A Special Report to
The President and
The Congress

Nuclear Waste Management and the Use of the Sea

National
Advisory
Committee on
Oceans and
Atmosphere

April 1984

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NATIONAL ADVISORY COMMITTEE
ON
OCEANS AND ATMOSPHERE
3300 Whitehaven Street, N.W.
Washington, D.C. 20235

To the President and the Members of the Congress:

I have the honor of submitting to you the report of the National Advisory Committee on Oceans and Atmosphere (NACOA), "Nuclear Waste Management and the Use of the Sea."

The question of how to best manage wastes is a serious one, and the urgency of the problem will increase in the future. In 1981, this Committee sent you a copy of our report on non-radioactive wastes entitled "The Role of the Ocean in a Waste Management Strategy." In our report, we recommended an integrated multimedia approach to waste management where the least harmful disposal media would be chosen for wastes, rather than a continuation of the U.S. practice of attempting to separately protect the oceans, land, freshwater, and air by unrelated statutes.

In this report, although we do not suggest a reversal of U.S. land-oriented disposal policy at this time, we do recommend a revision of policy that excludes the use of the ocean for low-level radioactive waste disposal, subject to adequately funded and well-identified monitoring and research efforts which would provide full assessment of the fate and effects of such disposal.

In preparing this report, the objective of NACOA has been to review the current situation regarding nuclear waste disposal policies in the United States and elsewhere, and to relate these to implications for the oceans. We did not, and do not, comment on nuclear power as an energy source, but the accumulation of radioactive waste both here and abroad is a fact of life that presents problems challenging all nations. NACOA hopes this report is a positive contribution to meeting that challenge.

Respectfully yours,

John A. Knauss
Chairman

TABLE OF CONTENTS

Foreword vii

PART I—THE NACOA REPORT

Management of Nuclear Waste: Conclusions and Recommendations 3

PART II—THE BACKGROUND

Chapter I: Radioactive Waste: An Inventory 13
- Introduction 13
- The Nuclear Fuel Cycle 14
- U.S. Inventory 15
- International Inventory 19
- Summary 21
- References and Footnotes 22

Chapter II: Radioactive Waste Management: An Evolving Strategy 25
- High-Level Waste 25
- Transuranic Waste 28
- Low-Level Waste 28
- Low-Level Waste Ocean Disposal by the United States 29
- Low-Level Waste Ocean Disposal by Other Nations 29
- Other Sources of Anthropogenic Radioactivity in the Ocean 32
- Summary 33
- References and Footnotes 34

Chapter III: Institutional Framework: Avenues and Roadblocks 39
- Domestic Laws and Policies 39
- International Law Regulating Ocean Disposal 42
- References and Footnotes 46
- Attachment 1 48

Chapter IV: Marine Radioactivity 51
- Sources of Oceanic Radioactivity 51
  - The Primordial Elements and Radioactivity 51
  - Cosmic Ray-Produced Radionuclides 52
- The Fate of Radionuclides in the Ocean 54
  - Dispersion and Advection 54
  - Chemical Cycles in the Ocean 55
  - Radioactive Marine Sediments 56
- Recent Advances in Ocean Science 57
- Anthropogenic Versus Natural Radioactivity 58
- Mechanisms for Human Exposure to Radioactivity in the Sea 59
- Summary 59
- References 60

Chapter V: Ocean Disposal of Nuclear Waste: Possible U.S. Proposals 61
- Disposal of Defueled, Decommissioned Nuclear Submarines 61
- Ocean FUSRAP Project 63
- Subseabed Disposal of High-Level Waste 63
- Decommissioned Nuclear Reactors 66

Low-Level Waste from Institutions and Facilities 66
Need for a National Consensus 66
References and Footnotes 68

APPENDICES

A. Nuclear and Health Physics 73
B. Summary of Waste Management Strategies of Other Nations 81
C. U.S. Ocean Dumping of Radioactive Waste 85
D. Signatory Countries to the London Dumping Convention 89
E. Case Histories 91
Hanford 91
Pacific Fallout 91
U.S. Ocean Dumping 92
THRESHER AND SCORPION Sinkings 92
Sellafield 93
F. Meeting Dates, Speakers, and Presentation Topics 95
G. Glossary of Acronyms 99
H. Glossary of Selected Terms 101
I. Glossary of Organizations 105
J. Selected National Legislation Pertaining to Radioactive Waste Disposal 107
K. Selected International Agreements Pertaining to Nuclear Energy (as of January 1, 1983) 109
L. NACOA Panel on Nuclear Waste Management 113

FOREWORD

In 1981, the National Advisory Committee on Oceans and Atmosphere (NACOA) published a report on non-radioactive waste entitled "The Role of the Ocean in a Waste Management Strategy." In that report, the Committee recommended that the oceans be considered along with other options in a multi-media approach to planning for waste disposal. In this report, "Nuclear Waste Management and the Use of the Sea," we extend our consideration of waste management to radioactive wastes.

In preparing this report, NACOA's objective has been to review the current situation regarding nuclear waste disposal policies in the United States and elsewhere, and to relate these to implications for the oceans. We did not, and do not, comment on nuclear power as an energy source. But the accumulation of radioactive waste both here and abroad is a fact of life that presents problems challenging all nations. NACOA hopes this report is a positive contribution to meeting that challenge.

This report resulted from the efforts of NACOA's Panel on Radioactive Waste, which consisted of NACOA members John A. Knauss (Chairman), Sylvia A. Earle, Jay G. Lanzillo, Vernon E. Scheid, S. Fred Singer, and Sharron Stewart. The Panel is indebted to the generous contributions of the many people who offered valuable insights to the NACOA review and who commented on the draft report. Lists of those who participated in the Panel's sessions are given in Appendix L. The Panel acknowledges the dedicated work of Cdr. William Lounsbery (NOAA Corps), Lt. Cdr. Douglas Hennick (NOAA Corps), and Victoria Jones Brimmer, all of the NACOA staff, and also the assistance of Dana R. Kester, University of Rhode Island, in preparing Chapter IV.

This report does not necessarily reflect the view of any of the individuals or organizations who participated with us or who provided us with information. The contents of the report and the recommendations made are the sole responsibility of the National Advisory Committee on Oceans and Atmosphere.

PART I
Management of Nuclear Waste: Conclusions and Recommendations

THE NACOA REPORT
Management of Nuclear Waste: Conclusions and Recommendations

The world's first controlled nuclear chain reaction occurred in December 1942. Since that time, the United States and successive nuclear-capable nations have bridled the developing nuclear technology for defense, energy, medical, and research purposes. A by-product of the world's nuclear industries is the accumulation of large quantities of radioactive materials, not just from nuclear power plants, but also from medical and research institutions and from the military. This waste takes a variety of forms, from the "high-level waste" of spent reactor fuel with high levels of radioactivity per unit mass to the "low-level waste" of hospitals which are large in volume but low in radioactivity per unit mass. Although some radionuclides decay to harmless stable isotopes in a matter of weeks, others, such as the anthropogenic transuranic elements, emit radioactive particles for thousands of years. The existence of radioactive waste poses a threat of varying degrees to humans and their environment.

The National Advisory Committee on Oceans and Atmosphere (NACOA) finds there is little consensus, in the United States at least, on the magnitude of the problem. Many believe that there has been too little thought and effort devoted to finding safe and secure disposal of radioactive waste. Others counter that the waste problem has been blown out of proportion and that problems associated with nuclear waste storage are minor. What is not in contention is the growing stockpile of spent nuclear fuel rods, aging nuclear submarines, and contaminated material from hospitals and research institutions. What is often overlooked in the debate is that this is not a problem for the United States alone. The stockpile of nuclear waste is growing in nearly all of the developed nations of the world and can be expected to grow in the developing world also. Nor will the problem go away even if we in the United States stop the construction of new nuclear power plants. Waste will still be generated by those commercial power plants on line in the United States and those on line and being built in the rest of the world. Additional waste will be generated by military nuclear power plants, as well as by the many hospitals, universities, and research institutions who routinely use small amounts of radionuclides.

Present U.S. policy emphasizes land-based disposal. There has been no authorized disposal of radioactive waste in the ocean by the United States since 1970. However, the possibility of resumption of ocean disposal by the United States cannot be ruled out given the following situations:

(a) **Aging Nuclear Submarines.** The Navy has over 100 operating nuclear submarines that will be decommissioned at a rate of three to five per year. A Navy Environmental Impact Statement has concluded that land disposal should be chosen, because the current regulatory status of sea disposal is highly uncertain. However, sea disposal of the entire submarine— minus its fuel— would be the least costly of three disposal options, all of which are environmentally safe according to the Navy's Environmental Impact Statement.

(b) **DOE Remedial Action Program.** The Department of Energy has several programs to evaluate and remedy radiological conditions at land sites used during Manhattan Engineering District and Atomic Energy Commission activities. One such site is in Middlesex Borough, New Jersey, where about 90,000 metric tons of slightly contaminated soil—about 4 curies—is contained within a 10-acre area. If the soil is removed, one option is to dispose of it at sea, either directly into the water column at a deepwater dumpsite, or encased and sunk far off the coast.

(c) **Subseabed Disposal of High-Level Nuclear Waste or Transuranics.** For several years, the United States—through a program coordinated at the Sandia National Laboratories, Albuquer-

que, New Mexico—has examined the possibility of subseabed disposal of high-level nuclear waste. Technical and environmental feasibility studies should be completed toward the end of this decade. Should these, and subsequent studies, prove that this method is practicable, a demonstration seabed repository could be scheduled for the 1990s.

(d) **Decommissioned Nuclear Reactors and Associated Equipment.** Several of our country's large commercial reactors are nearing the end of their life spans. It has been assumed that they would be entombed in concrete until their radioactivity decayed to safe levels; however, some reactor components retain this radioactivity for thousands of years. Although no proposals have been made to dispose of decommissioned nuclear reactors and ancillary components at sea, such proposals could come forth, particulary if a sea disposal precedent—such as nuclear submarines—were set.

NACOA reached several conclusions during its study of this issue. (See Appendix F for the chronology of the NACOA investigation.) The first is that the level of mutual distrust is so high that rational discussion of the issues is often difficult. On the one hand, large segments of the public and their spokespersons seem to be unaware that we are continuously bathed in low-level background radioactivity from natural sources, and fear even the lowest levels of contamination from anthropogenic sources. On the other hand, the track record of the experts in managing the radioactive waste problem in the past, and in keeping the public properly informed, does not instill confidence in their present management schemes.

A second NACOA conclusion is that ocean disposal is an international issue. Ocean processes do not recognize national boundaries. We should be concerned not only about U.S. policy for ocean disposal of radioactive material but other nations' policies as well. Furthermore, we must assume that any change in U.S. policy on ocean disposal of radioactive waste will strongly influence those of other nations.

Sources of Anthropogenic Radioactivity

Because of these conclusions, NACOA has not limited its summary to U.S. activities. Chapter I describes the growing international stockpile of radioactive waste. Roughly speaking, the stockpile can be divided into the spent fuel rods along with the other residue from nuclear reactors (commerical, military, and research), and nearly everything else. The bulk of the radioactive waste problem, including the prickly issue of how to dispose of the long-lived transuranic elements that decay over tens of thousands of years, concerns the handling of the spent fuel rods.

Some 96 percent of the radioactive material in a spent commercial reactor fuel rod is reusable uranium along with 1 percent plutonium that is generated in the fuel rods during reactor operations. The remaining waste residue becomes what is known in the United States as high-level waste; spent fuel rods are also considered high-level waste. From 1976 to 1981, the government banned reprocessing spent fuel rods from commercial reactors in the United States (reprocessing is done for some research and military reactors). The ban was enacted due to concern that reprocessing in the United States and elsewhere would create an international commerce in plutonium that might fall into the hands of terrorists or other nations currently unable to manufacture nuclear weapons because they lack plutonium. Although there is no longer a ban on commercial reprocessing, there appear to be no plans to reintroduce this activity in the United States in the near-term.

Lack of electrical demand, rising reactor costs, and public opinion have combined to limit the growth of the nuclear power industry in this country. Other nations, such as Japan and France, which have no significant deposits of oil or coal, are continuing to increase their nuclear power capacity. Thus, the spent fuel stockpile will continue to grow regardless of U.S. policy. In 1980, the United States generated about 40 percent of all commercial nuclear power; in the year 2000 the U.S. contribution is projected to be about 30 percent (Table I-3).

Although spent fuel rods are responsible for more than 99 percent of the radioactivity in the growing nuclear waste stockpile, they produce a very small part of its volume (Figures I-3 through I-6). The large volume of so-called low-level radioactive waste is composed of such material as the glassware, gloves, and clothing of those who use small amounts of radioactivity in hospitals and research, the machinery used in the processing of nuclear fuel, the remains of radionuclide experiments or processes, and a wide variety of similar material that may become contaminated by induced radiation or by carrying trace amounts of radionuclides.

Lastly, there are the mill tailings resulting from the milling and mining of uranium ore. Although this is clearly natural radioactivity of a kind that humans have lived with since our origin, its redistribution may be unnatural and its concentration may be enhanced locally, thereby requiring possible control actions with regard to disposal.

Radioactivity in the Ocean

The largest source of anthropogenic radioactivity in the ocean is the approximately 360 nuclear detonations by the United States, Soviet Union, the United Kingdom, France, and China that were on or above ground or in the ocean. About 55 million curies of radioactive cesium and strontium have found their way to the ocean from those explosions. In addition, the ocean received several hundred million curies of tritium (radioactive hydrogen) from these same explosions. Accidents are probably the second largest source of anthropogenic radioactivity in the ocean. The power plants of the two lost U.S. nuclear submarines, *THRESHER* and *SCORPION*, contained about a million curies each. Although there are no official figures on lost Soviet nuclear submarines, we believe there has been at least one and probably several. Other such sources include 10,000 curies of plutonium aboard a malfunctioning rocket and a nuclear weapon aboard an aircraft that crashed.

By comparison, the deliberate dumping of radioactive material in the ocean is relatively modest. Before the United States stopped ocean disposal of radioactive waste in 1970, we disposed of about 95,000 curies of low-level waste packaged in about 90,000 containers, mostly 55 gallon drums, in four major dumpsites offshore our coasts. About three times that amount of anthropogenic radioactivity in suspended or dissolved form flowed into the Pacific Ocean each year from the Hanford reactors on the Columbia River from 1955 to 1964.

Although the United States has stopped the deliberate release of anthropogenic radioactivity in the ocean, disposal is continuing elsewhere. The largest single contributer is the United Kingdom's Sellafield (formally Windscale) plant which pumps about 200,000 curies a year into the North Sea. In addition, the United Kingdom along with a number of European communities have until recently dumped an average of about 44,000 curies a year, mostly in 55 gallon drums, at a designated dumpsite 4,000 meters deep in the Northeast Atlantic Ocean. (See Table II-2 for a summary of anthropogenic radioactivity added to the ocean since 1944.)

Except for the accidents, all the anthropogenic radioactivity in the ocean qualifies as low-level waste. No nation has used the ocean for the deposition of high-level waste, and to the best of our knowledge, no nation is considering this option. Some, however, including the United States, are considering emplacement of this material deep in the sediments beneath the ocean floor. At present, this concept is being studied under a cooperative program coordinated through the Nuclear Energy Agency of the European-based Organization for Economic Cooperation and Development.

Present Policy

The Nuclear Waste Policy Act of 1982 defines U.S. policy for disposal of high-level radioactive wastes, i.e., the spent fuel rods and the radioactivity that remains from reprocessed nuclear fuel. Under this Act, the United States is expected to develop its first land-based repository by the 1990s. Present U.S. policy is to find land-based solutions to the question of where to dispose of high-level wastes. As near as NACOA can judge, all other cooperating nations in the deep seabed disposal program have similar policies. However, a number of possible sites in the United States have already been eliminated for disposal of high-level wastes. Perhaps even more importantly, the political issue of local concern, once a final site has been chosen, has not yet been joined. For these reasons, a number of observers believe the possibility of using the deep seabed for emplacement of high-level radioactive waste cannot be dismissed despite present official U.S. policy. Furthermore, other nations such as Japan and the United Kingdom are not as well endowed geologically as is the United States. Lacking suitable land-based sites, they may have little choice but to embrace the ocean option, if further research suggests that this is indeed a reasonably safe alternative.

The United States currently disallows ocean dumping of low-level waste as well as high-level waste into the ocean. Land-based disposal sites must be found for all material generated by hospitals, research labs, and others who generate low-level waste material. The 1980 Low-Level Radioactive Waste Policy Act holds each State responsible for disposing of its commercial low-level waste. Furthermore, a January 1983 amend-

ment to the Marine Protection, Research and Sanctuaries Act places a two-year moratorium on all ocean dumping of radioactive material except for small research projects. After the moratorium, both Houses of Congress must pass a joint resolution granting authority for each specific permit before the Environmental Protection Agency can issue permits for disposal of low-level waste in the ocean.

The London Dumping Convention of 1972 *(Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter)* is somewhat less strict. Although it bans the dumping of high-level wastes, it allows limited disposal of low-level waste. There has recently been some interest by a number of nations in further restricting the amount and kinds of material that can be dumped. (See Chapter III.)

The question of *emplacing* high-level waste in the sediments deep beneath the ocean is not specifically addressed by any international law. However, the United States and 54 other nations including Japan, the Soviet Union, and almost all western European nations, are party to the London Dumping Convention, and the issue of subseabed emplacement will be addressed in this forum.

The Issues

Those who contend that the ocean is an excellent repository for anthropogenic radioactive waste, as well as those who argue against ocean use, often evoke marine science as their champion. The latter often argue that we know so little about ocean processes that it is far better to err on the side of conservatism because it will be difficult to turn back if future studies show a mistake has been made. The argument for ocean use is more complicated but can be summarized as follows. The ocean already contains a large amount of natural radioactivity, either long-lived radionuclides and their daughter products that have been on Earth from the beginning, or relatively short-lived radionuclides formed by the interaction of cosmic radiation with the atmosphere. The total amount of anthropogenic radioactivity that has found its way into the ocean since 1944 is about one-tenth of one percent of the total natural radioactivity in the ocean. Those who favor consideration of the ocean for waste management further argue that our knowledge of ocean processes is good enough to make adequate estimates of the fate of any anthropogenic radioactivity placed in the ocean. Finally, they argue that the potential danger to humans is much less if radioactivity is placed in the ocean than in the various land-based alternatives. Humans are much less likely to be exposed to significant levels of direct radiation in the ocean than on land; there is minimal opportunity for radioactivity to find its way into the groundwater that we tap for drinking. And, although the probability of significant radioactivity finding its way to the fish we eat is not zero, it is less likely to find its way into the food we eat than it would through most land-based options. NACOA believes the truth likely lies somewhere between these two extremes and that is the basis for our recommendations which follow.

1. ***NACOA recommends that Congress and the Administration revise the present policy of excluding the use of the ocean for low-level radioactive waste disposal. Ocean disposal should not be initiated until adequately funded, well-identified monitoring and research efforts are established that provide a full assessment of the fate and effects of such disposal.***

We are not prepared at this time to suggest that the Administration should reverse its present land-oriented position. However, we do believe the ocean option should not be dismissed out of hand. The goals of any radioactive waste disposal policy must include the following:

1. Adverse health effects to humans should be minimized.
2. Adverse health effects to future generations should be minimized.
3. Adverse ecological effects, both present and future, should be minimized.
4. Opportunities to rectify mistakes should be maximized.

By comparison with various land-based disposal options, the ocean option has a number of advantages. The chances for prolonged direct exposure to humans are less in the ocean than in surface or near-surface disposal sites on land. If care is used in choosing the ocean site, the chances of radioactivity finding its way into the food we eat are minimal, as they are for land-based sites that are carefully separated from farm land. Groundwater contamination is always a risk on land but is not a problem in the ocean.

As for the ecological effects of prolonged exposure to low-level radioactivity, these are not well understood for either land or water ecosystems.

On the other side of the picture, if future research and monitoring discloses that a site or its containment strategy was poorly chosen or designed, it may be more difficult, if not impossible, to rectify at an ocean site than it would at a land site.

NACOA is concerned that too little attention is being paid to the requirement that radioactive waste disposal sites must be maintained for long periods. Low-level sites must be guarded for at least a hundred years, and high-level waste disposal sites must be maintained for thousands of years. History does not suggest that continuous vigilant efforts or adequate recordkeeping is likely over such long terms. Furthermore, climatic change may alter land values and usage, so sites now isolated may become less so. Because deep ocean sites would require high technology to disturb, it seems that ocean disposal could be designed to prevent unintentional human intrusion with more certainty than land disposal options.

2. *NACOA recommends the Federal Government intensify its research efforts on: the ecological effects of radioactivity in the marine environment; the possible pathways of anthropogenic radioactivity in the marine environment; monitoring; and on delivery and retrieval systems for radioactive waste disposal in the ocean.*

We recognize that present U.S. policy excludes the ocean as a possible disposal site for radioactive waste. NACOA is concerned that a rigid policy of exclusion will result in so lowering the perceived priority of research as to slow down, if not cut off entirely, Federal agency support for the research. The budget recommendations for Fiscal Year 1985 clearly demonstrate the effect of this policy on research.

Although the United States presently does not utilize the ocean for radioactive waste disposal, the past 40 years of U.S. management of its radioactive waste problem does not instill confidence that today's policy will be followed tomorrow. Given the present concern of many communities about dumpsites of any kind in their area, it would be foolish to assume that there will be no political difficulties in finding adequate land-based sites for the growing stockpile of low- and high-level radioactive waste. Present evidence suggests that under certain circumstances, at least, the ocean offers an attractive alternative to land-based disposal. If there are reasons why the ocean is unacceptable, we need to know them. Arguing that we cannot use the ocean as a disposal site for radioactive waste because we do not know enough about it may not be politically acceptable to those concerned with land-based disposal in their local communities. Research should not be limited to answering the first order scientific questions of the "routes, rates, reservoirs, and effects" of radioactive material, but should also address the first order technical questions of containment, monitoring (once a disposal site has been selected), and retrieval, if future monitoring indicates a mistake has been made in site selection.

3. *NACOA recommends that the Office of Science and Technology Policy (OSTP) establish an interagency coordinating committee to develop and budget the necessary research plan to implement recommendations 1 and 2.*

The National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), and the Department of Energy (DOE) have responsibility for some aspects of anthropogenic radioactivity in the ocean. Much of our current knowledge comes from the Department of Energy (and its predecessor, the Atomic Energy Commission). DOE is currently funding what is perhaps the best organized and most imaginative research in this area, the Deep Seabed Disposal Program, which is investigating the possibility of emplacing encapsulated high-level radioactivity 30 to 100 meters deep into the sediments of the ocean floor in water depths of 4,000 to 5,000 meters. A considerable amount of additional information about radioactivity in the ocean environment has come from work sponsored by the National Science Foundation. The contributions of EPA and NOAA have been more limited, perhaps in part because the present U.S. policy of not using the ocean for disposal of radioactivity has apparently limited the kinds of programs approved in these agencies. Both NOAA and EPA have devoted some effort to studying the fate of the relatively small amounts of radioactivity in the various containers that were deposited off both the east and west coasts during the 1960s. These have been projects of limited scientific value, given the lack of information about what was in these drums in the first place.

NACOA believes there are a number of issues that need addressing. For example, can we agree on a *"de minimis"* definition, a level of anthropogenic radioactivity sufficiently low, that we can ignore it? Given the varying levels of natural radioactivity on land and in the marine environ-

ment, is there clearly some level of anthropogenic radioactivity sufficiently low that it does not add significantly to the natural background level? The 4 curies of radioactivity remaining in the 90,000 tons of contaminated soil sitting in Middlesex, New Jersey might so qualify. If so, perhaps it could be disposed of at sea with the same precautions as dredge spoil, rather than treating it with extra precautions of radioactive waste.

A second possibility concerns dilution of those forms of radioactive elements we concentrate in our bodies. To a very high degree of approximation, our bodies cannot discriminate between the various isotopes of an element. Given the relatively large amounts of stable isotopes of most elements in seawater, it may be possible to devise mixing schemes for disposing of radioactive isotopes whereby in one or two hours the ratios of radioactive to stable isotopes reaches a *"de minimis"* level.

NACOA is less concerned with the above examples than we are that this Nation is not focusing sufficiently on the key issues of whether or not the ocean can be a relatively safe environment for the disposal of radioactive material under certain conditions. We believe the issue is an important one, and we call upon the Office of Science and Technology Policy to provide the necessary leadership.

4. *NACOA recommends that the Environmental Protection Agency establish ocean disposal regulations that are in agreement with international standards created by the International Atomic Energy Agency (IAEA) for the London Dumping Convention. Although the United States may not choose to dispose of low-level radioactivity in the ocean as presently allowed under the London Dumping Convention, it should at least adopt the IAEA definitions, guidelines, and criteria.*

Presently, in the United States high-level waste is defined qualitatively, as either spent fuel or the residue from fuel reprocessing, and large amounts of U.S. low-level wastes are identified only as those wastes remaining outside the definition of high-level waste. These do not meet the definition standards of the IAEA which are characterized generally by radioactivity levels. The United States should adopt the IAEA definition, guidelines, and criteria for ocean disposal. Exceptions to the same should be documented carefully.

Ocean disposal is an international problem. The United States has always been been a leader in research concerning natural and anthropogenic radioactivity in the ocean. U.S. policy on the use of the oceans for radioactive waste disposal will influence the policies of other nations. Insofar as possible the United States should work through the IAEA to determine acceptable standards and criteria for radioactive waste disposal. The alternative of each nation interpreting the London Dumping Convention to suit its own needs could result in widespread abuse of the spirit of the Convention.

5. *NACOA recommends that the United States urge the International Atomic Energy Agency (IAEA) to maintain a complete census of the level, kind, and distribution of human-derived radioactivity in the ocean, regardless of how it found its way there.*

Radioactive material enters the ocean in many forms and in many ways. More than 99 percent of the radioactivity in the ocean is natural radioactivity, mostly uranium and radioactive potassium eroded from the land and carried to the ocean via rivers. The largest single source of anthropogenic radioactivity in the ocean got there during the period 1946 to 1968 from the above ground or oceanic nuclear weapons tests. Other sources are the reactors of sunken nuclear submarines, effluent from reprocessing plants, and packaged low-level waste dumped by the United States and some western European nations. Table II-2 is NACOA's audit of all of the sources of anthropogenic radioactivity in the ocean using available data. It is undoubtably incomplete.

At least some of the radioactivity that finds its way to the ocean is short-lived. For example, the oceans probably contain less than 40 percent of the tritium that was present in 1963 at the time of the second nuclear test ban treaty; furthermore, the distribution in the ocean today of what remains is significantly different from what it was 20 years ago. One element of any decision to use the ocean for disposal of low-level radioactive waste is an inventory of what is already there. This is an international responsibility. To the best of our knowledge no such continuing audit exists.

6. *NACOA recommends that broadly based citizen groups take the lead in establishing a clear and rational public debate on disposal of radioactive materials. Further, they should assist in the creation of pub-*

lic forums for the education of the public. The Department of Energy should provide financial support for these efforts.

The Earth's environment has been partially radioactive since its creation. The existence of such natural radioactive sources as radium have been known since the late 19th Century, while nuclear energy has been harnessed since the 1940s. Today our Nation relies on fission reactors for more than a tenth of its electrical power; its defense posture is predicated on nuclear weaponry and nuclear-powered vessels; and thousands of research institutions, hospitals, and other facilities nationwide use various forms of radioactive materials.

But despite such apparent familiarity, radioactivity—and its effects upon humans and their environment—baffles much of the public. Such bewilderment retards national efforts to reach a consensus on nuclear waste disposal. Nuclear activity is a national phobia, and rational debate is difficult. The reasons given are many: nuclear power came to public attention in the form of a city-devastating weapon; the widely published specter of a nuclear core melt-down; and the steadily increasing safety standards for nuclear power plants and for people handling radioactivity which imply that perhaps the experts who set the rules know less than they claim.

At times rational debate on nuclear waste disposal is made difficult by statements of those who should know better. Many persons are genuinely concerned about the development of commercial nuclear power reactors. In recent years, one argument of this group is that nuclear power development should not go forward until there is an acceptable solution to the waste disposal problem. Any proposition that suggests a waste disposal solution is possible undercuts their main concern. One side effect of these tactics is that the concern about about radioactive waste disposal is not limited to spent fuel rods but includes the large amounts of low-level waste, most of which is not generated by power reactors.

For a number of reasons, the Federal Government and the nuclear power industry have limited credibility. Too often nuclear power reactors have proved to be less safe than advertised, and proposed waste disposal sites have shown more complex geology than originally suggested. As a result, statements by government or industry spokespersons about the relative safety of one or another waste disposal plan are greeted with skepticism.

The issues are too important for this lack of trust on both sides to continue to poison the air. NACOA calls upon such responsible public policy groups as the National Academy of Sciences, the League of Women Voters, university-based organizations, national environmental groups, and others to address these issues, not as advocates for a given position, but as concerned citizens searching together for solutions. Somehow public confidence in this debate must be restored. Study groups are expensive and most nonprofit organizations must make difficult decisions on what issues to expend their limited resources. NACOA believes limited DOE support for this effort would be a good investment.

PART II
The Background

CHAPTER I
Radioactive Waste: An Inventory

Introduction

Initial nuclear power research by the United States focussed on weapons production for World War II. Shortly after the war, however, the U.S. Government encouraged civilian applications for nuclear power, particularly for commercial electricity.

The development of nuclear power, coupled with U.S. Government encouragement, caused the demand for private industry's components and services to grow, such that by the mid-1960s Federal assistance was no longer necessary to build a nuclear reactor.[1] As of 1983, nearly 80 commercial nuclear reactors generated electricity in the United States.[2] Figure I-1 illustrates the status of U.S. nuclear power reactors as of January 1983. Government reactors on Federal sites continue to produce plutonium and tritium for military applications.[3] The United States has more commercial reactors than do other nations, but because of our country's size, these reactors still account for only a relatively small amount of our power output. France, for example, has 32 reactors producing over 40 percent of its national power.[4]

Nuclear reactor operations result in radioactive waste, which has accumulated in large quantities. Although the principal sources of waste are generated from fueling nuclear reactors, much radioactive material comes from educational, medical, and research institutions as well as from private and government laboratories. Currently, more than 20,000 facilities in the United States are licensed to use radioactive materials as part of their activities.[5] These facilities generate radioactive wastes that exist in various chemical forms and may be solid, liquid, or gaseous.[6] The Federal Government has classified these radioactive materials and placed them into the following categories.

Spent fuel is irradiated fuel discharged from nuclear reactors.[7] In commercial reactors, this material typically contains about 96 percent unused uranium, 1 percent plutonium, and 3 percent other fission products categorized as high-level waste.[8] Of the unused uranium, 99 percent is uranium-238, and 1 percent is fissile uranium-235.[9]

For continued operation, nuclear power plants require periodic replacement of uranium fuel with fresh fuel, which depends on the amount of reactor operating time; about one-third of the reactor core fuel is replaced every 12 to 18 months.[10] A standard nuclear power reactor discharges about 30 metric tons of spent fuel rods each year.[11]

Most U.S. spent fuel is stored in pools of circulating water at commercial nuclear power reactor sites. Special government fuels, used for defense and research purposes and not routinely reprocessed, are stored at the Savannah River Plant and the Idaho Chemical Processing Plant.[12]

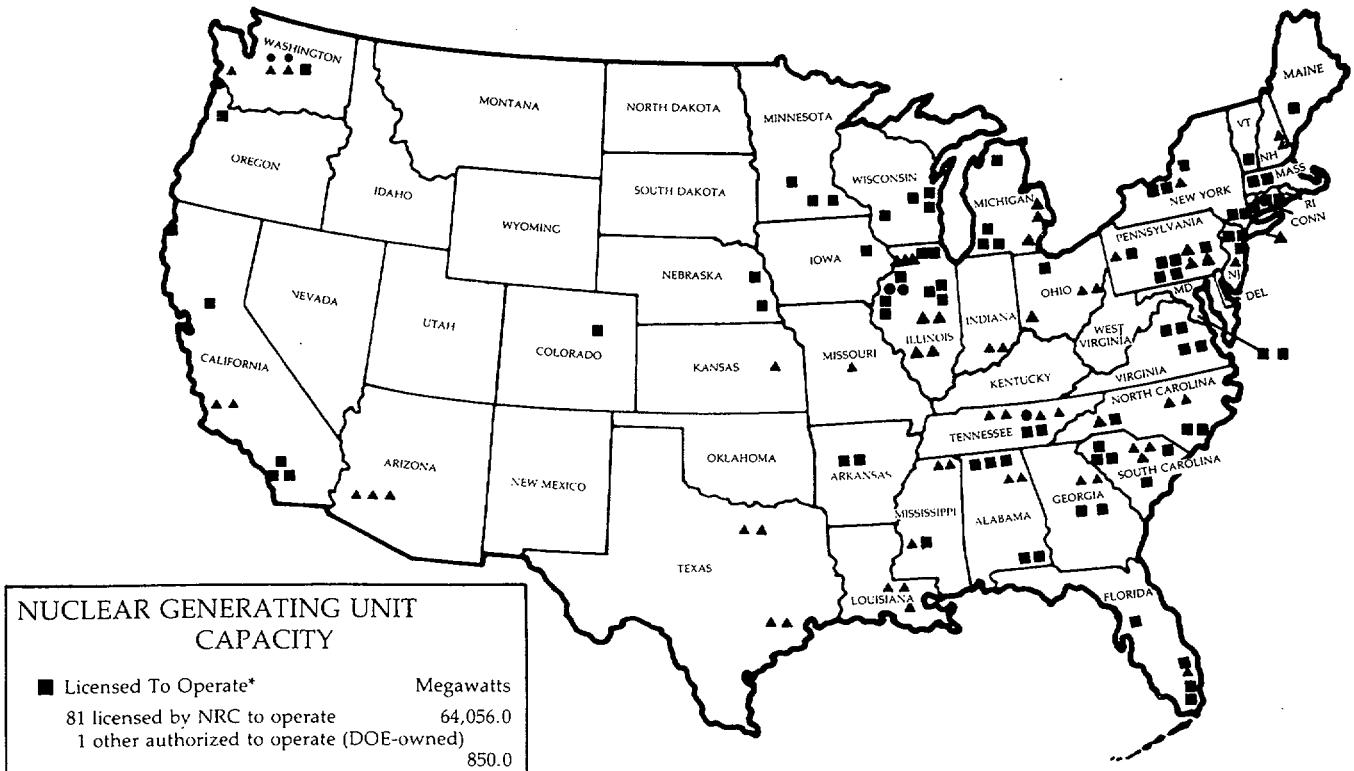
High-level waste (HLW) is a term with several different meanings. In the United States, HLW is sometimes defined as only the wastes generated in reprocessing spent fuel.[13] With this definition, most HLW in the United States is the residue from the reprocessing of irradiated fuel in the weapons program.[14] Unprocessed spent fuel, however, is often included in the definition of HLW[15], which thus creates some ambiguity in common usage and meaning. The International Atomic Energy Agency (IAEA) definition of HLW includes all waste, irrespective of source, in which concentrations of radionuclides are high enough to be considered unsuitable for disposal at sea. IAEA currently uses the following limits of activity to define HLW:[16]

Alpha emitters ..... 1 curie or more/metric ton
Beta or
Gamma emitters .... 100 curies or more/metric ton
Tritium ..... 10^6 curies or more/metric ton

(For more information on the IAEA definition, see Table III-1 in Chapter III of this report.)

Transuranic wastes (TRU), as defined by U.S. Department of Energy (DOE) Order 5820.2, contain at the end of their institutional control period 100 nanocuries (1 nanocurie = 10^{-9} curies) or more per gram of alpha-emitting radionuclides with an atomic number greater than 92 (uranium) and long half-lives (greater than 20 years). TRU arises primarily from the reprocessing of fuel and from the fabrication of plutonium weapons and plutonium-bearing reactor fuel.[17]

Low-level waste (LLW) is any radioactive waste not classified as mill tailings, HLW, TRU, spent fuel, or by-product material as defined in Public Law 96-573, the Low-Level Radioactive Waste Policy Act of 1980, and Public Law 97-425, the Nuclear Waste Policy Act



NUCLEAR GENERATING UNIT CAPACITY

	Megawatts
■ Licensed To Operate*	
81 licensed by NRC to operate	64,056.0
1 other authorized to operate (DOE-owned)	850.0
▲ Being Built	
60 construction permits	66,004.6
■ Planned	
5 reactors ordered	5,140.0
147	136,050.6

*Includes San Onofre 3 and Grand Gulf 1, which, as of Jan. 1, 1983 are authorized to load fuel and conduct low power testing.

There are no symbols for units planned but not sited. Because of space limitations, symbols do not reflect precise locations.

DOE-Department of Energy
NRC-Nuclear Regulatory Commission

Figure I-1.—Status of Commercial Nuclear Power Reactors in the United States as of January 1, 1983.

Source: U.S. Department of Energy. 1983. Nuclear Reactors Built, Being Built, or Planned. DOE/TIC-8200-R47, Technical Information Center, Oak Ridge, Tennessee, p. 6.

of 1982. LLW contains low, but potentially hazardous, amounts of radionuclides, and may have a radiation level high enough to necessitate shielding in handling or transport.[18]

Active uranium mill tailings are the earthen residue remaining after uranium ore extraction. Although tailings occur in very large amounts, they contain low concentrations of natural radionuclides, such as radon-222 and radium-226. The tailings derive from the conventional mining and milling methods to obtain uranium. Of the 26 licensed mills in the United States, 16 are currently active.[19]

Intermediate waste is not a category officially used by the United States. This term is, however, used by certain European countries to manage nuclear waste forms that do not require the rigid constraints of HLW but cannot be handled as LLW.[20]

Airborne waste pertains to krypton-85, iodine-129, carbon-14, tritium, and airborne radioactive particulates that require special treatment. According to DOE, these are considered effluents if released, but once trapped and retained are classified as LLW under current guidelines.[21]

The Nuclear Fuel Cycle

Most radioactive waste results from the various stages of the nuclear fuel cycle, which consists of all the steps needed for a nuclear power system, plus reprocessing

spent fuel. The cycle begins with the mining and milling of uranium ore. Centralized mills extract uranium from the ore and convert it to uranium oxide (U_3O_8), which is then shipped to specialized plants for conversion to uranium hexafluoride (UF_6). After enrichment of the ^{235}U component from 0.7 percent to about 3 percent, the UF_6 is shipped to commercial fabrication plants where it is converted to uranium dioxide (UO_2) powder. It is then pressed into pellets, stacked into fuel rods, and combined into fuel assemblies for use in reactors.[22]

Nuclear power reactors produce electrical power from the energy released during fission of the uranium fuel.[23] There are two isotopes of uranium in reactor fuel: 97 percent is ^{238}U; 3 percent is ^{235}U. Inside reactors the uranium in fuel rods is bombarded by neutrons. Upon absorbing a neutron, ^{235}U undergoes fission into two atoms of lighter weight elements called fission products. This reaction releases about two thirds of the heat generated by the reactor. Concurrently, ^{238}U absorbs neutrons, but instead of undergoing immediate fission, it is transmuted into plutonium-239, which is called a transuranic element, because it has a higher atomic number than does uranium. When plutonium absorbs a neutron, it undergoes fission, and this process generates about one-third of the heat released in a fission reactor. Once the reactions are started, they continue in a chain reaction, because one neutron causing fission in a ^{235}U atom releases two neutrons, and plutonium-239 releases three neutrons when it is bombarded. The processes continue at specified rates in reactors, because extra neutrons beyond those needed for proper operations are absorbed by non-reactive elements in "control rods" that can be inserted into or retracted from the reactor. When the reactor has operated long enough to reduce the percentage of ^{235}U to a concentration that will not sustain efficient fission reactions, the fuel is "spent." Spent fuel contains radioactive wastes in the form of residual uranium, plutonium, and unstable fission products. If spent fuel is reprocessed to retrieve the residual uranium and plutonium for further use in reactors a so-called "nuclear fuel cycle" is established. If those elements are not reclaimed, the nuclear fuel system proceeds from mining, to refinement, to use in a reactor, to disposal of spent fuel, without using a nuclear fuel "cycle."[24] Figure I-2 illustrates the fractional amounts of nuclear waste generated in the fuel cycle.

Thus, two options are available for spent fuel disposition. One is to handle the fuel as HLW and to dispose of it as such. Currently, spent fuel remains at nuclear power plants within holding pools. Another option is to reprocess spent fuel, extracting uranium and plutonium for use in reactors. The latter alternative calls for chopping the used fuel assemblies, treating them with nitric acid to leach spent fuel out of the cladding, and then chemically extracting residual uranium and the plutonium created in the fission process. The resultant liquid normally contains hundreds of thousands of curies of radioactivity per gallon. Technology exists to calcine (boil dry and bake into sand-like granules) or vitrify (evaporate and fuse into dense glass) the waste for ultimate disposition.[25]

Waste from the use of uranium for nuclear fuel varies in level and quantity, from large amounts of tailings produced in milling uranium ore to processed waste from UF_6 conversion and fuel fabrication, to fission products and plutonium, to routine reactor wastes, such as ion exchange resins, cartridge filters and combustible solids. At the end of a reactor's life, the decommissioning wastes, such as irradiated reactor internals and reactor components, will also require treatment or disposal.[26]

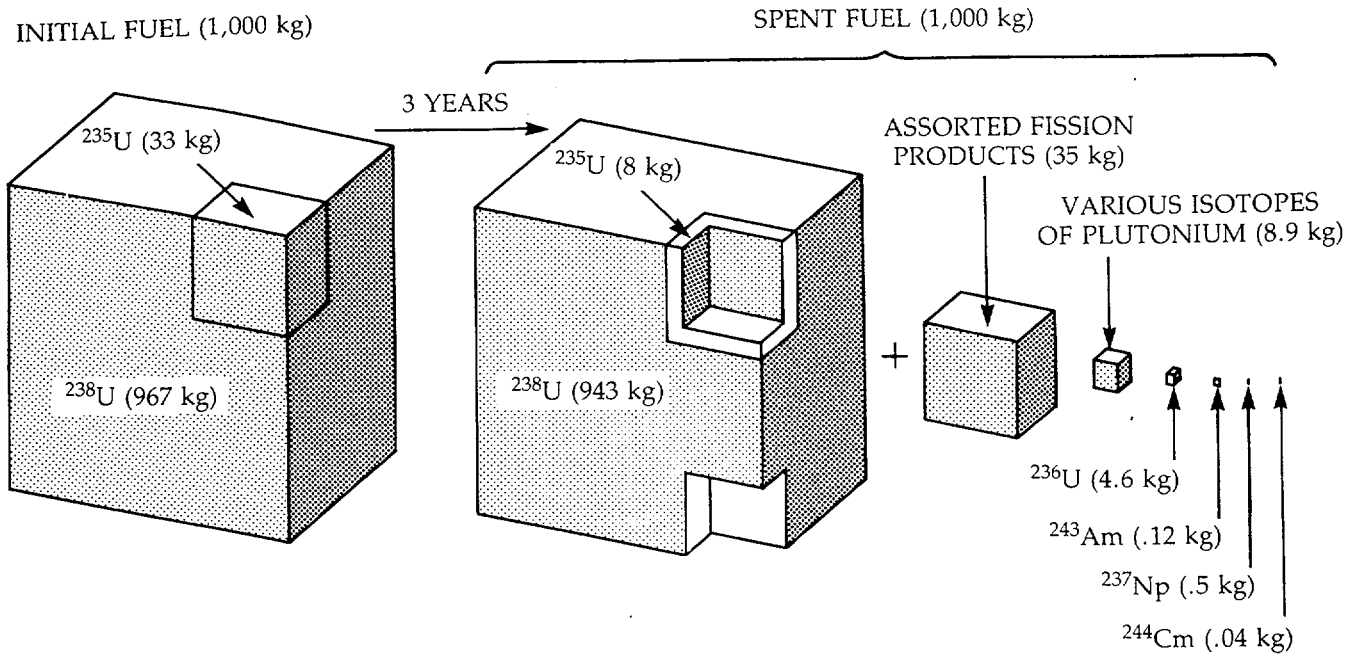
Domestic civilian nuclear power reactors vary in size from 50 to 1,250 megawatts of power produced for electricity. The average reactor size is about 1,000 megawatts, capable of supplying the electricity needs of about half a million people.[27]

Non-fuel cycle waste results from various applications, such as nuclear and medical research. Radioactive waste is generated by institutions not only as sophisticated by-products of research using neutron activation analysis, particle accelerators, and research reactors but also as bulk trash consisting of paper, towels, rubber or plastic gloves, broken labware, and disposable syringes.[28]

U.S. Inventory

The majority of our country's processed HLW has resulted from defense-related DOE activities and is stored at three Federal sites: Savannah River Plant, South Carolina; Idaho Chemical Processing Plant, Idaho; and Hanford Reservation, Washington.[29] Only a small amount of commercial reprocessed HLW, generated in the commercial operation of the Nuclear Fuels Services Plant at West Valley, New York, from 1966 to 1972, exists outside of these major locations.[30] This waste is currently in liquid form, and there are plans to vitrify it for final disposal.[31] Although most of the commercial spent fuel is stored at the nuclear power reactor sites of privately and publicly owned electric power companies, minor amounts are stored at two nonfunctioning civilian reprocessing plants at West Valley, New York, and Morris, Illinois.[32]

To comply with current U.S. policy, defense wastes are being converted for storage from their initial liquid form to intermediate solids, such as salt cakes, sludge, or calcine.[33] Final disposal forms have not been selected, except at Savannah River where plans are underway to vitrify wastes.[34] The Savannah River Plant and the Idaho Chemical Processing Plant also store spent test reactor and research fuel.[35] Besides military



This diagram shows the transformation that takes place in the composition of the nuclear fuel in a light-water reactor over a three-year period. For every 1,000 kilograms of uranium in the initial fuel load (*left*) 24 kilograms of uranium 238 and 25 kilograms of uranium 235 are consumed (*center*), reducing the "enrichment" of uranium 235 from 3.3 percent to .8 percent. Uranium that is consumed is converted into 35 kilograms of assorted fission products, 8.9 kilograms of various isotopes of plutonium, 4.6 kilograms of uranium 236, .5 kilogram of neptunium 237, .12 kilogram of americium 243 and .04 kilogram of curium 244 (*right*).

Figure I-2.—Fractional Amount of Nuclear Waste from Initial Fuel.

Source: The Disposal of Radioactive Wastes from Fission Reactors. Bernard Cohen. Copyright©1977 by Scientific American, Inc.

waste, DOE manages radioactive waste from its uranium enrichment and breeder reactor operations and from its space and naval programs.[36]

DOE stores military transuranic waste at the Idaho National Engineering Laboratory in surface storage facilities. The Waste Isolation Pilot Plant (WIPP), located in a deep salt layer near Carlsbad, New Mexico, is being constructed to provide a research and development facility to demonstrate the safe disposal of TRU waste from national defense programs. Authorized by Public Law 96-164, the DOE National Security and Military Application Nuclear Energy Authorization Act of 1980, WIPP is exempted from NRC licensing. The primary objectives of WIPP are "to demonstrate through a full-scale pilot plant the technical and operational methods for permanent isolation of defense-generated radioactive waste and to provide a facility for experiments on the behavior of high-level waste in bedded salt." The plant is designed to receive, inspect, emplace, and store defense waste.[37]

Table I-1 lists the 1982 inventory of U.S. spent fuel and reprocessed HLW from commercial and military sources. At the end of 1982, the United States was storing nearly 32,000 fuel rod assemblies that contained more than 8,700 metric tons of uranium and more than 11 billion curies of radioactivity. In addition, Federal Government sites contained over 310,000 cubic meters or about 1.4 billion curies of HLW. Most of this HLW resulted from military applications. Nearly 2.9 million cubic meters of LLW containing about 16,500 curies of radioactivity were disposed of at national LLW sites.

Table I-2 divides the inventory of HLW into its component parts and storage site. The HLW stored at the Nuclear Fuel Services Plant in West Valley, New York, resulted from reprocessing spent fuel from commercial plants and one reactor at Hanford, and from the reprocessing of a small amount of thorium-uranium fuel from another source. Reprocessing at the Nuclear Fuel Services Plant and Hanford Reservation was terminated in 1972, and no additional HLW has since been generated at these sites. Reprocessing of HLW does continue at the Savannah River and Idaho sites,[38] and it was restarted at Hanford in November 1983.

Figures I-3 and I-4 place this inventory into perspective by graphically showing that most of the 3.58 million cubic meters of radioactive waste is low-level, while spent fuel accounts for more than 88 percent of

Table I-1.—U.S. Spent Fuel and Radioactive Waste Inventories as of December 31, 1982

Commercial Spent Fuel[1]	*Mass(MTU)*[2]	*Activity (Thousands of curies)*	*Thermal Power (kilowatt)*
BWRs (20,702 assemblies)	3,733	3,530.00	12,900
PWRs (12,520 assemblies)	5,256	7,558.00	28,700
	Volume	*Activity*	*Thermal Power*
High-Level Waste	*(Cubic meters)*	*(Thousands of curies)*	*(kilowatt)*
Savannah River Plant	115,000	828.00	2,490
Idaho Chemical Processing Plant	11,500	72.00	217
Hanford Reservation	183,000	487.00	1,400
Nuclear Fuel Services Plant	2,320	36.00	106
	Volume	*Activity*	*Thermal Power*
Transuranic Waste[3]	*(Cubic meters)*	*(Thousands of curies)*	*(kilowatt)*
Department of Energy, buried	298,000	1.06	762
Department of Energy, stored	72,000	2.04	1,112
	Volume	*Activity*	*Land used*
Low-Level Waste[4]	*(Cubic meters)*	*(Thousands of curies)*	*(hectare)*
Department of Energy sites	1,971,000	9.80	122
West Valley, N.Y. (closed 1975)	66,500	0.58	3
Maxey Flats, Ky. (closed 1977)	135,000	2.40	10
Sheffield, Il. (closed 1978)	88,000	0.06	4
Barnwell, S.C.	397,000	2.10	20
Beatty, Nev.	94,000	0.44	12
Richland, Wash.	142,000	1.08	16
	Volume	*Activity*	*Thermal Power*
Active Uranium Mill Tailings[5]	*(Cubic meters)*	*(Thousands of curies)*	*(kilowatt)*
At all mill sites	98,500,000	0.41	9
	Volume	*Activity*	*Number of*
Remedial Action Programs[6]	*(Cubic meters)*	*(Thousands of curies)*	*Sites*
UMTRAP	Projected to begin in 1983	0.14	24
FUSRAP	27,000	——	36
SFMP	1,570	——	(about) 500
GJRAP	52,000[7]	——	——
	Low-Level Waste	*Activity*	*Number of*
Commercial Decommissioning	*(Cubic meters)*[8]	*(Thousands of curies)*	*Reactors*
Decomissioned reactors	——	——	5
"Mothballed" reactors	——	——	10

[1] BWRs: Boiling Water Reactors; PWRs: Pressurized Water Reactors.

[2] MTU: Metric Tons of Uranium. This unit refers to the mass of the radioactive fuel metal.

[3] The transuranic waste (TRU) in this table is based on its former definition of 10 nanocuries per gram. With the new definition of 100 nanocuries per gram, these volumes will decrease as the old wastes are reassayed. Because current requirements for identification and segregation of TRU waste did not govern burial practices, an accurate assessment of buried volumes of TRU wastes is difficult. Before 1970, the Federal Government allowed the disposal of TRU waste in low-level waste burial grounds where geological isolation seemed secure. The Atomic Energy Commission changed its policy in 1970 to reflect concerns about the breaching of burial waste containers and contamination of surrounding soil. DOE is, however, studying the government's early disposal practices to estimate the amount and nature of the waste that was buried.

Defense TRU waste is confined in interim storage at the Savannah River Plant, the Hanford Reservation, and the Idaho National Engineering Laboratory. Some defense TRU waste is also stored at the Oak Ridge National Laboratory, the Los Alamos National Laboratory, and at the Nevada Test Site.

(From: Gilbert, Charles F. 1984. Policy and Practices in the United States of America for DOE-Generated Nuclear Wastes. *In* Radioactive Waste Management, Proceedings of an International Atomic Energy Agency Conference, Seattle, 16-20 May 1983, Vol. 1, International Atomic Energy Agency, Vienna, Austria, p. 69-78.)

Commencing in October 1988, DOE TRU waste will be stored at the Waste Isolation Pilot Plant in New Mexico on a demonstration basis.

[4] DOE-generated low-level waste (LLW), which results from defense activities, uranium enrichment operations, the Naval Reactors Program, and various research and development programs, is buried at DOE sites with the exception some waste that is hydrofractured. The remaining sites store commercially generated waste from fuel cycle facilities and from various institutional and industrial activities.

[5] Licensed mills; 16 of the 26 licensed mills are currently in operation.

[6] DOE carries out remedial action activities in four programs. The Uranium Mill Tailings Remedial Action Program (UMTRAP), which includes only mill tailings at inactive uranium mills and an industrial park in Canonsburg, Pennsylvania, deals with 24 candidate sites classified according to potential health effects on the public. The Formerly Utilized Sites Remedial Action Program (FUSRAP) has identified 36 sites in 15 States used by the Manhattan Engineer District and the U.S. Atomic Energy Commission in their work with nuclear materials. The Surplus Facilities Management Program (SFMP) is geared to decontaminate about 500 current or potential surplus facilities. The Grand Junction Remedial Action Program (GJRAP) oversees the rehabilitation of about 650 structures that used uranium mill tailings in construction.

[7] In the form of mill tailings.

[8] Little commercial decommissioning has been done to date; most has been to small test reactors.

Source: U.S. Department of Energy. 1983. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics. DOE/NE-0017/2, Assistant Secretary for Nuclear Energy and Assistant Secretary for Defense Programs, Washington, D.C., p. 6, 13, 15, 16, 53, 54, 90, 169, 189, 91, 127, 169, 189.

the 12.5 billion curies of radioactivity in the U.S. radioactive waste inventory. Figure I-5 projects cumulative volumes for this inventory through 2020; Figure I-6 projects the radioactivity accumulated from 1980 to 2020. These projections are based on DOE estimates of future nuclear power growth as of January 1983. Figure I-5 illustrates the dramatic increase in the volume of LLW when projected to 2020. Dealing with this amount of waste will challenge individual States, which, as Chapter III of this report explains, are responsible for disposing of LLW generated within their borders. The volume of spent fuel rods stored at commercial reactor plants can barely be perceived when compared with the bulk of projected LLW. Figure I-6, however, shows that the radioactivity in spent fuel is much greater than in TRU or LLW. The predicted growth of

Table I-2.—Current inventories of high-level waste in storage by through 1982.

Site	Volume							Radioactivity	
	Liquid	Sludge	Salt Cake	Slurry	Calcine	Capsules[1]	Total	Radio-activity[2]	Heat Generation
	Thousands of Cubic Meters							Megacuries	Megawatts
Defense-related									
Savannah River Plant	72.900	12.300	29.800	——	——	——	115.000	827.000	2.490
Idaho National Engineering Lab.	9.100	——	——	——	2.400	——	11.500	71.600	0.217
Hanford Reservation	34.000	47.000	98.000	4.000	——	0.0049	183.000	486.600	1.400
Subtotal	116.000	59.300	127.800	4.000	2.400	0.0049	309.500	1,386.000	4.107
Commercially generated									
Nuclear Fuel Services									
Alkaline waste	2.100	0.170	——	——	——	——	2.270	32.900	0.097
Acid waste	0.045	——	——	——	——	——	0.045	2.970	0.009
Subtotal	2.145	0.170	——	——	——	——	2.315	35.870	0.106
Total	118.100	59.500	127.800	4.000	2.400	0.0049	311.800	1,422.000	4.213

[1] Capsules contain either strontium (^{90}SR-^{90}Y) fluoride or cesium (^{137}Cs-^{137m}Ba) chloride.

A waste encapsulation facility went into operation at Hanford in 1974. Strontium-90 and cesium-137 removed from high heat waste in the waste separation plant are converted to solids and then doubly encapsulated in Hastalloy or stainless steel containers about 2½ inches in diameter and 20 inches long. (From: Atlantic Richfield Hanford Company. 1976. Radioactive Waste Management at Hanford. Richland, Washington, p. 11.)

[2] Calculated values allowing for radioactive decay.

Source: U.S. Department of Energy. 1983. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics. DOE/NE-0017/2, Assistant Secretary for Nuclear Energy and Assistant Secretary for Defense Programs, Washington D.C., p. 64, 65.

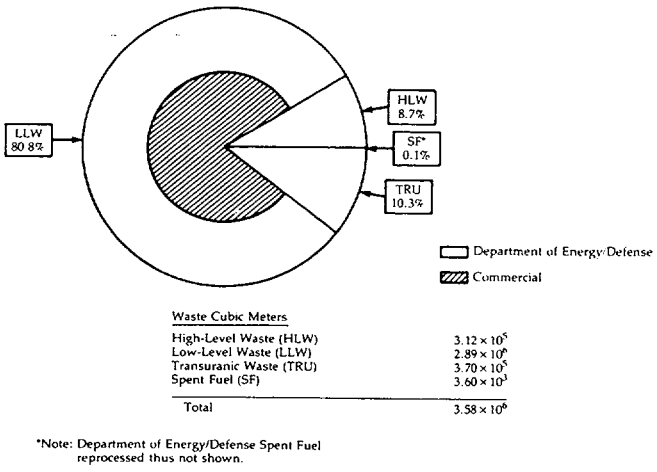


Figure I-3.—Volume of Commercial and Department of Energy/Defense Waste and Spent Fuel Accumulated through 1982.

Source: U.S. Department of Energy. 1983. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics. DOE/NE-0017/2, Assistant Secretary for Nuclear Energy and Assistant Secretary for Defense Programs, Washington, D.C., p. 8.

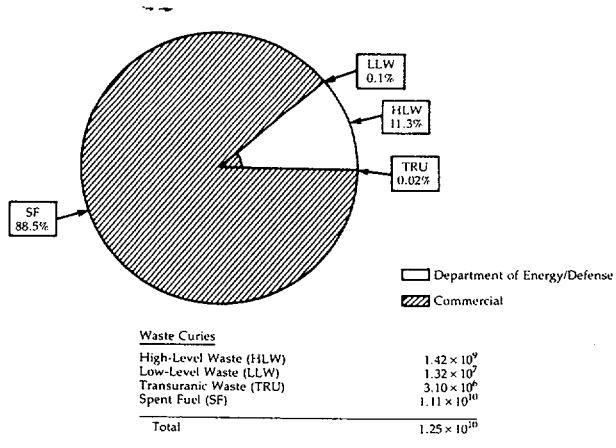


Figure I-4.—Radioactivity of Commercial and Department of Energy/Defense Wastes and Spent Fuel Accumulated through 1982.

Source: U.S. Department of Energy. 1983. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics. DOE/NE-0017/2, Assistant Secretary for Nuclear Energy and Assistant Secretary for Defense Programs, Washington, D.C., p. 8.

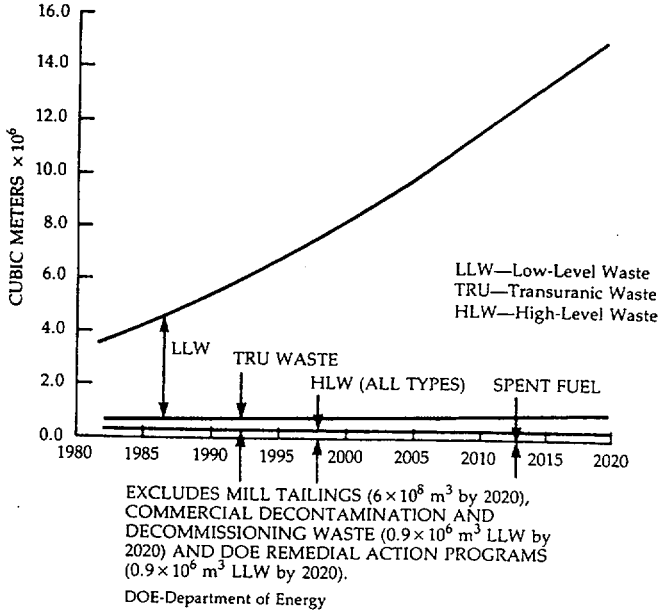


Figure I-5.—Projection of Cumulative Volumes for Various Wastes and Spent Fuel.

Source: U.S. Department of Energy. 1983. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics. DOE/NE-0017/2, Assistant Secretary for Nuclear Energy and Assistant Secretary for Defense Programs, Washington, D.C., p. 10.

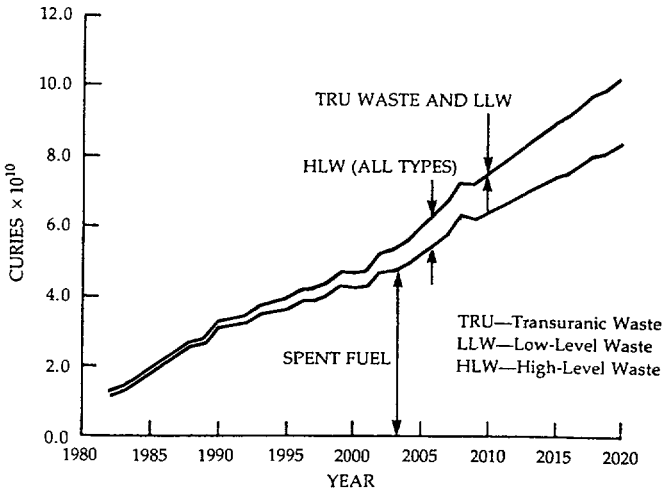


Figure I-6.—Projection of Cumulative Radioactivity for Various Wastes and Spent Fuel.

Source: U.S. Department of Energy. 1983. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics. DOE/NE-0017/2, Assistant Secretary for Nuclear Energy and Assistant Secretary for Defense Programs, Washington, D.C., p. 10.

spent fuel radioactivity dominates all forms of U.S. radioactive waste regardless of whether the rods remain in their current configuration or are transformed into another form of HLW.

International Inventory

The commitment to nuclear power in many other nations equals or exceeds that of the United States. Nuclear power accounts for more than 25 percent of the electricity generated in the Soviet Union, France, United Kingdom, Japan, Federal Republic of Germany, and Canada.[39] Moreover, in addition to the United States, 23 nations have nuclear reactors generating electricity, and an additional 17 have firm commitments for nuclear power programs.[40] At the beginning of 1983, there were 297 nuclear reactors generating more than 173 gigawatts of electricity in nations around the world.[41]

France's 32 operating reactors produce more than 40 percent of its electrical power output, and France intends to generate 85 percent of its electricity from nuclear reactors by the end of the century. Advancements in nuclear power are not limited to western nations—in 1982, the Peoples Republic of China ordered its first commercial reactor; Brazil installed a commercial reactor; India and Japan commenced construction of reprocessing plants; and the Republic of Korea began a program for fast breeder reactors.[42]

Cumulative spent fuel that will be generated by the year 2000 from the global use of nuclear power is estimated by one source to be about 300,000 metric tons of heavy metal. Spent fuel reprocessing capacity will probably increase to 7,000 metric tons per year by 2000. If all the spent fuel were to be reprocessed, some 10,000 cubic meters of conditioned high-level waste and nearly one million cubic meters of conditioned low-level waste would require disposal by 2000.[43]

There are several major international organizations involved in the problems of managing nuclear waste. The Organization for Economic Cooperation and Development (OECD) was formed in 1960 to promote global economic growth. The members of the OECD are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, the Federal Republic of Germany, Greece, Iceland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.[44] The OECD Nuclear Energy Agency (NEA), formed in April 1972, is designed to "promote cooperation between its member governments on the safety and regulatory aspects of nuclear development, and on assessing the future role of nuclear energy as a contributor to economic progress," and works in close collaboration with the International Atomic Energy Agency (IAEA).[45]

The IAEA, headquarted in Vienna, Austria, is comprised of 106 member nations whose mission is to develop the peaceful use of nuclear energy worldwide. As part of its waste management activities, IAEA uses outside consultants to develop safety standards and criteria to manage and dispose of radioactive wastes arising from the nuclear fuel cycle. IAEA also promotes information exchange, provides technical assistance, and coordinates research programs.[46]

The Soviet-sponsored Council for Mutual Economic Assistance (CMEA) is designed to promote economic and industrial cooperation among its member countries: Bulgaria, Cuba, Czechoslovakia, German Democratic Republic, Hungary, Mongolia, Mongolia, Poland, Rumania, Soviet Union, and Yugoslavia. CMEA's Standing Commission on the Use of Atomic Energy for Peaceful Purposes holds meetings to review waste management programs and research. CMEA research on radioactive waste management includes treatment of non-HLW, solidification and storage of radioactive waste, burial in geologic formations, and techniques for removing radioactive aerosols and gases from materials released into the atmosphere.[47]

Table I-3 projects the global growth of nuclear power plants by gigawatts of electricity generated and shows the type of reactor used in the nations listed. By 1990, CMEA nations are expected to generate about 18 percent of the total worldwide capacity. Table I-4 forecasts

Table I-3.—Global Nuclear Power Plant Growth Projections

Country	Plant Capacity (GWe)[1]				Reactors Used[2]
	1980	1985	1990	2000	
Argentina	0.34	0.94	1.60	3.70	PHWR
Belgium	1.70	5.40	5.40	8.00	PWR
Brazil	——	0.60	1.90	4.40	PWR
Canada	5.45	10.35	13.65	14.90	PHWR, BWR
Egypt	——	——	0.90	2.70	LWR
Finland	2.10	2.14	2.14	3.20	BWR, PWR
France	12.40	35.87	50.77	62.40	PWR, GCR, FBR, GCHWR
Federal Republic of Germany	8.60	16.40	22.90	28.80	BWR, FBR, PWR, HTGR
India	0.60	1.00	1.20	4.40	BWR, PHWR
Italy	0.41	1.28	1.28	6.70	BWR, PWR, GCR
Japan	14.41	21.31	31.99	50.03	PWR, HWR, FBR, GCR, BWR
Mexico	0.00	0.00	0.65	1.30	BWR
Netherlands	0.51	0.51	0.51	0.45	PWR, BWR
Pakistan	0.12	0.12	0.12	1.12	LWR, PHWR
Philippines	——	0.60	0.60	1.20	PWR
Republic of Korea	0.60	2.70	7.40	11.20	PWR, PHWR
South Africa	——	1.80	1.80	3.80	PWR
Spain	1.10	5.48	7.48	10.18	BWR, PWR, GCR
Sweden	4.60	8.40	9.40	9.40	BWR, PWR
Switzerland	1.92	2.90	2.90	3.40	BWR, PWR
Taiwan Republic of China	1.20	4.00	4.90	8.70	BWR, PWR
United Kingdom	6.45	10.15	11.24	13.55	GCR, FBR, PWR, AGR
United States	50.10	93.70	118.50	128.60	BWR, PWR
Soviet Union	13.40	26.60	42.60	——	PWR, LGR, FBR
Other CMEA[3] Countries	3.58	7.85	23.11	36.30-39.30	PWR, PHWR
Peoples Republic of China	——	0.60	0.60	10.00	PWR
Total	129.300	263.700	366.700	——	——

[1] GWe = gigawatt; a gigawatt of electricity is one billion watts of power supplied through electrical generators.

[2] PHWR: Pressurized Heavy Water Reactor
PWR: Pressurized Water Reactor
BWR: Boiling Water Reactor
GCR: Gas-Cooled Graphite Moderated Reactor
FBR: Fast Breeder Reactor
GCHWR: Gas-Cooled, Heavy Water Moderated Reactor
LWR: Light Water Reactor
HWR: Heavy Water Reactor
AGR: Advanced Gas-Cooled Reactor
HTGR: High-Temperature, Gas-Cooled Reactor

[3] Council for Mutual Economic Assistance. Comprised of Bulgaria, Cuba, Czechoslovakia, German Democratic Republic, Hungary, Mongolia, Poland, Rumania, Soviet Union, and Yugoslavia.

Source: Based on: Harmon, K.M., J.A. Kelman, D.A. Shields, and C.M. Bennett. 1982. International Nuclear Fuel Cycle Fact Book. PNL-3594 Rev. 2, Pacific Northwest Laboratory, Battelle Memorial Institute, p. Energy-6. These data were updated by Dr. Harmon in January 1984.
Data for the United States were taken from: U.S. Department of Energy. 1983. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics. Assistant Secretary for Nuclear Energy and Assistant Secretary for Defense Programs, Washington, D.C., p. 23.

global spent fuel accumulation in metric tons of uranium (MTU) and in metric tons of initial heavy metal for the United States. As seen in this table, nations for which estimates are available are expected to discharge 257,337 MTU by the turn of this century.

Summary

Many of the nations of the world are committed in varying degrees to the use of nuclear power. These nations include not only such developed nations as France and Japan but developing nations such as the Republic of Korea, Thailand, and Brazil. With this commitment to nuclear power comes the problem of safely and securely managing radioactive waste.

The United States has used nuclear power for nearly four decades. During this time, our Nation has generated enormous quantities of nuclear waste in a variety of forms. Even if the United States were to halt its use of nuclear power, the waste accumulated over the past 40 years would still have to be managed. The manner in which the United States has tackled this problem is discussed in Chapter II.

Table I-4.—Global Forecast of Spent Fuel Accumulation[1]

Country	*Fuel Discharged in Metric Tons of Uranium (MTU)*				
	1980	*1985*	*1990*	*1995*	*2000*
Argentina	416	940	1,900	3,300	5,800
Belgium	196	560	1,290	2,100	3,100
Brazil	0	32	180	510	1,010
Canada	3,650	8,800	17,700	28,000	39,000
Egypt[2]	0	0	0	70	360
Federal Republic of Germany	963	2,250	4,550	7,350	10,500
Finland[3]	48	350	650	950	1,450
France	5,848	10,700	18,100	26,400	35,300
India	368	776	1,580	2,730	4,920
Italy	1,067	1,520	1,980	2,630	3,630
Japan	2,140	5,025	9,360	14,990	21,450
Mexico	0	0	105	300	500
Netherlands	103	190	270	350	430
Pakistan	49	110	170	230	290
Philippines	0	0	80	160	270
Republic of Korea	17	360	1,450	3,010	4,450
South Africa	0	40	310	580	1,200
Spain	676	1,300	2,420	3,730	5,140
Sweden	465	1,330	2,360	3,660	5,000
Switzerland	381	650	1,090	1,530	2,090
Taiwan Republic of China	70	430	1,140	1,770	2,700
United Kingdom	18,250	24,830	35,032	38,580	40,330
United States[4]	6,635	13,812	27,074	42,002	57,887
Soviet Union	2,780	6,680	12,600	——	——
Other CMEA Countries[5]	394	1,225	3,525	5,594	9,240
Peoples Republic of China	0	8	90	400	1,290
Total[6]	44,516	81,918	145,006	190,896	257,337

[1] For all countries except the United States, the source author of this table based his estimates on the projections for nuclear power capacities shown in Table I-3.

[2] For Egypt, Mexico, Pakistan, Phillipines, Peoples Republic of China, Republic of Korea, South Africa, and the CMEA countries (Bulgaria, Cuba, Czechoslovakia, German Democratic Republic, Hungary, Poland, Rumania, and the Soviet Union), estimates are based on assumptions that expected fuel burnup is achieved and that plant operating efficiency is 60 percent.

[3] About one-third of Finland's spent fuel is expected to be returned to the Soviet Union.

[4] Units of mass for the U.S. data are in metric tons of initial heavy metal (MTIHM); data were compiled assuming no future reprocessing.

[5] Council of Mutual Economic Assistance. Comprised of Bulgaria, Cuba, Czechoslovakia, German Democratic Republic, Hungary, Mongolia, Poland, Rumania, Soviet Union, and Yugoslavia.

[6] These sums are approximate, because most units in this table are MTU, but the U.S. data are in MTIHM. These data are, however, useful for making comparisons, because the two units of measurement are relatively close.

Source: Based on: Harmon, K.M., J.A. Kelman, D.A. Shields, and C.M. Bennett. 1982. International Nuclear Fuel Cycle Fact Book. PNL-3594 Rev. 2, Pacific Northwest Laboratory, Battelle Memorial Institute, p. Fuel-3.

Data for the United States were taken from: U.S. Department of Energy. 1983. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics. Assistant Secretary for Nuclear Energy and Assistant Secretary for Defense Programs, Washington, D.C., p. 39-41.

References and Footnotes

[1] U.S. Department of Energy. 1982. Nuclear Power from Fission Reactors. An Introduction. DOE/NE-0029, Assistant Secretary for Nuclear Energy, Washington, D.C., p. 16-17.

[2] U.S. Department of Energy. 1983. Nuclear Reactors Built, Being Built, or Planned. DOE/TIC-8200-R47, Technical Information Center, Oak Ridge, Tennessee, p. 6.

[3] U.S. Department of Energy. 1983. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics. DOE/NE-0017/2, Assistant Secretary for Nuclear Energy and Assistant Secretary for Defense Programs, Washington, D.C., p. 53.

[4] Flanagan, Dennis. (Editor). 1983. Science and the Citizen. *Scientific American* 249(1):60.

[5] An Agreement State assumes regulatory authority and responsibility for licensing by-product material, source material, and less than critical quantities of special nuclear material, pursuant to Section 274 of the Atomic Energy Act of 1954, as amended. (See Figure I-7.)

EG&G Idaho, Inc. 1982. The 1980 State-by-State Assessment of Low-Level Radioactive Wastes Shipped to Commercial Disposal Sites. The National Low-Level Waste Management Program, Idaho Falls, Idaho, p. iii.

U.S. Nuclear Regulatory Commission. 1981. Draft Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Wastes." Summary. NUREG-0782, Vol. 1, Office of Nuclear Material Safety and Safeguards, Washington, D.C., p. 5.

[6] *Ibid.*, (NUREG-0782, Vol. 1), p. 5.

[7] U.S. Department of Energy, DOE/NE-0017/2, p. 2.

[8] Office of Technology Assessment. 1982. Managing Commercial High-Level Radioactive Waste. Summary. Washington, D.C., p. 15.

[9] *Ibid.*

[10] U.S. Nuclear Regulatory Commission. 1981. Draft Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Wastes." Appendices A-F. NUREG-0782, Vol. 3, Office of Nuclear Material Safety and Safeguards, Washington, D.C., p. D-9.

[11] The Ford Foundation. 1977. Nuclear Power Issues and Choices. Nuclear Energy Policy Study Group, Ballinger Publishing Company, Cambridge, Massachusetts, p. 252.

[12] U.S. Department of Energy, DOE/NE-0017/2, p. 2.

[13] *Ibid.*

[14] *Ibid.*, p. 4.

[15] U.S. Environmental Protection Agency. 1982. Draft Environmental Impact Statement for 40 CFR Part 191: Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste. EPA 520/1-82-025, Office of Radiation Programs, Washington, D.C., p. 13.

EPA states in this report:

In developing its regulations for disposal of high-level wastes in geologic repositories (10 CFR 60), the Nuclear Regulatory Commission (NRC) defined high-level wastes as:

> *. . . (1) irradiated reactor fuel, (2) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and (3) solids into which such liquid wastes have been converted.*
>
> *(Source: U.S. Nuclear Regulatory Commission. 1981. Notice of Proposed Rulemaking, 10 CFR Part 60: Disposal of High-Level Radioactive Wastes in Geologic Repositories. Federal Register 46(130): 35280.)*

For the purposes of our environmental standards, we are proposing a somewhat different definition of high-level wastes:

> *. . . any of the following that contain radionuclides in concentrations greater than those identified in Table 1: (1) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, in a facility for reprocessing spent nuclear fuels; (2) the concentrated wastes from subsequent extraction cycles, or equivalent; (3) solids into which such liquid wastes have been converted; or (4) spent nuclear fuel if disposed of without reprocessing.*

There are two substantive differences between our definition and the one in 10 CFR 60. The first is that our definition does not identify spent nuclear fuel as a waste unless it is determined that such fuel will be disposed of without reprocessing. Thus, provisions of our standards that specifically apply to waste would not apply to spent fuel until such a determination was made.

The other major difference is that our definition of high-level waste excludes materials with concentrations of radioactivity below those in Table 2-2 . . .

Table 2-2.—Concentrations Identifying High-Level Radioactive Wastes
(Table 1 in 40 CFR Part 191)

Radionuclide	*Concentration (Curies per gram of waste)*
Carbon-14	8×10^{-6}
Cesium-135	8×10^{-4}
Cesium-137	5×10^{-1}
Plutonium-241	3×10^{-6}
Strontium-90	7×10^{-1}
Technetium-99	3×10^{-4}
Tin-126	7×10^{-7}
Any alpha-emitting transuranic radionuclide with a half-life greater than 20 years	1×10^{-7}
Any other radionuclide with a half-life greater than 20 years	1×10^{-1}

NOTE: In cases where a waste contains a mixture of radionuclides, it shall be considered a high-level radioactive waste if the sum of the ratios of the radionuclide concentration in the waste to the concentration in Table 1 exceeds one.

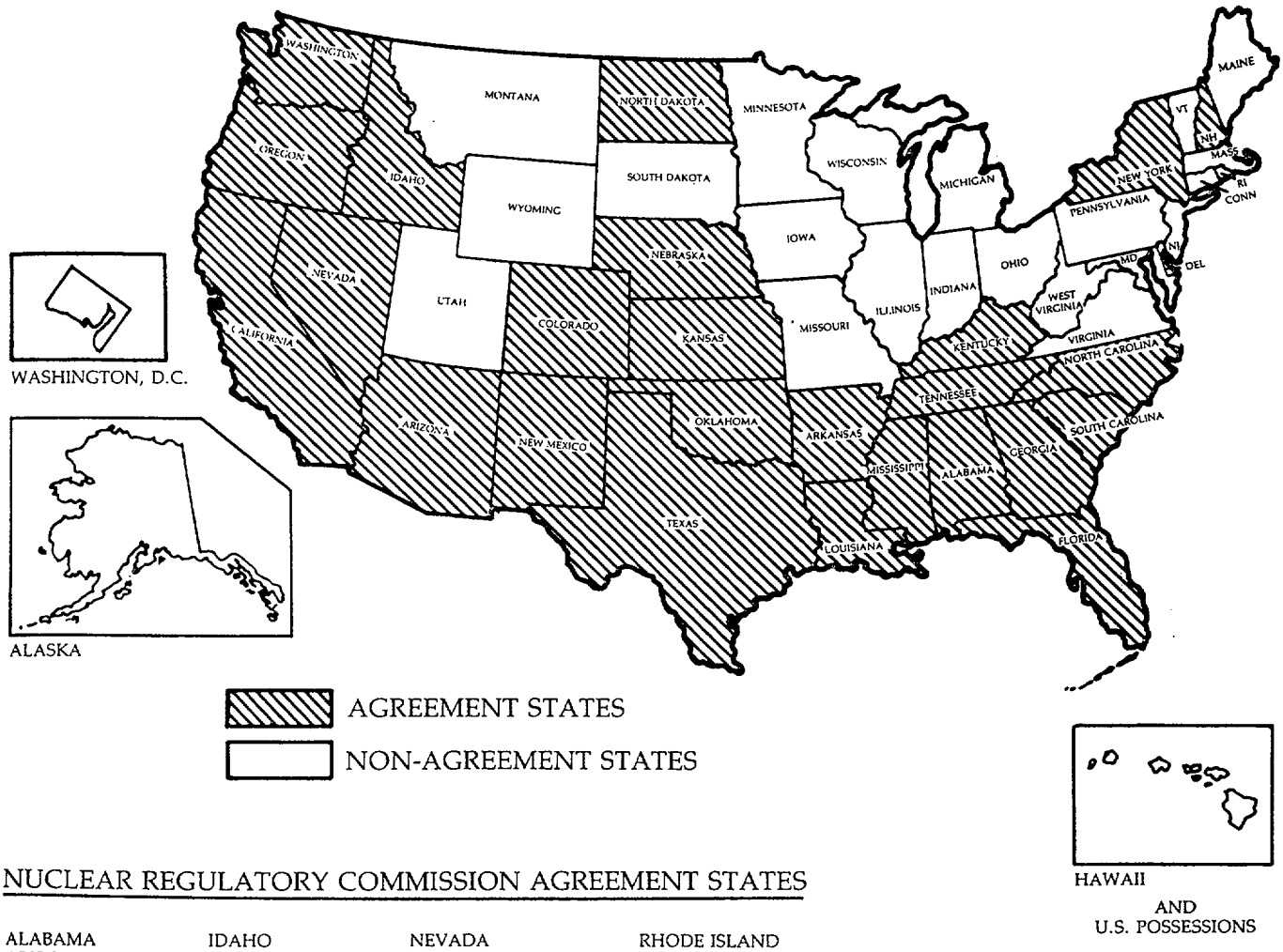
[16] International Atomic Energy Agency. 1978. *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter.* The Definition Required by Annex I, paragraph 6 to the Convention, and the Recommendations Required by Annex II, section D. INF CIRC/205/Add. 1/Rev. 1, Vienna, Austria.

[17] U.S. Department of Energy, DOE/NE-0017/2, p. 2.

[18] *Ibid.*

[19] *Ibid.*, p. 5.

The U.S. Government began licensing uranium mills in the 1950s, however; until the early 1970s, the U.S. Government did not recognize uranium mill tailings as hazardous and did not control nor



NUCLEAR REGULATORY COMMISSION AGREEMENT STATES

ALABAMA	IDAHO	NEVADA	RHODE ISLAND
ARIZONA	KANSAS	NEW HAMPSHIRE	SOUTH CAROLINA
ARKANSAS	KENTUCKY	NEW MEXICO	TENNESSEE
CALIFORNIA	LOUISIANA	NEW YORK	TEXAS
COLORADO	MARYLAND	NORTH CAROLINA	WASHINGTON
FLORIDA	MISSISSIPPI	NORTH DAKOTA	
GEORGIA	NEBRASKA	OREGON	

Figure I-7.—Agreement States as of July 7, 1982.

Source: U.S. Nuclear Regulatory Commission. 1983. Summary Information Report. NUREG-0871, Volume 2, Number 3, Office of Resource Management, Washington, D.C., p. 5.2.

regulate milling operations. As a 1982 report of the General Accounting Office indicated, studies showed that improper disposal of mill tailings could pose health and environmental hazards. In response to these studies, Congress passed the Uranium Mill Tailings Radiation Control Act of 1978 to develop standards to control and stabilize mill tailings at inactive and active mill sites.

U.S. General Accounting Office. 1982. Nuclear and Coal Waste Disposal Hampered by Legal, Regulatory, and Technical Uncertainties. EMD-82-63, Washington, D.C., Appendix I, p. 4.

[20] *Ibid.*, p. 2.

[21] *Ibid.*, p. 5.

[22] U.S. Nuclear Regulatory Commission, NUREG-0782, Vol. 3, p. D1-D24.

[23] *Ibid.*

Of the 82 light water power reactors operating in the United States as of April 1984, 52 are pressurized water reactors (PWR); 28 are boiling water reactors (BWR); 1 is a graphite nuclear power reactor (Hanford, Washington); and 1 is a high temperature gas-cooled reactor (Ft. St. Vrain, Colorado).

[24] U.S. Nuclear Regulatory Commission. 1976. Final Generic Environmental Impact Statement on the Use of Recycled Plutonium in Mixed Oxide Fuels in Light Water Cooled Reactors. Volume 1. NUREG-0002, Washington, D.C., p. ES-1.

Harmon, Kent. 1984. Personal communication. International Program Support Office, Nuclear Waste Technology Program Office, Pacific Northwest Laboratory, Battelle Memorial Institute, Richland, Washington.

[25] *Ibid.* (Harmon, Kent)

Lipschutz, Ronnie D. 1980. Radioactive Waste: Politics, Technology, and Risk. A Report of the Union of Concerned Scientists. Ballinger Publishing Company, Cambridge, Massachusetts, p. 44-48.

According to Dr. Lipschutz, at the end of 1978, about 4,400 metric tons of commercial spent reactor fuel was in storage. (1 metric ton = 2,200 pounds. Volume is about 13.1 cubic feet per metric ton of spent fuel.)

[26] U.S. Nuclear Regulatory Commission, NUREG-0782, Volume 3, p. D4-D24.

[27] U.S. Department of Energy. 1983. Nuclear Reactors Built, Being Built, or Planned. DOE/TIC-8200-R47, Technical Information Center, Oak Ridge, Tennessee, p. 13-15.

[28] U.S. Nuclear Regulatory Commission, NUREG-0782, Volume 3, p. D16-D17.

[29] Gilbert, Charles F. 1984. Policy and Practices in the United States of America for DOE-Generated Nuclear Wastes. *In* Radioactive Waste Management, Proceedings of an International Atomic Energy Agency Conference, Seattle, 16-20 May 1983, Vol. 1, International Atomic Energy Agency, Vienna, Austria, p. 69-78.

[30] U.S. Department of Energy, DOE/NE-0017/2, p. 53-55.

[31] U.S. Department of Energy. 1983. The Federal Nuclear Energy Program. DOE/NE-0042, Assistant Secretary for Nuclear Energy, Washington, D.C., p. 18.

[32] U.S. Department of Energy, DOE/NE-0017/2, p. 15.

Of the 8,989 metric tons of initial heavy metal (MTIHM) of spent fuel in inventory as of December 31, 1982, the Midwest Fuel Recovery Plant in Morris, Illinois, stores 318.9 MTIHM; the Nuclear Fuel Services Plant in West Valley, New York, stores 168.5 MTIHM.

[33] Raubvogel, Andrew. 1982. Nuclear Waste Disposal in the Oceans: A Current Status Report and Issues for Congress. Congressional Research Service, The Library of Congress, Washington, D.C., p. CRS-13.

[34] U.S. Department of Energy. 1983. Defense Waste Management Plan. DP-0015, Assistant Secretary for Defense Programs, Washington, D.C., p. 15-23.

[35] U.S. Department of Energy, DOE/NE-0017/2, p. 15.

[36] Gilbert, *op. cit.*

[37] Leclaire, David B. 1984. Testimony (February 29) before the Subcommittee on Procurement and Military Nuclear Systems, U.S. House of Representatives, Washington, D.C.

[38] U.S. Department of Energy, DOE/NE-0017/2, p. 53-56.

[39] Flanagan, Dennis, *op. cit.*

[40] *Ibid.*

[41] Blix, Hans. 1984. Opening Address. *In* Radioactive Waste Management. Proceedings of an International Conference, Seattle, 16-20 May 1983, Vol. 1, International Atomic Energy Agency, Vienna, Austria, p. 4.

[42] Flanagan, Dennis, *op. cit.*

[43] Semenov, B.A. 1984. The IAEA's Activities in the Field of Radioactive Waste Management. *In* Radioactive Waste Management. Proceedings of an International Conference, Seattle, 16-20 May 1983, Vol. 1, International Atomic Energy Agency, Vienna, Austria, p. 30.

[44] Organization for Economic Cooperation and Development. 1980. Review of the continued suitability of the dumping site for radioactive waste in the North-East Atlantic. Nuclear Energy Agency, Paris, France, p. i.

[45] *Ibid.*

The following countries are members of the IAEA:

Afghanistan
Albania
Algeria
Argentina
Australia
Austria
Bangladesh
Belgium
Bolivia
Brazil
Bulgaria
Burma
Byelorussian Soviet Socialist Republic
Canada
Chile
Colombia
Costa Rica
Cuba
Cyprus
Czechoslovakia
Democratic Kampuchea
Democratic People's Republic of Korea
Denmark
Dominican Republic
Ecuador
Egypt
El Salvador
Ethiopia
Finland
France
Gabon
German Democratic Republic
Germany, Federal Republic of
Ghana
Greece
Guatemala
Haiti
Holy See
Hungary
Iceland
India
Indonesia
Iran, Islamic Republic of
Iraq
Ireland
Israel
Italy
Ivory Coast
Jamaica
Japan
Jordan
Kenya
Korea, Republic of
Kuwait
Lebanon
Liberia
Libyan Arab Jamahiriya
Liechtenstein
Luxembourg
Madagascar
Malaysia
Mali
Mauritius
Mexico
Monaco
Mongolia
Morocco
Namibia
Netherlands
New Zealand
Nicaragua
Niger
Nigeria
Norway
Pakistan
Panama
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Romania
Saudi Arabia
Senegal
Sierra Leone
Singapore
South Africa
Spain
Sri Lanka
Sudan
Sweden
Switzerland
Syrian Arab Republic
Thailand
Tunisia
Turkey
Uganda
Ukrainian Soviet Socialist Republic
Union of Soviet Socialist Republics
United Arab Emirates
United Kingdom of Great Britain and Northern Ireland
United Republic of Cameroon
United Republic of Tanzania
United States of America
Uruguay
Venezuela
Vietnam
Yugoslavia
Zaire
Zambia

The IAEA's Statute was approved on October 23, 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on July 29, 1957. The Headquarters of the IAEA are located in Vienna, Austria.

[46] Harmon, K.M., J.A. Kelman, D.A. Shields, and C.M. Bennett. 1982. International Nuclear Fuel Cycle Fact Book. PNL-3594 Rev. 2, Pacific Northwest Laboratory, Richland, Washington, p. Intl-3-Intl-4.

[47] *Ibid.*

CHAPTER II
Radioactive Waste Management: An Evolving Strategy

As the world moves further into the nuclear age, the problem of disposal and management of the growing stockpiles of radioactive waste becomes more acute. As noted in Chapter I, the amount of radioactive material to be managed is not trivial, and because of its inherent toxicity and its prolonged existence, a successful national nuclear waste program must protect this and future generations beyond the life span of any conceivable social institution.

High-Level Waste

The U.S. definition of high-level waste (HLW) has included all spent reactor fuel plus all wastes from the reprocessing of spent fuel. As indicated in Chapter I, the Environmental Protection Agency (EPA) recently proposed a new U.S. definition of HLW according to concentration levels of certain radionuclides in reprocessed fuel wastes. The EPA definitions set broad limits for long-lived radionuclides (half-lives greater than 20 years).[1]

Such standards can be based on health and safety considerations or on concerns to establish regulations governing the safe transport of nuclear materials and operations at waste treatment plants. For the United States, these definitions serve mainly to provide descriptive information about the different types of waste. Although categorizing nuclear waste appears useful for management purposes, arriving at an effective strategy for disposing of this waste has proved costly and difficult.

High-level nuclear waste contains radionuclides whose half-lives require essentially permanent isolation. Table II-1 shows the principal radionuclides contained in nuclear waste. Unfortunately, past Federal attempts to manage this waste, even on a temporary basis, have generated problems that compound the threat. Large volumes of liquid waste evaporated and solidified by DOE may have been rendered impossible to move for permanent disposal, radioactive liquids have leaked from single-walked tanks,[2] and, before 1970, wastes contaminated with transuranics were not distinguished from other LLW and were buried in shallow land sites.[3]

Table II-1.—Principal Radionuclides Contained in Radioactive Waste[1]

Isotope	*Half-life (Years)*	*Radiation Emitted*
^{3}H (hydrogen; tritium)	12.30	Beta
^{14}C (carbon)	5,730.00	Beta
^{55}Fe (iron)	2.60	X-ray
^{60}CO (cobalt)	5.26	Beta, Gamma
^{59}Ni (nickel)	80,000.00	X-ray
^{63}Ni (nickel)	92.00	Beta
^{90}Sr (strontium)	28.10	Beta
^{94}Nb (niobium)	20,000.00	Beta, Gamma
^{99}Tc (technetium)	2.12×10^{5}	Beta
^{129}I (iodine)	1.17×10^{7}	Beta, Gamma
^{135}Cs (cesium)	3.0×10^{6}	Beta
^{137}Cs (cesium)	30.00	Beta, Gamma
^{235}U (uranium)	7.1×10^{8}	Alpha, Beta, Gamma
^{238}U (uranium)	4.51×10^{9}	Alpha, Gamma
^{237}Np (neptunium)	2.14×10^{6}	Alpha, Beta, Gamma
^{238}Pu (plutonium)	86.40	Alpha, Gamma
^{239}Pu (plutonium)	24,400.00	Alpha, Gamma
^{240}Pu (plutonium)	6,580.00	Alpha, Gamma
^{241}Pu (plutonium)	13.20	Alpha, Beta, Gamma
^{242}Pu (plutonium)	2.79×10^{5}	Alpha
^{241}Am (americium)	458.00	Alpha, Gamma
^{243}Am (americium)	7,950.00	Alpha, Beta, Gamma
^{243}Cm (curium)	32.00	Alpha, Gamma
^{244}Cm (curium)	17.60	Alpha, Gamma

[1] The radionuclides listed in this table represent those that would be normally found in the spent fuel extracted from a nuclear power reactor after storage of the fuel rods to allow the decay of short-lived radionuclides.

[2] Tritium.

Source: U.S. Nuclear Regulatory Commission. 1981. Draft Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste." Summary. Office of Nuclear Material Safety and Standards, Washington, D.C., p. 12.

Before 1977, reprocessing HLW was expected to occur on a commercial scale as soon as the nuclear power industry had expanded enough to justify the large facilities needed for economic operation.[4] It was thought that reprocessing would significantly reduce the total volume of material handled as HLW, because the fission products—such as cesium and strontium—would be separated from the remaining uranium and plutonium and then placed in a glass matrix for disposal.[5] Reclaimed uranium-235 and plutonium would be reused in the fission process.[6]

An attempt to commercially reprocess spent fuel was made by the Western New York Nuclear Fuel

Services plant at West Valley, New York. While in operation, the plant only reprocessed about 630 metric tons of spent fuel, generating about 600,000 gallons of HLW. Two additional commercial reprocessing plants also were constructed but never operated: the Midwest Fuel Recovery Plant, built by General Electric at Morris, Illinois, and the Allied-General Nuclear Services Plant at Barnwell, South Carolina.[7]

Political issues, technical problems, regulatory uncertainties, and unanticipated high costs have hampered the successful establishment of commercial reprocessing in the United States. And, according to studies cited by the Office of Technology Assessment (OTA), "reprocessing...does not offer advantages that are sufficient to justify its use for waste management reasons alone." Reprocessing generates additional radioactive waste and involves its own operational risks. Commercial investments in large-scale reprocessing of spent fuel and recycling of its unused fissionable material hinge on the actual costs and regulatory uncertainties involved and on the current worldwide excess of uranium ore. It is uncertain when, if ever, reprocessing will become more economically attractive than is the current mining of uranium ore.[8]

On October 28, 1976, President Gerald S. Ford halted reprocessing until proof could be found that the "world community could overcome effectively the associated risk of proliferation."[9] In April 1977, President Jimmy Carter reaffirmed the Ford initiative when he deferred commercial reprocessing of spent fuel to minimize the risk of diversion of the separated plutonium for illicit purposes.[10] Although operations never started at the Barnwell, South Carolina, reprocessing plant, owned by Allied-General Nuclear Services, the Carter Administration did provide funds for research and development (R&D) activities.[11] Since that time, President Ronald Reagan has supported the concept of reprocessing by private industry if economic conditions warrant.[12] However, when Congress suspended R&D funds for Barnwell in July 1983, Allied-General Nuclear Services decided to mothball the last facility available for commercial reprocessing in the United States in December 1983.[13]

To alleviate the buildup of U.S. spent fuel, both the Ford and Carter Administrations had planned to construct off-site, temporary away-from-reactor (AFR) storage facilities for cooling the fuel prior to its disposal.[14] These facilities, not an integral part of the reactor plant, were to retain fuel until such time for reprocessing or disposal.[15] However, these facilities have never been built; spent fuel rods remain temporarily stored at reactor sites originally designed for only one year's accumulation.[16] Although restricted storage space has been alleviated through such means as building special storage racks that allow for on-site storage of all the spent fuel a reactor generates during its life-time, the problem remains of how to permanently dispose of the spent fuel when they run out of storage space and at time of decommissioning.[17]

Such alterations and dilemmas in America's high-level nuclear waste management have been typical of the nearly four-decade history of this issue. During the initial stage of U.S. nuclear waste management in the 1940s and 1950s, the U.S. Atomic Energy Commission (AEC) constructed a system of tanks to store liquid HLW at the Hanford and Savannah River waste sites. After discovering leaks in 1958, the AEC started constructing double-walled tanks and transferred the waste to the new tanks. The AEC and its successors chose to solidify the waste in the form of salt cake and sludge, and then retain it in tanks at Federal sites until a permanent disposal option could be selected.[18]

In the 1960s, the AEC examined the feasibility of emplacing soldified HLW in deep underground salt formations. In 1963, the AEC initiated Project Salt Vault and investigated salt deposit sites in Kansas, Michigan, and New York. The Oak Ridge National Laboratory (ORNL) conducted experiments in an abandoned salt mine near Lyons, Kansas, but an attempt to develop this mine into a national HLW repository was thwarted for political and technical reasons. Kansas political leaders used scientific objections, e.g., insufficient information had been gathered about the behavior of hot radioactive canisters in salt and about the Lyons site in particular, to generate public opposition. The efforts of the Kansas politicians led to an amendment in the AEC Authorization Act (P.L. 92-84) for fiscal year 1972, which prohibited disposal of HLW at the Lyons site except for limited research and development. Moreover, hydraulic fracturing operations conducted at a salt mine near the Lyons test site resulted in an unexplained loss of water—questions then arose as to the site's geological integrity.

After Lyons, the AEC opted for monitored retrievable storage (MRS) facilities where HLW could be stored indefinitely while the Federal Government studied geologic formations for an acceptable repository site.[19] Development of these temporary MRS facilities has been initiated on several occasions to allow more time to develop permanent repositories and to allow more sites to be used for waste storage. Work on these plans has been stopped several times to save money and to expedite development of permanent repositories. The Department of Energy (DOE), successor to the AEC and the Energy Research and Development Administration (ERDA), is currently developing plans to construct MRS facilities if deemed necessary.[20]

After 1975, ERDA expanded its search for a U.S. HLW repository, using broad surveys in 36 States prior to specific site examinations. ERDA's efforts, however, were thwarted by political barriers in Michigan and Louisiana. By June 1980, about 25 States had placed

bans or restrictions on storage, disposal, or transport of radioactive waste within their borders.[21]

A 1982 report by the Office of Technology Assessment (OTA) highlights major policy issues dealing with HLW disposal and argues the need for a comprehensive U.S. waste management strategy although that report assumes waste disposal in a land-based geological repository.[22] The Department of Energy has examined nine disposal options: 1) mined geologic sites; (2) the subseabed; 3) very deep holes (around 10,000 feet); 4) islands; 5) space; 6) rock melt; 7) ice sheets; 8) well injection; and 9) transmutation. Of all alternatives, transmutation, or the transforming of long-lived radioactive waste nuclides into shorter-lived materials by neutron bombardment, would initially appear to be the most attractive. Strontium-90, with a 30-year half-life, could in theory be converted by this technique to its 9.7 hour half-life isotope strontium-91. Other possibilities, such as changing cesium-137 to cesium-138, exist. However, this alternative has not yet proved practical, because the necessary high neutron flux for transmutation requires the introducduction of additional concentrated high-level radioactive material into the reactor system, and thus creates another radioactive waste problem.[23]

As a result of its prior investigations, DOE favors land-based repositories for disposal of commercially generated high-level radioactive waste and spent fuel. In this process, a shaft will be cut into a stable geologic formation, and wastes will be emplaced in caverns excavated laterally off the main shaft deep below the Earth's surface. After the repository has been filled to capacity, all access to the underground repository (i.e., shafts and boreholes) will be filled and permanently sealed.[24]

DOE has considered the basalt underlying the Hanford Reservation in Washington, tuff at the Nevada Test Site, and several salt sites as a possible first repository.[25] As a second possible repository, DOE is studying crystalline rock in 17 States across the Nation; DOE plans to identify a possible second repository in early 1985.[26] Figure II-1 shows the four types of rock DOE is considering for geologic repositories.

Underground disposal of high-level waste, however, presents various geologic problems, which depend on the medium considered. The corrosive nature of rock salt poses complications, because it contains brine that tends to migrate toward a heat source, and waste canisters could thus become immersed in a "hot, highly corrosive bath."[27] Furthermore, as a recent report by the National Research Council of the National Academy of Sciences indicated, the heat generated by disposed waste could crack surrounding rock formations, such as granite or tuff.[28]

Every activity specified in the Mission Plan of the Civilian Radioactive Waste Management Program is geared to: "accept commercial high-level radioactive waste for safe management, storage, and permanent disposal on a firm schedule, beginning not later than January 31, 1998." For the first repository, DOE has identified nine potential sites and has notified the governors and legislators of each of the six States involved. The sites identified are:

- Vacherie Salt Dome, Gulf Coast Salt Dome Basin, Webster and Bienville Parishes, Louisiana.
- Cypress Creek Salt Dome, Gulf Coast Salt Dome Basin, Perry County, Mississippi.
- Richton Salt Dome, Gulf Coast Salt Dome Basin, Perry County, Mississippi.
- Yucca Mountain Site (tuff) on the Nevada Test Site, Southern Great Basin, Nye County, Nevada.
- Palo Duro Site A (bedded salt), Permian Basin, Deaf Smith County, Texas.
- Palo Duro Site B (bedded salt), Permian Basin, Swisher County, Texas.
- Davis Canyon Site (bedded salt), Paradox Basin, San Juan County, Utah.
- Lavender Canyon Site (bedded salt), Paradox Basin, San Juan County, Utah.
- A-11 Site (basalt) on the Hanford Reservavation, Pasco Basin, Benton County, Washington.

From these nine sites, DOE will nominate five sites for "characterization." Following characterization of these five, DOE must recommend three sites to the President for "detailed site characterization" by January 1985. Detailed site characterization comprises specific activities to "establish the geologic conditions and the ranges of the parameters of a candidate site relevant to the location of the repository." This also includes an examination of the many environmental

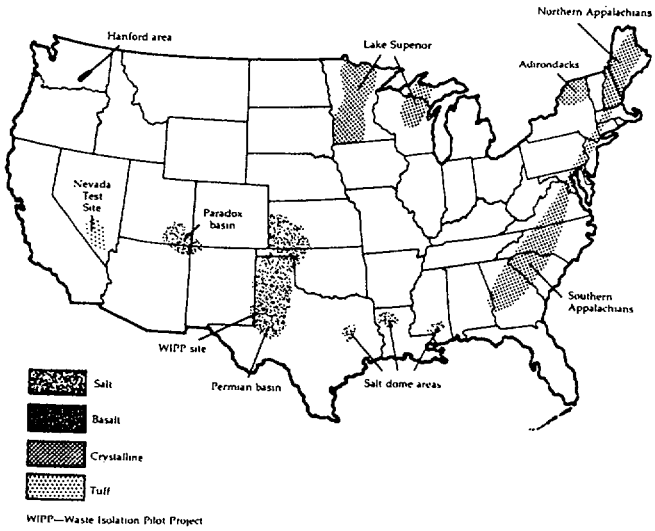


Figure II-1.—Rock Types Under Investigation as Possible Geologic Repositories.

Source: U.S. Department of Energy. 1983. Office of Civilian Radioactive Waste Management, Washington, D.C.

and socioeconomic factors involved. Public Law 97-425 calls for the President to recommend one site for the first repository to Congress by 1987.[29]

In this step-by-step process established by the Nuclear Waste Policy Act, the President, the Congress, the States, affected Indian tribes, DOE, and other Federal agencies must collaborate on all phases of the siting, construction, and operation of these geologic repositories.[30] Difficult political questions face decisionmakers: In which State(s) will the repository be located? Nearly 156 States and local governments have enacted legislation banning various waste activities within their borders, and several have sought to prevent DOE from conducting initial site investigations.[31] Although Congress has the right to override a State's refusal to accept a repository, the procedures outlined in the Nuclear Waste Policy Act were designed to instill confidence that the Federal Government is open to public concerns and attentive to health and safety issues.[32]

These location problems are familiar in other countries that are concentrating on land geologic formations as HLW repositories. In recent years, however, our Nation and others have initiated programs to investigate the subseabed as a possible HLW disposal site. Chapter V discusses these efforts in further detail, and Appendix B summarizes various global approaches toward HLW management. Meanwhile, the U.S. stockpile of HLW continues to grow.

Transuranic Waste

Transuranic wastes (TRU) contain alpha-emitting radionuclides with atomic numbers higher than 92 and half-lives greater than 20 years in concentrations of more than 100 nanocuries per gram. For the most part, handling transuranic waste requires little or no shielding when dealing with just alpha particle emitting radionuclides; however, energetic gamma and neutron emitting radionuclides and fission-product contaminants may cause the wastes to require shielding or remote handling.[33]

Before 1970, transuranics in low concentrations were disposed of as low-level waste, but since then new definintions and a new management plan have come into place. Under DOE's current plan, newly generated and readily retrievable TRU wastes are destined for geologic disposal in the Waste Isolation Pilot Plan (WIPP) in New Mexico. At that site, a shaft and lateral caverns have been excavated into a 200 million year old salt deposit. Currently, TRU waste is stored at the Savannah River Plant in South Carolina, the Hanford Reservation in Washington, the Idaho National Engineering Laboratory, the Oak Ridge National Laboratory in Tennessee, the Los Alamos National Laboratory in New Mexico, and the Nevada Test Site. Other generators of TRU waste currently send wastes to these six sites, but when WIPP begins to operate, TRU wastes will be processed as required and sent directly to WIPP for disposal. When WIPP opens, a five-year period of testing will begin. If operations proceed well, after five years a decision will be made to designate WIPP as a permanent repository for TRU wastes.[34]

TRU wastes that are not readily retrievable will be left in current disposal sites. The National Academy of Sciences and others have found that retrieval of the TRU wastes disposed of in shallow land burial sites before 1970 can be more hazardous than leaving them in place. The plan for managing this TRU waste is to monitor it, take remedial actions as may be necessary, and reevaluate its safety periodically.[35]

Low-Level Waste

Managing our Nation's low-level radioactive waste (LLW) has proved no less controversial than has managing our HLW. LLW results from almost every phase of nuclear technology, and each of our 50 States generates LLW in large quantities from myriad sources. Although the exact quantity of LLW generated in the United States is not known,[36] some scientists estimate the United States generated about 80,000 m^3 in 1980.[37] Of the LLW shipped to commercial disposal sites, DOE averages for 1978 to 1980 show that nuclear power reactors accounted for 54 percent, medical and research institutions accounted for 33 percent, industrial activities accounted for 10 percent, and Federal and military sources comprised 2 percent.[38] LLW in gaseous form is usually treated through a series of filters and then either released into the environment or disposed of at a LLW dump site; LLW in liquid form is usually treated, solidified, and then disposed of at a LLW dumpsite.[39] Solid LLW is primarily buried in shallow trenches with unsealed bottoms and mounded earthern caps; this method relies on such techniques as soil geochemistry to minimize the dispersal of radionuclides in the soil,[40] as well as on waste packaging, minimizing water infiltration, reducing water/waste contact time, and siting in areas of low moisture flux.

Between 1962 and 1971, the AEC (and subsequently the Nuclear Regulatory Commission) or the "situs State" under the States Agreement Program licensed six shallow land burial sites to receive commercially generated LLW and some unclassified Federal LLW.[41] In March 1975, however, the West Valley, New York, site was closed for radioactive water seepage problems; the Maxey Flats site closed in December 1977 when usage was discouraged after the Kentucky legislature imposed a 10-cent per pound excise tax on wastes received for disposal as a safeguard measure against unforeseen problems; and a third site in Sheffield, Illinois closed after licensed capacity had been reached and the operating company withdrew its application for renewal

of its NRC license.[42] At the three remaining sites—Beatty, Nevada; Barnwell, South Carolina; and Richland, Washington—various restrictions have been continued.[43] Projections for the 1980s suggest the United States could generate more LLW than existing disposal sites could accommodate.[44] This has raised the possibility that hospitals and institutions with constrained capacity for on-site storage would have to curtail their use of radioactive materials. In 1981, however, a new Federal rule governing medical radioactive wastes became effective and allowed for a large volume of medical wastes containing minute amounts of tritium and carbon-14 to be disposed of as nonradioactive wastes.[45] Although this ruling may temporarily postpone the time when disposal of LLW becomes critical, the basic problem of storage capacity remains.

Because States already hosting sites are reluctant to shoulder our Nation's entire LLW burden, additional disposal facilities and improved management practices are mandatory. DOE operates 13 LLW disposal sites on U.S. Government land; eight of these are small and used solely for local plant operations. And, although almost any Federal site is physically capable of storing commercial LLW, national security considerations could rule out several sites. The approach by the States has been to join in compacts, which are discussed in further detail in Chapter III of this report.[46]

Low-Level Waste Ocean Disposal by the United States

Before 1970, ocean dumping was the preferred U.S. method for LLW disposal. At that time, it was widely believed that if waste containers leaked, the large volume of ocean waters would dilute and disperse the waste dumped at sea. Because most LLW radionuclides have short half-lives, it was calculated that dilution plus decay would result in innocuous levels and pose minimal hazards to man. Furthermore, the sea was readily available and economical to use.[47]

For a quarter of a century (1946 to 1970), the United States disposed of about 90,000 containers having an initial radioactivity of 95,000 curies in four major dumping areas in the Atlantic and Pacific Oceans.[48] The United States held the position in the 1950s and 1960s that disposal of LLW in the ocean did not pose a significant environmental problem, and careful records were not kept of what was disposed of and where.[49] This lack of recordkeeping has haunted the Federal Government ever since, as public pressure continues to force the government to reconstruct previous disposal scenarios to prove its original opinions were correct.

More than 90 percent of our country's ocean dumping was generated by AEC contractors and defense facilities.[50] The U.S. Navy assisted in transporting LLW to sea until 1959, when AEC licensed private companies to do the job.[51] At about that time, heightened public concern and increased disposal costs caused the AEC to place a moratorium on new licenses for sea disposal of LLW.[52] AEC facilities at Oak Ridge, Tennessee, and Idaho Falls, Idaho, were designated as interim burial sites for AEC licensees.[53] Then, in 1962, the first land-based disposal site for commercial LLW was established at Beatty, Nevada.[54] In addition to deliberate dumping of wastes, the United States has allowed radioactive material from defense reactors at Hanford, Washington to enter the ocean via the Columbia River as shown in Table II-2 and Appendix E.[55]

Low-Level Waste Ocean Disposal by Other Nations

Second only to weapons testing, the greatest source of anthropogenic radioactivity in the ocean results from LLW discharged following the reprocessing of spent fuel and the dumping of solid LLW by various European countries.[56] The most significant of the five nuclear fuel reprocessing plants in the "European Community" are Sellafield (formerly Windscale), located on the northwest coast of England in Cumbria, and La Hague on the northern coast of France in Manche.[57]

Ocean dumping of LLW and discharges into the ocean from shore have been common practices in Europe. Between 1950 and 1967, the United Kingdom disposed of about 3,300 curies of alpha-emitting and 44,000 curies of beta-emitting wastes in the Northeast Atlantic Ocean near the Bay of Biscay. From 1950 to 1963, the United Kingdom and Belgium disposed of 390 curies of alpha-emitting and 1,176 curies of beta-emitting LLW in the "Hurd Deep," located about 20 miles north of Guernsey Island in the Channel Islands. Most of this waste was packaged in 55-gallon drums weighted with concrete.[58] From 1957 to 1980, the Sellafield plant discharged about 2.3 million curies of assorted radionuclides into the adjacent Irish Sea.[59] The French reprocessing plant at La Hague discharged LLW into the English Channel for 15 years until the French discontinued ocean dumping of LLW in 1969.[60]

In 1967, OECD's Nuclear Energy Agency agreed to supervise ocean disposal of LLW by NEA member nations. (See Chapter I for a listing of these nations.) Belgium, France, the Federal Republic of Germany, the Netherlands, and the United Kingdom participated in this first ocean disposal of LLW directed under international supervision. The second internationally supervised operation occurred in 1969 with the added participation of Italy, Sweden, and Switzerland and the abstension of the Federal Republic of Germany.[61]

Since 1971, only Belgium, the Netherlands, Switzerland, and the United Kingdom have chosen the ocean disposal option.[62] NEA records reveal the approximate

Table II-2.—Anthropogenic Radionuclides Added to the Sea[1]

Source and/or Location	*Years Used*	*Description*	*Activity[2] (curies)*
Nuclear weapons tests[3]	1946-68	360 Nuclear Explosives Detonated	10^9 total; includes 21×10^6 (Sr^{90}) 34×10^6 (Cs^{137})
U.S. Nuclear submarines[4]	1963 1968	USS THRESHER USS SCORPION	Classified
Hanford plant, Richland, Washington[5]	1944-71	8 plutonium-producting reactors	about 1,000 per day during the period of maximum reactor operations (1955-64)
Sellafield, United Kingdom	1952-today	reprocessing plant; restricted to total beta activity release of 300,000 curies per year and 6,000 alpha curies per year; principal components of activity: ^{137}Cs, ^{106}Ru, ^{90}Sr, ^{241}Pu, and ^{3}H.	225,000 per year (average) total
European Community nuclear power plants[8]	1956-today	Over 40 plants	826.4 (less H^3) total for 1978
U.K. LLW dumping[8]			
Hurd Deep	1950-63	61,570 containers	390 (alpha) total 1,176 (beta) total
U.K. area	1951-67	50,570 containers	3,331 (alpha) total 44,096 (beta) total
Northeast Atlantic LLW Dump Site[9]	1967-81	Generally concrete, bitumen, or, plastic matrices within steel and/or concrete containers	12,315 (alpha) total 420,512 (beta/gamma) total 434,256 (tritium) total
U.S. Low-Level Waste Dumpsites[10]			
Major Atlantic Ocean Dumpsites			
Sandy Hook 1 (N.J.)	1951-56 1959-62	14,301 containers	74,400 total
Sandy Hook 2 (N.J.)	1957-59	14,500 containers	2,100 total
Massachusetts Bay	1952-59	4,008 containers	2,440 total
Major Pacific Ocean Dumpsite			
Farallon Islands	1946-70	47,500 containers	14,500 total
38°30'N 72°06'W[11]	1959	Pressure vessel of Seawolf Reactor	33,000 total
Aerospace generator[12]	1964	SNAP-9A nuclear generator	10,000 (Pu^{238}) total
Thule, Greenland[13]	1968	Nuclear weapon aboard downed aircraft	a few curies, apparently less than 5
Possible Soviet Submarine wrecks and fallen Satellites		unknown quantity	unknown

[1] Table does not attempt to show all anthropogenic radioactivity in the ocean.

[2] Activity per day, per year, and total as indicated. Isotopes with short half-lives may have already undergone substantial reduction by radioactive decay, depending on when they were added to the ocean.

[3] Resulted from the testing programs of the United States, the Soviet Union, the United Kingdom, France, and China; total excludes underground detonations. Because of their long half-lives, strontium-90 and cesium-137 are frequently used as tracers of fallout depostition in the ocean.

Sources: Joseph, A.B., P.F. Gustafson, I.R. Russell, E.A. Schuert, H.L. Volchok, and A. Tamplin. 1971. Sources of Radioactivity and Their Characteristics. *In* Radioactivity in the Marine Environment, National Academy of Sciences, Washington, D.C., p. 9.

Templeton, W.L., and A. Preston. 1982. Ocean Disposal of Radioactive Wastes. *Radioactive Waste Management and the Nuclear Fuel Cycle* 3(1): 77.

[4] Nuclear fuel inventories for these lost submarines are classified, but land-based nuclear power reactors of similar size contain 10^8 to 10^9 curies of activity. As Triplett *et al.* indicate, core activity depends on fuel mix, fuel inventory, and burnup which, for the lost submarines, are not known. The authors based their estimate on a 1,000 MWe pressurized water reactor after 550 full power days; a core activity of 4×10^8 curies results.

Source: Triplett, Mark B., Kenneth A. Solomon, with Charles B. Bishop and Robert C. Tyce. 1982. Monitoring Technologies for Ocean Disposal of Radioactive Waste. Prepared for the National Oceanic and Atmospheric Administration, R-2773-NOAA, Rand, Santa Monica, California, p. 11.

[5] Radionuclides entering the ocean via the Columbia River were about 95 percent chromium-51 and most of the rest were zinc-65 and phosphorus-32.

Source: Seymour, Allyn H. 1980. Distribution of Hanford Reactor Produced Radionuclides in the Marine Environment, 1961-73. Wylie Eastern Limited, Bombay, India, p. 330-332.

[6] Sellafield, formerly Windscale, is Europe's major reprocessing plant; most of its liquid radioactive waste is discharged into the Irish Sea. Sellafield began using the Purex process in 1964. Activity based on average releases to coastal waters for 1977 and 1978; included are about 32,000 curies per year of ^{3}H and ^{241}Pu.

Source: British Nuclear Fuels Limited. 1979. Annual Report on Radioactive Discharges and Monitoring of the Environment 1978. Health and Safety Directorate, Risley, Warrington, Cheshire, United Kingdom, p. 10-11.

As cited in: Triplett, Mark B. *et.al.*: *op.cit.*, p. 10-11.

Europe has four other major reprocessing plants:

Facility/Location	First "Hot Run"	Water body recipient of waste
Federal Republic of Germany		
Wiederaufarbeitungsanlage (WAK)	1971	Rhine
France		
La Hague	1966	English Channel
Marcoule	1958	Rhone
United Kingdom		
Dounreay	1958	Atlantic Ocean

Source: Luykx, F. and G. Fraser. 1980. Radioactive effluents from nuclear power stations and nuclear fuel reprocessing plants in the European Community. Directorate-General Employment and Social Affairs, Commission of the European Communities, Plateau du Kirchberg, Luxembourg, Table XII (unnumbered page).

Radionuclides have also been released into the sea from several other research centers located in Trombay, India; Studsuik, Sweden; and Petten, the Netherlands.

Source: Foster, R.F., I.L. Ophel, and A. Preston. 1971. Evaluation of Human Radiation Exposure. *In* Radioactivity in the Marine Environment, National Academy of Sciences, Washington, D.C., p. 254.

[7] Nuclear power plants located in Belgium, Federal Republic of Germany, France, Italy, the Netherlands, and the United Kingdom. Of the active European nuclear power stations, the Calder plant in Cumbria, England was the first to go on line in October 1956. A large amount of radioactivity is discharged to the atmosphere as gaseous waste by these stations.

Figures based on 1978 data.

Source: Luykx, F., and C. Fraser, *op. cit.*, 49 p. and tables.

[8] "Hurd Deep"—area near 50°N 01°W; includes some low-level wastes dumped by Belgium.

U.K. area—through 1961, wastes were disposed of near 34°N 20°W; after 1961, except for 1967, disposal occurred in a rectangular area with the following coordinates: 40°20'N 13°53'W, 47°56'N 13°27'W, 48°43'N 13°05'W, and 48°19'N 12°39'W.

Source: Joseph, A.B. *et al., op. cit.*, p. 39.

To verify control of liquid radioactive waste dumping in the ocean and to ensure that the resultant public radiation exposure is within its nationally accepted limits, the United Kingdom initiated an environmental monitoring program under its 1960 Radioactive Substances Act.

Source: Hunt, C.J. Radioactivity in Surface and Coastal Waters of the British Isles, 1979. Aquatic Environment Monitoring Report Number 6, Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Lowestoft, United Kingdom, p. 1.

[9] Templeton, W.L., and A. Preston, *op. cit.*, p.101.

[10] According to the Environmental Protection Agency, most of the waste was either packaged in special containers placed in concrete-filled steel drums or was directly mixed in concrete and then placed in steel drums.

Source: Mattson, Roger J. 1980. Prepared Statement of Roger J. Mattson, Director, Surveillance and Emergency Preparedness Division, Office of Radiation Programs, U.S. Environmental Protection Agency. *In* Radioactive Waste Disposal Oversight Hearings (November 20) before the Subcommittee on Oceanography of the Committee on Merchant Marine and Fisheries, U.S. House of Representatives, 96th Congress, Serial No. 96-53, Washington, D.C., p. 361-366.

[11] Estimated number of curies of induced activity.

Source: Joseph, A.B. *et al., op. cit.*, p. 37.

[12] Templeton, W.L., and A. Preston, *op. cit.*, p. 79.

[13] Aarkog, A.

1971. Radioecological Investigations of Plutonium in an Arctic Marine Environment. *Health Physics* 20 (Jan.):31-47.

1977. Environmental Behavior or Plutonium Accidentially Released at Thule, Greenland. *Health Physics* 32 (April):271-284.

quantities of radioactive waste disposed of at the Northeast Atlantic Dump Site from 1967 through 1981: 12,315 curies of alpha-emitting radionuclides (radium-226 and plutonium-239); 420,512 curies of beta-gamma emitting radionuclides (strontium-90—beta emitter; cobalt-60, zinc-65, and cesium-137—beta-gamma emitters); and 434,256 curies of tritium.[63] Figure II-2 shows the NEA dumpsite for LLW in the Northeast Atlantic Ocean. (International activities concerning high-level waste will be discussed in Chapter III.)

Dumping of LLW was halted by a moratorium resolution adopted by the Seventh Consultative Meeting of the Parties to the London Dumping Convention in February 1983. (The "London Dumping Convention" derived its name from the *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter in the Oceans* held in London, England, in 1972.) The moratorium resolution called for an immediate two-year suspension of ocean dumping of radioactive waste. Although several nations announced they would not abide by this non-binding resolution, transport trade unions in the United Kingdom, and later in Belgium and Switzerland, boycotted the handling of radioactive wastes slated for ocean disposal. This action prevented any ocean dumping of radioactive wastes in 1983. The *de facto* moratorium will likely continue through September 1985.[64]

Although strong international resistance to ocean dumping of LLW continues to prevail, several nations have plans to either resume or start ocean dumping of this radioactive waste. Although the Netherlands no longer plans to resume ocean dumping, the United Kingdom and Switzerland hope to use the Northeast Atlantic Dump Site when the current boycott ends.[65] France is considering ocean disposal of certain types of radioactive waste, such as tritium and iodine which could be isotopically diluted in seawater, as part of its national waste management program.[66]

In 1976, Japan's Atomic Energy Commission set basic principles for disposal of LLW, including the ocean disposal option. The Japanese government favors ocean disposal of LLW. A participant of the London Dumping Convention and the Multilateral Consultation and Surveillance Mechanism for Sea Dumping of Radioactive Wastes, Japan has solicited not only the support of its people but also that of other South Pacific countries.[67]

Several Pacific governments, including the American Pacific islands and territories, districts of the Micronesian Trust Territory, members of the South

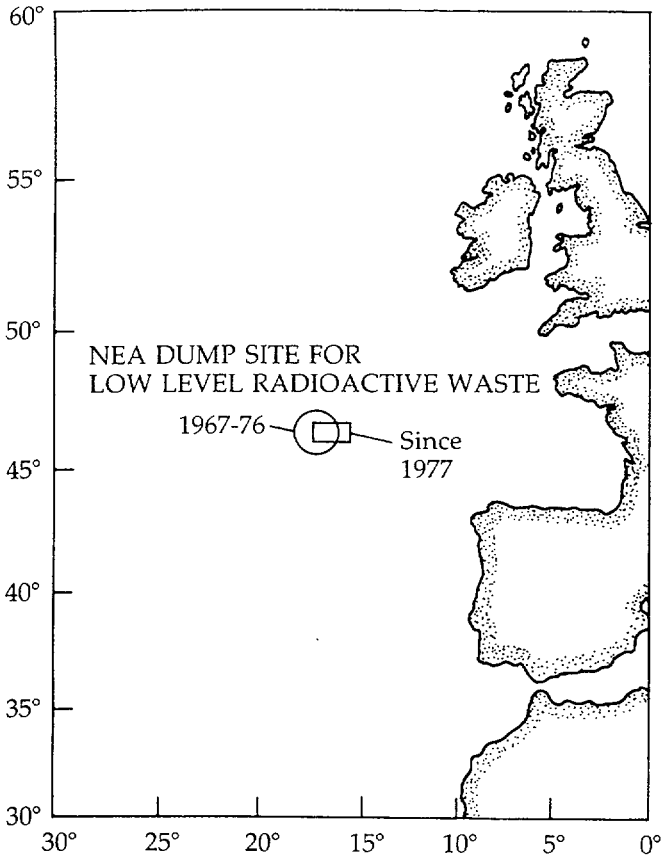


Figure II-2.—Dumpsite of the Nuclear Energy Agency (NEA) for Low-Level Radioactive Waste.

Source: Lounsbery, William J. 1981. High-Level Radioactive Nuclear Waste Disposal in the Sub-Seabed: Prospects for an International Waste Disposal System. Master of Marine Affairs Thesis, University of Washington, Seattle, Washington, p. 48.

Pacific Congress, and New Zealand, have made official protests or voiced concern about these Japanese plans.[68] In fact, the government of the Northern Marianas was reported to have threatened to prohibit Japanese fishing vessels from its fishing zone if dumping commenced.[69] Furthermore, in 1981, a professor from the University of California at Santa Cruz, acting as an adviser to the Pacific governments, called into question the reliability and accuracy of Japan's safety assessments made of the proposed operation.[70] The Japanese government, however, rejected the adviser's findings as scientifically inaccurate because of a misinterpretation of Japanese dose and disposal rates.[71]

Japan proposes to conduct a test—the dumping of 5,000 to 10,000 cement drums containing a total of about 500 curies of radioactivity at a 6,000 meter deep disposal site (30°N, 147°E). (See Figure II-3.) Although Japan has not yet determined the actual amount to be dumped, in assessing the radiological effects of full-scale ocean disposal, Japanese scientists assumed that 105 curies of radioactivity would be dumped into the ocean each year. Full-scale ocean disposal of LLW

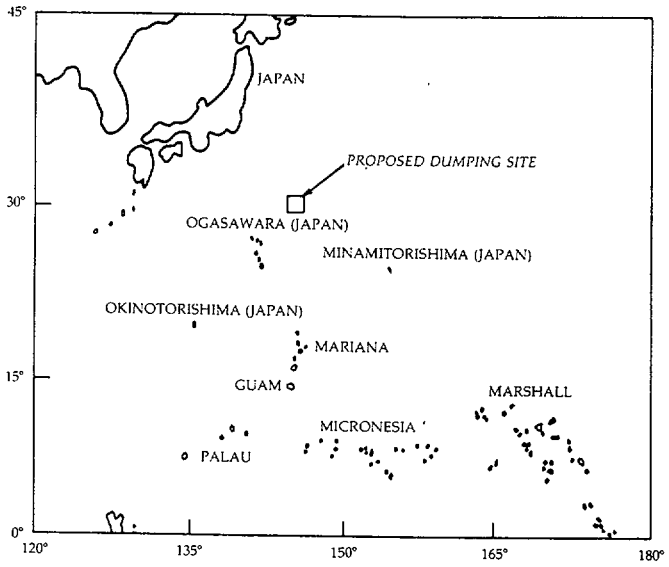


Figure II-3.—Proposed Dumpsite for Japan's Low-Level Waste.

Source: Lounsbery, William J. 1981. High-Level Radioactive Nuclear Waste Disposal in the Sub-Seabed: Prospects for an International Waste Disposal System. Master of Marine Affairs Thesis, University of Washington, Seattle, Washington, p. 50.

would begin if experimental ocean disposal over a 2- to 3-year period confirmed the procedure is environmentally safe.[72]

Other Sources of Anthropogenic Radioactivity in the Ocean

Ocean dumping and discharge from shore have not been the only source of anthropogenic radionuclides in the marine environment—most have resulted from the production and testing of nuclear weapons.[73] Fallout from weapons testing is the major contributor, and radionuclides from this source are spread relatively uniformly throughout the surface water of the world's oceans in low concentrations.[74] The radiation resulting from global nuclear weapons testing is estimated to be 0.1 percent of the total oceanic radionuclide inventory.[75] Contributions of radionuclides to the ocean from nuclear weapons testing have been estimated at one billion curies with tritium ranking as the largest contributor.[76] Additional anthropogenic radionuclides may reach the oceans as LLW from medical, pharmaceutical, industrial, and research activities, and from naval and civilian propulsion reactors, aerospace nuclear reactors, and radioisotopic power generators.[77]

In addition, accidents have been sources of anthropogenic radioactivity in the ocean. The loss of the nuclear submarines *THRESHER* and *SCORPION* in the Atlantic Ocean,[78] the crash near Thule, Greenland, of a U.S. airplane carrying nuclear weapons,[79] and the

re-entry of a U.S. aerospace nuclear power generator after a satellite launch malfunction[80] have contributed to the radioactivity of the ocean. Although Table II-2 lists several sources of anthropogenic radioactivity in the ocean, the listing is incomplete. A comprehensive international inventory of all anthropogenic radioactivity deposited in the ocean is needed.

Summary

For nearly 40 years, the United States has faced the problem of radioactive waste disposal. As our knowledge of radioactivity and its inherent dangers has increased over these years, so has the quest to find a permanent and safe repository for high- and low-level wastes. This national quest remains a matter of considerable debate, fueled by such questions as:

- Should radioactive waste be contained and isolated, or can tactics of dilution and dispersion be devised?
- Should radioactive waste be placed only in retrievable storage until advancements are made in treatment and disposal?
- How can the United States determine the reliability of various disposal systems and develop models to ensure effective containment?[81]

Although the United States and other nations have used the ocean for disposal of low-level waste, its total contribution to the ocean to date has been far less than that made by nuclear weapons testing and the rare accidents of sunken nuclear submarines or a fallen airplane carrying nuclear weapons. Presently, the United States is not using the ocean for the disposal of low-level radioactive waste. A few nations plan to resume dumping soon, and at least one, Japan, is considering starting. No nation has used the ocean for disposal of the dangerous high-level wastes.

References and Footnotes

[1] U.S. Environmental Protection Agency. 1982. Draft Environmental Impact Statement for 40 CFR 191: Environmental Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes. EPA 520/1-82-025, Office of Radiation Programs, Washington, D.C., p. 13-15.

For additional information on the U.S. definition of high-level waste, see footnote 15 in Chapter I of this report. The Nuclear Waste Policy Act of 1982 defines high-level waste; the Environmental Protection Agency sets standards pertinent to high-level wastes; and the Nuclear Regulatory Commission establishes regulations governing high-level waste.

[2] The Ford Foundation. 1977. Nuclear Power Issues and Choices. Nuclear Energy Policy Study Group, The MITRE Corporation, Ballinger Publishing Company, Cambridge, Massachusetts, p. 250-252.

High-level radioactive waste, primarily a by-product of producing plutonium in special reactors, resulted from the nuclear weapons program started in World War II. As of June 30, 1974, about 205 million gallons of high-level liquid waste had been generated, and according to this Ford Foundation report, about 7.5 million gallons of liquid HLW is generated annually from weapons work. This waste is stored in tanks at three Federal installations: Idaho Falls, Idaho; Savannah River Plant near Aiken, South Carolina; and the Hanford Reservation, near Richland, Washington. The Hanford Reservation stores most of this waste.

The integrity of the single-shelled tanks proved questionable when from 1958 to 1974, 18 leaks (totalling 429,400 gallons of waste) were detected at the Hanford Reservation. In fact, a 1973 leak of 115,000 gallons went unnoticed for 48 days, but fortunately, the arid soil surrounding the tanks prevented the waste from migrating significantly. This arid soil and the deep water table at the site resulted in some degree of complacency according to the Ford Foundation study. From 1956 to 1958, about 31 million gallons of radioactive waste, with strontium-90 and cesium-137 removed but still containing plutonium-239, were intentionally dumped. Moreover, until recently, the Hanford Plutonium Finishing Plant released liquid wastes directly into subsurface trenches that were not isolated from the surrounding dirt.

From 1944 to 1964, 149 single-shell tanks were constructed at the Hanford Reservation near Richland, Washington, to store liquid and solid high-level radioactive waste. The leakage problems cited above resulted in the construction of new double shell tanks with a one million gallon storage capacity. Thermocouples monitor heat distribution in the annular space between the carbon steel liners of the tanks to detect and trap any leakage. (From: Rockwell International. 1979. Radioactive Waste Management at Hanford. Rockwell Hanford Operations Energy Systems Group, Richland, Washington, p. 9.)

The tanks at the Savannah River were constructed with double carbon steel shells with automatic leak detectors. Only one small leak of 100 gallons of waste was discovered at Savannah River. The tanks at the Idaho Falls installation also have leak detectors but are made of double shell stainless steel; no leaks have occurred at Idaho Falls.

[3] Willrich, Mason, and Richard K. Lester. 1977. Radioactive Waste Management and Regulation. The Free Press, Macmillan Publishing Co., Inc., New York, p. 17.

After April 1970, the Atomic Energy Commission decided to segregate radioactive waste with known or detectable contamination of transuranic nuclides from other types of wastes and to store this transuranic waste in retrievable form. Of the 952 kilograms of plutonium contained in the transuranic waste buried at the five Federal sites, 740 kilograms were buried before 1970 with no provision for retrieval.

For additional information, see: U.S. General Accounting Office. 1976. Improvements Needed in the Land Disposal of Radioactive Wastes—A Problem of Centuries. Report to the Congress, RED-76-54, Washington, D.C., p. 4-5.

As stated in the Code of Federal Regulations for energy, revised January 1, 1983 (10 CFR Parts 0-199, §61.2), the law now prohibits the shallow land burial of commercial transuranic waste.

[4] The Ford Foundation. 1977. Nuclear Power Issues and Choices. Nuclear Energy Policy Study Group, Ballinger Publishing Company, Cambridge, Massachusetts, p. 29, 319-321.

[5] Goodman, Eli I. 1984. Personal Communication. Senior Technical Advisor, Office of Spent Fuel Management and Reprocessing, U.S. Department of Energy, Washington, D.C.

[6] Office of Technology Assessment. 1982. Managing Commercial High-Level Radioactive Waste. OTA-O-172, Congress of the United States, Washington, D.C., p. 16.

[7] The Ford Foundation, *op. cit.*, p. 321-322.

The West Valley Plant, built on land leased from the State of New York, cost $30 million to construct. About 60 percent of the spent fuel reprocessed until closure in 1972 came from Federal sources; because the price of reprocessing for commercial customers was $30 per kilogram, Nuclear Fuel Services did not regain its capital costs. Work on the Midwest Fuel Recovery Plant was suspended in 1974 after an investment of $64 million. The projected estimate to build the Barnwell facility was $70 million; by late 1975, costs had escalated to $250 million, and the plant never commercially reprocessed wastes.

[8] Office of Technology Assessment, *op. cit.*, p. 20.

[9] The Ford Foundation, *op. cit.*, p. 30.

While contained in the spent fuel, plutonium produced in a nuclear reactor is relatively inaccessible because of its high level of radioactivity. However, plutonium, separated from the other elements in the spent fuel by reprocessing, would be vulnerable to theft, to diversion, and to the production of crude nuclear weapons.

[10] Hart, Gary W., and Keith R. Glaser. 1981. A Failure to Enact: A Review of Radioactive Waste Issues and Legislation Considered by the Ninety-Sixth Congress. *South Carolina Law Review* 32(4):663.

[11] Bastin, Clint. 1984. Personal communication. Chemical Engineer, Office of Spent Fuel Management and Reprocessing Systems, U.S. Department of Energy, Washington, D.C.

[12] Cannon, Sandy. 1981. Reprocessing Central to Emerging Reagan Waste Strategy. *Nucleonics Week* 22(28):1.

[13] Bastin, *op. cit.*

[14] Hart and Glaser, *op. cit.*, p. 674.

[15] Goodman, *op. cit.*

[16] Office of Technology Assessment, *op. cit.*, p. 16-17.

[17] Goodman, *op. cit.*

The Nuclear Regulatory Commission has indicated that notwithstanding re-racking of storage pools, not all reactors will be capable of storing all the spent fuel generated during their operating life-

time. Many will require additional storage capacity to be provided by such measures as the use of dry storage casks.

[18] Hart and Glaser, *op. cit.*, p. 661-663.

The AEC and its successors also constructed 31 tanks at the Savannah River Plant and 15 tanks at the Idaho National Engineering Laboratory. The tanks at the Idaho Laboratory were made of expensive stainless steel that can contain unneutralized wastes without corrosion. The other tanks, however, were fabricated out of less expensive and readily available carbon steel. Because carbon steel can corrode, the AEC had to neutralize the acidic wastes for storage. Acidic wastes solidified in stainless steel tanks produce calcine, which can be stored and retrieved from underground stainless steel bins. On the other hand, neutralized wastes solidified in carbon steel tanks produce a damp "salt cake" and residual sludge. Questions remain on whether this salt cake and sludge can be transferred from the carbon steel tanks used at the Hanford Reservation to a permanent disposal site.

[19] *Ibid.*, p. 664-666.

[20] U.S. Department of Energy. 1983. Civilian Radioactive Waste Management Program Mission Plan. Volume 1. Overview and Current Program Plans. Office of Radioactive Waste Management, Washington, D.C., p. 2-1—2-16.

[21] Hart and Glaser, *op. cit.*, p. 668-669.

[22] Office of Technology Assessment, *op. cit.*, p. 36.

[23] Gilmore, William R. (Editor). 1977. Radioactive Waste Disposal. Low and High Level. Noyes Data Corporation, Park Ridge, New Jersey, p. 213.

[24] U.S. Department of Energy, Civilian Radioactive Waste Management Program Mission Plan, p. 3-A-2.

[25] *Ibid.*, p. 3-A-8—3-A-44.

On June 21, 1983, the Nuclear Regulatory Commission (NRC) issued technical criteria for geologic repositories. The objective of the NRC is to provide reasonable assurance that the geologic repositories selected will isolate the waste for at least 10,000 years without posing undue risk to public health and safety. Several major provisions of the technical criteria were:

- The waste package is to contain the waste for 300 to 1,000 years.
- The rates of radionuclide release from the engineered system are not to exceed one part in 100,000 per year after the containment period for each significant radionuclide.
- The pre-waste-emplacement groundwater travel times from the repository (more precisely, from the "disturbed zone" around the repository) to the accessible environment are to exceed 1,000 years.

[26] U.S. Department of Energy. 1983. DOEFACTS: Implementation of the Nuclear Waste Policy Act of 1982. Office of the Press Secretary, Washington, D.C., p. 3.

[27] Carter, Luther J. 1983. The Radwaste Paradox. *Science* 219 (4580):33-36.

[28] National Research Council. 1981. Rock-Mechanics Research Requirements for Resource Recovery, Construction, and Earthquake-Hazard Reduction. NRC/AMPS/RM-81-1, U.S. National Committee for Rock Mechanics, National Academy Press, Washington, D.C., p. 140-171.

[29] Office of Nuclear Waste Isolation. 1983. Response Report from U.S. Department of Energy' Hearings on Proposed Salt Site Nominations. BMI/ONWI-519, Battelle Memorial Institute, Columbus, Ohio, p. 5-7.

[30] U.S. Department of Energy, DOEFACTS, p. 1.

[31] Hill, Douglas, Barbara L. Pierce, William C. Metz, Michael D. Rowe, Edwin T. Haefele, F. Carlene Bryant, and Edwin J. Tuthill. 1982. Management of High-Level Waste Repository Siting. *Science* 218(4575):859-864.

[32] Zurer, Pamela S. 1983. U.S. Charts Plans for Nuclear Waste Disposal. *Chemical and Engineering News* 61:31.

[33] U.S. Department of Energy. 1983. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics. DOE/NE-0017/2, Assistant Secretary for Nuclear Energy and Assistant Secretary for Defense Programs, Washington, D.C., p. 2.

[34] U.S. Department of Energy. 1983. The Defense Waste Management Plan. DOE/DP-0015, Assistant Secretary for Defense Programs, Washington, D.C., p. 24-25.

[35] *Ibid.*

[36] Jordan, Elizabeth A. 1984. Personal communication. Low-Level Waste Program Manager, Office of Spent Fuel Management and Reprocessing Systems, Office of Nuclear Energy, U.S. Department of Energy, Washington, D.C.

[37] Park, Kilho P., Dana R. Kester, Iver W. Duedall, and Bostwick H. Ketchum. 1983. Radioactive Wastes and the Ocean: An Overview. *In* Park *et al.* (editors), Wastes in the Ocean. Volume 3. John Wiley & Sons, New York, p. 36.

[38] U.S. Department of Energy, DOE/NE-0017/2, p. 157-158.

[39] Jordan, *op. cit.*

[40] U.S. Department of Energy. 1981. Low-Level Radioactive Waste Policy Act Report. Response to Public Law 96-573. DOE/NE-0015, Assistant Secretary for Defense Programs, Assistant Secretary for Nuclear Energy, and the Office of Waste Management and Fuel Cycle Programs, Washington, D.C., p. 9.

For additional information on hydrogeological problems encountered at low-level disposal sites in the United States, see:

Jacobs, D.G., J.S. Epler, and R.R. Rose. 1980. Identification of Technical Problems Encountered in Shallow Land Burial of Low-Level Radioactive Wastes. ORNL/SUB-80/13619/1, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 180 p.

[41] Hart and Glaser, *op. cit.*, p. 773-774.

For additional information on LLW disposal problems, see: U.S. General Accounting Office. 1980. The Problem of Disposing Nuclear Low-Level Waste: Where Do We Go From Here? Report to the Congress, EMD-80-68, Washington, D.C.

[42] *Ibid.*

The six sites were licensed: Beatty, Nevada (1962); Maxey Flats, Kentucky (1963); West Valley, New York (1963); Hanford, Washington (1965); Sheffield, Illinois (1967); and Barnwell, South Carolina (1971).

[43] The Conservation Foundation. 1981. Toward a National Policy for Managing Low-Level Radioactive Waste: Key Issues and Recommendations. Dialogue Group on Low-Level Radioactive Waste Management, Washington, D.C., p. 1.

[44] U.S. Department of Energy, DOE/NE-0015, p. 4.

According to this DOE source, one projection estimates that 184,000 cubic meters of LLW will be generated by 1990, and that five to seven regional burial sites would be needed to accomodate this amount of waste.

[45] Park *et al.*, *op. cit.*, p. 36.

[46] U.S. Department of Energy, DOE/NE-0015, p. iv, 34.

[47] Raubvogel, Andrew. 1982. Nuclear Waste Disposal in the Oceans: A Current Status Report and Issues for Congress. Congressional Research Service, The Library of Congress, Washington, D.C., p. CRS 21-CRS 23.

[48] Mattson, Roger J. 1980. Prepared Statement of Roger J. Mattson, Director, Surveillance and Emergency Preparedness Division, Office of Radiation Programs, U.S. Environmental Protection Agency. *In* Radioactive Waste Oversight Hearings (November 20) before the Subcommittee on Oceanography of the Committee on Merchant Marine and Fisheries, U.S. House of Representatives, 96th Congress, Serial No. 96-53, Washington, D.C., p. 361-366.

[49] Raubvogel, *op. cit.*, p. CRS 21.

[50] *Ibid.*, p. CRS 23.

[51] Dyer, Robert S. 1981. Sea Disposal of Nuclear Waste: A Brief History. *In* Thomas C. Jackson (editor), Nuclear Waste Management. The Ocean Alternative, Pergamon Press, New York, p. 10.

[52] Raubvogel, *op. cit.*, p. CRS 23.

[53] Dyer, *op. cit.*

[54] *Ibid.*

[55] Seymour, Allyn H. 1983. Distribution of Hanford Produced Radionuclides in the Marine Environment, 1961-1973. *In* B. Batel (editor), Management of the Environment, Wylie Eastern Limited, Bombay, India, p. 330-331.

[56] Templeton, W.L., and A. Preston. 1982. Ocean Disposal of Radioactive Wastes. *Radioactive Waste Management and the Nuclear Fuel Cycle*, Vol. 3(1), p. 77.

[57] Luykx, F., and G. Fraser. 1980. Radioactive effluents from nuclear power stations and nuclear fuel reprocessing plants in the European Community. Discharge data 1974-1978. Radiological Aspects. Directorate-General Employment and Social Affairs, Commission of the European Communities, Luxembourg, p. 11.

1978 Effluent Discharges from Europe's Reprocessing Plants in curies per year

Discharge	WAK*	La Hague	Marcoule	Dounreay	Sellafield
alpha	$1.5x10^{-3}$	13.9	0.36	8	1,837
beta (less H^3)	.014	29,501	952	408	192,550
tritium	1,300	19,882	7,295	356	28,371
Sr^{90}	$3.0x10^{-3}$	3,789	23.7	80	16,160
Ru^{106}	——	21,661	667	3	21,897

* WAK—Wiederaufarbeitungsanlage.

[58] Joseph, A.B., P.F. Gustafson, I.R. Russell, E.A. Schuert, H.L. Volchok, and A. Tamplin. 1971. Sources of Radioactivity and Their Characteristics. *In* Radioactivity in the Marine Environment. National Academy of Sciences, Washington, D.C., p. 36-38.

[59] Templeton and Preston, *op. cit.*, p. 78.

The total discharge of radionuclides (in 10^3 curies) from Sellafield through 1980 is as follows:

Sr^{90} (140), Ru^{106} (630), Cs^{137} (910), Ce^{144} (160), $Pu^{239,240}$ (14), Am^{241} (14), and tritium (400).

[60] Hyacinthe, Jean-Louis. 1983. French Radioactive Waste Disposal Practices. Presentation (March 7) before the National Advisory Committee on Oceans and Atmosphere, Washington, D.C.

[61] Dyer, *op. cit.*, p. 11-12.

[62] *Ibid.*

[63] *Ibid.*, and Templeton, *op. cit.*, p. 101.

[64] Curtis, Clifton E. 1983. Testimony (November 2) on Ocean Disposal of Radioactive Wastes before the Subcommittee on Oceanography, Merchant Marine and Fisheries Committee, U.S. House of Representatives, Washington, D.C., p. 17-22.

According to Clifton Curtis, at the most recent 8th Consultative Meeting of the Parties to the London Dumping Convention in February 1984, the contracting parties agreed that the moratorium resolution adopted at the 7th Consultative Meeting would remain in effect until the 9th Consultative Meeting scheduled for September 1985.

[65] *Ibid.*

[66] Hyacinthe, *op. cit.*

[67] Shirakawa, Tetsuhisa. 1983. Japanese Sea Disposal Program of Low-Level Radioactive Waste. Presentation (March 7) before the National Advisory Committee on Oceans and Atmosphere, Washington, D.C.

For additional information on the Consultation and Surveillance Mechanism, see Chapter III of this report.

[68] Finn, Daniel P. 1983. Nuclear Waste Management Activities in the Pacific Basin and Regional Cooperation on the Nuclear Fuel Cycle. *Ocean Development and International Law Journal* 13(2):216.

[69] *Ibid.*

[70] *Ibid.*, p. 222.

[71] Shirakawa, *op. cit.*

[72] Government of Japan. 1980. Dumping at the Pacific. Radioactive Waste Management Center, Nuclear Safety Bureau, Science and Technology Agency, Japan, 10 p.

[73] Templeton and Preston, *op. cit.*, p. 77.

[74] *Ibid.*

In this article, the authors state: "It is important to note that although weapon fallout is the largest contributor to the artificial component it is spread relatively uniformly throughout the waters of the world's oceans and is therefore at very low concentrations; conversely the controlled released of radioactive wastes from nuclear energy activities are relatively as yet much more restricted in geographical distribution and therefore at relatively higher concentrations in the areas where they occur."

[75] Preston, A., D.S. Woodhead, N.T. Mitchell, and R.J. Pentreath. 1972. The Impact of Artificial Radioactivity on the Oceans and on Oceanography. *Proceedings of the Royal Society of Engineering (B)* 72(41):411-423. (As cited in Templeton and Preston, *op. cit.*, p. 111.)

[76] Templeton and Preston, *op. cit.*, p. 77, 101.

The 1971 report of the National Academy of Sciences (NAS), "Radioactivity in the Marine Environment," provides a breakdown of nuclear detonations through 1968. As the authors Joseph *et al.* indicate in the following table in the NAS report, the number, local environment, and elevation of explosions were as follows:

	Continental	Arctic Islands	Coral Islands	Open Ocean
Surface	58[a]	79[a]	16	——
Tower	45	——	11	——
Air and balloon[b]	47	——	48	1
High-altitude and rocket[c]	4	——	——	10
Barge and ship	——	——	35	——
Underwater	——	1	3	2
Underground	116	——	——	——

[a] Includes Soviet and Chinese shots indicated only as "atmospheric."
[b] Approximately 1,000-86,000-ft altitude.
[c] Approximately 141,000-ft to 300-mi altitude.

Source: Joseph, A.B. *et al.* 1971. Sources of Radioactivity and Their Characteristics. *In* Radioactivity in the Marine Environment. National Academy of Sciences, Washington, D.C., p. 9.

As Volchok *et al.* also indicate in this 1971 NAS report, bomb-produced radionuclides have been of interest to scientists both as potential contaminants and as radioactive tracers for studies of water masses, sediment movement, and various biological parameters.

In his 1976 report, "The health of the oceans," Edward Goldberg shows the levels of the major fallout radionuclides in surface sea water:

Location	Average concentration and/or range (pCi/l)				
	^{90}Sr	^{137}Cs*	^{3}H	^{14}C	^{239}Pu
North Atlantic Ocean	0.13 (0.02-0.50)	0.21 (0.03-0.8)	48 (31-74)	0.02 (0.01-0.04)	$(0.3\text{-}1.2)\times10^{-3}$
South Atlantic Ocean	0.07 (0.02-0.20)	0.11 (0.03-0.32)	19 (16-22)	0.03 (0.2-0.04)	0.2×10^{-3}
Indian Ocean North-West	0.10 (0.02-0.15)	0.16 (0.03-0.24)	———	———	———
Pacific Ocean South-West	0.54 (0.07-3.1)	0.86 (0.11-5.0)	29 (6-70)	0.03 (0.02-0.03)	$(0.1\text{-}1.4)\times10^{-3}$
Pacific Ocean North-East	0.08 (0.01-0.20)	0.13 (0.02-0.32)	8 (0.7-22)	———	———
Pacific Ocean South-East	0.27 (0.05-0.58)	0.43 (0.08-0.93)	44 (10-240)	0.03 (0-0.04)	$(0.1\text{-}1.3)\times10^{-3}$
Pacific Ocean	0.09 (0.03-0.33)	0.14 (0.05-0.53)	8 (0.3-34)	0.01 (0-0.03)	———
North Sea	0.05 (0.31-0.97)	0.80 (0.50-1.55)	———	———	———
Baltic Sea	0.71 (0.36-1.0)	1.1 (5.6-1.6)	———	———	———
Black Sea	0.47 (0.07-0.78)	0.75 (0.11-1.25)	———	———	———
Mediterranean Sea	0.23 (0.09-0.38)	0.37 (0.14-0.61)	———	———	———

* Calculated from the ^{90}Sr values on the assumption that the activity ratio $^{137}Cs/^{90}Sr = 1.6$. Reproduced from D.S. Woodhead, "Levels of Radioactivity in the Marine Environment and the Dose Commitment to Marine Organisms", in Radioactive Contamination of the Marine Environment, p. 499-525. Vienna, International Atomic Energy Agency, 1973.

Source: Goldberg, Edward D. 1976. The health of the oceans. The UNESCO Press, Paris, France, p. 87.

[77] Templeton and Preston, *op. cit.*

As scientists at the Woods Hole Oceanographic Institution further report, lead-210 and polonium-210 have increasingly become important as tracers to study marine geochemical processes because of their suitable half-lives and their measurable rates of supply to the oceans by decay of parent radio-nuclides.

(From: Bacon, Michael P., Derek W. Spencer, and Peter G. Brewer. 1978. Lead-210 and Polonium-210 as Marine Geochemical Tracers: Review and Discussion of Results from the Labrador Sea. In T.F. Gesell and W.F. Lowder (editors), Natural Radiation Environment, Volume 1, p. 473-501, Proceedings of a symposium held at Houston, Texas, April 23-28, 1978.)

[78] U.S. Department of the Navy. 1983. Environmental Monitoring and Disposal of Radioactive Wastes from U.S. Naval Nuclear Powered Ships and Their Support Facilities. Report NT-83-1, Naval Nuclear Propulsion Program, Washington, D.C., p. 9.

The submarine *USS THRESHER* sank on April 10, 1963, 100 miles off the New England coast in 8,500 feet of water at latitude 41° 45' north, longitude 55° 00' west; another submarine, the *USS SCORPION* sank between May 21 and 27, 1968, 400 miles southwest of the Azore Islands in the Atlantic Ocean in more than 10,000 feet of water. No samples taken in either area showed any evidence of the release of radioactivity from the reactor fuel element. However, cobalt-60 released from the coolant systems of both submarines was detectable at low levels in localized sediment samples.

As of December 1982, the U.S. Navy estimated that about 30,000 curies of fission products and neutron-activated metals remained in the reactor compartments of each submarine. The U.S. Navy reports that no release from either reactor compartment had occurred.

(From: U.S. Department of the Navy. 1982. Draft Environmental Impact Statement on the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants. Office of the Chief of Naval Operations, Washington, D.C.)

The U.S. Navy has not published data on the amounts of uranium and transuranic radionuclides left in the submarines. However, those long-lived radionuclides are in the fuel of the sunken submarines and will be released to the environment when the submarines deteriorate.

[79] Aarkog, A.

1971. Radioecological Investigations of Plutonium in an Arctic Marine Environment. *Health Physics* 20(Jan.):31-47.

1977. Environmental Behaviour of Plutonium Accidentially Released at Thule, Greenland. *Health Physics* 32(April):271-284.

A B-52 U.S. aircraft carrying nuclear weapons crashed on January 21, 1968, near Thule, Greenland, depositing plutonium isotopes onto the ice and into the sea. The U.S. Air Force removed wreckage debris and contaminated snow shortly after the accident. Scientific expeditions were later carried out in 1968, 1970, and 1974. The plutonium contamination was confined mainly to marine sediments that contained about 25 to 30 curies of radioactivity; plutonium-238 was about 0.5 curies. Compared to initial studies in 1968, concentration levels of the plutonium in the biota in 1970 and 1974 decreased by an order of magnitude; the decrease has been less evident since 1970. Fish, seabirds, and marine mammals have not shown increasing levels of plutonium since the accident.

[80] Hardy, E.P., P.W. Krey, and H.L. Volchok. 1973. Global Inventory and Distribution of Fallout Plutonium. *Nature* 241(5390):444.

In 1964, a SNAP-9A nuclear power generator, containing 17,000 curies of plutonium-238, aboard a TRANSIT navigational satellite re-entered the atmosphere following a launch malfunction. (Systems for Nuclear Auxiliary Power (SNAP)is a U.S. designation for devices that use the heat of radioactive decay to power small electrical generators.) This accidental "injection" of plutonium-238 caused an almost three-fold increase in the global fallout of the isotope.

As indicated in the 1971 NAS report, "Radioactivity in the Marine Environment," plutonium-238 in the generator was assumed to have ablated during reentry. The report further states:

It is interesting to compare the probable sensitivity required for observing the ^{238}Pu deposited on land and in the sea. By the end of 1971, when virtually all of the SNAP-9A debris will have been deposited on the Earth, the average concentration in the surface ocean water (assuming that the ^{238}Pu is homogeneously mixed to a depth of 100 m) will be approximately 0.0005 pCi per liter. Even within the latitude band of maximum deposition, 40°-50° S, assuming no horizontal mixing, we would not find concentrations much higher than 0.0001 pCi per liter. In contrast, the ^{238}Pu deposited on the land in the 40°-50° S band will be about 1 mCi per km², or about 1,000 pCi per m². Even in the northern hemisphere, the deposits in mid-latitudes will be in excess of 100 pCi per m². These projected concentrations on land and in the sea seem to indicate clearly that the 238Pu will be a very useful and practical tool for continental fallout studies. For marine studies, however, the concentrations will probably be beyond the range of practical measurement, using current equipment and technology. Therefore, if we are to make use of this radioactive source as an oceanic tracer, new systems for sampling of the sea—for determining chemical or physical concentrations of plutonium in seawater or for low-level alpha counting (or some combination)—must be developed.

From: Joseph *et al., op. cit.*, p. 34-35.

[81] Haggerty, Stephen E. 1983. Radioactive Nuclear Waste Stabilization: Aspects of Solid-State Molecular Engineering and Applied Geochemistry. *Annual Reviews of Earth Planetary Science* 11:134.

As a matter of perspective, the Department of Energy, the Nuclear Regulatory Commission, and other agencies are addressing these questions.

CHAPTER III
Institutional Framework: Avenues and Roadblocks

Domestic Laws and Policies

U.S. policies on radioactive waste disposal have reflected changing waste management philosophies since the introduction of nuclear technology in the 1940s. These changes have resulted from the passage of new laws and from the articulation of policy and regulatory approaches by various Federal agencies. At present, U.S. nuclear waste management emphasis is placed on land disposal. The following three laws currently stand out as the principal directives for U.S. nuclear waste management:

1. The Marine Protection, Research and Sanctuaries of 1972, as amended, prohibits ocean disposal of high-level waste and places special restrictions on ocean disposal of low-level waste, including a current 2-year moratorium on any low-level waste dumping other than for certain research purposes.
2. The Low-Level Radioactive Waste Policy Act of 1980 holds each State responsible for disposing of its commercial low-level waste within its own borders. The Act also allows regional management through State compacts and instructs the Department of Energy to assist in that effort.
3. The Nuclear Waste Policy Act of 1982 provides for the development of disposal repositories for high-level waste and spent fuel. The Act establishes programs for research, development, and demonstrations of disposal of high-level waste and spent fuel on land and under the seabed.

A brief examination of past U.S. policies concerning radioactive waste disposal provides an historical perspective that led to current domestic statutes and regulatory authorities. Following War II, the United States sought to protect its atomic energy knowledge and to prevent dissemination of nuclear materials for weapons production. To this end, Congress enacted the Atomic Energy Act of 1946 (Public Law 79-585). The Act established the Atomic Energy Commission (AEC) and provided the Federal Government with complete control over nuclear materials. Although the 1946 Act did not directly provide management disposal authority, the AEC assumed responsibility to manage and dispose of national radioactive wastes. Eight years later, the Atomic Energy Act (Public Law 83-703) was extensively revised to include the peaceful use of nuclear power by private firms, primarily to generate electricity.[1]

Through the Atomic Energy Acts of 1946 and 1954, the AEC exclusively regulated nuclear materials, including waste, and used the ocean as the primary means of disposing of low-level waste. But concerted opposition to ocean dumping began in the late 1950s when coastal States, concerned by the close proximity and shallowness of proposed dumpsites, first protested disposal in the Gulf of Mexico. Their protest led to legislation limiting AEC criteria for site selection, with the result that dumping in the Gulf of Mexico was denied.[2]

All ocean dumping of radioactive waste from 1946 to 1970 was conducted under the direction and licensing authority of the AEC. In 1960, the AEC placed a moratorium on issuing new ocean dumping licenses. In 1970, the United States ceased all ocean dumping of radioactive wastes following recommendations from the President's Council on Environmental Quality, although the AEC retained licensing authority until 1972. U.S. records of ocean dumping activities consist mainly of the AEC licenses issued to private contractors and of logs indicating approximate locations of disposal sites. Unfortunately, most of these records do not indicate the specific isotopic content of the waste, the content of the containers, nor verification of the precise dumping locations.[3] (See Appendix C for further discussion and a table of the Environmental Protection Agency's findings to date.)

In 1972, Congress enacted the Marine Protection, Research and Sanctuaries Act, commonly called the "Ocean Dumping Act." This Act governs ocean disposal of all waste materials and explicitly prohibits disposal of high-level waste and radiological warfare agents in the ocean. Title I, the primary regulatory mechanism of the Ocean Dumping Act, allows the Environmental Protection Agency (EPA) to grant permits for ocean dumping of non-dredged waste materials and to provide penalties for permit violations. Permits for low-level waste disposal are allowed only if determined that "such dumping will not unreasonably degrade or endanger human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities." However, the Nuclear Regulatory Commission (NRC), which regulates land burial of radioactive wastes, has ruled that ocean disposal of nuclear materials should only occur as a last resort.[4]

The 1969 National Environmental Policy Act sets out a general statement of U.S. policies on environ-

mental preservation, in particular the need for environmental impact statements. The Environmental Quality Improvement Act reaffirmed the principle that State and local governments have primary responsibility for environmental conservation, but this Act also enlarged EPA's activities by directing the Federal Government to encourage and support State efforts.

EPA regulations pursuant to the Ocean Dumping Act were first published in October 1973; substantive revisions were next published on January 11, 1977. EPA's regulations specify that:

1. Radioactive materials must be contained to prevent their dispersion into ocean waters, and
2. The containment system must be designed to remain intact until the radioactive materials decay to innocuous levels.

Moreover, before a permit for ocean dumping can be approved, the regulations require evidence that no alternative locations or methods of disposal are available that present less adverse environmental impact than would ocean disposal. An assessment of the impact on esthetic, recreational, and economic values also must be made prior to permit approval.[5]

EPA has been reviewing its 1977 regulations, primarily to determine how to incorporate the standards of the International Atomic Energy Agency (IAEA) that were adopted by the London Dumping Convention in 1978. To this end, EPA is developing criteria for evaluating a permit request to include considerations of environmental and economic impact, monitoring requirements, quality assurance in measurement programs, and alternatives to ocean disposal.[6]

Congressional amendments to the Ocean Dumping Act place a 2-year moratorium on the authority of the Administrator of EPA to approve permits for ocean dumping of radioactive waste, although limited disposal associated with research may be allowed. After the two-year moratorium ends on January 6, 1985, Congress has decreed that future permit applications for ocean disposal must be preceded by a Radioactive Material Disposal Impact Assessment which, among other criteria, includes: an environmental analysis of the dumping site; a plan for retrieval if containers leak or decompose; a comprehensive monitoring program; and an analysis of the resulting environmental and economic conditions if the containers fail to contain the radioactive waste material initially deposited at the specific site.[7] Not only must the Radioactive Material Disposal Impact Assessment address these economic and environmental concerns, it must include determinations by affected States that any proposed action is consistent with approved Coastal Zone Management Programs and must contain comments and results of meetings with State officials and public hearings in the affected States.[8] Furthermore, the amendments prohibit the Administrator of EPA from issuing a permit without the express approval of both Houses of Congress by resolution within 90 days of continuous session commencing on "the date after the date" of receipt of permit request. (The full text of January 1983 amendments is contained in Attachment 1 to this chapter.)

The 1980 Low-Level Radioactive Waste Policy Act (Public Law 96-573) directs that each State will dispose either "within or outside the State" the nuclear waste generated within its borders, other than that resulting from DOE activities. Each State may enter into compacts—with specific approval from Congress—that will establish regional facilities for low-level waste disposal. The compacts can restrict disposal of wastes from States outside the compact region, but restrictions will not take effect until Congress approves the compacts. DOE is not aware of any current State efforts to dispose of commercial low-level wastes in the oceans.[9]

The 1980 Act directs the Department of Energy to assist the States in their efforts to establish compacts for low-level waste disposal, and it tasks DOE with preparing a national plan of low-level radioactive waste management. The plan must take into consideration such aspects as the evaluation of disposal technology, the capacity required for present and future low-level radioactive waste disposal on a regional basis, measures to assure the protection of public health, and transportation requirements.[10]

The United States is currently divided into eight distinct compact regions: Central States, Midwest, Northeast, Northwest, Rocky Mountain, and Western. The State of Texas has elected to form its own compact. Although formulation of compacts is progressing at various rates throughout these regions, compacts will probably not have operating low-level waste disposal facilities in place by the required 1986 date.[11]

On January 7, 1983, the U.S. commitment for disposing of its high-level waste on land was strengthened by the Nuclear Waste Policy Act of 1982 (Public Law 97-425), which established a national policy for storage and disposal of high-level radioactive waste and pertinent research and development programs. As stated in Chapter II, this Act provides for completion of an initial U.S. high-level waste land repository by January 31, 1998, based on a national selection process managed by DOE, with local, State, and public involvement. It also provides rules for interim storage facilities if they are needed. The Act requires that by January 1, 1985, three sites be recommended to the President, who will in turn recommend one to the Congress by March 1, 1987. The U.S. repository for HLW, including spent fuel, is estimated to require an area of about one mile radius. The 1982 Act includes provisions for interim storage of 1,900 metric tons of commercial spent fuel at Federal facilities, with removal to occur within three years after completion of the repository.

The step-by-step process outlined for site selection in the Act enables States, affected Indian tribes, the public, and the Federal Government to have a reinforced role in site determination. The Act declares that this "participation in the planning and development of repositories is essential in order to promote public confidence in the safety of disposal of such waste and spent fuel...." After the President has recommended a final site, the governor, State legislature, or affected Indian tribe may submit a notice of disapproval to Congress. Overriding such a notice requires a joint resolution of Congress. DOE will file a license application for a construction permit with the NRC once site designation becomes effective.[12]

Although some of the deadlines specified in the Act for the first repository will not be met, DOE believes that the goal of completing a permanent repository by January 31, 1998, can still be achieved. For example, because of delays inherent in land acquisition and shaft construction, complete characterizations of three sites and the Presidential selection of one of them will not be possible until December 1990. However, if a limited work authorization is granted to allow DOE to proceed with preparatory construction during the three or four years that NRC will need to authorize use of the site, then the facility can be ready for use as required by January 31, 1998.[13]

The 1982 Act establishes a Nuclear Waste Fund to finance waste management activities, based on a charge of 1 mill per kilowatt-hour to nuclear utilities. The Act also directs the Federal Government to take title to commercial spent fuel beginning in 1998 and provides for such measures as local compensation and public hearings.

The legislation also authorizes research and development activities and includes responsibilities for international cooperation with "non-nuclear weapon states" for spent fuel storage and disposal. Egypt, Brazil, Korea, and the Netherlands have expressed interest to work with the United States in this technical disposal venture.[14]

To examine alternatives for permanent disposal of high-level waste, the 1982 Act calls for DOE "...to accelerate a program of research, development, and investigations of alternative means and technologies for the permanent disposal of high-level radioactive waste from civilian nuclear activities and Federal research and development activities...." In addition to its study efforts on mined land repositories, DOE is funding research on subseabed disposal of high-level waste. This program is based on a concept of burying containerized high-level waste in sedimentary clay below the seafloor. The United States is part of the international Seabed Working Group, established in 1976 under OECD's Nuclear Energy Agency, to assess seabed disposal feasibility. The major objectives of the program are to:

1. Determine the technical, environmental, and institutional feasibility of burying high-level radioactive waste in stable clay sediments of the deep ocean.
2. Cooperate with other nations in assessing seabed disposal.
3. Maintain seabed disposal as a possible disposal alternative until the second repository is selected, if the concept proves feasible.[15]

Although we discuss this program in further detail in Chapter V of our report, we note here that the concept of subseabed disposal of high-level radioactive wastes raises both domestic and international issues. A subseabed repository would probably be subject to international agreement. Although current U.S. law expressly prohibits ocean disposal of high-level waste, depositing wastes beneath the ocean sediments may not be considered to be "ocean disposal." However, Congressional clarification may be necessary.

Title II of the Marine Protection, Research and Sanctuaries Act sets forth Federal responsibilities for research on ocean dumping, which includes a comprehensive program on possible "long-range effects of pollution, overfishing, and man-induced changes of ocean ecosystems." The 1978 National Ocean Pollution Planning Act (NOPPA) establishes a 5-year plan for ocean pollution research and monitoring and designates the National Oceanic and Atmospheric Administration (NOAA) as the lead agency in preparing the plan. Through the interagency Committee on Pollution Research, Development and Monitoring (COPRDM), NOAA coordinates the development of a national plan for research and monitoring to evaluate the marine option for disposal of low-level radioactive wastes. Given the unlikelihood of a request for marine disposal of radioactive waste in the near future, some elements of this plan are not developed, although the Department of Energy has a research effort on subseabed disposal of high-level waste, and DOE supports "ecological research" programs that examine some aspects of low-level waste disposal. EPA's modest program is associated with dumpsite designation for low-level waste. NOAA does not conduct any specific radioactive waste disposal research in the marine environment.[16]

If ocean disposal of LLW is resumed, NOAA will most likely be called upon to do the required site-specific studies of proposed dumpsites to determine their suitability. NOAA would probably also be responsible for carrying out monitoring of the ocean environment after dumping occurred. However, in the past, EPA has surveyed the four major U.S. radioactive waste marine dumpsites, where the bulk of this country's dumping occurred. (See Appendix C.) These surveys, all by manned and unmanned submersibles, were made to determine the condition of the radioactive waste packages and to assess our Nation's capability to mon-

itor ocean dumpsites.[17] In other radioactive waste monitoring activities, EPA and the Food and Drug Administration have both conducted examinations of seafoods collected from marketplaces near the largest U.S. ocean dumpsites. EPA believes these marketplace seafood monitoring programs provide an adequate safeguard against humans receiving unacceptable doses of radiation from past ocean dumping.[17] (A description of EPA's activities is contained in Appendix E, Case Histories.)

Thus, because of its present land-oriented disposal policies, the United States does not currently have a well-coordinated research and monitoring effort related to low-level nuclear waste disposal in the ocean. Dumping of LLW was suspended allowing time for more research. However, because the prospect of near-term resumption of ocean dumping of LLW was removed, the priority for research in this area has, in effect, been lowered and support has subsequently been reduced.

International Law Regulating Ocean Disposal

International regulation of ocean dumping was first codified in 1958 in the *Geneva Convention on the High Seas,* with a provision requiring nations dumping low-level waste to take measures to prevent marine pollution.[19] A move by some states to adopt a provision in this convention barring all discharges of radioactive substances into the sea proved unsuccessful.

In 1961, the International Atomic Energy Agency (IAEA) outlined standards for radioactive waste disposal, including a recommendation to ban all ocean dumping of high-level waste and specific dumping recommendations for low-level waste.[20] No system of compulsory standards has ever been set up; however, the IAEA and the International Commission on Radiological Protection (ICRP) have established safety standards for radioactive waste disposal. Although nonbinding, these form the basis of most national controls; the IAEA has also called for the international registration of all ocean disposal of radioactive wastes.[21]

A number of countries continued ocean dumping until 1967, when the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD) agreed to coordinate such operations, and developed the *Multilateral Consultation and Surveillance Mechanism for Sea Dumping of Radioactive Waste* to provide a dumping system at the Northeast Atlantic site.[22] In association with the IAEA, the NEA has developed guidelines on the packaging and dumping of LLW. The Mechanism also provides for prior consultation one year in advance of projected dumping operations by member nations, a system of international surveillance on ships at the time of dumping, and the keeping of records that are sent to the International Maritime Organization (IMO).

In June 1972 at the *United Nations Conference on the Human Environment* (Stockholm Conference), among the declarations adopted was a general obligation of nations to preserve the marine environment. Global regulation of ocean disposal of radioactive waste came in November 1972 under the purview of the *Convention on the Prevention of Marine Pollution by Dumping of Waste and Other Matter.* Commonly called the "London Dumping Convention" (LDC), this international decree prohibits ocean disposal of high-level radioactive waste, but allows dumping of low-level waste after certain requirements have been met. (As shown in Appendix D, the LDC has been ratified by 55 nations, including the United States.) The IAEA has established specific criteria for low-level waste disposal in the sea, and the NEA requires special permit approval.[23] The LDC provides for the control "of any 'deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other manmade structures at sea' or any deliberate disposal of such vessels, aircraft, etc. themselves."

The LDC establishes three categories of waste: Category I—materials prohibited from dumping, which includes high-level radioactive waste; Category II—materials requiring a special permit for dumping, which includes lower levels of radioactive waste; Category III—all other materials which require a prior general permit. Permits may issued by the appropriate national authority only after careful consideration of all factors set out in Annex III of the Convention. These include the characteristics of the waste (toxicity, persistency, synergistic effects such as bioaccumulation), characteristics of the dumping site and method of deposit, effects on other ocean uses (fishing, amenities, navigation, use of the sea water for other industrial purposes), and the availability of alternative land-based methods of treatment or disposal that must be considered.

Although the LDC is not binding on nations that are not Contracting Parties to it, all nations that have recently disposed of radioactive waste at sea are party to the convention with the exception of Belgium. Thus, almost all radioactive waste disposal is subject to LDC direction. As directed by the Convention, the IAEA defined high-level waste and developed recommendations for the permit processes by contracting countries.[24] In 1974, the IAEA provisionally defined high-level radioactive waste for the purposes of exclusion from ocean disposal. The definition was provisional because of a general concern by IAEA scientists that the methodologies used, particularly those in connection with oceanographic processes, were deficient.[25]

In 1978, the IAEA refined its definition of high-level waste unsuitable for ocean dumping, and made recommendations for ocean disposal of other radioac-

tive materials. The IAEA recommendations were based on a model that had both an oceanographic and a radiological component. Limits were set on nuclear waste concentration in the ocean by defining projected radioactivity level constraints on alpha, beta-gamma, and tritium activity (Table III-I) and by outlining technical criteria for low-level waste (Table III-2). The IAEA is currently revising its definition for consideration at a 1985 intergovernmental LDC meeting. IAEA limits are now based on the radioactivity content of the waste rather than the release rate of radioactivity to the environment. Although release rates are recognized as the critical factor, they have not been used to date, because they are difficult to determine and to predict for the future.

Table III-1.—Definition of High-Level Radioactive Wastes or Other High-Level Radioactive Matter Unsuitable for Dumping at Sea.

For the purpose of Annex 1 to the Convention, high-level radioactive wastes or other high-level radioactive matter unsuitable for dumping at sea means any waste or other matter with an *activity* per unit gross mass (in tonnes) exceeding:

(a) 1 curie/ton (Ci/t) for alpha-emitters, but limited to 10^{-1} Ci/t for radium-226 and supported polonium-210 ("supported" means plutonium that is present in equilibrium concentrations because its relatively long-lived parent, lead-210, is present);
(b) 100 Ci/t for beta/gamma-emitters with half-lives of at least half a year (excluding tritium), and beta/gamma-emitters of unknown half-lives; and
(c) one million Ci/t for tritium and beta/gamma-emitters with half-lives of less than half a year.

The above activity concentrations shall be average over a gross mass not exceeding 1000 tonnes.

The definition must not be taken to imply that material falling outside the definition is deemed suitable for dumping.

[1.] The Definition is based on:
(1) An assumed upper limit to the mass dumping rate of 100,000 tonnes per year at a *single dumping* site; and
(2) Calculated upper limits to activity release rates from *all sources*, (other than natural sources) of:
  (a) 100,000 curie/year (Ci/yr) alpha-emitters (but limited to 10,000 Ci/yr for radium-266 and supported polonium-210);
  (b) 10 million Ci/yr for beta/gamma-emitters with half-lives of at least half a year (excluding tritium), and beta/gamma emitters of unknown half-lives; and
  (c) 10^{11} Ci/yr for tritium and beta/gamma-emitters with half-lives of at least half a year (excluding tritium), and beta/gamma emitters of unknown half-lives; and also in the case of alpha-emitters when released to an ocean basin of not less than 10^{17} cubic meters.

Source: International Atomic Energy Agency. 1978. *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter*. The Definition Required by Annex 1, paragraph 6 to the Convention, and the Recommendations Required by Annex II, section D. INF CIRC/205/ Add. 1/Rev. 1., Vienna, Austria, p. 3.

Table III-2.—International Atomic Energy Agency Recommendations for Ocean Dumping of Low-Level Nuclear Waste.

1. Sites should exist between 50°S and 50°N latitudes to avoid sources of bottom water (characterized by strong vertical mixing) and areas of high biological productivity (polar regions);
2. Depth should be 4,000 meters or more (biological, chemical, physical and topographical gradients are generally low, bottom water circulation is slower, and organic carbon in the sediments tends to be low);
3. Sites should be remote from continental margins to avoid regions of high biological productivity, active resource exploration and exploitation, and geologic unpredictability and instability (continental slope, rise and associated fans and canyons);
4. Sites should be away from areas of potential seabed resources; transoceanic cables in use; and areas where geologic hazards (such as submarine slides, volcanoes and earthquakes) decrease a site's environmental predictability;
5. The area of a site should be defined by precise coordinates, with an area as small as practicable; and, if possible, covered by precise navigational aids to assist in relocating the site;
6. Sites should be away from features such as submarine canyons which may unpredictably affect rates of exchange between deep and surface waters near the continental shelf;
7. Sites should be chosen for convenience of disposal operations and to avoid so far as possible, the risk of collision with other traffic and undue navigtional difficulties; and
8. Bottom current shear stress should not exceed critical erosional shear stress to prevent high rates of resuspension and eroding of the sediments.

Source: International Atomic Energy Agency. 1978. *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter*. The Definition Required by Annex 1, paragraph 6 to the Convention, and the Recommendations Required by Annex II, section D. INF CIRC/205/ Add. 1/Rev. 1., Vienna, Austria.

Any dumping operation involving radioactive waste to be carried out by a signatory nation is required to comply with the LDC and is required to be in accordance with the IAEA definitions. The Convention also requires notification to the IMO of any dumping permit issued.

As previously stated, permits for ocean dumping off Europe are issued by the OECD/NEA, pending compliance with standards. The NEA does site suitability studies and maintains a continuing "Research and Environmental Surveillence Programme" for the Northeast Atlantic Dumpsite.

The permit process recommended by the IAEA, which is not to be construed as encouragement by the IAEA for ocean dumping of nuclear waste, has been established to ensure that ocean disposal of low-level waste will involve no unacceptable degree of hazard to human health, harm to living resources and marine life, damage to amenities or interference with other legitimate uses of the sea. The models currently used by IAEA are

based on assumptions designed to guarantee conservative results. For example, in computing possible doses to humans caused by deep-sea disposal of wastes, the assumptions are made that all the waste dumped is immediately released to the ocean, all of it is immediately transported to the surface, and then immediately transported to shore. The models do not attempt to approximate reality, but rather to describe "worst case" possibilities.

Because the IAEA continually reviews its definitions and recommendations, it constantly seeks improvements in the oceanographic model. Advice on ocean dumping is offered by the United Nations Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), and through the IAEA's International Laboratory of Marine Radioactivity in Monaco. The IAEA is working on programs to define what concentrations and types of radioactive materials can be considered essentially non-radioactive, or *"de minimis,"* and therefore suitable for ocean disposal under general rather than special permit. Such a definition can be likened to the LDC's exemption from its pollution provisions of "trace" and "insignificant amounts of substances."[26]

In addition to the scientific evaluation by GESAMP on the oceanographic basis of the IAEA definition, the Scientific Committee for Oceanic Research of the International Council of Scientific Unions (ICSU/SCOR) is reviewing the potential use of the deep subseabed for high-level waste. Also, research on various oceanic processes dealing with problems similar to ocean dumping is being coordinated by such bodies as the UNESCO Intergovernmental Oceanographic Commission (IOC), the European-based International Council for the Exploration of the Sea (ICES), and independent scientific organizations funded by participating countries in Europe and North America.

Some of the research is motivated by political necessity. During the February 1983 meeting of contracting parties to the LDC, the delegations representing the Pacific Island nations of Kiribati and Nauru proposed amendments to the Convention to ban all ocean disposal of nuclear waste. In their view, current scientific evidence did not prove that dumping of nuclear waste would not have a detrimental effect on fisheries. The Nordic countries proposed to phase-out all sea disposal by January 1, 1990, to provide time necessary to find an alternative means of disposal. Owing to concerns stemming from scientific uncertainties and social protest over dumping at the Northeast Atlantic Dumpsite, the Spanish delegation submitted a draft resolution to suspend ocean dumping operations until the necessary research and evaluation was completed. A compromise resulted between those positions and others that favored continued dumping, calling for a nonbinding suspension of nuclear waste dumping at sea until examination of the issue by an international group of scientists with expertise in such areas as ecology, oceanography, radiological protection, marine chemistry, and mathematical modeling. (By Article 15 of the LDC, all decisions or amendments to the Convention must be based on technical and scientific information.) Contracting parties to the LDC called upon the IAEA and its secretariat, the International Maritime Organizaton (IMO), to collect the scientific data and information and to present a status report at the February 1984 consultative meeting.[27]

Although the moratorium resolution adopted at the seventh consultative meeting is not legally binding, several nations indicated that it should be viewed as morally binding. Other countries annóunced their intention to proceed with dumping activities in the summer of 1983. However, no sea disposal of radioactive waste occurred in 1983 because of national boycotts and protests that deterred transport of the wastes.[28]

The eighth consultative meeting of the contracting parties to the LDC was held in London in February 1984. At this meeting, the resolution suspending all radioactive waste dumping at sea was reaffirmed pending presentation of the final scientific and technical report in September 1985.[29]

Attention at the February 1984 meeting also focussed on the contentious issue of the legality of emplacement of high-level radioactive waste in the seabed. Some Contracting Parties believe high-level waste disposal is covered by the LDC and hence prohibited; others contend that seabed disposal of high-level waste is not covered by the LDC and therefore not prohibited. Although no consensus was reached among the parties on the issue, the session did conclude:

Without prejudice to the question of the applicability of the London Dumping Convention to disposal of high-level radioactive wastes or other high-level radioactive matter into the sea-bed, the Consultative Meeting arrived at a consensus on the following:

1. *The Consultative Meeting of the Contracting Parties to the London Dumping Convention is the appropriate international forum to address the question of the disposal of high-level radioactive wastes and matter into the sea-bed, including the question of compatibility of this type of disposal with the provisions of the London Dumping Convention;*
2. *No such disposal should take place unless and until it is proved to be technically feasible and environmentally acceptable, including a determination that such wastes and matter can be effectively isolated from the marine environment, and a regulatory mechanism is elaborated under the London Dumping Convention to govern the disposal into the sea-bed of such radioactive wastes and matter.*[30]

Another international treaty that could affect ocean disposal of radioactive materials is the *Convention on the Law of the Sea* (LOS). Although the United States has decided not to sign the convention, it has been signed

by 132 nations and ratified by 11. The LOS treaty will govern the international marine affairs of those nations that ratify it once the convention has been ratified by 60 countries. During the discussions at the Third United Nations Conference on the Law of the Sea, the issue of radioactive waste disposal was not directly considered. The resultant treaty, however, does incorporate a sense of the now established environmental norms that all nations should protect the marine environment, and that they should be liable for any breach of this obligation.

The LOS Convention reflects this concern through Article 192 in which "States have the obligation to protect and preserve the marine environment." In addition, Article 194 declares that "States shall take...all measures...necessary to prevent, reduce and control pollution of the marine environment from any source...." Articles 232 and 235 assert that States are liable for pollution damages caused by them, and that States are required to ensure that prompt and adequate compensation will be paid for losses resulting from pollution.

By Article 56, nations have jurisdiction within their exclusive economic zones to protect and preserve the marine environment. It is not clear how the development of such extended coastal State jurisdiction over large areas of the ocean will eventually affect ocean dumping or effluent discharges from nuclear reprocessing facilities. However, ratifying States must endeavor to establish global and regional rules concerning control of marine pollution, acting especially through competent international organizations or diplomatic conference. Because "competent international organizations or diplomatic conference" can reasonably be interpreted to include the IAEA and the LDC, it is likely that the provisions of these or similar agreements will become binding on all nations that are party to the LOS Convention. Because the jurisdiction of the LDC extends through the EEZ and territorial sea, widespread adoption of the LOS Convention will probably contribute to international efforts to control ocean dumping of radioactive wastes, even in the EEZs.

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As the authors indicate, by combining the responsibilities for promoting and regulating nuclear power within a single agency, the 1954 Atomic Energy Act created an inherent conflict of interest. In 1974, Congress passed the Energy Reorganization Act (Public Law 93-438, 88 Stat. 1233), which abolished the Atomic Energy Commission (AEC) and formed the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC). ERDA assumed AEC's promotional functions, and the NRC was given responsibility for regulating nuclear facilities and licenses. In 1977, ERDA was abolished as an independent agency; its activities were absorbed into the Department of Energy.

A listing of the evolution of federal agency responsibilities for nuclear activities is given in Appendix I.

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Note: Monitoring in this report will be considered in the context of the definition set at the Fifth Consultative Meeting of the London Dumping Convention:

> Monitoring is the assessment of changes in the marine environment caused by dumping operations. This comprises two components:
>
> 1. Monitoring for the purposes of surveillance of the marine environment is meant as the assessment of the spatial and temporal changes in the distribution, fates and effects of contaminants introduced by specific dumping operations; and
> 2. Monitoring as part of *scientific investigation* and research programs is aimed at increasing knowledge of the processes that control the transport, fate and effects of contaminants released to the marine environment through dumping.

[17] Dyer, Robert S. 1981. A Review of Field Studies at United States Dump Sites. *In* Thomas C. Jackson (editor), Nuclear Waste Management. The Ocean Alternative. The Pergamon Press, New York, p. 38.

[18] Sjoblom and Johnson, *op. cit.*

[19] Queneudec, Jean-Pierre. 1982. The Effects of Changes in the Law of the Sea on Legal Regimes Relating to the Disposal of Radioactive Waste in the Sea. Unpublished Paper, Nuclear Energy Agency, Organization for Economic Cooperation and Development, Paris, France, 25 p.

[20] International Atomic Energy Agency. 1961. Radioactive Waste Disposal into the Sea. Safety Series No. 5, Vienna, Austria.

[21] Moore, Gerald. 1976. Legal aspects of marine pollution control. *In* R. Johnson (editor), Marine Pollution, Academic Press, New York, p. 623.

[22] Dyer, *op. cit.*, p. 13.

The following nations are party to the *Multilateral Consultation and Surveillance Mechanism for Sea Dumping of Radioactive Waste:* Belgium, Canada, Denmark, Finland, France, the Federal Republic of Germany, Greece, Ireland, Italy, Japan, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

[23] Curtis, Clifton E. 1983. Statement of Clifton E. Curtis on behalf of the Clean Water Action Project, Critical Mass Energy Project, The Farallon Foundation, Friends of the Earth, Greenpeace, U.S.A., Hudson River Sloop Clearwater, Inc., Natural Resources Defense Council, U.S. Nuclear Free Pacific Network, Nuclear Information Resource Service, Oceanic Society, Palmetto Alliance, Scenic Shoreline Preservation Conference, Sierra Club, Southwest Research and Information Center, Union of Concerned Scientists, United Methodist Church Joint Law of the Sea Project, and The Wilderness Society. *In* Radioactive Waste Disposal Oversight Hearings (November 2) before the Subcommittee on Oceanography of the Committee on Merchant Marine and Fisheries, 98th Congress, Serial No. 98-26, Washington, D.C., p. 604-638.

[24] International Atomic Energy Agency. 1978. *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter.* The Definition Required by Annex I, paragraph 6 to the Convention, and the Recommendations Required by Annex II, section D. Information Circular/205/Add. 1/Rev. 1, Vienna, Austria, 26 p.

[25] Templeton, William. 1983. Presentation (March 7) before the National Advisory Committee on Oceans and Atmosphere, Washington, D.C.

[26] International Atomic Energy Agency. 1979. Considerations Concerning *"De Minimis"* Quantities of Radioactive Waste Suitable for Dumping at Sea Under a General Permit. IAEA-TECDOC-244, Vienna, Austria, 25 p.

[27] International Maritime Organization. 1983. Report of the Seventh Consultative Meeting of Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 14-18 February 1983. London, p. 19-31, Annex 6.

[28] Curtis, Clifton E., *op. cit.*, p. 620-623.

[29] International Maritime Organization. 1984. Report of the Eight Consultative Meeting of Contracting Parties to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 20-24 February 1984. London, p. 17-22.

The parties agreed to the following timetable for the scientific and technical review process:

1. Nomination of experts by 13 April 1984.
2. Meeting and preparation of the report by expert panel by 31 October 1984.
3. Circulation of the report by 30 November 1984.
4. Submission of scientific and technical comments to Secretariat by 29 March 1985.
5. Expanded meeting and preparation of the final report at IMO Headquarters by 30 April 1985.
6. Circulation of final report by 28 June 1985.
7. Ninth Consultative Meeting, 30 September 1985.

[30] *Ibid.*, p. 22-31.

ATTACHMENT 1

Amendments to Section 104 of the Marine Protection, Research and Sanctuaries Act of 1972 Public Law 97-424

Effective date. 15 USC 713c-3 note.

OCEAN DUMPING

SEC. 424. (a) Section 104 of the Marine Protection, Research, and Sanctuaries Act of 1972 (33 U.S.C. 1431(b)) is amended by adding the following new subsections at the end thereof:

33 USC 1414.

Permit issuance. 33 USC 1414.

"(h) Notwithstanding any provision of title I of the Marine Protection, Research, and Sanctuaries Act of 1972 to the contrary, during the two-year period beginning on the date of enactment of this subsection, no permit may be issued under such title I that authorizes the dumping of any low-level radioactive waste unless the Administrator of the Environmental Protection Agency determines—

"(1) that the proposed dumping is necessary to conduct research—

"(A) on new technology related to ocean dumping, or

"(B) to determine the degree to which the dumping of such substance will degrade the marine environment;

"(2) that the scale of the proposed dumping is limited to the smallest amount of such material and the shortest duration of time that is necessary to fulfill the purposes of the research, such that the dumping will have minimal adverse impact upon human health, welfare, and amenities, and the marine environment, ecological systems, economic potentialities, and other legitimate uses;

"(3) after consultation with the Secretary of Commerce, that the potential benefits of such research will outweigh any such adverse impact; and

"(4) that the proposed dumping will be preceded by appropriate baseline monitoring studies of the proposed dump site and its surrounding environment.

Each permit issued pursuant to this subsection shall be subject to such conditions and restrictions as the Administrator determines to be necessary to minimize possible adverse impacts of such dumping.

Radioactive Material Disposal Impact Assessment.

"(i)(1) Two years after the date of enactment of this subsection, the Administrator may not issue a permit under this title for the disposal of radioactive waste material until the applicant, in addition to complying with all other requirements of this title, prepares, with respect to the site at which the disposal is proposed, a Radioactive Material Disposal Impact Assessment which shall include—

"(A) a listing of all radioactive materials in each container to be disposed, the number of containers to be dumped, the structural diagrams of each container, the number of curies of each material in each container, and the exposure levels in rems at the inside and outside of each container;

"(B) an analysis of the environmental impact of the proposed action, at the site at which the applicant desires to dispose of the material, upon human health and welfare and marine life;

"(C) any adverse environmental effects at the site which cannot be avoided should the proposal be implemented;

"(D) an analysis of the resulting environmental and economic conditions if the containers fail to contain the radioactive waste material when initially deposited at the specific site;

"(E) a plan for the removal or containment of the disposed nuclear material if the container leaks or decomposes;

"(F) a determination by each affected State whether the proposed action is consistent with its approved Coastal Zone Management Program;

"(G) an analysis of the economic impact upon other users of marine resources;

"(H) alternatives to the proposed action;

Consultation and public hearing results.

"(I) comments and results of consultation with State officials and public hearings held in the coastal States that are nearest to the affected areas;

"(J) a comprehensive monitoring plan to be carried out by the applicant to determine the full effect of the disposal on the marine environment, living resources, or human health, which plan shall include, but not be limited to, the monitoring of exterior container radiation samples, the taking of water and sediment samples, and fish and benthic animal samples, adjacent to the containers, and the acquisition of such other information as the Administrator may require; and

Comprehensive monitoring plan.

"(K) such other information which the Administrator may require in order to determine the full effects of such disposal.

"(2) The Administrator shall include, in any permit to which paragraph (1) applies, such terms and conditions as may be necessary to ensure that the monitoring plan required under paragraph (1)(J) is fully implemented, including the analysis by the Administrator of the samples required to be taken under the plan.

"(3) The Administrator shall submit a copy of the assessment prepared under paragraph (1) with respect to any permit to the Committee on Merchant Marine and Fisheries of the House of Representatives and the Committee on Environment and Public Works of the Senate.

Assessment, copy to congressional committees.

"(4) (A) Upon a determination by the Administrator that a permit to which this subsection applies should be issued, the Administrator shall transmit such a recommendation to the House of Representatives and the Senate.

Recommendation to Congress.

"(B) No permit may be issued by the Administrator under this Act for the disposal of radioactive materials in the ocean unless the Congress, by approval of a resolution described in paragraph (D) within 90 days of continuous session of the Congress beginning on the date after the date of receipt by the Senate and the House of Representatives of such recommendation, authorizes the Administrator to grant a permit to dispose of radioactive material under this Act.

Ocean dumping permit, restricted issuance.

"(C) For purposes of this subsection—

"(1) continuity of session of the Congress is broken only by an adjournment sine die;

"(2) the days on which either House is not in session because of an adjournment of more than three days to a day certain are excluded in the computation of the 90 day calendar period.

"(D) For the purposes of this subsection, the term 'resolution' means a joint resolution, the resolving clause of which is as follows: 'That the House of Representatives and the Senate approve and authorize the Administrator of the Environmental Protection Agency to grant a permit under the Marine Protection, Research, and Sanctuaries Act of 1972 to dispose of radioactive materials in the ocean as recommended by the Administrator to the Congress on _____, 19__.'; the first blank space therein to be filled with the appropriate applicant to dispose of nuclear material and the second blank therein to be filled with the date on which the Administrator submits the recommendation to the House of Representatives and the Senate.".

"Resolution."

33 USC 1401 note.

CHAPTER IV
Marine Radioactivity

For the past 25 years, oceanographers have obtained considerable information about marine radionuclides and about the oceanic processes—physical, chemical, biological, and geological—that influence them. This information can be applied to the issue of radioactive waste disposal. This chapter summarizes our present understanding of the sources and fate of marine radionuclides and the mechanisms for human exposure to oceanic radioactivity. In addition, this chapter identifies some other areas requiring more research and greater understanding.

Sources of Oceanic Radioactivity

The Periodic Table of Chemical Elements provides a framework for relating radionuclides to each other and to their chemical properties. Figure IV-1 (a modified version of the Periodic Table) identifies some of the important radionuclides in the marine environment and their sources: primordial radionuclides generated from decay of primordial isotopes; radionuclides produced by cosmic rays; or radionuclides produced by humans (anthropogenic). Elements in the table that indicate an atomic mass are radioactive, and those with only a chemical symbol are essentially stable. For the known 104 chemical elements, about 1,400 radioactive nuclides have been identified, although many of these nuclides have very short half-lives (i.e., less than an hour).[1] Because only those with moderate to long half-lives are important in natural systems, about 60 radionuclides are significant. About half of these occur naturally; the other half are anthropogenically produced.

It is useful to consider radioactive waste disposal in the context of the existing natural marine radioactivity. Primordial radioactive elements were present during the Earth's formation; these that are still with us must have half-lives that are comparable to the age of the Earth or the universe (5 or 9 billion years). Upon decay, these primordial elements generate radioactive daughter products that exhibit a wide range of chemical and radioactive characteristics. In addition, about 10 important radionuclides, which are generated by the interaction of cosmic rays with gas molecules in the Earth's upper atmosphere, are transported to the oceans, the biosphere, and land.

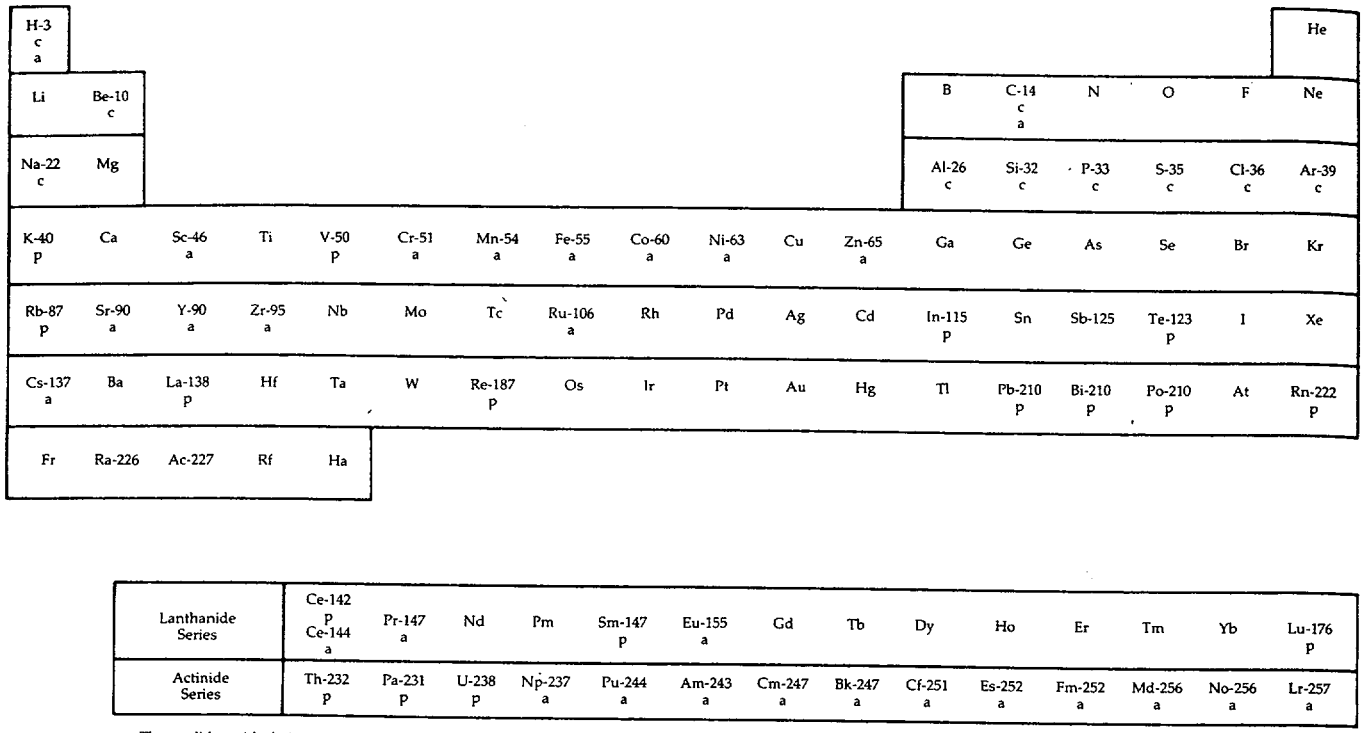
Primordial and cosmic ray-induced radionuclides have been sources of marine radioactivity throughout biological evolution. To these natural sources, however, humans have introduced a variety of additional sources of radioactivity called anthropogenic radioactivity.

The Primordial Elements and Radioactivity

Chemical elements were formed through a series of thermonuclear reactions that generated a wide range of stable and unstable nuclides. A stable atom has a certain proportion of protons and neutrons in its nucleus. For the lower mass elements, this proportion tends to be about an equal number, for the heavier nuclides the number of neutrons generally exceeds the number of protons. Without this favorable proportion, an element will be radioactive and will emit radiation to become stable. This process is known as radioactive decay. An element undergoes this process at a characteristic rate—known as its half-life—which characterizes the time of decay for half of the atoms of a given radionuclide. (A brief description of this process is found in Appendix A.)

Early in the history of the universe, there were undoubtedly a large number of primordial radioactive elements. But after billions of years, many of those radionuclides have virtually all decayed. Today we are left with only those that have very long half-lives and with their decay products. On human time-scales, the Earth's quantity of the remaining nuclides is essentially constant. There is no present source to renew them, and their decrease in the future will be determined by their half-lives, which are very long on human time scales. Thus, the radioactivity they produce will not diminish significantly.

It is useful to separate the primordial radionuclides into two groups: 1) those that decay directly to a stable product; and 2) those that generate a series of daughter products spanning a range of chemical elements each with a distinctive behavior in the marine environment. Table IV-1 lists the first group. The radioactivity



The nuclides with their atomic mass shown are radioactive. For elements with more than one principal nuclide, the one with the longest half-life is shown. The letters beneath each nuclide indicate their sources: p = primordial; c = cosmic ray produced; and a = anthropogenic.

Figure IV-1.—Periodic Table of Elements.

Source: Kester, Dana R. 1983. Graduate School of Oceanography, University of Rhode Island, Kingston, Rhode Island.

Table IV-1.—Primordial Radionuclides that Decay Directly to Stable Products

Radionuclide	*Half-life (years)*	*Type of Decay*
^{40}K (potassium)	1.28×10^{9}	beta, EC[1]
^{50}V (vanadium)	6×10^{15}	beta, EC
^{87}Rb (rubidium)	4.8×10^{10}	beta
^{115}In (indium)	5.1×10^{14}	beta
^{123}Te (tellurium)	1.2×10^{13}	EC
^{138}La (lanthanum)	1.1×10^{11}	beta, EC
^{142}Ce (cerium)	5×10^{15}	alpha
^{147}Sm (samarium)	1.1×10^{11}	alpha
^{176}Lu (lutetium)	3.6×10^{10}	beta
^{187}Re (rhenium)	4×10^{10}	beta

[1] EC—electron capture mode of decay.

Data from: Friedlander, G., J.W. Kennedy, and J.M. Miller. 1964. Nuclear and Radiochemistry. John Wiley & Sons, New York, 585 p.

resulting from each isotope is directly proportional to its abundance, and is inversely proportional to its half-life. Those with exceptionally long half-lives (e.g., greater than 10^{12} years) decay slowly and consequently contribute very little to natural terrestrial radioactivity. The types of radiation emitted by the first group of nuclides include alpha particles, beta particles, and the gamma rays and X-rays that result from the electron capture mode of decay. Of the primordial radionuclides listed in Table IV-1, potassium-40 and rubidium-87 are the most important contributors of natural radioactivity to the ocean.

The second group of primordial radionuclides consists of three nuclides (thorium-232, uranium-235, and uranium-238), each of which initiates a complex series of decay products ending with stable isotopes of lead. Table IV-2 lists primary components of these three series.

The chemical elements in these series have a wide range of marine geochemistries. The concentration of uranium is relatively uniform in the ocean and the element does not adsorb strongly onto particles. Thorium, protactinium, polonium, and lead tend to adsorb onto particles and become enriched in marine sediment. Radium is relatively soluble in seawater. After radium is generated from the decay of thorium in sediment, it enters an aqueous phase and diffuses out into seawater. Radon, produced from the decay of radium, is an inert gas that can be transferred to the atmosphere.

Cosmic Ray-Produced Radionuclides

Cosmic rays are high-energy atomic nuclei of galactic origin, consisting primarily of protons (86%) and helium nuclei (13%), with small amounts of heavier

Table IV-2.—Decay Series Initiated by Three Primordial Radionuclides Showing the Daughter Products with Half-lives Greater than One Day

Nuclide	*Half-life*	*Type of Decay*
Uranium-238 series		
^{238}U (uranium)	4.47 x 10^9 years	alpha
^{234}Th (thorium)	24.1 days	2 beta
^{234}U (uranium)	2.45 x 10^5 years	alpha
^{230}Th (thorium)	8.0 x 10^4 years	alpha
^{226}Ra (radium)	1,600 years	alpha
^{222}Rn (radon)	3.8 days	3 alpha, 2 beta
^{210}Pb (lead)	22.3 years	beta
^{210}Bi (bismuth)	5.01 days	beta
^{210}Po (polonium)	138 days	alpha
^{206}Pb (lead)	stable	——
Uranium-235 series		
^{235}U (uranium)	7.1 x 10^8 years	alpha
^{231}Th (thorium)	25.5 hours	beta
^{231}Pa (protactinum)	3.48 x 10^4 years	alpha
^{227}Ac (actinium)	21.8 years	beta
^{227}Th (thorium)	18.7 days	alpha
^{223}Ra (radium)	11.4 days	4 alpha, 2 beta
^{207}Pb (lead)	stable	——
Thorium-232 series		
^{232}Th (thorium)	1.41 x 10^{10} years	alpha
^{228}Ra (radium)	5.76 years	2 beta
^{228}Th (thorium)	1.9 years	alpha
^{224}Ra (radium)	3.66 days	4 alpha, 2 beta
^{208}Pb (lead)	stable	——

Note: Decay proceeds in the sequence listed for each series.
Source: Adapted from: Friedlander, G., J. W. Kennedy, and J.M. Miller. 1964. Nuclear and Radiochemistry. John Wiley & Sons, New York, 585 p.
Consult this source for a more complete representation of these decay series.

nuclei—all of which are accelerated to very high energy by interstellar magnetic fields. Solar flare activity also contributes to the cosmic ray flux received by the Earth.

When these rays collide with gas molecules in the upper atmosphere they produce neutrons, protons, and alpha particles. These secondary particles then initiate nuclear reactions that produce radioactive nuclei, notably hydrogen-3 (tritium) and carbon-14. (Table IV-3 lists the cosmic ray produced radionuclides and their half-lives.) Other sources of radioactive nuclides are the spallation of heavy atmospheric constituents (e.g., argon), and entry to the atmosphere of interplanetary dust (e.g., aluminum-26). Because radionuclides are being produced continuously in the upper atmosphere, their concentration at the Earth's surface approaches a steady state between the rate of production and the rates of removal and decay. Their half-lives are short compared to the age of the Earth. They have been extremely useful in radioactive age-dating, particularly carbon-14 which becomes incorporated into living organisms and thus provides a means of dating organic remains over the range of hundreds to tens of thousands of years.

Table IV-3.—Radionuclides Produced in the Upper Atmosphere by Cosmic Rays

Radionuclide	*Half-life*	*Type of Decay*
^{3}H (hydrogen; tritium)	12.3 years	Beta
^{7}Be (beryllium)	53.3 days	EC[1]
^{10}Be (beryllium)	1.6 x 10^6 years	Beta
^{14}C (carbon)	5,730 years	Beta
^{22}Na (sodium)	2.60 years	Beta, EC
^{26}Al (aluminum)	7.4 x 10^5 years	Beta
^{32}Si (silicon)	650 years	Beta
^{32}P (phosphorus)	14.3 days	Beta
^{33}P (phosphorus)	25.3 days	Beta
^{35}S (sulfur)	87 days	Beta
^{36}Cl (chlorine)	3 x 10^5 years	Beta
^{37}Ar (argon)	35 days	EC
^{39}Ar (argon)	269 years	Beta

[1] EC—electron capture mode of decay.
Source: Friedlander, G., J.W. Kennedy, and J.M. Miller. 1964. Nuclear and Radiochemistry. John Wiley & Sons, New York, 585 p.

Figure IV-2 shows the concentrations of the major radionuclides in seawater. Potassium-40 accounts for more than 90 percent of the radioactivity in seawater. The relative abundance of radionuclides in seawater and in marine sediments is illustrated by comparing Figure IV-3 with Figure IV-2. Potassium-40 is important in sediments as well as in seawater, but there are also a large number of other radionuclides that contribute to the total radioactivity of sediments.

Table IV-4 lists the characteristics of significant anthropogenic radionuclides. Of these, the transu-

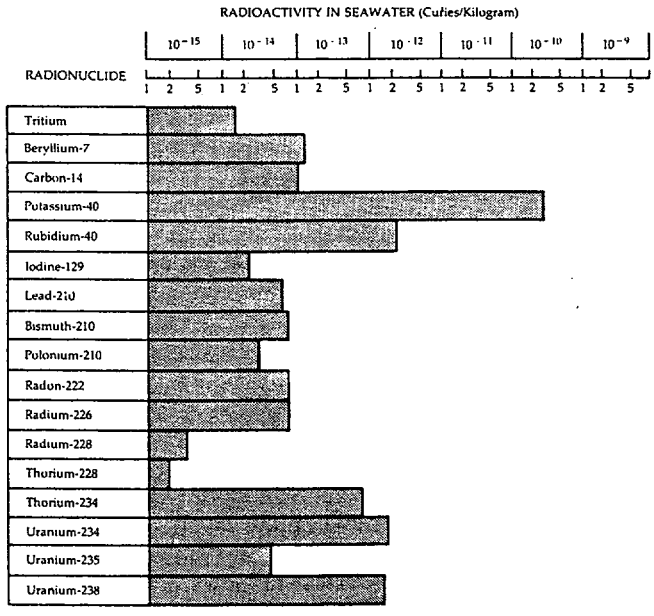


Figure IV-2.—Concentrations of Major Radionuclides in Seawater.

Source: Kester, Dana R. 1983. Graduate School of Oceanography, University of Rhode Island, Kingston, Rhode Island.

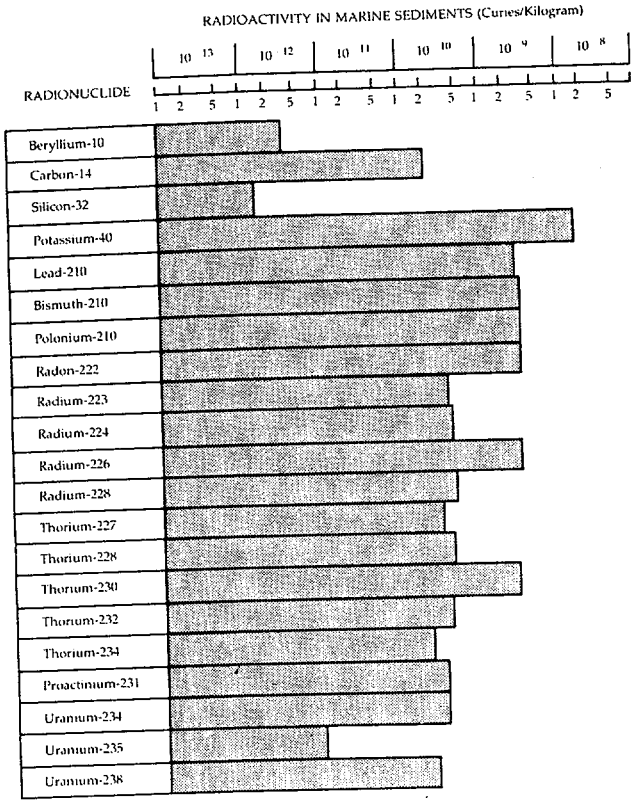


Figure IV-3.—Concentrations of Major Radionuclides in Marine Sediments.

Source: Kester, Dana R. 1983. Graduate School of Oceanography, University of Rhode Island, Kingston, Rhode Island. Adapted from: Park *et al.* 1983. Radioactive Wastes and the Ocean: An Overview. *In* Park *et al.* (editors), Wastes in the Ocean. Volume 3. John Wiley & Sons, New York, p. 23-25.

ranic nuclides are noteworthy, because each of the lower transuranic elements (neptunium, plutonium, americium, curium, berkelium, and californium) have one or more nuclides with half-lives ranging from one hundred to ten million years. Thus, they are capable of persisting in the marine environment for a long time.

The Fate of Radionuclides in the Ocean

A variety of oceanic processes determine the fate of radioactive substances: physical dispersion and advection, isotopic dilution with stable nuclides of the same element or with isotopic analogs of chemically similar elements, marine chemical cycles, adsorption onto suspended particles, and uptake and transfer through the marine food web—with possible transfer to humans. Marine sediments also play a very important role in the fate of radionuclides, because they become a repository for some elements and a site of release to the ocean for other elements.

Table IV-4.—Anthropogenic radionuclides from fission and neutron activation products

Radionuclide	*Half-life*	*Type of Decay*
Fission Products		
^{89}Sr (strontium)	51 days	Beta
^{90}Sr (strontium)	28 years	Beta
^{91}Y (yttrium)	58.1 days	Beta
^{95}Zr (zirconium)	65 days	Beta
^{103}Ru (ruthenium)	40 days	Beta
^{106}Ru (ruthenium)	368 days	Beta
^{125}Sb (antimony)	2.7 years	Beta
^{137}Cs (cesium)	30 years	Beta
^{141}Ce (cerium)	33 days	Beta
^{144}Ce (cerium)	282 days	Beta
^{147}Pr (praeseodymium)	2.6 years	Beta
^{155}Eu (europium)	4.9 years	Beta
Neutron Activation Products		
^{3}H (hydrogen; tritium)	12.3 years	Beta
^{14}C (carbon)	5,730 years	Beta
^{32}P (phosphorus)	14.3 days	Beta
^{35}S (sulfur)	87 days	Beta
^{46}Sc (scandium)	84 days	Beta
^{51}Cr (chromium)	28 days	EC[1]
^{54}Mn (manganese)	300 days	EC
^{55}Fe (iron)	2.6 years	EC
^{59}Fe (iron)	45 days	Beta
^{57}Co (cobalt)	270 days	EC
^{58}Co (cobalt)	72 days	EC
^{60}Co (cobalt)	5.26 years	Beta
^{63}Ni (nickel)	92 years	Beta
^{65}Zn (zinc)	246 days	EC

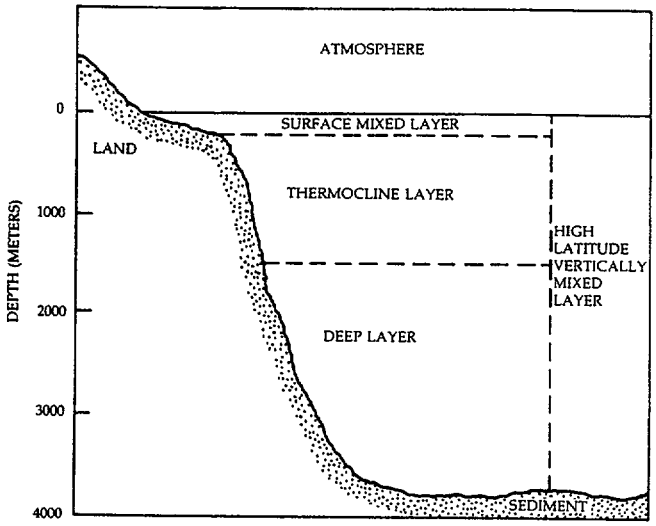
[1] EC—Electron capture mode of decay.

Adapted from: Burton. J.D. 1975. Radioactive Nuclides in the Marine Environment. *In* J.P. Riley and G. Skirro (editors), Chemical Oceanography. Volume 3, Academic Press Inc., London, p. 91-191.
Friedlander, G., J.W. Kennedy, and J.M. Miller. 1964. Nuclear and Radiochemistry. John Wiley & Sons, New York, 585 p.

Dispersion and Advection

Oceanic dispersion and advection dilute concentrations of substances away from their sources and transport material throughout the world's ocean. These processes range in scale from tens of meters to thousands of kilometers. An important oceanic feature in the physical distribution of material is the main thermocline, where density increases downward at depths ranging from about 200 to 1,500 meters, with depth and gradient depending primarily on location, season, and storms. This thermocline is present in nearly all regions of the ocean except high latitudes, where extensive cooling by the atmosphere leads to mixing of ocean waters to depths of several thousand meters.

To simplify the concept of ocean transport processes, the ocean can be featured as four boxes (Figure IV-4): a surface mixed layer, a deep mixed layer, a thermocline layer of restricted mixing, and a high latitude layer that is vertically mixed throughout its entire depth range. This simplified model accounts for many aspects of ocean transport processes over periods of years, because seasonal effects which vary latitudinally



*The relative sizes of the boxes in this illustration do not correspond to their relative volumes in the ocean.

Figure IV-4.—Schematic Box Model of the Ocean.

Source: Kester, Dana R. 1983. Graduate School of Oceanography, University of Rhode Island, Kingston, Rhode Island.

in the surface mixed layer are averaged. The rate at which a substance will be diluted by dispersion and transported by advection will depend on which of the four "boxes" it enters. Present research suggests the rates are greatest in the surface mixed layer and next in the high latitude box; they are smallest in the thermocline and the deep layer. A typical time scale for exchange of waters among the four boxes through the Atlantic, Indian, Pacific, Antarctic, and Arctic Oceans is on the order of a thousand years.

Consider the sources and fates of radionuclides in these boxes: Cosmic ray-produced nuclides and radioactive fallout from atmospheric nuclear weapons testing both enter the ocean in the surface mixed box and the high latitude vertically mixed box (e.g., tritium, carbon-14, and strontium-90). Physical processes then distribute these nuclides within and among the boxes. For many of the primordial radionuclides and their progeny, entry to the ocean can be directly into the deep ocean box or at the continental boundaries. For example, radium enters the deep ocean water from marine sediments, or uranium is eroded from the land and washed into the ocean by rivers.

Chemical Cycles in the Ocean

One of the most rapid mechanisms for transporting radionuclides among the boxes is through oceanic chemical cycles, which generally combine the effects of the elements' specific chemical behavior, their participation in geochemical processes, and their incorporation into marine organisms. Many chemicals in the ocean are depleted in the upper waters where they are taken up by marine organisms. They are regenerated back to the water column by organic degradation processes at mid-depths or at the seafloor.

One type of chemical cycling is through marine biota, which can vertically transfer substances from the surface mixed box into the thermocline and deep layer boxes by gravitational sinking of particles or by vertical migration of organisms. The cycle is completed by mixing and advection processes that return the chemicals from the deeper boxes back to the surface box on time scales of hundreds of years. Two examples are the major marine phytoplankton nutrients, phosphate and nitrate, which are reduced to low concentrations in the surface waters of the ocean (the upper 50 to 150 meters) because of uptake by plants, and regenerated at mid-depths (300 to 1500 meters) by the degradation of organic material. Another example is silica, which is depleted in surface waters but regenerated principally at the seafloor. The difference between silica and phosphate or nitrate is that the latter two are incorporated mainly into the organic tissues of organisms, whereas silica is used to form the hard skeletal material of some organisms. Furthermore, silica redissolves back into seawater at a slower rate than the microbial degradation of the organic material.

A second type of chemical cycling occurs through marine sediments, where particulate material and dissolved constituents in seawater undergo a variety of chemical reactions that can either release substances to the ocean or can incorporate them into solid phases. One example is the formation of manganese nodules on the seafloor.

An important feature of marine chemical cycles is *isotopic dilution* of radionuclides. Chemical processes, even by biota, treat all nuclides of a chemical element similarly. Thus, the fact that (radioactive) strontium-90 has two more neutrons in its nucleus than does the most abundant stable isotope strontium-88 makes very little difference in the chemical reactivity of these nuclides. One difference is that nuclides having smaller atomic mass can react a bit faster than their heavier counterparts. This advantage is proportional to the difference in mass, which, in the example of strontium, is a difference of about 2 percent and 5 percent in carbon. Although these differences can cause measurable differences in chemical and biochemical reaction rates, and even can allow for some fractionation of isotopes of the same element, in general isotopes of the same element are chemically very similar. Consequently, when a radionuclide enters the ocean, it becomes not only physically diluted by dispersion but also isotopically diluted by the stable forms of that element already in seawater. If a thousand atoms of strontium-90 enter a volume of seawater that contains a million atoms of stable strontium, and a marine organism incorporates some of the strontium into its

tissue or skeletal parts, the organism will never have more than 0.1 percent of its strontium in the radioactive form. (This assumes that both isotopes are in the same chemical form and that the water is well mixed.)

Radioactive Marine Sediments

A radionuclide will accumulate in marine sediments according to the nature of the solid phases in the sediment and according to the geochemical behavior of the nuclide considered. Table IV-5 summarizes the radioactivity levels of principal nuclides in some marine sediments.

Table IV-5.—Concentration and Radioactivity of Nuclides With Half-lives Greater Than One Day in Marine Sediments

Radionuclide	*Half-life*	*g per kg*	*Curie per kg*
^{10}Be (beryllium)	1.6×10^{6} years	1.5×10^{-10}	3.4×10^{-12}
^{14}C (carbon)	5,730 years	0.5×10^{-10}	2.2×10^{-10}
^{32}Si (silicon)	650 years	1×10^{-13}	1.7×10^{-12}
^{40}K (potassium)	1.28×10^{9} years	2.6×10^{-3}	1.8×10^{-8}
^{210}Pb (lead)	22.3 years	4.5×10^{-11}	3.4×10^{-9}
^{210}Bi (bismuth)	5.01 days	3.1×10^{-14}	3.8×10^{-9}
^{210}Po (polonium)	138 days	8.8×10^{-13}	4.0×10^{-9}
^{222}Rn (radon)	3.8 days	2.5×10^{-14}	3.9×10^{-9}
^{223}Ra (radium)	11.4 days	8.5×10^{-15}	4.4×10^{-10}
^{224}Ra (radium)	3.66 days	3.4×10^{-15}	5.4×10^{-10}
^{226}Ra (radium)	1,600 years	4.0×10^{-9}	4.0×10^{-9}
^{228}Ra (radium)	5.76 years	2.3×10^{-12}	6.3×10^{-10}
^{227}Th (thorium)	18.7 days	1.3×10^{-14}	4.0×10^{-10}
^{228}Th (thorium)	1.51 years	7.0×10^{-13}	5.8×10^{-10}
^{230}Th (thorium)	8.0×10^{4} years	2.0×10^{-7}	3.9×10^{-9}
^{232}Th (thorium)	1.41×10^{10} years	5.0×10^{-3}	5.5×10^{-10}
^{234}Th (thorium)	24.1 days	1.4×10^{-14}	3.2×10^{-10}
^{231}Pa (protactinium)	3.28×10^{4} years	1.0×10^{-8}	4.7×10^{-10}
^{234}U (uranium)	2.45×10^{5} years	8.1×10^{-8}	5.0×10^{-10}
^{235}U (uranium)	7.1×10^{8} years	7.1×10^{-6}	1.5×10^{-11}
^{238}U (uranium)	4.47×10^{9} years	1.0×10^{-3}	3.4×10^{-10}

Adapted from: Park, P. Kilho, Dana R. Kester, Iver W. Duedall, and Bostwick H. Ketchum. 1983. Radioactive Wastes and the Ocean: An Overview. *In* Park *et al.* (editors), Wastes in the Ocean. Volume 3. John Wiley & Sons, New York, p. 3-46.

A widely studied radionuclide has been uranium, whose geochemical behavior is fairly well known.[2] Generally, its concentration is relatively constant in clay minerals, which compose a major fraction of deep-sea sediments. This background concentration is altered in some areas of the ocean, depending on contributions from other sediment phases and the geochemical behavior of uranium associated with the formation of those phases. For example, calcium carbonate solid phases produced by marine organisms are low in uranium compared to clay minerals, and regions of the seafloor with high concentration of calcium carbonate have correspondingly less uranium. In other areas of the ocean where the sediments are influenced by hydrothermal activity (such as near the mid-ocean ridges and in regions of volcanic activity), there is an enrichment of uranium owing to its tendency to become extracted from seawater and incorporated into iron and manganese oxides.[3] Another notable aspect of uranium's marine geochemistry is its high concentrations in those sediments which have sufficient organic matter (and correspondingly low oxygen) that they are anoxic. Finally, some sediment phases that form chemically from seawater, such as manganese nodules and phosphorites, contain elevated concentrations of uranium.

Thorium, protactinium, lead, and polonium tend to accumulate and are enriched in sediments relative to seawater. Some of the radium generated by thorium decay, on the other hand, is released from marine sediments and becomes distributed throughout the ocean. Potassium-40 is a highly soluble constituent in the ocean, so that portion which occurs in marine sediments is tightly bound within the mineral lattice of the solids. Radon, which forms upon decay of radium, is an inert gas dissolved in seawater. Radon is also radioactive with a half-life of 3.8 days. At the sea surface radon escapes to the atmosphere, which contains very little radon, because it decays within a couple of weeks of entry to the atmosphere. Consequently, surface waters of the ocean are deficient in radon relative to their radium content, and this deficiency can be used to estimate the rate at which gases are exchanged between the ocean and atmosphere. An opposite effect of radon occurs near the seafloor. The radium content, and hence the radon content, in sediments is greater than that in seawater. There is a diffusion of radon from the sediment to the overlying waters, so that waters near the seafloor have more radon than would be expected based on their radium content. This excess radon decays with a 3.8 day half-life, and its measurement can provide a means of estimating the rate of mixing of waters near the seafloor. This use of radon could be especially important in evaluating the rate at which substances might be mixed away from a radioactive disposal site on the seafloor.

Hydrogen-3 (tritium), carbon-14, and silicon-32 enter the ocean from the atmosphere where they are formed by cosmic-ray interactions. In the ocean, they become components of the biologically cycled elements. They are transported vertically through the ocean with the flux of biogenic particles, and become incorporated into marine sediments and regenerated back to the water column through degradation and dissolution processes.

Tritium, a radioactive isotope of hydrogen, exists in the ocean as tritiated water molecules—one of the hydrogen atoms of the water molecule is replaced by a tritium atom. Consequently, tritium is highly diluted by seawater and its distribution is controlled by physical processes; it is not associated with marine sediments. As a form of water, tritium will participate in the

photosynthetic production of organic matter and in other biochemical processes, but it will be highly diluted by the large amount of ordinary water molecules available for these processes in the ocean.

Recent Advances in Ocean Science

Because of recent advancements in marine science, we are far better equipped today to address questions of disposal of radioactive materials in the ocean than we were 20 years ago. For example, the GEOSECS (Geochemical Ocean Sections Study) project sponsored by the National Science Foundation used radiotracers—tritium, radon, radium, and carbon-14—to better understand the dynamics of chemical and physical processes in major ocean basins.[4] In so doing, much information was gained regarding these nuclides.

The tritium story illustrates the global impact of human actions. Natural tritium from cosmic ray-induced reactions in the upper atmosphere yields a steady-state global inventory, estimated to be in the range of 3 to 7 kilograms. Atmospheric tests of nuclear weapons prior to 1963 added 100 kilograms of tritium to this global inventory, increasing tritium's inventory by a factor of 15 to 30. No evidence exists of any ecological impact resulting from such an increase, but oceanographers have utilized this alteration of the environment to learn about oceanic water transport rates. For example, GEOSECS has been able to trace the bomb-produced tritium in the upper 500 meters of the Atlantic Ocean and to depths greater than 4,000 meters in the North Atlantic (Figure IV-5).

Radon has been used to determine vertical ocean movement. Because of the short half-life of its most abundant isotope (3.8 days), radon gives information about transport processes that occur within time scales of up to two weeks. Radon measurements from GEOSECS revealed that the spatial extent of upward mixing waters above the seafloor varies greatly. In one Pacific Ocean location, the waters 400 meters above the seafloor had radon concentrations indicating recent contact with the seafloor.[5]

The use by GEOSECS of carbon-14 has helped in understanding the pathways of organic and inorganic carbon through the ocean. As with tritium, significant quantities of carbon-14 were produced by atmospheric tests of nuclear weapons. All of the radioactive carbon has long since decayed in such fossil fuels as petroleum, coal, and natural gas. Thus, the burning of fossil fuels reduces the ratio of carbon-14 to stable carbon-12 in the atmosphere. One of the main lessons from carbon-14 is that while it provides information about the rates of organic production cycles and deep circulation in the sea, the reading of this "radiochemical clock" is not a simple matter. It requires a complete understanding of the pathways and processes involving organic and inorganic carbon in the ocean.

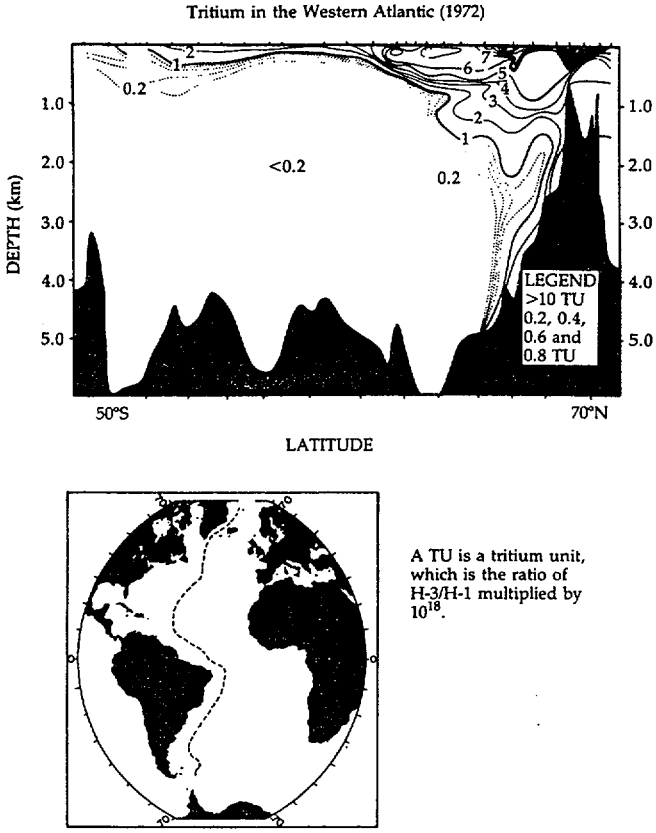


Figure IV-5.—Tritium Concentration in the Atlantic Ocean from North of Ireland to the Falkland Islands.

Source: Ostlund, M.G., and R.A. Fine. 1979. Oceanic Distribution and Transport of ^{3}H. *In* Behavior of ^{3}H in the Environment. International Atomic Energy Agency, Vienna, Austria, p. 303-304.

Use of these tracers has revealed two interesting points. First, the ocean, particularly the deep ocean, is a more dynamic environment than most oceanographers would have believed a decade ago. Second, the chemical nature of radionuclides, not the fact that they are radioactive, is a more important factor in determining their fates in the ocean. This latter point appears to be ignored by the practice of reporting and monitoring radioactive wastes placed into the ocean solely in terms of alpha and beta/gamma radioactivity. From that information, one cannot know the half-life of the radiation and hence the time scale of its importance nor can one make estimates about a nuclide's geochemical, physical, or biological cycling and transport in the sea.

Many of the anthropogenic radionuclides are metals such as strontium, cesium, iron, and zinc. Most naturally occurring metals are at very low concentrations in the marine environment and are affected to varying degrees by biological processes, hydrographic or oceanic water mass variations, and by sediment

release.[6] Chemical studies of marine metals show that their chemistry is influenced by the formation of complexes with inorganic and organic substances in seawater, by their adsorption onto particles suspended in the ocean, and, in some cases, by the solubility of solid phases. Such chemical reactions influence the metal's availability for incorporation by marine organisms,[7] and determine the conditions under which some metals can be toxic to marine organisms.

The mixing of water (and hence of radionuclides) appears to be both more complex and more dynamic than was believed 20 years ago. The Gulf Stream and other major currents are continuously throwing off rings and eddies, some more than 100 miles in diameter. Other types of eddies have been found in the central ocean basin and at varying depths. These phenomena have proved to be far more common than had been first anticipated. Because rings and eddies may be a major oceanic stirring mechanism, their passage through a radioactive waste dumpsite could influence the transport of radionuclides to a substantially greater degree than would be predicted based on average rates of oceanic mixing and advection.[8]

Hydrothermal vents are the most recent example that the ocean is still capable of providing new, important, and unexpected discoveries. These vents, or locations where hot water is streaming out of rocks in the seafloor, occur along the mid-ocean ridge in the eastern equatorial and the north Pacific Ocean. Recent chemical studies reveal that the hot water from these vents is seawater seeping along cracks in the rocks of the mid-ocean ridge that becomes heated by local geothermal heat fluxes. Chemical reactions occur between the seawater and the hot rocks, so that the water's chemical composition is considerably altered. Geochemical processes associated with these vents are of considerable importance to understanding the cycling of some chemicals in the sea.

The vents also support a heretofore unknown biological ecosystem at depths of 2 to 3 kilometers beneath the sea surface, in permanent darkness. The hydrothermal vent ecosystem is supported by both geothermal heat and chemical reduction. In vent communities, chemosynthetic bacteria occupy the same primary role as photosynthetic plants in surface communities. Because individual vents are episodic, there must exist a means for colonizing new vents on the order of a few decades. Thus, hydrothermal vents have implications for the disposal of radioactive wastes, because radionuclides could interact with the vent communities.

Anthropogenic Versus Natural Radioactivity

One of the most striking statistics is that there is now about a thousand times more natural radioactivity in the ocean than there is anthropogenic radioactivity, including the relatively large amounts of radioactivity that have entered the ocean from nuclear weapons tests. By comparison, the amount of radioactivity that would be added to the ocean, even if it were to become the final repository for all of the world's low-level radioactive waste, is relatively small. However, providing a comparison between the human input of radionuclides to the marine environment and natural levels of radioactivity is not as straightforward as one might think. The comparison should consider the characteristics of the particular marine environment, the sources of the anthropogenic and natural radioactivity and the behavior of specific nuclides in the sea. The total volume of the ocean is not available to assimilate anthropogenic radionuclides on reasonable time scales. Even for the radionuclides produced during atmospheric testing of nuclear weapons, which were widely dispersed in the atmosphere before finding their way to the Earth's surface, there was a strong hemispherical and latitudinal variation in the deposition of fallout on the continents and the ocean. The middle latitudes of the northern hemisphere received most of the fallout. Furthermore, the ocean is not well-mixed vertically on time scales of centuries at most latitudes. (See the distribution of tritium in Figure IV-5 from the nuclear weapons test.) Only at the northern latitudes has mixing extended from the surface layer to the deep water; elsewhere the tritium is concentrated in the surface layer.

Most methods that are being considered for the disposal of radioactive wastes in the marine environment would result in the designation of a particular location or disposal site for the material to be placed. If radionuclides escape from containers and become dispersed, they will initially affect that region of the ocean. On time scales of decades to possibly centuries, we can expect that the waters within a given ocean basin, say the western North Atlantic, will mix within that basin but not throughout the entire ocean.

Various disposal scenarios have been formulated and played against different kinds of ocean mixing models. Although the ocean has a large capacity to accommodate additional radioactivity without an appreciable increase in background radiation, its capacity is finite, particularly on a regional scale or for time scales of decades. The ocean's capacity for a waste also depends on whether the waste remains in the water column or becomes associated with the surface sediments on the seafloor. Efforts should be made to refine our assessments of the behavior of anthropogenic radionuclides in the sea by obtaining a more complete understanding of their marine chemistry. Only when radioactive wastes have been characterized in terms of specific nuclides can we hope to make a meaningful assessment of their effect on the environment.

Mechanisms for Human Exposure to Radioactivity in the Sea

The ocean is an inherently dispersive medium and generally more remote from humans than continental nuclear waste repositories. Nevertheless, humans can be exposed to marine radionuclides through direct exposure from contact with seawater, marine organisms, and sediments, from ingestion of marine food sources, or from possible contamination of a marine resource that might be utilized in the future, such as manganese nodules.

Direct exposure—through swimming, boating, marine transportation, or aerosol particles produced in the ocean by spray—appears infinitesimally small. With a few exceptions, the disposal methods that have been used in the past and that are likely to be used in the future place the waste away from the coastal zone where humans have the greatest contact with the sea. When the United States deposited containerized radioactive wastes in the ocean, they were usually placed below the main thermocline at depths greater than 2,000 meters.[9] An exception to this practice was 4,008 cannisters placed on the continental shelf off Boston. A potentially more significant exposure to humans could result from long-term discharges to coastal waters of radionuclides from nuclear facilities such as fuel reprocessing plants or electrical power plants.

The largest part of the radiation dose that the public receives from nuclear material in the ocean is from radionuclides in seafood. The technique that has been used to establish safe limits for the disposal of radioactive wastes in the marine environment is known as the critical pathway analysis. (Examples are presented in Appendix E, Case Histories.) This technique identifies pathways to humans from particular radionuclides and pinpoints the segment of the population that will receive the greatest exposure to that nuclide. Table IV-6 provides examples of the critical pathway and the population group for eight nuclear facilities.

Table IV-6.—Critical Pathway of Radionuclides from the Marine Environment to Humans at Selected Coastal Sites

Site	*Critical Pathway*	*Principal Exposed Group*
Hanford, Washington (plutonium production reactors)	Oyster Flesh	General public on coast
Sellafield, United Kingdom[1] chemical reprocessing)	Fish Flesh	Local Fishermen
	Porphyra (Seaweed)	General Public (recreation)
	Estaurine Sediment	Local Fishermen
Bradwell, United Kingdom (power reactors)	Oyster Flesh	Oyster Fishermen and Families
Dungeness, United Kingdom (power reactors)	Fish Flesh Beach Sediment	Local Fishermen and Families
		Bait Diggers
Dounreay, United Kingdom (chemical reprocessing)	Detritus on Fishing Gear	Local Fishermen
La Hague, France (chemical reprocessing)	Fish Flesh Seaweed	Local Fishermen
Trombay, India (research and development)	Fish Flesh	Local Fishermen
Tokaimura, Japan (chemical reprocessing)	Fish Shellfish	Local Fishermen

[1] Formerly Windscale.

Source: Park, P. Kilho, Dana R. Kester, Iver W. Duedall, and Bostwick H. Ketchum. 1983. Radioactive Wastes and the Ocean: An Overview. *In* Park *et al.* (editors), Wastes in the Ocean. Volume 3. John Wiley & Sons, New York, p. 3-46.

Summary

The fate of radionuclides in the ocean is determined in part by such oceanic processes as dispersion, advection, incorporation into marine organisms, and deposition in sediments. With these processes, there can be substantial chemical transformations that alter the chemical behavior of the nuclide in the ocean.

Besides understanding these processes, we must also know the quantities disposed of specific radionuclides and the type of radiation they emit. Although much knowledge has been gained recently about marine radionuclide behavior, further information is needed in such areas as the deep ocean environment and its biological communities and marine chemical cycles.

A comparison of anthropogenic and natural radioactivity in the marine environment indicates that present human activities are not increasing the level of total radioactivity in the ocean. The ocean has, however, a limited capacity to accommodate anthropogenic radionuclides of specific species and in specific regions for time periods of decades to centuries. This limited capacity is especially important for the surface sediments on the seafloor and for the upper mixed layer of the ocean. The continental shelves are especially poor regions for radioactive waste disposal, because these are regions of generally high biological activity, are close to human activity, and are in the upper layer of the ocean.

The most likely link between marine radioactivity and humans is through seafood. There have been a few instances in which a critical path assessment has indicated that exposure to coastal sediment or detritus could be significant.

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[6] For instance, see:

Boyle, E.A., F.R. Sclater, and J.M. Edmond. 1977. The Distribution of Dissolved Copper in the Pacific. *Earth and Planetary Science Letters* 37(1977):38-54.

Klinhammer, G.D., and M.L. Bender. 1980. The Distribution of Manganese in the Pacific Ocean. *Earth and Planetary Science Letters* 46(1980):361-384.

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[8] For instance, see:

Backus, R. *et al.* 1981. Gulf Stream Cold Core Rings: Their Physics, Chemistry, and Biology. *Science* 212: 1,091-1,100.

Schink, D. et. al. 1983. Multidisciplinary Program to Study Warm Core Rings. *Transactions of the American Geophysical Union* 63(44):834-835.

[9] Park, P. Kilho, Dana R. Kester, Iver W. Duedall, and Bostwick H. Ketchum. 1983. Radioactive Wastes and the Ocean: An Overview. *In* Park *et al.* (editors), Wastes in the Ocean. Volume 3. John Wiley & Sons, New York, p. 3-46.

CHAPTER V
Ocean Disposal of Nuclear Waste: Possible U.S. Proposals

Chapter III explained that this Nation presently follows a land-based radioactive waste disposal policy. Nevertheless, several developments are stimulating continued examination of possibilities for resumption of ocean disposal of radioactive materials.

Disposal of Defueled, Decommissioned Nuclear Submarines[1]

The U.S. Navy has about 120 nuclear submarines now in operation, 100 of which will be taken out of service in the next 20 to 30 years at a rate of three to five a year. Five already have been decommissioned and await permanent disposal.[2]

The Navy presented three disposal options for these defueled craft in a Draft Environmental Impact Statement (DEIS) dated December 1982: bury the radioactive hull section and reactor at existing governmental land disposal sites; drop the entire defueled submarine onto a predetermined part of the ocean floor off a U.S. coast; or continue protective storage at an inactive ship facility until permanent disposal is decided.[3]

If land disposal is the choice, the submarine's reactor compartments would be buried either at the Hanford Reservation in Washington or at the Savannah River Plant in South Carolina—each of which is already a LLW disposal site.[4]

If they are to be disposed of in the ocean, the submarines would be towed to designated sites and sunk by a system of controlled interior flooding, to rest intact on the sea floor.[5] Since the fuel would be removed before disposal, the remaining radioactivity in the submarine at the time of disposal would be radionuclides that are neutron-activated metal atoms within the structure of the reactor compartment. Those radionuclides could only be released by corrosion of the metal structure.[6] Over a period of about 100 years, the reactor compartment containment barrier would be penetrated by corrosion, and bottom currents would begin to flow through it, transporting corrosion products into the adjacent environment.[7] Naval engineers and radiologists calculate, however, that by then such reduced radionuclide emissions would be harmless to man.[8] Although the total radioactivity initially contained within the 100 submarines may be 6×10^6 curies, the maximum release in any one year would be 39 curies during the 1,800 years required for decay or release of 99 percent of the radioactivity.[9]

The Navy DEIS does not select potential disposal sites, although study areas avoided regions that: (1) produce large amounts of seafood or which are food sources for commercial fishes; (2) are currently used by humans for any purpose; or (3) have future resources potential—such as oil and gas fields, or ocean mining areas.[10]

Figure V-1 shows two Atlantic study areas over 200 miles east of Cape Hatteras, North Carolina, in depths of 13,000 to 16,000 feet.[11] Figure V-2 shows the Pacific study area, about 160 miles west of Cape Mendocino, California. Water depths here are from 13,500 to 14,800 feet.[12] Study criteria for these areas were developed by the Navy, based primarily upon IAEA standards (noted in Chapter III) with the following additions:[13]

1. Sites should avoid such areas as submarine canyons, where high rates of exchange occur between the bottom water mass and surface layers over the adjacent continental shelf—to avoid shortening any potential pathways to man.
2. Bottom current shear stress in the study area should not exceed critical erosional shear stress. This precludes high rates of sediment resuspension, and thus rapid movement of material.
3. Sites should be away from areas of intense mesoscale eddy activity, since eddy diffusivity shortens the pathway to man.

The Navy lists the following adverse effects of ocean disposal:[14]

1. Submarine disposal restricts the use of the seafloor for other activities. (If all 100 submarines were placed in the same general area, the region would be a circle of 11 statute miles in diameter, or an area of about 100 square miles.)
2. About 3,000 tons of recyclable material—mostly steel—would be lost per submarine; however, the cost to recover the steel is greater than its scrap value.
3. The ocean environment—primarily the sediment area—would absorb about 4,000 tons of corro-

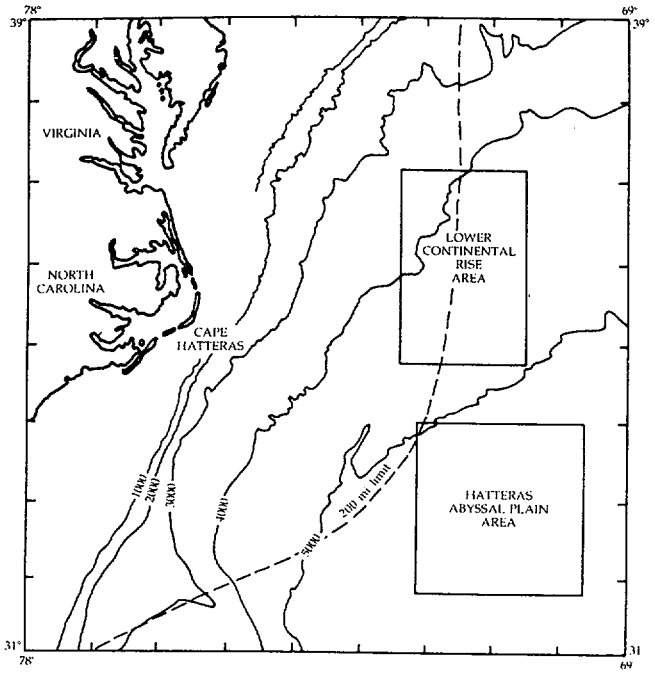


Figure V-1.—Atlantic Ocean Areas for Possible Disposal of Nuclear Submarines.

Source: U.S. Navy. 1982. Draft Environmental Impact Statement on the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants. Office of the Chief of Naval Operations, Washington, D.C., p. 3-7.

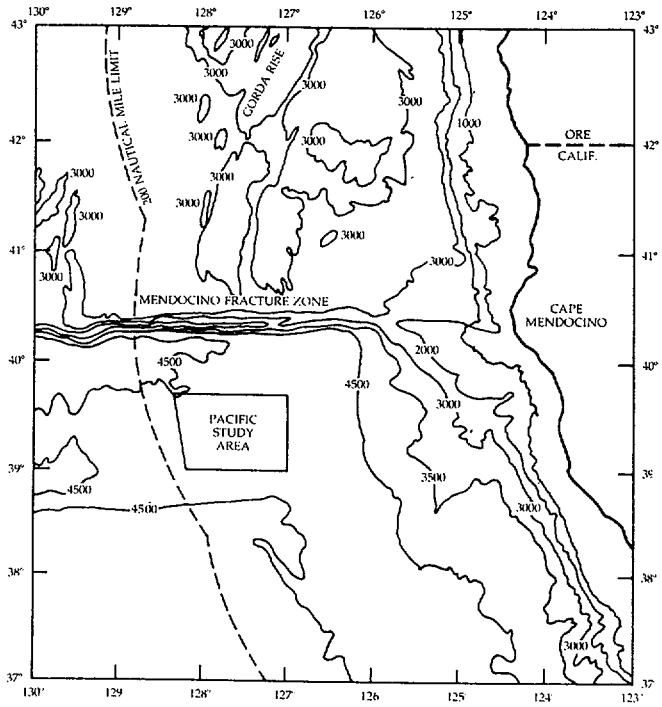


Figure V-2.—Pacific Ocean Areas for Possible Disposal of Nuclear Submarines.

Source: U.S. Navy. 1982. Draft Environmental Impact Statement on the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants. Office of the Chief of Naval Operations, Washington, D.C., p. 3-8.

sion products per submarine, including a small amount of intermediate and long-lived radionuclides. (About 120 curies of nickel-59 per submarine would be released.)

The Navy summarizes the financial and regulatory advantages and disadvantages of sea disposal of nuclear submarines as follows:[15]

1. Advantages
   a. *The cost of sea disposal would be significantly lower than either of the land disposal options, approximately $1.9 million per ship less than land disposal with sea disposal of the remainder of the ship and approximately $8.0 million per ship less than land disposal with the remainder of the ship scrapped.*
   b. *Sea disposal would be simpler than land disposal, requiring less shipyard production work to prepare and sink the ship compared with the work required for land disposal.*
   c. *Radioactivity would be far from human activities and unlikely to be disturbed inadvertently.*
2. Disadvantages
   a. *The environmental aspects of sea disposal are more controversial than those of land disposal. However, disposal at sea of low level radioactive waste is not prohibited by laws of the United States. Controversy has recently been focused on ocean dumping activities of the United States from 1946 to 1970, resulting in a review of the issues by the General Accounting Office. This review determined that the "overwhelming body of scientific research and opinion shows that concerns over the potential public health and environmental consequences posed by past ocean dumping activity are unwarranted and overemphasized."*[16]
   b. *The sea disposal option would take longer to put into use than the land disposal option because sea disposal sites would have to be designated by the U.S. Environmental Protection Agency, and a permit from that agency would be required.*

The other general alternative—delayed protective storage—the Navy considers to be a satisfactory interim measure.[17]

Finding fault with the Navy's DEIS is a national coalition of environmental and public interest organizations that believe that the DEIS does not provide a sound basis for consideration of sea disposal. Among the shortcomings the coalition found were:[18]

(a) **Difficulties in monitoring deepsea ecosystems**—Neither available scientific technology nor the monitoring program proposed in the DEIS would adequately gauge the incremental environmental impacts of disposed submarines.

(b) **Need to identify critical pathways**—Potential pathways for transport of radioactivity from the submarines toward human consumers of seaweed and seafood should be identified.

(c) **Site-specific concerns**—The impact on local fisheries and potential seismic activity at Cape Mendocino should be determined; and transport by benthic currents and fish toward shallow waters should be determined off North Carolina.

(d) **Availability of radioactivity**—The coalition questions whether the bulk of the submarine's radioactivity will decay before corrosion allows ocean currents to carry that radioactivity into the marine environment.

(e) **Cumulative impacts**—The coalition cited the need for a comprehensive register of all radioactivity known or reasonably expected to enter the ocean, and that this assessment should include an estimate of the ocean's assimilative capacity for radioactivity.

(f) **Indirect effects**—Considerations such as impact upon commercial fishing or shoreline tourism should be considered.

(g) **Cost estimates**—The coalition notes short-falls in the Navy estimates; for instance, the establishment of an adequate monitoring program connected with ocean disposal could eliminate the savings of $2 million per submarine over land disposal.

(h) **Irretrievability of submarines**—The coalition believes that the size of the submarines and their corrosive state would preclude successful future retrieval.

Several of the perceived shortcomings, among others, were addressed by EPA in its comments on the Navy's DEIS. In those comments, EPA assigned the DEIS a rating of ER-2, indicating that agency officials had "environmental reservations about the proposed Navy program and that additional information should be presented in the Final EIS."[19]

Ocean FUSRAP Project

The U.S. Department of Energy's (DOE) Ocean FUSRAP project presents another possibility for ocean disposal. FUSRAP—or Formerly Utilized Sites Remedial Action Program—identifies and evaluates radiological conditions at sites formerly used by the Corps of Engineers Manhattan Engineer District and the Atomic Energy Commission (AEC).[20] The purpose of the Ocean FUSRAP project is to assess the feasibility of disposing of FUSRAP waste containing trace amounts of natural radioactivity in the ocean or on the ocean floor.[21]

The Project has concentrated on the Middlesex, New Jersey Sampling Plant site where the United States handled and sampled Belgian Congo uranium ore through 1955.[22] Potential Middlesex soil contaminants include natural radionuclides, dominated by uranium-238 series nuclides, although thorium series nuclides are present, and several nonradioactive trace elements which are frequently enriched during processing along with uranium and thorium (i.e., arsenic, selenium, and other heavy metals). These contaminants are present in soil contained within the fenced perimeter of the 9.6 acre Middlesex Sampling Site,[23] which presently costs $200,000 annually to maintain. There are about 4 curies of radioactivity in 64,000 cubic yards of soil.[24]

The citizens of Middlesex, who live in an industrial area, are concerned about the local high incidence of cancer, which is higher than the State and national averages. It is unknown whether there are any combined effects of radioactivity with other pollutants in the Borough's air and water.[25] To address these these concerns, DOE is considering several options, among them: stabilizing the material in place at a cost of $24 million by covering it with soil; moving the contaminated soil to another land location where it might be stabilized at a cost of $30 million; or ocean disposal at significantly less cost.[26]

With regard to ocean disposal, Ocean FUSRAP Project personnel have screened suitable sites for possible ocean disposal based on: (1) London Dumping Convention requirements for a depth greater than 4,000 meters, (2) a location within the 200-mile Exclusive Economic Zone (to enhance EPA authority), and (3) the shortest distance possible—to minimize sea transportation costs.[27] One site could be the U.S.-designated Deep Water Dumpsite (DWD 106), which is now used for the disposal of industrial wastes in slurry form. A second site, based on a survey of the areas proposed for disposal of obsolete nuclear submarines, is off Cape Hatteras.[28]

Dumping scows could remove the soil to DWD 106; or it could be transported in surplus ship hulls to the site off Cape Hatteras, where the entire hull would be scuttled. An estimated cost for disposing of the soil by the first method would be $1.65 million; by the second it would be $6.35 million.[29]

The total radioactivity of the Middlesex soil is about 5×10^{-8} curies/kilogram, less than the natural background level in many parts of the world, including ocean sediments. (See Figure IV-3.) FUSRAP Project personnel consider their proposal for ocean dumping feasible and favor DWD 106, because it is already a designated site, and because a large amount of baseline data already exists to support that designation.[30]

Subseabed Disposal of High-Level Waste

Another U.S. ocean disposal activity could evolve from the results of the DOE's Subseabed Disposal Program (SDP). Its major objective is to assess the technical, environmental, and engineering feasibility of disposing high-level waste in the sediments beneath the

oceans. The program seeks also to develop and maintain the capability to assess the seabed nuclear waste disposal programs of other nations.[31]

Under the direction of the Sandia National Laboratories in Albuquerque, New Mexico, more than 100 scientists and engineers from a number of U.S. universities, oceanographic institutions, and research centers are involved. They are part of the Department of Energy's Office of Civilian Radioactive Waste Management, which has the goal of identifying and developing technologies that can isolate HLW from the biosphere in a safe and environmentally acceptable manner.[32]

Subseabed feasibility studies are scheduled through the 1990s, subject to some planned external reviews, and will culminate in a demonstrator subseabed repository. A chart of the program's milestones appears in Figure V-3, and program activity is depicted in Figure V-4. The studies are sequential with limited funding—and with the understanding that they could terminate should the program find that SDP is not feasible.[33]

What physical advantages would the subseabed offer for HLW disposal? Subseabed Disposal Program personnel believe there are several:

1. First, stability. Scientific investigation of the ocean floor has revealed vast areas of deep ocean sediment considered by geologists to be some of the most stable formations in the world. These regions have been the scene of continuous sedimentary deposition for millions of years. Based on their geologic and climatic stability, long-term predictions can be made for sediment integrity. Ice ages and other large climatic changes have little or no effect on the stability and uniformity of the deep ocean environment.[34]
2. Next, the nature of the sediment itself is an asset. These sediments are made up of minute, uniformly sized grains that would be highly nuclide-adsorbing. The grains are packed together such that the pores surrounding them have a very high resistance to water movement. The sediment environment has a low temperature (about 1° C) that varies little; thus chemical processes, such as leaching, are retarded. And pressures are high so the sediment adjacent to the waste will remain uniformly saturated (without voids), and the pore water will not boil with the conditions of heating that occur under the disposal designs of the studies.[35]
3. A final factor is the water column above the seafloor repository. It would serve as an essentially infinite sink for heat generated by decaying radionuclides in nuclear waste.[36] However, the ocean is not considered a primary radioactive

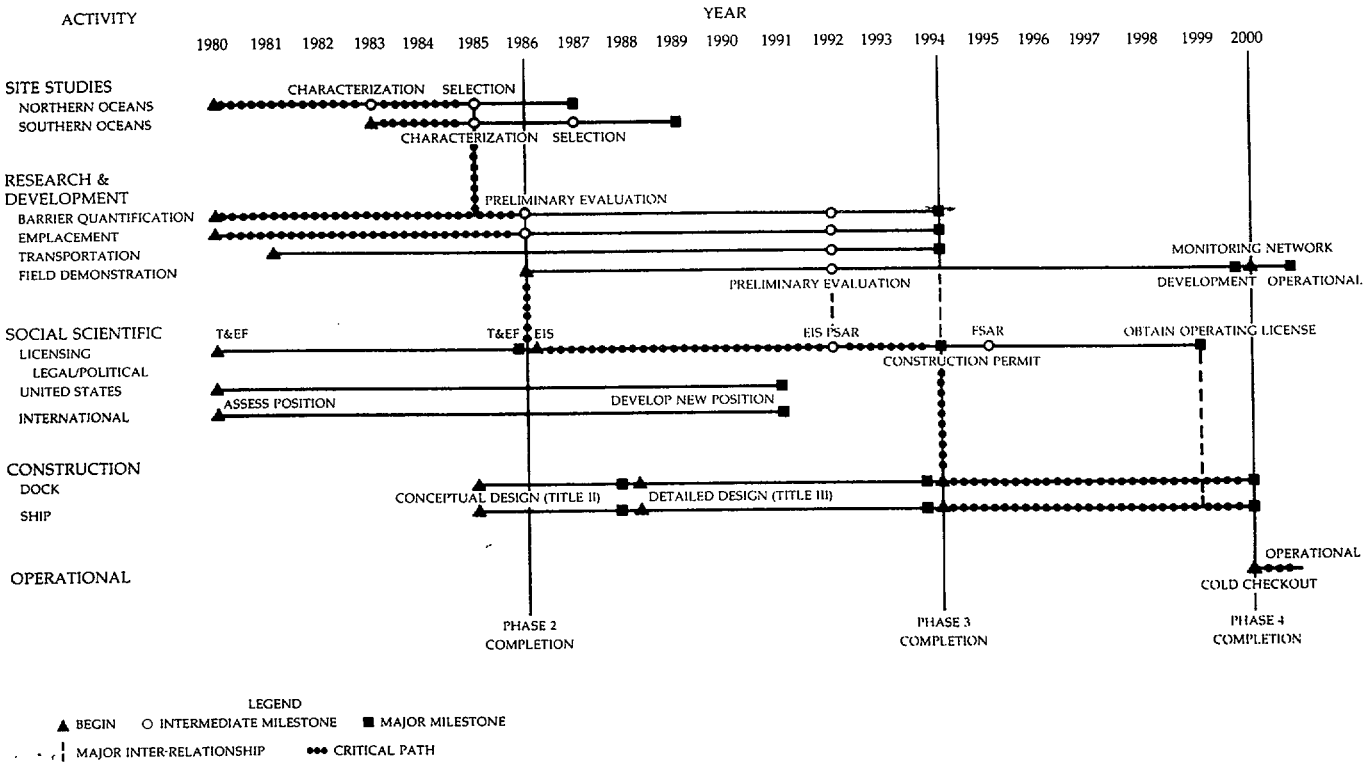


Figure V-3.—Major Milestones for the Subseabed Disposal Program.

Source: Sandia National Laboratories. 1980. Subseabed Disposal Program Plan. Volume 1: Overview. SAND80-0007/1, Seabed Programs Division, Albuquerque, New Mexico, p. 60.

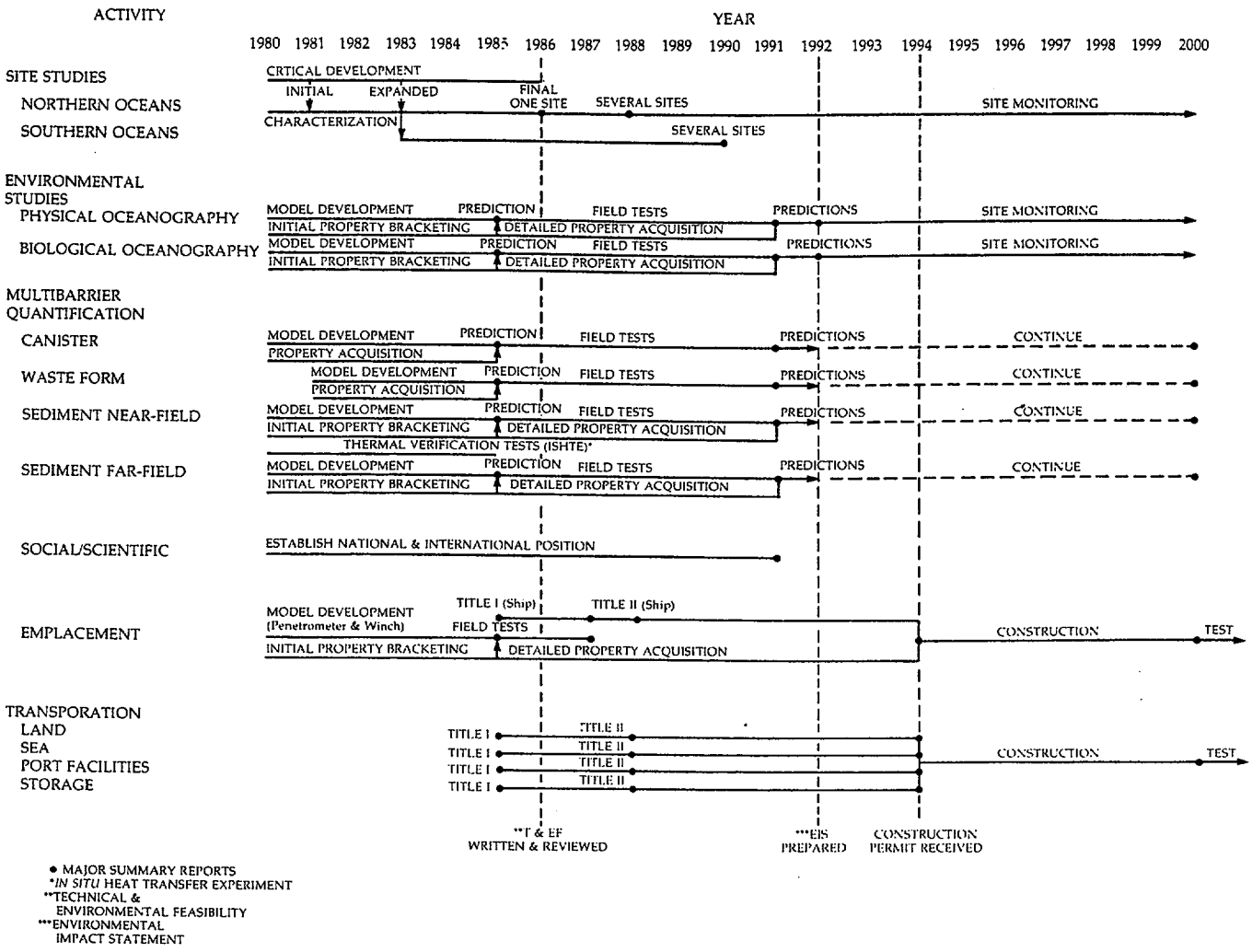


Figure V-4.—Programmatic Activity Chart for the Subseabed Disposal Program.

Source: Sandia National Laboratories. 1980. Subseabed Disposal Program Plan. Volume 1: Overview. SAND80-0007/1, Seabed Programs Division, Albuquerque, New Mexico, p. 61.

material barrier by the program.[37] Rather, the program is predicated on the ocean sediments serving as an adequate shield with no significant radioactivity escaping from the sediment into the ocean.

In addition to the physical advantages, there may be several other benefits to subseabed disposal. It is in the U.S. interest that other nations dispose of their wastes properly. It is not reasonable to expect small nations that run a few reactors to undergo the huge effort the United States is making to find safe land-based repositories. Development of subseabed repository techniques might keep many small users from establishing a variety of land-based repositories of questionable safety standards. Additionally, subseabed disposal may prove beneficial from the standpoint of security and safeguards. Placing HLW in the subseabed in isolated areas under the ocean and its seafloor would set up a major barrier to terrorists attempting to retrieve forms of HLW.

A subseabed repository large enough to accommodate the HLW generated by the U.S. nuclear industry this century would require less than 2,000 square kilometers, or about 0.0005 percent of the world ocean area. HLW canisters would be placed 100 meters apart, and each would serve as its own "mini-repository," so any event which might disturb one emplacement would not impair the others.[38]

Originally focused on technical and environmental studies, the U.S. Subseabed Disposal Program has expanded to consider political, social, legal, and economic ramifications as well. Further, its scope has broadened to include international consultations and a shared research agenda on common problems in nuclear waste management. Specialists from the Commission of European Communities, the Federal Republic

of Germany, the United Kingdom, France, the Netherlands, Switzerland, Canada, and Japan have joined with U.S. scientists and engineers in forming an international Seabed Working Group under the auspices of the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD).[39]

As noted in Chapter III, U.S. subseabed disposal of HLW may require amending the Ocean Dumping Act, and clarification of the London Dumping Convention which does not specifically address such disposal. And although subseabed disposal places HLW in regions far removed from direct human contact, it also incurs potential risk to many coastal nations that do not yet benefit from nuclear power. If the global community of coastal nations views subseabed HLW disposal as an ecological threat to the oceans, the system could prove difficult if not impossible to implement. However, should the ocean sediment prove to have a protective capacity greater than geological formations on land, its capability to isolate HLW could be an advantage generating serious consideration.

Decommissioned Nuclear Reactors

Other proposals to dispose of nuclear materials in the ocean could evolve, but no national programs currently exist to consider them. One possibility is the disposal of large commercial reactors nearing the end of their life spans. Within a few years, several reactors may be shut down and dismantled; the first being a 90-megawatt unit installed in 1957 at Shippingport, Pennsylvania.[40] Table V-1 shows a statistical summary of U.S. nuclear reactors as of December 31, 1982.

Low-Level Waste from Institutions and Facilities

As noted in Chapter I, the United States generates a large amount of commercial low-level waste through academic research, electricity generation, medical services, and manufacturing processes, but only three sites presently exist to accept it. Although the Low-Level Radioactive Waste Policy Act has encouraged States to join in regional compacts to create LLW sites, a possible supplemental means of disposal for coastal States could be ocean dumping if other ocean concepts for LLW prove feasible.

Need for a National Consensus

Present U.S. policy is to not use the ocean for radioactive waste disposal. However, new proposals are continuously advanced, and in some cases at least, proponents can make a favorable case for ocean disposal as compared to land disposal. Proponents of ocean disposal argue mainly about the comparison of land and ocean with regard to human exposure. It is land that provides humans with 99 percent of their food, and 100 percent of such natural resources as wood and natural fibers.[41] Proponents also note the ocean's capacity to absorb radioactivity. The natural level of radioactivity in the ocean waters and the marine sediments is not zero, and most proposals for radioactive waste disposal would not raise radioactivity significantly above the total background level. The requirement is to devise a practical dilution scheme, or a containment/trickle-in scheme that introduces small amounts over long periods into large volumes.

Basic to any U.S. consideration to resume nuclear waste disposal in the ocean is the political issue of burden of proof. Opponents believe that all ocean dumping of nuclear waste should be terminated until the environmental and health consequences of LLW disposal can be completely resolved. They are not convinced that the level of scientific knowledge is sufficient to satisfy all reasonable doubts.

Opponents to ocean dumping also cite the fact that the United States has a lesser need to use the ocean than nuclear-capable countries with a shortage of land mass—such as the United Kingdom, Japan, and the Netherlands. Why should this nation be the bellweather for global criticism of ocean disposal of nuclear waste when other nations have a greater need for ocean disposal?

One fundamental concern by opponents of ocean disposal of nuclear waste is that of precedence. If the United States adopts ocean disposal, then other nations with less technology and capability for monitoring and research are likely to follow our lead and use the ocean for nuclear waste disposal, but with fewer safeguards than has the United States. Therefore, the United States has a great responsibility to act cautiously and not to resume ocean disposal simply because it is expedient to do so.

Societal consensus on nuclear waste management is mandatory. Unfortunately previous government attempts to permanently dispose of U.S. radioactive waste have resulted in an erosion of credibility. Waste disposal is a complex problem and reaching agreement among America's many competing interests will be difficult. The ocean is not presently part of our Nation's radioactive waste disposal plan and NACOA does not suggest that the present land-oriented disposal policies should be reversed at this time. We do believe, however, that given increasing national and international pressures it is unrealistic to assume that ocean disposal will continue to be prohibited in the future, and therefore, we should not close our minds to the possibility of ocean disposal.

Table V-1.—Statistical Summary of U.S. Nuclear Reactors as of December 31, 1982

	Operable	*Being built*	*Planned*	*Shut down or dismantled*
CIVILIAN REACTORS				
Power Reactors				
Central-Station Electric Power[1]	81	58	5	10
Dual-Purpose Plants[2]	1	2		
Propulsion (Maritime)				1
Experimental Power-Reactor Systems[3]				
Electric-Power Systems	1			23
Auxiliary Power (SNAP)				9
Space Propulsion (Rover)				21
Test, Research, and University Reactors				
General Irradiation Test[4]	2			5
High-Power Research and Test[5]	7			5
Safety Research and Test[6]	3			9
General Research[7]	21	1		46
University Research and Teaching[8]	50			14
PRODUCTION REACTORS				
Materials Production	3			10
Process Development	1			4
MILITARY REACTORS				
Defense Power-Reactor Applications				
A. Remote Installations				6
B. Propulsion (Naval)	138	32		8
Developmental Power				
A. Electric-Power Experiments and Prototypes				3
B. Propulsion Experiments and Prototypes	8			7
Test and Research				
Test				4
Research	4		2	5
REACTORS FOR EXPORT				
Power Reactors				
Central-Station Electric Power	38	27	9	3
Propulsion	1			
Test, Research, and Teaching				
General Irradiation Test	7			
General Research	23	4		8
University Research and Teaching	24			

[1] A facility designed and constructed for operation on a utility system.

[2] A nuclear power facility designed, constructed, and operated for more than one purpose. Possible purposes include: generation of electricity, production of nuclear materials, and process-heat applications including desalting.

[3] A facility designed, engineered, constructed, and operated to test the technical feasibility of a concept or to provide the technical basis for a similar type nuclear power plant in a large size.

[4] A reactor having (1) a thermal power level exceeding 10,000 kW; (2) test loops or experimental facilities within, or in proximity to, the core; and (3) the use of nuclear radiation for testing the life or performance of reactor components as its major function.

[5] A reactor having a relatively high thermal power level (5000 kW or more) but not classed as a general irradiation test reactor.

[6] A reactor associated with a nuclear safety research or engineering-scale test program conducted for the purpose of developing basic design information or demonstrating safety characteristics.

[7] A reactor--excluding that located at a university--whose nuclear radiations are used primarily as a research tool for basic or applied research, and whose thermal power level is less than 5000 kW. It may include facilities for testing reactor materials.

[8] A reactor located at a university and usually operated for the primary purpose of training in the operation and utilization of reactors and for instruction in reactor theory and performance.

Source: U.S. Department of Energy. 1983. Nuclear Reactors Built, Being Built, or Planned in the United States as of December 31, 1982. DOE/TIC-8200-R47, U.S. DOE Technical Information Center, Oak Ridge, Tennessee, p. 3.

References and Footnotes

[1] As this report was being prepared for publication, the U.S. Department of the Navy published the "Final Environmental Impact Statement on the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants," dated May 1984. The abstract of the report is:

This statement describes two methods for permanent disposal of decommissioned, defueled reactor plants: land disposal by burial at exisiting Federal sites and deep sea diposal. The "no action" alternative of long-term protective storage prior to permanent disposal at some time in the future is also discussed. Based upon the research work performed in support of this effort, and review of the public comments received, the Navy considers that permanent disposal can be conducted in an environmentally safe manner. Largely as a result of the highly uncertain regulatory status of sea disposal, the Navy considers land burial at existing Federal sites to be the preferred alternative. The "no action" alternative would only delay the decision for permanent disposal and would result in increased costs without significantly changing the environmental impact.

[2] U.S. Department of the Navy. 1982. Draft Environmental Impact Statement on the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants. Office of the Chief of Naval Operations, Washington D.C., p. S-1—S-16, 1-7.

A naval vessel that no longer has sufficient military value to justify its maintenance can be placed in temporary protective storage until such time as its permanent disposition is determined. Should that vessel be a nuclear submarine, defueling occurs in which the nuclear fuel is removed from the submarine's reactor pressure vessel. Although this process removes most of the submarine's radioactivity, the irradiated reactor pressure vessel and metal structure remain.

Four submarines have been decommissioned and await disposal in naval shipyards: *TRITON, HALIBUT, ABRAHAM LINCOLN,* and *THEODORE ROOSEVELT.* A fifth, the *NAUTILUS,* has been decommissioned and designated an historic ship. These ships may remain in protective storage for an indefinite time without hazard to personnel or the environment.

[3] *Ibid.*, p. 2-1—2-14.

[4] Ibid., p. 2-1.

Although the size of the reactor compartment is relatively large, the disposal of the compartment would be consistent with current practice. Hanford and the Savannah River Plant were selected, because they were close to navigable waters and groundwater at these sites is not near the soil surface.

[5] *Ibid.*, p. 2-11.

[6] *Ibid.*, p. 4-10.

[7] As shown in Table 4-2 of the DEIS, the Navy considers a sequence of radioactivity release events as follows:

Time after Scuttling (years)	Event
0	Submarine rests intact on seafloor. Corrosion begins, but limited to minute releases from hull and bulkheads.
75	Reactor vessel interior partially penetrated.
100	Reactor compartment containment barrier penetrated. Bottom currents begin to carry water-transportable corrosion products to environment.
400	Currents flowing fully through reactor vessel.
4300	Radioactivity release 99 percent complete. (If an accident occurred, and all containment were open to the sea at once, the radioactivity release would occur in 1,800 years.)

The Navy predicts that the total maximum release from all significant radionuclides from one submarine would be 0.65 curies per year, and that this would occur after 100 years. The total amount released would be 183.9 curies, as indicated in Table 4-4 of the DEIS.

[8] *Ibid.*, p. S-12, 1-6—1-7.

Of the radioactive material that remains in the submarine, 99.9 percent is an integral part of the corrosion-resistant alloy forming the plant components. The predominant nuclide present is cobalt-60, whose half life is 5.26 years. In 52.6 years cobalt-60 activity is reduced by a factor of 1024.

In all, there are 16 significant radionuclides present with an initial total radioactivity of 62,000 curies. This radioactivity would be contained within the reactor pressure vessel, a steel container several inches thick and which is sealed.

Because of the delay effect, most of the radioactive nuclides within the metal matrix would decay to stable atoms before corrosion release occurred. Those nuclides with long half-lives—nickel-59 (80,000 years) and nickel-63 (92 years)—represent the principal threat of release into the marine environment.

A table of comparable radiation exposure for conservative estimates of the Navy's options shows:

Option	Exposure
Land—100 reactor compartments	0.006 millirem
Ocean—100 submarines	0.0002 millirem

The estimate is for the time of largest impact (after 100 submarines are disposed of, and significant corrosion occurs.)

Source: *Ibid.*, p. S-14.

[9] *Ibid.*, p. 1-2, 4-12, 4-14.

[10] *Ibid.*, p. S-11.

[11] *Ibid.*, p. 3-10.

One Atlantic study area, the Lower Continental Rise Area, is centered at 36°N, 71.5° W, approximately 220 nautical miles east of Cape Hatteras, North Carolina. The second study area, the Hatteras Abyssal Plain Area, is 280 nautical miles southeast of Cape Hatteras.

[12] *Ibid.*, p. 3-11.

The center of the Pacific study area is 160 nautical miles west of Cape Mendocino, California, at 39° 20' N, 127° 40' W.

[13] *Ibid.*, p. 3-9, 3-10.

[14] *Ibid.*, p. 2-12, 2-13.

According to the Navy's DEIS, the annual radiation level due to the disposal of all submarines to the most exposed individual would be 3×10^{-3} mrem per year. In an extreme occurrence, in which the reactor compartment and reactor vessel provided no containment, the maximum annual exposure would be 6×10^{-2} mrem per year.

The DEIS states that minimal effects on sea life would be anticipated since very low external radiation is anticipated and there is limited potential for internal exposure—mainly ingestion of sediment.

[15] *Ibid.*, p. 2-14.

[16] U.S. General Accounting Office. 1981. Hazards of Past Low-Level Radioactive Waste Ocean Dumping Have Been Over-Emphasized. Report EMD-8209, Washington, D.C. (As quoted in U.S. Department of the Navy's DEIS, p. 2-14.)

[17] *Ibid.*, p. 2-15.

A yearly cost of $90,000 per year per ship is required to maintain nuclear submarines at inactive ship facilities. After 20 years of waterborne storage, the ship would require dry-docking for inspection and maintenance, which adds additional costs.

[18] Center for Law and Social Policy and the Oceanic Society. 1983. Joint Comments of Environmental And Other Citizen Organizations in Response to the Department of Navy's Draft Environmental Impact Statement on the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants, hereafter referred to as Joint Comments, Washington D.C., p. i.

The coalition is composed of the following organizations: American Cetacean Society, Ban Ocean Nuclear Dumping, CAN-Disarm, Center for Environmental Education, Clean Water Action Project, Committee to Bridge the Gap, Critical Mass Energy Project, Environmental Defense Fund, Farallon Foundation, Friends of the Earth, Greenpeace USA, Hudson River Sloop Clearwater Inc., National Audubon Society, Natural Resources Defense Council, Nuclear Free Pacific, Nuclear Information Resource Service, Ocean Education Project, Oceanic Society, Palmetto Alliance Scenic Shoreline Preservation Conference, Sierra Club, Southwest Research and Information Center, Union of Concerned Scientists, United Methodist Church Joint Law of the Sea Project, United Methodist General Board of Church and Society, and the Wilderness Society.

The Coalition concludes with the following observations (p. 15-50):

1. The consequences of delay are not significant in light of the two year moratorium recently placed on radioactive waste ocean dumping by Congress in the amendments to the Ocean Dumping Act.
2. The present state of information regarding ocean disposal is not well developed.
3. The U.S. needs to conduct research and studies to determine the effects of ocean disposal of radioactive waste.
4. To correct the deficiencies in the DEIS a supplemental draft EIS must be prepared with its preparation awaiting the accumulation of relevant data.

A final concern by the Coalition is that without a delay to undertake needed research, the Navy's EIS will run the very likely risk of illegally serving "as a *pro forma* ritual preceding a predetermined result."

[19] Alberico, Pasquale A. 1983. Cover letter of June 29, 1983, accompanying the "U.S. Environmental Protection Agency Comments Pertaining to U.S. Navy Draft Environmental Impact Statement On the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants."

[20] FUSRAP is one of four programs initiated by the Department of Energy to assess national sites that might require remedial action to restore the site to its original condition, or nearly so. The radioactive wastes from these sites normally will have very low activity level from residues of natural radionuclides. The FUSRAP sites are located primarily in the Eastern U.S., and at the time of their use were active industrial areas convenient for the storage and processing of imported ores and other radioactive materials.

From: U.S. Department of Energy. 1983. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics. DOE/NE-0017/2, Assistant Secretary for Nuclear Energy and Assistant Secretary for Defense Programs, Washington, D.C., p. 190-218.

[21] Kupferman, S.L., D.R. Anderson, L.H. Brush, L.S. Gomez, J.C. Laul, and L.E. Shephard. 1982. Ocean FUSRAP: Feasibility of Ocean Disposal of Materials from the Formerly Utilized Sites Remedial Action Program (FUSRAP). Paper delivered at Waste Management '82, Tucson, Arizona.

[22] Dobies, Ronald S. 1983. Remarks to the National Advisory Committee on Oceans and Atmosphere on Middlesex Borough Low-Level Radioactive Waste. Presentation (April 13) before the National Advisory Committee on Oceans and Atmosphere, Washington, D.C.

Mr. Dobies is Mayor of Middlesex Borough, New Jersey. Middlesex Borough, about 4 square miles in area, is situated in the northeastern corner of Middlesex County, New Jersey; about 33 miles from New York City and 60 miles from Philadelphia. At its southern tip, adjacent to Piscataway Township, lies the Middlesex Sampling Plant.

[23] Kupferman, *op. cit.*, p. 3-4.

[24] Baublitz, Jack. 1984. Personal Communication. Director, Division of Remedial Action Projects, U.S. Department of Energy, Washington, D.C.

[25] Cohen, Ronald. 1984. Personal Communication. Health Officer, Middle Brook Regional Health Commission, Middlesex, New Jersey.

[26] Baublitz, *op. cit.*

[27] Kupferman, *op. cit.*, p. 9.

[28] *Ibid.*, p. 10-11.

[29] *Ibid.*, p.12.

The price difference is due mainly to the cost of the surplus ship hulls.

[30] Kupferman, S.L., D.R. Anderson, L.H. Brush, L.S. Gomez, and L.E. Shephard. 1982. FODOCS Annual Report, March 1-September 30, 1981. SAND 82-0292, Albuquerque, New Mexico.

[31] Sandia National Laboratories. 1980. Subseabed Disposal Program Plan, Vol. I, Overview, Document SAND 80-0007/I, Albuquerque, New Mexico, p. 11.

The Program is divided into four phases: (1) development of historical data, (2) determination of technical and environmental feasibility based on oceanographic and effects data, (3) determination of engineering feasibility, and (4) demonstration of capability.

The Program is based on four assumptions:

1. A definable system of natural barriers exists which will provide the required containment of waste constituents.
2. A system of manmade barriers can be constructed such that the integrity of the waste form can be ensured for the duration of the credible heat life of the canister.
3. The total time of containment by both the above systems will at least be of magnitude greater than the half-lives of the radionuclides of interest.
4. Since the required isolation period is so long, the attributes of each component of the barrier system must be adequately known.

From: Sandia National Laboratories. 1980. Subseabed Disposal Program Annual Report January to December 1978. Vol. I, Albuquerque, New Mexico, p. 1.

[32] Sandia National Laboratories. 1980. Subseabed Disposal Program Annual Report, January to December 1980. Volume 1. Summary. SAND-1095, Albuquerque, New Mexico, p. 11.

[33] Sandia National Laboratory. 1980. Subseabed Disposal Program Plan. Volume 1. Overview. SAND 80-0007/11, Albuquerque, New Mexico, p. 12.

[34] *Ibid.*, p. 8-9.

[35] *Ibid.*

[36] *Ibid.*, p. 9

[37] Sandia National Laboratories, SAND-1095, p. 10.

[38] Sandia National Laboratories. 1980. Subseabed Disposal Program Annual Report, January to December 1980. Vol. 1. Summary. Albuquerque, New Mexico, p. 13.

The total area of the ocean is 361 million km², or 70 percent of the Earth's surface.

[39] Sandia National Laboratories. 1982. Seventh International NEA/Seabed Working Group Meeting, La Jolla, California, March 15-19, 1982. SAND 82-0460, Albuquerque, New Mexico.

The NEA Seabed/Working Group has divided its efforts into several tasks: system analysis, site selection, biology, physical oceanography, sediment and rock studies, waste form and canister, and engineering studies. These are handled through Task Groups supervised by an Executive Committee.

[40] A summary of the potential for disposal of nuclear reactors is contained in "A Long-Term Problem for the Nuclear Industry," 22 January 1982, *Science* 215:376-379.

[41] Osterberg, Charles. 1982. Presentation (October 25) before the National Advisory Committee on Oceans and Atmosphere, Washington, D.C.

Dr. Osterberg was the Director of the IAEA's Marine Radiological Laboratory at Monaco from June 1976 to June 1979.

APPENDICES

A. Nuclear and Health Physics 73
B. Summary of Waste Management Strategies of Other Nations 81
C. U.S. Ocean Dumping of Radioactive Waste 85
D. Signatory Countries to the London Dumping Convention 89
E. Case Histories 91
   Hanford 91
   Pacific Fallout 91
   U.S. Ocean Dumping 92
   THRESHER AND SCORPION Sinkings 92
   Sellafield 93
F. Meeting Dates, Speakers, and Presentation Topics 95
G. Glossary of Acronyms 99
H. Glossary of Selected Terms 101
I. Glossary of Organizations 105
J. Selected National Legislation Pertaining to Radioactive Waste Disposal 107
K. Selected International Agreements Pertaining to Nuclear Energy (as of January 1, 1983) 109
L. NACOA Panel on Nuclear Waste Management 113

APPENDIX A
Nuclear and Health Physics

Nuclear Physics

An atom can be visualized as being composed of neutrons and protons within its nucleus, with electrons moving in stable orbits around that nucleus. Normally, chemical reactions involve interactions between orbiting electrons, with relatively small energy changes.[1] However, the phenomenon of radioactivity involves changes in the nuclei of atoms in which a nucleus spontaneously emits a particle and changes into another type of nucleus. Other types of nuclear reactions are brought about by the bombardment of nuclei by particles such as neutrons, protons, alpha particles, or gamma rays.[2] Compared to chemical reactions, nuclear reactions can involve very large amounts of energy.

The number of protons in the nucleus of an atom determines the element and its atomic number. Atoms containing the same number of protons but varying numbers of neutrons are called isotopes of that element. An element may have several isotopes. Examples are the two isotopes of uranium found in nature (uranium-235 and uranium-238), which each have 92 protons. However, uranium-235 contains 143 neutrons (92+143=235) while uranium-238 has 146 neutrons. The numbers 235 and 238 indicate the mass number of these isotopes, which is the sum of the protons and neutrons in the nucleus of each.[3] At the other end of the atomic scale is hydrogen. Its most common state is one proton and no neutrons; however, another isotope of hydrogen called deuterium has one proton and one neutron and comprises about 0.015 percent of all hydrogen.[4] The third isotope (called tritium) has one proton and two neutrons.

Many isotopes are stable, meaning they undergo no spontaneous nuclear changes.[5] Isotopes that are not stable may gain stability during radioactive decay by releasing nuclear energy, mostly in emitted particles and/or emitted electromagnetic radiation. Such unstable isotopes are called radionuclides, and the process is referred to as radioactivity.[6]

Some nuclear emissions can cause ionization in the atoms they strike by causing orbital electrons to be separated from their atoms.[7] Essentially five types of ionizing nuclear emissions and one type of ionizing radiation from orbital electrons can be initiated by nuclear reactions. They are alpha particles, beta particles, protons, neutrons, and gamma and x-rays.

Alpha particles: These are nuclear emissions consisting of particles composed of two neutrons and two protons, which makes them essentially the nuclei of helium atoms.[8] Alpha particles are the largest particles emitted during radioactive dacay. Compared to other types of radiation, alpha particles have great ability to ionize atoms, because they transfer more of their energy to each of the atoms they meet than do other types of emissions. Consequently, alpha particles are brought to rest rapidly, penetrating less than 0.013 centimeters in soft tissues; low energy alpha particles penetrate only 0.0008 centimeters. Because of the inability of alpha particles to penetrate deeply into tissue, alpha-emitting radionuclides are generally hazardous to humans only if they decay while inside the body.[9]

Beta particles: These are electrons emitted during radioactive decay of nuclides.[10] High energy beta particles can penetrate 1.5 centimeters in soft tissue, and low energy beta particles can penetrate 0.025 centimeters. Because of these short ranges, beta-emitting nuclides are of concern mainly when they decay within the body. However, beta penetration can be deep enough to constitute some danger from decay of nuclides on the ground or on skin.[11]

Protons: These are particles of positive electricity, with charges equal in magnitude to electrons, but with 1,836 times the mass of electrons. When emitted from nuclei, protons can ionize atoms.[12] Protons are not emitted during the spontaneous radioactive decay of atoms, but rather they must be given energy through a nuclear collision with a high energy photon (such as a gamma ray) before they can be expelled from the nucleus.[13]

Neutrons: These are uncharged particles, normally constituting parts of atomic nuclei, each with a mass about equal to one proton. Because they have no charge, they do not transfer energy to atoms by electrical attraction and replusion as do alpha, beta, or proton emissions, Thus, there is little impediment to neutron passage through atoms, and they are deeply penetrating. Neutrons can react with atomic nuclei, causing them to emit gamma rays or protons that in turn ionize other atoms,[14] but most damage from neutrons occurs during collisions with atoms that recoil from the momentum, become charged, and then penetrate tissue as directly ionizing particles.[15] However, neutrons are rarely encountered in nature, because very few radioactive materials spontaneously emit them.[16]

Gamma rays and X-rays: These are essentially identical forms of electromagnetic radiation differing only in their energy levels and in their places of origin within the structure of the atom.[17] Gamma rays are emitted from the nucleus during nuclear changes, and X-rays radiate from the orbital electrons as the electrons change energy levels. Energy from a nuclear reaction can be transferred to an orbital electron, which in turn can emit X-rays.[18] Gamma and x-rays are very penetrating. In general, the greater the energy of the ray the greater the penetration into tissue. The energy of gamma rays varies over a wide range, so penetration also varies widely. However, gamma radiation that strikes a human can always be considered to carry at least some of its initial energy entirely through the body.[19]

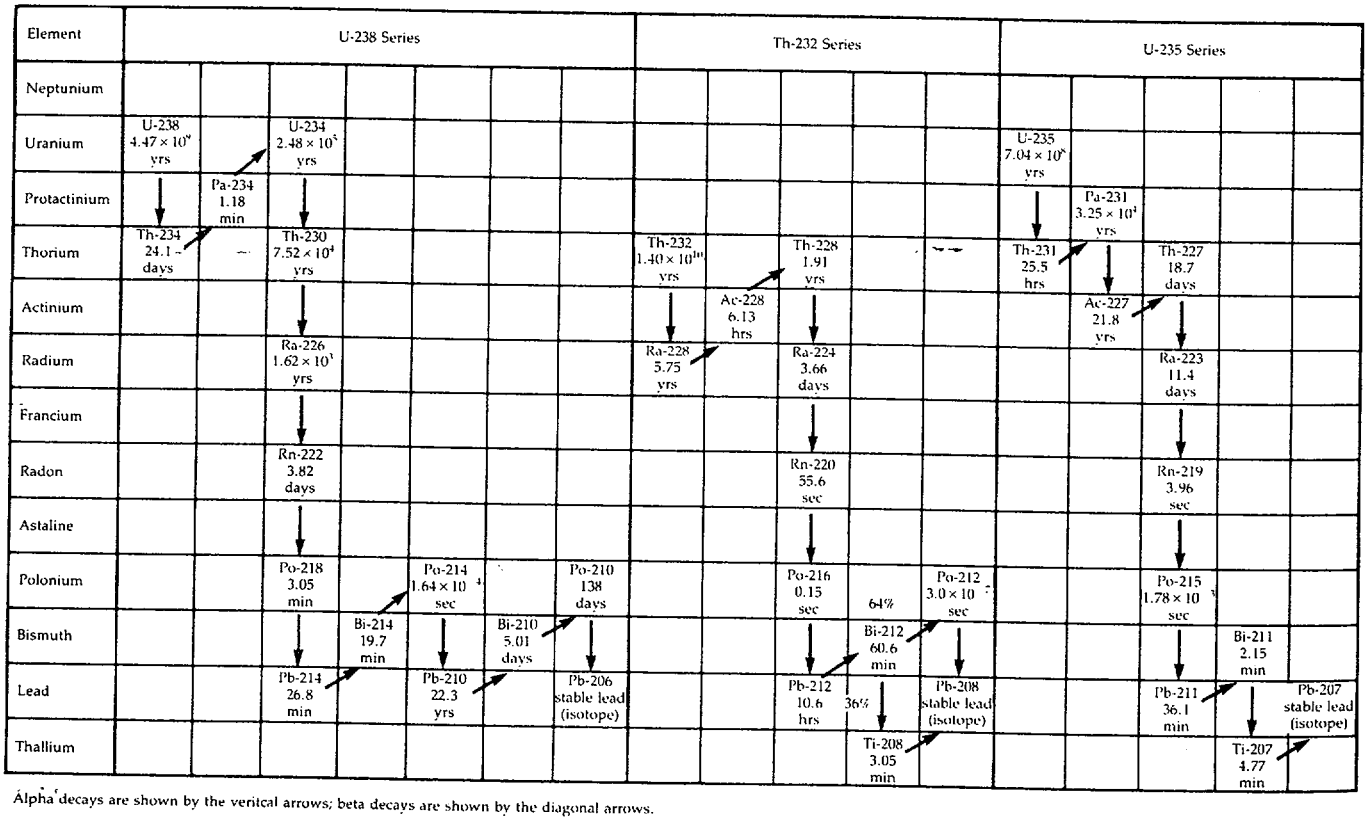
The travel distance of emitted particles depends upon their energy, usually measured in millions of electron volts (Mev), and upon the medium through which they are traveling.[20] Distances vary greatly by particle. In air, for example, the approximate path lengths are: three quarters of a centimeter per Mev for an alpha particle, and 2.5 meters per Mev for a beta particle.[21] The energy emitted by radionuclides varies from 0.019 Mev for tritium emissions to 10.54 Mev for alpha emissions from thorium.[22]

There is no simple relationship between energy and travel distance. For example, the neutron, which has the same atomic mass as a proton, travels a greater distance than does a proton, because the neutron has no charge.[23] Travel paths are reduced when particles travel in denser media.[24]

The decay time, called *half-life*, is the time required for one half the atoms in a sample of a radioactive element to decay.[25] Radionuclides with short half-lives decay quickly to stability. For example, tritium whose half-life is 12.26 years, decays to less than one-thousandth of its original number in ten half-lives (or 122.6 years). Emission rates and decay rates of radionuclides vary considerably; it takes 1.28 billion years for half of a quantity of potassium-40 nuclides to decay to the stable isotope potassium-39; the same number of oxygen-19 nuclides would take 29 seconds to decay to the stable nuclide oxygen-18.[26]

Some elements decay to another unstable radionuclide rather than to a stable isotope. An example is the complicated uranium-238 decay series, shown in Figure A-1, in which uranium decays 14 times before it finally comes to rest as the stable lead-206 isotope.

A common measure of radioactivity is the *curie*, defined as the quantity of any radioactive nuclide which undergoes 3.7 x 10^{10} disintegrations per sec-



Alpha decays are shown by the veritcal arrows; beta decays are shown by the diagonal arrows.

Figure A-1.—Decay Chain of the Uranium and Thorium Series Isotopes.

Source: Broecker, W.S., and T.-H. Peng. 1982. Tracers in the Sea. Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York.

ond.[27] Thus, a curie measures only the number of disintegrations, not the kind of radiation emitted, nor the energy emitted. For example, potassium-40, the main contributor to natural radioactivity in seawater, (see Table IV-2 of this report) emits a beta particle of relatively high maximum energy (1.35 Mev) and a gamma ray of high energy (1.46 Mev). In contrast, the radionuclide tritium, a hydrogen isotope that contributed most of the radioactivity to the sea from the nuclear weapons tests (see Table II-2 of this report) emits only a weak beta particle (0.019 Mev).[28] Thus, a curie of potassium-40 represents a far greater potential for physiological damage than does a curie of tritium.

There are three sources of ionizing radiation on Earth. Cosmic radiation consists of both the charged particles arriving from outer space and the secondary particles generated from the interaction of the original particles with the atmosphere.[29] Other radiation results from the decay of radionuclides that are naturally present in the Earth's components. These two sources together are called natural radiation. The third source of ionizing radiation results from the activities of human beings, including nuclear weaponry, nuclear power, medical procedures, and consumer products.[30]

Radiation from nuclear fission and the resulting radionuclides is by far the largest source of radiation hazard.[31] So far nuclear fission has been the source of energy for all nuclear power plants. Of all the isotopes known, only uranium-233, uranium-235, and plutonium-239 are fissionable.[32] Of these, only uranium-235 is found in nature;[33] the other two are anthropogenically produced in nuclear reactors. When an atom of one of these three isotopes is struck by a neutron, the neutron may be absorbed into the nucleus, causing the fissile isotope to break into two roughly equal parts, releasing energy and usually two or three neutrons. The energy at first is in the form of kinetic energy of the fission fragments,[34] but this is converted into heat as the fragments slow down. A typical fission reaction is:[35]

$$^{235}_{95}U + n = {}^{95}_{42}Mo + {}^{139}_{57}La + 2n + 205 \text{ Mev energy}$$

(In other words: uranium-235 absorbs a neutron and yields the elements molybdenum and lanthanum, plus two neutrons and 205 million electron volts of energy.)

Fissile atoms can be caused to undergo fission by a single neutron, fast or slow, with kinetic energy that may be no greater than a small fraction of an electron volt.[36] If one of the neutrons released during fission can be used to induce another atom to fission, the process can be maintained. The amount of fissile material required to sustain a chain reaction is called the critical mass. This amount depends on the concentration of the fissile material and its surroundings, which may or may not be reflective of neutrons. Devices used to control the rate of the fission process after critical mass is reached are called nuclear reactors. If two subcritical masses are combined very quickly so that an uncontrolled chain reaction occurs, the violent explosion of an atomic bomb occurs.[37]

In nuclear reactors, the neutrons given off during fission must be slowed down because at first they are too energetic and the probability of causing fission is much greater for slow neutrons. The fissile material is therefore surrounded by a light material such as hydrogen or carbon with which neutrons collide and thereby lose energy. The rate of fission in a reactor is controlled by control rods, made of materials such as boron or cadmium, which have extremely large probabilities of absorbing neutrons. The rods are gradually pulled out of the reactor to allow fission to proceed, and adjusted to produce the desired rate of fission.[38]

Health Physics

Ionizing radiation can injure humans by causing changes in the chemical reactivity of cellular components. Molecules can be damaged so they cannot function normally, or the products of molecular disintegration can tend to clog and poison the cell. If only a relatively few atoms in a cell are ionized, it may recover from the damage without difficulty. But if a relatively large number of ionizations occur, the cell may be unable to carry on its activities and die. Injury to chromosomes can occur when cells are irradiated, and it has been proved by experiments with insects, mammals, and plants that X-rays and the nuclear radiations (alpha, beta, gamma, neutron) cause mutations. There is every reason to believe that cosmic rays have similar genetic effects.[39]

The degree of injury caused by radiation depends in part on the type of particle or ray,[40] and the amount of energy in the emission.[41] The relative localization or dispersion of the effects of ionizing radiation affects the body's ability to repair damage; the massive local damage done by non-penetrating particles is generally more harmful than is the damage caused by rays that spread the same amount of energy through larger volumes of the body. Alpha particles cause damage that is essentially non-repairable.[42] The degree of damage also depends on the type of tissue irradiated, with rapidly dividing cells being especially sensitive.[43]

The basic unit of radiation dose is the rad. One rad equals 100 ergs of energy deposited per gram of absorption material.[44] The basic health radiation unit is the rem, which is an abbreviation of "rad equivalent in man."[45] A rem is that dose of ionizing radiation, measured in rads, which produces in humans a biological

effect equivalent to that produced by one rad of X-rays or gamma rays.[46] For example, for equal amounts of energy transferred to tissue, neutrons cause 10 times the damage of X-rays, and alpha particles cause 20 times the damage of X-rays. Therefore, one rad of neutrons represents 10 rems, and one rad of alpha radiation represents 20 rems. X-rays, gamma rays, and beta particles all cause about equal damage per unit energy, so for these radiations one rad equals one rem.[47]

Organisms living on Earth receive ionizing radiation from a variety of sources, and the amount of natural radioactivity to which humans are subjected is varied. The intensity of cosmic radiation depends on altitude due to absorption of the rays by the atmosphere, and on latitude, because the Earth's magnetic field deflects cosmic rays away from the equator. Inhabited areas of the Earth receive cosmic radiation varying from 35 millirems per year to 300 millirems per year. Seattle receives about 50 millirems and Denver about 90 millirems per year from cosmic radiation.[48]

Natural radiation from the radionuclides in the Earth's crust also is highly variable from one region to another. In general, natural radionuclides are concentrated in granite rocks. Limestone and sandstones are low in radioactivity, but certain shales are very radioactive, especially those containing organic matter. The average dose at a height of about one meter above limestone is about 20 millirems per year, while for granite areas the corresponding figure is 150 millirems per year.[49]

In some places, natural radioactivity is much higher than average. In India, a population of over 100,000 people live in an area that gives them an average dose of 1,300 millirems per year. In the Northern Nile Delta, people in several villages receive doses of 300 to 400 millirems per year. About seven million people in France live in areas where the rocks are principally granite, which exposes them to doses of 180 to 350 millirems per year.[50]

So far it has not been possible to establish any connection between the level of background radiation and differences in biological disorders. Differences in other health-related factors between various areas of the world make conclusions about the effects of background radioactivity difficult; however, no differences have so far been detected in genetic anomalies or the incidence of cancer between various peoples of the world who live in areas where natural background radiation levels differ by a factor of 10. This gives some justification for thinking that small amounts of anthropogenic radiation are unlikely to cause detectable harm to a human population.[51]

In the last century, human exposure to natural radiation has increased due to such technological developments as air travel and the use of naturally radioactive goods—phosphate fertilizers, natural gas, coal, and oil. Additional exposure occurs from radiation-emitting consumer products, medical uses of radiation, the nuclear fuel cycle, and nuclear explosions.[52] The total exposure to U.S. citizens each year is summarized in Table A-1.

What constitutes a safe level of radiation for humans? The potential effects of ionizing radiation have been a concern to scientists for several decades. The International Commission on Radiological Protection (ICRP), formed in 1928, and the National Council on Radiation Protection and Management (NCRP), a U.S. organization formed in 1929 as the Advisory Committee on X-Ray and Radiation Protection, are the oldest scientific organizations with responsibility for the health effects of the radiation. Since their beginnings, the accepted "safe level" of radiation dose has steadily decreased from 0.1 roentgen/day in 1934 to 15 rem/year in 1950, and to 5 rem/year today.[53] (See Table A-2.) Recommendations by research groups to advisory bodies have become more conservative as knowledge of radiation effects and the desire to avoid those effects have increased. Radiation protection guidelines have become dependent upon public value judgments and a concept that some risk exists at all levels of exposure.[54]

The present system of ICRP dose limits, summarized in Table A-2, incorporates objectives which aim to ensure that: 1) no practice shall be adopted unless its introduction causes a positive net benefit (that is the combined effects of the costs, risks, and benefits of procedures utilizing radiation must be more favorable than those of alternative procedures that do not use radiation); 2) all exposures shall be kept "as low as reasonably achievable," with economic and social factors being taken into account, (known as the ALARA principle for *a*s *l*ow *a*s *r*easonably *a*chievable); and 3) the dose equivalent to individuals shall not exceed the limits recommended by the ICRP.[55]

In setting a tolerance level of 5 rem per year, the ICRP has not defined an acceptable level of risk, but rather taken the position that this level is the maximum allowable and should be rarely approached and never exceeded. Together with the ALARA principle, the 5 rem/year limit results in individuals working around radioactive materials receiving only about one-tenth of that level, or 500 mrem per year. Furthermore, the ICRP limits result in the general public receiving no more than 50 mrem per year beyond natural doses.[56]

Table A-1.—Annual Dose Rates from Radiation Exposure in the United States

Source	*Exposed Group*	*Part of body exposed*	*Average dose mrems/year*
Natural Background			
Cosmic radiation[1]	Total Population	Whole Body	28
Terrestrial radiation[2]	Total Population	Whole Body	26
Radionuclides inside human bodies	Total Population	Gonads	28
Radionuclides inside human bodies	Total Population	Bone Marrow	24
Medical X-rays	Patients	Bone Marrow	106
Medical radiopharmaceuticals	Patients	Bone Marrow	300
Atmospheric weapons testing	Total Population	Whole Body	4 to 5
Nuclear power plants	Population within 10 miles of plant	Whole Body	Less Than 10
Research activities	Research Workers	Whole Body	Unknown
Consumer products			
Building materials	Population in Brick and Masonry Buildings	Whole Body	7
Television receivers	Viewing Populations	Gonads	0.2 to 1.5
Luminous compounds			
Wrist Watches	Persons using product	Gonads	1 to 3
Clocks	Persons using product	Whole Body	9
Cumbustion of fossil fuels			
Coal	Persons using Product	Lungs	0.25 to 4
Oil	Persons using Product	Lungs	0.002 to 0.4
Natural gas			
Cooking ranges	Persons using Product	Bronchial Epithelium	6 to 9
Unvented heaters	Persons using	Product	22

Sources: Adapted from: Committee on the Biological Effects of Ionizing Radiations. 1980. The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980. (commonly called the BEIR III Report) National Academy of Sciences, National Academy Press, Washington, D.C., p. 38, 42, and 66.

National Council on Radiation Protection and Measurements. 1977. Radiation Exposure from Consumer Products and Miscellaneous Sources. NCRP Report No. 56, Washington, D.C., p. 29.

Table A-2.—Guidelines for Radiation Protection

	National Council on Radiation Protection (NCRP)		International Commission on Radiological Protection (ICRP)	
Year	*Limit*	*Annual Equivalent*	*Limit*	*Annual Equivalent*
1934	0.1 R/day[1]	30 R[2]	0.2 R/day[3]	60 R
1949-54	0.3 rem/week	15 rem*		
1950-54			0.3 rem/week	15 rem
1957	5(N- 18) rem[4] 10 rem/30 year	5 rem (15 rem maximum) Public: 1/3 rem average		
1958			5(N-18)rem	5 rem (15 rem maximum) Public: 5 rem/30 year 170 mrem average
1971	5(N- 18) rem	5 rem (15 rem maximum) Public: 500 mrem, individual 170 mrem, average		
1977			5 rem/year	5 rem Public: 500 mrem (maximum) 50 mrem average

[1] The original levels were set at 1/10 the dose that caused abnormal redness of the skin. When radiation use was seen to be increasing, the limits were lowered, just to be more cautious. In the 1950s, concern over genetic effects of radiation caused the limits to be lowered still further.

[2] Although roentgens were originally used as the unit of measure, rems are now used so the biological significance of all forms of ionizing radiation can be considered and controlled. (For X-rays and gamma rays, 1 roentgen = 1 rad = 1 rem).

[3] ICRP used the same information as NCRP to set this level, but ICRP rounded the data differently and arrived at higher allowable limits.

[4] Represents the person's age in years.

Source: Warren K. Sinclair, 1981. Radiation Protection: The NCRP Guidelines and Some Considerations for the Future. *Yale Journal of Biology and Medicine* 54:473.

References and Footnotes

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[3] *Ibid.*, p. 2.

[4] United States Public Health Service. 1970. Radiological Health Handbook. Department of Health, Education, and Welfare, Washington, D.C., p. 231.

[5] Lyman, James D. 1966. Nuclear Terms, A Brief Glossary. U.S. Atomic Energy Commission, Oak Ridge, Tennessee, p. 57.

[6] Sorenson, *op. cit.*, p. 13, 18.

[7] *Ibid.*, p. 137.

[8] *Ibid.*, p. 27.

[9] Davis, George E. 1967. Radiation and Life. The Iowa State University Press, Ames, Iowa, p. 8, 149-150.

[10] Sorenson, *op. cit.* p. 19.

[11] Davis, *op. cit.*, p. 7, 148.

[12] *Ibid.*, p. 260.

[13] Shapiro, Jacob. 1981. Radiation Protection: A Guide for Scientists and Physicians. Harvard University Press, Cambridge, Massachusetts, p. 36.

[14] Davis, *op. cit.*, p. 150.

[15] Shapiro, *op. cit.*, p. 38.

[16] Davis, *op. cit.*, p. 150, 260.

[17] *Ibid.*, p. 265.

[18] Sorenson, *op. cit.*, p. 22, 23.

[19] Davis, *op. cit.*, p. 165, 265, 269.

[20] Sorenson, *op. cit.*, p. 1, 2, 146.

An electron volt is defined as the amount of energy acquired by an electron when it is accelerated through an electrical potential of one volt; it is approximately 1.602×10^{-12} ergs. A million electron volts, then, is about 1.6×10^{-6} ergs.

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[26] *Ibid.*, p. B-256--B-261.

[27] *Ibid.*, p. F-87.

[28] *Ibid.*, p. B-256, B-261, B-341.

[29] National Council on Radiation Protection and Measurements. 1975. Natural Background Radiation in the United States. NCRP Report No. 45. Washington, D.C., p. 8.

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[38] *Ibid.*, p. 48.

[39] Davis, *op. cit.*, p. 260, 291.

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[41] Shapiro, *op. cit.*, p. 8.

[42] *Ibid.*, p. 34.

[43] Ford Foundation. 1977. Nuclear Power Issues and Choices. Nuclear Energy Policy Study Group, The Mitre Corporation, Ballinger Publishing Company, Cambridge, Massachusetts, p. 164-165.

[44] Sorenson, *op. cit.*, p. 171.

[45] Hall, *op. cit.*, p. 18.

[46] Davis, *op. cit.*, p. 278.

[47] Sorenson, *op. cit*, p. 347.

[48] Hall, *op. cit*,. p.50.

[49] *Ibid.*, p. 50-51.

[50] *Ibid.*, p. 52-53.

[51] *Ibid.*, p. 53-54.

[52] National Council on Radiation Protection and Measurements. 1977. Radiation Exposure From Consumer Products and Miscellaneous Sources. NCRP Report No. 56. Washington, D.C., p. 1.

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[54] National Council on Radiation Protection and Measurements. 1971. Basic Radiation Protection Criteria. NCRP Report No. 39. Washington, D.C., p. iii.

[55] Temple, *op. cit.*, p. 5.

[56] Sinclair, *op. cit.*, p. 475.

APPENDIX B
Summary of Waste Management Strategies of Other Nations[1]

(as of February 1984)

NATION	*WASTE MANAGEMENT STRATEGY*
Argentina	Argentina is considering vitrifying liquid high-level waste and placing it in a granite repository at a depth of 500 meters.
Belgium	Belgium's nuclear fuel cycle activities and waste management research are centered at Mol, where area residents are receptive to its location. (The Belgian centralized government has conducted an extensive public information program.) Boom clay underlies the Mol area and is being investigated as a permanent repository for high-level waste, which is presently contained in stainless steel tanks.
Canada	Canadian research for a repository for high-level waste is focused on the use of the crystalline Canadian granite shield in Ontario, an area where most of the nuclear power facilities are located. Canada does not reprocess spent fuel; its spent fuel is contained in surface and near-surface engineered structures.
Czechoslovakia	Czechoslovakian spent fuel is returned to its supplier, the Soviet Union. A pilot scale solidification process for high-level waste was due on line in 1982, and an experimental storage facility is due in the late 1980s.
Denmark	Denmark is examining underground disposal of vitrified high-level waste—most probably in natural salt domes such as those located at Mors.
Egypt	Egypt is constructing an experimental radioactive waste management station at its Nuclear Research Center near Cairo.
Federal Republic of Germany	The Federal Republic of Germany is studying various salt formations for disposal of vitrified waste. An abandoned salt mine at Asse has functioned as a pilot plant and test facility (1967-1978). Gorleben, located in Lower Saxony, has been approved as a permanent repository. Liquid wastes from the reprocessing plant at Karlsruhe are stored in stainless tanks.
Finland	Finland is investigating crystalline rocks for possible repositories for solidified wastes returned from the Soviet Union, its fuel supplier and reprocessor.
France	France's treatment of high-level waste is the most advanced among the nations of the Organization for Economic Cooperation and Development (OECD). The central government exerts authority among the local populace through its appointed officials, the prefects. This authority is supplemented by strong centralization through the French Atomic Energy Agency (CEA), and its nationalized electricity supplier, (EdF). This centralized role of French government is reinforced by an active program of public education on the benefits of nuclear power. A pilot scale vitrification plant has operated at Marcoule, in Southeast France, since 1978. A second full-scale plant is targeted for 1986. Several sites are under study for disposal of vitrified waste after interim storage in air-cooled vaults.

German Democratic Republic	The German Democratic Republic disposes of its radioactive wastes in a reconstructed salt mine operated by its nuclear power utility. Spent fuel is returned to its supplier, the Soviet Union.
India	High- and medium-level liquid reprocessing wastes are kept in interim storage at Tarapur. A small vitrification plant has been in operation since 1981. Vitrified wastes are stored in air-cooled vaults. India is examining igneous and sedimentary rock formations as eventual repository sites.
Italy	A pilot reprocessing plant has been in operation since 1970. Small quantities of liquid high-level waste are stored in stainless steel tanks awaiting vitrification. Italy plans an underground research laboratory for studying geological disposal of high-level waste.
Japan	The Japanese strategy for gaining acceptance of its nuclear facilities—located at remote coastal regions—is to financially compensate the local public. The Tokaimura reprocessing plant is well established, and about 100 companies have joined together to develop an 1,100 metric tons per year plant by 1990. Japan has investigated tuff, shale, and clay as possible repository sites. The waste generated at Tokaimura is stored in stainless steel tanks awaiting solidification. Other wastes from contract reprocessing by the United Kingdom and France eventually will be returned to Japan. Officials are investigating granite and zeolite rock formations for waste repositories. Japan plans to dispose of low-level waste in the sea, and is actively seeking political support among Pacific Ocean nations to attain that goal.
The Netherlands	The government of the Netherlands is examining a state-owned northeastern region of the country and salt deposits off the Dutch coastline; these rock salt formations in the continental shelf under the the North Sea could serve as repositories for returned solidified wastes. Spent fuel is reprocessed under contract in the United Kingdom and France. The Dutch have conducted low-level waste dumping at the Northeast Atlantic dumpsite, although this dumping has met with resistance from organized environmentalists and has been discontinued.
Spain	Spain is examining salt formations for location of two high-level waste repository sites.
Sweden	Sweden was the first OECD nation to approve an away-from-reactor storage site for spent fuel assemblies. The eventual location for the waste reprocessed from these assemblies is the granite rock of the Baltic Shield, where extensive research is underway at the Stripa abandoned iron mine. Spent fuel is reprocessed under contract to France and the United Kingdom. When returned, it will be stored in air-cooled vaults prior to permanent disposal. Temporary storage facilities are being constructed in southern Sweden for unreprocessed spent fuel. By parliamentary decision, Sweden's nuclear power program is limited to 12 reactors, all of which are to be shut down by the year 2010.
Switzerland	The Swiss—a nation of local political autonomies—have sustained public resistance to national programs of waste repository siting. The nuclear power referendum in 1979 gave the government support to proceed with a provision for safe demonstration prior to locating any permanent repository. By 1985, nuclear industry officials must show that safe disposal methods have been devised for high-level waste expected to be generated over the next 60 years. Research is focusing on deep rock caverns for both unreprocessed spent fuel and vitrified wastes returned from the United Kingdom and France. The Swiss have dumped low-level waste at the Northeast Atlantic dumpsite.
United Kingdom	Most of the promising sites in the United Kingdom for high-level waste disposal have been locally resisted; therefore, emphasis is currently directed toward interim storage of high-level waste. The only repository now under investigation is that at Dounreay, Scotland. High-level waste is stored as liquid in stainless steel tanks at Sellafield, the accumulation of 30 years from the U.K. nuclear program. The British decided to adopt the French vitrification process and are building a plant targeted for 1990. The United Kingdom plans surface storage for at least 50 years, although studies will be conducted on possible future disposal in deep

geologic formations. The United Kingdom was the primary nation dumping low-level waste at the Northeast Atlantic dumpsite.

Union of Soviet Socialist Republics	The Soviets are generally secretive about their waste disposal procedures, but some information is known. They probably do not reprocess spent fuel from nuclear power generating stations. They are probably working on a vitrification process for high-level waste in anticipation of reprocessing spent fuel, but it has probably not yet been demonstrated. They are currently testing metal and concrete canisters for surface land-based storage of high-level waste, and they are investigating various geological formations, especially salt deposits, for repositories of high-level waste. They have reportedly experimented with injecting liquid high-level waste into water-bearing porous rock 350 meters below the surface of the land. The water in these rocks is said to be stagnant. The wastes are injected at 10 to 12 atmospheres pressures. Reports concerning Soviet low-level waste and intermediate level waste disposal are several years old and include storage of low-level waste in metal-lined concrete reservoirs, and injection of liquid wastes into underground strata that are said to contain "stagnant" groundwater. In 1976, they injected 75,000 cubic meters of intermediate-level waste into strata 1,500 meters deep. In 1977, the Soviets reported that they think pressurized injection into the groundwater of certain deep strata is adequate for disposal of wastes containing up to 100 curies of radioactivity per liter.

In 1976, a Seabed Working Group was established to coordinate international assessment of subseabed disposal under the auspices of the Nuclear Energy Agency in the Organization for Economic Cooperation and Development. Nations currently researching subseabed disposal of high-level waste are Canada, Federal Republic of Germany, France, Japan, the Netherlands, Switzerland, the United Kingdom, and the United States. The Commission on European Communities also is a member of the Seabed Working Group, and Belgium and Italy have participated as observers at meetings on subseabed disposal research.[2] In the United States, DOE has lead responsibilities for directing the U.S. Subseabed Disposal Program. The prime contractor for DOE is Sandia National Laboratories; about 50 percent of the research and development is subcontracted to academic institutions.

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For additional information on strategies for disposal of high-level wastes of other countries, see:

Layman, Patricia. 1983. Other countries choose various high-level waste disposal strategies. *In* Pamela S. Zurer, U.S. Charts Plans for Nuclear Wastes Disposal. *Chemical and Engineering News* (61):34-35.

APPENDIX C
U.S. Ocean Dumping of Radioactive Waste

From 1946 to 1970, the United States dumped low-level radioactive wastes into the ocean under the licensing and contracting authority of the Atomic Energy Commission (AEC). Most of these wastes, packaged in steel drums weighted with concrete, were dumped in the ocean at various depths. As a 1981 report of the General Accounting Office (GAO) stated:

At the time, the containers were not intended to permanently contain the waste. They were intended only to ensure that it descended to the ocean floor where ocean currents would dilute and disperse the radioactivity to insignificant concentrations.

In 1960, the AEC opened land burial sites to all generators of radioactive waste, and ocean dumping decreased dramatically. By 1970, ocean dumping of radioactive waste had ceased.

During the almost 25 years of ocean dumping, the U.S. Navy performed most of the actual dumping for the AEC. When ocean dumping of radioactive wastes was performed under contract or interagency agreement directly for the AEC, no license and definitive accounting of the waste was required. Information that was reported varied greatly and often did not indicate the amount of waste involved or the exact location of its dumping.

On the other hand, licenses, issued by the AEC, were required for commercial disposal agents to dispose of low-level radioactive waste in the ocean. According to GAO, "a disposal agent's license prescribed an area of the ocean where the waste could be dumped, the basic types of waste that could be dumped, and the depth of the water at the dumpsite." The material to be reported fell into one of three categories: by-product, source, or special nuclear material. GAO reports that these agents were not, however, required to report the specific amounts or kinds of waste, and consequently, records for commercial dumping activities "were no more than gross approximations of their extent and location."

According to GAO, DOD reporting policies were equally as vague:

... In fact, the Navy had no detailed information on its Pacific Ocean dumping activities, and its information regarding the Atlantic Ocean was nonexistent with the exception of a few years. Moreover, for the years in which records were available, they included only dates, locations, broad characterizations of the contents such as "atomic waste' or "radioactive waste" and the volume of material in the waste containers. There was no information about the specific kinds of material or its radioactive level.

NACOA's search of the literature on U.S. ocean dumping practices during this period reveals many discrepancies in the actual number and location of these dumpsites. It appears that most of the radioactive waste was dumped at four major dumpsites, three in the Atlantic Ocean and one in the Pacific Ocean. The fact remains, as GAO clearly states:

... —the Federal Government has no complete and accurate catalogue of information on how much, what kind, and where low-level nuclear waste was dumped because detailed records were not required....

As part of its mandated responsibility under the 1972 Marine Protection, Research and Sanctuaries Act, Public Law 92-532, the Environmental Protection Agency (EPA) is attempting to collect data on the extent and location of past U.S. ocean dumping practices for low-level waste. The table contained in this appendix represents information gathered by EPA and presented in testimony before the House Subcommittee on Oceanography of the Merchant Marine and Fisheries Committee.

Source: U.S. General Accounting Office. 1981. Hazards of Past Low-Level Radioactive Waste Ocean Dumping Have Been Overemphasized. EMD-82-9, Washington, D.C., p. 2-9.

TABLE OF U.S. OCEAN DUMPING Of RADIOACTIVE MATERIALS

(as prepared by the Environmental Protection Agency)

Pacific Ocean Disposal Sites

Recorded Site Designation(s)[1-8]	Depth (meters)	Central Coordinates[2]	Relation to Land[3]	Material[4]	Activity[5]	Containers[6]	Agents[7]	Years Used
P1 Farallon Islands (8)	896-1,700	37°38'N 123°08'W	25-60 miles WSW of San Francisco	B,S, SNM	14,500	47,500	NEC,OTC, CR, AEC, USNRDC	1946-1970
P2 Hawaiian Island (8)[9]	3,500	21°28'N 157°25'W	20 miles NE of Honolulu*	B	00.9	39	UH	1959-1960
P3 Midway Island (1)	5,490	34°58'N 174°52'W	300 miles NE of Midway Islands*	B	14	7	MSTS	1959-1960
P4 Santa Cruz (3)	1,830-1,940	33°40'N 119°35'W	35 miles SW of Port Hueneme	B,S	108	3,114	PN,AEC	1946-1962
P5 (1)	3,294	42°12'N 129°31'W	230 miles W of Or/Ca border*	B	0.95	26	CR	1955-1958
P6 (1)	2,928	43°52'N 127°44'W	190 miles NW of Or/Ca border*	B	0.08	4	CR	1960
P7 (1)	4,099	42°04'N 125°01'W	35 miles W of Or/Ca border*	B	0.08	4	CR	1960
P8 Los Angeles (2)	3,660-4,570	30°43'N 139°05'W	1000 miles WSW of Los Angeles*	B	0.95	26	CR	1955-1958
P9 (1)	3,477	28°47'N 135°00'W	800 miles SW of San Francisco*	B	1.1	29	CR	1955-1960
P10 San Diego (1)	2,210-3,660	32°00'N 121°30'W	225 miles SW of San Diego	B,S, SNM	34	4,415	CMDC, ISC	1959-1962
P11 Cape Mendocino (1)	1,830-1,990	40°07'N 135°24'W	800 miles WNW of San Francisco*	B,S	0.22	29	AML	1960
P12 Cape Scott 1 (1)	3,294	50°56'N 140°12'W	350 miles NW of Cape Flattery*	B,S	96	197	AML[10]	1958-1966
P13 Cape Scott 2 (1)	3,294	52°25'N 140°12'W	550 miles NW of Cape Flattery*	B,S	28	163	AML[10]	1962-1969
North Pacific (1)		51°30'N 136°31'W			0.54	38		1946-1962
North Pacific (1)		52°05'N 140°00'W			0.54	41		1946-1962
North Pacific (Unk.)		47°00'N 138°54'W			97.4	361		1946-1966
(1)	1,830				1.2	37		1946-1962
(1)					96.5	231		1963-1966

Atlantic Ocean Disposal Sites

Recorded Site Designation(s)[1-8]	Depth (meters)	Central Coordinates[2]	Relation to Land[3]	Material[4]	Activity[5]	Containers[6]	Agents[7]	Years Used

A1 Massachusetts Bay (1)	92	42°25'N 70°35'W	Massachusetts Bay	B,S	2,440	4,008	CMDS	1952-1959
A2 Cape Henry (5)	1,830-1,967	36°56'N 74°23'W	80 miles E of Cape Henry	B	87	843	NIH	1949-1967
A3 Sandy Hook 1 (1)	1,830-2,800	38°30'N 72°06'W	140 miles SE of Sandy Hook*	B	74,400	14,301	AEC	1951-1956 1959-1962
A4 Sandy Hook 2 (1)	1,830-3,800	37°50'N 70°35'W	220 miles SE of Sandy Hook*	B	2,100	14,500	AEC	1957-1959
A5 Charleston (13)	915-3,660	31°32'N 76°30'W	220 miles E of Charleston*	B	0.66	119	SMO, ARC	1955-1962
A6 Morehead City (1)	18	34°32'N 76°40'W	15 miles S of Morehead City*	B	0.3	unpackaged	FWS	1955-1961
A7 thru A11 Central Atlantic	3,660-5,289	36°20'N 43°49'N 45°00'W		B	480	432	MSTS	1959-1960
A12 Sapelo Island	11		Off Coast of Sapelo Islands	B	0.005	liquid	UG	1955-1960

Gulf of Mexico Disposal Sites

Recorded Site Designation(s)[1-8]	Depth (meters)	Central Coordinates[2]	Relation to Land[3]	Materials[4]	Activity[5]	Containers[6]	Agents[7]	Years Used
GM1	1,930	27°14'N 89°33'W	170 miles S of New Orleans, LA*	B	10	I	MP	1958
GM2	3,111	25°40'N 85°17'W	250 miles SE of Appalachicola, Fla*	B	0.002	78	SMO	1955-1957

[1] In contracting and licensing the ocean dumping of radioactive wastes, the AEC designated general areas for approved dumping. In some instances these areas were identified by single coordinates and the wastes were concentrated in relatively specific areas, while in other instances the AEC designated much broader areas and allowed those dumping to proceed according to general guidelines. Dumping under these designations resulted in much less concentrated dumping activities and a multitude of individual "dumpsites." The number of such individual dumpsites under a particular heading in this column is indicated in parentheses. The designation A1 through A12, GM1 and GM2, and P1 through P13 refer to the NRC site numbering system.

[2] Central coordinates designate dumping areas thought to have received concentrations of waste materials. Actual coordinates may have varied over wider distances.

[3] Approximations for land references: an asterisk means that EPA has not plotted the coordinates on nautical charts to confirm the stated distance from land; blanks mean we haven't found the information yet.

[4] Three types of materials were dumped under AEC licenses or by AEC contractors: by-product materials (B), source materials (S), and special nuclear materials (SNM). By-product materials refer to a wide variety of substances which were exposed to incidental radiation. Source materials include uranium and thorium. Special nuclear materials include plutonium, uranium-233, enriched uranium-233 or 235, and any other materials which the AEC may have determined to be special nuclear materials.

[5] Radioactivity is given in estimated curies at the time of packaging.

[6] Waste materials were generally either packaged in special containers which were then placed in concrete-filled steel drums, or mixed directly in concrete which was in turn placed in the steel drums.

[7] AEC: U.S. Atomic Energy Commission; AML: American Mail Lines; ARC: Atlantic Refining Company; CMDC: Coastwise Marine Disposal Corporation; CR: Chevron Research; FWS: U.S. Fish and Wildlife Service; ISC: Isotope Specialty Company; MP: Magnolia Petroleum; MSTS: Military Sea Transport Service; NEC: Nuclear Engineering Company; NIH: U.S. National Institute of Health; NRDL: U.S. Naval Radiation Development Laboratory; OTC: Ocean Transport Company; PN: Pneumodynamics; SMO: Socono-Mobile Oil; UG: University of Georgia; UH: University of Hawaii.

[8] There were some AEC approved ocean dumping sites for which EPA has no records of dumping activities. They are as follows:

Pacific Ocean

39°30'N; 125°40'W
37°40'N; 124°50'W
36°00'N; 124°00'W
34°30'N; 122°50'W

Atlantic Ocean

41°33'N; 65°30'W
41°33'N; 65°33'W
41°28-38'N; 65°28-45'W
38°30'N; 72°00'W
36°30'N; 74°13'W
36°15'N; 76°35'W
34°15'N; 76°35'W

[9] Based on NRC memorandum of 8/14/80 additional dumpings appear to have taken place in the 1960's and are being characterized in ongoing records research.

[10] Under the terms of the AML license, AML was authorized to dunp along the path of its shipping route beyond depths of 1,000 fathoms (1,850 meters).

[11] Report published by NOAA in April 1973, *Submersible Inspection of Deep Ocean Waste Disposal Sites Off Southern California* describes survey of Santa Cruz Basin.

* See note number[3], above.

Source: Mattson, Roger J. 1980. Prepared Statement of Roger J. Mattson, Director, Surveillance and Emergency Preparedness Division, Office of Radiation Programs, U.S. Environmental Protection Agency. *In* Radioactive Waste Disposal Oversight Hearings (November 20) before the Subcommittee on Oceanography of the Committee on Merchant Marine and Fisheries, U.S. House of Representatives, 96th Congress, Serial No. 96-53, Washington, D.C., p. 361-366.

APPENDIX D
Signatory Countries to the London Dumping Convention

Contracting Parties to the *Convention on the Prevention of Marine Pollution by Dunping of Wastes and Other Matter* (December 29, 1972 London: IMO, 1972), as of January 1, 1983:

Afghanistan
Argentina
Belize
Brazil
Byelorussian Soviet Socialist Republic
Canada
Cape Verde
Chile
Cuba
Denmark
Dominican Republic
Federal Republic of Germany
Finland
France
Gabon
German Democratic Republic
Greece
Guatemala
Haiti
Honduras
Hungary
Iceland
Ireland
Japan
Jordan
Kenya
Kiribati
Libya
Mexico
Monaco
Morocco
Nauru
Netherlands
New Zealand
Nigeria
Norway
Onam
Panama
Papua New Guinea
Philippines
Poland
Portugal
Seychelles
Solomon Islamds
South Africa
Spain
Suriname
Sweden
Switzerland
Tunisia
Tuvalu
Ukrainian Soviet Socialist Republic
Union of Soviet Socialist Republics
United Arab Emirates
United Kingdom
United States
Yugoslavia
Zaire

Source: U.S. Department of State. 1983. Treaties in Force. A List of Treaties and Other International Agreements of the United States in Force on January 1, 1983. Publication 9351, Office of the Legal Advisor, Washington, D.C., p. 253.

APPENDIX E
Case Histories

Hanford

The first deliberate introduction of anthropogenic radioactivity into the ocean was via the Columbia River when nuclides were added to the river at the Hanford Reservation near Richland, Washington, 360 miles upstream from the mouth of the river. Beginning in the 1940s, thousands of curies of low-level nuclides were discharged through the cooling water of Hanford's reactor plants. Unlike present nuclear power reactors where the primary coolant is contained in a closed system, the Hanford plutonium production reactors were cooled by water that passed through the reactors and was then discharged into the Columbia River. Nine reactors were built at Hanford; during full operation (from 1955 to 1964), about 1,000 curies per day were deposited directly into the Columbia. The first plutonium-producing reactor at Hanford began operations in 1944, and the last reactor to be cooled by river water was shut down in January 1971.[1]

To determine the effects of Hanford's discharges on the Columbia River, laboratory studies were initiated at the University of Washington in 1943 and at the Hanford Laboratories in 1945. Field studies were begun in 1946 by Hanford. After the detonations of the atomic bombs at Hiroshima and Nagasaki, public awareness of Hanford's operations and programs grew substantially. By 1950, seven State and Federal agencies had participated in reviews of Hanford's programs related to the Columbia River, including the Columbia River Advisory Group, which was formed in 1949. For 15 years, they provided advice on program direction and waste disposal practices. In 1950, the U.S. Public Health Service undertook a two-year comprehensive study of radionuclides in the Columbia River. The study of the estuary and marine environments were incidental to the studies of the river itself until the Columbia River Marine Programme was organized by the Atomic Energy Commission in 1960. Participants in the program were the University of Washington, Oregon State University, the Oregon Fish Commission, and the U.S. Bureau of Commercial Fisheries. The fruits of their efforts were published in the 1972 book, "The Columbia River Estuary and Adjacent Ocean Waters."[2]

Such major U.S. living marine resources as fish, razor clams, dungeness crabs, and oysters were in the pathway of Hanford's radioactive outpourings. Although 20 radionuclides accounted for 98 percent of the radioactivity in reactor cooling water four hours after irradiation, by the time the water reached the ocean only three nuclides (chromium-51, zinc-65, and phosphorus-32) remained as significant contributors to the radioactivity in the river. Some radionuclides still remain in river bottom sediments, mostly behind the four dams between Hanford and the ocean. However, the results of the investigations by independent academic researchers is summed up by one of the primary researchers, who concluded that "... the discharge from the Columbia River of ^{51}Cr, ^{65}Zn, and ^{32}P from the Hanford plutonium producing reactors into the North Pacific Ocean at the rate of about 1000 curies per day did not affect marine organisms or jeopardize the health of man."[3]

Pacific Fallout

On March 1, 1954, a small Japanese fishing vessel, the *DAIGO FUKURYU-MARU (LUCKY DRAGON V)*, was working 110 kilometers east of the Bikini-Eniwetok atolls during U.S. nuclear testing. The fishermen were heavily exposed to radiation, and upon return to port their fish catch was found to be heavily contaminated by fallout. Many other fishing boats were also heavily contaminated. In response to this incident, the research vessel *SHUNKOTSU-MARU*, which belonged to the Japanese Fisheries Agency, was sent to the equatorial North Pacific in May of 1954. From an area west of Bikini, the research vessel tracked residual radiation in the upper surface waters westward toward Japan, and found high activity in the seawater 450 km west of Bikini (91,000 dpm/l), and activity greater than 1,000 dpm/l 2000 km from Bikini along the North Equatorial Current.

In the spring of 1955, the U.S. Atomic Energy Commission, in cooperation with the Scripps Institution of Oceanography and the University of Washington's Applied Fisheries Laboratory, conducted an expedition aboard the U.S. Coast Guard Cutter *TANEY)* to trace the radioactivity discovered during the *SHUNKOTSU-MARU* cruise. The contaminated area was located off the coast of Luzon Island of the Philippines, indicating the radioactivity was being carried west by the North Equatorial Current. In the summer of 1955, an international cooperative study by

Canada, Japan, and the United States detected radioactivity in seawater in a still larger area of the Western Pacific, indicating dispersion by the Kuroshio Current, as well as the North Equatorial Current.[4]

Beyond the findings of the Eniwetok-Bikini expeditions, a large volume of literature concerning radionuclide distribution and cycling from both fallout and waste disposal has led to an understanding of critical pathways and bioaccumulation potentials in different marine organisms.[5]

U.S. Ocean Dumping

When the United States dumped low-level waste (LLW) at sea between 1946 and 1970, four major dumpsites received more than 97 percent of the total amount: an Atlantic Ocean site 140 miles southeast of Sandy Hook, New Jersey in 2,800 meters of water; another site 220 miles southeast of Sandy Hook in 3,800 meters (combined Atlantic total: about 50,000 containers, 99,500 curies); Massachusetts Bay, 15 miles east of Boston (4,000 containers, 2,400 curies in about 100 meters); and near the Farallon Islands in 1,000 to 2,000 meters 50 miles west of San Francisco (about 45,000 containers, 14,500 curies.[6]

Beginning in 1957, several surveys were conducted at these sites. The first was an examination sponsored by the Atomic Energy Commission (AEC) of the water column, sediment, and biota at the Farallon Islands by the Scripps Institution of Oceanography. Results did not reveal "easily detectable amounts of radioactivity even in the immediate vicinity of the oldest official marine disposal area."[7] The AEC initiated a similar study in 1960 by the Pneumodynamics Corporation, which found that "within experimental error there was no radioactivity detected that exceeded background levels" at the Farallons.[8]

A year later, the U.S. Coast and Geodetic Survey, now part of NOAA's National Ocean Service, investigated the Atlantic dumpsites. Although the survey underwater photos did not show any drums so samples may not have been taken in the immediate vicinity of the containers, they found no positive indication of released radioactivity.[9]

From 1974 through 1978, the Environmental Protection Agency (EPA) surveyed the major sites using manned and unmanned submersibles, noting that the condition of LLW packages at these sites varied from "very good with little surface corrosion to very poor with severe hydrostatic implosion."[10] In 1981 and 1982, at EPA's request, the National Oceanic and Atmospheric Administration (NOAA) surveyed the Massachusetts Bay using a side-scan sonar, and gathered bottom biota and sediment samples for radioanalysis by EPA. Although detailed analysis needs to be completed, preliminary results show "radioactivity concentrations were found to be within normally expected ranges for background levels."[11]

As a result of its studies of past U.S. dumpsites, EPA's overriding conclusion has been that there is "no evidence of harm either to people or the marine environment resulting from past U.S. practices of ocean disposal of radioactive material." The sediment acts to accumulate radionuclides. Evidence showed that radioactivity decreased from close to the container to normal background level only a few meters away.[12]

This conclusion was supported by the U.S. General Accounting Office which, in late 1981, summarized the results of U.S. marine dumpsite investigations by observing that the "overwhelming body of scientific research and opinion shows that concerns over the potential public health and environmental consequences posed by past ocean dumping activity are unwarranted and overemphasized."[13]

THRESHER and SCORPION Sinkings

Two U.S. nuclear submarines, the *USS THRESHER* and the *USS SCORPION*, were lost at sea in the Atlantic Ocean. In the event of serious accidents such as these, U.S. submarine reactors are designed to withstand severe damage and to corrode slowly. Thus, the radioactive material in the reactors' fuel elements should continue to be contained for long periods of time while the fission products and the neutron-activated metals decay to reduced activity levels.[14] However, the uranium and plutonium nuclides remaining in the fuel rods are very long-lived; they will be released to the environment when the submarines finally disintegrate.

Radiation measurements were made, and various samples of water, sediments and debris were collected for analysis at the *THRESHER* site shortly after its sinking in May of 1963, and were again collected in 1965. Similarly, seawater and sediment samples taken near the *SCORPION's* hull were analyzed for radioactivity. None of the samples showed radioactivity above background levels, and no evidence indicates that radioactivity had been released from either the *THRESHER* or the *SCORPION*.[15]

Direct radiation measurements were made of the gamma-emitting radionuclides contained in the upper sediment layers at the *THRESHER* (in 1977) and *SCORPION* (in 1979) sites. Water, sediment, marine life and debris also were collected for analysis. Again, as of those dates, there was no evidence of release of radioactivity from reactor fuel elements. Cobalt-60, however, was detected at low levels in the sediment samples of both sites. Its source would be the submarines' coolant systems or internal surfaces of piping or components. The nuclide was not present in the samples of water, marine life, or debris.[16]

ellafield

The United Kingdom's Atomic Energy Authority's uclear facility at Sellafield (formerly Windscale) on he Cumberland coast[17] contains the largest and best ocumented nuclear reprocessing plant. Operated by ritish Nuclear Fuels Ltd., the plant has discharged ffluent from a two-mile pipe into the Irish Sea since 952.[18]

The radionuclide in the effluent that most restricts ıe total discharge of radioactive waste was first iden- fied as the fission product, rubidium-106. The criti- ıl pathway that limits the amount of rubidium-106 hich can be discharged is the consumption of contami- ated seaweed by a small human population.[19]

The ingestion rates of radionuclides have also been measured in consumers of fish and shellfish within the local fishing community and in a larger population of consumers of commercial fisheries products caught from vessels operating out of ports along the Northeast coast of the Irish Sea. The consumption rates estimated for local consumers yielded a maximum dose in 1979 of 21 percent of the limit recommended by the International Commission on Radiological Protection (ICRP) for members of the public. Maximum dose to consumers of the commercial catch from the North East Irish Sea ports was 12 percent of the ICRP limit.[20]

References and Footnotes

[1] Seymour, Allyn H. 1980. Distribution of Hanford Reactor Produced Radionuclides in the Marine Environment, 1961-73. *In* B. Batel (editor), Management of Environment. Wylie Eastern Limited, Bombay, India, p. 331.

[2] *Ibid.*, p. 331-333.

For further information on the Columbia River Marine Programme, see:

Pruter, A.T., and D.L. Alverson (editors). 1972. The Columbia River Estuary and Adjacent Ocean. University of Washington Press, Seattle, Washington.

[3] *Ibid.*, p. 331-350.

[4] Miyake, Yasuo. 1971. Radioactive Models. *In* Donald W. Hood (editor), Impingement Of Man On The Oceans. Wiley-Interscience, New York, p. 565-588.

[5] See, for example: International Atomic Energy Agency. 1966. Disposal of Radioactive Wastes into Seas, Oceans and Surface Waters. Proceedings of a symposium held at Vienna, 16-20 May, 1966, Austria.

International Atomic Energy Agency. 1973. Radioactive Contamination of the Marine Environment. Proceedings of a symposium held in Seattle, Washington, 10-14 July, 1972, Vienna, Austria.

[6] Glen L. Sjoblom and Raymond H. Johnson. 1982. EPA Program for Ocean Disposal Permits and Ocean Monitoring for Low-Level Radioactive Wastes. Presentation (December 14) before the National Advisory Committee on Oceans and Atmosphere, Washington, D.C.

[7] Faughn, J. L. *et al.* 1957. Radiological Survey of the California Disposal Areas. A University of California Project prepared for the U.S. Atomic Energy Commission and the Office of Naval Research. (quoted in Robert S. Dyer, Sea Disposal of Nuclear Waste: A Brief History. *In* Thomas C. Jackson (editor), Nuclear Waste Management: The Ocean Alternative. Pergamon Press, New York, p. 10.)

A number of reports have been prepared by EPA's Office of Radiation Programs that describe past surveys of U.S. dumpsites. See: House Committee on Government Operations. 1981. Ocean Dumping of Radioactive Waste Off The Pacific Coast, 96th Congress, 2nd session, October 7, 1980, Washington, D.C., p. 75-84.

[8] Pneumodynamics Corporation. 1961. Survey of Radioactive Waste Disposal Sites. Report No. Tid-13665, U.S. Atomic Energy Commission. (quoted in Dyer, *op. cit.*)

[9] Jones, Edmund L. 1961. Waste Disposal Program Project No. 10,000-827. Special report of the U.S. Coast Guard prepared for the U.S. Atomic Energy Commission (quoted in Dyer, *op. cit.*)

[10] Dyer, *op. cit.*, p. 11.

The surveys' primary objective was to gather data upon which to develop criteria to regulate amy future ocean disposals for low-level radioactive wastes.

From: Sjoblom and Johnson, *op. cit.*, p. 16.

[11] Curtis, William, Raymond H. Johnson, and H. Michael Mardis. 1983. Recent Surveys of Radioactive Waste Dumping Areas in Massachusetts Bay. *In* Radioactive Waste Management, Proceedings of an International Atomic Energy Agency Conference, Seattle, 16-20 May 1983, Vol. 5, International Atomic Energy Agency, Vienna, Austria, p. 355.

[12] Sjoblom and Johnson, *op. cit.*, p. 15-16.

[13] U.S. General Accounting Office. 1981. Hazards of Past Low Level Radioactive Waste Ocean Dumping Have Been Overemphasized. Report No. EMD-82-9, Washington, D.C., p. ii.

The GAO's conclusions were faulted by Clifton E. Curtis in a report entitled "Monitoring of Past Radioactive Waste Ocean Dumpsites And 'Test' Sites Is Needed To Provide Effective Assurances That There Are No Undue Hazards To To Human Health and The Environment, And To Assist In The Development of Future Policies," (Washington D.C.: Center for Law and Social Policy, 3 August 1982). Curtis argues that "an issue as complex and controversial as ocean dumping of radioactive wastes must be done with documentation and an accurate representation of all the pertinent evidence," and that the GAO report "falls far short in both those tasks." Curtis, whose views were endorsed by 15 environmentally concerned public information groups, believes that incomplete and inaccurate information still plague the issue of past dumping and such dumping could be a threat to public health and the environment. He advocates good monitoring programs of previously used and "test" sites off U.S. coasts. Curtis also cites sources which indicate that highly contaminated wastes and high-level wastes were disposed in the oceans and criticizes GAO for misleading use of the term "low-level."

[14] U.S. Department of the Navy. 1982. Draft Environmental Impact Statement on the Disposal of Decommissioned, Defueled Naval Submarine Reactor Plants. Washington, D.C., p. D-Al - D-A18.

[15] *Ibid.*

The *THRESHER* site lies on the upper continental rise east of George's Bank and Brown 's Bank in 2,590 meters of water. The *THRESHER* debris lies in an area along the Western Boundary Undercurrent flow. The *SCORPION* site is 400 miles southwest of the Azores in 10,000 feet of water in a basin at the eastern edge of the Mid-Atlantic ridge.

[16] *Ibid.*, p. D-A1.

[17] Foster, R.F., I.L. Ophel, and A. Preston. 1971. Evaluation of Human Radiation Exposure. *In* Radioactivity in the Marine Environment, National Academy of Sciences, Washington, D.C., p. 253.

[18] Templeton, W.L., and A. Preston. 1982. Ocean Disposal Of Radioactive Wastes. *Radioactive Waste Management and the Nuclear Fuel Cycle* 3(1):77.

[19] Foster *et al.*, *op. cit.*, p. 253.

[20] Templeton and Preston, *op. cit.*, p. 91.

APPENDIX F
Meeting Dates, Speakers and Presentation Topics

Titles of each participant are listed according to the title held at the time of presentation to the Committee.

ker	Topic
gust 30, 1982	
es Mangeno ity Director of the Nuclear chnology Division il Sea Systems Command ear Propulsion Directorate Navy	Navy's Efforts to Safely Dispose of Aging Submarines
chard Anderson sion Supervisor, Seabed eabed Disposal Program ia National Laboratories	Subseabed Disposal and Ocean FUSRAP Programs
Boyer ram Manager of Subseabed Program sion of Waste Dispository Deployment Department of Energy	Subseabed Disposal Program
ober 25, 1982	
on Curtis rney at Law er for Law and Social Policy	Views on Radioactive Waste Disposal in the Marine Environment
on Thompson ulting Scientist n of Concerned Scientists	Concerns about Radioactive Waste Disposal in the Marine Environment
les Osterberg ne Scientist gical Research Division Department of Energy	Views on Radioactive Waste Disposal in the Marine Environment
ember 14, 1982	
nas Kitsos lative Analyst hant Marine and Fisheries Committee House of Representatives	Policy Trends as seen within the Merchant Marine and Fisheries Committee, U.S. House of Representatives
Sjoblom tor, Office of Radiation Programs onmental Protection Agency	EPA Regulations for Ocean Disposal of Radioactive Waste
nond Johnson Officer e of Radiation Programs onmental Protection Agency	EPA Monitoring and Surveying Activities at Previous Dumpsites

Speaker	*Topic*
January 24, 1983	
Susan Wiltshire Senior Consultant Technology Management Division Research and Planning, Inc.	Role of the Public in Nuclear Waste Management
William Barnard Program Director Ocean Programs Office of Technology Assessment	National Legislation regarding Nuclear Waste Management
Christopher Roosevelt President The Oceanic Society	Overall Concerns regarding Possibilities of Ocean Disposal of U.S. Radioactive Waste
Colin Heath Manager of Northern Operations NUS Cooperation	National Efforts to Dispose of High-Level Radioactive Waste
Jon Hinck National Campaign Director Greenpeace	Environmental and Ecological Concerns
Loring Mills Vice President Nuclear Institute Edison Electric Institute	Public Utilities and the Storage of Spent Fuel Rods
Peter Sears Member of the Public Ban Ocean Nuclear Dumping (Public Interest Group)	Environmental and Ecological Concerns
March 7, 1983	
William Templeton Associate Manager Environmental Sciences Department Northwest Laboratory, Battelle Chairman, Nuclear Energy Agency's Research Committee on Sea Dumping of Radioactive Waste in the Ocean	International Research on Ocean Dumping of Low-Level Radioactive Waste
Bertrand Barre Attache for Nuclear Activities French Scientific Mission	French Nuclear Waste Management
Tetsuhisa Shirakawa First Secretary of Science Embassy of Japan	Japan's Nuclear Waste Management and Proposals for Ocean Dumping of Low-Level Radioactive Waste
Mark Wimbush Associate Professor of Oceanography Graduate School of Oceanography University of Rhode Island	Oceanic Processes (notably physical) that Affect Radionuclides
Mohammed Shaker United Nations Representative International Atomic Energy Agency	IAEA Definitions and Recommendations regarding Ocean Disposal of Radioactive Waste

peaker	*Topic*
'ean Louis Hyacinthe \ttache for Oceanography 'rench Scientific Mission	French Activities regarding the Possibility of Ocean Disposal of Certain Forms of Radioactive Waste
\pril 13, 1983	
lary White lanager rand Junction Remedial Action Program .S. Department of Energy	DOE Efforts to Stablize FUSRAP sites
onald Dobies layor liddlesex Borough ew Jersey	Disposal of FUSRAP Material at Middlesex Borough, New Jersey
lay 24, 1983	
o speaker	Panel work session
uly 12, 1983	
o speaker	Panel work session
.ugust 25, 1983	
o speaker	Panel work session
ctober 19, 1983	
ɔ speaker	Plenary. Review of the findings of the NACOA Panel. Review of preliminary report outline.
ecember 6, 1983	
ɔ speaker	Panel work session. Review of preliminary report draft.
ınuary 31, 1984	
ɔ speaker	Panel work session. Consideration of reviewers' comments. Tentative approval of recommendations.
ıarch 19, 1984	
ɔ speaker	Plenary. Review and approval of report.

APPENDIX G
Glossary of Acronyms

AEC	Atomic Energy Commission
AFR	Away-From-Reactors Storage Facilities
BNFL	British Nuclear Fuels Limited
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CMFA	Council for Mutual Economic Assistance (Eastern Block Nations)
COPRDM	Committee on Pollution Research, Development, and Monitoring
DOE	Department of Energy
DOT	Department of Transportation
EEZ	Exclusive Economic Zone
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
GEOSECS	Geochemical Ocean Sections Study
GESAMP	(United Nation's Joint) Group of Experts on the Scientific Aspects of Marine Pollution
HLW	High-level waste (radioactive)
IAEA	International Atomic Energy Agency
ICES	International Council for the Exploration of the Sea
ICRP	International Commission on Radiological Protection
ICSU	International Council of Scientific Unions
IOC	Intergovernmental Oceanographic Commission
ISHTE	In-Situ Heat Transfer Experiment
LDC	London Dumping Convention
LLW	Low-level waste (radioactive)
LOS	Law of the Sea
MPC	Maximum Permissible Concentration
UPC	Mid-plate, mid-gyre
MRS	Monitored Retrievable Storage (Facilities)
MTHM	Metric tons of heavy metal (includes plutonium, etc.)
MTU	Metric tons of uranium
NACOA	National Advisory Committee on Oceans and Atmosphere
NEA	Nuclear Energy Agency (Part of the Organization for Economic Cooperation and Development)
NFS	Nuclear Fuel Service
NCRP	National Council on Radiation Protection and Measurement
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmosphere Administration
NOPPA	National Ocean Pollution Planning Act
NRC	Nuclear Regulatory Commission
OECD	Organization for Economic Cooperation and Development (Western Europe)
OSTP	Office of Science and Technology Policy
PWR	Pressurized water reactor
SCOR	Scientific Committee for Oceanic Research
SDP	Subseabed Disposal Program
SI	International System of Units
TRU	Transuranic waste (radioactive)
UK	United Kingdom
WIPP	Waste Isolation Pilot Plant

APPENDIX H
Glossary of Selected Terms

ıtion—the action of a body, such as charcoal, in ısing amd holding a gas or soluble substance upon face; distinguished from absorption in which the al is taken up within the body by either physical or cal forces.

particle—a positively charged nuclear particle con- of two protons and two neutrons (essentially ıcleus of the helium atom.) Alpha radiation, the ı of alpha particles, is the most densely ionizing ast penetrating type of radiation; alpha particles stopped by several sheets of paper. Alpha- ng radionuclides are generally hazardous to ıs only if they decay while inside the body.

vogenic—originated through human activities.

-a basic component of all matter; the atom is the t part of an element having all the chemical prop- of that element; basically composed of protons ıtrons in the nucleus and electrons in outer orbits.

mass—the mass of any species of an atom, ex- in atomic mass units (equal to 1/12 of the atomic the most abundant carbon isotope, carbon-12).

number—a number characteristic of an element o represent the positive charge on the nucleus tom of the element normally equal to the number ons in the nucleus the atomic nunber is equal to nber of electrons outside the nucleus in a neu- m.

weight—the relative weight an atom on the basis n-12 defined as 12. For a pure isotope, the atomic rounded off to the nearest integer gives the total of nucleons (neutrons and protons) making up nic nucleus.

el (Bq)—international unit of radioactivity one nuclear disintegration per second.

icle—an electron or positron emitted by the nu- an atom during radioactive decay. Beta radia- stream of beta particles, is, a more penetrating ionizing radiation than is alpha. Beta particles topped by a thin sheet of metal. Most fission s in spent fuel and reprocessed waste (e.g., 31, cesium-137, and strontium-90) are beta . Beta-emitting nuclides are of concern main- they decay within the body.

Bioaccumulation—the build-up of radionuclides in living organisms. The chemical similarities between some radionuclides and naturally occurring elements in the human body makes this a potentially dangerous process. (For example, strontium-90 resembles calcium and concentrates in bones). A danger also exists in that marine organisms can bioaccumulate radionuclides and then be consumed by man.)

By-product material—"waste produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content, including discrete surface waste resulting from uranium solution extraction processes; excludes fission products and other radioactive material covered in 10 CFR Part 20.3 (3)". (DOE order 5820.2)

Cesium-137—a radioactive fission product with a 30-year half-life.

Chain reaction—a self-propagated fission of atomic nuclei continued by the further action of one of the products, best exemplified by the fission of a uranium nucleus by a neutron that causes the release of more neutrons that cause further fissions, etc.

Cladding—protective alloy shielding in which fissionable fuel is inserted; is relatively resistant to radiation and the physical and chemical conditions in a reactor core; may be stainless or some alloy such as zircaloy.

Cosmic rays—radiation of intense penetrating power, emanating from outer space and consisting mainly of high energy positively charged particles.

Critical pathway approach—evaluation of a series of events through which radioactive material that is introduced into the marine environment is diluted or concentrated, and eventually reaches humans in food or from other contacts.

Curie—a measure of the rate of radioactive decay, equivalent to that of radium, in which exactly 3.7×10^{10} disintegrations occur per second.

Decay product—nuclide resulting from the radioactive disintegration of a radionuclide, formed either directly or as the result of successive transformations in a radioactive series; may be radioactive or stable.

Disposal—nuclear waste isolation that relies on natural and anthropogenic barriers. Disposal does not permit easy human access to the waste after its final emplacement, and does not require continued human control and maintenance.

Entombment—process by which nuclear reactor plants are sealed with concrete or steel after liquid waste, fuel and surface contamination have been removed to the greatest extent possible.

Fission—process by which an atomic nucleus is split or broken apart (as by bombardment with neutrons) into approximately equal parts. The fission of certain heavy elements (as uranium and plutonium) results in the release of enormous quantities of energy.

Fission product—a nuclide produced either directly by the fission of a chemical element or by the subsequent disintegration of products of this process.

Gamma radiation—high-energy electromagnetic waves. Gamma radiation has greater penetrating power than have alpha or beta radiation, and usually accompanies beta emission. Gamma radiation can penetrate and damage critical organs in the body.

Geologic repository—a mined underground cavity for the disposal of radioactive waste.

Gigawatt—billions of watts of electricity generated: (1 GW_e=1,000 MW_e).

Gray (Gy)—the international unit of absorbed radiation dose (1 Gy=1 joule of absorbed energy per kilogram of material=100 rad.)

Half-life—time required for half of the atoms of a radioactive substance to disintegrate to another nuclear form, which may range from seconds to billions of years.

High-level waste—defined by the United States as spent reactor fuel and any wastes generated during reprocessing spent fuel above a defined concentration. The International Atomic Energy Agency (IAEA) definition is any waste with radioactivity too concentrated or present in amounts too large to be considered suitable for disposal at sea. IAEA currently uses the following limits of activity to define high-level waste:

Alpha emitters:	1 curie or more/metric ton
Beta or gamma emitters:	100 curies or more/metric ton
Tritium:	10^6 curies or more/metric ton.

Irradiation—intentional exposure of a substance to radioactivity.

Isotope—one of two or more species of atoms of the same chemical element that have the same atomic number, and which occupy the same position in the periodic table. Isotopes are nearly identical in chemical behavior but differ in atomic mass or mass number, and so behave differently in radioactive transformations and in physical properties (for example, diffusion in the gaseous state).

Megawatt—one million watts of electricity generated.

Microfauna—small or strictly localized minute animals, especially those invisible to the naked eye.

Monitoring—systematic observations of predetermined pollutants or pertinent components of the marine ecosystem over a length of time sufficient to determine: (1) the existing level, (2) the trend, and (3) the natural variation of parameters of the water column, sediments, or biota.

Mothballing—decommissioning a nuclear facility.

Low-level waste—any radioactive waste that is not classified as mill tailings, high-level waste, transuranic waste, spent fuel, or the by-product material defined in the Low-Level Radioactive Waste Policy Act of 1980.

Nuclear reactor—device in which a controlled nuclear chain reaction is maintained, either for the purposes of experimentation, production of weapons grade fissionable material, or generation of electrical power.

Nuclide—type of atom characterized by the constitution of its nucleus, and hence by the number of protons, neutrons, and its energy content.

Parent—a radionuclide that upon disintegration yields a specified nuclide, called the "daughter," either directly or as a later member of a radioactive decay series.

Penetrometer—a projectile housing high-level waste which, when dropped from a ship or lowered from a winch, would penetrate soft sediments.

Phytoplankton—free floating microscopic aquatic plants.

Plutonium—a radioactive metallic element of the actinide series, similar chemically to uranium, that is usually produced in nuclear reactors as the long-lived isotope plutonium-259 (half-life of 24,000 years) by spontaneous emission of an electron from neptunium, obtained in turn from uranium-238. Plutonium is also found in minute quantities in pitchblend and other uranium-containing ores.

Rad—measurement of the amount of energy absorbed per gram of material, such as human tissue, from ionizing radiation. 1 rad=100 ergs/gram.

Radioactivity—the spontaneous emission of various forms of radiation (usually alpha or beta particles or gamma rays) by the disintegration of the nuclei of atoms.

Radioisotopes—an unstable isotope of an element that will eventually undergo radioactive decay.

Radium—an intensely radioactive metallic element of the alkaline earth group, that occurs principally as the isotope radium-226 formed from uranium-238 and having a half-life of 1,620 years. Radium-226 emits alpha particles or gamma rays to form radon.

Radon—a heavy radioactive gas with a half-life of 3.8 days; formed by disintegration of radium and used similarly to radium in medicine; hazardous in unventilated areas because it can build up to high concentrations and cause lung disease if inhaled for long periods of time.

Rem—(roentgen equivalent man) a unit expressing the effective radiation dose equivalent for all forms of ionizing radiation. The rem is that amount of any ionizing radiation that will cause the same amount of biological injury to human tissue as one rad of X-ray or gamma ray dosage.

Reprocessing—chemical process by which unfissioned uranium-235 and plutonium-239 are removed from spent reactor fuel.

Roentgen—measures the amount of energy lost in air by the passage of gamma or X-rays, by generating (through ionization) one electrostatic unit of charge in one cubic centimeter of dry air at standard conditions of temperature and pressure.

Sievert(Sv)—international unit of radiation dose that is multiplied by a quality factor dependent upon the type of radiation distribution within biological material (=100 rem.)

Sorption coefficient—(^{K}d) an inverse measure of the potential for nuclide transport through sediments. Refined as the ratio of solid phase concentration to solution phase concentration.

Spallation—a nuclear reaction in which light particles are ejected as the results of bombardment (as by high-energy protons); especially a reaction resulting in numerous products.

Spent fuel—irradiated fuel discharged from nuclear reactors; in commercial reactors, this material typically contains about 96 percent unused uranium, 1 percent plutonium, and 3 percent other fission products categorized as high-level waste.

Storage—isolation permitting easy access to the waste after emplacement; requires human control and maintenance to guarantee isolation.

Tailings—residue from uranium mining and milling operations (in the form of fine sand) that contain low concentrations of naturally occurring radioactive materials.

Thorium—a radioactive metallic element usually associated with rare earths principally as the isotope thorium-252 having a half-life of 1.4×10^{10} years.

Tracer—a radionuclide that can be traced through a chemical, biological, or physical system in order to study the system.

Transuranic waste—any material containing at the end of its institutional control period 100 nanocuries (1 nanocurie=10^{-9} curies) or more per gram of alpha-emitting radionuclides with an atomic number greater than 92 (uranium) and long half-lives (greater than 20 years).

Tritium—a radioactive isotope of hydrogen with two neutrons and one proton in the nucleus and a half-life of 12.3 years.

Tuff—fragmented rock consisting of the smaller kinds of volcanic detritus, usually more or less stratified.

Uranium—a heavy radioactive metallic element of the actinide series, that exists naturally as a mixture of three isotopes: uranium-238 (99.28%), uranium-235 (0.71%), and uranium-234 (0.006%). Uranium undergoes very slow radioactive decay and captures neutrons in a nuclear reactor to produce a heavier isotope, uranium-239, which decomposes by beta emission and is used primarily in atomic energy programs to sustain chain reactions, to provide a source of the light isotope uranium-235, and to make plutonium.

Vitrification—formation of glassy or noncrystalline material out of nuclear wastes after subjection to temperatures between 950°C and 1,150°C.

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U.S. Department of Energy. 1983. Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics. DOE/NE-0017/2, Assistant Secretary for Nuclear Energy and Assistant Secretary for Defense Programs, Washington, D.C., p. 2.

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APPENDIX I
Glossary of Organizations

UNITED STATES

Atomic Energy Commission (AEC). From 1946 to 1974, the AEC was the agency responsible for developing, promoting, and regulating U.S. nuclear activities. The Energy Reorganization Act of 1974 abolished the AEC, dividing its responsibilities between the Energy Research and Development Administration and the Nuclear Regulatory Commission.

Energy Research and Development Administration (ERDA). From 1974 to 1977, ERDA was responsible for nuclear research and development, including the nuclear waste management program. In 1977, ERDA was abolished as an independent agency, and its activities were absorbed into the Department of Energy.

Nuclear Regulatory Commission (NRC). Established in 1974, the NRC is an independent board whose five members are appointed by the President. The NRC regulates all U.S. commercial nuclear activities (including active uranium mill tailing sites). All private nuclear facilities must be licensed by the NRC before starting operation. Although Federal radioactive waste storage and disposal activities are not generally subject to NRC review, DOE must get an NRC license for some HLW disposal facilities. In addition, the NRC regulates the packaging of radioactive material for transport.

Department of Energy (DOE). Formed in 1977, DOE absorbed the responsibilities of the Energy Research and Development Administration for nuclear research and development, including: research necessary to make policies concerning radioactive waste management; actual handling and storage of all nuclear defense wastes; and disposal of commercial high-level waste and/or spent fuel.

Environmental Protection Agency (EPA). Established in 1970, EPA assumes lead responsibility in the Federal Government for identifying, evaluating, and controlling environmental pollutants. The purview of EPA includes freshwater, estuarine, coastal, and oceanic pollution. EPA is responsible for issuing permits for the ocean dumping of any material (except dredged material), including low-level radioactive waste.

Department of Transportation (DOT). DOT regulates the safe transport of privately owned radioactive materials, including nuclear waste, by all modes and means of transport.

National Oceanic and Atmospheric Administration (NOAA). Established in 1970, the mission of NOAA includes conducting or supporting programs of research, development, and monitoring to understand the effects of various pollutants and activities on ocean, coastal, and Great Lakes ecosystems. NOAA is the lead organization in planning and coordinating Federal activities in ocean pollution research and monitoring.

National Council on Radiation Protection and Measurements (NCRP). The NCRP is a non-profit corporation chartered by Congress in 1964 to collect, analyze, develop, and disseminate information about protection against radiation amd about radiation measurements.

INTERNATIONAL

International Atomic Energy Agency (IAEA). Since its establishment in 1957, the IAEA has been concerned with radioactive waste management within its general mandate of seeking to accelerate and to enlarge the contribution of atomic energy to peace, health, and prosperity throughout the world.

Organization for Economic Cooperation and Development—Nuclear Energy Agency (OECD, NEA). The mission of NEA is to promote orderly development of peaceful uses of nuclear energy through cooperation among Member States. NEA initiates, encourages, and coordinates cooperative work in reactor research, nuclear fuel cycle studies, radiation protection, waste management, nuclear safety regulatory matters, amd nuclear data collection.

International Commission on Radiological Protection (ICRP). The ICRP has functioned since 1928, when it was established as the International X-ray and Radium Protection Committee. It is the international body that has given global guidance on the use of radiation sources caused by the developments in the field of nuclear energy. Its mission is to provide principles of radiation protection as a basis for each country to use to establish technical codes of practice.

APPENDIX J
Selected National Laws Pertaining to Radioactive Waste Disposal

Atomic Energy Act of 1954,
42 U.S.C. §§2011 et seq. (1982 & Supp. 1983).

National Environmental Policy Act of 1969,
42 U.S.C. §§4321 et seq. (1982 & Supp. 1983).

Federal Water Pollution Control Act Amendments of 1972,
33 U.S.C. §§1251 et seq. (1982 & Supp. 1983).

Marine Protection, Research and Sanctuaries Act of 1972,
33 U.S.C. §§1401 et seq. (1982 & Supp. 1983).

Energy Reorganization Act of 1974,
42 U.S.C. §§5801 et seq. (1982).

Transportation Safety Act of 1974,
46 U.S.C. §§2101 et seq. (Supp. 1983).

Clean Air Act Amendments of 1977,
42 U.S.C. §§7401 et seq., §7422 (1983).

National Ocean Pollution Planning Act of 1978,
33 U.S.C. §§1701 et seq. (1982 & Supp. 1983).

Uranium Mill Tailings Radiation Control Act of 1978,
42 U.S.C. §§7901 et seq. (1982).

Department of Energy National Security and Military Applications of Nuclear Energy Authorization Act of 1979, 42 U.S.C. §§7235, 7271; 1980, 42 U.S.C. §§7272, 7273; 1981, 42 U.S.C. §§7272, 7273; 1982, 42 U.S.C. §§2021a, 2168, 2201, 2231 (1982 & Supp. 1983).

Low-Level Radioactive Waste Policy Act of 1980,
42 U.S.C §§2021(b)—2021(d) (Supp. 1983)

Indian Health Care Amendments of 1980,
25 U.S.C. §§1601, 1677(a) (Supp. 1983).

Nuclear Waste Policy Act of 1982,
42 U.S.C. §§1010 et seq. (1982 & Supp. 1983).

Department of Energy Organization Act,
42 U.S.C. §§7101 et seq. (1982).

Territories and Insular Possessions,
48 U.S.C. §§1491(a) (Supp. 1983).

Hazardous Materials Transportation Act,
49 U.S.C. §§1801 et seq. (1982 & Supp. 1983)

APPENDIX K
Selected International Agreements Pertaining to Nuclear Energy

Part A: Selected Treaties to Which the United States is Party (as of January 1 1983)

Convention on the High Seas, April 29, 1958, 13 UST 2312, TIAS 5200.

International Convention for the Safety of Life at Sea, November 1, 1974, TIAS 9700.

U.N. Conference on the Human Environment (Stockholm Conference), UN DOC. A/CONF. 48/14 (1972).

Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention), December 29, 1972, 26 UST 2403, TIAS 8165.

Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space, and Under Water, August 5, 1963, 14 UST 1313, TIAS 5433.

Treaty on the Prohibition of the Emplacement of Nuclear Weapons and other Weapons of Mass Destruction on the Seabed and the Ocean Floor and in the Subsoil Thereof, February 11, 1971, 23 UST 701, TIAS 7337.

Antarctic Treaty, December 1, 1959, 12 UST 794, TIAS 4780.

Agreed Declaration on Atomic Energy by the United States, United Kingdom, and Canada, November 15, 1945, 60 Stat. 1479, TIAS 1504.

Agreement as to Disposition of Rights in Atomic Energy Inventions, September 24, 1956, 7 UST 2526, TIAS 3644.

Statute of the International Atomic Energy Agency, October 26, 1956, 8 UST 1093, TIAS 3873.

Agreement Concerning a Joint Project for Planning, Design, Experiment Preparation, Performance and Reporting of Reactor Safety Experiments Concerning Containment Response, January 24, 1975, 28 UST 629, TIAS 8479.

Implementing Agreement for a Cooperative Research and Development Program Leading to Construction of an Intense Neutron Source, May 20, 1976, 28 UST 8185, TIAS 8754.

Agreement Concerning a Joint Project for Planning, Design, Experiment Preparation, Performance and Reporting of Reactor Safety Experiments Concerning Critical Flow, April 14, 1977, 30 UST 129, TIAS 9184.

Agreement Amending the Agreement of February 11, 1977, between the United States and the Federal Republic of Germany in the Field of Gas-cooled Reactor Concepts and Technology, September 30, 1977, 29 UST 4039, TIAS 9047.

Agreement on Research Participation and Technical Exchange in the In-pile CABRI and Annular Core Pulsed Reactor (ACPR) Research Programs Related to Fast Reactor Safety, May 2, June 7 and 22, 1978, 30 UST 7545, TIAS 9603.

Agreement on Research Participation and Technical Exchange in the United States Power Burst Facility (PBF) and Heavy Section Steel Technology (HSST) Research Programs and the Nordic Group's Water Reactor Safety Research Programs, June 26, 1979, 31 UST 985, TIAS 9627.

Arrangement on Research Participation and Technical Exchange in a Coordinated Analytical and Experimental Study of the Thermohydraulic Behavior of Energency Core Coolant during the Refill and Reflood Phase of a Loss-of-coolant Accident in the Pressurized Water Reactor, January 25, March 20 and April 18, 1980, TIAS 9835.

Treaty on the Non-proliferation of Nuclear Weapons, July 1, 1968, 21 UST 483, TIAS 6839.

Additional Protocol I to the Treaty of February 14, 1967 for the Prohibition of Nuclear Weapons in Latin America, February 14, 1967, TIAS 10147.

Additional Protocol II to the Treaty of February 14, 1967 for the Prohibition of Nuclear Weapons in Latin America, February 14, 1967, 22 UST 754, TIAS 7137.

Trilateral Agreements signed at Vienna among the International Atomic Energy Agency, the United States, and Other Countries for the Application of Safeguards by the International Atomic Energy Agency to Equipment, Devices and Materials Supplied under the Bilateral Agreements for Cooperation Concerning Civil Uses of Atomic Energy between the United States and the following countries:

Argentina, June 13, 1959, 20 UST 2629, TIAS 6722.
* Australia, September 26, 1966, 17 UST 1612, TIAS 6117.
* Austria, August 20, 1969, 21 UST 56, TIAS 6816.
Brazil, March 10, 1967, 19 UST 6322, TIAS 6583 (Amendment: July 27, 1972, 23 UST 2526, TIAS 7440).
China (Taiwan), December 6, 1971, 22 UST 1837, TIAS 7228.
Colombia, December 9, 1970, 21 UST 2677, TIAS 7010 (Extension: March 28, 1977, 28 UST 2404, TIAS 8556).
India, January 27, 1971, 22 UST 200, TIAS 7049.
* Iran, March 4, 1969, 20 UST 2748, TIAS 6741.
Israel, April 4, 1975, 26 UST 483, TIAS 8051 (Extension: April 7, 1977, 28 UST 2397, TIAS 8554).
Japan, July 10, 1968, 19 UST 5371, TIAS 6520.
Korea, January 5, 1968, 19 UST 4404, TIAS 6435 (Amendment: November 30, 1972, 24 UST 829, TIAS 7584).
* Philippines, July 15, 1968, 19 UST 5426, TIAS 6524.
* Portugal, July 11, 1969, 20 UST 2564, TIAS 6718.
South Africa, July 26, 1967, 18 UST 1643, TIAS 6306 (Amendment: June 20, 1974, 25 UST 1175; TIAS 7848).
Spain, December 9, 1966, 17 UST 2351, TIAS 6182 (Amendment: June 28, 1974, 25 UST 1261; TIAS 7856).
* Sweden, March 1, 1972, 23 UST 195, TIAS 7295.
* Switzerland, February 28, 1972, 23 UST 184, TIAS 7294.
Turkey, September 30, 1968, 20 UST 780, TIAS 6692 (Extension: June 30, 1981, TIAS 10201
Venezuela, March 27, 1968, 19 UST 4385, TIAS 6433 (Extension: February 18, 1981, TIAS 10096).

* Suspended by agreement.

Trilateral Agreements Signed at Vienna among the International Atomic Energy Agency, the United States, and Other Countries for the Suspension of the Application of Safeguards and Providing for the Application of Safeguards Pursuant to the Non-proliferation Treaty of July 1, 1968, have been concluded with the following countries:

Australia, July 10, 1974, 25 UST 1325, TIAS 7865.
Austria, September 21, 1971, 23 UST 1308, TIAS 7409.
Denmark, March 1, 1972, 23 UST 167, TIAS 7289.
Greece, March 1, 1972, 23 UST 169, TIAS 7290.
Iran, June 19, 1973, 25 UST 853; TIAS 7829.
Norway, September 25, 1973, 24 UST 2046, TIAS 7721.
Philippines, February 21, 1973, 25 UST 2967, TIAS 7957.
Portigal, September 23, 1980, TIAS 9899.
Sweden, April 14, 1975, 26 UST 478, TIAS 8049.
Switzerland, September 23, 1980, TIAS 9900.
Thailand, June 27, 1974, 25 UST 1178; TIAS 7849.

Agreements among the International Atomic Energy Agency, the United States, and Other Countries for the Supply of Nuclear Material or Equipment have been concluded with the following countries:

Argentina-Peru, May 9, 1978, 30 UST 1539, TIAS 9263.
Indonesia, December 7, 1979, TIAS 9705.
Malaysia, September 22, 1980, TIAS 9863 (Amendment: June 12 and July 22, 1981, TIAS 10202).
Mexico, December 18, 1963, TIAS 9906; October 4, 1972, TIAS 9906; February 12, 1974, TIAS_____; June 14, 1974, TIAS_____; March 6, 1980, TIAS 9906.
Yugoslavia, June 14, 1974, TIAS 9728; January 16, 1980, TIAS 9767; February 26, 1980, TIAS 9728; December 14, 15 and 20, 1982, TIAS_____.

Source: U.S. Department of State. 1983. Treaties in Force. A List of Treaties and and other International Agreements on the United States in Force on January 1, 1985. Publication 9351, Office of the Legal Advisor, Washington, D.C., 324 p.

Part B: Selected International Nuclear Agreements to Which the United States is Not Party

Worldwide Nuclear Liability Agreements

Convention on Third Party Liability in the Field of Nuclear Energy, Paris, July 29, 1960.
A Convention Supplementary to the Paris Convention on Third Party Liability in the Field of Nuclear Energy, Brussels, January 31, 1963.
International Convention on the Liability of Operators of Nuclear Ships, Brussels, May 25, 1962.
Convention on Civil Liability for Nuclear Damage, Vienna, May 21, 1963.
Convention relating to Civil Liability in the Field of Maritime Carriage of Nuclear Material, Brussels, December 1971.

Regional Agreements on Nuclear Waste

Treaty Establishing the European Atomic Energy Community, Rome 1957.

Treaty for the Prohibition of Nuclear Weapons in Latin America, Mexico City, 1967.

Convention for the Prevention of Marine Pollution from Land-based Sources, Paris, February 1974.

Convention on the Protection of the Marine Environment of the Baltic Sea Area, Helsinki, March 1974.

Nordic Mutual Emergency Assistance Agreement in Connection with Radiation Accidents, October 1963.

APPENDIX L
NACOA Panel on Nuclear Waste Mangement

Chairman
John A. Knauss

Panel Members
Sylvia A. Earle
Jay G. Lanzillo
Vernon E. Scheid
S. Fred Singer
Sharron L. Stewart

NACOA Panel Staff Members
William Lounsbery
Douglas Hennick
Victoria Jones Brimmer
Alice Roberson
Catherine L. Mills
Juanita Thomas
Charlee Bellamy