OCEAN FUSRAP: FEASIBILITY OF OCEAN DISPOSAL OF MATERIALS FROM THE FORMERLY UTILIZED SITES REMEDIAL ACTION PROGRAM (FUSRAP)

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The Formerly Utilized Sites Remedial Action Program (FUSRAP) of the Department of Energy is designed to identify and evaluate the radiological conditions at sites formerly used by the Corps of Engineers Manhattan Engineer District (MED) and the U. S. Atomic Energy Commission (AEC). Where required, remedial action will be instituted to remove potential restrictions on the use of the sites due to residual low-level radioactive contamination. A total of 35 sites that may require remedial action have been identified.[1,a]

The purpose of the Ocean FUSRAP Program, which began in March 1981, is to assess the technical, environmental, and institutional feasibility of disposing, in the ocean and on the ocean floor, of FUSRAP waste which contains traces of natural radioactive materials. The initial planning has focused on the Middlesex, New Jersey, Sampling Plant site and surrounding properties, which contain on the order of 100,000 metric tons of material. The Belgian Congo uranium ore and other uranium ores used by the United States were handled at the sampling plant site and have since been removed.[2]

In carrying out the Ocean FUSRAP Program, our approach has been 1) to identify and investigate the institutional requirements to be met in order to facilitate the ocean disposal of FUSRAP wastes; 2) to estimate the inventory of toxic chemical and radiochemical components in the source material; and 3) to evaluate the potential environmental impact of the toxic components of the source material in the marine environment.

This paper reviews progress since the inception of the program.

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[a] Thirty-one sites are described in the referenced document. Four more have since been added.

INSTITUTIONAL REQUIREMENTS

International

The primary international control on ocean dumping is the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972), commonly referred to as the London Dumping Convention (LDC). The treaty, to which the United States is a signatory, entered into force on August 30, 1975. Among its extensive provisions, the LDC prohibits the dumping of high-level radioactive waste or other radioactive materials deemed unsuitable for dumping at sea by the International Atomic Energy Agency (IAEA), which functions in a special advisory status to the Convention. It also requires that radioactive materials may only be dumped at sea under a special permit issued by the national authority after taking into account any IAEA recommendations on the conditions to be observed in the issue of such permits.

The LDC notes that the marine environment contains a wide range of natural radionuclides, mainly ^{40}K, ^{87}Rb, members of the uranium and thorium series, and ^{14}C and ^{3}H. The total radioactivity in all of the sea (mainly ^{40}K) amounts to more than 300 Ci/km^3, and nearly 500,000 MCi in total. Radium alone accounts for more than 1000 MCi. The doses to marine organisms are usually on the order of 10 mrem/yr to 100 mrem/yr.

Section 2.3.14 of the annex to LDC recognizes that no material is totally devoid of radioactivity. However, the Convention acknowledges that every material should not be treated as a potential radioactive pollutant, and that the competent authorities of the Contracting Parties will wish to define some "de minimis" level of specific activity below which a material will not be regarded as "radioactive" for the purposes of the Convention. No such numbers are suggested at this time, and some flexibility of interpretation is therefore left to the appropriate national authorities. Although not derived for the purpose of dumping, some guidance may be found in the levels set forth for exemption of radioactive materials from regulatory control in various international and national standards and regulations; such levels are generally within an order of magnitude of 10^{-3} Ci/t.

National

The Environmental Protection Agency (EPA) was given the responsibility under the Marine Protection Research and Sanctuaries Act of 1972 (MPRSA), also known as the Ocean Dumping Act, to regulate all dumping of wastes and other matter, including radioactive waste, into the oceans. The U.S. used the ocean for the disposal of some radioactive waste from 1946 until land burial

sites were available in the early 1960s. During 1962 to 1970, the use of sea disposal decreased, and after 1970 this method of disposal was discontinued. The total estimated activity at the time of dumping was 94,600 Curies in about 89,500 containers.[3] Opposition within the United States to land burial, the need to evaluate ways to dispose of aging nuclear-powered submarines, and the dawning awareness that wastes should be disposed of in the manner and medium that minimizes the risk to human health and the environment and at a reasonable price,[4] have all resulted in increased interest in examining the potential merits and problems associated with the disposal of low level wastes in the oceanic regime.

We believe that in view of the low concentrations of natural radionuclides and trace metals in the Middlesex waste, which are probably typical of those at most of the FUSRAP sites, and because of the new awareness of the importance of the ocean for waste disposal, this material will be considered in the trace contaminant category in the revisions being prepared for the ocean dumping regulations.

WASTE CHARACTERIZATION

The objective of this effort is to provide data which can be used to evaluate the feasibility of the ocean-disposal option and to support a permit application if this option appears feasible. In addition, these data could prove useful in the evaluation and pursuit of land-disposal options.

Potential contaminants at Middlesex fall into the following categories:

Natural radionuclides

This group includes nuclides which belong to the two uranium decay series and the thorium decay series. Members of the ^{235}U series need not be considered because the contamination at Middlesex was caused by ore materials, and ^{235}U makes up only 0.72% of natural uranium. Although we are considering the possibility that thorium and its daughters are present in excess of background, the history of the site clearly suggests that members of the ^{238}U decay series are the dominant radionuclides in the contaminated materials at Middlesex (see discussion of Preliminary Analytical Results, below).

Trace Elements That Associate With Uranium and Thorium

Several toxic elements are frequently enriched along with uranium and thorium in ore deposits. Arsenic, selenium, and a

number of heavy metals, for example, are often found in uranium deposits. This group of elements may be of as much concern as the natural radionuclides. However, preliminary results (see below) indicate that concentrations of these elements in the Middlesex FUSRAP material will not be troublesome.

In addition, the redox state, mineralogy, particle size, etc., would affect the behavior of the contaminants after disposal at sea. These parameters will be determined as the work continues.

Sampling

Program personnel made two trips to Middlesex in 1981 to survey and sample contaminated materials. We will discuss only the first trip in detail, since samples from the second trip have not yet been analyzed.

The area of paramount importance for sampling was the 9.6-acre area within the fenced perimeter of the sampling plant site; the largest volume of contaminated material at the Middlesex FUSRAP site is contained therein. This material was sampled with plastic corers in order to prevent contamination of the samples with metallic fragments from trowels, shovels or drill bits. This method was only partially successful because the corers could not penetrate the crushed stone and asphalt which cover most of the contaminated material within the sampling plant site. Eleven core samples were obtained from four locations (On the second trip, which coincided with construction activities at the site, we were much more successful at getting beneath the asphalt cover.) All of the core samples from the first trip were analyzed.

Another type of contaminated material sampled was sediments and water from the streams which drain the sampling plant site. A large ditch receives runoff from the underground drainage system that runs north-south through the sampling plant site and empties into a local stream. We sampled sediments and water from the ditch and stream to see if there had been any chemical or mechanical separation of mobile from immobile contaminants over an an approximately 1-km distance. (Vertical profiles were sampled on faces exposed by excavations around the perimeter of the sampling plant site with the same objective.) Quantification of possible fractionation would be necessary to estimate the inventories of certain contaminants, and could be useful in predicting the beH'dior of this material in the marine environment. We have not yet analyzed any of these sediments or water samples.

On the first trip to Middlesex, we boxed and shipped to Sandia almost two hundred samples of soil taken from properties adjacent to or near the sampling plant site. These samples were taken by others during construction activities in 1980 and represent contaminated material taken decades ago from the sampling plant site to these properties as landfill.

These samples were taken with metallic tools and, for the most part, stored in metallic containers. They may, therefore, be unsuitable for heavy metals analysis, but are probably suitable for analysis for natural radionuclides and organic contaminants. Four of these samples have been analyzed to date.

The initial emphasis has been on determining the concentrations of trace metals; thus, most of the sampling this year has been conducted using plastic tools and containers. This minimized the danger of contaminating the samples with metallic fragments. A suite of samples from within the sampling plant site will be taken with metallic implements for any necessary analysis for organic substances.

We will also take a suite of samples for use in bioassays of contaminated materials (to be discussed below). Short-term (10-day) bioassays will require at least 12.5ℓ of sample for each type of contaminated material or concentration level that is tested. Additional material will be required for long-term tests to determine if marine organisms pick up significant quantities of radionuclides under simulated disposal-site conditions.

Preliminary Analytical Results

Fifteen samples were selected for the preliminary analysis. Eleven of them represent material from within the perimeter of the sampling plant site (the area in which most of the contaminated material resides). Four samples represent material from adjacent properties.

The samples were analyzed for major elements, natural radionuclides and trace metals at Battelle Pacific Northwest Laboratories. Only the natural radioactivity and trace metal results will be discussed here.

The mean concentrations of natural radionuclides are shown in Table I. Except for total uranium, data were obtained by direct counting of γ-rays emitted during the decay of these radionuclides. Three conclusions can be drawn from these data:

First, the samples analyzed are more contaminated on average than our estimate for "average" Middlesex FUSRAP material, due

to our efforts to sample over a wide range of radioactivity levels. We estimate, on the basis of extensive radiological surveys,[5,6] that the average ^{226}Ra content of the contaminated material at Middlesex will be between 40 and 80 pCi/g, depending upon how much material is removed in the final cleanup operation; the former if all the material above ^{226}Ra background is removed, (i.e. above about 1pCi/gm), the latter if only the material in excess of 5 pCi/gm above background is removed. The mean ^{226}Ra content of the 15 samples that we analyzed is 108 pCi/g. It should be kept in mind that because the ^{226}Ra concentration is higher than the site mean value, the concentrations of all radioisotopes and trace metals that are correlated with the ^{226}Ra concentration would also be expected to be higher than their site mean values.

Second, these data indicate that the isotopes of the ^{238}U decay series (and the ^{232}Th decay series) are, on the whole, nearly in secular equilibrium; the mean activity of ^{238}U in the 15 samples analyzed is 142 pCi/g, and that of ^{226}Ra is 108 pCi/g. If one anomalous sample is neglected, the mean values are 78 and 83 pCi/g, respectively. This conclusion agrees with those of the previous radiological surveys at Middlesex.[5,6] This means that we can accurately estimate the inventories of other radionuclides in the ^{238}U decay series from the extensive data for ^{226}Ra that has accumulated from earlier surveys. The data also indicate that we can correlate the concentrations of some trace metals of interest which occur with uranium in ore deposits to the concentration of ^{226}Ra in the contaminated material, and use the data for ^{226}Ra to estimate their inventories as well.

Table I. Mean Concentrations of Natural Radioisotopes

Isotope	Mean (pCi/gm)
^{238}U	142
U[b]	433[b,c]
^{230}Th	108
^{226}Ra	108[c]
^{214}Pb	95
^{210}Pb	102
^{235}U	7[c]
^{232}Th	6
^{212}Pb	5
^{212}Bi	5[c]
^{208}Tl	4[c]

[b] By atomic absorption (AA), in ppm.

[c] When analyses were below detection limit, the detection limit was halved to compute the mean.

Finally, the radioactive contaminants in these 15 samples belong, for the most part, to the ^{238}U decay series; ^{232}Th and its daughters are present at much lower concentrations, relative to average crustal materials, than are ^{238}U and its daughters. These results are reasonable, given the history of the Middlesex site. If they continue to be supported by future analyses, emphasis should be placed on members of the ^{238}U decay series and any trace metals that were released at Middlesex along with uranium ores.

Trace Metals

The mean concentrations of trace metals in our first 15 samples from Middlesex are listed in Table II. These elements have been considered by the EPA in setting standards for water quality and by the International Atomic Energy Agency (IAEA) in setting standards for ocean dumping, or by both agencies. In addition, the concentrations of cobalt and molybdenum are listed; we analyzed for these two elements to further test the hypothesis that the concentrations of elements which normally are enriched with uranium in ore deposits can be correlated with the concentrations of ^{226}Ra (for which a large data base exists) and for ^{238}U in the contaminated materials at Middlesex. These data were obtained using X-ray flourescence, flameless atomic absorption, and plasma emission spectroscopy. There are no results for Tl yet; a more sensitive analytical technique is necessary for Ag and Cd. It is important to bear in mind, first, that some of the mean values in Table II will be higher than in "average" Middlesex FUSRAP material because of our sampling philosophy (see above), and second, that concentrations expected in Middlesex material are not likely to be in excess of those found in typical shales and soils.

We have attempted to correlate the concentrations of the elements shown in Table II with those of ^{238}U and ^{226}Ra; to the extent that such correlations exist, fewer costly analyses will be required to adequately characterize the waste when applying for a permit for ocean disposal. Table III shows the correlation coefficients that were obtained for ^{226}Ra using a linear least squares computer program.

The results for ^{238}U are similar to those for ^{226}Ra, and are not discussed here. Further discussion of the data in Tables I, II, and III may be found elsewhere.[7]

Table II. Mean Concentrations of Trace Metals

Element[d]	Mean (ppm)
As	29
Ag	<6
Be	5[e]
Cd	<5
Co	41[e]
Cr	100[e]
Cu	97
Hg	0.16
Mo	22
Ni	114
Pb	208
Sb	6[e]
Se	2[e]
Tl	NA
V	83[e]
Zn	194

[d] As, Ag, Be, Cd, Cr, Cu, Hg, Ni, Pb, Sb, Se, Tl, and Zn from EPA Priority Pollutant list; As, Be, Cd, Cr, Cu, Hg, Ni, Pb, V, and Zn controlled by London Dumping Convention; Co and Mo are of geochemical interest.

[e] When analyses were below detection limit, the detection limit was halved to compute the mean.

Table III. Correlations Between Radium and Toxin Concentrations

Element	Degree of Correlation		
	Probably None (r=0.00-0.24)	Correlation Possible (r=0.25-0.74)	Good Correlation (r=0.75-1.00)
As		X	
Ag	Below limit of detection		
Be		X	
Cd	Below limit of detection		
Co		X	
Cr	X		
Cu		X	
Hg	X		
Mo			X
Ni			X
Pb		X	
Sb	Sufficient data not available at this time		
Se		X	
^{232}Th		X	
Tl	Data not available at this time		
^{238}U			X
V	X		
Zn		X	

Additional Requirements for Characterization of Middlesex Materials

Although we have made significant progress characterizing these materials this year, several additional requirements remain:

First, more analyses are needed for natural radionuclides in the ^{238}U and ^{232}Th decay series, and for the trace metals that associate with these elements. We hope to establish reliable correlations between the concentrations of these metals and that of ^{238}U (and perhaps ^{232}Th as well). For the elements for which this turns out to be impossible, we must obtain enough data for reliable estimates of the inventories of these elements in the material at Middlesex. It is unclear how many analyses will be required in either case; discussions with EPA officials will be most helpful in this regard.

Second, sampling and analyses may be required for possible organic contaminants. Because the history of the site suggests that these types of contaminants are not likely to be present at Middlesex, we did not focus on them in the preliminary characterization studies we report here. Results for ^{137}Cs, a fallout radionuclide for which analysis was carried out, indicate levels expected from atmospheric fallout from nuclear weapons testing.

Third, information is needed on the redox state, mineralogy, particle size, and particle density of the contaminants. This information is essential to model the behavior of this material in the water after release from the conveyance, and the release of soluble contaminants to the water after the material has settled to the bottom.

Finally, the samples that will be used for the bioassays and the leaching experiments must be characterized. This is essential to interpret the results of these experiments, and will include all of the analyses discussed above.

POTENTIAL OCEAN DISPOSAL SITES

The initial screening for suitable sites was based on: 1) a need to maintain the depth requirement for disposal sites of greater than 4000 m, specified in an annex to the LDC; 2) a requirement that the site be within the two hundred mile economic zone around the United States to maximize the authority of the EPA; and 3) a requirement that the distance from land be as short as practicable to minimize sea transportation costs. In discussions with EPA about the suitability of these criteria, and about the possibility that the natural activity in the FUSRAP could be

considered a trace contaminant, a potential site, Deep Water Dumpsite 106 (DWD 106), was identified. This site, approximately 240 km NE of Cape Henlopen, Delaware (Fig. 1) is now used for the disposal of industrial wastes in slurry form. Consolidated Edison of New York City has applied for a permit to dump 500,000t/y of coal ash at the site. This material is, at least superficially, similar in its physical properties to Middlesex FUSRAP soil. While the industrial waste slurries are believed to disperse widely in the water column, a greater proportion of the coarser grained coal ash and FUSRAP soil would be expected to settle locally.

DWD 106 lies in the slope water hydrographic regime, a transition region between the relatively low salinity shallow water over the continental shelf, which is the flooded seaward extension of the continent, and the relatively high salinity (particularly in the near surface layers) deep water of the Western North Atlantic Ocean, which lies to the east. The entire slope water region has been relatively well-studied by oceanographic standards, while DWD 106 and the region surrounding it have been intensively studied in

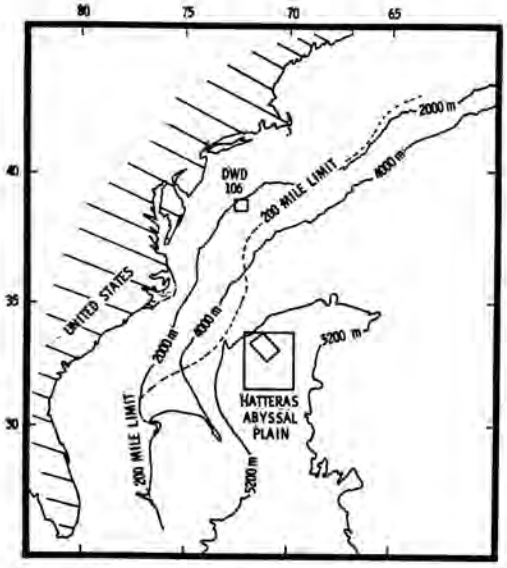

Fig. 1. Location of Possible Sites for the Disposal of FUSRAP Material.

obtaining the information to support the Environmental Impact Statement resulting in its designation as a disposal site.[8] Adequate information[9] is available at and around the site for standard hydrographic quantities (salinity, temperature, dissolved oxygen), nutrients (nitrate, nitrite, ammonia, phosphate, silicate), and some heavy metals. There are some ^{226}Ra measurements in the sediments in the vicinity of the site and in the surface waters. There is also a fairly complete data base for the biota in the sediments and water column of the region.[9]

At the time when we began considering sites, a survey had just been carried out for another Sandia National Laboratories program addressing disposal of large irradiated metallic structures, with essentially the same criteria as specified above. Based on the results of the survey, we were able to identify a second potential site in the area to the east of Cape Hatteras (Fig. 1). This site is presently of secondary interest because of the possible availability of DWD 106, an already designated EPA site.[9] The data base for the Hatteras site, reviewed in Jackson, is less complete than for DWD 106.

Bioassay

Discussions between Sandia National Laboraories personnel and EPA officials have identified solid-phase bioassays as being the critical bioassay procedure to be performed on FUSRAP waste material, since it was generally felt that the solid phase would be most likely to have detectable impact. This is because the solid material may not mix or disperse in the water as rapidly or as greatly as the liquid and suspended particulate phases, and benthic organisms live and feed in and on the deposited solid phase for extended periods. Due to the complexity of the system, chemical procedures alone are not always useful in identifying the severity of the environmental impact. Therefore, animals will be used in a bioassay to provide a measurement of environmental activity of the FUSRAP waste material. "Implementation Manual for Section 103 of Public Law 92-532"[10] provides guidance for performing solid-phase bioassays, including a description of the aquarium system, collection of sediment and test organisms, species selection, experimental conditions, bioassay procedures, and analysis and interpretation of results.

SCOPING CALCULATIONS

A number of scoping calculations have been carried out in order to estimate the order of magnitude of certain processes and costs. The results and significance of those calculations which we believe to be of particular interest are summarized below. More detailed information may be found in the Ocean FUSRAP Annual Report.[7]

Cost of Ocean Dumping for Two Options

The options are disposal from dump scows at DWD 106, and disposal with containment in surplus ship hulls at the Cape Hatteras Site. A number of additional options were initially considered but were discarded because of handling problems, high costs, use of unacceptable materials, or possible extended development periods. The cost components considered for the two options were land transportation from the site at Middlesex, N. J., to the Port of Perth Amboy, N. J.; loading at the site; loading on the sea transportation conveyance; and sea transportation. The cost to dispose of 100,000 metric tons of material is $1,650,000 for the DWD 106 site by dump scow, and $6,350,000 for the Cape Hatteras Site by containment in surplus ship hulls. Costs in each case are exclusive of any dock alteration or construction (assumed to be essentially the same for either case) which may be required. The difference between the cost of the two options is due primarily to the cost of the surplus ship hulls. It should be noted that the difference in the overall costs of disposal at the two sites would be still greater than it would appear from these estimates because of the cost of the additional research and the time necessary to support an EPA designation of a new dump site in the Cape Hatteras area versus that necessary to show that the FUSRAP material can be safely disposed of at the already designated DWD 106 site. It should also be noted that more exact engineering calculations, carried out by the FUSRAP engineering contractor and not yet published, show higher transportation costs, but this should not affect the relative cost advantage of ocean over land disposal.

Depth of Initial Sinking of a 500 Ton Bolus of Soil Released Instantaneously from a Dump Barge

A simple calculation was carried out assuming that the soil behaves as a negatively buoyant fluid sinking in a fluid with a vertical density gradient. For a soil bulk density of 1500 kg/m^3, the calculated ultimate vertical displacement of the soil mass was 250 m. By the time the soil reaches this depth, sea water entrained during sinking has reduced the density of the soil-water cloud to that of the ambient fluid. The cloud of entrained fluid and soil particles is now neutrally buoyant and begins to spread laterally; the soil particles begin to behave more as individual entities rather than as part of a soil-water mass in collective motion. Because the internal friction in a soil mass is different from that in the negatively buoyant fluid which was assumed for this calculation, the estimate of 250 m can be considered to be only order of magnitude. It should be noted, however, that in a research dump of fly ash from a dump scow at DWD 106, sponsored by Consolidated Edison of New York City, the major portion of the material released was observed to sink rapidly below 100 m.

Particle Sinking Times for a Typical Central New Jersey Soil

Particle sinking velocities and times to sink to 4000 m were calculated for a particle size distribution typical of that found in a Central New Jersey soil. Sinking rates and times were also calculated for a range of pitchblende particle sizes. Pitchblende is of interest since it is believed that an as-yet-unknown portion of the contamination in the FUSRAP soils may be in the form of pitchblende particles. Size ranges, weight percent of soil in the various size ranges and sinking times are shown in Table IV.

Dose to Person

Data obtained from literature reviews will be used as a data base for a marine ecosystem model presently being developed by Sandia National Laboratories for the U. S. Subseabed Disposal Program.[11] This ecosystem model serves more as a mechanism for summarizing our knowledge and organizing our understanding of the biological dynamics with respect to radionuclide transport in the oceans, than for predictive calculations. It is useful for parameter studies of simple pathways to man.

Figure 2 is a diagram illustrating a worst case scenario for a generic disposal site where several "short circuits" are assumed to rapidly transport radionuclides from the ocean floor to a person in a boat over the site. It should be noted that such pathways are not known to exist and are not expected to be important in the radionuclide transport process for FUSRAP material if they do exist. A preliminary estimate of the 50 year dose commitment from ^{226}Ra, the radioisotope of greatest concern for the Middlesex material, indicates that the dose to a person receiving all his food for 50 years via pathways one to four from organisms living in the waste material is negligible in comparison to the dose from background ^{226}Ra in the body.

Table IV. Sinking Times for Typical Central New Jersey Soil (Particle Density Same as Illite)

Size Range (mm)	Percent	Sinking Time (to 4000 m)
Less than 0.002	15	Greater than 40 years (could be accelerated by biological processes to months)
0.002 - 0.05	35	40 years to 1 month (could be accelerated by biological processes)
0.05 - 4.7	30	1 month to 2 hours
Greater than 4.7	20	Less than 2 hours

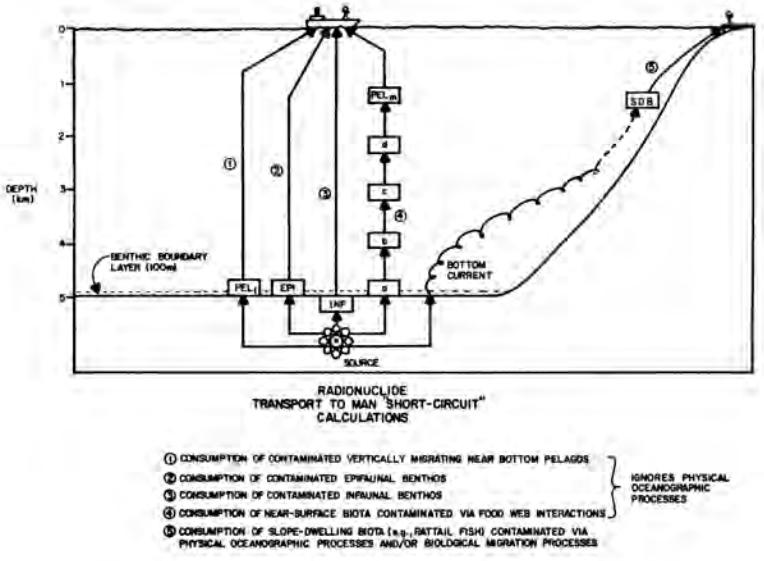

Fig. 2. Component of Submarine Ecosystem Model.

CONCLUSIONS

In studying the feasibility of ocean disposal of FUSRAP material as typified by that found at Middlesex, New Jersey, we have begun to examine institutional requirements to be met, the composition of the source material with regard to its inventory of toxic chemical and radiochemical components, and the impact of the source material in the marine environment. To date we have found nothing that would preclude safe and inexpensive disposal of this material in the ocean.

Acknowledgments

This work was performed at Sandia National Laboratories supported by the U.S. Department of Energy under contract number DE-AC04-76DP00789. We would like to thank J. L. Krumhansl and D. M. Talbert for helpful comments on the manuscript and A. A. McConnell for editorial assistance.

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