DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
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August 29, 2018

Mr. Shawn Seeley
U.S. Nuclear Regulatory Commission
Region I, DNMS
2100 Renaissance Blvd, Suite 100
King of Prussia, PA 19406-2713

Dear Mr. Seeley:

Subj: REQUEST FOR TECHNICAL ASSISTANCE IN THE ABANDONMENT OF RADIOISOTOPE THERMOELECTRIC GENERATORS IN SITU AT THE BOTTOM OF THE OCEAN

03029462

The Navy's radioactive materials program is licensed with the Nuclear Regulatory Commission under Master Materials License (MML) 45-23645-01NA. Under the MML, Naval Radioactive Materials Permit (NRMP) 45-45650-N1NP was generated for the storage of radioisotope thermoelectric generators (RTGs) on the ocean bottom pending a viable abandonment option. Enclosure (1) provides background information for the RTGs and justifications for abandonment in situ at the ocean bottom. Enclosure (2) is the Naval Ocean Systems Center evaluation and risk assessment for abandonment of the RTGs in situ. Enclosure (3) provides recommendations from the National Committee on Radiation Protection for radioactive waste abandonment in the ocean. Enclosure (4) is the U.S. Environmental Protection Agency evaluation and interpretation that abandonment of the RTGs in-situ does not constitute dumping and complies with the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matters, and the Marine Protection, Research and Sanctuaries Act of 1972, as amended, Ocean Dumping: 33 U.S.C.A. 1402(f).

The shielding of the RTG is expected to last past the 300-year mark; after this time the radioactive material in the fuel capsules (Strontium 90) would have passed through 10 radioactive half-lives and the activity remaining would be low. While the consequences of in situ abandonment of the RTGs are predictably small, recovery for the purpose of terrestrial disposal involves other non-radiological hazards. Because in situ abandonment offers less risk to the general public, the Navy plans to terminate NRMP 45-45650-N1NP. Supporting documents for in situ abandonment are forwarded in enclosures (1) through (4). Unless otherwise directed, the Navy will terminate the RTGs permit upon concurrence by the NRC of this action.

609885

NMSS/RGN1 MATERIALS-002

If you have additional questions, please do not hesitate to contact me via telephone at (703) 695-5259 or through electronic mail at jerry.n.sanders@navy.mil.

Sincerely,

S.T. Goodfellow
Director, Energy and Environmental Readiness Division
Director, Naval Radiation Safety Committee

Enclosures:
1. Background Information and Justification for Abandonment of RTGs In Situ and Termination of NRMP 45-45650-N1NP
2. Naval Ocean Systems Center Technical Report 1106, March 1986, Radioisotope Thermoelectric Generators Emplaced in the Deep Ocean
3. U.S. Department of Commerce Handbook 58, Radioactive Waste Abandonment in the Ocean
4. U.S. Environmental Protection Agency (Marine Pollution Control Branch) Letter of 14 March 1995

Copy to: Nuclear Regulatory Commission
Naval Sea Systems Command (04N)
Naval Sea Systems Command Detachment, Radiological Affairs Support Office

BACKGROUND INFORMATION AND JUSTIFICATION FOR ABANDONMENT OF RTGS IN-SITU AND TERMINATION OF NRMP 45-45650-N1NP

References: (a) U.S. Department of Commerce Handbook 58, Radioactive Waste Abandonment in the Ocean
(b) Naval Ocean Systems Center Technical Report 1106, March 1986, Radioisotope Thermoelectric Generators Emplaced in the Deep Ocean
(c) London Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matters
(d) Marine Protection, Research and Sanctuaries Act (MPRSA) of 1972, as amended, Ocean Dumping: 33 U.S.C.A. 1402(f)

1. Background.

In 1970 and 1977 the Navy emplaced a total of six radioisotope thermoelectric generators (RTGs) in the deep oceans. These devices were installed to provide power for acoustical transponders that served as geodetic benchmarks. The fuel capsules of the RTGs are designed to retain their integrity for at least 300 years while exposed to seawater at 10,000 pounds per square inch. Each RTG consists of a strontium-90 titanate heat source, thermoelectric generator, thermal insulation, biological shielding, and a pressure vessel/housing which has the proven ability to withstand at least 20,000 feet of ocean depth. The location, emplacement date, depth, radioactivity level at the time of emplacement, current radioactivity level based on radioactive decay, and model of each RTG as well as the name of each manufacturer are listed in Table 1 below. The three URIPS-P1 RTGs are located in the Pacific Ocean. The SNAP-21 and the two RG-1 models are located in the North Atlantic.

Table 1

Manufacturer	Model Number	Initial Activity at Emplacement (Ci)	Current Activity Corrected for Decay (Ci)	Location of RTG	Depth (feet) Approx	Notes
3M	SNAP-21 (No. S10P2)	28980	9304	[redacted]	14,400	(1)
General Atomics	RG-1 (No. 37)	7086	2646	[redacted]	10,860	(2)
General Atomics	RG-1 (No. 38)	6781	2532	[redacted]	10,344	(2)
Aerojet General Corp	URIPS-P1 (No. 15)	7949	2544	[redacted]	16,120	
Aerojet General Corp	URIPS-P1 (No. 16)	7949	2544	[redacted]	16,119	
Aerojet General Corp	URIPS-P1 (No. 18)	7949	2544	[redacted]	16,169	

Note (1): Includes 270 pounds of depleted uranium (DU) used as shielding in the RTG
Note (2): Includes 360 pounds of depleted uranium (DU) used as shielding in the RTG

2. Justification.

a. Reference (a), Section 1.2.a, recommends abandonment of all "packaged wastes" be in regions where water depths exceed 1,000 fathoms (6000 feet). All of the RTGs listed in Table 1 above are located on the ocean floor at depths greater than 10,000 feet.

b. As recommended in reference (a), Section 1.g, adequate records and information for the abandonment of the RTGs will be maintained and made available to requesting agencies.

c. As stated in reference (a), Section 2.2, it is of the utmost importance that radioactive isotopes introduced into the ocean in ways considered desirable for waste abandonment never be removed or recovered. At sea abandonment should be used only for materials for which there is no foreseeable future use. For disposal of the RTGs at a terrestrial site, recovery by a manned deep submergence vehicle capable of operating at depths greater than 16,000 feet would be highly difficult and risky. Reference (b) details the failed recovery attempt of the three URIPS-P1 RTGs located near Midway Island in August 1978. These details convey the complexities and risks associated with recovery and terrestrial disposal. While recovery by unmanned vehicles conveys less risk to human lives, it is costly and not guaranteed to be successful. It can be concluded that removal and recovery of the RTGs (which have no foreseeable future use) would be extremely difficult and costly.

d. Reference (a), Section 2.1 states that any recommendations concerning the abandonment of radioactive wastes in the ocean not only provide adequate safety but also be such that they will minimize (or if possible, eliminate) the possibilities of undue public alarm. Section 2.3 states in all planning for sea abandonment every possible precaution must be taken to avoid hazards to individuals through accidental and unknowing contact with potentially dangerous amounts of the isotopes. The outer hulls of the RTGs are designed to maintain system integrity for 50-150 years, depending on RTG model. Furthermore, based upon a corrosion rate of 10^{-4} inches per year, the fuel capsules can sustain immersion at 10,000 psi for at least 300 years without deformation. Nonetheless, a number of risk analyses have been performed that assume the worst situation and do not take advantage of these barriers, but rather consider rupture of the capsule and exposure of the strontium-90 titanate to the marine waters at the time of emplacement. This radiological impact is summarized in reference (b) which concludes that the risk to the environment and the general public is insignificant.

e. Reference (a), Sections 4.2 and 5 state, in part, that to minimize or eliminate hazards from packaged wastes, containers must be of such a nature that they sink to the bottom, remain intact until they reach the bottom, and are not dumped in any region where they might be accidently or intentionally retrieved during fishing or salvage operations. Direct hazards, by definition, are those that might arise from exposure to dangerous levels of radiation. Therefore, the waste material should be isolated to avoid the possibility of close proximity. Effective isolation can best be achieved by disposing of the material in the deep ocean far from land. Virtually complete isolation can be achieved by depositing the material on or in the sediments of the deep ocean floor. As detailed in reference (b), the RTGs are located at extreme depths (>1000 fathoms) and partially embedded in the ocean floor sediment. Commercial fishing operations do not occur at these depths and salvage operations would require specialized deep diving equipment.

f. Reference (a), Section 4.3 states, in part, that indirect hazards are those that might arise from the accumulation of potentially harmful amounts of radioactive isotopes in marine organisms used for human food. To avoid such hazards, the objective would be to dispose of waste materials in such locations that the likelihood of their reappearing in the food chain is minimized. Again, this involves the principals of isolation of the material. The RTGs deposited on the bottom of the deep sea do not contribute any foreseeable indirect hazard, because there is no significant biological exchange between the deep sea and the surface layers and because there is no fishing at depths of 1000 fathoms or more.

g. Reference (c), Articles III(l) (a) (i) and (ii) define dumping as any deliberate abandonment at sea of wastes or other matter from vessels, aircraft, platforms or other manmade structures at sea. Reference (c), Article III(l) (b) (ii) provides that "dumping" does not include placement of matter for a purpose other than the mere abandonment thereof, provided that such placement is not contrary to the aims of reference (c). By defining "dumping" to exclude "placement of matter for a purpose other than mere abandonment" reference (c) acknowledges that the eventual result of the placement of a device or matter might be its abandonment. Since the primary purpose of the placement of the RTGs was scientific, their placement or subsequent abandonment does not constitute dumping.

h. Reference (d) provides that dumping means a disposition of material. Dumping does not mean a disposition of any effluent from any outfall structure to the extent that such disposition is regulated under the provisions of the Federal Water Pollution Control Act, under the provisions of Section 407 of this title, or under the provisions of the Atomic Energy Act of 1954, nor does it mean a routine discharge of effluent incidental to the propulsion of, or operation of motor-driven equipment on, vessels. Furthermore, dumping does not mean the construction of any fixed structure or artificial island nor the intentional placement of any device in ocean waters or on or in the submerged land beneath such waters, for a purpose other than abandonment, when such construction or such placement is otherwise regulated by Federal or State law or occurs pursuant to an authorized Federal or State program. Since the placement of the RTGs was intentional, for purposes other than abandonment, pursuant to an authorized federal program, their subsequent abandonment would not constitute dumping under reference (d). In view of paragraphs 2.g and h, the contemplated abandonment does not violate either references (c) or (d).

NOSC
NAVAL OCEAN SYSTEMS CENTER San Diego, California 92152-5000

Technical Report 1106
March 1986

Radioisotope Thermoelectric Generators Emplaced in the Deep Ocean

Recover or Dispose In Situ?

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ADMINISTRATIVE INFORMATION

This work was conducted over the period May 1981 to March 1982 for the Naval Sea Systems Command, Radiological Affairs Support Office, Yorktown, VA, under NAVCOMPT140 NO537A81, WR00026. During the preparation of this report, Mr. J.F. Vogt was on the staff of Radiological Affairs Support Office.

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The risk to man of disposing, either in situ or by recovery and removal to a terrestrial site, of radioisotope thermoelectric generators deployed in the oceans is evaluated. It is concluded that in situ disposal will have benign consequences, whereas recovery would entail significant nonradiological hazards. In situ disposal is recommended.

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CONTENTS

INTRODUCTION

In 1970 and 1977 the Navy emplaced a total of six radioisotope thermoelectric generators (RTGs) in the deep ocean. These devices were installed to provide power for acoustical transponders that served as geodetic benchmarks.

The fuel capsules of the RTGs are designed to retain their integrity for at least 300 years during exposure to seawater at 10,000 psi. They are fueled with radioactive strontium-90, whose half-life (27.7 years) is such that only a small fraction (5.5×10^{-4}) of the initial radioactivity remains at the end of this 300-year interval.

The purpose of this report is to consider the risk to man of in situ disposal of the RTGs versus recovery for ultimate disposal at a terrestrial site. A description of the RTGs, their emplacement sites, and their ability to contain the strontium-90 while exposed to a deep-ocean environment are provided. For in situ disposal, the strontium-90 concentration in seawater is calculated and the resulting dose to man estimated. Summaries of earlier safety analyses which considered in situ disposal are also included. For disposal at a terrestrial site, recovery of the RTGs from the deep oceans must utilize the submersible vehicle TRIESTE. Descriptions of this vehicle, a typical mission, and an attempted RTG recovery are included. Also, a general appraisal of the risks involved in the recovery and terrestrial disposal of the RTGs is provided. Finally a conclusion is drawn regarding the merits of the disposal alternatives.

RTG DESCRIPTIONS

Each RTG consists of a strontium-90 titanate heat source, thermoelectric generator, thermal insulation, biological shielding, and a pressure vessel/housing. Thermal energy generated within the heat source as a result of the radioactive decay process is converted into low-voltage dc electrical power within the thermoelectric generator. Thermal insulation is included to channel the heat flow through the thermoelectric generator and minimize parasitic heat losses. Although the beta particle emissions from strontium-90 and its daughter, yttrium-90, are absorbed within the fuel and fuel capsule, bremsstrahlung radiation is produced in the process, and this circumstance requires shielding. These components are enclosed in a pressure vessel/housing which has the proven ability to withstand at least 20,000 ft of ocean depth.

Three different models of RTGs, designated as SNAP-21, URIPS-P1, and RG-1, produced by the 3M Company, Aerojet-General Corporation, and General Atomic Company, respectively, were deployed. A diagram of each appears in Fig 1, 2, and 3. Each conforms in principle to the description given above and varies only in detail (Ref 1, 2, 3).

The fuel consists of hot-pressed strontium-90 titanate. The hot-pressed pellet is sealed in a stainless steel liner. Final encapsulation is within a nickel alloy, Hastelloy C or Hastelloy C-276, both highly resistant to the corrosive action of seawater. All of the capsules conform to the requirements listed in the International Atomic Energy Agency Safety Series No. 33, "Guide to the Safe Design, Construction, and Use of Radioisotope Power Generators for Certain Land and Sea Applications." Fuel, fuel liner, and fuel capsule characteristics are shown in Table 1.

IN SITU DISPOSAL

SITE DESCRIPTIONS

The location, emplacement date, depth, radioactivity level at the time of emplacement, and model of each RTG as well as the name of each manufacturer are listed in Table 2. The three URIPS-P1 RTGs reside at depths of 16,119-16,169 ft in the Pacific Ocean. The others are situated in the North Atlantic, a SNAP-21 at a depth of 14,400 ft, and two of the RG-1 models at depths of 10,344 and 10,860 ft.

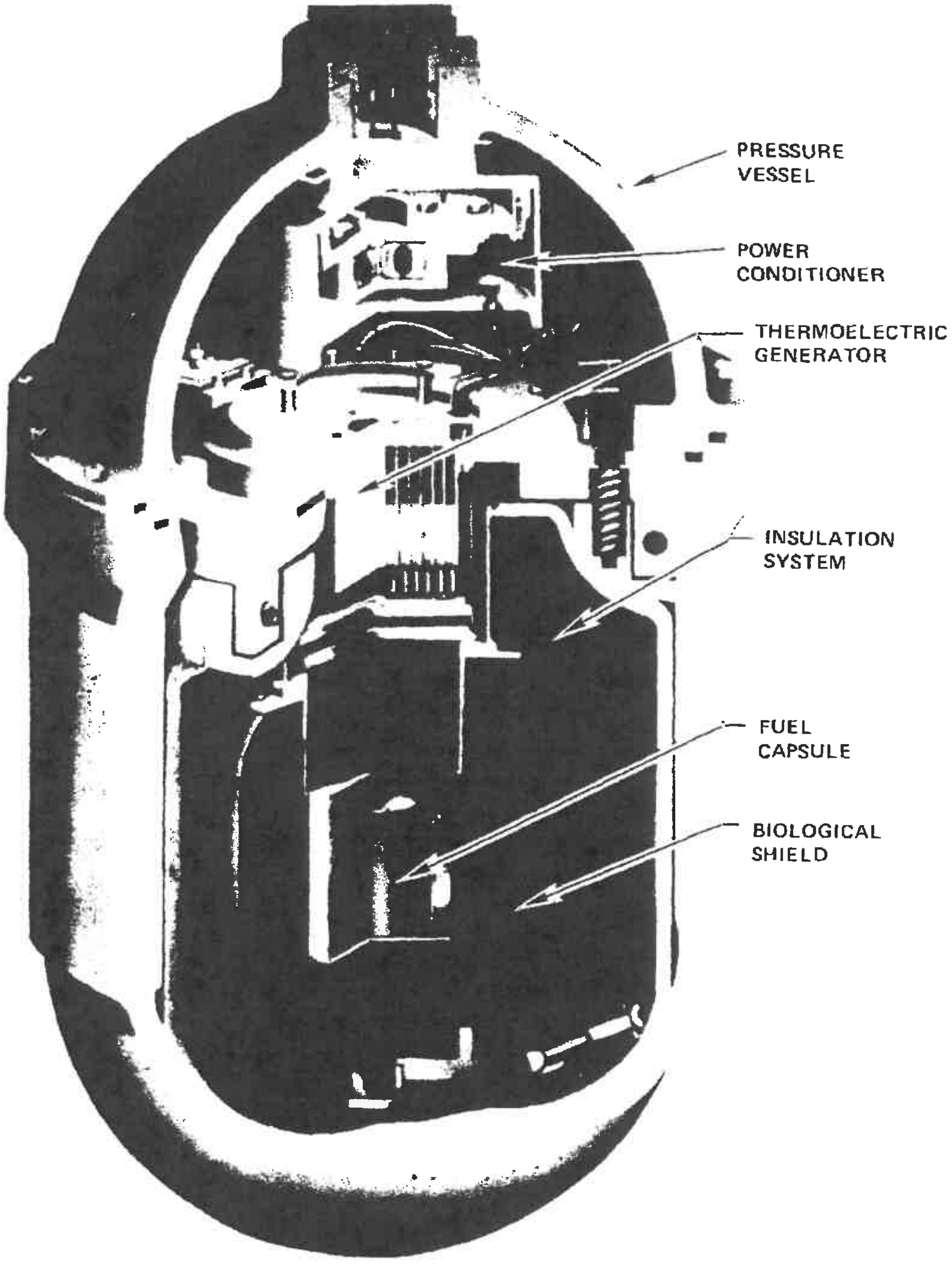


Figure 1. SNAP-21.

1 WATT(e) URIPS-P1, LEAD SHIELD

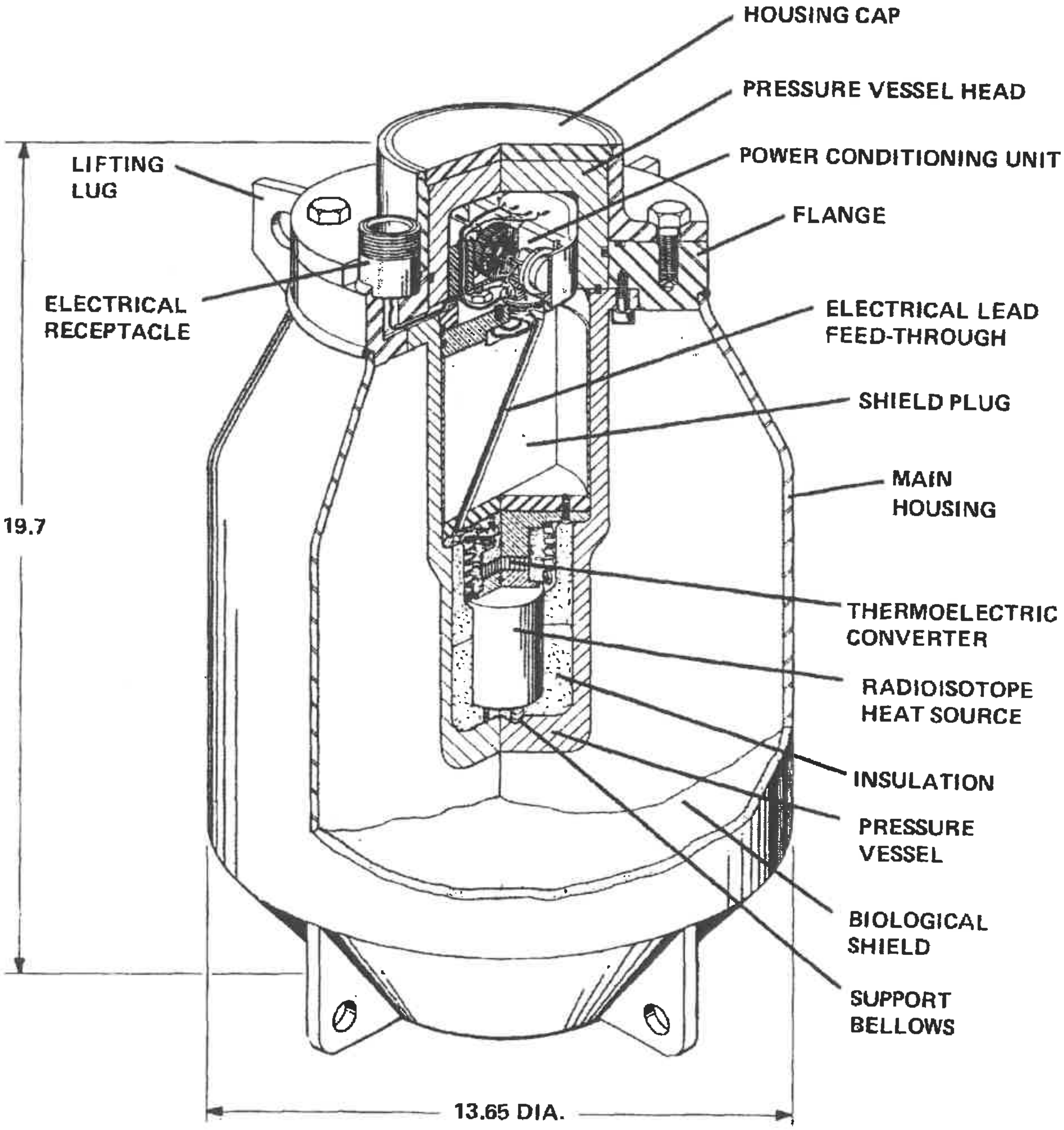
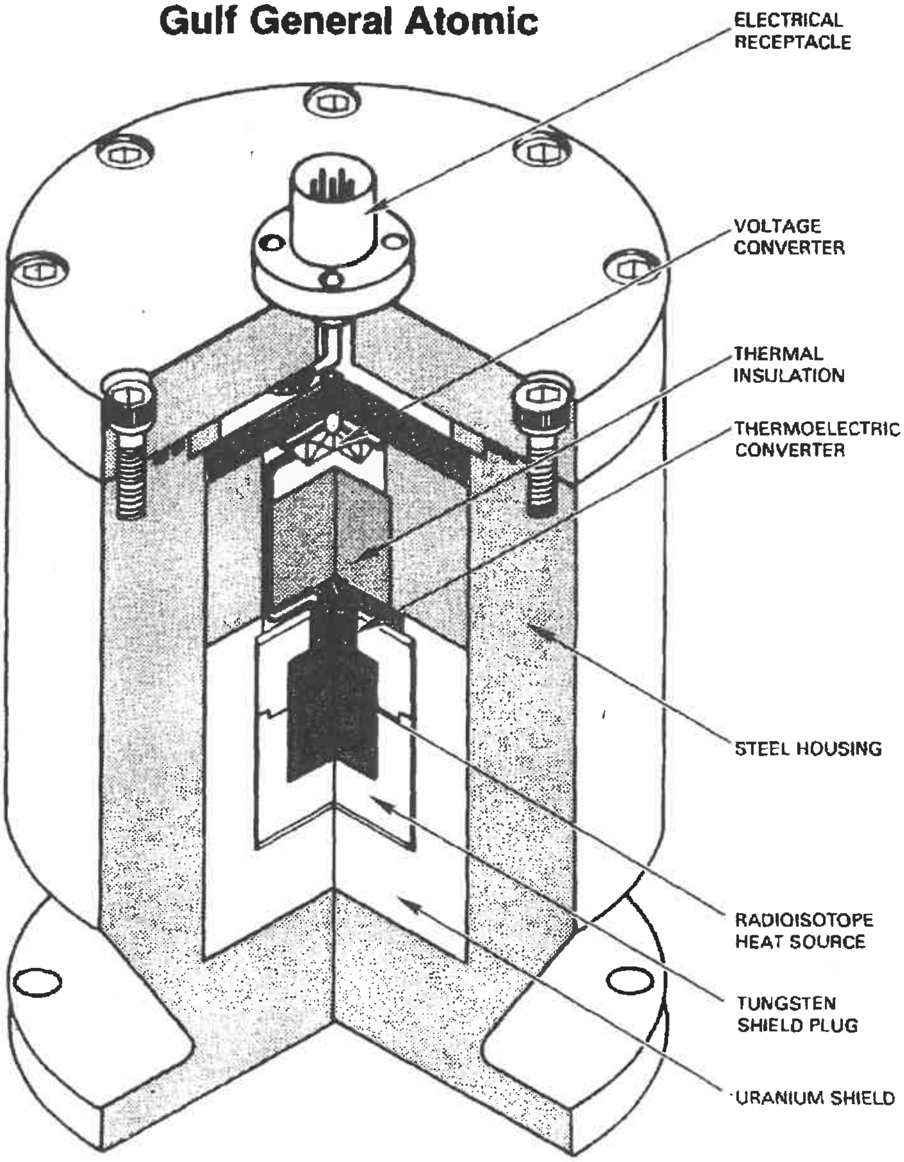


Figure 2. URIPS-P1

Gulf General Atomic



1-WATT RADIOISOTOPE GENERATOR

Figure 3. RG 1

Table 1. URIPS-P1, RG-1, and SNAP-21 RTG fuel, fuel liner, and fuel capsule characteristics (nominal values).

	URIPS-P1	RG-1	SNAP-21
Specific Activity ($Ci\ ^{90}Sr/gm\ SrTiO_3$)	34	33	33
Density $SrTiO_3$ ($gm\ cm^{-3}$)	5.1	5.03	3.7
Fuel Dimensions (in.)			
Length	1.810	1.52	2.73
Diameter	1.560	1.70	2.71
Fuel Liner			
Composition	Type 304 L SS	Type 304 L SS	Type 304 L SS
Thickness (in.)			
Wall	0.040	0.038	0.020
Top	0.140	0.140	0.075
Bottom	0.040	0.040	0.075
Diameter* (in.)	1.670	1.776	2.767
Length* (in.)	2.14 (overall)	1.780	2.909
Fuel Capsule			
Composition	Hastelloy C	Hastelloy C	Hastelloy C-276
Thickness (in.)			
Wall	0.200	0.250	0.200
Top	0.260	0.350	0.200
Bottom	0.280	0.350	0.200
Diameter* (in.)	2.090	2.290	3.197
Length* (in.)	2.700	2.530	3.339
Weld Penetration (in.)	0.130-0.150	0.080 (min) 0.100 (typical)	0.205

*Outside

Table 2. Inventory of Navy radioisotope thermoelectric generators emplaced in the oceans.

LOCATION	DATE OF EMPLACEMENT	APPROX. DEPTH (ft)	ACTIVITY (Ci) WHEN EMPLACED	MANUFACTURER & RTG MODEL	US NAVY RTG NO.
Atlantic Ocean	21 Nov 1970	14,400	28980	3M SNAP-21	S10P2
	27 Feb 1977	10,860	7086	Gen. Atomic RG-1	37
	1 Mar 1977	10,344	6781	Gen. Atomic RG-1	38
Pacific Ocean	4 Oct 1970	16,120	7949	Aerojet Gen. Nucl. URIPS-P1	15
	5 Oct 1970	16,119	7949	Aerojet Gen. Nucl. URIPS-P1	16
	2 Oct 1970	16,169	7949	Aerojet Gen. Nucl. URIPS-P1	18

IMPACT OF STRUCTURAL COMPONENTS

The major components of the RTGs consist of metals such as lead, tungsten, a molybdenum/uranium alloy, and copper. The total of the aggregates for the heaviest of the RTGs (SNAP-21) is only 800 lb. The oceans contain from 10^{11} to 10^{13} lb of these elements. Thus the small absolute quantities of the elements involved coupled with their recognized inherent insolubility in seawater strongly indicates that no adverse environmental effect can be anticipated from their disposal in the oceans.

RADIOLOGICAL IMPACT

The outer hulls of the RTGs are designed to maintain system integrity for 50-150 years, depending on RTG model. Furthermore, based upon a corrosion rate of 10^{-4} in./year, which was determined after a 10-year ocean test (Ref 4), the fuel capsules can sustain immersion at 10,000 psi for at least 300 years without deformation. Nonetheless, a number of risk analyses have been performed that assume the worst situation and do not take advantage of these barriers, but rather consider rupture of the capsule and exposure of the strontium-90 titanate to the marine waters at the time of emplacement.

In 1964 a safety analysis (Ref 5) conducted by the Irradiated Fuels Branch, Division of Materials Licensing, U.S. Atomic Energy Commission, of a SNAP 7E RTG with a heat source containing 3.1×10^4 Ci of strontium-90 titanate concluded that "using available strontium titanate solubility data and diffusion data for radioactive material in great depths of seawater, we have made calculations which show that a man could live and feed indefinitely in the environment which would exist at a distance of 1 meter from the SNAP 7E without attaining his maximum permissible body burden of 2 microcuries--we conclude that even if the SNAP 7E were not recovered and did release its strontium-90 titantate for dissolution it would not endanger the health and safety of the public."

Another analysis (Ref 6) considered a rupture of the SNAP-21 fuel capsule. In this case the initial strontium-90 titanate inventory was exposed to seawater. For the purpose of this analysis, the solubility of strontium titanate was taken as 1 mg cm^{-2} day^{-1}, although previous experimental work had shown that this compound dissolves initially at a rate of 0.5 and 0.7 mg cm^{-2} day^{-1} in the absence or presence of sediment and that the rate diminishes to 0.09 and 0.16 mg cm^{-2} day^{-1} at the end of 180 days (Ref 7). With this rate, diffusion into the ocean environment was calculated by Mikhail (Ref 8) using the Carter-Okubo model and assuming a continuously releasing source. Expressed in terms of iso-contours, a maximum permissible concentration (MPC) was contained within a volume of 3.57×10^2 m^3. To convey the biological significance of the contaminated patch, a comparison was drawn between the volume of contaminated seawater and the volume of seawater required to support production of an annual supply of seafood for an individual receiving his entire protein supply from seafood. For this analysis it was assumed that the release occurred in California coastal waters (average depth of 30 m), where a kilogram of seafood is produced in 10^4 m^3. The protein requirement for an individual is satisfied upon ingesting 75 kg $year^{-1}$, which is the amount contained in 150 kg of raw seafood. This quantity of seafood demands a volume of 1.5×10^6 m^3 for its support. Therefore the water contaminated at an MPC level or greater constitutes only 3×10^{-4} of the volume required to produce the annual protein supply for a single individual. This example indicates the trivial nature of the problem even if rupture of the fuel capsule is considered to occur at the time of emplacement.

In the present evaluation another approach was undertaken to analyze the risk to man. Two cases were considered. In the first, it was assumed that fuel was exposed to seawater at the time of RTG emplacement. In the second case, it was assumed that the RTG would contain the fuel for at least 300 years. The analysis is based upon methodology proposed by the U.S. Nuclear Regulatory Commission (NRC) for the estimation of doses to man from discharges of radioactive material to the hydrosphere (Ref 9).

In this method the concentration of a radionuclide in aquatic foods is assumed to be directly related to the concentration of the nuclide in seawater. To estimate this concentration, the results of Shepherd's studies on the dispersion of radioactive materials in a closed and finite ocean were applied. Shepherd developed a model to estimate equilibrium concentrations of radionuclides in seawater arising from a disposal site located on the bottom of the deep ocean (Ref 10). This model was later used as the basis for the London Dumping Convention. Shepherd suggests that safety assessments of deep sea disposals should be based on the long-term average concentration reached in a well-mixed ocean. This approach presumes that the initial release rate is maintained indefinitely, makes no allowances for mixing time, and assumes that the only removal process is radioactive decay. Thus, the methodology is deemed extremely conservative. Shepherd shows that the "well-mixed" average concentration is greater than the equilibrium concentration in biologically productive coastal waters.

To calculate the well-mixed average concentration in seawater, a measure of the quantity of strontium-90 that dissolves from each heat source per unit of time is required. This quantity was computed from the information available on the dimensions of each fuel pellet (Table 2) and a solubility rate, taken as 1 mg cm^{-2} day^{-1}. These values together with the specific surface concentration in the ocean (Ci m^{-3} per unit release in Ci s^{-1}) provided by Shepherd for a nuclide with the half-life of strontium-90 afforded computation of the strontium-90 well-mixed average concentration. In addition, a safety factor of ten was imposed upon the well-mixed average concentration to allow for the improbable event of a continuing rapid upwelling of the deep waters (Ref 10).

The well-mixed average concentration in each of the oceans was computed. The concentrations derived for the situation where fuel is exposed to seawater at the time of RTG emplacement were 1.64×10^{-2} and 5.0×10^{-3} pCi kg^{-1} for the North Atlantic and North Pacific Oceans, respectively. An example of the calculations is given in Appendix A. It should be noted that the RTGs were functional at the time of emplacement; thus fuel exposure at this time is contrary to fact. The concentrations are reduced by a factor of 5.5×10^{-4} were fuel, more realistically, to be exposed to seawater at least 300 years later.

With these concentrations, the annual dose to man was calculated as prescribed by NRC Regulatory Guide 1.109 (Ref 9). Bioaccumulation data, consumption rates of fish and other edible marine life for the maximum exposed individual, and ingestion dose factors for adults, teenagers, and children were taken from Tables A-1, E-5, E-11, E-12, and E-13, respectively, of NRC Regulatory Guide 1.109. An example of the calculations appears in Appendix B.

Annual doses to man for each of the situations considered are shown in Table 3. An example of the calculations is given in Appendix B. Even where the doses were calculated for an unrealistically premature exposure to seawater, the values are orders of magnitude below acceptable limits for the whole body. See Table 4.

TERRESTRIAL DISPOSAL

For ultimate disposal of the RTGs at a terrestrial site, recovery by the mannned submersible TRIESTE would be required. Only this vehicle is certified for operation at these depths. A description of the TRIESTE, a general mission profile, and a recovery attempt are presented in detail to convey the complexities and risks associated with recovery and terrestrial disposal.

VEHICLE DESCRIPTION

The TRIESTE is a self-propelled bathyscaph and consists of two main assemblies, a buoyancy chamber (float) and a cabin (sphere). The overall length and height of the vehicle is about 78 by 27 ft, and it displaces 268 tons at the surface. The craft is designed to ascend and descend by weight control. This control is accomplished by discharging shot ballast or by valving off aviation gasoline (AVGAS) to make the vehicle lighter or heavier than the surrounding water.

The float hull is essentially a hydrodynamically shaped container which houses ballast (BB-size iron shot) and AVGAS (66,000 gal) and serves as support for batteries, propulsion motors, sensors and other devices and equipment. End compartments in the float are floodable, and when filled with seawater the craft has a slight negative buoyancy.

Table 3. Dose (rem/yr) to the maximally exposed individual of an age group, for hypothetical capsule rupture and fuel release at the time of RTG deployment (A) and 300 years later (B).

A. Release at time of deployment

	BONE		TOTAL BODY		LOWER LARGE INTESTINE	
	ATLANTIC	PACIFIC	ATLANTIC	PACIFIC	ATLANTIC	PACIFIC
Adult	1.77×10^{-5}	5.38×10^{-6}	4.33×10^{-6}	1.32×10^{-6}	5.10×10^{-7}	1.56×10^{-7}
Teenager	1.47×10^{-5}	4.49×10^{-6}	3.63×10^{-6}	1.11×10^{-6}	4.13×10^{-7}	1.26×10^{-7}
Child	1.33×10^{-5}	4.07×10^{-6}	3.39×10^{-6}	1.03×10^{-6}	1.80×10^{-7}	5.47×10^{-8}

B. Release 300 years after deployment

Adult	9.74×10^{-9}	2.96×10^{-9}	2.38×10^{-9}	7.26×10^{-10}	2.81×10^{-10}	8.58×10^{-11}
Teenager	8.09×10^{-9}	2.47×10^{-9}	2.00×10^{-9}	6.11×10^{-10}	2.27×10^{-10}	6.93×10^{-11}
Child	7.32×10^{-9}	2.24×10^{-9}	1.85×10^{-9}	5.67×10^{-10}	9.88×10^{-11}	3.01×10^{-11}

Table 4. Dose-Limiting regulations and recommendations.

GROUP	DOSE LIMIT
Individual Members of the Public or Occasionally Exposed Individuals	0.5 rem in any one year (Ref 11,12)
Population (as a whole)	0.17 rem average per person per year (Ref 12)

The sphere is occupied by the operators. This chamber is the major pressure-resistant part of the vehicle and is designed for operation at depths exceeding 20,000 ft. Its pressure is maintained at 1 atm. Operating controls, monitoring devices, and an independent life support system are contained within this chamber. An observation window is oriented forward and slightly downward for providing a view of the ocean floor.

Silver-zinc storage batteries power the propulsion motors, lights, and the scientific and operational equipment.

GENERAL MISSION PROFILE

A mission profile (Ref 13) is presented to describe the considerations, risks, and sequence of steps that enter into the successful recovery of an object by TRIESTE. The preferred and more simplified method of operation includes support by a surface vessel dedicated exclusively to TRIESTE activities. This description will assume its availability, although the USS PT LOMA, which has served this function, currently is under other assignment.

Pre-mission planning focuses upon the mission site, methods of locating the object, water depth, bottom topography, sediment characteristics and the projected approach to be followed in the recovery. According to the plan developed, a suite of inboard and outboard equipment is selected for installation on the TRIESTE.

A provisioning phase involves the logistics of supplying expendable items such as AVGAS, various oils, ballast, nitrogen gas, and a number of other consumables. The transit phase aboard the POINT LOMA is used to prepare the TRIESTE for its assigned task. During this period project planning and command instructions are also reviewed. The TRIESTE crew receives final briefings on the task, and POINT LOMA personnel are instructed in detail to ensure a safe operation.

Upon arrival at the diving area all systems and equipment are examined with comprehensive and detailed check-off lists. Various lines, supply hoses, cabling and rigging for AVGAS, shot ballast, and communications are readied. Boats are launched to provide assistance in moving the TRIESTE out of the POINT LOMA. The well of the POINT LOMA is flooded, and the hawser boats pull the TRIESTE to a point about 500 ft astern.

Service lines between the POINT LOMA and TRIESTE are connected by divers, AVGAS tanks are filled, and shot ballast onloaded. During this period divers from the POINT LOMA check underside arrangements and open gates on the shot valves. Simultaneously, within the sphere, electronic and battery tests, shot valve readings, and other details are checked.

When TRIESTE is readied for the dive, its ballast tanks take on water and it begins descent. The rate of descent (about 2.5 ft/s) is controlled by venting AVGAS or discharging bursts of shot. If the vehicle descends at an angle, correction is managed by release of shot from the fore or aft tank as required. When the vehicle is approximately 1200 ft from the bottom, the release of shot ballast is accelerated to reduce the descent rate to about 1 ft/s. If the vehicle is properly trimmed, the descent is almost stopped when a 250-lb trail ball suspended 15-30 ft below the vehicle touches bottom. The TRIESTE then rides the trail ball line to the bottom.

The hull of the TRIESTE is relatively thin. Thus it is essential that the vessel not collide with any feature of the ocean bottom. Navigation on the bottom is primarily conducted through use of a navigation computer and the outboard sensor suite coupled to the computer. A manual mode is also available. TV cameras, searchlights, and visual observations are also used as aids to navigation.

Upon completion of the recovery, preparation for ascent is initiated. Check-off procedures are performed, which include monitoring breathing gas, carbon dioxide levels, and humidity. The vehicle is trimmed, and the ascent is started by dropping shot. The rate of ascent is carefully monitored and controlled by further shot release at 5- to 8-s intervals. During ascent all of the nonessential systems are shutdown to conserve power.

When the vehicle breaks surface, divers board to establish phone communications. Water is blown from the two end tanks to create slight positive buoyancy, causing the vehicle to rise sufficiently to provide an exit for the crew. AVGAS is pumped back to the POINT LOMA, and the tanks are purged with nitrogen gas to discharge the residual flammable vapors. Up to 5000 gal of AVGAS remain in the TRIESTE, and strict precautions must be observed to prevent static electricity and sparking.

Finally the POINT LOMA is flooded, docking procedures are carried out basically by the same steps as described for undocking, except in reverse order, and the return transit completes the mission.

Clearly, a TRIESTE mission is a major undertaking that poses certain recognized risks. The launching of the vehicle and support boats, diver activities with numerous lines in the water, the transfer of flammable AVGAS, operation at great depths in environments of unknown topography, dependency on an independent life support system, and recovery of the crew upon surfacing are but a few of the non-trivial tasks involved.

RECOVERY ATTEMPT BY TRIESTE

In August 1978 the TRIESTE and POINT LOMA were requested to recover the three URIPS-P1 RTGs located near Midway Island. In the recovery plan developed for this event, an RTG was to be secured to the TRIESTE and carried to the surface. (Sketches of the RTG system and pre-dive recovery hardware appear in Fig 4 and 5.) The bow winch cable was to be lowered and a hook at its terminus grasped by the manipulator arm. The hook was to pass around one or two of the standframe legs of the RTG and then snapped onto the bow winch cable. An alternate point of attachment was the RTG's power adapter assembly. Once hookup was accomplished, the bow winch was to lift the RTG from the bottom. If problems were encountered with the bow winch, the centerline lift rig was to be used. Plans also considered the possibility of securing a second RTG on the same dive—time, battery power, and the availability of the centerline lift rig permitting.

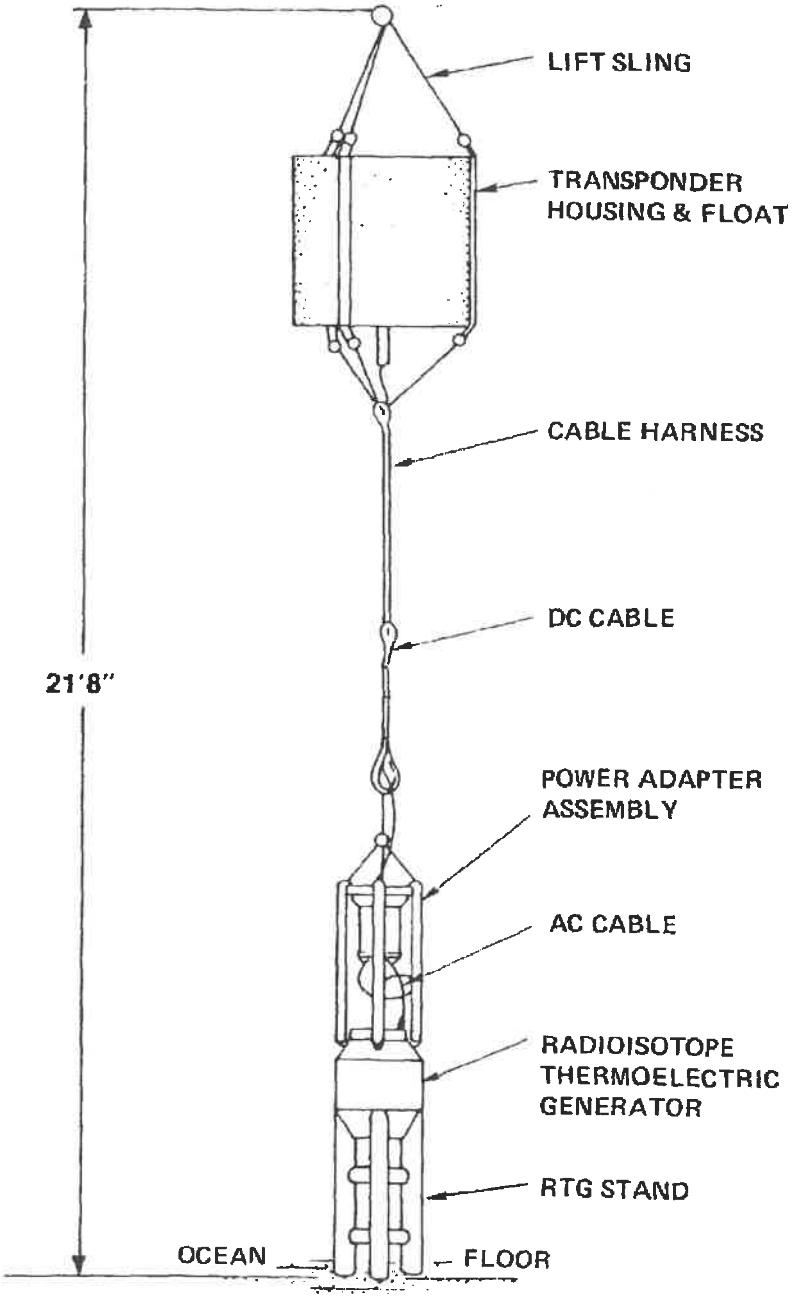


Figure 4. Deep ocean transponder system.

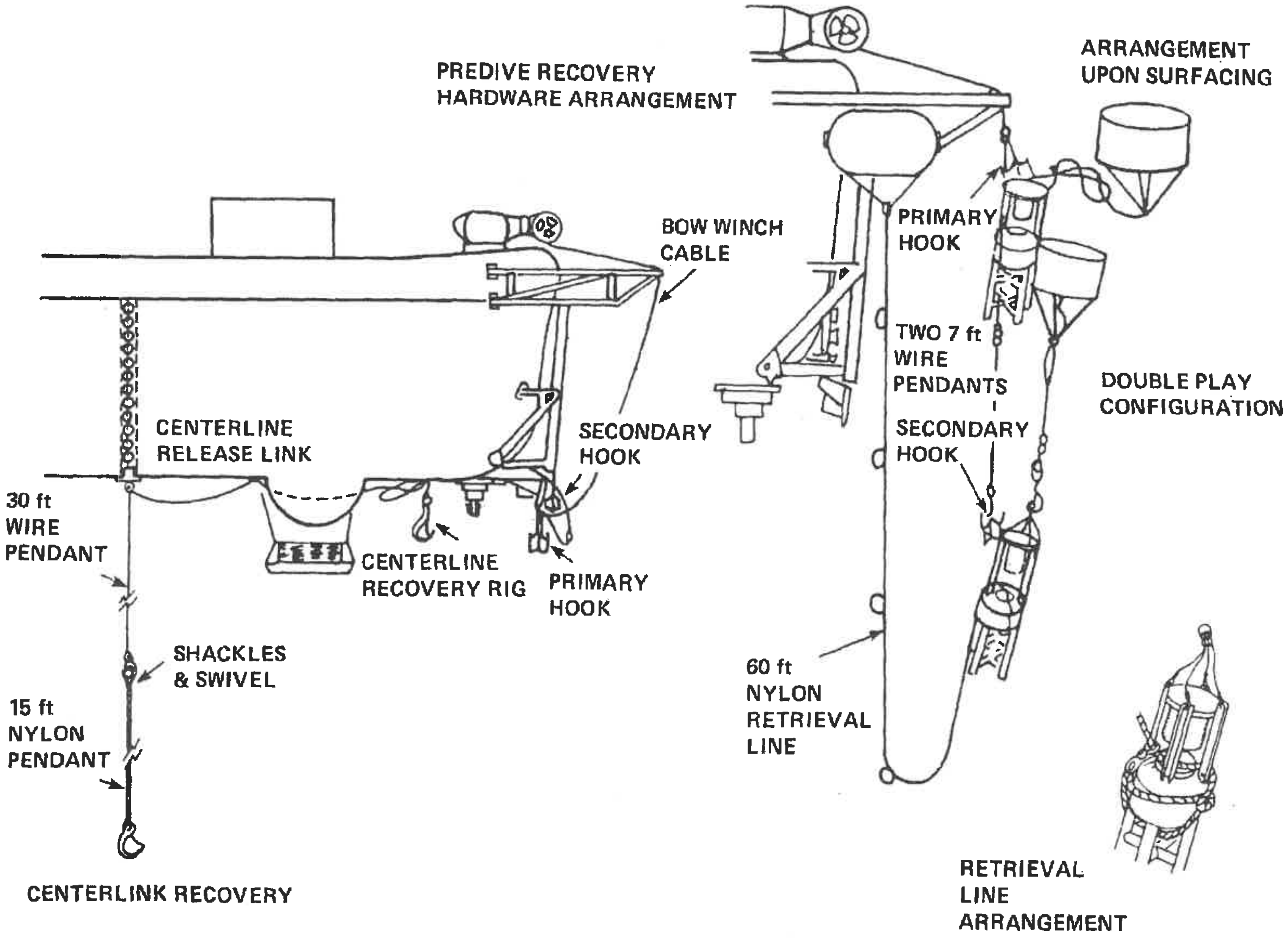


Figure 5. Midway RTG recovery equipment.

The POINT LOMA sailed from Pearl Harbor on 17 August and arrived on station the evening of 21 August. Evaluation of the accuracy of various means of navigation was immediately undertaken, and by 22 August the location of the POINT LOMA had been accurately defined.

The TRIESTE was prepared for launch on 23 August; however, the prevailing sea state prevented launch until 28 August. Pre-dive checkouts were conducted, and the descent started at 1000 on 29 August. The bottom was reached 1 1/2 hours later. After making contact with a sonobuoy, information was received from the surface tracking party to establish the position of the TRIESTE. Within 1/2 hour one of the RTGs was observed. The distance to the RTG was closed carefully, since movement of the vehicle produced dense clouds of silt that required about an hour to clear. About two-thirds of the RTG system was observed to be embedded in the sediment (Fig 6), and the only accessible lift points were the wire rope bridle and part of the power adapter assembly. When the manipulator arm was used to attempt to loosen and lift the RTG from the silt, a bridle cable fitting snapped. Upon attempting to free the RTG by grasping its power adapter assembly, hydraulic fluid was noted to be oozing from the manipulator arm, and it was secured. The RTG was subsequently lost from sight in another cloud of disturbed sediment. Repeated attempts to grapple the power adapter assembly with the bow winch hook were unsuccessful. The TRIESTE started its ascent at 1845 and surfaced 2 hours later. Since the recovery operation was severely hampered by loss of the manipulator arm, the mission was terminated.

IMPACT OF RECOVERY ON MAN

If the RTGs could be recovered from the ocean floor at this time, exposure to strontium-90 contamination is not anticipated. It is emphasized that the properties of the fuel capsule are such that exposure of strontium-90 to the environment appears improbable over the next several centuries. Nonetheless, an evaluation should be instituted by collection and analysis of waters and sediment in proximity to the RTGs before an attempted recovery. In the unlikely event that radioactivity is detected in these samples, it would be

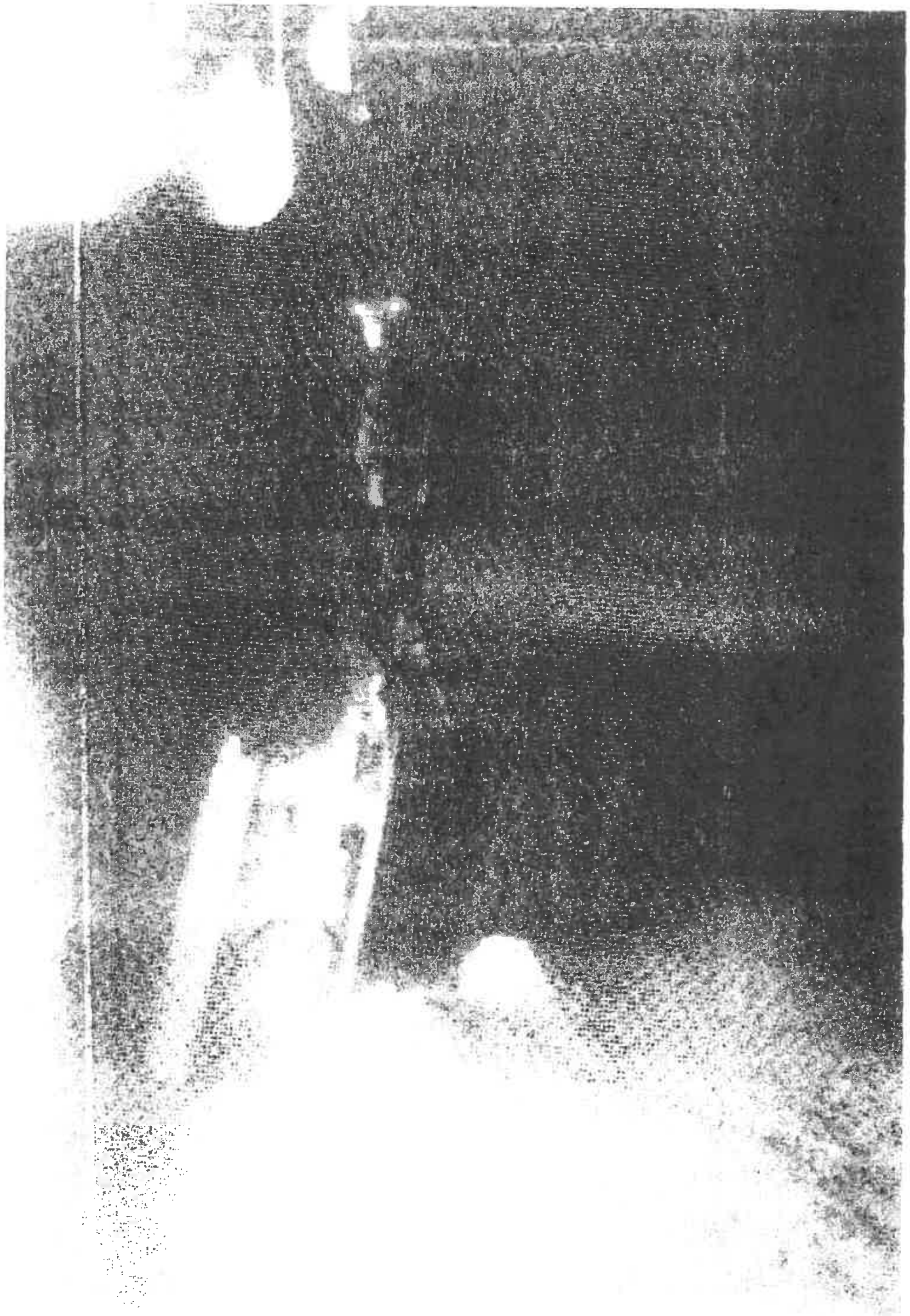


Figure 6. RTG as viewed from TRIESTE.

imprudent to recover the source unless a suitable scheme of contamination containment were devised and implemented from the onset of recovery until final disposal.

On the other hand, the exposure rate at the surface of the RTGs ranges from 100-120 mR/hr, and at 1 m, the rate is 5-6 mR/hr. Thus, personnel involved in transferring the recovered RTGs to the deck of the support ship, packaging them in shipping containers, and securing the containers for shipment would unavoidably receive a finite radiation dose. Additionally a radiation dose would be received by those individuals involved in offloading the shipping containers from the support ship, loading them onto a vehicle for transportation to a terrestrial disposal site, unpackaging the RTGs at the disposal site, and placing them into the disposal structure. Although the number is difficult to estimate, it is conceivable that many people could be exposed. The potential for transportation accidents also exists. Though TRIESTE has an excellent safety record, several scenarios may be developed from the mission profile that present a significant degree of non-radiological risk to the TRIESTE crew and support personnel.

SUMMARY AND CONCLUSIONS

From 1970 to 1977, six RTGs with kilocurie quantities of strontium-90 titanate were deployed at depths that range from approximately 10,000 to 16,000 ft. These devices were designed to withstand the corrosive action of seawater without exposing the strontium-90 fuel to the environment for at least 300 years. At that future time, only a small fraction of radioactivity (5.5×10^{-4}) would persist. The fraction remaining is further reduced by a factor of 1.6×10^{-4} to 13×10^{-5} if the 50 to 150 years of protection afforded by the outer hull is considered. Risk evaluation using the methodology proposed by the NRC was performed for an in situ disposal. The seawater concentration required for this evaluation was calculated by a method that provides a considerable margin of safety. Also exposure of the fuel to the environment was considered to occur at the time of deployment, thus deriving no benefit from radioactive decay, although it was recognized that the RTGs were functioning and therefore intact at that time. Even under these conservative circumstances, the results of the analysis indicate that the risk to man is insignificant.

Recovery of an RTG with the manned submersible TRIESTE was attempted in 1978. Navigation to the source was precise; however sediment character was such that much of the RTG structure was buried. A cable bridle and a portion of an assembly mounted on top of the RTG were visible above the sediment surface and available for attachment; however the bridle lacked sufficient strength to enable recovery, and due to equipment failures, the assembly could not be grasped.

The safety record of TRIESTE notwithstanding, the activities involved in a recovery mission are not without risk to its crew and support personnel; nor is recovery of the RTGs assured. Further, were the RTGs to be recovered successfully, the necessary actions involved in terrestrial disposal entail exposure of personnel to a measureable radiogical dose and potential transporation accidents.

In summary, in situ disposal of the RTGs is of predictable benign consequence, while recovery for the purpose of terrestrial disposal involves significant non-radiological hazards; furthermore measurable levels of dose to personnel participating in recovery and terrestrial disposal are inevitable. Accordingly, since the in situ plan offers less risk to man than the alternative, it is recommended as the method of disposal.

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APPENDIX A

A CALCULATION OF THE STRONTIUM-90 CONCENTRATION IN THE OCEAN

The ^{90}Sr well-mixed average concentration in the North Atlantic Ocean, postulating fuel release at the time of deployment of the SNAP-21, was calculated by the following formulation:

$$C = \frac{(SA)(DR)(A)(SF)}{(V)(D)}$$

where

C is the well-mixed average concentration of ^{90}Sr in seawater of the North Atlantic Ocean (pCi/kg).

SA is the surface area of the fuel (224.14 cm^2) derived from the dimensions of the fuel given in Table 1.

DR is the dissolution rate of the strontium-90 titanate in $g/cm^2/s$ and is equal to $\frac{0.001\ g/cm^2/day}{86,400\ s/day}$.

A is the activity of the fuel (28,980 Ci) as given in Table 1.

V is the volume of the fuel (257.63 cm^3) derived from the dimensions given in Table 1.

D is the density of the strontium-90 titanate (3.7 g/cm^3) as shown in Table 1.

SF is Shepherd's Factor in pCi/kg as deduced from Fig 7 of Ref 10 and (including a safety factor of 10) is equal to:

$$\frac{1.28 \times 10^{-7}\ \text{Ci/m}^3\text{/Ci/s} \times 10^{12}\ \text{pCi/Ci}}{10^{3}\ \text{kg/m}^{3}}$$

Upon substitution

$C = 1.01 \times 10^{-2}$ pCi/kg.

APPENDIX B

A CALCULATION OF RADIATION DOSE

The following is a calculation of the radiation dose to the bone of an adult from the ingestion of marine foods derived from North Atlantic Ocean waters contaminated with ^{90}Sr from RTGs that hypothetically ruptured at the time of their deployment.

The equation used from NRC Regulatory Guide 1.109 was

$$R_{aj} = (C)(U_a)(B)(D_{aj})$$

where

R_{aj} is the annual dose to organ <u>j</u> of an individual of age group <u>a</u> in mrem/yr.

C is the well-mixed average concentration of ^{90}Sr in the seawater (pCi/kg). The concentration calculated for the North Atlantic Ocean is 1.64 x 10^{-2} pCi/kg, of which 1.01 x 10^{-2} pCi/kg is derived from the SNAP-21 (see Appendix A) and 6.26 x 10^{-3} pCi/kg from the RG-1 sources.

B is the bioaccumulation factor, which is 2* for fish and 20* for invertebrates.

D_{aj} is the ingestion dose factor specific to age group and organ. For bone of an adult this factor is 7.58 x 10^{-3} mrem/pCi**.

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*Table A-1, ** Table E-11

U_a is the intake rate for an age group (kg/yr). For an adult the intake rate of rate of fish is 21*** and of invertebrates 5***.

Thus:

$$R_{aj} = 1.64 \times 10^{-2} \, [21(2)+5(20)] \, 7.58 \times 10^{-3}$$
$$= 1.77 \times 10^{-2} \text{ rem/yr of } 1.77 \times 10^{-5} \text{ rem/yr.}$$

***Table E-5 of NRC Regulatory Guide 1.109.

Fisher

RADIOACTIVE-WASTE DISPOSAL IN THE OCEAN

Handbook 58

U. S. Department of Commerce
National Bureau of Standards

U. S. Department of Commerce, Sinclair Weeks, Secretary
National Bureau of Standards, A. V. Astin, Director

Radioactive-Waste Disposal in the Ocean

Recommendations of the
National Committee on Radiation Protection

National Bureau of Standards Handbook 58
Issued August 25, 1954

For sale by the Superintendent of Documents, Washington 25, D.C. - Price 20 cents

Preface

The Advisory Committe on X-ray and Radium Protection was formed in 1929 upon the recommendation of the International Commission on Radiological Protection, under the sponsorship of the National Bureau of Standards, and with the cooperation of the leading radiological organizations. The small committee functioned effectively until the advent of atomic energy, which introduced a large number of new and serious problems in the field of radiation protection.

At a meeting of this committee in December 1946, the representatives of the various participating organizations agreed that the problems in radiation protection had become so manifold that the committee should enlarge its scope and membership and should appropriately change its title to be more inclusive. Accordingly, at that time the name of the committee was changed to the National Committee on Radiation Protection. At the same time, the number of participating organizations was increased and the total membership considerably enlarged. In order to distribute the work load, ten working subcommittees have been established, as listed below. Each of these subcommittees is charged with the responsibility of preparing protection recommendations in its particular field. The reports of the subcommittees are approved by the main committee before publication.

The following parent organizations and individuals comprise the main committee:

American College of Radiology: R. H. Chamberlain and G. C. Henny.
American Medical Association: P. C. Hodges.
American Radium Society: E. H. Quimby and T. P. Eberhard.
American Roentgen Ray Society: R. R. Newell and J. L. Weatherwax.
National Bureau of Standards: L. S. Taylor, Chairman, and M. S. Norloff, Secretary.
National Electrical Manufacturers Association: E. D. Trout
Radiological Society of North America: G. Failla and R. S. Stone.
U. S. Air Force: S. E. Lifton, Maj.
U. S. Army: J. P. Cooney, Brig. Gen.
U. S. Atomic Energy Commission: K. Z. Morgan and J. C. Bugher.
U. S. Navy: C. F. Behrens, Rear Adm.
U. S. Public Health Service: H. L. Andrews and E. G. Williams.
Representatives-at-large: Shields Warren and H. B. Williams.

The following are the subcommittees and their chairmen:

Subcommittee 1.	Permissible Dose from External Sources, G. Failla.
Subcommittee 2.	Permissible Internal Dose, K. Z. Morgan.
Subcommittee 3.	X-rays up to Two Million Volts, H. O. Wyckoff.
Subcommittee 4.	Heavy Particles (Neutrons, Protons, and Heavier), H. H. Rossi.
Subcommittee 5.	Electrons, Gamma Rays, and X-rays Above Two Million Volts, H. W. Koch.
Subcommittee 6.	Handling of Radioactive Isotopes and Fission Products, H. M. Parker.
Subcommittee 7.	Monitoring Methods and Instruments, H. L. Andrews.
Subcommittee 8.	Waste Disposal and Decontamination, J. H. Jensen.
Subcommittee 9.	Protection Against Radiations from Radium, Cobalt-60, and Cesium-137 Encapsulated Sources, C. B. Braestrup.
Subcommittee 10.	Regulation of Radiation Exposure, L. S. Taylor, Acting.

There are many possible methods for disposing of unwanted radioactive wastes. It is the purpose of this Handbook to bring to the attention of those concerned, the many different factors that should be taken into account when radioactive wastes are to be dumped into the ocean, and to make recommendations for the proper use of this disposal method. The recommendations contained in this Handbook represent what are believed to be the best available opinions on the subject as of this date, but recommendations made now and in the future must be reviewed from time to time in the light of new knowledge and experience. Comments on the recommendations here presented will be welcomed by the committee.

The present Handbook was prepared by the Subcommittee on Waste Disposal and Decontamination. Its membership is as follows:

J. H. Jensen, Chairman.
W. F. Bale.
R. H. Chamberlain.
W. D. Claus.
S. Feitelberg.
R. H. Fleming.
J. C. Geyer.

G. W. Morgan.
R. Overstreet.
O. Placak.
E. H. Quimby.
C. C. Ruchhoft.
W. H. Sullivan.
F. Western.

A. V. Astin, *Director*.

Contents

Radioactive-Waste Disposal in the Ocean

1. Introduction and Summary of Recommendations

1.1. Introduction

The ever-increasing production and use of radioactive isotopes has raised numerous questions concerning their handling, transportation, and ultimate disposal. It appears that the sea may be an appropriate place for the disposal of intermediate and large amounts of isotopes having long half-lives (more than 1 year) or high radiotoxicity. It is the purpose of this Handbook to outline some of the factors that must be considered in the disposal in the ocean of unwanted radioactive wastes.

Two factors will generally be involved in any decision as to the method of disposal employed—safety and convenience. In many instances where the quantities are small or the half-lives relatively short, unwanted isotopes or contaminated equipment and materials may be safely disposed of by storage, flushing into the sewage or drain systems, incineration, or by burial on land.[1] [2] The choice between sea disposal and other methods will in part be determined by the quantity of the radioactive material, its half-life, and its type; but in many instances the selection may be based upon convenience and economics. It seems very reasonable to assume that producers or users of radioactive isotopes located on or

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[1] Some phases of these various methods are discussed in previous reports of this Committee. See National Bureau of Standards Handbook 42, Safe handling of radioactive isotopes; NBS Handbook 48, Control and removal of radioactive contamination in laboratories; NBS Handbook 49, Recommendations for waste disposal of phosphorus-32 and iodine-131 for medical users; and NBS Handbook 53, Recommendations for the disposal of carbon-14 wastes.

[2] This is not to imply that disposal by burial in soil should be limited to small quantities and short half-lives. Land storage of solids by direct burial or in vaults, and of residues from liquid wastes in underground tanks, may be safe in specific areas. There will be a report on this subject by the National Committee on Radiation Protection in the near future.

near the coasts, or on inland waterways, may find it simpler to dispose of virtually all wastes at sea; whereas agencies that are isolated from the ocean or have only small amounts of wastes may prefer to use land burial or other methods of disposal.

This Handbook presents recommendations concerning the sea disposal of radioactive wastes that have been enclosed in massive containers. Formulation of these recommendations required a careful consideration of both immediate and long-term effects that could result from the introduction of radioactive materials into the ocean. These effects could only be estimated from an understanding of some of the basic characteristics of the oceans. The following material, upon which the recommendations for packaged waste disposal are based, is therefore necessary for an understanding of the acceptable procedures and will be helpful in dealing with specific waste-disposal problems and in evaluating other proposed methods of disposal. The problems raised are in many ways unique, and they brought to light the lack of knowledge that exists concerning many of the factors that will be involved in the ultimate distribution and fate of radioactive isotopes dumped in the ocean. Much research on the basic factors, as well as engineering investigations of specific methods of disposal, remains to be done to provide the proper guidance in this problem that is of ever-increasing local, national, and international concern.

1.2. Summary of Recommendations

a. Site

Disposal of all packaged wastes shall be in regions where water depths exceed 1,000 fathoms. The disposal of bulk wastes shall also be confined to regions where water depths exceed 1,000 fathoms, except for small quantities of liquid waste or as experimental studies indicate conditions under which disposal of liquid wastes may be safely conducted in other areas. Within these limitations, designation of specific sites does not appear necessary at the present time.

b. Transportation

All personnel handling or transporting radioactive wastes should follow recommendations given in National Bureau of Standards Handbook 42 to hold exposure to a minimum. The whole-body exposure to gamma radiation shall not exceed 300 mr/week measured in air, and exposure of the hands shall not exceed 1,500 mr/week measured in the skin.

Although recommendations cannot be made about the type of vessel to be used for sea disposal, present experience indicates that a hopper-type vessel, such as a garbage scow, may be the most suitable.

c. Regulations

There exists no authority at the present time for the control of dumping of radioactive wastes on the high seas. Packaging and handling of radioactive materials for transportation shall conform to regulations of the U. S. Interstate Commerce Commission and of the U. S. Coast Guard, wherever applicable. Regulations of the U. S. Atomic Energy Commission, the U. S. Interstate Commerce Commission, and the U. S. Coast Guard require specification labeling of packages containing radioactive materials.

d. Methods of Disposal—Packaged

Disposal of all packaged wastes shall be in regions where water depths exceed 1,000 fathoms. Containers for packaged disposal shall be designed, constructed, and filled in such a way as to insure that the package:

(a) cannot be easily damaged or broken, and will reach the bottom without appreciable loss of contents;

(b) is free of voids;

(c) has a minimum average density of 1.2 g/cm^3, or 10 lb/gal;

(d) has sufficient shielding for safe storage, shipment, and handling, and

(e) is of a size and shape to be handled quickly and conveniently.

It is recommended that packages have an identification semipermanently impressed in a concrete or metal surface; including the name of the organization preparing the package, the date, and (for use in case of accident) indication of the most hazardous radioisotope involved and of the level of activity contained.

e. Methods of Disposal—Bulk

Bulk disposal includes all operations in which radioactive wastes are discharged directly into the sea in unpackaged form. It is preferable that the material be in such a form that it will sink when discharged. For example, the material could be prepared in the form of insoluble beads, pellets, or briquettes; or it may form a precipitate of high density. Liquid materials should have a density greater than 1.1 g/cm^3 to facilitate mixing. Greasy or oily materials that would float or coagulate and form a scum are unsuitable for bulk disposal.

Except for small quantities or experimental operations, bulk disposal shall be confined to areas in which the depth is 1,000 fathoms or greater.

f. Methods of Disposal—Pipeline

The disposal of radioactive wastes through pipelines is considered undesirable.

g. Records

Adequate records of dumping operations shall be kept. Such information, listing amounts and types of different radioisotopes, methods of disposal, localities, and dates, shall be available to the U. S. Coast Guard or to other cognizant agencies upon request.

2. General Considerations

In formulating the principles involved in radioactive-waste disposal, one immediately encounters items that cannot be evaluated numerically. Statements of maximum clarity concerning these intangibles are essential if the proposals to be made are to be understandable. Before describing the factors that affect methods of sea disposal, it is necessary to explain briefly some of the basic premises that are involved.

2.1. Public Relations Aspect

Any recommendations concerning the disposal of radioactive wastes in the ocean shall not only provide adequate safety but also be such that they will minimize (or if possible, eliminate) the possibilities of undue public alarm. Unfavorable situations might arise if a package of radioactive material were found on the shore or recovered in a fisherman's net or by a trawler or dragger. In addition to such material evidence of poor practices, there is every reason to anticipate that any decline in the sportsmen's catch, or in a commercial fishery, might be attributed to the dumping of radioactive wastes. Unsound rumors that marine food products contain sufficient quantities of radioisotopes to be detrimental to health should be countered rapidly and effectively. Last but not least, it is possible that waste-disposal practices may be responsible for international incidents leading to formal protests being lodged between nations. Advance publicity might help avoid unfavorable public reactions, and it is obvious that any recommendations should be entirely justifiable in the light of existing knowledge.

2.2. Finality of Disposal

It is of the utmost importance to remember that radioactive isotopes introduced into the ocean in ways considered desirable for waste disposal can never be removed or recovered. This point is stressed because it represents a major distinction from land burial. Because any land burial site can be either intentionally or accidentally reopened, the material is capable of recovery. There are already cases on record where for one reason or another land disposal sites have had to be shifted. In the case of sea disposal, as discussed here, the act is final. There are two aspects of this situation that should be recognized: first, sea disposal should be used only for materials for which there is no foreseeable future use; and second, if disposal at sea is carried on under conditions or to an extent that later appears to have been ill-advised or dangerous, there is no way of correcting the situation. If for any reason it becomes desirable to deposit materials on the sea floor for future recovery, appropriate methods, beyond the scope of this report, will need to be developed.

2.3. Accidental Hazards

In the laboratory, in the factory, and on land burial sites, hazards involved in radioactive wastes can be minimized or eliminated by posting notices, by erecting barriers, or by actually policing the areas. None of these can be done at sea except under extreme situations such as the tests at Bikini and at Eniwetok. In all planning for sea disposal every possible precaution must be taken to avoid hazards to individuals through accidental and unknowing contact with potentially dangerous amounts of the isotopes. The situation is analogous to "fire prevention" rather than "fire fighting." Procedures should be such that the accessible portions of the ocean are not altered to any appreciable extent. Then in this case warnings and policing are quite unnecessary.

2.4. Rate of Disposal

Waste isotopes with long half-lives (more than 1 year) are those that are most likely to be introduced into the ocean. At the present time the potential amounts are small, but in the foreseeable future these may have to be disposed of at a high rate. It is not possible at this time to set "maximum permissible concentrations" for sea water similar to those for potable water. If the rate of supply is greater than the rate of decay, the total amount of activity in the sea will increase. It must be recognized that this will in theory set a limit on the rate at which material can be introduced into the ocean. In practice, this may prove no limit at all because of the immense volume of the ocean waters. On the other hand, we cannot assume that the materials introduced will be uniformly distributed through the entire volume. Nothing is known of how long it would take for material introduced at any locality to be more or less uniformly distributed throughout a large portion of the ocean waters, but it is undoubtedly measured in thousands of years. Therefore, there will be a practical limit to how much can be introduced at a single location or dumping ground.

The "maximum permissible concentrations" of radioactive isotopes in sea water will differ from those in drinking water. The greatest hazard will probably arise through the accumulation of radioactive isotopes in organisms that are later consumed as human food.

2.5. General Responsibilities

Any proposals for sea disposal of radioactive wastes should cover the entire problem of packaging, transportation, temporary storage, and methods and locations of discharge into the ocean. Proper safety regulations already in effect govern certain of these procedures but by no means all of them. There may be certain legal questions concerning sea disposal of radioactive wastes that must be resolved. At the present time there is no established authority to regulate matters of possible interest such as disposal areas, maximum limits, and records. The principles set forth in this Handbook are, therefore, not within any framework of recognized regulations.

3. Characteristics of the Ocean

Although the oceans are bodies of tremendous volumes, an appreciation of the broad problems involved in the disposal of radioactive wastes in the oceans should take into account not only the volumes concerned but also other physical, chemical, and biological characteristics. It is hoped that a brief outline of certain aspects of oceanography, largely extracted from "The Oceans" [1],[3] may prove helpful as a background in rendering judgment on this problem.

3.1. Volume of Ocean Waters

All oceans	1.37×10^9 km^3, or 3.27×10^8 mi^3
Atlantic Ocean	0.35
Indian Ocean	.29
Pacific Ocean	.72

3.2. Relief of the Ocean Basins

Continental land masses are surrounded by a *continental shelf* that is characterized by a very small seaward slope. The continental shelf may extend seaward to depths of 200 m (100 fathoms) or more beyond which there is a much steeper slope extending down into the deep ocean basins with depths of about 4,000 m or more. The average width of the continental shelf over the earth is about 30 miles, it varies from virtually zero off certain mountainous coasts to several hundred miles off coasts with extensive coastal plains. In general, the shelf is wider off the east coast of the United States than it is off the west coast.

The shelf is not smooth but is characterized by minor terraces, hummocks, and depressions. In certain areas submarine valleys and canyons cut into the shelf. The ocean basins contain features of relief as large as those found on land. Depths exceeding 6,000 m are limited to deep trenches paralleling coastal mountain chains and island arcs like the Aleutian Islands. Certain portions of the ocean are partially isolated by submarine ridges that greatly restrict the exchange of water with the adjacent deep ocean. The Black Sea and Mediterranean Sea are the classical examples. Partially isolated basins in the sea floor exist off Southern California. The Black Sea and certain fjords in Scandinavia and along the coast of British Columbia and Alaska

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[3] Figures in brackets indicate the literature references at the end of this report.

are stagnant; that is, all dissolved oxygen has been utilized at subsurface levels and the deeper waters contain hydrogen sulfide.

3.3. Chemical Composition of Sea Water

Sea water is an aqueous solution of a variety of dissolved solids and gases containing small amounts of suspended material of organic and inorganic origin. It has been found that regardless of the absolute concentration of the dissolved solids, the ratios between the more abundant substances are virtually constant. The concentration of the dissolved solids is generally expressed as the *salinity*, a value slightly less than the total dissolved solids present. Units used are parts per thousand by weight ($^{\circ}/_{\circ\circ}$). For most ocean waters the salinity is between 33 and $37^{\circ}/_{\circ\circ}$. Lower values occur in coastal areas and in and near river mouths; higher values are found in areas of excessive evaporation, such as the Red Sea. Vertical variations in salinity are usually small. In the open ocean in midlatitudes the salinity first decreases with depth and then increases slightly in the deeper water. The relative quantities of the major dissolved constituents are shown in table 1.

TABLE 1. *Major constituents of sea water*

The quantities given in this table are for a salinity of $34.325^{\circ}/_{\circ\circ}$ and can be taken as representative of ocean water. It will be noted that they make up 99.9 percent of the dissolved solids.

Ion	$^{\circ}/_{\circ\circ}$ (parts per thousand)	Percentage of total dissolved solids
Anions:		
Chloride	18.98	55.04
Sulphate	2.65	7.68
Bicarbonate	0.140	0.41
Bromide	.065	.19
Fluoride	.0013	.00
Boric acid	.0260	.07
Cations:		
Sodium	10.56	30.61
Magnesium	1.27	3.69
Calcium	0.40	1.16
Potassium	.38	1.10
Strontium	.013	0.04
Total	----------	99.9

There are 44 elements listed in table 2, to which may be added the dissolved gases nitrogen, oxygen, neon, helium, and argon. It will be noted that a range in values is given for a number of elements present in small quantities, notably silicon, nitrogen (in compounds), phosphorus, arsenic, iron, manganese, and copper. These are substances essential to plant life that under certain instances are reduced to zero. Too much significance should not be attached to many of the individual values, as in many cases they are little better than estimates.

TABLE 2. *Elements present in solution in sea water with a salinity of $34.325^{\circ}/_{\circ\circ}$ (omitting dissolved gases)*

Element	Quantity (in milligrams) of element in 1 kg of sea water	Element	Quantity (in milligrams) of element in 1 kg of sea water
	ppm [a]		*ppm* [a]
Chlorine	18,980	Copper	0.001 to 0.01
Sodium	10,561	Zinc	.005
Magnesium	1,272	Lead	.004
Sulfur	884	Selenium	.004
Calcium	400	Cesium	.002
Potassium	380	Uranium	<.0015
Bromine	65	Molybdenum	.0005
Carbon	28	Thorium	.0005
Strontium	[b]13	Cerium	.0004
Boron	4.6	Silver	.0003
Silicon	0.02 to 4.0	Vanadium	.0003
Fluorine	1.4	Lanthanum	.0003
Nitrogen (compound)	0.01 to 0.7	Yttrium	.0003
Aluminum	.5	Nickel	.0001
Rubidium	.2	Scandium	.00004
Lithium	.1	Mercury	.00003
Phosphorus	0.001 to 0.10	Gold	.000006
Barium	.05	Radium	0.2 to 3×10^{-10}
Iodine	.05	Cadmium	Trace
Arsenic	0.01 to 0.02	Chromium	Trace
Iron	0.002 to 0.02	Cobalt	Trace
Manganese	0.001 to 0.01	Tin	Trace

[a] Parts per million.

[b] Recent analyses indicate that this value should be reduced to about two-thirds of the content reported. (This table is taken from "The Oceans" [1].)

The values in table 2 can be used to estimate the total amount in metric tons of any element in the ocean by multiplying by the factor 1.42×10^{12}. Values in terms of grams per cubic kilometer can be obtained by use of the factor 10^9. For example, from the higher value shown for radium, it may be estimated that the ocean contains $3\times10^{-10}\times1.42\times10^{12}=4.2\times10^{2}$ metric tons; or to put it in more familiar terms, 420 million curies.

Sea water is normally slightly alkaline. In contact with the atmosphere the pH varies between 8.1 and 8.3. In water in which virtually all the dissolved oxygen has been converted to carbon dioxide in respiration, the pH will be about 7.5.

Dilution by river water and the freezing and thawing of sea ice *tend* to alter the relative composition, but the effects are very slight. As a working hypothesis, it is generally safe to assume that the material introduced by the rivers is balanced by biological or chemical deposition on the sea floor. This appears to be reasonable for calcium, silicon, phosphorus, manganese, iron, and several others. From the estimated rate of deposition of deep-sea sediments, some idea can be gained of rates of removal of certain elements.

3.4. Physical Properties of Sea Water

Physical properties of sea water, with the exception of transparency and color, are functions of temperature, salinity, and pressure. Temperatures range from about −2° C the initial freezing point) to about 30° C. With few exceptions the highest temperatures occur at the surface or in a homogeneous surface mixed layer that may be as much as several hundred meters thick. Below this the temperature decreases to about 5° C at 1,000 m, and to about 1° or 2° C at the greater depths. In deep ocean basins the adiabatic heating is sufficient to produce slight increases in temperature with depth. In high latitudes temperatures will be within a degree or two of 0° C from top to bottom.

Hydrostatic pressures in the sea increase approximately 1 atm for each 10 m in depth. At 2,000 m the pressure will be about 200 atm, or 3,000 lb/in^2.

The density of sea water decreases with increasing temperature but increases with increasing salinity and pressure. The normal range of the density *in situ* in the ocean is between about 1.02 and 1.06. Except in dilute sea water, the temperature of maximum density is lower than the freezing point. Hence the density increases until the freezing point is reached at about −2° C. As soon as ice forms, the "brine" of slightly higher salinity sinks to the sea bottom.

In general, the other physical properties of sea water do not differ materially from those for fresh water except for such characteristics as the electrical conductivity.

Many of the processes in the sea depend upon the vertical distribution of density. The generalized picture is that the deep ocean basins are filled with waters of relatively high density produced in high latitudes. "Floating" on this is the warm low-density surface-layer of the lower and middle

latitudes. Beneath the surface mixed layer, is a zone of density increase that tends to inhibit vertical mixing and overturn. The large effect of temperature on density is such that a first approximation of the change of density with depth can be assumed to be the mirror image of the temperature distribution.

3.5. Currents and Mixing

Currents in the sea are generated and maintained by differential heating and cooling and by energy imparted by the winds. Such water movements are relatively shallow, usually less than a few hundred meters, and speeds rarely exceed 0.5 to 1.0 m/sec (1 to 2 knots). Only in the Gulf Stream, Kuroshio, and other isolated instances do speeds reach 2.5 m/sec (5 knots). In the deep basins the magnitudes of the currents are not known, but are believed to be of the order of a few centimeters per second (a fraction of a mile a day). In addition to the major current movements, tidal currents and other periodic oscillations will contribute to the local motion. Because this motion is turbulent, it tremendously increases the rates of mixing in the sea. The existence of density layers, however, interferes with vertical mixing, so that materials tend to be spread laterally rather than vertically.

3.6. Biology of the Oceans

Plant growth in the sea is limited to the surface layers where there is adequate illumination. The thickness of this layer rarely exceeds 75 m. It will be less in turbid coastal waters and will be reduced to zero in high latitudes during the winter season. Plants growing within this layer remove CO_2 and the other substances essential for plant growth. With the exception of a few higher plants inhabiting shallow water, only algae and dinoflagellates occur in the sea. Large fixed algae are abundant in coastal areas in depths with adequate light, but for the oceans as a whole the microscopic diatoms and dinoflagellates are the great food producers. The photosynthesis in the surface layers must provide the primary food source of all animal life in the sea. Animals are present at all depths but are most abundant in the upper several hundred meters and on the sea bottom. The attraction of gravity on dead organisms and on fecal material is such that there tends to be a general removal of the essential elements from the surface layers. Most of the detrital material is ultimately mineralized and returned to solution by bacterial action, but the *net* effect is for this to occur at depths below the photosynthetic layer. Regional plant production will be large where there are processes that by one means or another bring fertilizer-rich water back to the surface. The principal agencies that do this are winter overturn in high latitudes, upwelling along certain continental coasts (California, Peru, and the West Coast of South Africa), and violent turbulent mixing associated with strong tidal currents in shallow water. In such areas the plant production is probably of the same magnitude as that obtained on fertile land. On the other hand, in the open ocean in middle and lower latitudes where the plant foods are depleted, there are "desert" conditions.

No significant quantities of marine plants are used for human consumption. The exceptions are certain of the larger algae that are used as vegetables and also as cattle feed, and others that are sources of commercial products such as agar, and the group of alginate products made from kelp. *Animals taken for human food include mammals, fish, crustaceans (crabs, lobsters, shrimp), mollusks, and a few representatives of other groups.* In discussions of productivity, it is necessary to consider *food chains.* For example, oysters may feed directly upon the diatoms and dinoflagellates. On the other hand, high predators, such as the tunas, may feed on smaller fish, that in turn have eaten other fish that depended upon small arthropods that were the original grazers feeding on plant life. Virtually nothing is known of the efficiency of tissue formation at each step in the food chain but it is estimated that it is about 10 percent. In other words, there is a decrease by an order of magnitude in the living organic matter at each step in a food chain.

The microscopic plant life is referred to collectively as phytoplankton; the small floating animals that feed upon it and upon each other, as zooplankton. During the daylight the zooplankton tends to remain below the lighted photosynthetic layer, rising at sunset to feed during the night, and returning to deeper water at sunrise. This mechanism contributes to the net removal of materials from the surface layers. Zooplankton and some fish (such as the herring) are filter feeders and gather in the particulate food indiscriminately. The same method of feeding is apparently true for many of the bottom-living marine invertebrates such as mussels, clams, barnacles, etc. The larger and more active forms are apparently more selective. Certain forms of fish and some invertebrates, such as crabs, are scavangers, eating any organic material that comes their way. Some are mud eaters, depending upon the detrital material in the sediment for their supply of organic matter.

Various indirect methods have been used to estimate rates of production and total annual production of plants in various localities. Daily rates range between 0.01 and 1.0 g of carbon per cubic meter with an average of about 0.15. Estimates of annual production on an areal basis range between about 10 and 1,000 g of carbon per square meter per year. If it is assumed that photosynthesis is limited to a layer 50 m thick, these values become 0.2 and 20 g/m^3/year. Plant production in most regions is limited by the depletion of the fertilizers, phosphate and nitrate. It is possible to determine concentration factors for the elements that are present in the sea in small amounts. For example, carbon appears to be concentrated in marine organisms by a factor of about 10^3, nitrogen and phosphorus by factors of 10^5 or 10^6, iron and copper by a factor of 10^3. As stated earlier, the microscopic plants are apparently able to remove substances such as phosphate and nitrate almost completely.

Rates of growth are almost unknown. Phytoplankton increase by binary fission, roughly once a day, and consequently under favorable conditions will accumulate at tremendous rates. Zooplankton forms probably go through several life cycles in a year. Fish of commercial importance have life spans of at least several years.

Some mention has been made of the daily vertical migrations of the zooplankton. The same apparently applies to many species of fish and mammals. On the other hand, many bottom-living forms such as halibut, flounder, etc., may spend their entire adult lives on the bottom. There is a tremendous range in the extent of the horizontal migrations. Certain forms such as eels and tuna travel thousands of miles, whereas others spend their entire lives within a limited area. Migrations are, however, the rule rather than the exception. It is only some invertebrates such as oysters and clams that remain in one place after settling of the larvae. Fish and other forms used for human food are most abundant in the upper few hundred meters and they are especially abundant on the continental shelf. For economic reasons, extensive fisheries tend to be on or near the continental shelf in proximity to centers of large populations.

The animal population on the deep ocean floor is very sparse in comparison to shallow bottoms. *There is no commercial fishery of the deep sea bottom and no significant migration of bottom-living forms between the deep and shallow waters.*

3.7. Marine Sediments

The marine sediments in shallow water do not differ materially in composition or texture from those of the adjacent beaches and coasts. On the continental shelf the sediments are sandy or silty except in depressions and off river mouths where soft muds will be formed. In the deep ocean basins the sediments are typically fine-grained clays with variable amounts of skeletal remains of planktonic plants and animals. These may be siliceous (diatoms and radiolarians) or calcareous (coccolithophores, foraminifera, and pteropods). The proportion of siliceous remains in the sediments is rarely very high. Certain calcareous sediments contain virtually no materials other than calcium carbonate. Sediments in depressions are soft and fine-grained; those on elevations, regardless of depth, are hard and coarse-grained; or may be lacking, so that the rocky surfaces of the elevations are exposed. In shallow water the calcareous remains of certain algae and animals will accumulate in the sediments. In warm tropical waters, so-called coral reefs and islands may contain nothing except the remains of corals and calcareous algae. Deep sea sediments are, therefore, made up of fine-grained material of terrigenous origin (red clay), volcanic debris, skeletal remains derived from dissolved material, and some decomposable organic detritus. The accumulation of organic detritus implies the removal from the water of certain of the plant fertilizers. In addition there are elements that by some means apparently accumulate on the sea floor; these include manganese, iron, phosphorus, and radium. Whether or not biological processes are involved in these cases, and in others, is not definitely known.

Rates of sedimentation for the deep-sea deposits have been estimated to be of the order of 1 cm per 1,000 years, being less for red clay and slightly more for the calcareous deposits. Rates of deposition off rivers will be large but, except in particular areas, the accumulation on the shelf is very small. On the continental slopes, rates of accumulation are probably of the order of tens of centimeters per 1,000 years.

Most of the organic detritus reaching the sea floor is undoubtedly broken down by bottom-living animals and bacteria. Where the supply is relatively abundant, burrowing animals undoubtedly overturn the sediments in the same way as earthworms do on land. However, in the deep ocean basins the sediments do not indicate any such overturn. The interstitial water does not differ materially from that in the water column above except in regions where, because of relatively high rates of supply of organic debris and low rates of supply of oxygenated water, stagnation develops and only anaerobic bacteria can survive. Such conditions exist in the Black Sea and certain fjords. In other coastal regions the sediments may be stagnant although the overlying water column is not.

The foregoing information indicates the mechanisms whereby materials introduced by rivers are removed from the water column, so that for many purposes it is reasonable to assume that a condition of dynamic equilibrium exists in the ocean. This, however, will not be true when we consider smaller areas or short time intervals. River water on entering the sea forms a "puddle" because of its lower density. This layer spreads and gradually mixes with the sea water, primarily because of turbulence created by wind waves and tidal currents. Solid particles tend to flocculate and settle, and certain chemical precipitation may occur for such elements as iron and manganese. It is estimated that each year rivers introduce 2.7×10^9 metric tons of dissolved solids and comparable amounts of particulate sedimentary material.

3.8. Pollution

Activities of man contribute to the supply of materials to the sea and sometimes affect the biologic balance. Locally, these effects are sometimes sufficient to cause unfavorable changes in the natural environment. As a result, fish and other forms taken by sportsmen and commercial fishermen may decrease in abundance or disappear entirely; or an area may be rendered unattractive for human use and recreation. Such effects are usually called pollution. In other cases, dumping of unwanted materials into the sea has no apparent detrimental effect, and consequently few or no objections are raised. To date, two types of pollution seem to be the cause of the greatest trouble. These arise from (a) the discharge of large quantities of organic debris, such as domestic sewage and industrial effluents from the food and beverage industries, and (b) the discharge of large quantities of industrial effluents that contain toxic chemicals. Whenever there are large local supplies of organic debris there is an increased probability of oxygen depletion, which will then kill all higher forms of life. Chemical wastes can be toxic directly to the fish or to some lower form involved in the food chain. To avoid undesirable pollution, submarine pipelines are sometimes extended as far as a mile off shore, sites of discharge are selected so as to be in regions of strong currents and active mixing, or in extreme cases the material is taken out to sea by barge and released in such a way as to minimize undesirable effects. In many instances pollution reaches damaging proportions before any remedies are sought or controls are established. Although recovery from damage due to organic pollution is fairly rapid, effective recovery for long-lived radioactive pollution may require long periods of time.

The altered and narrowed fauna in industrial harbors compared to previous rich growth shows the results of cumulated pollution. *Control of dumping of domestic and industrial wastes is a matter of concern to Federal, State, and local agencies concerned with fisheries, public health, and recreation.* Because of their responsibilities for navigable rivers and harbors, the Army Engineers have certain regulatory powers. Enforcement of regulations is in the hands of the local authorities and the U. S. Coast Guard. The authority of all such agencies usually ends at the 3-mile territorial limit. *Unless it is in any way a danger to shipping, anything can be dumped anywhere on the high seas. The only United States control over such practices is the authority of the U. S. Coast Guard to control the types and quantities of dangerous substances that can be carried aboard U. S. vessels.* The claims made in recent years to the national interests in the resources of the continental shelves indicate that in the foreseeable future regulatory control may be extended beyond the present 3-mile limit (or greater distances off certain foreign countries). At the present time, there are no regulations for disposal of radioactive wastes on the high seas. For such regulations to be fully effective, they should be by international agreement.

The introduction of radioactive wastes into the ocean is an entirely new practice and unless conducted properly can result in new kinds of pollution in the sense given above. As mentioned, protests against waste disposal arise because of catastrophic or cumulative effects on sea life, spoilage of the shoreline, or creation of obvious public-health hazards. The indiscriminate dumping of radioactive wastes could lead to a far more insidious type of pollution, primarily because of the absence of immediate effects that would arouse public indignation. *The onus therefore rests upon agencies responsible for radioactive-waste disposal to see that such practices never will constitute a pollution hazard.*

4. Fate of Radioactive Materials Introduced into the Ocean

4.1. Factors Favoring Dilution or Dispersal

Two primary factors should be considered in the disposal of wastes in such a way as to minimize or eliminate hazards. These are dilution (or dispersal) and isolation. Disposal in deep water far from land takes advantage of both factors. If the materials are in such a form that they will come to rest on the sea floor or actually penetrate the soft sediments, they can be considered as removed from all foreseeable opportunities for human hazard, either through direct contact or indirectly through raw materials or marine animals used as food.

Among the natural characteristics that will reduce or eliminate hazards from radioactive wastes are:

(a) *Natural decay:* The degree of reduction of hazards will depend upon the individual isotope.

(b) *Isotopic dilution:* Reference to table 2 will indicate whether or not the naturally occurring element is present in solution in sufficient abundance to reduce the hazards that might arise from the accumulation of the radioactive isotope by plants and animals.

(c) *Dilution:* The mixing of the water will rapidly reduce local concentrations and, except on the continental shelf, the net effects of current movements and mixing will tend toward horizontal spreading. Initial dilution or dispersal at the time of disposal will, of course, favor this process.

At this time it is necessary to examine some of the hazards that may arise from sea disposal of radioactive wastes.

4.2. Direct Hazards

To minimize or eliminate hazards from packaged wastes, containers must be of such a nature that they sink to the bottom, remain intact until they reach the bottom, and are not dumped in any region where they might be accidently or intentionally retrieved during fishing or salvage operations. Bulk wastes shall be discharged in such a way that the initial concentrations are below levels that might be dangerous. Accumulations of certain isotopes might occur on nets and on ships' hulls, sanitary systems, and condenser systems. The exposure of swimmers precludes the disposal of materials near beaches used for recreation. Future large-scale desalination of sea water for irrigation or for industrial or domestic use might conceivably create hazards in the processing plants.

4.3. Indirect Hazards

Indirect hazards are those that might arise through the accumulation of radioactive isotopes by marine organisms used for human food. As described in the section on the chemistry of sea water, it is possible for a few elements to be concentrated by a factor of 10^6. This would mean that all of the element originally present in 1 m^3 of sea water is concentrated in 1 cm^3, or 1 g, of fish. The only elements known to be concentrated to this extent are phosphorus and nitrogen, and hazards from radioactive isotopes of these elements are lessened because of their short half-lives. Whether any other element is concentrated to this degree is unknown, but it would seem reasonable to assume that a factor of 10^3 might be anticipated. This would correspond to the accumulation in 1 g of tissue of the material initially present in 1 liter of water.

As an example, radium may be used. One liter of sea water contains about 1×10^{-13} g. Assuming that this is concentrated 1,000-fold, if a person ate 100 g of fish per day for 25,000 days (70 years), he would ingest a total of $10^{-13} \times 100 \times 2.5 \times 10^4 = 2.5 \times 10^{-7}$ g, or 0.25 μc. This example is not intended to do more than indicate a very conservative way by which tolerable limits for radioactive isotope concentrations might be established.

The maximum permissible concentration in drinking waters for radium has been set at 4×10^{-8} $\mu c/cm^3$ [2]. This is equivalent to 4×10^{-11} g/liter, a concentration 400 times greater than that naturally occurring in sea water. If our fish supply were grown in water containing this amount of radium, the indirect hazards would be much increased. However, if it were possible to allow concentrations of radium as large as this, namely, 400 times greater than the amount naturally present, it is easy to determine how much radium could be added to sea water to raise the content to drinking-water tolerance. A cubic kilometer contains 10^{12} liters. Therefore: radium in 1 $km^3 = 10^{-13}$ g/liter $\times 10^{12}$ liters/$km^3 = 0.1$ g. To raise the concentration to the permissible level would permit the addition of 39.9 g/km^3.

These calculations emphasize the fact that it is highly improbable that disposal of radioactive wastes at sea will ever materially affect the ocean as a whole. Local concentrations, however, might become hazardous unless precautions are taken to avoid their accumulation by marine organisms. *This emphasizes the desirability of disposal in the deep basins or at initially low concentrations.*

Studies made on the disposal of chemical wastes from barges [3] afford an estimate of the magnitude of the "immediate" dilution. While the barge was underway the wastes were discharged through the two vents located at the bottom of the barge. The cross section of the barge was about 7×5 m and it was being towed at a rate of 6 knots (300 cm/sec). The turbulent wake was therefore generated at the rate of $7 \times 5 \times 3 = 105$ m^3/sec, giving immediate dilution of 300 to 1 for wastes being discharged at about 0.3 m^3/sec. In addition the turbulent wake spreads both horizontally and downward; so it can be assumed that the immediate dilution is of the order of 1 in 1,000. This could be increased by another factor of 10 by reducing the rate of discharge. It is therefore entirely feasible to obtain immediate dilution by barge disposal of the order of magnitude of 1 part in 10,000. These generalizations assume that the waste liquid is entirely miscible with water and of equal or slightly greater density. Whether or not the isotopes remain in solution or precipitate when mixed with sea water does not appear to be a major factor as long as the disposal is made over deep water. Engineering study of the limitations of barge disposal of radioactive wastes appears to be warranted.

5. Considerations for Selection of a Disposal Method

The choice between sea disposal and other methods will depend upon the quantity and type of radioactive waste, its physical and chemical state, and upon the convenience for the agency involved. The selection of the best method of disposal at sea will depend upon more factors than can be considered here in detail. It is, however, desirable to outline the general criteria that should be met and to indicate the various means that might be employed in radioactive-waste disposal.

The practical solution of waste-disposal problems will involve consideration of the following characteristics of the isotopes involved:

(a) Half-life,

(b) Chemical properties, and initial chemical state,

(c) Physical state (liquid, solid, occluded, or adsorbed on inert material),

(d) Biological properties (radiotoxicity, biochemistry of element), and

(e) Amount on hand and rates of supply.

The chemical properties will be important with respect to whether or not the isotope will react with the dissolved constituents in sea water. The physical state will be a determining factor in many problems and may dictate the means of disposal. The indirect hazards will depend upon the biological properties of the isotope (such as its radiotoxicity), the role it may play in the bioeconomy of the sea, and the possibilities of its accumulation in human food supplies. Finally, the selection of any acceptable method of disposal will depend upon the amounts of the isotopes involved and upon whether or not the disposal is a single event or must be planned for repeated operations. These items will usually be known or can be estimated with reasonable accuracy.

Consideration of the criteria that must be met in sea disposal is complicated by our lack of knowledge of many of the factors involved, so that they can be stated only in general terms. The most important criteria are that methods of radioactive-waste disposal should (a) avoid foreseeable direct hazards, (b) avoid foreseeable indirect hazards, and (c) avoid undesirable long-term consequences.

Direct hazards, by definition, are those that might arise from exposure to dangerous levels of radiation (see section 4.2). Therefore the waste material should be *isolated*, to avoid the possibility of close proximity, or should be *diluted* to a level that is completely safe. Effective isolation can best be achieved by disposing of the material in the deep ocean far from land. Virtually complete isolation can be achieved by depositing the material on or in the sediments

of the deep ocean floor. Obviously, isolation is the prime consideration for large amounts of isotopes, insoluble materials, contaminated equipment, apparatus, etc. This will also be true of packaged materials *in any amounts*, for it is most undesirable to permit the package and its contents (or whatever type) to be recovered. Dilution is the obvious method of disposing of small quantities of isotopes, particularly those of short half-life and those in solution. The problem becomes more complicated when the amounts are large.

Indirect hazards, by definition, are those that might arise from the accumulation of potentially harmful amounts of radioactive isotopes in marine organisms used for human food (see section 4.3). To avoid such hazards the objective should be to dispose of waste materials in such locations that the likelihood of their reappearing in food is minimized. This again involves the principles of isolation or dilution of the material. However, the concentrations permissible in the water are minute compared to those that represent direct hazards; and as described in section 4.2, it is the processes of biological accumulation that will establish the permissible concentration of isotopes in the ocean waters. Packaged waste deposited on the bottom of the deep sea does not contribute any foreseeable indirect hazard, because there is no significant biological exchange between the deep sea and the surface layers and because there is no fishing at depths of 1,000 fathoms and more. Bulk disposal, which is made at or near the sea surface, does not satisfy the criterion either of isolation or of immediate dilution to negligible activity levels. However, practical consideration of the problem shows that the quantities to be disposed of, the types of material, etc., will be important factors in deciding whether or not bulk disposal is allowable. In all cases depth of water and distance from shore, as well as major fishing areas and shipping lanes, should be considered.

Undesirable long-term consequences are those that might arise because of the slow accumulation of long-lived radioactive isotopes in the ocean. If the rates of disposal exceed the rates of decay it is obvious that the amounts present will increase. If the materials form insoluble precipitates, or were originally insoluble, they will accumulate on the sea floor; and as long as this is in deep water they are not hazardous. If, however, the materials are soluble or were in solution, processes of mixing and the ocean currents will ultimately bring them near the sea surface and into coastal areas where biological processes may concentrate them. Because of the tremendous volume of the ocean waters, it appears at the present time, that this is a negligible hazard. *In reviewing long-term consequences of radioactive-waste disposal, it should be remembered that the half-lives of many of the isotopes are long, compared to the probable life of the container.* Furthermore, any damage to the container will accelerate the escape of the contents. Any assumption concerning long-term effects of wastes in the sea should consider that the container merely delays the diffusion of the material through the water mass. A further step toward retarding such accumulations in the water would be actually to bury the container in the sediments. The natural rate of sedimentation in the deep ocean basins is inadequate. However, if topographic elevations are avoided, the sediments are sufficiently soft that a dense container dropped from the sea surface would sink to depths of several feet into the ooze. Here it is in effect completely isolated unless heat generated by the contents is sufficient to produce convective flow in the surrounding sediments. Even if the container disintegrated, there would be limited opportunity for the escape of the contents into the water.

It is conceivable that the disposal of radioactive wastes into the ocean might someday attain such proportions that it would become necessary thenceforth to limit disposal to rates not greater than the rates of decay of the accumulated wastes.

6. Means of Disposal

For convenience, it is possible to consider all methods of sea disposal under three general types: Package disposal, bulk disposal at sea, and pipeline disposal.

6.1. Packaged Disposal

The problems of recommendations concerning packaged disposal have already been presented in this Handbook and will not be considered any further.

6.2. Bulk Disposal at Sea

Bulk disposal includes all operations in which radioactive wastes are discharged directly into the sea in unpackaged form. The tanks, barges, or other means used for transportation are, in effect, reclaimable containers. Bulk disposal has many advantages where the wastes are of large volume but relatively low radiation intensity.

In bulk disposal, it seems reasonable to assume that safety measures governing the transportation and handling of the material will set practical limits on radiation levels from the material after discharge. A primary consideration is to minimize the possibilities of the waste being concentrated by marine organisms and ultimately appearing in foods. This can be achieved by dumping the material far away from centers of population and of fishing activity and in the deep ocean where the abundance of plankton is small. It is preferable that the material be in such a form that it will sink when discharged into the sea. This could be achieved by preparing the material in the form of dense briquettes, pellets, or beads by mixing the isotopes with inert insoluble materials that could, if necessary, be of resistant ceramic or concrete. Such solid objects would sink rapidly and hence the material would be quickly carried to an inaccessible location. This procedure possesses a number of advantages if the quantities are large, and if the chemical and physical characteristics of the radioactive wastes lend themselves to such handling. The pelleted material can be handled in bulk and transported and discharged at sea with the same convenience as liquids; and it has the further advantage that it can be prepared in characteristic shapes or colors for easy identification and recovery if accidentally spilled. *Such material shall be dumped only in areas where the water depths exceed 1,000 fathoms.*

Wastes in liquid form will mix with sea water while being discharged, and advantage should be taken of ways that will accelerate mixing and dilution. An example of liquid waste disposal from a barge is described in section 4.3. To facilitate mixing, the wastes should be in a water solution having a density greater than that of sea water. Greasy or oily materials that would tend to float or coagulate and form a scum are unsuitable for bulk disposal because of the possibilities of the material drifting ashore.

Experimental studies may indicate conditions under which disposal of large quantities of bulk liquid wastes may be safely conducted in certain areas of depths less than 1,000 fathoms. Until such studies are made, except for small quantities, liquid wastes shall not be released in waters of depths less than 1,000 fathoms, except under experimental conditions.

6.3. Pipeline Disposal

One of the traditional methods of disposing of unwanted wastes is by means of pipelines entering the sea. Such means are used for domestic sewage and by many industrial plants. The very undesirable pollution resulting from such practices can be observed near any coastal community. To reduce the possibilities of such pollution, installations of longer pipelines have been made in order to have the outfall in deeper water and farther from shore. This reduces the concentration of material that reaches the beach because the turbulence and along-shore currents tend to disperse the material. Such systems presuppose that the effluent is of lesser density than the sea water, and will therefore rise and mix with the water over the outfall. Although submerged outfalls with discharge at a distance of a mile or more from the coast may appear to have certain advantages in ease of disposal, such systems fall far short of meeting the general requirements for safe disposal of radioactive isotopes. Disposal will usually be made near centers of population and in shallow water. The possibilities of direct hazards are great. In addition, the possibilities of indirect hazards are increased by the accumulation of isotopes that will occur in the water and sediments and therefore be available to organisms that will be used as food. For these and other reasons the disposal of radioactive wastes through pipelines is undesirable.

7. Designation or Selection of Sites of Disposal

Disposal of all packaged wastes shall be in regions where water depths exceed 1,000 fathoms. The disposal of bulk wastes shall also be confined to regions where water depths exceed 1,000 fathoms except for small quantities of liquid waste or as experimental studies indicate conditions under which disposal of liquid wastes may be safely conducted in other areas. Within these limitations, designation of specific sites does not appear necessary at the present time.

It may be stated immediately that from the public-health point of view, there is no short-term advantage to be gained from the designation of specific dumping areas for either packaged or bulk radioactive wastes. Long-term consequences, resulting from the gradual accumulation of isotopes in the water, will not be materially affected by the exact localities of disposal.

It should be recognized that the dumping of radioactive wastes will raise the normal radiation background of the water. With the development of nuclear power for the propulsion of naval vessels, including submarines, and of nuclear weapons, detection by means of radiation-measuring systems may be a matter of military concern. It is believed, that the location of disposal of radioactive wastes may be of concern to military authorities.

The U. S. Coast Guard is responsible for all U. S. shipping, other than military vessels, and this agency is charged with the enforcement of many regulations governing safety of personnel, pollution, and activities of vessels. In problems arising in the disposal of explosives and industrial wastes, it is customary to designate specific dumping areas. Selection of such sites is a problem of mutual concern to the U. S. Navy, the U. S. Coast Guard, the U. S. Public Health Service, and the U. S. Fish and Wildlife Service. If experience indicates the desirability of large-scale disposal of radioactive wastes in the ocean, these and other agencies may become interested in the question of whether or not the designation of specific dumping areas is desirable; and if so, what specific localities may be appropriate.

8. Recommended Containers for Packaged Disposal in the Ocean

8.1. General Characteristics

Containers used for packaged disposal of radioactive wastes into the ocean should be designed, constructed, and filled in such a manner as to achieve the following objectives:

(a) Structural design to insure, under conditions of shipment and handling, that the package cannot be easily damaged or broken and will reach the bottom of the ocean without appreciable loss of contents;

(b) Sufficiently high specific gravity to insure sinking to the bottom;

(c) Sufficient shielding from radiation originating within the container to prevent excessive exposure of personnel during shipment, storage, or handling; and

(d) Size, shape, and accessory features to facilitate safe, convenient, and quick handling.

8.2. Materials of Construction

The most economical materials of construction commensurate with the above objectives appear to be concrete and steel in suitable combination. Adaptations of commercial "shapes" are advantageous where appropriate. The most common example of such adaptation is the use of standard 55-gallon steel drums, which serve as external containers and forms in which the radioactive materials are embedded in concrete. The National Institutes of Health have found standard concrete burial vaults generally useful for the same purpose [4, 5].

8.3. Design of Package

Although it is not considered appropriate to specify standard packages, the following comments on current practices may be found helpful. A common method of use of steel drums is to pour several inches of concrete into the bottom, build up the content to within a few inches of the top by placing radioactive objects near the center and pouring concrete around them, and complete the package by filling to the top with concrete. In other cases the radioactive material is confined in a smaller drum concentric with the outer one and the space between them filled with concrete.

Eyes or rings for convenient handling should be cast in the concrete or fastened to the outer metal container. The degree to which reinforcing of the concrete should be used will depend upon the nature of the contents. Steel reinforcing should be designed to prevent rapid loss of contents in the event that the package is ruptured by hydrostatic pressure. In the event that the package contains objects that would normally float, reinforcing should be designed to prevent their separation from the concrete. In addition to rods, the use of heavy woven wire may be desirable.

Packages should be filled in such a manner as to be free of voids and, if possible, of considerable volumes of compressible materials. In general it is impractical to design a package containing large voids that will not be ruptured by hydrostatic pressures at depths of several thousand feet. In cases in which it is desirable to include large volumes of compressible material, it will be desirable to include appropriate means for equalization of pressure between such volumes and the exterior of the package without any loss of contents of the package from handling and transportation. For example, a small, thin-walled metal tube extending into the

compressible material from outside, and with the inner end of the tube crimped shut to prevent leakage during handling or shipment. This should be acid resistant if the material is corrosive.

8.4. Specific Gravity of Package

The maximum density of water in the ocean is estimated to be approximately 1.1 g/cm^3. It is recommended that the actual minimum density of any package prepared for disposal in the ocean should be at least 1.2 g/cm^3 or 75 lb/ft^3 or 10 lb/gal. In cases in which the determination of the volume of the package is subject to uncertainties, the design density should be increased sufficiently to insure that the actual density is never less than the above value.

8.5. Identification

Regulations of the U. S. Atomic Energy Commission, U. S. Interstate Commerce Commission, and U. S. Coast Guard require specification labeling of packages containing radioactive materials. In addition, it is suggested that persons preparing packages for disposal at sea may find it advantageous to provide a semipermanent identificaion impressed in a metal or concrete surface for use in the event that subsequently it becomes desirable to distinguish them from similar packages prepared by other persons. Such identification should include the name of organization preparing the package, the date, and (for use in case of accident) indication of the most hazardous radioisotope involved and of the level of activity contained.

9. Recommendations for the Transportation of Radioactive Materials

Packaging and handling of radioactive materials for transportation shall conform to regulations of the U. S. Interstate Commerce Commission and of the U. S. Coast Guard wherever applicable [6]. Storage of containers of such wastes before shipment should be under proper posting or in defined enclosures. In the actual handling and transfer of waste containers, any safe method is acceptable. Some commonly used procedures include hoists, fork lifts (using pallets), and similar mechanical devices.

For complete information on this subject, the shipper should refer to U. S. Interstate Commerce Commission and

U. S. Coast Guard documents in which these regulations are published. A summary of the current regulations includes the following provisions: The design and preparation of the package shall be such that there will be no significant radioactive surface contamination of any part of the container; that the gamma radiation will not exceed 200 mr/hr or equivalent at any point of readily accessible surface; and that the gamma radiation at 1 m (distant) from any point on the radioactive sources will not exceed 10 mr/hr. These regulations provide also that, except by special arrangement, the radioactive content of any single package shall not exceed 2 c of radium, polonium, or any other member of the radium series; and not more than that amount of any other radioactive substance that disintegrates at a rate greater than 10^{11} atoms/sec.

All personnel handling or transporting radioactive wastes should follow recommendations given in National Bureau of Standards Handbook 42 to hold exposure to the minimum, and maximum-permissible-exposure values recommended in that publication shall not be exceeded. The whole-body exposure to gamma radiation shall not exceed 300 mr/week measured in air, and exposure of the hands shall not exceed 1,500 mr/week measured in the skin.[4]

Although recommendations cannot be made relative to the type of vessel to be used for sea disposal, present experience indicates that a hopper-type vessel, such as a garbage scow, may be the most suitable; because (a) waste containers don't have to be lashed to the deck during their sea journey, (b) the lower center of gravity (with containers in the hold) reduces the pitch and roll of the ship, and consequently (c) the hazards of the dumping operations at sea are lessened.

10. General Responsibilities and Problems for Consideration

It is the purpose of this Handbook to bring to the attention of those concerned, the many different factors that should be taken into account when radioactive wastes are to be dumped into the ocean. In many instances, it has been impossible to give anything more than general statements. Knowledge concerning the physical processes that will distribute the wastes through the ocean waters is almost completely lacking. The biological processes by which isotopes may be concentrated by marine organisms are, as yet, quantitatively unknown and for this reason it is not currently possible to set maximum permissible levels for sea water. Such values should be established for the guidance of those concerned with waste-disposal practices and for those agencies that may be charged with the responsibility of supervising disposal operations or of monitoring the conditions in the ocean. Natural backgrounds are virtually unknown and these should be determined at an early date.

Procedures for the disposal of packaged wastes are reviewed in this Handbook. For the handling of bulk wastes, each case may very well be a specific problem because of differences in types and amounts of the isotopes, their physical state, levels of activity, etc. In such cases, definite regulations may not be pertinent because the operations will probably involve specially designed facilities for both land and water transportation. The U. S. Interstate Commerce Commission and U. S. Coast Guard have procedures for the approval, under special permit, of the handling of shipments that do not fully meet the detailed provisions of published regulations but are consistent with the general standards of safety maintained by these agencies.

It has been pointed out that there exists no authority for the control of dumping of radioactive wastes on the high seas. To be of any real value, ultimate authority should rest on international agreement.

In a field as new as this, it is impossible to foresee what quantities of activity discharged into the oceans will produce undesirable consequences. Such recommendations as are made now and in the future must be reviewed from time to time in the light of new knowledge and experience. For this reason, as well as for others, *adequate records of dumping operations shall be kept. Such information, listing amounts and types of different radioisotopes, methods of disposal, localities, and dates, shall be available to the U. S. Coast Guard or to other cognizant agencies upon request.* At the present time, no agency has assumed this responsibility, but it is desirable that such agency be designated.

From this Handbook, it is apparent that problems of radioactive-waste disposal are of concern to many different interests. Responsibilities for the safe handling and disposal of the wastes rest upon one or more of the following: The original producer, the user, and the agency conducting the dis-

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[4] National Bureau of Standards Handbook 59, Permissible dose from external sources of ionizing radiation (1954).

posal operation. Regulations or recommendations concerning the methods of transportation and disposal may be issued by public health authorities, the U. S. Atomic Energy Commission, the U. S. Interstate Commerce Commission, the U. S. Coast Guard, the U. S. Public Health Service, the U. S. Army Engineers, and/or other local, State, or national agencies. Selection of sites of disposal, methods of disposal, amounts, and/or rates of disposal should ultimately be matters of international concern. The practical considerations of national advice and/or control, monitoring of levels of activity, etc., have not yet been solved but are of concern to the U. S. Public Health Service, the U. S. Coast Guard, and the U. S. Navy.

It should be stated specifically that two major aspects of radioactive contamination have been completely omitted from this report; (a) the fate of materials entering the ocean from the atmosphere, and (b) the catastrophic effects that might arise from the accidental release of large amounts of materials resulting from disasters on or near the sea or those resulting from military action. These problems are being dealt with by other agencies, but many of the items discussed in this report are applicable to them.

11. References

[1] H. U. Sverdrup, M. W. Johnson, and R. H. Fleming, The Oceans (Prentice-Hall, Inc., New York, N. Y., 1952).

[2] National Bureau of Standards Handbook 52, Maximum permissible amounts of radioisotopes in the human body and maximum permissible concentrations in air and water (1953).

[3] A. C. Redfield and L. A. Walford, A study of the disposal of chemical waste at sea, National Research Council Pub. No. 201 (1951).

[4] Clinton C. Powell and Howard L. Andrews, Radioactive waste disposal, Reprint No. 2314, U. S. Public Health Reports **67**, No. 12, 1214 (Dec. 1952).

[5] G. W. Morgan, Considerations on disposal at sea, Isotopics **3**, No. 1, p. 5 (1953).

[6] U. S. Interstate Commerce Commission regulations: Title 49, Code of Federal Regulations, Parts 71 to 78. Part 73, paragraphs 73.391 to 73.396, 73.401 to 73.404, 73.414, 73.427, 73.428, 74.566, 77.823, and 77.841 contain the principal regulations of especial interest to shippers of radioactive materials. Authorized reprints of parts 71 to 78 are issued by the Bureau of Explosives of the Association of American Railroads, 30 Vesey Street, New York 7, N. Y., Agent H. A. Campbell's Tariff No. 8; and by the Tariff Bureau of the American Trucking Association, 1424 16th Street, N. W., Washington 6, D. C., Agent F. G. Freund's Tariff No. 7.

U. S. Coast Guard regulations: Title 46, Code of Federal Regulations, Part 146. Paragraphs 146.05-15, 146.05-17, 146.25-1, 146.25-20, 146.25-25 and 146.25-30 contain the regulations of especial interest to shippers. An authorized reprint of part 146 is issued by the Bureau of Explosives of the Association of American Railroads (see address above) as Agent H. A. Campbell's Tariff No. 6.

Submitted for the National Committee on Radiation Protection.

Lauriston S. Taylor, *Chairman.*

Washington, April 23, 1954.

U. S. GOVERNMENT PRINTING OFFICE: 1958

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

MAR 1 4 1995

OFFICE OF
WATER

Commander Robert Thompson
Radiological Controls Program Office
Naval Sea System Command (SEA 07R)
2531 Jefferson Davis Highway
Arlington, Virginia 22242-5160

Dear Commander Thompson:

Last spring you and other naval officials met with myself and others from the Environmental Protection Agency (EPA) to discuss the possible application of the Marine Protection, Research, and Sanctuaries Act (MPRSA) and the London Convention (LC) to six Radioactive Thermoelectric Generators (RTGs) that are currently resident on the ocean floor. I am writing to formalize the preliminary oral advice we have given you on this issue since that meeting.

You have provided us with the following information. The RTGs were emplaced in the ocean between 1970 and 1977 as part of an acoustical transponder/beacon system. They contain fuel capsules that are surrounded by various layers of shielding, including depleted uranium shielding in some cases. All the fuel capsules are designed to withstand the marine environment for 300 years before showing degradation. After 300 years, the radioactive material in the fuel capsules (Strontium 90) would have passed through 10 radioactive half-lives and the activity remaining would be extremely low. The navigation system that utilized the RTGs has been inoperative for several years, and the Navy has considered various options for disposition of the associated RTGs. However, the Navy continues to maintain control over the RTGs. The RTGs were initially subject to Nuclear Regulatory Commission (NRC) License No. 04-07316-04 issued to the Navy. That license subsequently was converted to Navy Radioactive Materials Permit (NRMP) No. 45-45650-N1NP, which is currently effective. NRMP No. 45-45650-N1NP was issued under the authority of the Navy Master Materials License (MML) issued by the NRC.

Your specific question was whether, if the Navy leaves the RTGs on the ocean floor and maintains the current NRMP in effect, this would violate the MPRSA or the LC. Based on the foregoing facts, we do not believe this would be the case. The Navy emplaced the RTGs in the ocean, pursuant to an authorized Federal program, for a purpose other than disposal. Also, the devices are regulated by the NRC. Therefore, their emplacement in the

[illegible]

ocean was authorized under the MPRSA without the need for a permit. MPRSA § 3(f), 33 U. S. C. A. §1402(f). The emplacement of the RTGs was not subject to the London Convention. LC Article III(1)(b)(II). The continued presence of the RTGs in the ocean, in the factual circumstances you have described to us, also is consistent with the MPRSA and the LC.

Please let me know if we can be of further assistance. I can be reached at (202) 260-9180. Alternatively, you may contact David Gravallese of the Office of General Counsel at (202) 260-7704.

Sincerely,

John Lishman, Chief,
Marine Pollution Control Branch

NRC FORM 532
(05-2016)

U.S. NUCLEAR REGULATORY COMMISSION

ACKNOWLEDGEMENT - RECEIPT OF CORRESPONDENCE

Name and Address of Applicant and/or Licensee

CAPT Jerry N. Sanders, Jr.
Executive Secretary
Office of the Chief of Naval Operations
Department of the Navy
Radiological Controls & Health (N455) Energy and Environmental Readiness Division
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Washington, D.C. 20350-2000

Date
September 13, 2018

License Number(s)
45-23645-01NA

Mail Control Number(s)
609885

Licensing and/or Technical Reviewer or Branch
Shawn Seeley

This is to acknowledge receipt of your: ☑ **Letter and/or** ☐ **Application** **Dated:** August 29, 2018

The initial processing, which included an administrative review, has been performed.

☑ **Amendment** ☐ **Termination** ☐ **New License** ☐ **Renewal**

☑ **There were no administrative omissions identified during our initial review.**

☐ **This is to acknowledge receipt of your application for renewal of the material(s) license identified above. Your application is deemed timely filed, and accordingly, the license will not expire until final action has been taken by this office.**

☐ **Your application for a new NRC license did not include your taxpayer identification number. Please complete and submit NRC Form 531, Request for Taxpayer Identification Number, located at the following link: http://www.nrc.gov/reading-rm/doc-collections/forms/nrc531.pdf**

Follow the instructions on the form for submission.

☐ **The following administrative omissions have been identified:**

Your application has been assigned the above listed MAIL CONTROL NUMBER. When calling to inquire about this action, please refer to this control number. Your application has been forwarded to a technical reviewer. Please note that the technical review, which is normally completed within 180 days for a renewal application (90 days for all other requests), may identify additional omissions or require additional information. If you have any questions concerning the processing of your application, our contact information is listed below:

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