhow, blew the, what turned out to be jellyfish and what else was whatever out there. We did see after that in operating, lots of jellyfish in that area and we're convinced that that was what finally did us in, the jellyfish on top of the hydroids. And blew it out and we got going back on the line. I only cite this to show that very small things, very small things can lead to success or failure. Now in this case it was initial trials, that's what we run trials for, we go find out these things, another case, one of our ships took a very severe down angle, and why? Because a valve stuck. A valve stuck. Forward tanks are flooding all right, but the after tanks wouldn't vent, and when you do that, you flood the forward tanks, the valve was down and the after tanks won't vent, it stays up, and that can get very embarrassing too. Along about the time you pass the forty-five-degree angle you start getting nervous in the service **(laughter)**. Details, and I mean that literally. Details. One lousy valve hanging up on you. Sure, you could put a hundred of those valves in, ninety-nine of them will work, but one of them doesn't work, things happen in a hurry. They happen doggone fast.

So, I would like to at least try to encourage any of you that have anything to do with training engineers to make them worry about details. Don't be above a detail. It's a detail that kills you every time. I don't know what's gonna come outta this situation, Arco, with the Army reactor plant that blew up, and nobody else knows right now either. But I'm willing to bet you that you could put together a story not too far different from our hydroids and jellyfish and a gauge that didn't work et cetera. Well we didn't have a real problem, and never was safety involved in any way, but nevertheless it had considerable consequence to us, and always on these things, you can put together a story like it and the only way you can beat it is to worry about the details, and to think about it, and then think about it again. And in this business the only way you do, you worry about it is to look at what you're getting and look at it again.

Of all the components we get in, one out of four pieces of hardware that I get requires something to be done to it before I can use it. And this is after it's been certified and we can assure you the manager of the company thinks it's the grandest thing that ever happened, that we have checked it and checked it, and checked it, and very often it is junk. Literally. We had to cut a ship open here recently and take a component out that everybody said was just fine, and we finally found out it wasn't. Very poor welding. Very, very poor welding. Out of the eighty-eight joints it had in it, there were eighty-seven that had cracks in them. Made by a manufacturer and we stumbled on to it and we had to take it out of there, and there are many other ships being cut open today to take the same things outta their ships. From fine U.S. industry. So, I don't want my remarks to be taken as being critical of the United States government or the great American people. But, if they want to compete, if they want to compete in technology today, they gotta work harder and they gotta be more careful of what they're doing. You've got to be and you've got to train your people that way. You've got to train them to worry. You gotta train them to look at what they're doing and look at it one hundred percent and then look at it again. And to worry about how one thing affects another. Well, if it's anything I can say, that you'll believe me, I hope that's it. Because that is something that in this program we have tried to do, is to worry. A lot of us spend a lot of hours worrying and that is why I think, that nuclear power plants have been reliable and why these ships can cruise around the world submerged, they can go to the North Pole and come back, they can go on station with Polaris missiles and make the enemy worry. But, we aren't gonna make the enemy worry until we worry, and we oughta make our products work. Are there any questions? Yes, sir?

AUDIENCE MEMBER: Speaking of worry, does a submariner worry about getting all sixteen Polaris missiles off the submarine with no malfunctions?

LEIGHTON: Well, submariners get paid submarine pay, I guess that's to take care of the worries. The obvious thing there is, that a tremendous amount of effort has gone in to trying to make these ships reliable and make their systems reliable. You read in the papers of course, where some of them have been fired, some functioned and some did not function. As far as the submariner is concerned though, he doesn't really worry about the thing blowing up his submarine, he is concerned, whether he can deliver all his missiles to the target, and actually all these can function. But the system is such that the missile does not ignite its engine while it's in the ship. It's ejected by air, so if it didn't eject, the missile hasn't been activated. He doesn't have to worry about it sitting there going off and it's held back and it's gonna burn up the ship. It is an air ejection system as you may have noticed from Edward R. Murrow's program on "The Year of Polaris." It is hurled to the air and then ignited. So he's not worried from that standpoint, but actually he's concerned that he has a reliable system and that's why such a tremendous amount of effort goes in to checking these out. That's why these things cost one hundred million dollars apiece, it's because of worrying about these things. Is it worth one hundred million dollars? I don't know, what is freedom worth? And certainly this is one of the things that's helping to protect what freedom we do have. Another question? Yes, sir?

Audience member asks a question.

LEIGHTON: The question is, what do we put on these ships in case we just miss the enemy ship you wanna shoot? The Polaris submarine, is designed as a deterrent weapon. It is not designed to shoot at enemy shipping, from the standpoint of going to war to do that. It is armed with torpedoes to defend itself. But, the function of this ship is to be a deterrent to enemy attack for wholesale war. You just can't design every function in to the same ship. We've got the deterrent power; we've got to be able to fight another war. These are all attack submarines, and they fire torpedoes, their function is to shoot at enemy shipping. Submarine or surface ship. That is their function. Not to shoot at cities, to shoot at ships.

AUDIENCE MEMBER: They have no deck guns?

LEIGHTON: No, no, they don't surface to shoot, they fight their war underwater. They fight their war underwater, no guns. There's no point in putting guns in these things. If this guy can't perform his mission submerged, he isn't gonna bother coming home, or somebody's gonna pick it up so he does.

Audience member asks a question.

LEIGHTON: The question is, "Is the torpedo used today the same as it was twenty-five years ago?" The answer is no, a tremendous amount of development has gone on to try and develop better torpedoes. If you'd asked that question at the beginning of World War II, the answer would have been yes, but because of course that was one of the real problems in the Navy, that there had not been torpedo development between World War I and World War II, and of course the Japanese had torpedoes far superior to ours, the great Americans did not have them, but I hope again that we learned our lesson, and an awful lot of effort went to improve torpedoes, but I can't go in to any details in that. Yes, sir?

Audience member asks a question.

LEIGHTON: Well, that's a good question, there are a lot of arguments of one screw versus two screws and of course the obvious question is, if you have two screws and something happens to one of them, you can run on the other. If you only have one, then you've had it as far as operating. Another means of propulsion which I don't want to discuss is provided, but will not give you any speed at all, but the answer to that is, what you do, you buy one screw in order to get the improved ship performance, and then you do everything you can to guard this propeller. To keep it. It's one thing about it is, it's centrally located, you've got the planes and the rudder to help protect it and to divert things, and you build as much guard around the propeller as you can to prevent damage to the one propeller, but if you in fact do any major damage to the one propeller, then you seriously immobilize the ship. As I said there's another means of propulsion, but nothing than other just a slow speed.

Audience member asks a question about noise.

LEIGHTON: Quieter than diesels. Well, I don't wanna get into what's quieter and what's noisier because I get in to classified areas. All I can say for that is that a tremendous amount of effort. First of all, we have high powered machinery which automatically generates a lot of noise. Now a lot of effort goes in to trying to find means of making them as quiet as possible. I can say this, that those people who, in our Navy, that have tried to stand up against the nuclear submarine in attack exercises find that they have enough trouble with conventional submarines, it's even more trouble with nuclear submarines. But, I can't get in to definite noise comparison. Always get in trouble. See, I'm lucky - I don't know the answers to these questions, but I can say it's classified **(laughter)**. And, in fact it is classified but also in fact, well I know the answers to some of them, but not all of the details. Yes, sir?

Audience member asks a question.

LEIGHTON: Are any of the nations of the free world building nuclear submarines. The British have launched their first nuclear submarine. The propulsion plant for the *Dreadnaught* is the same as this type of propulsion plant, and was procured from the United States under a special contract bilateral agreement between the United States government and the British government. The British worked for several years on the development of a nuclear propulsion plant for a submarine and finally concluded that they just couldn't afford to keep working on it. They're better off to buy one of ours and work on development from there. So, arrangements were made to sell them one propulsion plant of the *Skipjack* type, or the *Scamp*. This is same type. All these, well this, and this one, and that other one have the same basic propulsion plant, and they're buying one of that type. That ship hasn't been launched, I'm not sure when she's going to sea, someone here might know the answer to that. Now that's the only one I know of that is anywhere near completion. I think the French have announced that they're working on the design of a nuclear-powered submarine, but I don't know the status of it. The Russians, that's something else again, and the Russians of course have stated that they are building it. The first official statement, or first statement by an official to a member of our government, that they were building a nuclear submarine was when Mr. Kozlov told Admiral Rickover that they definitely were working on nuclear submarines. And as far as I know, this was the first official statement on their part, but they have made statements since, and Mr. Khrushchev has stated that they have nuclear submarines. But, they have made no official statements as to how many and what their state of completion is. They of course have built the *Lenin*, which is the nuclear-powered ice breaker, with three reactors in it. The power of each of those things…

AUDIENCE MEMBER: … four Russian nuclear subs that are actually in the water?

LEIGHTON: I can't answer that; it may have but Janes may have listed that. Janes usually has some pretty good dope that's usually on that sort of thing somewhere close to the truth. I don't question for a minute that the Russians have nuclear submarines or have them under construction. If they don't, they certain can have, let's put it that way. No question the Russians have the technical capability to build nuclear-powered submarines. Now, whether they're building them or not, how many, I don't know. Yes, sir?

AUDIENCE MEMBER: Is zirconium considered an absolute requirement for a workable submarine?

LEIGHTON: The question here was, "is zirconium considered an absolute requirement for workable submarines?" No, I wouldn't say that. Zirconium is a very good material for what we want, but the *Seawolf* had no zirconium in it. And it was a workable submarine. So, it's not an absolute requirement, but it is the, of the metals that we know, it is one of the best, and it's the one that we are making a lot of use of. Yes, sir?

Audience member asks a question.

LEIGHTON: Oh, I mentioned a pebble-type reactor. I'd rather not take the time on that. There were some discussions of a reactor using so-called pebble. You put the fuel in the little pebbles and then you ran, or you actually fluidize the bed, you ran a gas stream through it and actually ran the stuff in suspension in the gas stream. It's just a conceptual design study. Submitted by some company, I forget, Flue or something like that, or somebody. People, you can, if you think of it, it can be done. Well, somebody thought about it for a reactor design and of course it's true of any business, and some of these things may be good concepts.

AUDIENCE MEMBER: Are they graphite pebbles?

LEIGHTON: I can't answer that. I don't recall. As far as I know nobody's talked about actually building one. Yes?

Audience member asks a question.

LEIGHTON: Oh, the activated rudder.

AUDIENCE MEBMER: Yes.

LEIGHTON: I don't know. I guess people still work on that sort of thing. I can't tell you the status of the concept of the activated rudder today, it's been proposed off and on for many many years. I don't know. It's not, well, let me put it this way, it's not currently employed in any U. S. warship. But, if it's another subject, it has nothing to do with nuclear power, this is a question of an activated rudder, which makes a ship swim like a fish tail. Any other questions? Yes, sir?

Audience member asks a question.

LEIGHTON: how long does it take to refuel one of these. That gets in to a classified area. How should I answer that? *Nautilus* has been refueled, what, now refueled twice now, right? Or three. *Nautilus*. Been refueled twice, been refueled twice. I don't know. You talk, you do it, the concept of refueling nuclear submarines is to do it during an overhaul where the refueling is not the controlling item. You do, as in any machinery plant, you have to overhaul, and so you save them all up, and you overhaul it, and while you're doing it, you refuel it.

Audience member asks a question.

LEIGHTON: The question is, on the wings, the, with the *Albacore* hull form, going to nuclear power, the bow planes were moved, *Sargo*, *Halibut*, all the World War Two submarines, the bow planes are on the bow. In this hull form, they've been moved to the sail and it gives you a better hydrodynamic performance submerged in the high-speed submarine of this hull form. It's a better control over the ship's angles at high speed.

AUDIENCE MEMBER: But the *Halibut* had none.

LEIGHTON: No, with the *Halibut* you can't see it, there are bow planes on the bow on the *Halibut*. You can't see it from where you're sitting. But these, all of these high speed submarines, this hull form, single screw boats, all of them moved the bow planes to here. It just gives you better control submerged, which is a Naval architects' problem and I won't try and explain it to you all the reasons why.

Audience member asks a question.

LEIGHTON: No sir, no. Bilge keels are not common on submarines.

AUDIENCE MEMBER: do any of the component tests from the alloy or lower alloys able to compete with the stainless hardware?

LEIGHTON: For…

AUDIENCE MEMBER: Pressure vessels.

LEIGHTON: No, I don't think so.

AUDIENCE MEMBER: Are there still stainless steel fabrication problems?

LEIGHTON: Right now we're having stainless steel fabrication problems, that's right, and there are problems. Now, these are not unsolved problems, our problem is find one to go solve it, you can do it, but we can weld stainless steel, the problem is to do it in production. The problem is to do it with the kind of welder you can hire and the kind of training you give them, anything that requires a higher state of training costs you more money, fewer people that can do it, a higher rate of inspection. It's a cost proposition. There's no question that we can weld stainless steel. We can build stainless steel components, the question is, can we do it on a production basis, and do it repeatedly, at any reasonable price? That's our problem. These problems are obviously solved, you can build these plants, the question is, can you do it at any kind of reasonable price? Yes, sir?

Audience member asks a question.

LEIGHTON: Can't answer that one. I think, I'm not even sure what the unclassified depth you're allowed to say is. I think over two hundred feet or something. Can't talk about submergence. Another question back there?

AUDIENCE MEMBER: Is there any bright future for conversion of heat to electricity?

LEIGHTON: Oh, any bright future for the conversion of heat to electricity. Well, that really has nothing to do with nuclear power, so I won't go in to that.

AUDIENCE MEMBER: I meant, instead of running a generator.

LEIGHTON: I know exactly what you mean, but it ain't got nothing to do with nuclear power **(laughter)**. No, this is one, well let me just take a moment on that. That's been one of our problems. People have all kinds of idea, and naturally, in order to sell those ideas, they go to a program that is moving and has money in it **(laughter)**. That's literal, don't laugh, that's so. For example, for years people tried to sell the idea you should work on direct conversion of heat to electricity, and based on the nuclear program. Missiles have got money today, and I wouldn't be the least bit surprised to see that come in, and people come and say well now, this is what you need for your missile. People naturally go where they think there's some money that they can work on their idea. And this isn't an unreasonable thing, but it is as long as you're associating in your mind that these things have anything to do with nuclear power. When you can get a good heat conversion straight to electricity fine, the talk about applying it to nuclear power which is a heat source. But get your thermal-electric power first and then talk about applying it to nuclear power. If it's hard to do with heat, it's gonna be harder to do when you've got radiation involved in it, and if it's hard to get materials to produce thermal-electric power, it's gonna be even harder when you add on to the fact to the material you get all the problems of the materials to start with to get thermal-electric power, now you say they must stand high radiation fields, and that makes it even tougher.

I have a personal opinion in this subject, I don't think the thermal-electric power for nuclear application is going to be seen to any advantage in any near future. There is no question that you can get thermal-electric power, heck the Russians power their radios in their homes, and a lot of rural communities with a kerosene lamp and you may have seen one of the Russian radios with a little kerosene lamp, and it provides the electrical power for running the radio. Or an ice box that way. They've got ice boxes you can run off a kerosene lamp. Refrigerators. So there's no question that thermal-electric power, well let's start with the thermocouple, we use those every day, and go on from there, and it is a subject which needs greater exploration, a lot of work should be done. I don't wanna say it isn't important, but I think for nuclear applications as a source of heat, it's not be coming in the near future to an advantage.

AUDIENCE MEMBER: It does seem like a nice quiet way to run a submarine.

LEIGHTON: It seems like a nice quiet way to run a submarine. One of the fundamental problems with thermal-electric power for a nuclear plant is that, by it's nature requires the establishment of a thermal gradient, and to establish a thermal gradient requires a large amount of power. Now, what do you do when you wanna go from full power to zero power? You reject some, even at twenty percent efficiency in a thing which is very hard to get, you reject eighty percent of your heat to the sea, and if you've gotta run your reactor at eighty percent power to run the shaft at zero power, you gotta be real careful how you go in to this. Furthermore, you have to have maneuvering transients in these. You talk about a base load plant that's gonna run at full power the whole time, it's a different proposition than a submarine which has to maneuver, and when you're gonna maneuver, you either run this doggone thing at high power, you additionally have to worry about thermal shock. So, there are a lot of problems, but they're not insurmountable problems perhaps. It's another whole major field. Yes, sir?

Audience member asks about materials after exposure to radiation.

LEIGHTON: Well, I did say that we do lack information, and one of the best places to get information on the technical nature on this, is of course in the experimental piles at Arco, the materials testing reactor, the engineering test reactor at Arco, that are built specifically for the subject of putting experiments inside them and taking out the results at a given time, and looking at them to see what happens. All I can say on our course, we're not experimental reactors. We put them in there to give them life and when the fuel is burned out, we take them out and put more fuel in. What I can say is, that before we ever commit a core to a nuclear reactor, we have ensured within the capability of engineering development, that that core will last the life of the fuel before we put it in. In other words, that the material will stand up throughout the life of that core. We don't put it in until we feel convinced that it will. So where we get the engineering information to determine our limits is out of experimental facilities.

Now, the land prototypes I might add are a real asset to the country, the land prototypes are used as experimental facilities in addition to being land prototypes. All of our land prototypes for the propulsion plants are built to simulate submarines and we train our crews on those land prototypes. A crew gets trained to operate a reactor before it ever sees a ship on the land prototypes. But in addition to that, the land prototype reactors are designed to be able to run experiments in them in addition to actually being operating reactors, we can run experiments in them to gain such information as you're talking about. Although, in the prototypes, we do not run experiments which we think will lead, or are liable to lead, to failure of fuel, in the experiments. We run those in places like, at Arco in the engineering test reactor, materials testing reactor. Today, a lot of information's available, on the other hand, a lot of times it takes a year, or two years from the time we start the experiment, you start the experiment, until you've got back the results. It's a very slow and painstaking process to develop information. Particularly for trying to get cores to last the length of a war for example. Now you're trying to get a long-life core and you want to subject it to life testing, you gotta subject it to a long-time test. And then when you get it out, it's highly radioactive so in order to analyze it, you have to do it in very, you have to do it in these hot cells, you know, where you can do remote control et cetera. Yes, sir?

Audience member asks a question.

LEIGHTON: I would say the question is, are costs going up or are they coming down when you get the multiplicity? Where we have built multiple submarines and the prices have come down. Electric Boat's prices on three nuclear submarines of the attack-type, some are displayed over here, were considerably less than prices for individual submarines. Now there's no question that multiplicity will lead to some reduction in price, but we are in a high price business nonetheless.

AUDIENCE MEMBER: Still changing so frequently.

LEIGHTON: You're still high priced, you're still making changes, you're still trying to improve, but we get some price reduction from multiplicity, but we're still in an expensive business no matter what we do. We aren't gonna cut by a factor of ten or anything like that, but you can pare off ten percent, twenty percent, something like that. Any other questions? It's getting pretty late here.

Audience member asks about testing components and accepting weld x-rays.

LEIGHTON: We use x-ray and ultrasonic both to a great degree, yes.

AUDIENCE MEMBER: So the failure of these welds, have they been weld x-rayed?

LEIGHTON: Generally speaking, if we have satisfactory radiographs, for example I failed to mention a heat exchanger, uh, a component we had to take out **(laughter)** the particular welds concerned which had cracking had not been radiographed. That's how we found out about it, we radiographed them. They had not been radiographed. It was a type of a weld that was very difficult to interpret the radiography on, and therefore it had been put together with a dye-check team, dye-checking every pass, et cetera, and not radiographed and we happened to find reason to radiograph them and did radiograph and found defects and went from there. But we do use radiography a great deal on our welding and we of course accept the results of that, as leading us where to go.

END OF LECTURE.