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Oceanic Disposal of Radioactive Wastes: Effects and Proposals

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THESIS

OCEANIC DISPOSAL OF RADIOACTIVE WASTES --EFFECTS AND PROPOSALS

by

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The contents of this paper reflect my own personal views and are not necessarily endorsed by the University of Rhode Island or the Department of the Navy.

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Abstract of

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--EFFECTS AND PROPOSALS

An investigation of the effects of radioactive waste disposal into the oceans pursued by an examination of the hazards involved, the present sources of radioactive wastes and the future prospects. The longevity of many radioactive elements, coupled with the awesome consequences to which even a slight miscalculation may lead, are convincing arguments for the most conservative approach to the problem of disposal of radioactive wastes. Present day disposal of radioactive wastes in the oceans, while significant, have not yet had major discernable effects on man or marine life. However, with the worldwide explosion of electrical power demand and the increasing use of nuclear fission as a source of power, the accumulation of non-destructible radioactive wastes on land will tempt industrially crowded nations to turn to the sea as a receptacle for this unwanted material. It is not reasonable to assume that nations can store in perpetuity an ever increasing volume of long lived radioactive waste. Development of controlled nuclear fusion as a source of power, eliminating the generation of radioactive wastes, is urged. No international rules being in effect concerning radioactive pollution of the seas, greater international cooperation in development of controls is recommended.

PREFACE

Having been associated with nuclear propulsion engineering for several years, the author has been concerned and somewhat uneasy about the dumping of radioactive wastes into the oceans. In conducting the research in preparation of this paper, the author was able to satisfy himself as to the nature of the hazards involved, as well as to what limits of dumping were permissible.

Aware of many misconceptions by the general public concerning radiation and nuclear power plants, it is hoped that a paper such as this, written for the layman, might prove useful in disspelling some groundless fears, while at the same time, pointing out some legitimate hazards.

The technical information synthesized in these pages may be familiar in varying degrees to different readers, but it is hoped that there will be enough that is novel to retain the interest of those with fairly extensive scientific backgrounds. By and large, the paper is directed to those who do not have professional familiarity with the fields on which the study draws; for this reason it tends to be less esoteric than other examinations of the complexities of atomic waste disposal.

TABLE OF CONTENTS

OCEANIC DISPOSAL OF RADIOACTIVE WASTES --EFFECTS AND PROPOSALS

CHAPTER I

INTRODUCTION

It need hardly be observed that mankind has a common interest in the most productive utilization of the oceans, notably for the purposes of communication and exploitation of both living and other resources. To safeguard and promote this interest, common sense demands that measures be taken to minimize the dangers of oceanic pollution, which might have serious effects on marine resources and severely restrict the use of the seas for many activities. An especially grave menace in this respect is the radioactive contamination which looms as an ominous possibility in the atomic age.

The magnitude and nature of the dangers from radioactive pollutants are so different and so grave that what little experience we have falls far short of affording a clear and simple precedent for action. The practical test of man's wisdom in the peaceful development of nuclear energy will be his ability to extract the great advantages promised by atomic fission while minimizing the attendant disadvantages, among which the question of radioactive waste disposal may well become primary.

In evaluating the prospects for oceanic disposal of unwanted radioactive materials, one must first have some idea of the harmful effects which may result from such disposal; i.e., what the dangers are to man; what the nature is of the radioactive wastes in question; what the sources are of these wastes; and what procedures for disposal are now in effect. Succeeding chapters will attempt to answer these questions.

This paper is limited to the question of disposal of radioactive wastes in the ocean. No attempt will be made to analyze the effects of nuclear weapons testing, nor of the natural background radiation which is present in the oceans as well as on all land masses. Suffice it to say that everyone on earth is bombarded with radiation from all sides. Penetrating rays zoom in from the sun and the cosmos. Radioactive elements in the earth's crust and in our bodies contribute to this cosmic drizzle, adding up to an annual dose of 0.10 to 0.13 Roentgens for most Americans. In some parts of the world the dose is far higher--as much as 38 times higher in Kerala, India, for example, whose inhabitants live on thorium-containing sands.[1] There is no escape from this natural background radiation and the question in setting standards from man-made radiation is simply: How much do we wish to add to the normal annual dose? Clearly, given a choice, one would elect to take zero additional radiation. But where there are benefits, there are usually risks. A person taking a chest

X-ray or other diagnostic X-ray takes the risk of radiation for a rather obvious advantage to his health. In the case of nuclear power, the world community is asked to take a slight radiation risk for the benefit of having adequate electrical power.

There should be no mystery about nuclear power. It is simply a new source of heat generated by a machine called a nuclear reactor. The core of this reactor serves as a hot but flameless substitute for the firebox of a conventional coal or oil burning boiler. In the core, presurized water is heated to above the normal boiling point. This superheated water is piped through the coils of a heat exchanger where it gives up its heat to a separate water system, producing steam, and is then pumped back to the reactor core to be reheated. The steam is forced around in another closed loop so that it hits the blades of a turbine, spinning it at high speed. The turbine is coupled to a propeller in the case of nuclear powered ships, or to the drive shaft of a generator in the case of electrical power plants. Thus, propulsion or electricity, is thereby produced just as in a conventional power plant.[2]

A nuclear reactor inherently produces a variety of unwanted radioactive by-products, the most important of which, and the most radioactive, being the fission products themselves. When a fuel atom, usually uranium, absorbs a neutron, it fissions or splits into two chemically different atoms, while at the same time releases a tremendous amount of heat energy. These two new atoms, the fission products, are highly radioactive, the radioactivity persisting anywhere from a few seconds to thousands of years,[3] depending on which two new elements were produced.

For technical reasons, namely, the tendency of certain of these split atoms accumulating in the fuel clusters to rob neutrons from the chain reaction, as well as the depletion of some of the nuclear fuel, it is necessary to periodically replace the fuel clusters.[4] This spent fuel is then re-processed to recover the unused fuel.[5] The radioactive fission products as well as the tremendous volume of liquids used in the re-processing must then be disposed of.

It is the disposal of this radioactive material, which will remain radioactive for hundreds of years, that is the concern of this writer. In particular, use of the seas as a receptacle for this unwanted material should land storage facilities become saturated, is of primary concern.

CHAPTER II

THE HAZARDS OF RADIOACTIVE WASTES IN THE OCEANS

In recent times, peoples of industrial nations, particularly the Americans, have become more and more preoccupied with the subjects of pollution and of maintaining the ecological balance. Their concern thus far has centered on the more obvious sources of pollution, the common industrial wastes that foul the air and water and which are usually readily apparent. Very little attention by the general public seems to have been given to an unseen but potentially the most dangerous type of pollution--radioactive pollution. This type of pollution, if allowed to occur, could annihilate man in the most torturous manner. We will investigate in later chapters the extent of present and probable future problems of radioactive pollution, but first let us look at how man can come into contact with radioactivity deposited in the oceans and the effects resulting therefrom.

Radiation Effects on Humans.

It might be useful at this point to define "radiation". Generally speaking, it is the emission and propagation of energy through a medium in the form of waves or particles. The radiations from radioactive substances include three principal types:[1] (1) alpha particles, which are identical with the nuclei of helium atoms, and which are spontaneously ejected with considerable energy from the nuclei of many of the radioactive nuclear species among the heavy elements. Alpha particles have a very short range in air and generally are dangerous to humans only if taken internally through ingestion or respiration; (2) beta particles, which are energetic electrons (positive or negative) emitted spontaneously from the nuclei of a large number of the radioactive nuclear species. Beta particles are more energetic than alpha particles, but they can be stopped by clothing or a sheet of paper. They can cause damage to humans if they penetrate the skin, or are taken internally; (3) gamma rays, which are quanta of electromagnetic radiation identical, except in origin, with X-rays of very short wave length. Because of the high energy and great penetrating ability of gamma rays, they perhaps constitute the greatest hazard to humans, and are the most difficult to shield against. One inch of lead will reduce the number of radium gamma rays to one-tenth the original number.[2] Higher energy rays of course would require thicker shielding for the same attenuation.

The passage of radiation through body tissue causes ionization by removal of electrons from their position in the atom. If these electrons form part of a chemical bond, the bond will then be ruptured with resultant destruction of the biological tissue.[3] Man can be subjected to this kind of radiation damage either externally or internally. Being in close proximity to a radioactive emitter results in the receipt of an external dose. Much more dangerous, however, is an internal dose resulting from ingestion of radioactively contaminated food or air.[4] Some radioisotopes when ingested have a particular affinity for certain areas or organs of the body, such being the case of strontium-90 which concentrates in the bones resulting in bone tumors.[5]

Acute external exposure over the whole body of a dose of 600 Roentgens (R) will cause death within 30 days. A dose of 450 R will bring about death in 30 days in 50% of the cases. Doses below 25 R produce no directly observable effects, but as exposures approach the 100 R level various symptoms and blood changes occur. At 200 R half of those exposed will suffer radiation sickness and at 300 R nearly everyone will experience radiation sickness and approximately 25% will die.[6] Thus, a fairly accurate basis for prediction is available insofar as acute exposure is concerned. However, not much is known about the results of chronic exposure.

Most of the data on chronic exposure is far less precise than the information concerning momentary, intensive irradiations. A few very crude observations have been made on the basis of frequent contacts with radiation through time, as in the well known cases of the radium-dial painters, uranium miners, and professional radiologists. These observations, however, were generally made subsequent to the exposures, after serious diseases or injuries had become manifest, and therefore involve considerable guesswork as to just what levels of exposure in the past histories of the patients had been responsible for the detectable effects.[7] It is chronic exposure, of which so little is known, that is a prime danger in the addition of artifical radioactivity to the environment. Although a person might be exposed to radiation either internally or externally, the effects may not be readily apparent until years later.

A number of things have been reasonably well established, nonetheless. Individuals like those mentioned above, i.e., persons subject to occupational exposure and relatively more frequent contact with radiation than other people, reveal statistically higher percentages of certain types of injuries and diseases. Among these may be cited leukemia and bone cancer in the radium-dial painters, lung cancer in uranium miners, and various forms of cancerous growths in radiologists.[8]

The specific effects listed above are classified as somatic injuries, as opposed to genetic injuries, which have also been linked to radiation and which, because of their long-range significance for mankind as a whole, must be a major factor in all policy calculations. In brief, competent geneticists are satisfied that radiation increases the number of mutations in the exposed population's genetic constitution, that these mutations are almost always undesirable ones, and that relatively low levels of radiation may do disproportionate damage to extremely sensitive reproductive organs and cells.[9] A notable discovery has been that, while other cells in the body at least give evidence of some recovery in many cases, reproductive cells do not repair themselves after radiation damage. In a radiation field the chromosomes in the reproductive cells may break up and their fragments may rejoin in a different arrangement such that mutations will result with subsequent deleterious effects on future generations.[10] Thus, radiation effects may not only be real time in nature, but may affect many generations to come.

Ocean Dumping of Radioactive Waste.

The radioactive wastes that find their way unshielded into the oceans may either go into solution, precipitate or coagulate. Additionally, they may interact with each other to attain colloidal size and be absorbed, or ingested by marine life.[11] The ultimate fate of radioactive wastes disposed of into the sea depends not only on the chemical and physical form of the material itself, but on the amount of dilution that occurs upon entry into the sea and upon the degree of transport by currents and upwelling.[12]

To assist in categorizing radioactive wastes, the International Commission of Radiological Protection (ICRP) recommended in 1954 that wastes be considered low level if they emitted gamma rays in the air at no more than 10^{-10} microcuries per cubic centimeter, or if their activity in water would be more than 10^{-7} microcuries per cubic centimeter. By definition, a curie is the quality of any radioactive substance to decay at a rate of 3.7×10^{10} disintegrations per second. This decay includes alpha, beta, and gamma radiation. Any radioactivity over that mentioned above is classed within the medium to high level ranges.[13]

The oceans have been receiving radioactive waste material for two and a half decades. The United States has been dumping unwanted isotopes at selected sites in the oceans since 1946.[14] The United Kingdom has been discharging aqueous wastes in the Irish Sea since 1952.[15] Low level wastes are also dumped into the Columbia and Clinch Rivers from the United States Atomic Energy Commission's nuclear plants at Hanford and Oak Ridge.[16] Fortunately, both the United States and the United Kingdom have followed the policy of dumping only low-level wastes into the sea. Because of the very serious hazards connected with high-level wastes, the latter have been stored on land.[17]

Thereis a widespread expectation among scientists that a policy of dumping only low-level wastes into the oceans will be applied conistently among all nuclear powers, but this expectation may not be well-founded. First of all, the total amounts of high-level radioisotopes which have accumulated to date are but a small fraction of what may be expected to be accumulated by the end of the century. Moreover, the United States, where most of the high-level wastes have been created up to the present, is a spacious country which has relatively little difficulty in finding some out-of-the-way area for ground disposal of particularly dangerous wastes. This will not be true of many of the nations that are now or soon may be reaping the benefits and bearing the burdens of a nuclear power program. Smaller crowded nations may be sorely tempted to take the short range expedience of ocean disposal of high-level wastes.[18]

Since radioisotopes cannot be destroyed by any known means other than through their own decay, two alternatives are open to policy-makers. The wastes may either be concentrated and isolated, or they may be so dispersed that concentrations of radioactivity at any one location are well below levels considered a threat to man.[19] In pursuing either alternative, the oceans offer a very attractive and convenient disposal site.

Hazards.

Of the several hazards accompanying sea disposal, the governing one must be the possibility of return of the radioactivity to man. The probability of radioactivity entering man's food chain depends upon the life span of the activity itself. If it is short lived, it will decay to a level where it is harmless. If, however, it has a long lifetime, it might take hundreds of years to decay to a safe level. In this case, it could easily enter the marine food chain, concentrate, and eventually be ingested by man.[20] Plankton, the lowest link of the marine food chain, readily absorbs radioactivity.[21] Also, sedentary forms of marine life such as clams and oysters are known to concentrate radioactivity by factors of up to one million times.[22] This ability to concentrate radioactivity derives from the fact that these sedentary creatures are filter feeders with enormously enlarged gills which serve not only for respiratory purposes but as sieves to collect fine particles of food from the water.[23] Thus, through the long and complex marine food cycle, man could easily be the end member of a highly radioactive chain.

Another hazard resulting from oceanic disposal of radioactive wastes is the menace posed by the radioactive materials to the living resources of the sea, some of which will become increasingly significant to man as the world's food requirements expand. A general and probably valid hypothesis is that, the more complex the organism, the greater is its susceptibility to radiation damage. The lethal dose of external radiation for most higher aquatic forms is in the vicinity of 1,000 Roentgrens of whole body radiation, not far above the amount fatal to man.[24] It is conceivable that, through somatic or genetic damage or a combination of the two, a disaster might result at some peculiarly sensitive level of the marine food chain. The biological balance of the oceans could be severely and unfavorably altered.[25]

Besides the menace to man and to the living resources of the ocean, one must not neglect the possible interference of radioactive waste disposal with other uses of the seas. Account must be taken of present and future activities on the continental shelves and deep ocean beds including exploration and exploitation of mineral resources, scientific research activities, and laying and repairing submarine cables.

Present efforts to assess the magnitude of these several dangers are restricted by the rudimentary state of scientific knowledge of the physical, chemical, and biological processes of the oceans. Oceanography, a synthetic science scarcely older than nuclear physics, is still in its adolescent stages. Marine biology, physics, and chemistry, if for no other reasons than the enormity of the oceans and the difficulties of access to their respective subjects in the depths of the seas, are also comparatively primitive sciences.

The upshot of these limitations on man's data concerning the oceans is that is not yet possible to predict precisely the modes and paths by which radioactive materials deposited in the oceans might return to man. If the radioactive waste does not dilute or sink rapidly at sea, the plankton in the upper layer of the ocean can become radioactive. In coastal waters, if there is little dilution or burying effect by sediment, sedentary creatures can become highly contaminated. If wastes sink to the ocean floor they may be relatively safe for hundreds of years, but if deposited in areas of upwelling they may be rapidly brought to the surface, later to enter man's food chain. Thus, beyond the caution demanded by inadequate knowledge of radiation effects on human beings, policy calculations must include an additional safety factor to allow for the defects of our information on this aspect of the problem.[26]

Although precise predictions may not be presently possible concerning the fate of radioactive material deposited in the seas, a goodly amount of oceanographic knowledge has been accumulated in recent years. Insofar as purely physical processes in the oceans are concerned, most of the important surface currents have now been charted, so that they can be utilized or avoided depending on whether a policy of concentration or dispersal is chosen. The locations of major fishing grounds are fairly well known, although frequent shifts may occur, and there is a sizable body of data on the habits and migrations of many marine organisms, especially those of commercial value.[27]

No commercial fishery is based on the animals of the great depths, although a number of harvested varieties depend on food from several hundred meters below the surface. Plankton thrives in the uppermost 100 meters of the oceans where they can be exposed to life-giving sunlight.[28] Therefore, because of their dependence on plankton for food, or on smaller fish that eat the plankton, almost all the commercial ocean fish thrive in this same upper layer.[29] However, if coastal waters are radioactively contaminated, the abundance of both fin and shell fish in those areas would almost certainly become contaminated.

But concerning deep ocean disposal, while no exact forecast can be made of the rates at which radioactive materials may be returned from the deep waters, it is possible to offer comparisons among potential disposal sites. Mixing of the deep and surface ocean waters is effected for the most part by currents and upwelling. Upwelling occurs when a main ocean current splits, such as at the equator, causing a surface void, or when winds blowing parallel to shore in such a direction that the wind force combines with the coriolis force to cause a surface void.[30] In either case, waters from the deep rise to fill these voids bringing with it nutrients, sediments, or perhaps radioactive particles if they were present in the deep waters. Caused by factors related to temperature, salinity, pressure, and wind force, surface currents move the warmer equatorial waters poleward, while the deep waters move from the upper latitudes back to the equator.[31] Thus, there is a continual interchange of surface and deep waters. In most cases this interchange is extremely slow. It has been estimated that for deep waters to move from the pole to near the equator and surface in the Atlantic Ocean would take from 750 to 1,000 years while it may take from 1,500 to 2,000 years in the Pacific.[32] Having such knowledge of currents and areas of upwelling, one may then choose a site for radioactive disposal that may be least likely to return the material to an area where it could harm man or the seas' living resources.

On January 23, 1960, the bathyscapth Trieste settled on the bottom of the Marianas Trench almost 38,000 feet below the surface and the second deepest hole known to exist.[33] A most important discovery of these unprecedented explorations was that currents, some of them stronger than had been anticipated, do exist on the bottoms of these abysses. This was blow to the hopes of those who had previously though ocean trenches might be the most suitable sea locations for disposal of rather high-level radioactive wastes. The descent into the Marianas Trench also revealed the presence of marine life at those depths, apparently unaffected by pressures of nine tons per square inch.[34]

If waste is concentrated and sent to the bottom of the sea, there is the danger that, by freak accident or by natural processes, the container may somehow be returned to man. It may be recovered by fishermen or by cable-laying personnel and result in measurable irradiation of human beings. Or, if the container is improperly weighted it may be swept ashore onto the continental shelf far from the point at which it was introduced. An additional consideration is that, if and when the container ruptures and releases its contents to the environment, "hot spots" may be created in the ocean owing to the inefficient dispersal of the isotopes by the generally sluggish bottom currents.

Direct introduction of uncontained wastes into the sea has even more obvious disadvantages. Such a practice makes no attempt at lessening radioactivity by allowing time for some decay before the wastes are admitted freely to the enivronment. For at least a short time the concentrations of radioisotopes in the vicinity of the original point of discharge remain above acceptable limits. If sites are not carefully selected, hazardous contamination may build up to permanently unsafe concentrations, or radioisotopes in harmful quantities may be swept into the midst of schools of fish by fast moving currents. It is clear that this method has limited applications. Dispersal cannot be employed continuously for sizable amounts of high-level wastes. Within a few months or a few years, the background radiation of the ocean could be multiplied several times.[35]

It should be pointed out however, that although limited amounts of radioactive wastes have been dumped at sea since 1946, surveys for the most part do not indicate its presence. Surveys taken in the vicinity of the early United States' dump-sites in Massachusetts Bay and later dump sites at sea show no appreciable rise in radioactivity.[36] The British have been dumping low-level wastes in the Irish Sea since 1952 with no known ill effects.[37] Surveys taken in the vicinity of the wreckage of the nuclear submarine Thresher produced no evidence of radioactivity.[38]

Conclusions.

In assessing the significance of present knowledge for the determination of policies dealing with radioactive hazards, one cannot overlook the inherent admonition for extreme caution.

When pondering the possibility of environmental pollution, the unique characteristics of radioactive contaminants require unprecedented care. The longevity of many radioactive elements, coupled with the awesome consequences to which even a slight miscalculation may lead, and the serious limitations on our understanding of so many aspects of the radiation menace, are convincing arguments for the most conservative approach to such matters as disposal of radioactive wastes.

A mistake in the initial formulation of policy may not be realized until disaster has struck. A change in policy may not be possible in time to forestall extensive damage to populations and resources. These somber remarks must not be taken to paralyze action; rather they are intended to stimulate sensible and positive undertakings reasonably designed to safeguard community interests. If we err, let it be on the side of too much caution, rather than too little.

CHAPTER III

SOURCES OF RADIOACTIVE WASTES

This chapter deals with the sources of the radioactive wastes that presently are being disposed of at sea. These sources include nuclear powered ships, land based nuclear sites which dump wastes into rivers and streams, and deliberate dumpings into the sea of radioactive wastes which were generated at land based nuclear activities.

Radioactive wastes are generated in practically all areas of the nuclear fuel cycle and accumulate as either liquids, solids, or gases at varying radiation levels. The liquid radioactive wastes are generally classified as high, intermediate, or low-level, based on the concentration of radioactivity in specific waste streams.[1] These classifications are of importance primarily to the plant operator as an approximate indication of the degree of confinement and control which must be provided for the processing or interim storage of each type of waste.

High level liquid wastes are those which, by virtue of their radio-nuclide concentration, half-life, and biological significance, require perpetual isolation from the biosphere.[2] The chemical reprocessing of irradiated fuels at the reprocessing plant is the primary source of all high level wastes. These wastes are presently stored as liquids in large underground tanks; however, increasing emphasis is being focused on research and development programs aimed at converting and reducing the high level liquid waste to solid form.[3]

Intermediate level liquid wastes is a term applicable only to radioactive liquids in a processing status which must eventually be treated to produce a low level liquid waste (which can be released) and a high level waste concentrate (which must be isolated from the biosphere).[4]

Low level liquid wastes are defined as those wastes which, after suitable treatment, can be discharged to the biosphere without exposing people to concentrations in excess of those permitted by AEC regulations.[5] Sea disposal of radioactive wastes is presently limited to low-level liquid and solid wastes.

Wastes From Nuclear Powered Ships.

The sources of nuclear wastes in a nuclear powered ship are the ion-exchange resins used for keeping the primary coolant free from large amounts of radioactive material; the water displaced from the coolant system during startup, due to expansion during heating of the system; and the miscellaneous small amounts of wastes resulting from routine day-to-day operation.[7] Thus f r, with the limited number of nuclear powered ships in operation, waste disposal has not been a difficult problem.[8]

Normally, the most radioactive substance discharged by nuclear ships at sea is the spent ion-exchange resin.[9] This is a resin contained in the purification system demineralizer through which a portion of the primary coolant is circulated. Any ionic impurities contained in the coolant is filtered out by the resin through an ion-exchange process. Most of these ionic impurities are the result of corrosion and erosion of the metallic surfaces of the reactor and coolant system internals. These impurities are irradiated as they pass through the reactor and become highly radioactive, and if not removed from the coolant system, would constitute a hazard to the plant operators. These radioactive impurities accumulate in the demineralizer after reacting with the ion-exchange resin. After a few hundred hours of operation, the now radioactive resin must be flushed overbroad and replaced with a fresh charge.[10]

The important corrosion isotopes in the demineralizer resin of the NS Savannah after fifty days of operation were forecast to be iron-59, iron-55, cobalt-60, tantalum-182, and chromium-51, with a total gross activity of 405 curies.[11] For disposal at sea, according to the system of calculation advocated by the National Academy of Sciences Panel Report, this resin would have have to be mixed into 1.4×10^9 cubic meters of sea water, which is practicable only in the open sea.[12]

The most abundant form of shipboard radioactive waste is low-level liquid waste, namely the primary coolant, of which there is a periodic outflow.[13] As a reactor plant is heated to operating temperature during startup, the primary coolant expands and a portion of it must be discharged either directly to the sea or to holding tanks for later discharge. The NS Savannah discarged 2,170 gallons of primary coolant for each heatup operation.[14]

There are several reasons why the primary coolant becomes radioactive, even though the nuclear fuel is contained in cladded fuel plates. As described previously, impurities caused by corrosion and erosion of the plant internals are irradiated and become radioactive. The same occurs to other impurities such as metal particles, dust, or paint chips which may enter the system during construction, maintenance, or when water is added to the system during cool down.[15] In addition, nuclear reactions with the coolant fluid itself or with chemical additives add to the radioactive level of the coolant.[16] As the coolant is irradiated, a small amount disassociates into hydrogen and oxygen some isotopes of which are radioactive.[17] To minimize corrosion, hydrogen or hydrozene is added to the coolant to combine with the free oxygen. These additives, like the coolant, when bombarded by neutrons, form new isotopes, some of which are radioactive.[18] A third cause of radioactive coolant is the escape of fission products from the fuel plates. Fission fragments can, if they possess the proper energy, eject from the fuel and pass through the metallic cladding directly into the coolant. The probability of this occurring increases if the thickness of the cladding has been reduced by corrosion or erosion, or if the cladding has damaged through thermal stress caused by improper operation of the reactor.[19] Rupture of the fuel cladding is one of the most serious types of accidents, causing the coolant to reach unacceptable levels of radioactivity.[20]

The amount of radioactive material contained in the coolant discharged during warm up is about0.7 curies of gross activity, consisting of 99.9% corrosion products and 0.1% fission products. The main constituent of the fission products is Cesium-137. These amounts are too great for discharge in an enclosed harbor, but would be permissible in coastal waters or the open sea.[21]

Other miscellaneous radioactive wastes which must be disposed of by crews of nuclear powered ships include coolant samples drawn for testing, about five gallons per day on NS Savannah;[22] the usual heterogeneous mixture of wastes arising from leaks, cleanup of spills, and other semi-accidental occurences;[23] tools and parts removed during maintenance;[24] and drains from personnel decontamination showers and contaminated clothing laundries.[25]

Wastes Entering Oceans From Rivers and Streams.

A second major source of radioactivity contributing to pollution or possible pollution of the sea comes from the land based nuclear sites which use rivers and streams for dumping radioactive waste. Also where ground disposal of wastes is employed, the radioactivity may, over a long period of time, and under certain conditions, find their way to the sea.

Concerning the medium active liquid effluent resulting from fuel processing, these solutions may contain 0.5% fission-product activity consisting of plutonium, uranium and fission products in which the organic soluble ruthenium, zirconium and niobium predominate.[26] With this waste there has been a difference between United States and European practice. On the American continent it has been found possible to dispose of some of these wastes to ground, whereas in Europe the tendency has been to discharge to coastal waters. No doubt the denser population in Western European countries, especially the United Kingdom, has been a big factor in this decision.

At Hanford, Washington, with a water table of 175-320 meters down and a low (17 cm) annual rainfall with a consequent low rate of water movement, conditions are favorable for ground disposal.[27] It is estimated from laboratory experiments that the shortest time of travel to the Columbia River is about 50 years. No evidence has been obtained of long-lived radionuclides in ground water at more than 350 meters from the disposal point.[28]

At Oak Ridge and Savannah River projects, conditions are less favorable for ground disposal,[29] rainfall is higher (132 cm and 100 cm respectively) and the water-tables only 15 meters deep. Disposals at these sites, as of 1962, were respectively 100,000 curies in 26 million liters and 240 curies in 500 million liters. The latter is considered a quite low-activity waste. As might be expected, the movement of activity in the ground is greater at these establishments than at Hanford.

The Oak Ridge National Laboratory has now developed, and is now routinely operating, a "hydraulic fracturing" technique by which intermediate wastes are disposed of by injection into the ground. The radioactive waste is first concentrated by evaporation, then mixed in storage tanks with cement and other additives, and then pumped under high pressure into suitably oriented factures in impermeable shale formations 700-1,000 feet deep. According to the AEC, the slurry establishes itself in a thin horizontal sheet configuration several hundred feet across which permanently sets in this position.[30] The AEC's Savannah River Operations Office has a study underway which involves long-term storage of high level wastes in caverns excavated deep in the bedrock under the Savannah River site.[31]

In Europe, the preference is for disposal of these medium level effluents to surface water. At Windscale, the waste is first treated to minimize the activity level before dumping to the Irish Sea.[32] The overall efficiency of removal is about 92%-95% for fission products and 98% for plutonium. The final solids content of the discharged effluent is about three percent. The authorized discharge activity is 20,000 curies per month.

Many countries are discharging low-level liquid wastes to streams and rivers after various types of treatment and dilution. At Harwell, England, low-level effluent is treated, monitored, and then discharged to the Thames River.[33] The sludge resulting from the treatment is formed into a cake which is then dumped into the sea. The permissible discharge to the Thames is fixed by a formula which takes into account the different types of radiation emitters in the effluent and is related to a nominal flow of 150 million gallons a day in the River.

At the Mol Laboratories in Belgium, at Lillestrom, Norway, and Studsvik, Sweden, the treatment of the effluent is similar to that at Harwell, before it is discharged to small rivers.[34]

At Sarclay, France, after treatment, low-level radioactive effluent is discharged to the Paris sewers pending preparation of a discharge point in the Seine downstream of Paris.[35]

In the U.S.S.R., low-level effluent is discharged to a river after treatment. Permissible levels are fixed for individual radionuclides--e.g., 10^{-5} microcuries/milliliter for cesium-137 and 5×10^{-7} microcuries/milliliter for strontium-90.[36]

It seems to be normal practice in most countries to dispose of liquid waste from hospitals and research laboratories to the sewers or to rivers. Occasionally, when the activity is high or dilution is inadequate, a treatment plant may be installed.[37]

In referring to the treatment of radioactive effluents in preceding paragaphs, it should be pointed out that treatment does not, in fact, destroy the hazard but merely concentrates the activity in solid form, usually on chemical precipitates or ion-exchange resins.[38] These solid wastes are additional to the normal arisings of solid radioactive wastes, which already present a formidable problem in disposal.

Waste Dumping into the Oceans.

The third and final major source of radioactivity entering the oceans is the deliberate dumping of radioactive wastes which were generated at land based nuclear activities then transported out to sea.

For waste of low activity, dumping on the continental shelf (100 fathoms or more) at recognized dumping grounds is presently considered to be satisfactory.[39] For more active wastes, deeper water is used. Steel drums with an inner layer of concrete think enough to reduce the surface dose-rate below 20 millirem/hour are most frequently used.[40]

Early in the nuclear history of the United States, periodic dumping of low-level solid waste was accomplished in Massachusetts Bay and other selected ocean sites.[41] The materials so disposed of at sea have apparently been small in radioactive contribution.[42] So many unknowns and unpredictables with respect to oceanic behavior still remain that the safer practice of keeping high-level radioactive materials under more obvious scrutiny and control has prevailed. Storage on land or burial has been the practice in managing high-level radioactive wastes.

The European Nuclear Energy Agency (ENEA) of the Organization for Economic Co-operation and Development (OECD) has been sponsoring an experimental project involving sea disposal of low level solid radioactive waste. In the summer of 1967, 11,000 tons of solid radioactive waste were dumped into the Atlantic.

Waste from nuclear installations in Britain, France, West Germany, Belgium, and the Netherlands was packaged in containers and dumped at a depth of 16,400 feet.[43] The Agency's annual report concludes that the dumping will represent no risk either to man or marine organisms. Another experimental sea disposal, amounting to 9,000 tons of waste, was accomplished during the summer of 1969, at approximately the same location as the first project.[44]

For these experimental dumpings, new or second hand oil drums of about 200 liters capacity were generally used as containers, some of which were concrete reinforced.[45] ENEA engineers estimated that the expected life of the containers on the seabed would be at least ten years.[46] However, it is the author's opinion that this estimate is overly optimistic. Hydrostatic pressure tests conducted by other organizations on concrete filled steel containers have indicated a cracking and crushing of the concrete as well as the development of pin-hole leaks in the welds of the steel encasement.

General Considerations.

In spite of the apparent favorable results obtained from sea disposal, such operations are very unpopular with the press, fishermen, operators of resorts, and the general public. Political pressure to prevent any disposal into the sea has resulted in efforts to establish international regulations to control, if not to eliminate, the use of international waters for dispersion of radioactive materials.

A panel appointed by the International Atomic Energy Agency (IAEA), under the chairmanship of H. Brynielsson, has issued a report[47] that discusses the problem in detail. The panel was opposed to the liberation of high or medium level wastes into the sea, but the report shows that, if suitable precautions are taken, low-level wastes, including those from a large number of nuclear powered ships, can be disposed of safely in this way.

Thus, from present evidence, the amount of radioactive wastes entering the oceans, while considerable in volume, has thus far apparently had little if any adverse effects. However, the effects of continued disposal of radioactive wastes in ever increasing volume at sea over a number of years can only be a matter for conjecture.

CHAPTER IV

THE WASTE ACCUMULATION PROBLEM AND A LOOK AT THE FUTURE

Electrical Power Production.

America is the most power-hungry nation in the world and it shows no sign of a letup in increasing its demands for electricity. At the turn of the century, the annual per capita consumption of electricity amounted to 50 kwh, enough energy to keep a 100-watt bulb burning for about three weeks. Some authors estimate that by the end of this century, the United States will use 30,000 kwh per person per year, a 600 fold increase.[1]

Already, power companies, especially on the East Coast, cannot get enough low-sulphur coal to meet the new pollution control standards; natural gas is in short supply, and low-sulphur oil is hard to come by. As a result, utilities are turning to uranium as a new source of "clean" power. As an example, Consolidated Edison of New York will end its coal era next summer. Then, it hopes to have in operation a huge 783,000 Kw nuclear power plant at Indian Point, 30 miles up the Hudson River.[2]

As for the competitive relationship of nuclear power to conventional fuels, it should suffice to point out that, as the earth's supplies of other power resources are exhausted and as world demand for such fuels increases relative to man's capacity to exploit them, costs of conventionally generated power will rise, making acceptable rather higher expenditures for nuclear power than now deemed permissible.

Although conversion of nuclear energy to electricity is relatively new, the growth and acceptance of nuclear electric power over the past few years is spectacular. While total world electric power consumption is increasing steadily, installation of nuclear sources is growing much faster. In 1960 about one-tenth of one percent of total electric power was derived from nuclear sources. In 1967, nuclear capacity was one percent of total electric power generated. The real period of explosive growth, based on projections of current orders, will occur between now and 1980. Nuclear capacity will grow to an estimated 12.5% by 1974 and about 30% by 1980. Most recent estimates are 50 to 100% higher than forecast three to four years ago. The effect of this demand for nuclear plant construction is a six to eight year backlog of orders.[3]

The Atomic Energy Commission estimates that by 1980, the nuclear generating capacity in the United States will be 130,000 to 170,000 Megawatts,[4] with the estimate from other energy sources being about 540,000 Megawatts.[5] As of September, 1970, there were in the United States 17 nuclear power plants operable, 54 being built, and 38 more on order.[6] The total capacity of these 109 reactors is 86,689 Megawatts.[7]

The European Nuclear Energy Agency member countries, consisting of Belgium, France, Germany, Italy, Netherlands, Spain, Sweden, Switzerland, and the United Kingdom, have 51 power reactors in operation, 38 under construction, and 10 additional ones decided upon. Total generating capacity of these 99 reactors is approximately 34,000 Megawatts.[8]

Additional foreign installations of U.S.-type enriched uranium power reactors include one in India (380 Mw), seven in Japan (4,016 Mw), one in Korea (560 Mw), and one in Taiwan (550 Mw).[9] There are, of course, nuclear reactors in several other countries that are not of United States origin.

It is estimated that for every 11,000 megawatts of power, four tons per year of fission products will be generated.[10] If reactors are 25% efficient in the conversion of nuclear fuel, for each 1,000 Mw produced, 1.46 tons per year of spent fuel will be generated.[11] Taking the above 1980 estimates for nuclear power generation in the United States and for the thirty-three U.S.-type reactors abroad, 360 tons of spent fuel will be generated each year. Some of this will be reprocessed for re-use with the remainder requiring disposal. This amount, however, is but a small fraction of the total radioactive wastes which must be disposed of, when compared to the tremendous volume of radioactive liquid waste produced in reprocessing this fuel. The accumulation of this liquid waste is discussed in greater detail in a later section of this chapter.

Nuclear Power in Undersea Development.

It appears to be but a matter of time before nuclear power plants are developed for submerged use on the continental shelf.

The President's Commission on Marine Science, Engineering and Resources recommended in its Panel Reports that the AEC and the new oceanic agency in cooperation with private industry sponsor development and construction of an experimental continental shelf submerged nuclear power plant.[12] The technology developed would permit later construction of relatively small (5,000 to 10,000 Kw) power sources to support undersea operations. A possible subsequent development would be huge stationary electric generating facilities (thousands of megawatts). Such large facilities will become increasingly important as coastal land grows scare and expensive and as it becomes necessary to shift thermal pollution loads from the nearshore areas.

A concept developed for the Naval Civil Engineering Lab of a five-man, 6,000-foot undersea station includes a nuclear reactor for main power. A unit recommended for a power demand of 38 Kw was the TRIGA Oceanographic Power Supply with a steam turbine generator power conversion system. The Navy and the AEC are working to develop yet more suitable nuclear reactors for other future deep ocean applications.[13]

Except for power plant maintenance problems and some materials development, current technology is adequate to provide submerged nuclear power plants.[14] The role of nuclear power systems in the sea's exploration and exploitation is as certain as man's ability to develop the technology, equipment, plans, and support operations to delve into the environment--and his determination to do so.

Such uses of nuclear power, while being a major breakthrough in the development of the continental shelves, would but add to the radioactive waste disposal problem. As a minimum, the low-level wastes resulting from day-to-day operations would be discharged to the sea.

Radioactive Waste Accumulation.

The Atomic Anergy Commission has the responsibility in the United States for controlling the handling and disposal of radioactive waste material. A general requirement for establishment of a land burial site is that the land be owned by the Federal or a State Government. There are two federally licensed commercial radioactive waste disposal companies in operation in the United States, with low-level burial sites at Richland, Washington; Beatty, Nevada; Sheffield, Illinois; Morehead, Kentucky; and West Valley, New York.[15] There are, in addition, numerous private firms licensed by agreement States to receive radioactive wastes.[16]

Present estimates indicate an accumulated volume in the United States of intermediate level wastes from the reprocessing of nuclear fuels of about 3 1/2 million gallons by 1980, and 60 million gallons by the year 2000, assuming all the wastes are stored as liquid at a rate of 100 gallons of high activity waste generated per ton of uranium processed.[17]

The low-level volumes of solid wastes available annually for commercial burial in the United States are estimated at one million cubic feet in 1970, three million cubic feet by 1975, and six million cubic feet by 1980.[18] In addition to private burial, the burial of solid radioactive waste generated at AEC burial sites has been proceeding at a fairly constant rate of slightly less than two million cubic feet per year since 1963.[19]

At the Nuclear Fuel Services reprocessing plant at West Valley, the high-level liquid wastes are stored in large, concrete enclosed, carbon steel tanks (600,000 gallons capacity). The NFS operation results in a generation rate of 400 gallons of high-level liquid waste per metric ton of uranium processed.[20] General Electric, in its plant to be constructed at Morris, Illinois, plans to convert to solid form all process waste streams, except the gaseous effluents. In the GE process, the high-level wastes will first be concentrated in an evaporator, then fluid-bed calcined to a solid form, and the resulting calcined solids will then be submerged in a water-filled basin to provide cooling and shielding, pending shipment to a permanent storage site. About two cubic feet of waste per ton of uranium is anticipated.[21]

Lacking any long-term answer to the problem of high-level radioactive waste disposal, the AEC has simply stored the wastes in special underground tanks. Some 80 million gallons have been accumulated to date.[22] The ultimate disposal of these radioactive wastes is a problem that continues to vex atomic authorities. It appears clear that safe disposal requires concentration of the liquids, preferably into a solid form that is more convenient to hide away. Even then, what does one do with them? Fortunately, authorities have abstained from disposal of large amounts into the oceans. The final disposition of these wastes will most probably be burial, about 1,000 feet deep in salt mines.[23] The radioactive wastes, packed in shielded cylinders 10 feet long and a half-foot in diameter, would be inserted into holes drilled in the mine floor. The space above would be packed with salt, and the residual heat remaining in the radioactive wastes would fuse the surrounding salt, sealing them in place. Salt mines are the tightest geological formations known to man and the AEC has tentatively picked a site near Lyons, Kansas, as an initial federal waste repository.[24]

Among other interesting investigations into the problem of containment are those seeking to devise a way to fuse radioactive wastes in various solid materials. Glass has been used experimentally for this purpose and has exhibited good qualities, as well as potentially reasonable costs, but it is thought best at present to store such glass only in dry locations.[25] Research is being directed toward evaluating the prospects for fusion of wastes in ceramic glazes,[26] which have proven highly resistant to weather and chemical action and which have demonstrated long-term stability, if one recalls the many archeological discoveries of well-preserved ceramics. For possible oceanic disposition the latter materials appear superior to glass. At any rate, if a satisfactory mode of containment can be developed, the virtues of the oceanic depths for the complementary function of isolation may turn out to be enormously valuable.

Use of By-products.

Hope has been expressed that by recovery of valuable selected isotopes as by-products from radioactive waste, the waste disposal problem would be reduced. It is true that the production of selected radio isotopes for beneficient uses in medicine, in biological laboratories, in industry, and in general research can be, and is being, accomplished. But there are still problems of supervision, inventory, transportation, and eventual disposal.

Fission products, such as strontium, cesium, and promethium, recovered during irradiated fuel processing operations, are already finding some useful commercial applications such as industrial thickness gauges, food irradiators, teletherapy units, and as power sources in remote weather stations, etc.[27] Others such as xenon, krypton, rhodium, and palladium, are being considered for recovery because of their potential use in the electrical, jewelry, oil, and chemical industries.[28] Possible markets for the expanded use of these materials in the near future offer many challenging opportunities.

Of particular interest in the by-product category is neptunium, which is used as the target material in the production of plutonium-238. It is possible that at some future date there will be a very large demand for plutonium-238 for use as a power source in the space program. There could also be large demands for plutonium-238 for the artifical heart program if it is successful.[29]

The recovery of valuable by-product materials, particularly cesium-137 and strontium-90, would have two important assets. The selective high efficiency removal of such specific nuclides from high-level wastes would reduce somewhat the high-level waste disposal problem. It would not, however, eliminate it, but would make the holding of such materials less difficult in time and in risk. One must distinguish between recovery and removal. For example, 95% recovery of cesium-137 might be considered fine for fission product utilization, but does not do much good for waste disposal directly.[30]

The search for valuable by-products of industrial wastes is interminable in the nuclear as well as in other industries. Historically, it is unfortunately true that promises of great financial returns from waste recovery by-products, or solutions to waste problems through by-products use have fallen far short of fulfillment in most industries.

The Promise of Nuclear Fusion.

The most promising solution to the radioactive waste disposal problem is the prospects of utilizing controlled fusion for the generation of power, completely eliminating the generation of radioactive wastes. At least three nations, the United States, United Kingdom, and the U.S.S.R., are pursuing multiple approaches to controlled fusion and the outlook may be characterized as hopeful.[31] Although the uncontrolled release of fusion energy has been achieved in the thermonuclear bomb, the problems of achieving self-sustaining controlled fusion reactions from which useful power could be extracted are of an entirely different sort, involving unique and formidable physical requirements.[32]

Nuclear fusion was discovered many years before the discovery of the fission reaction. Soon after the invention of the high-voltage particle accelerator in the 1930's we found that when nuclei of low atomic number are accelerated to many-thousand-volt energy and caused to bombard other light elements, nuclear reactions occur. These reactions were found to result from the "sticking together" or fusion of parts of the colliding nuclei to form heavier elements, accompanied by a release of energy.[33]

Not only does nuclear fusion eliminate the knotty problems of radioactive waste disposal associated with fission power, but the primary fuel used in nuclear fusion is cheap and its source is practically inexhaustible. The primary fuel of nuclear fusion, the heavy isotope of hydrogen known as deuterium, is easily recovered from ordinary sea water,[34] and thus is so abundant that it could not be exhausted for billions of years, even if the world's power demands were to increase a thousand-fold from the present figure.

Nevertheless, in view of the numerous major questions which have to be answered before power from fusion can begin to contribute to the world's energy requirements, policy-makers cannot count on the success of research into controlled fusion to relieve them of their responsibility to deal wisely with the problem of radioactive wastes from nuclear fission. One must base one's actions on present facts and future probabilities.

Exhortation.

Scientist's efforts should be devoted to determining the imperatives of nature in the matter of waste disposal. For the time being and for some time to come, the fundamental goal of scientific inquiry should be not the answer to the question, "How much will waste disposal cost?", but rather the solution to the problems of "What limits of artificial radioactivity will nature tolerate in the environment?" and "What disposal procedures will conform to those limits?". Let scientists discover how radioactive wastes may safely be disposed regardless of the costs. In short, scientists are exhorted to seek safe and effective methods of disposal. Once developed, their costs may more properly be weighed, taking into account the magnitude of the dangers which surround cheaper but less effective alternatives.

CHAPTER V

SOME LEGAL ASPECTS

No attempt will be made to describe in detail various laws governing the management of radioactive wastes because these differ from one country to another and a comparison of legal practices in many different countries would be of little value. Certain general principles are, however, common to most regulatory systems and an outline of this common ground may be useful.

Waste management is under the control of some form of government license in all countries with nuclear industries. A licensee is required to show that he is professionally competent, and also that he will use a disposal area and disposal facilities that are satisfactory to the technical advisers of the government.[1]

In some countries government authorities are not prepared to place the responsibility for waste management in private hands.[2] It is difficult to see how a private corporation can undertake to operate, maintain, and control a disposal facility in perpetuity. In these circumstances, the government prefers to operate the facility through one of its own agencies.

In granting a license to operate a waste management undertaking, conditions are defined to restrict the amount of radioactive material on hand at any one time. This is intended to limit hazards to the public from accidents in storage depots. The operator must abide by special transport and packaging regulations, and he must keep adequate records of wastes disposed of in specified ways.[3]

Concerning international obligations, when wastes are discharged into rivers or lakes that are not wholly within one country, or into the sea, the effects may bear upon people who have no control over the regulation of the discharge. A degree of contamination that would be acceptable to one nation might be quite unacceptable to another. For example, an upstream nation situated on an international river might be so anxious to develop nuclear industry that it would be prepared to tolerate a relatively high radiation exposure to its population, whereas a downstream nation, interested only in agriculture and using the water for drinking and irrigation, might be reluctant to accept any contamination at all. A large industrial nation might wish to dump wastes on the high seas at a point where another nation operated an important fishing ground. Problems of this kind are real and have led to difficult diplomatic situations.

There are no international regulations on disposal of radioactive wastes at sea, but the Brynielsson Report[4] was written in the hope that it would assist in the drafting of an International Convention on sea disposal. The Brynielsson panel, accepting the principle that disposal of radioactive wastes into the sea should not be permitted to restrict the harvest of marine products or any other normal use of the sea by man, has calculated what proportion of wastes from nuclear industry could be safely deposited in deep ocean waters. Assuming a future power industry producing 1,000 metric tons of fission products per year, less than than two percent of this material could be placed in the deep sea without raising the strontium-90 content of the upper layers beyond a suggested maximum permissible concentration of 10^{-9} microcuries/milliliter.[5] For this reason liberation of high-level wastes at sea was considered to be inadmissible.[6] There seems to be no real problem in disposal of wastes from nuclear shipping on the high seas, most of these wastes being low-level. There is general agreement with the Brynielsson Report that high-level wastes could not be liberated into the sea, although certain nonleachable materials such as glasses might be used for this purpose.[7] Thus it should not be difficult to write an acceptable convention for ocean waters. Difficulties do rise, however, near the coast.

Regulations governing discharge into coastal waters and into the ocean over the continental shelf are the most difficult to draft, but suggestions are made in the Brynielsson Report which should ensure safety. It might not, however, be easy to convert these technical recommendations into legal language.

In February 1958, the United Nations Conference on the Law of the Sea was held in Geneva. Apparently the question of sea disposal of radioactive wastes encountered unanticipated concern on the part of the participating nations.[8] Prior to the Conference, the International Law Commission had recommended an article which provided that "Every State shall draw up regulations to prevent pollution of the seas from the dumping of radioactive wastes." This recommendation generated considerable discussion, controversy, and confusion. A number of nations favored the article as drafted. Others objected, presumably on grounds that the draft article could be construed as prohibiting any sea disposal of radioactive wastes, any oceanographic research employing radioactive materials as research tools, and, in the particular case of the United States and the United Kingdom, any nuclear weapons tests affecting the high seas.[9] The Conference redrafted the article to express a rule of reasonableness with respect to pollution of the seas by radioactive wastes. States were required to take measures to prevent pollution, "taking into account any standards and regulations which may be formulated by the competent international organizations."[10] In addition, the Conference adopted a resolution proposed jointly by the United States and the United Kingdom. The Resolution noted that the International Commission for Radiological Protection (ICRP) had made recommendations regarding maximum permissible concentrations of radioisotopes in water and recommended that:

> . . . the International Atomic Energy Agency, in consultation with existing groups and established organs having acknowledged competence in the field of radiological protection should pursue whatever studies and take whatever action is necessary to assist States in controlling the discharge or release of radioactive materials to the sea,

> promulgating standards, and in drawing up internationally acceptable regulations to prevent pollution of the sea by radioactive material in amounts which would adversely affect man and his marine resources.[11]

Thus, in effect, what the Conference achieved was a clear recognition that a problem exists, a referral of the problem to an expert agency, and a general policy statement prescribing caution.

Pursuant to the Resolution adopted by the Conference on the Law of the Sea, the International Atomic Energy Agency (IAEA) established a panel of experts to study the problems of the disposal of radioactive wastes in the sea.[12] This resulted in the Brynielsson Report discussed above.

There are two international organizations of interest within the European community that concern themselves with the problems of radioactive waste disposal, Euratom and the European Nuclear Energy Agency (ENEA).[13]

The Council of the Organization for European Economic Cooperation established the ENEA in September 1957 and directed the Agency to encourage the harmonization of legislation on nuclear energy in participating countries, in particular regard to the protection of public health.[14] For this purpose, the Steering Committee was directed to prepare common rules to serve as a basis for national laws and regulations. In a longer term sense, it was proposed that the Agency deal with practical cases put before it and examine projects for the discharge of radioactive waste concerning a number of countries.

The Euratom Treaty directs the Community to establish, and ensure the application of, uniform safety standards to protect the health of workers and the general public, and specifically requires the establishment of basic standards, including the maximum permissible degree of contamination.[15] Thus, the Euratom Treaty enables the Commission to wield considerable influence over the waste disposal activities of member states. In this connection, the Euratom Commission's authority appears to be more precise and comprehensive than the authority of the ENEA.

It should be pointed out, however, that both Euratom and ENEA are regional in nature, while the nuclear sea disposal problem is of global proportions. Consequently, the activities of these two organizations may be of limited import in the context of the total problem. It appears that the best hope for expanded international cooperation in the adoption of standards and regulations in radioactive waste disposal is vested in the United Nations' International Atomic Energy Agency.

Under the existing structure, while the IAEA does have authority to establish radiation safety standards for protection of health and minimization of danger of life and property, the obligatory application of such standards, and the Agency's authority to enforce them, is restricted to three particular types of actvities.[16] These are: (1) the operation of facilities which the Agency has acquired; (2) the conduct of "Agency projects", namely, projects in which the Agency is providing Member Nations with materials, services, equipment, facilities or information; and (3) those activities with respect to which the Agency is requested to apply its standards. Member Nations, therefore, have no general obligation to conform to or comply with the radiation health and safety standards established by the Agency.

CHAPTER VI

CONCLUSIONS

In assessing the significance of present knowledge for the determination of policies dealing with radioactive hazards, one cannot overlook the inherent admonition for extreme caution. When pondering the possibility of environmental pollution, the unique characteristics of radioactive contaminants require unprecedented care. The longevity of many radioactive elements, coupled with the awesome consequences to which even a slight miscalculation may lead, and the serious limitations on our understanding of so many aspects of the radiation menace, are convincing arguments for the most conservative approach to such matters as disposal of radioactive wastes. The dangers are too great and the stakes too high to risk haphazard procedures in radioactive waste disposal.

Since radioisotopes cannot be destroyed by any known means other than through their own decay, two alternatives are open to policy-makers. The wastes may either be concentrated and isolated, or they may be so dispersed that concentrations of radioactivity at any one location are well below levels considered a threat to man. In pursuing either alternative, the oceans offer a very attractive and convenient disposal site. Of the several hazards accompanying sea disposal, the governing one must be the possibility of return of the radioactivity to man.

find remote areas for land storage of radioactive waste, but the crowded small industrial countries may find it all too convenient to turn to the sea for disposal of this unwanted material. It is not reasonable to assume that nations can store in perpetuity an ever increasing volume of long-lived radioactive waste.

The development of techniques for the use of by-products from radioactive waste is not encouraging from the view point of lessening the disposal problem. Because of the long-lived radioactivity in these products, their ultimate disposal would merely be shifted from the nuclear industry to some other industry, perhaps one not so well qualified to deal with the disposal problem.

The most promising solution to the radioactive waste disposal dilemma is the prospects of utilizing controlled fusion for the generation of power, completely eliminating the generation of radioactive wastes. The continuation of our present course of expanding a nuclear industry utilizing fission for power generation can only lead to the logical conclusion--the ultimate uninhabitability of the earth. Research and development efforts must be redoubled and must receive top priority to harness nuclear fusion instead of fission for our power needs.

Meanwhile, we must cope with the present problem of radioactive waste disposal. International cooperation in adhering to safe standards seems to be of paramount importance.

The development of an international legal framework has not made significant progress over the past two decades of the atomic age. However, each nation's local laws do appear to be comprehensive and mindful of public protection.

A concerted effort should be made to obtain general international agreement on safe methods for oceanic disposal of atomic wastes. Since technical questions are central to the whole problem, such agreement can most properly be pursued by an international conference of scientific experts. Secondly, an intensified program of research to ferret out the data necessary for evaluating and improving disposal procedures is needed. The existing organization, the International Atomic Energy Agency of the United Nations, could perform a most useful service in pursuing these two proposals.

What then are the prospects for an agreement as suggested above? One may realistically describe them as good. It has been widely noted that international law is most effective when it is self-enforcing, that is, when the several States recognize their common interest and act accordingly. This is really the sort of situation which confronts mankind in the matter of radioactive waste disposal in the seas.

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APPENDIX I

HALF-LIVES OF SELECTED ISOTOPES

APPENDIX I

Half-Lives of Selected Isotopes[1]

Half-Life[2]	Radioisotope	Half-Life[2]	Radioisotope
24.2s	Silver-110	35d	Niobium-95
30s	Rhodium-106	39.8d	Ruthenium-103
72s	Indium-114	43d	Cadmium-115
2.6m	Barium-137	45d	Hafnium-181
17.5m	Prasecodymium-144	45d	Mercury-203
12.44h	Potassium-42	45.1d	Iron-59
12.8h	Copper-64	49d	Indium-114
13.6H	Palladium-109	53d	Strontium-89
14.3h	Gallium-72	59.5d	Yttrium-91
15.06h	Sodium-24	60d	Antimony-124
19h	Iridium-194	65d	Zirconium-95
19.2h	Praseodymium-142	72d	Cobalt-58
23h	Mercury-197	73.2d	Tungsten-185
24.1h	Tungsten-187	74.37d	Iridium-192
26.8h	Arsenic-76	85d	Scandium-46
35.87h	Bromine-82	87.1d	Sulfur-35
38h	Arsenic-77	112d	Tin-113
40h	Lanthanum-140	115d	Tantalum-182
47h	Samarium-153	120d	Selenium-75
53h	Cadmium-115	163d	Calcium-45
2.44d	Ruthenium-97	250d	Zinc-65
2.54d	Yttrium-90	270d	Silver-110
2.7d	Gold-198	282d	Cerium-144
2.71d	Mercury-197	1.0y	Ruthenium-106
2.79d	Molybdenum-99	2.3y	Cesium-134
2.8d	Antimony-122	2.6y	Promethium-147
3.15d	Gold-199	2.7y	Antimony-125
3.87d	Rhenium-186	4.0y	Thallium-204
5.02d	Bismuth-210	5.27y	Cobalt-60
7.6d	Silver-111	9.5y	Barium-133
8.08d	Iodine-131	10.27y	Krypton-85
11.1d	Neodymium-147	12.46y	Hydrogen-3
11.52d	Barium-131	13y	Europium-152
12.8d	Barium-140	16y	Europium-154
13.95d	Praseodymium-143	25y	Strontium-90
14.3d	Phosphorus-32	30y	Cesium-137
16d	Osmium-191	85y	Nickel-63
19.5d	Rubidium-86	5568y	Carbon-14

[1]John F. Hogerton, The Atomic Deskbook (New York: Reinhold, 1963), p. 456.

[2]s, second; m, minute; h, hour; d, day, y, year.

Half-Life[2]	Radioisotope	Half-Life[2]	Radioisotope
27.8d	Chromium-51	2.12×10^5y	Technetium-99
32.5d	Corium-141	3.08×10^5y	Chlorine-36
		1.72×10^7y	Iodine-129

[2]s, second; m, minute; h, hour; d, day; y, year.

APPENDIX II

GLOSSARY

APPENDIX II

GLOSSARY

Explanations of the following terms are provided for the convenience of the non-technical reader who may not have ready access to more comprehensive reference material.

Alpha particle. A positively charged particle composed of two protons and two neutrons that is emitted from certain radioactive nuclei. It is identical in all measured properties with the nucleus of a helium atom.

Attenuation. The reduction in the intensity of radiation upon passage through matter.

Beta particle. A negative electron emitted from a nucleus during beta decay.

Chain reaction. A reaction in which one of the necessary agents is itself produced by the reaction so as to cause like reactions. In the neutron-fission chain reaction, a neutron entering a fissionable atom causes it to fission, resulting in the emission of a number of neutrons which can in turn cause other fissions.

Cladding. A thin metal coating over the nuclear fuel plates to prevent corrosion, erosion, and the escape of fission products.

Contamination. Deposition of radioactive materials in any undesired placed, and particularly in any place where they may be harmful.

Core. In a nuclear reactor, the region containing the fissionable material. The body of fuel, or moderator and fuel, in a nuclear reactor.

Curie. A unit of radioactivity equal to the quantity of any radioactive nuclide in which the number of disintegrations per second is 3.7×10^{10}.

Decay, radioactive. The spontaneous transformation with a measurable lifetime of a nuclide into one or more different nuclides.

Decontamination. The removal of unwanted radioactive substances from a material.

Demineralizer. A component of the primary system of a nuclear plant containing an ion-exchange resin which filters the primary coolant, removing radioactive ions.

Dose, permissible. The amount of radiation that can be received by an individual within a specified period with expectation of no harmful result to himself.

Electron. An elementary particle of negligible mass having either a negative or positive charge. The positive electron is usually called a position.

Element. A substance all of whose atoms have the same atomic number, i.e., the same number of protons.

Fission. The splitting of a nucleus into two more-or-less equal fragments.

Fission fragments. The nuclear species which are first produced when a nuclide such as U-235 or Pu-239 undergoes fission.

Fission products. The nuclides produced by the fission of a heavy-element nuclide.

Fusion. A nuclear process whereby particles are joined together to form a heavier nucleus.

Gamma ray. A quantum of electromagnetic radiation emitted by a nucleus.

Half-life. The average time required for the decay of one-half the atoms of a sample of radioactive substance.

Heavy water. Water in which the hydrogen of the water molecule consists entirely of the heavy hydrogen isotope of mass 2, deuterium.

Ion. A charged atom or molecularly bound group of atoms. An ion pair consists of a positive ion and a negative ion.

Ionization. Any process by which a neutral atom or molecule loses or gains electrons.

Irradiation. The exposure of material to radiation.

Isotope. One of several nuclides having the same number of protons in their nuclei.

Microcurie. One millionith of a curie.

Moderator. Material used in a nuclear reactor to moderate, i.e., slow down, neutrons from the high energies at which they are produced in fission.

Neutron. A nuclear particle of zero charge and mass number 1.

Nuclear reactor. An apparatus in which nuclear fission can be sustained in a self-supporting chain reaction.

Nucleus. The positively charged core of an atom, with which is associated practically the whole mass of the atom, but only a minute part of its volume.

Nuclide. A species of atom characterized by the constitution of its nucleus.

Primary coolant. The fluid circulated through the core of a reactor to remove the heat and transfer it to a secondary steam system. In a pressurized water reactor, this medium is ordinary water which also acts as a moderator.

Radiation. The emission and propagation of energy through space or through a material medium in the form of waves or particles.

Radiation damage. A general term for the effects of radiation upon substances.

Radioactivity. Spontaneous nuclear disintegration with emission of corpuscular or electromagnetic radiations.

Radioisotope. Any radioactive isotope of an element. See isotope.

Reactor. See nuclear reactor.

Roentgen (R). A quantity of X or gamma radiation, the associated corpuscular emission of which per 0.001293 grams of air produces, in air, ions carrying 1 esu of electricity of either sign.

Roentgen equivalent man (Rem). The dose of any ionizing radiation that will produce the same biological effect as that produced by one roentgen of high-voltage X radiation.

X-rays. Electromagnetic radiation having wavelengths of less than about 100 A.