MEMORANDUM FOR THE SECRETARY OF THE NAVY

SUBJECT: EVALUATION OF POSSIBLE HAZARDS CREATED BY LOSS OF USS THRESHER

SUMMARY

Any hazard from the THRESHER would have to derive from the radioactive fission products which were created during operation and are now held in the reactor fuel alloy. Physical damage to the reactor could not by itself lead to release of these fission products; release could result only from melting of the reactor or very slowly by corrosion. The total quantity of radioactive fission products in the reactor is small, since the reactor had been shut down for nine months prior to her sinking. The maximum rate of release and dispersal of this radioactivity in the ocean is low.

These conclusions are confirmed by measurements of seawater, ocean bottom, air and debris collected near the THRESHER, all of which have shown no radioactive contamination.

(b) (6) , 45764

4/19/63 . retype of pages 1, 2, 3 & 4 only

The question of what hazard if any is created by sinking of the nuclear submarine THRESHER has been analyzed; the conclusions are summarized below:

a. There is no way the nuclear material in the THRESHER could be made to undergo a nuclear explosion, ie. there is no danger that it can or will explode like a bomb.

b. The radiation outside the ship is normally undetectable a few feet away--even when the reactor is operating at full power.

c. The reactor is designed so that it will shut down automatically in the event of any casualty. (For example, flooding of the electrical equipment will cause the reactor to shut down) It is inconceivable that the reactor could still be operating.

d. The hafnium control rods in the reactor corrode even more slowly than the zirconium. Moreover, they are several times thicker than the fuel pieces. Thus, the control rods could not corrode away and leave an uncontrolled reactor. I know of no plausible way for the reactor to start up by itself due to corrosion or mechanical damage.

e. Thus, any hazard would have to derive from the radioactive fission products built up in the reactor core during its operation. The question is: is there any way these radioactive fission products could escape from the [redacted] reactor core? If they did escape, could they pose a hazard? Measurements have been made to detect any radioactivity in seawater, air, ocean bottom and debris collected in the area where the THRESHER went down. No radioactivity above the natural background has been found (see Table I). These measurements confirm expectations that no radioactive hazard would be created by the THRESHER's sinking. The matter is discussed further below in terms of worst possible assumptions and their consequences.

f. The THRESHER's nuclear reactor core (designated Type S5W-2) is designed to operate in water. The reactor core is made up b(3) AEA of uranium-zirconium fuel alloy b(3) AEA which is highly resistant to seawater. This fuel alloy holds the radioactive fission products. Further, the fuel alloy is covered with a cladding made of another zirconium alloy which has even greater corrosion resistance. This zirconium cladding totally encloses the fuel alloy. Even if the fuel b(3) AEA were to be broken or smashed, the fission products would still remain metallurgically bound within the fuel alloy and would not disperse.

g. The reactor core is located inside a heavy pressure vessel. It has been calculated that this pressure vessel and the other components and piping of the reactor system, which were hydrostatically tested in the ship to an internal pressure of b(3) AEA would not collapse under the sea pressure at b(3) AEA feet depth. It is expected however that there would be leakage of seawater into the reactor system around the edges of the handhole covers on some of the reactor system components. It is possible, of course, that the reactor plant system may have been damaged or broken in some way, but this would still not change the conclusions stated below nor would it increase the hazard. In any event, it can only be concluded that the reactor core is submersed in water, either the original fresh water or seawater.

b(3) AEA

h. Zirconium is chemically similar to titanium. ~~Its~~ The corrosion of zirconium in seawater is so small that it is difficult to measure accurately; experiments show the corrosion rate to be about 10 millionths of an inch per year, with no evidence of pitting or other local attaack. At this rate, it would take over b(3) AEA years to corrode through the protective cladding which is b(3) AEA thick and which encloses the fuel alloy. After the cladding corrodes through, the fuel alloy itself would begin to dissolve, at a rate twenty or thirty times faster. An additional b(3) A years would than be required to dissolve the fuel alloy and expose all of its fission products.

i. It is difficult to envision a casualty which could cause the reactor fuel to melt. The "decay heat" given off by the fission products after shutdown is small b(3) AEA, and decreasing since the reactor had been shut down nine months prior to the sinking and the ship had accumulated only a few hours of power operation since her overhaul b(3) AEA Thus the "decay heat" could not melt the b(3) AE pounds of fuel elements (melting point: 3300°F), even if the reactor core remained dry for some time. When flooded, the core will not even get warm.

j. Even if a nuclear casualty of some sort were postulated which could have caused a meltdown of part of the fuel, the hazard posed to the public from this casualty would be negligible. It has been calculated that if a "nuclear run-away" of 500 megawatt-seconds were somehow to occur (this is four times as big as the accident which destroyed the Army's SL-1 reactor in Idaho) this would melt only a part of the reactor core and would probably not create a large enough pressure surge to rupture the reactor system. The quantity of fission products created by such a "nuclear run-away" would be no greater than that already produced by previous reactor operation, and most of them would be short lived.

k. The <u>total long lived fission product inventory</u> now in the THRESHER reactor core is about 30,000 curies--comparable to the 43,500 total curies dumped under USAEC auspices into the Atlantic Radioactive Waste Burial Site twenty miles inland of where the THRESHER lies. This quantity of radioactivity is such that, if all the THRESHER fuel cladding were removed and the unprotected fuel alloy were corroding and dispersing into the sea without impediment, the <u>solution rate would be only 300 to 500 curies per year.</u> This rate is harmless; it is comparable to rates calculated by the National Academy of Sciences (Reports NAS-NRC 655 & 658, 1959) to be acceptable for continuous dumping of radioactive wastes into shallow coastal waters near US cities. For the open sea, those NAS-NRC studies conclude that 400,000 curies per month would be acceptable.

l. <u>Even if this reactor core had melted</u>, the rate of solution of biologically significant fission products would be slow. This is because these <u>fission products would be in the form of refractory oxides which will dissolve ~~only~~ slowly in seawater</u> and will not float. Even after the fission products dissolve in the seawater, their dispersion would be impeded by the reactor pressure vessel and by the ship's hull, to whatever extent these present a barrier to convection and diffusion from the reactor into the ocean.

DRAFT

Estimate of Possible Hazards Created by Loss of USS THRESHER

SUMMARY

Any hazard from the THRESHER would have to derive from the radioactive fission products created during operation and now ~~held~~ retained in the reactor fuel alloy. Physical damage to the reactor could not by itself lead to release of these fission products; release could result only from melting of the reactor or slowly by corrosion. The total quantity of radioactive fission products in the reactor is small, since the reactor had been shut down for nine months. The maximum rate of release and dispersal of this radioactivity in the ocean is shown to be small. These conclusions are confirmed by measurements of seawater, ocean bottom, air and debris collected near the THRESHER, all of which have shown no radioactive contamination.

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4/19/63

DRAFT

The question of what hazard if any is created by the sinking of the nuclear submarine THRESHER has been analyzed, and the conclusions are summarized below:

a. There is no way the nuclear material in the THRESHER could be made to undergo a nuclear explosion, i.e. there is no danger that it can or will explode like a bomb.

b. The radiation outside the ship is normally undetectable a few feet away--even when the reactor is operating at full power.

c. The reactor is designed so that it will shut down automatically in the event of any casualty. (For example, flooding of the electrical equipment will cause the reactor to shut down) It is inconceivable that the reactor could still be operating.

d. The hafnium control rods in the reactor are several times thicker than the fuel pieces and also corrode even more slowly then the zirconium. I know of no plausible way for the reactor to start up again due to corrosion or mechanical damage to the fuel or control elements.

e. Thus, any hazard would have to derive from the radioactive fission products built up in the reactor core during operation. The question is: is there any way these radioactive fission products could escape from the ship's reactor core? If they did escape, could they pose a hazard? Measurements have been made to detect any radioactivity in seawater, air, ocean bottom and debris collected where the THRESHER went down; no radioactivity above the natural background has been found (see Table I). Although these measurements confirm expectations that no radioactive hazard would be created by the THRESHER's sinking, the matter is discussed further below in terms of worst possible assumptions and their consequences.

f. The THRESHER's nuclear reactor core (designated Type S5W-2) is designed to operate fully submerged in water. It is made up of pieces of uranium-zirconium fuel alloy b(3) AEA which is highly resistant to seawater. This fuel alloy holds the radioactive fission products. The fuel alloy is covered with a cladding made of another zirconium alloy, developed for even greater corrosion resistance. This zirconium cladding totally encloses the fuel alloy. Even if the fuel pieces were to be broken or smashed, the fission products would still remain metallurgically bound within the fuel alloy and would not disperse.

g. The reactor core is located inside a heavy pressure vessel. (It has been calculated that this pressure vessel and the other components and piping of the reactor system, which were hydrostatically tested in the ship to an internal pressure of b(3) AEA would not collapse under the sea pressure at b(3) AEA depth. It is expected however that there would be some leakage of seawater into the reactor system around the edges of the handhole covers on some of the reactor system components. It is possible, of course, that the reactor plant system may have been damaged or broken in some way by the accident, but this would not change the conclusions below or increase the hazard.) In any event, it seems highly probable that the reactor core is submersed in water.

h. Zirconium is chemically similar to titanium. Its corrosion in sea-water is so small that it is difficult to measure accurately; it is estimated from experiments to be about 10 millionths of an inch per year, with no evidence of pitting or other local attack. At this rate, it would take b(3) AEA [redacted] to corrode through the protective cladding b(3) AEA [redacted] which encloses the fuel alloy. After the cladding had been dissolved, the fuel alloy itself would dissolve at a rate twenty or thirty times faster, which would still require nearly b(3) AEA [redacted] to dissolve the fuel alloy and expose its fission products. The hafnium control rods would dissolve even more slowly than the zirconium.

i. It is difficult to envision a casualty which could have caused the reactor fuel to melt. The "decay heat" given off by the fission products after shutdown is small b(3) AEA [redacted] and decreasing), since the reactor had been shut down nine months prior to this test dive and had only accumulated a few hours of power oper ation since her overhaul (--equivalent full power hours). Thus it is not expected that "decay heat" could melt the b(3) AE [redacted] pounds of zirconium fuel eleements (melting point: $3300^{\circ}F$).

j. Even if a nuclear casualty of some sort were postulated which could have caused a meltdown of some of the fuel, the hazard posed to the public would be negligible. It has been calculated that a nuclear transient of 500 megawatt-seconds (5 times the SL-1 transient) would b(3) AEA [redacted] would not create a large enough pressure surge to rupture the reactor system. The fission products created during such a transient would be no greater quantity than those already produced by previous operation.

k. The total long-lived fission product inventory now in the THRESHER reactor core is about 30,000 curies--comparable to the 43,500 curries dumped under USAEC license into the Atlantic Radioactive Waste Burial Site twenty miles inland from where the THRESHER lies. (Table II lists for comparison several other radioactive sources.) If all the THRESHER fuel cladding were removed and the unprotected fuel alloy were corroding and dispersing into the sea without impediment, the solution rate would be 300 to 500 curies per year. This rate is comparable to rates calculated by the National Academy of Sciences (Reports NAS-IVRC 655 & 658, 1959) to be harmless for continuous dumping of radioactive wastes into shallow coastal waters off the US cities.

l. Even if the reactor core had melted, the rate of solution of significant fission products is expected to be slow. This is because these fission products would be in the form of refractory oxides which are highly insoluble in seawater. Even after the fission products dissolve in the seawater, their dispersion would be impeded by the reactor pressure vessel and by the ship's hull, to whatever extent these present a barrier to convection and diffusion from the reactor into the open ocean.

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TABLE I
RADIOACTIVITY SURVEY

All samples of debris checked in detail for signs of beta-gamma and alpha activity--no indications

25 Samples of water collected by USS Seawolf down to her design depth checked for gross beta-gamma and alpha activity--no indications

Samples of Bottom, Deep Water and Plankton collected by the oceanographic ship Atlantis II--no gross radioactivity indications--detailed checks for various particular isotopes being completed this week by the AEC's Knolls Atomic Power Laboratory.

AEC Aerial Gamma Survey over 500 mile square area--results negative.

Air activity checked by AEC-DOD Weapons Monitoring Stations--no indications

US Public Health Service checking water, air, fish, etc. in various locations along the East Coast; these will be continued routinely

If ship is located, underwater gamma levels and radioactivity of water around the hull will be checked.

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TABLE II
VARIOUS RADIOACTIVE SOURCES*

Fission Product Inventory now in THRESHER Reactor	30,000 curies
Radioactive Wastes Dumped in Atlantic Burial Site to date	43,500 curies
Average Fallout during 1962 in 100 mile square in Northeastern US	30,000 curies
Natural Radioactivity in Seawater (K-40)--100 mile square, 1 mile deep	1,000,000 curies
Short-lived fission Products in THRESHER (10 day half-life)	1,000,000 curies
Radioactivity Discharged Annually into Columbia River from Hanford Reactor Operations (Mostly Short-lived)	1,000,000 curies
Fission Products from 100 Kiloton Weapon (1 week after detonation--mostly short-lived)	100,000,000 curies

* Quantitative comparison of these numbers can be misleading unless the considerable differences in half-lives and biological significance of the various isotopes is taken into account. The numbers are given for qualitative comparison only.