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An Evaluation of Techniques for Ocean Disposal of Soils Containing Naturally Occurring Radionuclides (FUSRAP Wastes)

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AN EVALUATION OF TECHNIQUES FOR OCEAN DISPOSAL OF SOILS CONTAINING NATURALLY OCCURRING RADIONUCLIDES (FUSRAP WASTES)

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FOREWORD

In 1972 the Congress enacted Public Law 92-532, the Marine Protection, Research and Sanctuaries Act, which authorized the Environmental Protection Agency (EPA) to regulate any future ocean disposal of waste materials, including low-level radioactive wastes (LLW).

Thus, since 1974, the EPA Office of Radiation Programs (ORP) has conducted studies to determine effects from previous U.S. ocean disposals of LLW, and to develop criteria for regulating any future disposals.

In recent years the oceans have been considered as a disposal option for soils, containing very low levels of naturally occurring radionuclides, from the Department of Energy's (DOE) Formerly Utilized Sites Remedial Action Program (FUSRAP). This report discusses and evaluates five potential techniques or methods, as proposed by the DOE, for ocean disposal of FUSRAP wastes.

The Agency invites all readers of this report to send comments or suggestions to Mr. Martin P. Halper, Director, Analysis and Support Division (ANR-461), Office of Radiation Programs, Environmental Protection Agency, Washington, DC 20460.

Richard J. Guimond

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SUMMARY

This report presents and discusses five alternatives (techniques) for ocean disposal of soils, containing very low levels of naturally occurring radionulcides, from the Department of Energy's (DOE) Formerly Utilized Sites Remedial Action Program (FUSRAP). These five techniques include: (1) disposal of unsolidified wastes in a closed barge; (2) disposal of unsolidified wastes in closed containers; (3) disposal of solidified wastes in a closed barge; (4) disposal of solidified wastes in closed containers; and, (5) disposal of solidified wastes without containerization.

Each technique is evaluated with respect to how it conforms to eleven waste package performance criteria for ocean disposal of LLW. The criteria, proposed in 1988, and specifications are listed in Section 2 of this report. The results of evaluating techniques and criteria are discussed in Section 4. Two of the five disposal techniques conform to all of the draft packaging criteria, namely: disposal of solidified wastes in a closed barge, and disposal of solidified wastes in closed containers.

The report further states that the waste package performance criteria, proposed for ocean disposal of LLW, are actually inappropriate for FUSRAP and other long-lived radionuclide wastes. Thus, it is recommended that a new set of criteria should be developed for ocean disposal of FUSRAP, and other wastes, where solidification or containerization provides no reduction of long-term risk(s).

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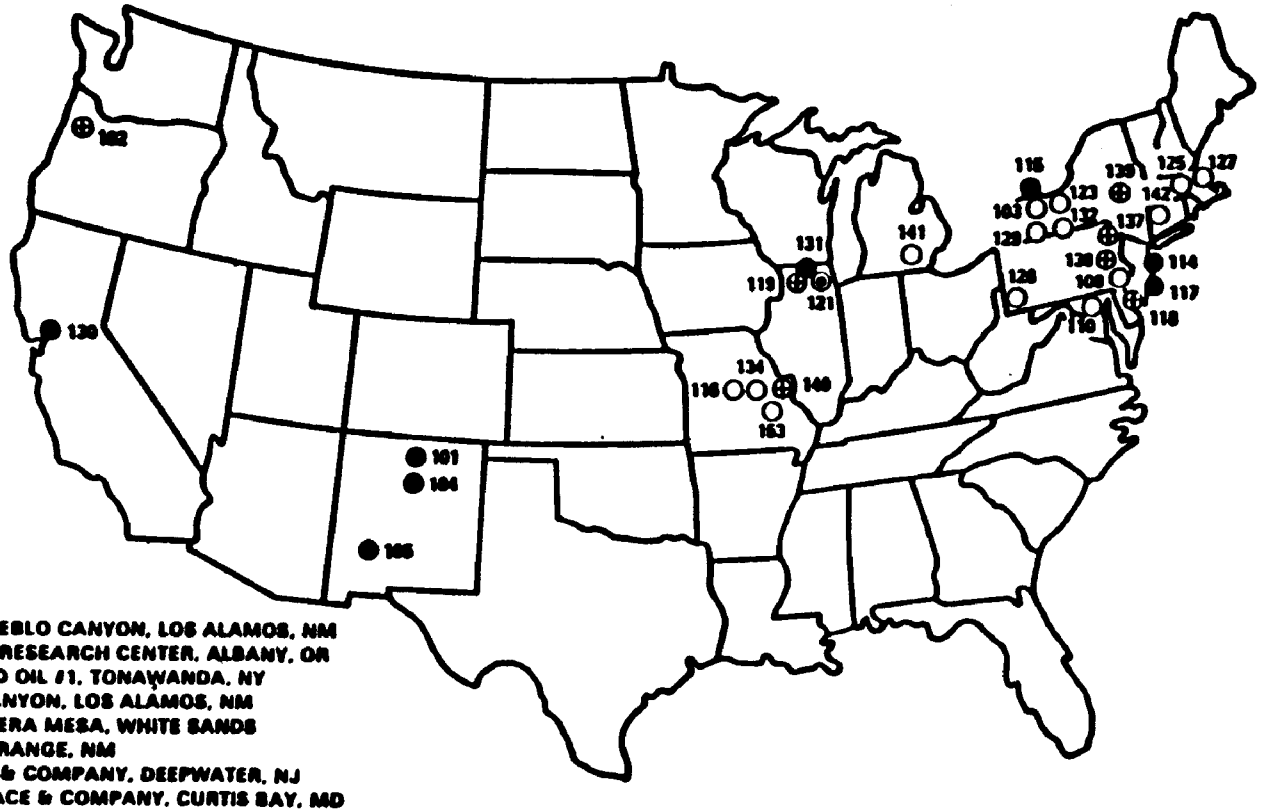
1. INTRODUCTION AND BACKGROUND

The Formerly Utilized Sites Remedial Action Program (FUSRAP) of the U.S. Department of Energy (DOE) is a program to identify, characterize and remediate sites that were used in the past for processing, research, development and storage of uranium and thorium ores, concentrates and residues [1]. There are 29 sites requiring remedial action in 12 states and one radiological surveillance site, as shown in Figure 1 [2]. The sites are locations that were used by the Manhattan Engineering District of the former U.S. Atomic Energy Commission (AEC) from the early 1940's to the early 1960's. Estimated total volumes of FUSRAP waste are 1.2×10^6 m^3 [2].

A variety of options have been considered for disposal of FUSRAP waste. They have been described by Gilbert, et al, [3] and are shown in Table 1. The ocean disposal option presents several advantages in cases where on-site disposal is not practicable. Long-term risks are minimized by this option since there is no need for concern about on-site intruders or groundwater contamination. Moreover, long-term institutional control and alternate land-use policy questions become moot. The ocean disposal option does, however, have the associated risk of food-chain contamination due to the potential for dispersion of wastes, both during disposal operations and after disposal on the seafloor. To minimize the potential for such food-chain contamination, the International Atomic Energy Agency (IAEA) has recommended a minimum depth of 4,000 m for ocean disposal of low-level radioactive waste (LLW) materials.

In 1986 the Environmental Protection Agency's (EPA) Office of Radiation Programs (ORP) reported on two studies pertaining to ocean disposal of FUSRAP wastes from the Middlesex, NJ, FUSRAP site [4, 5].



101 ACID/PUEBLO CANYON, LOS ALAMOS, NM
102 ALBANY RESEARCH CENTER, ALBANY, OR
103 ASHLAND OIL #1, TONAWANDA, NY
104 BAYO CANYON, LOS ALAMOS, NM
105 CHUPADERA MESA, WHITE SANDS MISSILE RANGE, NM
108 DUPONT & COMPANY, DEEPWATER, NJ
110 W.R. GRACE & COMPANY, CURTIS BAY, MD
114 KELLEX/PIERPONT, JERSEY CITY, NJ
116 NIAGARA FALLS STORAGE SITE (VICINITY PROP.) LEWISTON, NY
118 MALLINCKRODT, INC., ST. LOUIS, MO
117 MIDDLESEX LANDFILL, MIDDLESEX, NJ
118 MIDDLESEX SAMPLING PLANT, MIDDLESEX, NJ
119 NATIONAL GUARD ARMORY, CHICAGO, IL
121 PALOS PARK FOREST PRESERVE, COOK COUNTY, IL
123 SEAWAY INDUSTRIAL PARK, TONAWANDA, NY
125 SHPACK LANDFILL, NORTON, MA
126 UNIVERSAL CYCLOPS, ALIQUIPPA, PA
127 VENTRON, BEVERLY, MA
129 LINDE AIR PRODUCTS, TONAWANDA, NY
130 UNIVERSITY OF CALIFORNIA, BERKELEY, CA
131 UNIVERSITY OF CHICAGO, CHICAGO, IL
132 ASHLAND OIL CO. #2, TONAWANDA, NY
134 ST. LOUIS AIRPORT SITE (VICINITY PROP.), ST. LOUIS, MO
137 WAYNE/PEQUANNOCK, NJ
138 MAYWOOD, NJ
139 COLONIE, NY
140 HAZELWOOD (LATTY AVENUE), MO
141 GENERAL MOTORS, ADRIAN, MI
142 SEYMOUR SPECIALTY WIRE, SEYMOUR, CT
153 ST. LOUIS AIRPORT SITE, ST. LOUIS, MO

○ REMEDIAL ACTION PLANNED
⊕ REMEDIAL ACTION PARTIALLY COMPLETED
● REMEDIAL ACTION COMPLETED
● RADIOLOGICAL MONITORING ONLY

Figure 1. Locations for Formerly Utilized Sites Remedial Action Program Sites

Table 1. Disposal/Stabilization Alternatives [1] for FUSRAP Wastes

A. No Action

B. Onsite Containment

B.1. Containment without future disposal
- **B.1.a. Above-surface containment**
- **B.1.b. Near-surface containment**

B.2. Containment with monitored future disposal
- **B.2.a. Institutional controls only**
- **B.2.b. In-situ stabilization**
- **B.2.c. Above-surface containment**
- **B.2.d. Near-surface containment**

C. Offsite Containment

C.1. Containment without future disposal
- **C.1.a. Above-surface containment**
- **C.1.b. Near-surface containment**
- **C.1.c. Intermediate-depth containment**

C.2. Containment with monitored future disposal
- **C.2.a. Above-surface containment**
- **C.2.b. Construction use**
- **C.2.c. Near-surface containment**
- **C.2.b. Intermediate-depth containment**

C.3. Containment with unmonitored future disposal
- **C.3.a. Containerized ocean disposal**
- **C.3.b. Land disposal in deep geological structures**

D. Offsite Immediate Disposal

D.1. Ocean Disposal

D.2. Land Disposal

---

[1] No action = site released for unrestricted use.
Institutional controls only = regulatory-controlled access/use only; no physical action.
In-situ stabilization = in place waste stabilization.
Above-surface containment = above ground emplacement in an engineered structure.
Near-surface containment = land disposal in/within upper 15-20 m of earth's surface.
Intermediate-depth containment = land disposal in/within 20-100 m of earth's surface.

This report presents and discusses five proposed techniques for ocean disposal of FUSRAP waste. Each technique is based on preventing waste dispersal during disposal so that large quantities of the material will not remain in the water column. All five techniques are evaluated with respect to proposed waste package performance criteria for deepsea disposal of LLW [6].

1.1 Waste Characterization

Most FUSRAP waste is by-product material, which is defined in the Atomic Energy Act of 1954 [Public Law 703, Aug. 30, 1954, 42 U.S.C. 2014 Section II(e)(1)] as "any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material" [2]. While by-product material is excluded from the Resource Conservation and Recovery Act as defined in IIe(2), there is some question regarding standards for disposal of by-product wastes that are mixed with non-radioactive hazardous materials. Guidance is being prepared by an interagency working group for the disposal of mixed IIe(2) by-product waste [2].

FUSRAP wastes have been characterized in the draft Environmental Impact Statements applicable to the various sites. These types of wastes most often consist of soil and building rubble that is contaminated by ore or residue from ore processing. Contamination frequently occurs when wind and water borne particles, from outdoor piles of higher activity material, are mixed into soil. On occasion, transportation by moving water, or deliberate removal of the material for construction fill, has scattered wastes to many "vicinity properties" surrounding the original storage site.

Most of the radionuclide contaminants consist of U-238 and the products in its decay series. At some sites, Th-232 and its decay products are also of concern. The decay chains for U-238 and Th-232 series radionuclides are shown in Figures 2 and 3, respectively [7]. An example (Middlesex, NJ site) of radionuclide concentrations in FUSRAP wastes is given in Table 2. FUSRAP soil wastes also contain metallic substances, as shown in Table 3.

For FUSRAP wastes in general the prinicpal hazard is from Ra-226 and its short-lived decay products (see Figure 2) [7]. Because this waste (at least as determined at the Middlesex, NJ site) [8] is in secular equilibrium, the hazard will exist as long as the U-238 is present. Average concentrations range from 20 to 200 pCi/g for U-238, and from 50 to 500 pCi/g for Th-230 and Ra-226. Localized concentrations, however may exceed these values by factors of 10 to 100 [9]. Nevertheless, in at least some cases, the overall activity of FUSRAP wastes is sufficiently low that the wastes are classified as nonradioactive for transportation purposes [9].

Table 4 indicates that much of the waste is in the form of soil, typically having a significant percentage of very fine grained material. For example, waste from the Niagara Falls site are 37 percent sand-size, 26 percent silt, and 37 percent clay [9]. Other sites have much larger average grain sizes since the bulk of the waste is building rubble. In some cases, the wastes contain significant amounts of wood or leaf litter.

Radiological impacts from ocean disposal of FUSRAP waste would be small, as can be seen by comparing the amount of activity naturally present at a disposal site with the amount of activity in the FUSRAP waste. The sediment characteristic and radioactivity data that follows are from the Atlantic Ocean 3800 m disposal site.

A site having an area of 2500 km^2 has been assumed. Only the sediment to a depth of 5 cm has been included because it is in contact with the sediment/seawater interface through bioturbation. Density of the sediment is taken to be 1.1 g/cm^3. The activity of ^{238}U is 14 pCi/g [11], which is in the midrange of oceanic sediments (0.1 to 27 pCi/g) [10], and was determined as the average of 12 samples analyzed at Brookhaven National Laboratory (BNL) for the Atlantic 3800 meter site. Activity of ^{226}Ra in this sediment was 0.56 pCi/g [11], with the range for oceanic sediment being 0.3 to 39 pCi/g [10].

Using these values and the data presented earlier for FUSRAP waste, a comparison can be made. The activity in the surficial sediment of the entire site is 190 Ci and 7.8 Ci for ^{238}U and ^{226}Ra respectively. If the entire inventory of FUSRAP waste (1.2×10^6 m^3) is dumped at this site, an event that will not occur, the activity deposited will be between 0.55 and 5.5 Ci of ^{238}U. This is between 1 and 3 percent of the ^{238}U activity naturally present at the site. The activity of ^{226}Ra that will be deposited from the waste is between 1.4 and 14 Ci, bracketing the amount naturally present at the site with the maximum FUSRAP deposition being about double the natural activity.

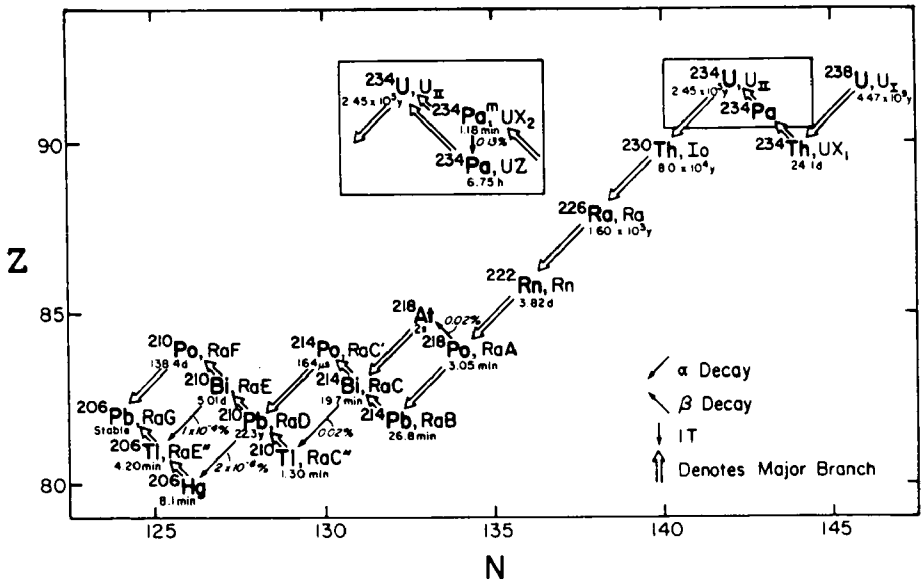


Figure 2. The U-238 decay series, showing the half-life of each isotope [7].

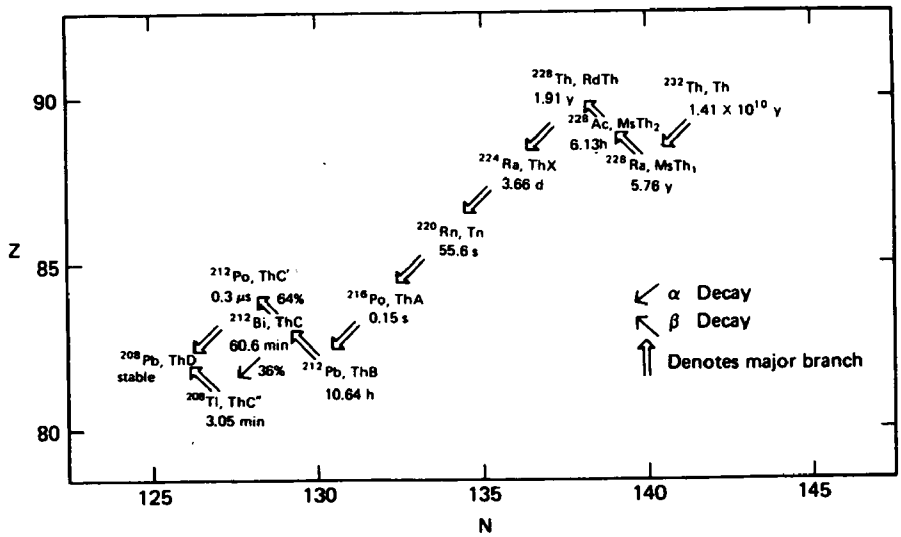


Figure 3. The Th-232 decay series, showing the half-life of each isotope [7].

Table 2. Radioisotopes[a] in FUSRAP Waste [8]

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

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

Table 3. Mean Concentrations of Trace Metals[a] in Middlesex FUSRAP Waste [8]

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

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

TABLE 4
PROJECTED QUANTITIES AND CHARACTERISTICS OF WASTES COLLECTED BY FUSRAP ACTIVITIES[a]

State and site	Site area (ha)	Estimated waste volume (m^3)	Principal constituents	Identified contaminants
California				
Gilman Hall, Univ. of California, Berkeley	ND[b]	23[c]	Floor tile, piping	Alpha, ^{137}Cs
Connecticut				
Seymour Specialty Wire	ND	33	Rubble, metal	^{238}U
Illinois				
Palos Park Forest Preserve Cook County	7.7	d	Soil, rubble	HTO, ^{238}U, ^{239}Pu, ^{137}Cs, ^{155}Eu, ^{90}Sr, ^{60}Co
Laboratories at Univ. of Chicago, Chicago	3.8	57[e]	Building masonry, floor tile, wood, glass, carpet	^{238}U, alpha, beta-gamma
National Guard Armory	ND	38	Building masonry and rubble material, floor tile,	^{238}U
Subtotal		95		
Maryland				
W.R. Grace and Company Curtis Bay		27,526	Soil	^{232}Th
Massachusetts				
Shpack Landfill, Norton	3.2	306[f]	Soil, concrete, metal, rubble	^{238}U, ^{226}Ra, ^{235}U, ^{210}Pb
Ventron, Beverly	ND	3,823	Soil, concrete, rubble, metal, and building material	^{238}U
Subtotal		4,129		

TABLE 4
PROJECTED QUANTITIES AND CHARACTERISTICS OF WASTES COLLECTED BY FUSRAP ACTIVITIES (cont.)

State and site	Site area (ha)	Estimated waste volume (m^3)	Principal constituents	Identified contaminants
Missouri				
St. Louis Airport	8.8	107,034	Soil	^{238}U, ^{230}Th, ^{226}Ra
St. Louis Airport (vicinity properties), St. Louis	1	15,290	Soil	^{238}U, ^{226}Ra
Latty Avenue, Hazelwood	4.7	68,807[g]	Soil, rubble	^{238}U, ^{231}Pa, ^{227}Ac, ^{230}Th, ^{226}Ra
Mallinckrodt, Inc.	ND	53,522	Soil, building materials, rubble	^{238}U, ^{230}Pa, ^{226}Ra
Subtotal		244,653		
Michigan				
General Motors, Adrian	ND	153	Soil, building material, and metal	^{238}U
New Jersey				
E.I. du Pont de Nemours and Co., Deepwater	283	5,350	Soil, building material, rubble, road material	^{238}U, ^{232}Th, ^{226}Ra, ^{210}Pb
Kellex Research Facility, Jersey City	6.2	134[h]	Soil	^{238}U, ^{226}Ra, ^{232}Th, ^{230}Th, ^{210}Pb
Middlesex Municipal Landfill, Middlesex	1.2	25,232[i]	Soil	^{238}U
Middlesex Sampling Plant, Middlesex	3.9	43,580[j]	Soil, building material, rubble	^{238}, 232Th, ^{226}Ra
W.R. Grace/Sheffield Brook/other properties, Wayne and Pequannock	ND	91,740[k]	Soil, rubble	^{232}Th, ^{228}Th, ^{226}Ra, ^{238}U
Stepan Chemical Co., Ballod property and private properties on Latham St. and Davison Ave., Maywood	ND	206,422[l]	Soil, rubble	^{232}Th, ^{226}Ra, ^{235}U, ^{238}U, ^{40}K
Subtotal		372,458		

TABLE 4
PROJECTED QUANTITIES AND CHARACTERISTICS OF WASTES COLLECTED BY FUSRAP ACTIVITIES (cont.)

State and site	Site area (ha)	Estimated waste volume (m^3)	Principal constituents	Identified contaminants
New Mexico				
Acid/Pueblo/Los Alamos Canyons, Los Alamos	51.6	298[m]	Soil	^{239}Pu, ^{241}Am, fission products
Bayo Canyon, Los Alamos	137	1,163[n]	Soil, building material, rubble	^{238}U, ^{90}Sr
Chupadera Mesa, White Sands	ND	ND[o]	Soil	Fission products
Subtotal		1,461		
New York				
Linde Air Products Div., Tonawanda	22.2	19,727	Soil, building material, equipment	^{238}U, ^{232}Th, ^{230}Th, ^{226}Ra
NL Bearings Plant and private properties on Central, Palmer, and Yardboro Avenues, Albany, Colonie	ND	22,938[p]	Soil, building material, equipment, rubble	^{238}U, ^{226}Ra
Niagara Falls Storage Site (vicinity properties), Lewiston	525	36,697[q]	Soil	^{238}U
Ashland Oil Co. (No. 1) Tonawanda	3	64,226	Soil	^{238}U, ^{232}Th, ^{226}Ra
Ashland Oil Co. (No. 2) Tonawanda	1	36,701	Soil	^{238}U, ^{232}Th, ^{226}Ra
Seaway Industrial Park, Tonawanda	4.8	37,007	Soil	226Ra
Subtotal		217,296		

TABLE 4
PROJECTED QUANTITIES AND CHARACTERISTICS OF WASTES COLLECTED BY FUSRAP ACTIVITIES (cont.)

State and site	Site area (ha)	Estimated waste volume (m^3)	Principal constituents	Identified contaminants
Oregon				
Albany Metallurgical Research Center, Albany	ND	2,294	Soil, building material, plumbing	^{238}U, ^{232}Th
Pennsylvania				
Universal Cyclops, Inc., Aliquippa	0.34[r]	23	Soil, concrete, metal	^{238}U alpha, beta-gamma
Total (all sites)		870,144		

[a]Taken from Reference 1.
[b]Not determined.
[c]Remedial action completed; 25 m^3 of waste sent to LLW burial ground at NTS.
[d]Authorized for radiological surveillance only. Estimated 15,830 m^3 of stabilized waste entombed onsite being monitored.
[e]Remedial action completed; 57 m^3 of waste sent to EG&G, Idaho Falls, for disposal.
[f]Remedial action partially complete; <1 m^3 of waste generated.
[g]Remedial action partially complete; 10,322 m^3 of offsite property waste transferred to Interim storage onsite.
[h]Remedial action completed; 134 m^3 of waste sent to LLW burial ground at Barnwell, SC.
[i]Remedial action partially complete; 11,469 m^3 of waste transferred to Middlesex Sampling Plant for Interim storage.
[j]Remedial action partially complete; 26,763 m^3 of offsite property waste transferred to Interim storage onsite.
[k]Remedial action partially complete; 2,675 m^3 of waste transferred to Interim storage onsite.
[l]Remedial action partially complete; 30,589 m^3 of offsite property waste transferred to Interim storage onsite.
[m]Remedial action completed; 298 m^3 of waste to LLW burial ground at LANL.
[n]Remedial action completed; In-situ stabilization of 1,162 m^3 of waste.
[o]Remedial action not required.
[p]Remedial action partially complete; 612 m^3 of offiste property waste transferred to Interim storage onsite.
[q]Remedial action partially complete; 34,816 m^3 of offsite property waste transferred to Interim storage onsite.
[r]Total floor area that was surveyed; only isolated patches of radioactive contamination were found.

2. PROPOSED WASTE PACKAGE PERFORMANCE CRITERIA FOR DEEPSEA DISPOSAL OF LLW

Performance criteria have been developed for ocean disposal of LLW packages, containers and waste forms [6]. For each criterion in this report, an associated specification is recommended that gives a value or condition to be met for a waste package to be acceptable for ocean disposal. The specifications, therefore, provide values against which waste packages (or their components) can be evaluated or from which information gaps can be identified. The performance criteria were developed based on the following assumptions [6].

2.1 Assumptions

- Existing Federal regulations govern the interim storage, transportation and disposal of radioactive wastes. Waste packages intended for ocean disposal should meet all minimum Federal requirements, including relevant United States international treaty commitments.

- Only LLW, as defined in the Low-Level Radioactive Waste Policy Act (PL 96-573), is considered for ocean disposal.

- The disposal site has an average water depth greater than 4,000 meters.

- Package performance criteria are based upon a multiple barrier concept which considers the contributions of engineered barriers (waste form, container) and natural barriers (water column, physical and geochemical properties of the sediment).

2.2 Waste Package Performance Criteria and Specifications

1. **Criterion:** The package should have adequate density to ensure sinking to the seabed.

   Specification: The specific gravity of the package should not be less than 1.2 to ensure sinking to the seabed.

2. **Criterion:** The package should be designed to remain intact upon impact with the sea surface and the seabed.

   Specification: The package should be designed to maintain its integrity upon impact with the sea surface and the ocean floor at a minimum calculated and/or measured velocity of 10 m/s.

3. **Criterion:** The container should be capable of maintaining its contents until all radionuclides have decayed to acceptable limits, as determined by appropriate regulatory authorities.

   Specification: The container should have an expected lifetime in the deepsea environment of 200 years or 10 half-lives of the longest lived radionuclide, whichever is less.

4. **Criterion:** Liquid radioactive waste should be immobilized by suitable solidification agents.

   Specification: Liquid wastes should be solidified to form a homogeneous, monolithic, free-standing solid containing no more than 0.5 percent of free or unbound liquid by volume of the waste form.

5. **Criterion:** Buoyant material should be excluded or treated to preclude its movement or separation from the waste form during and after disposal.

   Specification: Buoyant materials should be treated to form a homogeneous free-standing monolithic solid having a specific gravity of not less than 1.2.

6. **Criterion:** The package should be able to withstand the hydrostatic pressure encountered during and after descent to the seabed.

   Specification: The triaxial compressive strength of a package should be 25 percent greater than the pressure encountered at the disposal depth. Uniaxial compressive strength of a package may be measured (triaxial strength is taken to be 4 times the uniaxial compressive strength). Pressure equalization devices that allow only ingress of water can be used.

7. **Criterion:** The leach rate of the waste form should be as low as reasonably achievable (ALARA).

   Specification: The leach rate for Cs-137, Sr-90 and Co-60, as well as other radionuclides of concern in the waste, should be no greater than regulatory guidelines as measured by the ANS 16.1 Leach Test for leaching in seawater.

8. **Criterion:** Particulate wastes should be rendered nondispersible.

   Specification: Particulate wastes, such as ashes, powders and other dispersible materials should be immobilized by a suitable solidification agent to form a homogeneous, monolithic, free-standing solid.

9. Criterion: Free radioactive gaseous wastes should be prohibited from ocean disposal.

Specification: No radioactive gaseous wastes should be accepted for ocean disposal unless they have been immobilized into stable waste forms such that the pressure in the waste package does not exceed atmospheric pressure.

10. Criterion: Mixed wastes, which contain hazardous constituents, should not be disposed of at a LLW ocean disposal site.

Specification: Wastes that contain constituents prohibited, as other than contaminants in 40 CFR, Subchapter H, Subpart B, part 227.6 should not be disposed of at a LLW ocean disposal site.

11. Criterion: The waste should be physically and chemically compatible with the solidification agent.

Specification: Waste forms should retain their structural stability after immersion in seawater for 180 days.

In view of recent EPA/ORP bioeffects studies, an additional consideration is that LLW should be present in quantities to ensure that no localized, adverse effects would occur, as determined by using bioassay/bioeffects testing procedures, should the waste package rupture. Further, any dose to a sensitive, benthic species for the radionuclides under consideration should be at or below the lowest observable effects-levels (LOEL's) measured by laboratory exposure procedures. This concept will presumably supercede proposed criterion number 3, above, which requires a container lifetime of sufficient length that the contents will have decayed to innocuous levels before the container fails. However, uncertainties of the exact activities allowed and how the dose to biota should be determined, based on any given failure scenario, preclude the use of this concept in evaluating the disposal techniques presented later in this report.

3. TECHNIQUES FOR OCEAN DISPOSAL OF FUSRAP WASTES

Five techniques or methods have been developed for ocean disposal of FUSRAP waste. An alternative (technique) in which "as is" or untreated FUSRAP waste, without containerization, is dumped into the ocean was not considered because of the dispersive nature of the waste [3]. Each technique is presented with a level of detail that allows for a comparison of relative merit. Each was also evaluated in terms of the proposed waste package performance criteria described in Section 2. A listing of advantages and disadvantages is provided.

3.1 Technique #1 - Disposal of Unsolidified Waste in a Closed Barge

3.1.1 Description. Untreated waste is transported by dump truck to a dock where it is transferred to a barge. The barge conveys the waste to the disposal site and serves as the disposal container. After being towed to the disposal site the barge is sunk by flooding it with water. Consequently, the barge must be constructed in such a way that it can be easily loaded and then sealed to ensure that waste cannot be released during disposal. Pressure equalization devices are necessary to maintain the integrity of the barge during descent. Technique #1 is illustrated in Figure 4.

Note that two sequences of events are possible after the barge is sunk. In the first situation, the barge remains intact after its descent to the seafloor. Since the barge was flooded, the waste is already in contact with water. However, the barge is intact and the waste is contained until the barge corrodes to the point of failure. While releases of contaminants that have leached into the water in the barge will occur with time, the waste will not be dispersed until corrosion destroys much of the hull.

The lifetime of the barge's hull is a function of corrosion rate (the general corrosion rate of mild steel in the deep Atlantic is about 0.08 mm/yr, although pitting may be much faster) and metal thickness. Assuming a typical hull thickness of 10mm, a maximum period of barge integrity ("lifetime") would be approximately 120 years.

In the second possibility, a barge could break-up during descent or impact with the seafloor; allowing the wastes to disperse and come into contact with marine life.

3.1.2 Evaluation. Technique #1 does not meet proposed waste package performance criterion 8 which requires that particulate wastes be rendered non-dispersible by solidification. Because a barge is used as the waste container, there are questions regarding the ability of a heavily laden barge to survive the descent and impact on the seafloor, without breaching, as illustrated in Figure 4. Some means of ensuring that the barge fully floods during descent is necessary. In addition, one way valves would be required to let water enter during descent so that pressure inside and outside the hull are equalized, thus minimizing the chances of rupture.

Generalized advantages and disadvantages associated with using technique #1 are listed below. The advantages are precluded by the failure of this disposal method to satisfy proposed waste package performance criterion # 8 because waste solidification is not employed in this technique.

Advantages	Disadvantages
• No solidification costs	• Waste is dispersible
• No volume increase	• May require specially designed barges
• Reduced transportation costs	• Requires large number of barges

OCEAN DISPOSAL OF FUSRAP WASTE

Technique # 1 Unsolidified Waste/Closed Barge

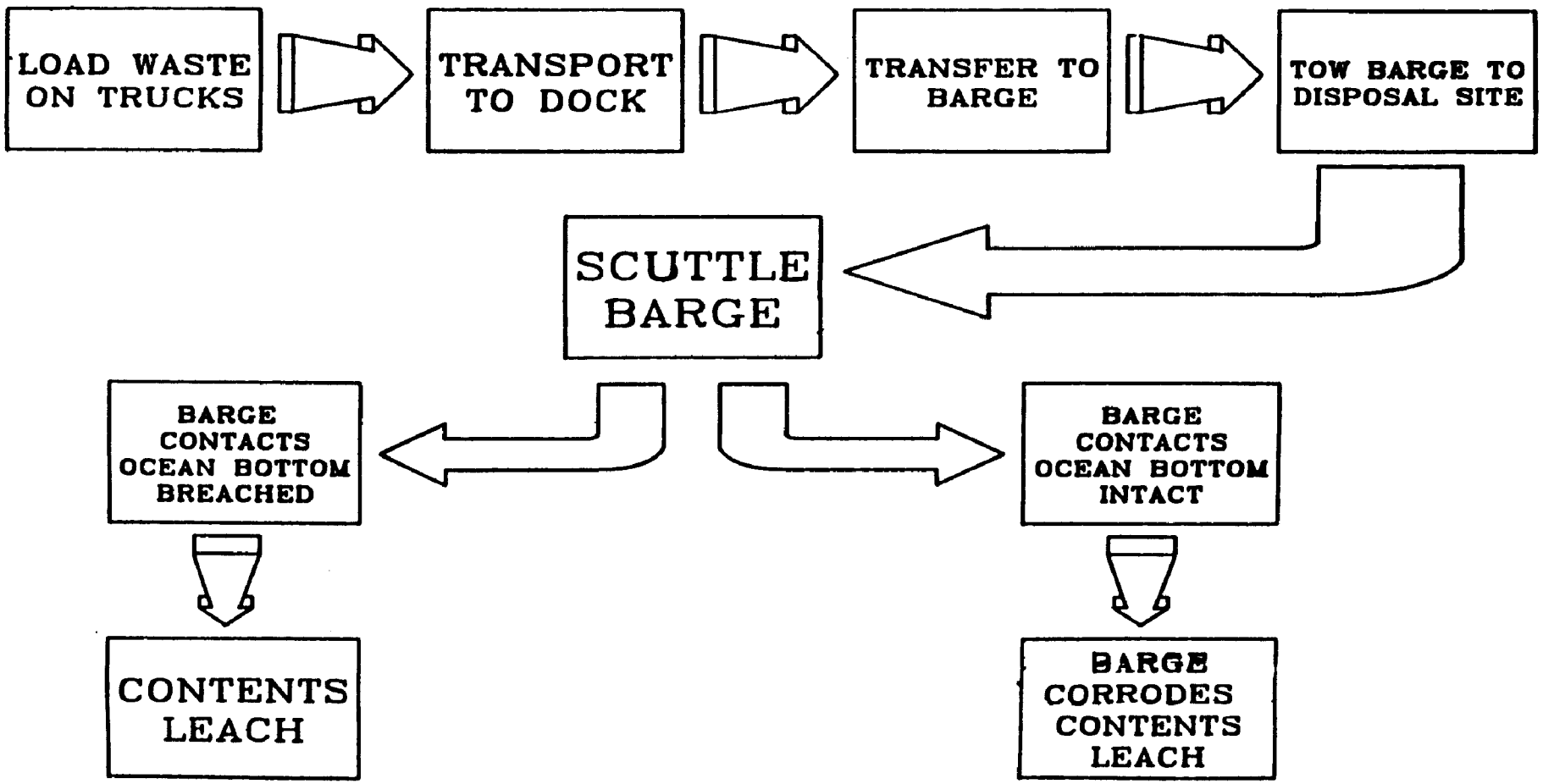


Figure 4. Disposal of Unsolidified Wastes in A Closed Barge

3.2 Technique #2 - Disposal of Unsolidified Waste in Closed Containers

3.2.1 Descrption. Untreated waste is loaded into containers at the storage site. These containers may be of any size. It is envisioned, for convenience, that 55-gallon drums would be used; but large, steel, 210 ft^3 liners or some other configuration would also be appropriate. The sealed containers are transported by truck to a dock where they are loaded onto a ship. The ship transports the containers to the site where they are dumped overboard. The act of disposal may actually be via a ramp to minimize impact between the container and the sea surface. Each disposal container would require a pressure equalization device to allow water to enter, but not to escape, thereby equalizing the hydrostatic pressure on the container during its descent to the seafloor. Once disposed in the ocean, the containers will be subject to the effects of corrosion. Thus, the wastes will eventually be exposed and subject to physical and/or biological transport and dispersion. Technique #2 is depicted in Figure 5.

3.2.2 Evaluation. Technique #2, as was the case for Technique #1, does not meet criterion 8 which requires solidification of dispersible waste. Pressure equalization devices would be required since loose, soil-like waste cannot support containers against the hydrostatic pressure of the deep ocean. Thin-walled containers, such as 55-gallon mild steel drums, cannot be expected to survive more than 10 to 20 years. However, thicker steel containers or other materials, such as some polymers, may last significantly longer. There is a degree of uncertainty as to how many, or what percentage, of these smaller (than barge-sized) containers would remain intact after impact on the ocean bottom. It is likely, however, that the percentage of smaller containers subject to such damage would be less than expected with the barges used in Technique #1.

OCEAN DISPOSAL OF FUSRAP WASTE

Technique # 2 Unsolidified Waste/Closed Containers

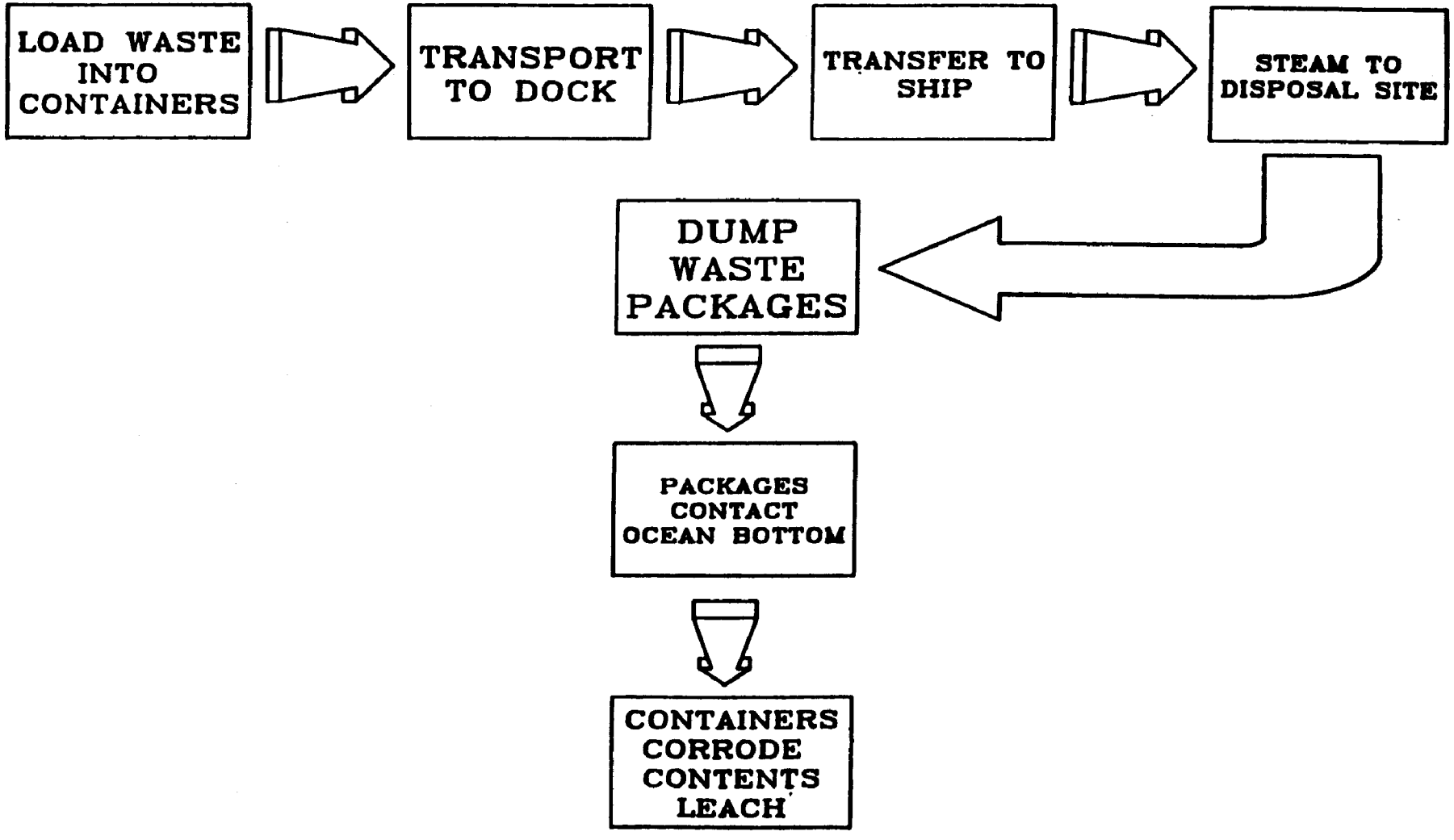


Figure 5. Disposal of Unsolidified Wastes in Closed Containers

Advantages	Disadvantages
• No solidification costs • No volume increase • Minimized dispersion during handling, transportation and disposal • Control over distribution of waste packages on ocean floor	• Cost of containers • Increased transportation costs

3.3 Technique #3 - Disposal of Solidified Waste in a Closed Barge

3.3.1 Description. As stated in waste package performance criterion 8, the waste materials should be immobilized with a solidification agent before disposal, to minimize their dispersion after disposal. This technique, as do techniques 4 and 5 which follow, uses hydraulic cement as the solidification agent, but other materials may also be suitable for this purpose. These three techniques only differ in when or where the waste is solidified, and in the method used for disposal.

In technique #3 (see Figure 6), the waste is transported to a barge-loading dock where it is mixed with hydraulic cement (e.g., Portland cement) and water. The wet mixture is then poured or pumped into a barge and allowed to set (harden). Afterward, the barge is sealed, towed to a disposal site and flooded for sinking. With time on the seafloor, as with smaller containers, the barge will eventually corrode to the point of failure. The solidified waste would then be subject to disintegration by the action of currents and biota, but the radionuclides in that waste would be released for dispersal at a slower rate than would unsolidified wastes from a corroded barge.

OCEAN DISPOSAL OF FUSRAP WASTE

Technique # 3 Solidified Waste/Closed Barge

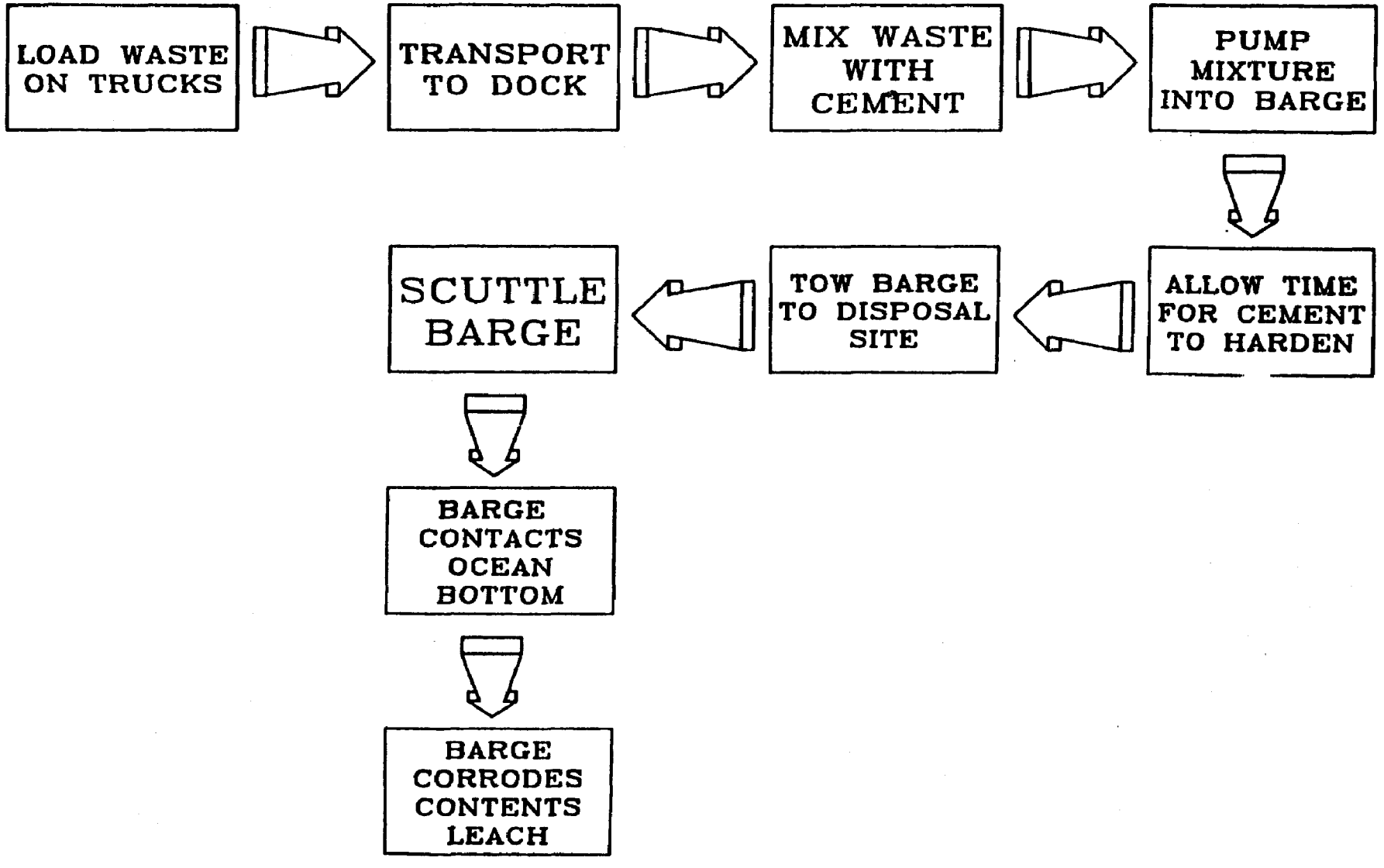


Figure 6. Disposal of Solidified Wastes in A Closed Barge

3.3.2 Evaluation. Technique #3 appears to meet all of the waste package performance criteria, with the exception of the container lifetime criterion (#3). One unknown factor is the ability of a barge to survive descent and impact on the ocean floor without breaching. The mass of solidified waste may improve survivability of the barge by making it more rigid, and more stable during descent, as compared to a barge containing loose waste.

Advantages	Disadvantages
• Reduced transportation cost from site of origin to dock • Waste rendered non-dispersible	• Dispersible waste transported and handled at dock • Solidification costs • Volume increase • May require specially designed barges • Requires large number of barges

3.4 Technique #4 - Disposal of Solidified Waste in Closed Containers

3.4.1 Description. The waste is mixed with water and hydraulic cement at the storage site. This can be done in large mixers and subsequently poured into containers. After allowing time for the mixture to harden, the drums are transported to the dock and loaded onto a ship. The waste containers are then transported to the disposal site where they are dumped. To eliminate damage from the effects of hydrostatic pressure during descent to the seafloor, the containers will need pressure equalization devices. The containers will eventually corrode, ultimately exposing the solidified waste to seawater. This technique is illustrated in Figure 7.

OCEAN DISPOSAL OF FUSRAP WASTE

Technique # 4 Solidified Waste/Closed Containers

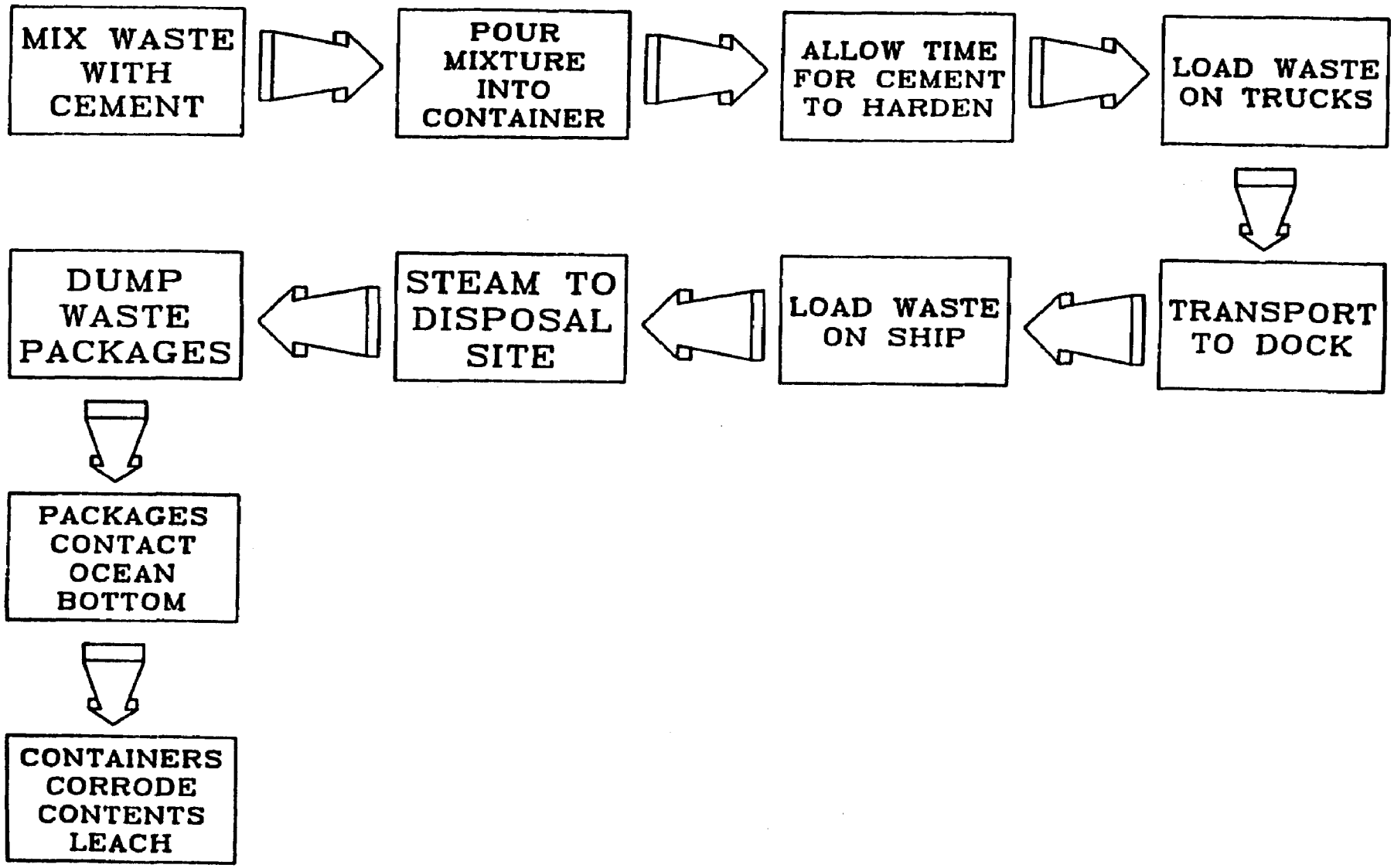


Figure 7. Disposal of Solidified Wastes in Closed Containers

3.4.2 Evaluation. Technique #4 is much the same as technique #3 in that it passes all of the proposed waste package performance criteria, except for container lifetime. There is less uncertainty about the ability of small containers to survive descent and impact on the bottom when they have been filled with solidified waste, than there is about larger containers (e.g. barges) filled with unsolidified waste.

Advantages	Disadavantages
• Waste is rendered non-dispersible at site of origin	• Solidification costs
• Control over distribution of waste packages on ocean floor	• Volume increase
	• Cost of containers
	• Increased transportation costs

3.5 Technique #5 - Disposal of Solidified Waste without a Container

3.5.1 Description. This technique (see Figure 8) takes advantage of the low activity of the FUSRAP waste by eliminating containers. At the storage site, the waste is mixed with hydraulic cement and water and cast into block-molds where it hardens. For larger waste forms, some reinforcement and lifting eyes may be included in the casting. After hardening, the molds are removed and the waste (in block waste forms) is transported to a dock and loaded onto the disposal ship. After dumping the waste blocks at the disposal site, leaching starts immediately.

3.5.2 Evaluation. This concept is significantly different than those previously described because no container is used. Consequently, it does not meet proposed waste package performance criterion # 3. However, the waste is not dispersible at any time after the blocks are produced as long as they are not damaged during loading and transport.

OCEAN DISPOSAL OF FUSRAP WASTE

Technique # 5 Uncontained Solidified Waste

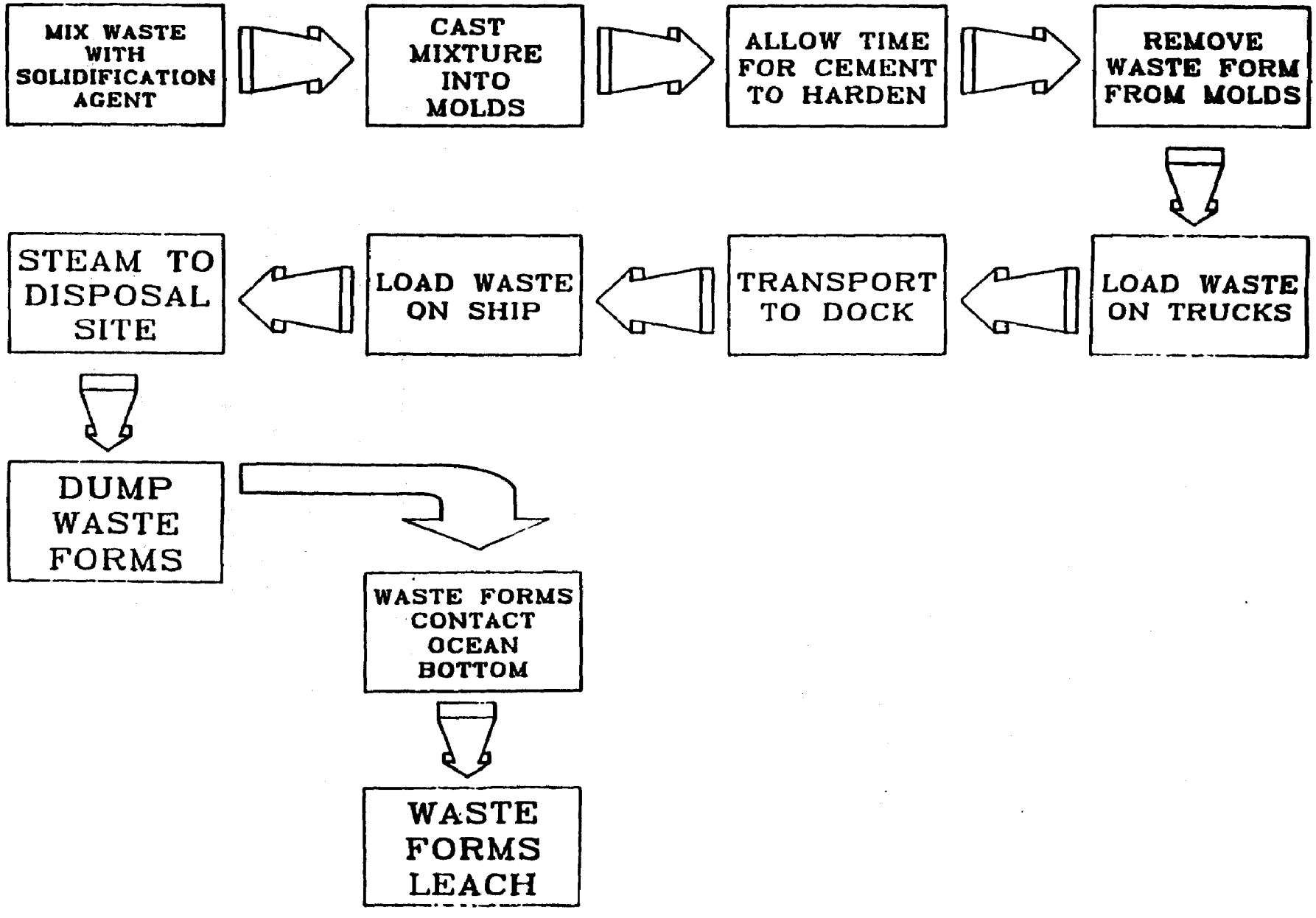


Figure 8. Disposal of Solidified Wastes Without Container(s)

Advantages	Disadvantages
No Container costs	Solidification costs
Waste rendered non-dispersible at site of origin	Volume increase
	Increased transportation costs

4. RESULTS AND DISCUSSION

4.1 Summary of Results

Table 5 summarizes the results from evaluating disposal techniques and proposed waste package performance criteria.

Criterion # 7 (leachability), is not addressed in this discussion because it is site dependent. It's applicability should be determined/evaluated by site-specfic monitoring and modeling.

The question of mixed (hazardous and radioactive) waste has yet to be resolved for FUSRAP wastes. It was not evaluated herein since this report focuses on packaging criteria.

Waste package performance criterion # 3 is not specific about how long a container must last because the container lifetime is based on the half-lives of whatever radionuclides are in the waste. FUSRAP waste loses its hazardous constituents (primarily Ra-226) at a rate governed by the half-life of U-238, which is 4.47×10^{9} years. Obviously, this is longer than any container could last, so none of the disposal techniques in this report meet that criterion.

It is important to note that a lowest observable effects level (LOEL) criterion may be promulgated for ocean disposal of LLW. In that event, proposed waste package

performance criterion # 3 (container lifetime) would be superceded and the amount of activity in each container would become important. Additional information, about acceptable doses to biota, waste package release models and near-field dispersion rates, is needed to apply the LOEL concept to regulating ocean disposal of LLW.

Table 5. Evaluation of Ocean Disposal of FUSRAP Waste for Conformance with Proposed Waste Package Performance Criteria

	Disposal Technique Number				
Criterion	1	2	3	4	5
1. Density	Yes	Yes	Yes	Yes	Yes
2. Impact	?	Yes	?	Yes	?
3. Container	No	No	No	No	No
4. Liquids	Yes	Yes	Yes	Yes	Yes
5. Buoyant Material	Yes	Yes	Yes	Yes	Yes
6. Hydrostatic Pressure	Yes	Yes	Yes	Yes	Yes
7. Leachability	*	*	*	*	*
8. Dispersibility	No	No	Yes	Yes	Yes
9. Gases	Yes	Yes	Yes	Yes	Yes
10. Mixed Waste	?	?	?	?	?
11. Compatibility	NA	NA	Yes	Yes	Yes

NOTES TO TABLE

Yes = Fulfills Criterion
No = Does Not Fulfill Criterion
? = Unknown For Criterion
* = Leach Rate Unspecified
NA = Not Applicable

4.2 Discussion

In evaluating the five techniques/methods presented in this report, it is apparent that disposal of FUSRAP wastes presents certain problems relative to the proposed waste package performance criteria. This is a result of the very long half-lives of the major contaminants in FUSRAP waste. These issues are discussed below.

4.2.1 Containers. Most FUSRAP wastes are "byproduct" wastes, having a different radionuclide content than the types of LLW considered when the proposed waste package performance criteria were developed. Because the long-lived FUSRAP "byproduct" wastes were not considered at that time, a discrepancy exists between the proposed container lifetime criterion (# 3) and its 200-yr expected lifetime specification. This container lifetime specification becomes irrelevant for such long-lived FUSRAP radionuclides as U-238. For very long-lived radionuclides, the only reasonable argument for requiring a container is to keep the waste from dispersing during disposal, allowing it to arrive at its intended location on the ocean bottom. Therefore, the entire concept of using containers to retain FUSRAP wastes long enough for radioactivity to decay to "acceptable limits" is inappropriate.

In addition, if the question of container lifetime is ignored and if it is acknowledged that a container is desirable to minimize dispersion, another practical matter arises. That is the large number of containers that would be required for ocean disposal of all FUSRAP wastes. If barges with a capacity of 2600 m^3 each, see [3], are used for unsolidified waste, more than 450 barges are required. If 55-gallon drums are used, then 5.8×10^6 drums will be needed. If the waste is to be solidified, these numbers double. Thus, as shown above, there are at least two reasons to question the use of containers for ocean disposal of FUSRAP wastes.

Introduction of the LOEL concept to this discussion would eliminate the need to provide a guaranteed lifetime for the containers. Instead, it sets limits (unknown at this time) on the amount of activity allowed in any one container. Significant questions arise when one takes a target dose to biota and works backward to obtain an allowable total activity per container. The geochemistry of the elements of concern will be important in determining how releases occur from the waste and at what rate. In the case of uranium, releases will be particularly sensitive to the oxidation-reduction environment. This is also the case when discussing corrosion rates of containers that are partially embedded in the sediment. The near-field dispersion of dissolved radionuclides and their interaction with the sediment and nepheloid materials will also significantly impact dose calculations. It is doubtful that enough is known about these processes in the deepsea to derive any useful dose values.

4.2.2 Solidification. Disposal techniques 3, 4, and 5 use the concept of solidification to minimize dispersibility of the waste in accordance with criterion #8, which states that "particulate wastes shall be rendered nondispersible." A key issue that arises here, then, is whether there is any rationale for minimizing dispersion of FUSRAP wastes after disposal.

No solidification agent can last long enough to have any impact on doses caused by ingestion of this waste. For example, waste solidified by cement will be reduced to particulates long before even a small part of the U-238 half-life has passed. Thus, as with containerization, solidification of FUSRAP wastes will provide no long-term benefit.

4.2.3 Leaching. Proposed criterion # 7 requires that the leach rate of a waste be "as low as reasonably achievable" and that leach rates will be no greater than

regulatory guidelines as measured by the ANS 16.1 test method. The concept of leaching is connected with solidification of waste in the ANS 16.1 test methodology. In the same way that solidification of FUSRAP waste provides no long-term benefits, leach rate limits do nothing to minimize long-term doses. Even very low leach rates will ultimately result in the release of all soluble contaminants because of the very long half-lives.

In the long-term, the amounts of U-238, Th-232 and their decay products present in seawater as a result of FUSRAP disposal will be controlled by the geochemical behavior of these elements in seawater, and the nature of the marine environment in which they are dumped. Thorium, for example, associates itself with particles very readily. Consequently, its residence time in seawater is short; about 100 years or less [13]. Uranium, in oxic seawater, is stable in the U^{+6} state as $UO_2(CO_3)_3^{-4}$ and has a mean residence time of 400,000 years [13]. If, however, the environment is not oxidizing, but reducing, uranium is present as U^{+4} which reacts to form lower solubility compounds and is, therefore, much less mobile than the oxidized form [14]. Radium is more soluble than its parent element and much of the radium in seawater is released from sediment where it is produced [10]. Radium-226 concentrations in Atlantic Ocean bottom water are typically about 0.1 pCi/l. Disposal of FUSRAP wastes from the Niagara Falls storage site into an area of approximately 2.6 km in diameter and 7 cm thick, would lead to an increase in Ra-226 concentration of 0.002 pCi/l in a one-meter-thick layer of water moving over the waste [15].

5. CONCLUSIONS

Disposal techniques 3 and 4, described in this report, meet the proposed waste package performance criteria in that the wastes are both contained and solidified.

Solidification, however, will approximately double the volume of waste for disposal. In addition, solidification (e.g., using portland cement) also would require containers. If barges, with capacities of 2600 m^3 each, are used as containers, approximately 900 would be needed. If 55-gallon drums are used, almost 12 x 10^6 would be needed.

From the previous discussions, it is evident that the proposed waste package performance criteria for LLW are inappropriate for regulating by-product materials containing long-lived istopes (e.g. FUSRAP wastes). In proposing these criteria [6], it is made clear that they were intended for regulating LLW containing radionuclides such as Cs-137, Sr-90 and Co-60. These are short half-life radionuclides (compared to the isotopes in FUSRAP waste) which would pass through many half-lives during the required 200-year container lifetime. The long half-lives of the contaminants in FUSRAP waste (which are naturally occurring), the very low activity and the large volume all make solidification and containerization unfeasible.

If the LOEL concept is to be applied to this type of waste, significant questions regarding geochemistry and near-field dispersion remain to be answered before reasonable limits can be defined for either FUSRAP (by-product) waste or for LLW.

Thus, the proposed LLW package performance criteria bear little useful relationship to FUSRAP waste. It is recommended that a new set of criteria be written for disposal of wastes, such as the FUSRAP materials, which could also be applicable to other waste types, where solidification or containerization provide no reduction of long-term risk.

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