NUREG/CR-3844
BNL-NUREG-51787

Characterization of the Radioactive Waste Packages of the Minnesota Mining and Manufacturing Company

Prepared by C. R. Kempf, B. Siskind, R. E. Barletta, D. R. Dougherty

Brookhaven National Laboratory

Prepared for
U.S. Nuclear Regulatory
Commission

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, or any of their employees, makes any warranty, expressed or implied, or assumes any legal liability of responsibility for any third party's use, or the results of such use, of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street, N.W.
   Washington, DC 20555
2. The NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission,
   Washington, DC 20555
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations,* and *Nuclear Regulatory Commission Issuances.*

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

GPO Printed copy price: $4.50

NUREG/CR-3844
BNL-NUREG-51787

Characterization of the Radioactive Waste Packages of the Minnesota Mining and Manufacturing Company

Manuscript Completed: May 1984
Date Published: July 1984

Prepared by
C. R. Kempf, B. Siskind, R. E. Barletta, D. R. Dougherty

Brookhaven National Laboratory
Upton, NY 11973

Prepared for
Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN A3172

ABSTRACT

An evaluation of the low-level waste packages generated by Minnesota Mining and Manufacturing Co. (3M) was made on the basis of 10 CFR Part 61 criteria and on the Technical Position on Waste Form and Waste Classification (TP). This evaluation was the result of a study initiated by the U.S. Nuclear Regulatory Commission (NRC), in which 3M participated.

3M produces a variety of radioactive products and wastes. The dominant radioisotopes are Po-210 and Cs-137. The Po-210 packages are generally Class A and meet the requirements in 10 CFR Part 61. The Cs-137 and Sr-90 packages fall into all three waste classifications (A, B, and C). These wastes are packaged by 3M in 30-gallon or 55-gallon carbon steel drums (Class A) or 30-gallon lined drums (Class B and C). The Class B and greater lead- and concrete-lined packages have been evaluated with respect to meeting the stability requirements for waste disposed of in a high integrity container. When so evaluated, eleven areas of concern were identified with respect to the regulations and recommendations in the TP.

CONTENTS

CONTENTS, Continued

TABLES

ACKNOWLEDGMENTS

The authors would like to thank Drs. M. Sue Davis and R. E. Davis for review of the manuscript and helpful contributions to the report. In addition, the authors would like to extend sincere appreciation to Ms. Nancy Yerry for her skillful coordination and typing of the drafts and to Ms. Mary McGrath for final preparation of the manuscript.

CHARACTERIZATION OF THE RADIOACTIVE WASTE PACKAGES OF THE MINNESOTA MINING AND MANUFACTURING COMPANY

1. INTRODUCTION

The low-level radioactive waste generated by many non-fuel cycle industries and institutions is not as well characterized as that produced by nuclear power plants. As part of a program to characterize non-fuel cycle wastes shipped for commercial shallow land burial, Brookhaven National Laboratory (BNL) has identified, contacted, and visited a number of non-fuel cycle waste generators. For selected generators, BNL has performed detailed evaluations of their low-level radioactive waste. These evaluations were performed with respect to criteria in 10 CFR Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste." These evaluations included (1) an assessment of the chemical, physical, radiological, and biological degradation mechanisms of the waste form and waste container which may affect the ability of the waste package to meet the acceptance criteria for disposal, and (2) the identification of chemical hazards in the waste packages which by themselves or in conjunction with the radiological hazards may affect the behavior of the waste packages and the ability of the site to perform adequately. To date, two such evaluations have been performed. They are an evaluation of the Class B waste packages of the New England Nuclear Corporation(1) and an evaluation of the large quantity waste packages of the Union Carbide Corporation.(2)

A third generator, the Minnesota Mining and Manufacturing Company (3M), is the subject of this study. This work has been conducted in cooperation with 3M in order to provide the Nuclear Regulatory Commission with an evaluation of 3M's low-level wastes with respect to 10 CFR Part 61 criteria, as well as the recommendations for Class B and C wastes specified in the Technical Position on Waste Form [Revision 0, May 1983 (TP)]. The relevant sections of 10 CFR Part 61 used in this study are those on waste classification and waste characteristics. These sections, 61.55 and 61.56, respectively, have been included in Appendix A. The relevant sections of the TP are included as Appendix B.

3M generates low-level waste in the production of radiopharmaceuticals, radioactive surgical implants, and radioactive sources. A description of the processes in which these wastes are generated can be found in Section 3. In an effort to categorize 3M's wastes according to the waste classification system set forth in 10 CFR Part 61, a review of the wastes shipped by 3M during a recent 19 month period has been performed by surveying the radioactive shipping records (RSRs) for this period. The results of this survey are given in Section 2. 3M has provided a description of the waste packages and overpacks used for their wastes. These descriptions are given in Sections 3 and 4.

As mentioned above, the evaluation of the 3M wastes is twofold. First, waste packages are evaluated to determine if they meet the minimum requirements for all wastes to be disposed of by commercial shallow land burial, as well as the stability requirements for Class B and C wastes, as appropriate. This evaluation includes a consideration of pertinent degradation mechanisms, as well as the recommendations set forth in the TP for the demonstration of waste form/package stability. In the case of 3M's Class B and C wastes, the waste form is not monolithic nor is it of itself likely to meet the 300-year stability or recognizability requirements of 10 CFR Part 61. Thus, rather than evaluating waste form stability, the packaging of the waste was evaluated to determine if stability could be provided by the container for the waste. Guidelines for such an evaluation are provided in the TP in the form of recommendations for high integrity containers (HICs). The requirements and recommendations for each class of waste, as well as the evaluations of the 3M waste packages are given in Section 5. This evaluation has resulted in some concerns and recommendations regarding 3M's waste which are provided in Section 6.

The second part of this study was an identification of those components of the 3M wastes which are either hazardous or which could affect the performance of the site in which these wastes are buried. As can be seen from the package descriptions and evaluations, it was felt that no such concerns existed with the 3M wastes themselves. Biodegradation of the wooden overpacks used by 3M may lead to formation of natural organic chelating agents. However, as indicated in Section 5, it is recommended that these overpacks not be buried in trenches containing stabilized waste.

2. QUANTITIES OF LOW-LEVEL WASTE GENERATED BY 3M

During previous studies conducted for the NRC, the 3M Corporation was identified by BNL as a potentially significant generator of low-level radioactive waste. In a telephone survey conducted by BNL under FIN A-3165, "Study of Non-Fuel Cycle Wastes," 3M was contacted and questioned about the low-level radioactive waste which it ships to commercial shallow land burial sites.(3) It was learned that 3M generates several kinds of low-level radioactive wastes. Much of the waste, about 30%, contains Po-210, which is used as the radiation source in static eliminator devices. Based on a preliminary review of 3M's Radioactive Materials Licenses, it was expected that 3M waste would contain tritium, radioactive iodine, technetium, ytterbium, and carbon (medical applications), as well as several other isotopes used in the manufacture of sealed radiation sources.(4)

BNL has also been conducting a review of the Radioactive Shipment Records (RSRs) of wastes sent for disposal to eight trenches at the Sheffield, Illinois, burial site in order to obtain data required to develop a source term for the non-fuel cycle waste at the site.(5) Although 3M is currently shipping its waste to the Hanford commercial low-level waste disposal site, the data on waste sent to Sheffield are illustrative of 3M's contribution to the low-level waste sent for burial. In this study, it was found that 3M contributed large amounts of activity to the waste buried in several trenches. Based on the RSRs for these trenches, it was found that 3M shipped waste containing the following isotopes: Co-57, Po-210, Tc-99, Cs-137, Sr-90, natural thorium, and mixed fission products. Cs-137 and Sr-90 were singled out for the Sheffield analysis and for these two isotopes, in particular, 3M's contribution to the waste in the eight trenches considered in this work are given in Table 2.1. As can be seen from this table, 3M's contribution to the waste buried varied enormously with time as indicated by the variability of amount with trench. The major contribution was to Trenches 1 and 2. In Trench 1, 3M wastes accounted for 99% of the Cs-137 buried and 97% of the Sr-90. Similarly in Trench 2, it accounted for 85% of the Cs-137 and 86% of the Sr-90. Indeed, for the eight trenches considered in this study, 3M wastes accounted for 89% of the estimated Cs-137 and 88% of the Sr-90.

As a result of more recent contacts with 3M, the RSRs for six waste shipments spanning a period from February 1982 to August 1983 were obtained by BNL. The information in these RSRs is summarized in Table 2.2. There were a total of 620 packages shipped, a total shipping volume of 8550 cubic feet, and a total activity of 2299 Ci. A sample RSR and a computer printout of the data as extracted from 3M's RSRs are given in Appendix C. Most of the activity (2139 Ci) was in one shipment of 19 packages, RSR 0376, which had a combined shipping volume of 161 cubic feet, about one-tenth of the combined shipping volume given on any of the other five RSRs under consideration. Six packages containing 50 to 786 Ci of Cs-137 account for 2030 Ci in shipment 0376. According to the classification scheme of 10 CFR Part 61, the specific activity for Cs-137 in these six packages exceeds the Class B limit, and for the package with the highest activity, may exceed the Class C limit. The designation of these six packages as Class C is based on a package volume equal to the overpack volume, 14.6 cubic feet (0.413 m^3). If only the capacity of the primary container, a 30-gallon drum (0.114 m^3), is considered in the calculation of the specific activity, then a Cs-137 activity greater than 534 Ci exceeds the Class C limit. These six packages are all overpacked, 30-gallon lead-lined drums. Another shipment (RSR 8281) consisted of 111 packages with a total volume of 1505.5 cubic feet and a total activity of 26.01 Ci. Nineteen of these packages would be considered Class B under the present regulations because of their Cs-137 or Sr-90 activities. Two packages listed in RSR 8105 and one from RSR 8107 would also be considered Class B because of their Cs-137 activities. One package from RSR 8108, within Class B limits for tritium and Sr-90 concentrations, was considered by the 3M staff to be a one-time, unusual event not likely to occur again.

Table 2.1

Contribution of 3M Wastes to Sr-90 and Cs-137 Buried in Eight Trenches at the Low-Level Waste Burial Site at Sheffield, Illinois

	Amount of Isotope (Ci)[a]			
	Sr-90		Cs-137	
Trench	3M[b]	Trench Total	3M[b]	Trench Total
1	393	406	999.2	1010
2	859.9	996	924.5	1093
7	2.6	3	2.6	3
11	0	4	4.6	5
14A	0	11	11.1	60
23	0	1	9.0	21
24	0	11	4.2	10
25C	0	1	0	1
Total	1255.5	1443	1955.2	2203

[a] Data taken from Reference 5.

[b] Based on shipments >1 Ci.

Table 2.2

Summary of the Six 3M Low-Level Radioactive Waste Shipments Discussed in Text

RSR	Date	No Packages	Total Volume (cu ft)	Total Activity (Ci)	Activity/Volume (Ci/cu ft)
0376	2/05/82	19	160.67	2138.81	13.31
8195	7/12/82	176	1549.37	18.14	0.01
8107	11/15/82	60	1821.70	19.62	0.01
8108	1/25/83	111	1811.84	75.56	0.04
8281	8/22/83	187	1505.51	26.01	0.02
8300	6/06/83	67	1700.83	21.03	0.01
		620	8549.72	2299.17	

The species of radionuclides shipped and the number of occurrences in the packages of each species is summarized in Table 2.3.

Table 2.3

Radionuclide Species Listed in the 3M RSRs

Occurrences	Radionuclide
1	Ag-110m
3	Ce-141
3	Cr-51
193	Cs-137
75	C-14
6	Fe-59
25	H-3
2	In-111
3	In-114m
48	I-125
4	Nb-95
42	Pm-147
319	Po-210
22	Sc-46
12	Sr-85
22	Sr-90
1	Tc-99
2	Th-232
1	Tl-204
31	Yb-169
20 distinct species.	
815 total occurrences.	

Summary

The 29 packages which would be considered greater than Class A under the final rule of 10 CFR Part 61 are listed in Table 2.4. From this table, it may be seen that 18 of the 29 packages containing radionuclide concentrations within the Class B limit or greater consist of wastes with Cs-137 packaged in lead- or concrete-lined 30-gallon drums and that Class B concentrations of Cs-137 and Sr-90 have been packaged in unlined drums and wooden crates as well. Based on the RSRs, Class A concentrations of radionuclides have been packaged in every container type used by 3M (see Section 4) except the 30-gallon lead-lined drums, which have been used exclusively for wastes of Class C and greater.

Table 2.4

Summary of Packages Class B and Greater From 3M Radioactive Shipment Records

RSR	Package Type	External Package Volume (m^3)	Radionuclide	No. of Such Packages	Activities Per Isotope by Package (Ci)	Total Activities[a] (Ci)	Volume[a] (m^3)
0376	lead-lined, 30-gal drum in overpack	0.413	Cs-137	6	50 184 249 250 511 788	2030	2.48
8105	55-gal drum	0.212	Cs-137	2	1.2 1.8	3.0	0.424
8107	wooden crate	1.124	Cs-137	1	2.50	2.5	1.124
8108	wooden crate	1.124	H-3 Sr-90 Pm-149 Cs-137 Yb-169 Po-210	1	37.4 0.042 0.100 0.010 0.010 0.0001	37.6	1.124
8281	30-gal concrete-lined drums	0.114	Cs-137	12	0.150 0.424 0.5 0.6 0.6 0.91 1.5 1.5 1.5 2.0 2.0 2.8	14.48	1.254
	30-gal unlined drum	0.114	Cs-137	1	0.5	0.9	0.114
			Sr-90	5	0.005 0.005 0.005 0.005 0.010	0.025	0.570
	wooden crate	2.13	Sr-90 Cs-137 Po-210	1	0.096 0.001 0.005	0.09	2.13
Totals for all packages Class B and greater						2088	9.22

[a] For each package type by RSR.

3. GENERAL DESCRIPTION OF 3M WASTES

Minnesota Mining and Manufacturing (3M) produces four categories of radioactive materials that can result in radioactive wastes designated for disposal in a shallow land burial site. These products include radiopharmaceuticals, surgical implants, labeled compounds for research, and radioactive sources for static eliminators and other applications (e.g., gauging devices, etc.). A summary of 3M radioactive products or services and the isotopes involved is given in Table 3.1.

Table 3.1

Summary of 3M Radioactive Products and Services

Isotope	Typical Waste Package Classification	Product/Service
Sr-90 Cs-137	B,C	Sources (labeled ceramic microspheres)
Ra-226	A	Disposal service for new cesium users
Yb-169		Yb-169 DTPA (diethylenetriaminepentaacetic acid)
Tc-99m		Human serum albumin microspheres labeled with Tc-99m
I-125 Ce-141 Cr-51 Sr-85 Nb-95 Sc-46	A	Stock microspheres
Po-210	A	Static Eliminators
Yb-169 Fe-59 Ca-45 In-114m	A	Customer requested microspheres
I-125	A	Seeds for surgical implants (iodine plated on silver wire)

Most of the volume of radioactive wastes resulting from the production activities at 3M is within the limits specified in 10 CFR Part 61 for Class A wastes. These wastes are described in Section 3.1 and are evaluated with respect to their acceptability for disposal in Section 5.1.

The primary emphasis of this report, however, is the evaluation of Class B and Class C wastes resulting from the production of radioactive sources containing Cs-137. These wastes are described in Section 3.2. A detailed description of the packages/containers used to dispose of these wastes and a discussion of the acceptability of the wastes for disposal under the criteria for B and C Class wastes are given in Sections 4 and 5, respectively.

3.1 Class A Wastes

The isotopes in 3M wastes which may be present in concentrations that do not exceed the limits for Class A wastes are included in Table 3.1. There may also be generated (from the production of microspheres), some wastes which contain concentrations of Cs-137 and Sr-90 within the limits set for Class A wastes. These wastes may include liquids such as glycerol from source leak tests and contaminated water from cleanup of the areas around the hot cells.

Po-210 Wastes

By volume, the 3M wastes are dominated by Po-210 contaminated materials which fall into the Class A category. Po-210 is used in the fabrication of several types of static eliminators. The Po-210 wastes result from isolation and purification of the isotope, formation of Po-210 microspheres, incorporation of the labeled microspheres into the static eliminators, and returned static eliminators.*

The entire production process is performed in a series of glove boxes. 3M receives approximately 6000 Ci of Po-210 in the form of irradiated bismuth slugs [209-Bi (n,γ) 210-Po] with an aluminum cladding. The Po-210 is extracted in a pryochemical exchange-type process in which the bismuth is melted and sodium hydroxide (NaOH) is added. Each individual extraction run utilizes approximately 1,000 Ci. This removes the Po-210 and the residual bismuth which is disposed of with approximately 100 Ci of the original Po-210.

The Po-210 is then purified and sorbed into ceramic microspheres of approximately 30 μm diameter. The labeled microspheres are fired and then plated with approximately 1-μm thick coating of nickel.

To determine leaching behavior, 3M subjects these microspheres to two different 24-h soak tests. The first involves immersion of 20-mg microsphere samples in 3 to 4 mL of 3N HCl solution. To pass this test, microspheres must release less than $1 \times 10^{-3}\%$ of their activity. The second test is identical to the first except the soaking solution is 1% EDTA (ethylenediamine tetraacetic acid) and the pass limit is $5 \times 10^{-4}\%$ activity. Not all microspheres

---

*Static eliminators are leased by 3M to customers for a one-year period after which they are returned to 3M for disposal.

are tested. If the tested samples pass the leach tests, the entire sampled batch is passed.

Microspheres may be put in the static eliminators by silkscreening or tape transfer. An epoxy spray is used as an overcoat in the silk-screened devices. This overcoat is applied after incorporation in the device.

The waste resulting from the production of static eliminators includes the bismuth slugs which are placed in mild steel containers, contaminated solutions that are evaporated to dryness, labeled "leach-test failed" or waste microspheres, parts associated with the silkscreening process, dried epoxies, and assorted beakers, glass, plastics, etc. All of these wastes are placed in 55-gallon or 30-gallon mild steel drums that are doubly lined with 4 mil wall thickness polyethylene bags. The wastes are simply placed in the drums and the polyethylene bags are double taped to seal them. After the drum is filled, the drum lid is closed with a ring bolt.

Most of the returned static eliminators, which comprise one third of the volume of 3M Po-210 waste, are disposed of in the same type of waste package used for production activities (polyethylene lined 55- or 30-gallon drums). Those static eliminators that will not fit into drums are disposed of in one or two cubic yard wooden crates.

Finally, there are miscellaneous Po-210 contaminated wastes including gloves and shoe covers. These are compacted in the polyethylene liners in 30-or 55-gallon drums by a plunger-type compactor. The liners rupture in the drum on compaction. Specific Po-210 activities and/or concentrations per waste container are determined from accounting of assay data obtained during the production process.

Other Class A Wastes

Tritium and carbon-14 labeled radiotracers are used at the 3M Research Center in St. Paul, Minnesota. Waste from these activities results in an annual waste production of 20 to 30, 55- and 30-gallon drums of waste contaminated with very low activities of these isotopes.

Iodine-125 is used by 3M in the production of surgical implant seeds. It is received in curie amounts per year, typically as an aqueous solution of the sodium salt. Prior to incorporation into seeds, the I-125 may be pre-treated in one of two ways: deposition on Dowex* resin beads or plating on silver wire.

The average seed activity is 0.55 mCi "compensated", i.e., the seeds can be considered point sources of I-125 with allowance having been made for self absorption by the seed capsule.(6) The seeds are leak-tested before being sent out and leak test failed seeds are sometimes included in the waste along

---

*"Dowex" is a brand name of the Dow Chemical Company. The particular type of resin was not specified.

with other contaminated materials (I-125-contaminated glass, paper, shoe covers, gloves, some metals) generated throughout the production process.

Scandium-46, niobium-95, chromium-51, iodine-125, strontium-85, and cerium-141 are incorporated as gamma labels in carbonized Dowex resin beads that are used for circulation studies in animals. Production wastes may contain any or all of these isotopes.

Kits of radiopharmaceutical ytterbium-169 diethylenetriamine pentaacetic acid (Yb-169-DTPA) solutions are also made by 3M. The typical Yb-169 activity per kit is 2.5 mCi. There is a production of kits every month. 3M indicated that all wastes from this process are kept at the 3M site. However, in the survey of RSRs provided by 3M, it was found that there were 31 instances of Yb-169 shipped during the 19-month period covered by these records. The exact character of these Yb-169 wastes is not known at this time. 3M has stated that Yb-169 disposed of during past years was not in the chelate form. All chelate form material is held at the New Brighton, Minnesota plant. 3M now has a license amendment allowing decay in storage of radioactive material with half life less than 65 days (Yb-169, $t_{1/2} = 32d$) and Sc-46.

Another radioisotope used in nuclear medicine handled by 3M is Tc-99m. Tc-99m is used to label human serum albumin microspheres which are produced and sold as part of a kit.

Krypton-85, obtained originally from Oak Ridge National Laboratory, is repackaged to produce Kr-85 sources in a distillation-type process. The Kr-85 sources are used for industrial gauging devices. No packages containing Kr-85 were found on the RSRs provided by 3M. However, the company plans to place rejected (failed) and returned Kr-85 sources in a steel jacket which can be sealed by welding and leak tested. If the sources are above atmospheric pressure, the jackets would be evacuated to compensate for the overpressure. The steel jackets will be packaged with fiberboard discs in 30-gallon mild steel drums for shipment and disposal.

3M has stockpiled curie quantities of Sr-90-labeled microspheres. The waste materials associated with their production were disposed of some time ago so the only currently shipped waste materials that are Sr-90 contaminated are related to manufacture of sources, i.e., loading, handling and counting of the microspheres and cleaning and leak testing the finished sources.

Disposal Methods

In general, 3M disposes of low activity, Class A wastes in wooden crates and 55-gallon or 30-gallon unlined drums. In a few cases, Class A wastes have been placed in concrete-lined drums. These wastes can contain any of the isotopes just discussed.

3.2 Class B and Class C Wastes

Most of the 3M Class B and C wastes result from the production of Cs-137 microspheres. These microspheres are produced in a manner similar to those labeled with Po-210. The cesium, obtained as a CsCl powder from Oak Ridge National Laboratory, is incorporated in ceramic microspheres. The microspheres average 60 to 100 μm in diamater and are not plated with nickel (as the Po-210 labeled microspheres are). These microspheres are used to produce sources. They are placed in stainless steel (or K-monel) cylinders of various lengths and diameters. The cylinders are closed by welding, cleaned with trisodium phosphate (TSP) and leak tested. Approximately one percent of the sources are rejected. In addition to failed sources and materials resulting from the hot-cell fabrication of Cs-137 microspheres, the wastes also consist of contaminated equipment, paper, plastic vials, HEPA filters, evaporates of aqueous solutions, glassware, metal, and some failed microspheres. Additionally, contaminated glycerol from source leak tests and water from cleanup of the hot cell area may be included. The cesium hot cell waste is primarily in the chloride form although a few percent of $CsNO_3$ may be present.

3.2.1 Wastes Disposed of in Lead-Lined Drums

Nalgene* Container-Emplaced Wastes

Most of the hot cell wastes are placed in Nalgene containers on removal from the cell. Estimates of volume percent fractions of these materials(7) were 50% plastic, 10% HEPA filters, and the remaining 40% glass, paper, metal, and waste microspheres. The 50% plastic fraction has been further subdivided into the representative volumes of different types of plastics: 60-70% low density polyethylene, (30-40%) linear and high density polyethylene and a few percent (5%) a combination of polypropylene, polymethylpentene, polystyrene, polycarbonate, "Teflon FEP", and linear polyethylene.(8) This information is summarized in Table 3.2. These wastes are placed in 30-gallon steel drums that are lined with 2 or 3 inches of lead. Due to limitations imposed by remote handling, void spaces exist in the lead-lined drums. The Cs-137 activities present in the drums are currently limited only by the radiation risks associated with shipping and handling. The activity was estimated by 3M to vary in the past from 10 to 800 Ci of Cs-137 per container. Present practice is to place no more than 500 Ci of Cs-137 in a container. Typically, six packages per year are produced although the number of waste packages can vary from one to ten. A full description of the container is given in Section 4.

---

*Brandname of low density polyethylene held by the Nalge Company, a Division of Sybron Corporation, Rochester, New York.

Table 3.2

Volume Fraction of Hot Cell Process Wastes
(Nalgene Container Enclosed Waste)

Material	Percent Volume (%)
low density polyethylene	30-35
linear and high density polyethylene	15-20
polypropylene	3
polymethylpentene	
polystyrene	
polycarbonate	
"Teflon FEP"	
HEPA filters	10
glass	40
paper	
metal	
waste microspheres	

Odd-Size Item Waste Packages

On occasion, 3M disposes of contaminated hot cell equipment items (e.g., oversize oven, etc.) that do not fit in the Nalgene containers. These items are placed directly in a lead-lined drum for disposal.

Lead "Pig" Filled Waste Packages

Cesium-137 sources are sometimes returned to 3M. These sources are placed in lead "pigs" and disposed of in a lead-lined drum. Additionally, leak test reject sources can be disposed of in lead "pigs". It was estimated by 3M that enough leak test reject and returned Cs-137 sources are collected in a two-to-three year period to result in a waste container filled with pigs. The numbers and activities of sources which could fit in a pig and the number of pigs that could fit in a lead-lined drum is not known. The Cs-137 loadings in these drums are such that some of them are Class B and some are Class C.

3.2.2 Wastes Generally Disposed of in Concrete-Lined Drums

Low activity waste results from the trisodium phosphate used for cleaning sources. This activity could be on wipes or beakers. The 3M staff estimates that this activity is on the order of millicuries but it was not quite clear how many wipes or beakers this would represent. Only leaky sources will produce contamination during cleaning.

Because of their relatively low activity compared to the hot cell microsphere manufacture materials, wastes such as the beakers used for the residuals from cleaning the sources after fabrication do not go into lead-lined drums. These wastes are placed in concrete-lined 30-gallon drums with a metal liner inside the concrete (see Section 4 for a description of these drums).

In general, 3M higher activity Class B and C wastes are packaged in 30-gallon lined drums. Cesium-137 is the principal contaminant in these wastes, although Sr-90 may also be present. Strontium-90 wastes with specific activities in the lower Class B range have been found disposed of in unlined 30-gallon drums and, in one case, in a 75.2 ft^3 wood crate.

3.3 Potential Future Waste

In the past, 3M was involved in the production of Pm-147-containing microspheres for radioluminous sights for weapons. The Pm-147 microspheres would be mixed with a binder to make a type of paint. The current inventory of Pm-147 is approximately 1000 Ci and 3M is no longer in the Pm-147 business.

Additionally, 3M is licensed to have Pu-239 (two sealed sources, $\leq$30 mCi each) and Am-241 (sealed sources, $\leq$200 μCi/source, no total limit). Although 3M might, therefore, be expected to have some transuranic wastes from the disposal of these sources, they have indicated that any disposal of transuranic source material will be by return to the manufacturer.

While the production of Sr-90 microspheres does not presently occur, future productions may result in larger amounts of Sr-90 wastes. However, the characteristics of such waste cannot be defined at present. 3M has indicated that no production of Sr-90 microsphere is anticipated in the near future.

In the past, 3M has offered a radium-226 disposal service for its new cesium users. 3M has recently disposed of all Ra-226 in its inventory. Disposal was by placing sources in lead pots in concrete-lined drums. 3M will not be accepting any further Ra-226 nor does it have any Ra-226 on hand for disposal.

3.4 Summary/Conclusion

The largest volume of radioactive waste generated by 3M consists of wastes containing short-lived (<5 year) radionuclides. Small amounts of tritium and carbon-14 wastes result from research activities at 3M. Production of Cs-137 and Sr-90 sources results in the generation of Class B and Class C wastes. The number of Cs-137 high activity (Class B and C) waste packages (lined drums) shipped for disposal averages six per year although this can vary from one to ten packages per year.

4. DESCRIPTION OF 3M RADIOACTIVE WASTE PACKAGE CONTAINERS

3M generates radioactive waste containing a variety of radioactive isotopes, as discussed in Section 3. 3M disposes of this waste in several different types of containers, depending upon the activity. Waste containers include three varieties of lined 30-gallon carbon steel drums for the higher activity wastes plus 55-gallon carbon steel drums and four varieties of wooden crates for lower activity wastes. Additionally, the 30-gallon and 55-gallon drums may be overpacked in wooden disposal crates which provide Type A packaging for 30-gallon and 50-gallon drums which show signs of damage.

Three types of lined 30-gallon drums are used. There are two which are lead-lined and one which is lined with concrete. The lead-lined drums are lined with either two or three inches of lead. They are purchased by 3M from Allied Metal.* Diagrams of these drums provided by 3M are shown in Figures 4.1 and 4.2. The concrete-lined drum is fabricated by 3M; no diagram of this drum was available. However, 3M provided a description of the fabrication process for these drums.(8) This fabrication process is summarized below.

a. The concrete used in these drums is "4000 lb concrete" which is mixed to a "3 inch slump."

b. The concrete is poured to a depth of 3 inches in the bottom of a 30-gallon carbon steel drum and allowed to "set up." A 22-inch long, galvanized, 26 gauge, sheet metal sleeve liner is next placed on this 3-inch base such that there is a 3-inch gap between sleeve and drum. Finally, the annulus between the sleeve and the inner wall of the 30-gallon drum is filled with concrete and allowed to set. There is no reinforcing steel placed in the concrete.

c. The lid for this container consists of a 3-inch thick concrete disc which just fits inside the sleeve. There is no "step" on the lid, it is simply placed on top of the waste items in the drum. The outer drum lid is ring-bolt sealed.

d. These drums generally sit for weeks or months before they are used -- thus the concrete has quite a long time to air cure.

The lead-lined containers have been stated by the manufacturer to meet the DOT transportation specifications for Type A packaging.

---

*Allied Metal, 249 Fornoff, Columbus, OH 43207.

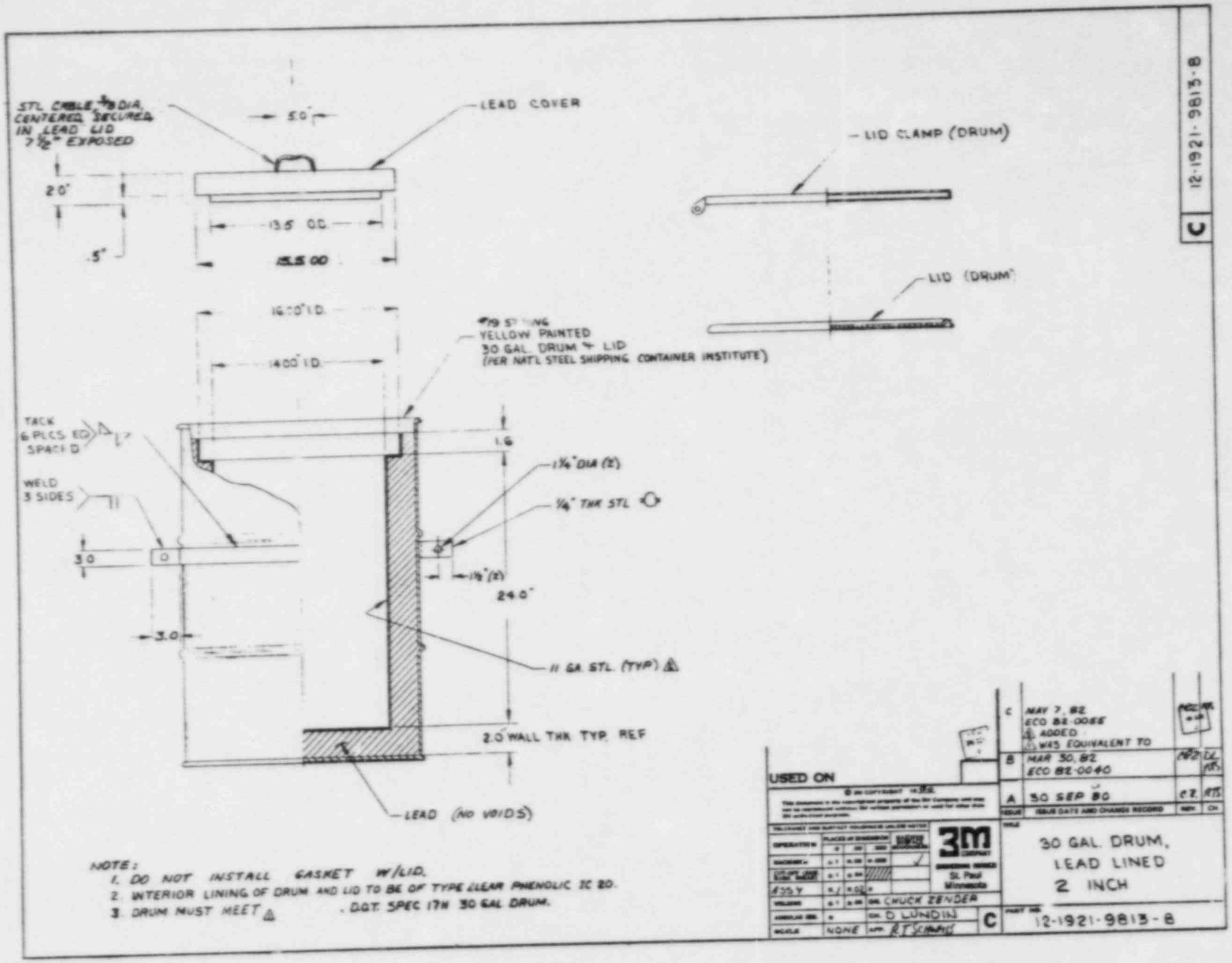


Figure 4.1 Diagram of the 30-gallon drum, 2-in. lead-lined.

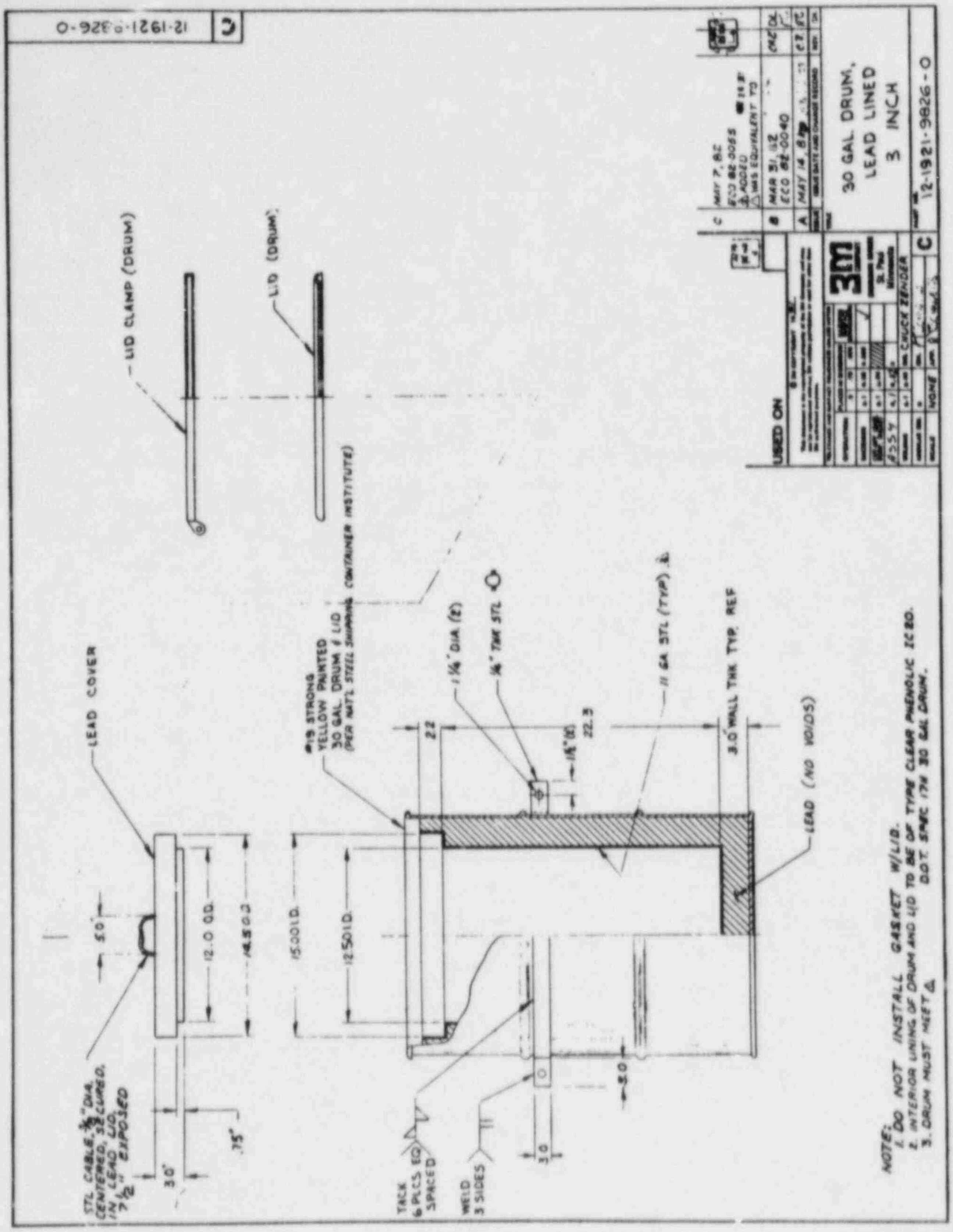


Figure 4.2 Diagram of the 30-gallon drum, 3-in. lead-lined.

The characteristics of the three lined 30-gallon drums are the main ones of concern as these drums generally contain B and C class wastes. Further, the wood and carbon steel containers would not, of themselves, meet the stability requirements for Class B and C wastes as given in 10 CFR Part 61.

The disposal volume of a 30-gallon drum is 4 ft^3 according to 3M's radioactive shipment records (RSRs). Overpacked with a wooden crate, the disposal volume is approximately 14.7 ft^3. The actual interior volumes of the 2-in. and 3-in. lead-lined drums are 2.1 and 1.6 ft^3, respectively, as calculated from the interior measurements of these drums shown in Figures 4.1 and 4.2. The interior volume available in the concrete-lined drum is taken as 1.6 ft^3. Table 4.1 summarizes these and other specifications for the lined 30-gallon drums.

Table 4.1

Information on Lined Containers Used by 3M for Disposal of Class B and C Radioactive Wastes

Container[a]	Lining[b]	Weight of Empty Package[c] (lb)	Lined Volume Inside Package[d] (ft^3)
30-gal mild steel drum	2-in. lead	1700	2.1
30-gal mild steel drum	3-in. lead	2100	1.6
30-gal mild steel drum	3-in. concrete	425	1.6

[a] DOT 17H 30-gallon drums. The lid is fastened to the drum with a steel ring and bolt.

[b] Lead is poured into the drum around an 11-gauge steel liner to form the bottom and sides of the lining. The lining lid is not sealed into place upon closure. With lining lid in place and the drum lid bolted on, there is a space between the lining lid and the drum lid. This space is approximately 1/2-inch wide.

[c] No estimate of expected or allowed variation in these weights was available.

[d] Calculated from dimensions of the lined volumes for the lead-lined drums given in Figures 4.1 and 4.2. The lined volume in the 3-in. concrete-lined drum is assumed to be the same as that in the 3-in. lead-lined drum.

The lining lids of the lead-lined drums are stepped (see Figures 4.1 and 4.2). They fit snugly into the lined drums and the step assures that there is no direct path (such as would be the case for a lining lid with no step) for radiation from the inside of the lined drum to reach the outside. The lead lids are not secured onto the top of the drum. They are held in place by the presence of the outer carbon steel drum lid which is secured to the drum with a bolt-ring seal. Given dimensions in Figures 4.1 and 4.2, the fact that the drum lid is raised and the height, 28.75 in., for a standard 17H 30-gallon drum, one can calculate as ~ 1/2 inch the space between the drum lid and the lining lid for both lead-lined drums. If these lined drums are inverted, the lining lid could be partially dislodged. Such dislodgement of a lining lid would probably result in increased radiation levels in certain directions around the waste package. If the waste inside the lined drum were to shift position while the lining lid was out of position, the lining lid might not fall back into place upon righting the drum.

Summary

3M ships wastes in wooden crates, 55-gallon carbon steel drums, 30-gallon concrete-lined (3-inch lining) or 30-gallon lead-lined (2- and 3-inch lining) drums. Wastes that are Class A have been disposed of by 3M in any of these containers except the lead-lined drums. Class B and C wastes are generally disposed of in either the concrete-lined or lead-lined 30-gallon drums.

5. EVALUATION OF 3M RADIOACTIVE WASTE PACKAGES

The "Licensing Requirements for Land Disposal of Radioactive Wastes " 10 CFR Part 61, establishes minimum requirements for those wastes disposed of in a shallow land burial site. Wastes are classified by their radionuclide specific concentrations.* Wastes containing only the long-lived radionuclides listed in Table 5.1(a), in which the concentration does not exceed 10% of the value listed in Table 5.1(a) are Class A. Wastes whose concentration exceeds 10% of the values listed but does not exceed the maximum values are Class C wastes. If wastes do not contain the long-lived radionuclides listed under Table 5.1(a), then the waste classification is determined from Table 5.1(b) in the following manner. Class A wastes are those wastes in which the concentration of the short-lived radionuclides does not exceed that given in column 1. Class B limits are listed in column 2 and Class C limits in column 3. Any wastes whose concentrations exceed the concentration limits in Table 5.1(a) or column 3 of Table 5.1(b) are generally not acceptable for near surface disposal.

If the wastes contain mixtures of long-lived and short-lived radionuclides, the classification is determined from Table 5.1(b), given that the concentration of the long lived radionuclides does not exceed 10% of the value given in Table 5.1(a). When the concentration of the long-lived radionuclides exceeds 10% of the value given in Table 5.1(a) but does not exceed the limit given in column 3, the waste is Class C as long as the concentration of any short-lived radionuclides does not exceed the limits for Class C waste. [column 3, Table 5.1(b)].

The minimum waste form requirements that must be met by all wastes (Class A, B and C) are set forth in 10 CFR Part 61 Section 56(a) (see Appendix A). These requirements include the stipulation that wastes containing liquids must be packaged with enough adsorbent material to absorb twice the volume present. For solid wastes containing liquid, the amount of free liquid should in no case exceed 1.0% of the volume. Class B waste must meet these requirements and in addition, must be stabilized. The stability requirement is meant to ensure that the waste does not compromise the integrity of "the disposal unit and thereby lead to the infiltration of water" as well as limit exposure to the inadvertent intruder by rendering wastes recognizable.

At present, the means by which the stability requirements for Class B and C wastes can be met are by the waste form itself, by processing the waste to a stable form, or by placing the waste in a container (high integrity container, HIC) or structure that provides stability. Structurally stable waste will maintain both its physical dimensions and form under expected disposal conditions (e.g., overburden, microbial action, the presence of water) and under internal stress such as chemical changes and radiation. In addition to the

---

*In all cases when the waste contains mixtures of radionuclides the total concentration is determined by the sum of fraction rule [10 CFR Part 61, Section 61.55(a)7].

minimum requirements on liquid wastes or solid waste containing liquids, there should be as little free liquid as possible and in no case should the liquid exceed 1% of the waste volume when the waste is disposed of in a container for stability or 0.5% of the volume of waste for waste processed to a stable form.

Table 5.1

Concentration Limits for the Classification of Radioactive Waste(9)

(a)

Radionuclide	Concentration (Ci/m^3)[a]
C-14	8
C-14 in activated metal	80
Ni-59 in activated metal	220
Nb-94 in activated metal	0.2
Tc-99	3
I-129	0.08
Alpha emitting transuranic nuclides with half-life greater than five years	100[b]
Pu-241	3500[b]
Cm-242	20000[b]

[a] Volumes of containers used by 3M are given in Tables 2.3 and 4.1.

[b] Units are nanocuries/gram.

(b)

Radionuclide	Concentration (Ci/m^3)[a]		
	Col. 1	Col. 2	Col. 3
Total of all nuclides with less than five year half-life	700	b	b
H-3	40	b	b
Co-60	700	b	b
Ni-63	3.5	70	700
Ni-63 in activated metal	35	700	7000
Sr-90	0.04	150	7000
Cs-137	1	44	4600

[a] Volumes of containers used by 3M are given in Tables 2.3 and 4.1.

[b] There are no limits established for these radionuclides in Class B or C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling, and disposal will limit the concentrations for these wastes. These wastes shall be Class B unless the concentrations of other nuclides in Table 5.1a determine the waste to be Class C independent of these nuclides.

In general, for Class B and C waste, liquids must be solidified. The waste must be recognizable and maintain structural stability for 300 years. In principle, these requirements can be met by a waste form, a HIC, or both. There are no leach or release requirements specified in 10 CFR Part 61 although a waste form or package that limits the release of radionuclides offers distinct advantages in ensuring the health and safety of the public. Performance recommendations such as that pertaining to leachability index are specified in the TP (see below).

Class C waste must meet all the criteria for Class B waste. In addition, it must be intruder protected either by disposal at a greater depth or by use of engineered barriers (e.g., concrete covers) whose lifetime is 500 years.

In addition to 10 CFR Part 61, the NRC has provided guidance in the form of a Technical Position on Waste Characteristics and Waste Form (a copy is included as Appendix B). The Technical Position specifically outlines test methods and criteria for waste forms "acceptable to the NRC staff for implementing the 10 CFR Part 61 waste form requirements." The Technical Position specifically provides a guideline for mechanical stability of solidified wastes, outlines procedures for determining the sensitivity of solidified wastes to radiation, biodegradation and thermal degradation, limits the amount of free liquid, and the leachability of stabilized waste. In addition, the Technical Position also addresses the use of high integrity containers (HICs) for the disposal of Class B and Class C wastes. A HIC should have a design goal of a minimum lifetime of 300 years. Tests are recommended to determine its resistance to corrosion or degradation from chemical effects, resistance to radiation damage and biodegradation, and tests to determine its mechanical stability. It is recommended that a HIC have closures designed for a positive seal that will last the lifetime of the container. Passive vents to release internal pressure are allowed. The amount of free liquid present should not exceed one percent of the waste volume, and voids should be eliminated to the extent practicable.

5.1 3M Class A Waste Package Evaluation

The 3M wastes resulting from the production of radiopharmaceuticals, surgical implants, labeled compounds for research, Po-210 sources for static eliminators and returned static eliminators are all Class A wastes. The largest volume of the Class A wastes is due to production of static eliminators and those static eliminators that have been returned to 3M.

In all of these wastes, the radionuclides have half-lives of less than 5 years. The Class A limit in this instance is 700 Ci per cubic meter (147 Ci in a 55-gallon drum). If the total non-decay-corrected annual Po-210 inventory of 6000 Ci were disposed of, this would be the equivalent of about forty 55-gallon Class A drums per year. Approximately one-third of the total radioactive waste volume is Po-210 contaminated material. This is solid waste, packaged in 55-or 30-gallon drums or wooden crates. No hazardous, pyrophoric or explosive wastes are present. Similarly, wastes generated in the production of microspheres for surgical implants and other biomedical applications consist primarily of general trash (glass, paper, plastic). There is no indication from past shipping records that these wastes have exceeded the Class A limits and no components of the wastes appear to compromise the acceptability of these wastes for disposal as Class A waste.

The 20 to 30 drums of H-3 and C-14 wastes shipped annually consist of trace-contaminated general trash. Past shipping records* do not indicate the shipment of wastes containing these radionuclides in which the concentration exceeds the limits for Class A wastes.

The Yb-169 wastes are presently stored at 3M pending a license amendment allowing their disposal. In the event that these wastes constitute future shipments to a shallow land burial facility, steps should be taken to ensure the minimum requirements are met. 10 CFR 61 requires that chelating agents present in waste in concentrations in excess of 0.1% be identified. Thus, any amount of chelating agents (e.g., DTPA) in these wastes in quantities exceeding 0.1% by weight should be identified by 3M.

The Kr-85 in 3M wastes is not specifically listed in Part 61 and Kr-85 is therefore, a Class A waste. However, since it is a gas, this waste must be packaged so that the internal pressure does not exceed 1.5 atmospheres and the total activity does not exceed 100 Ci per package. 3M does, in fact, plan to repackage any Kr-85 wastes to ensure the pressure limit as not exceeded.

Contaminated liquid wastes such as glycerol from source leak tests and water from cleanup around the hot cell area may be disposed of as Class A wastes. Both of these types of liquid have been stated to be absorbed on an excess of diatomaceous earth prior to disposal.(10) 3M's Quality Assurance Program for waste packaging dictates that in a 30 gallon drum filled with diatomaceous earth no more than 10 gallons of liquid are to be disposed of. This is based on tests at 3M indicating that this provided twice the absorbent volume necessary for the liquid.

Radium-226 sources represent a special case. The following guidance concerning this waste has been taken from 10 CFR Part 61.

> It appears that there are two types of radium wastes to be considered: (1) small concentrated sources of radium such as radiation sources or luminescent dials, and (2) wastes which contain small amounts of radium incidental to other radioisotopes, such as radium contained in wastes from uranium separation processes. The former is not subject to regulation by the Commission, .since radium is a naturally-occurring isotope and is not

---

*A one-time shipment of H-3 sources (copper tritide) was made. However, this is not expected to occur in the future.

> included in the provisions of the Atomic Energy Act of 1954, as amended. The Environmental Protection Agency has a program for collection of radium sources. This program may be phased out in the next few years. Such sources are expected to be transferred to the Department of Energy for storage and disposal. As for radium incidental to other types of waste, the Commission has made provisions for disposal of small quantities of uranium tailings as Class A waste. For purposes of this provision, a small quantity is defined as 10,000 kilograms containing not more than 5 millicuries of radium-226. This concentration is typical of uranium mill tailings (0.5 nanocuries per gram). The quantity of radium-226 is that contained in 150 pounds of natural uranium at equilibrium with its daughter products. 10 CFR Part 40 permits any person to possess and use under general license 150 pounds of source material per year. Permitting the disposal of such a quantity in a near-future disposal facility is judged to be acceptable. For larger amounts, specific approval would be required.

It would appear that, depending on the amount disposed, small quantities would be acceptable for near surface disposal; larger quantities may require specific approval by the states regulating the commercial disposal facilities. In addition, site specific regulations may have to be met. As mentioned earlier, 3M has already disposed of their Ra-226 inventory.

Summary/Conclusion

The largest volume of waste shipped by 3M would be categorized as Class A. The radioisotopes contained in this waste generally have half lives of less than 5 years (except Kr-85) although there are some wastes contaminated with trace amounts of C-14 and H-3. These wastes appear to meet most of the minimum requirements for Class A wastes, i.e., no free liquid, no hazardous pyrophoric or explosive components of the wastes and no cardboard or fiberboard packages. With respect to liquid wastes, 3M's Quality Assurance Program for waste packaging dictates that in a 30 gallon drum filled with diatomaceous earth no more than 10 gallons of liquid are to be disposed of. This is based on tests at 3M indicating that this provided twice the absorbent volume necessary for the liquid. The future disposal of Yb-169 waste may necessitate identification of any package that contains chelating agents in excess of 0.1%, and Kr-85 waste should be packaged in a manner consistent with the requirements of 10 CFR Part 61.

5.2 3M Class B and C Waste Package Evaluation

5.2.1 3M Lead-Lined Drums - 10 CFR Part 61 Requirements

As was discussed in Section 3.2, the 3M wastes of activities high enough to be classed as B or C according to the classification scheme of 10 CFR Part 61 fall into three main categories:

a. wastes in Nalgene containers (from hot cell processes, principal radioisotope Cs-137),

b. outsize item wastes (furnaces and contaminated equipment from hot cell processes too large to fit Nalgene containers), and

c. source-filled lead "pigs" (returned and reject sources placed in lead pigs, principal radioisotope Cs-137).

According to the survey of 3M RSRs, all wastes over Class B are packaged in 2-or 3-inch wall thickness lead-lined drums. The minimum waste characteristic requirements in 10 CFR Part 61 Section 56 (see Section 5 - Introduction) are, in general, met by the 3M lead-lined drum waste packages.

Summary/Conclusion

3M Class B and C waste packages appear to meet the minimum requirements in 10 CFR Part 61 Section 56.

5.2.2 3M Lead-Lined Drums - Technical Position Recommendations for High Integrity Containers

As can be seen from the earlier discussion (Section 3), all of the 3M Class B and C wastes disposed of in the lined drums are non-monolithic and do not qualify as stabilized waste. For the purpose of this evaluation, the 3M container design was reviewed for consistency with the high integrity container guidelines in the TP.

The recommendations for high integrity containers as outlined in the Technical Position on Waste Form (Appendix B) are considered individually below as they pertain to the 3M 30-gallon lead-lined drum Class B and/or C waste packages.

5.2.2.1 Free Liquid Fraction and Process Control

Maximum allowable free liquid in a HIC should be less than one percent of the waste volume [as measured by the method of ANS 55.1 (Appendix D)]. 3M has indicated that there are no free liquids in the wastes which are disposed of in lead-lined drums. All hot cell manufacturing process liquids/solutions are evaporated to dryness prior to disposal.

5.2.2.2 Design Goal of Minimum 300-Year Container Lifetime

A design goal for minimum 300-year maintenance of structural integrity of the high integrity container is required under 10 CFR Part 61. The 30-gallon 2-and 3-inch lead-lined drum manufacturer has conditionally estimated the service life of the lead lining as several hundred years.(11) The carbon steel components of the container (outer drum and inner liner) are expected to corrode at a higher rate than the lead. Physical conditions specified by the drum manufacturer as potentially destructive to the structural integrity of the container relate to drop or puncture processes. It is expected that the lifetime of the container used as a radioactive waste container to be buried in soil will vary with the magnitude of chemical degradation mechanism effects. The handling procedures exercised at 3M and at the burial site as well should preclude occurrences that violate stipulations imposed by the drum manufacturer. Thus, effects likely to affect the drum lifetime lie beyond the scope of design planning by a manufacturer whose purpose has been to supply a lead-lined container and not necessarily to supply a container that needs to meet requirements set for a high integrity container.

5.2.2.3 Consideration of Corrosion and Chemical Effects - Wastes and Environment

The corrosive and chemical effects of both the waste contents and the disposal trench environment must be considered in regard to their impact on the ability of the high integrity container to meet the performance recommendations of the TP. The three main potential types of wastes that 3M generates (of activity and distribution to be categorized as Class B and/or C waste) have been discussed earlier (Section 5.2.1). The corrosive and chemical effects of these wastes can be considered with respect to the package condition (1) at burial (i.e., assumed to have undergone no radiolysis) and (2) subsequent to radiation exposure. The corrosive and chemical effects of the wastes independent of the radiation-induced effects are discussed in the following section. Similarly, the effects of the disposal trench environment on the waste package (again, independent of the radiation-induced effects) are discussed in the succeeding section. The discussion of corrosive and chemical effects in relation to the radiation exposure is given in Section 5.2.2.7.

(1) Effect of Wastes. The initial situation is one in which there is only solid-solid contact between waste components, i.e., closed hot cell-process-waste-filled Nalgene containers, oversize pieces of contaminated equipment, or lead pigs filled with waste sources. Chemical effects from the materials external to the Nalgene containers (i.e., effects from contaminated equipment and lead pigs) should be minimal. Inside the Nalgene containers there may be remnants of solutions evaporated to dryness which, were they to come in contact with water, might produce acidic or otherwise corrosive solutions. Specifically, resulting from the cleaning and leach testing of labeled microsphere sources, there are expected to be hydrochloric acid, trisodium phosphate and EDTA (ethylenediamine tetraacetic acid) residuals. It should be noted that the amounts of these materials are generally quite small compared to the other wastes and the likelihood of their becoming wet is uncertain since, in addition to the barrier presented by the outer waste container and the two polyethylene liners, the Nalgene containers are known to be friction sealed. In general, then, it is expected that degradative chemical effects of these types of wastes at the time of disposal should be minimal. The presence of radioactive contaminants in the wastes will, however, lead to the occurrence of radiolysis and the discussion of the effects of such radiolysis is part of Section 5.2.2.7.

(2) Effect of Disposal Trench Environment. The 30-gal lead-lined waste package as shipped by 3M consists of three components: an overpack, a carbon steel drum, and a lead inner container. The anticipated lifetime of each of these barriers should be considered in assessing whether the container will last for 300 years once it is buried. In addition, since each of these barriers is made from different material, the interactions between these barriers will also be considered where applicable.

Overpack

All of the overpacks for the 3M radioactive containers are wooden boxes (see Section 4). In the case of the 30-gal lead-lined drums, the overpack (crate) has a volume of approximately 0.31 m^3 and the drum itself has a volume of 0.16 m^3. The crate is constructed mainly from plywood. Given the materials of construction, it is anticipated that the crate is susceptible to biodegradation(12) and little or no credit can be given to it to supply stability beyond a few years. Degradation of the wooden crate is likely to be relatively complete and to result in the production of humic acids, as well as a decrease in the package volume of approximately a factor of two. Subsidence resulting from this volume change would be expected during the period of active site maintenance. Further, some of the products of biodegradation can act as chelating agents which might affect wastes buried near the 3M wastes, as well as the 3M wastes themselves. In light of consequences of the biodegradability of the overpacks, it is recommended that the crates be removed prior to burial.

Carbon Steel Outer Container

Waste packed in lead-lined drums at 3M is, in actuality, in a double container, a carbon steel outer drum and a 3-in. lead liner (see Figures 4.1 and 4.2). Gause et al.(2) have considered the stability of carbon steel drums in a trench environment. As they point out, it is not possible to accurately estimate the drum lifetime at a disposal site from existing data on carbon steel corrosion in soil. They have, however, estimated a time to pitting of from 2.5 to 9.6 years and a container lifetime of from 10 to 120 years depending on soil conditions. In the case of the 3M drum, corrosion is likely to be accelerated due to the presence of humic acids from the degradation of the wooden overpacks should the crate be buried with the waste. Once pit penetration takes place, it is likely that a galvanic couple between the outer carbon steel drum and the inner lead liner may occur. Given the relative difference in electrode potentials between these two materials, the lead may be cathodically protected by the iron (in the outer drum). Hence, the corrosion of the drum is most likely to be enhanced. This, of course, will be mitigated by the decreased corrosion rate of the lead container (see below). Romanoff(13) gives some data on the protection of steel pipes provided by a lead coating. The effects of this galvanic couple cannot be quantitatively estimated, and hence, will not be considered further. Certainly, there is no evidence that the carbon steel drum will provide either stability or containment for an appreciable length of time relative to the required design lifetime of 300 years for the container.

Lead Liner

As with the carbon steel outer container, the corrosion in soil of the lead liner cannot be estimated with accuracy in the absence of data from site specific testing of container materials and designs. Romanoff(13) provides the results of field tests of commercial lead coupons in 38 different soils. A maximum penetration of greater than 120 mils in 11.65 years was reported (>0.024 cm/yr). A minimum penetration of (2.2×10^{-3} cm/yr) was also reported. The Romanoff data have been found conservative; Gilbert and Porter(14) report a maximum depth of attack on lead sheet as 1.7×10^{-3} cm/yr. Taking the Romanoff data and assuming these pit penetration rates can be extrapolated linearly with time, these rates would imply that, for the 3-in. lead-liner, it would take between less than 3×10^2 years and 3.5×10^3 years to breach the liner by pitting. For the 2-in. lead container, this range is reduced to less than 2×10^2 to 2.3×10^3 years.

In terms of uniform corrosion, the data in Romanoff yields a rate of 4.6×10^{-4} to 1.3×10^{-2} $g{\cdot}cm^{-2}{\cdot}yr^{-1}$. For lead, with a density of 11.34 g/cc, these rates result in an average thickness loss due to uniform corrosion of 4.1×10^{-5} $cm{\cdot}yr^{-1}$ to 1.1×10^{-3} $cm{\cdot}yr^{-1}$. For a 3-in. liner, this implies a lifetime of between 7×10^3 yr and 2×10^5 yr, while for a 2-in. liner, a lifetime of 5×10^3 and 1×10^5 yr is implied. Given the ranges of uniform and pitting corrosion rates and the fact that, for a time, the lead may be cathodically protected by the carbon steel drum, it would appear that a 3-in. thickness of lead and possibly the 2-in. thickness of lead have the potential to provide stability over the 300-yr design lifetime. Further, containment over much of that period could also be provided by either a 2- or 3-in. thickness of lead. (This latter conclusion is design independent. For a discussion of containment, see Section 5.2.2.12 below.) It must be stressed that the range estimates made in this section are based on several assumptions including linear extrapolation of the Romanoff soil corrosion rate data and application of non-site-specific and non-container-specific data to the particular case of the lead-lined drum. On the basis of this analysis, it appears likely that the lead liners may provide stability over the design lifetime. However, 3M should provide an analysis of container lifetime based upon anticipated burial site conditions and container design.

5.2.2.4 Mechanical Strength

The mechanical strength of the high integrity container must be sufficient to withstand horizontal and vertical loads equivalent to those brought about by a soil cover of density 120 lb/ft^3. The maximum load to which the 3M lead-lined drums may be subjected (Hanford burial site) is that from a soil column 45 ft. high.(15) This leads to the loads on the different drum components summarized in Table 5.2. The yield strengths of these materials generally increase with decreasing temperatures so the actual yield strengths at the ambient temperature of the trench should be somewhat greater than those in Table 5.2. The loads have been calculated for the components individually, i.e., for the lead, the pressure experienced was calculated neglecting the presence of any carbon steel, and for the pressure on the carbon steel, the lead was neglected. The container as a whole should be able initially to withstand greater pressure than the individual component strengths given in Table 5.2 due to mutual support effects, not only from the carbon steel and lead but also, to some extent, from the wastes themselves.

Table 5.2

Comparison of Soil Stress to Yield Strengths for 3M Lead-lined Waste Package Components

	Soil Stress Vertical[a]	Yield Strength
Lead (2-in.) Annulus	0.6 MPa, 87 psi	Lead (20°C) 6-8 MPa[b] 900-1200 psi
Lead (3-in.) Annulus	0.5 MPa, 73 psi	
Carbon Steel (2-in) (outer drum and inner steel liner)	14 MPa, 2000 psi	Carbon Steel (27°C) 250-290 MPa[c] 36,000-42,000 psi
Carbon Steel (3-in) (outer drum and inner steel liner)	15 MPa, 2200 psi	

[a] Calculated wall stress. Total vertical load experienced by the lid "area" of the container is actually impressed upon the ring-shaped area representing the wall.

[b] Reference 16.

[c] Reference 17.

The fact that the values for the lead yield strength and the calculated loads to be experienced are within an order of magnitude of each other becomes of potential concern for two reasons:

(1) The carbon steel outer drum and, possibly, the carbon steel inner liner will be subject to corrosion degradation at a rate much greater than that experienced by the lead. (This is due both to the lead's greater corrosion resistance and to its "galvanic" protection at the expense of the carbon steel mentioned in Section 5.2.2.3.) Thus, the lead may be expected to outlast the carbon steel components and, at some point, be subjected to all or nearly all of the soil load. In other words, the degree of conservatism resulting

from the fact that the container components will initially reinforce each other becomes compromised at some later time when the lead will, essentially, need to withstand the soil load pressures alone.

(2) The lead yield strength represents a uniaxial property that is not independent of the three-dimensional structure of the material, i.e., it cannot readily be used to address the issue of multiaxial stresses on a columnar or annular structure. Generally, cylindrical structures are subject to failure under pressure by bending or buckling. An engineering judgment of this effect indicates that this design, i.e., 3 inches of lead, should not fail due to buckling.* However, 3M, should they wish to complete the mechanical strength analysis, would need to consider bending and/or buckling pressures in conjunction with the effects of corrosion and/or long-term creep on specific portions of the container design.

In summary, the carbon steel container components should initially be of sufficient mechanical strength, but the strength of the lead components has not been determined by a structural analysis.

5.2.2.5 Polymeric Material Creep Test Data Extrapolation

The recommendation for polymeric material of design mechanical strength extrapolation from creep test data does not explicitly apply to the 3M Class B and C lead-lined containers. It is known, however, that lead will creep, and, therefore, creep should be considered in a container evaluation.

5.2.2.6 Thermal Load Effects

The effects on the 3M lead-lined waste packages of the thermal loads of processing, storage, transporation, and burial should be minimal. Over the temperature range -40°C to 60°C specified for testing in Section C2(g) of the technical position, carbon steel is expected to be unaffected. For lead, the recrystallization temperature is near 0°C,(15) which means that below this temperature, the lead will become harder and less ductile such that more force is required for deformation. From the point of view of handling and storage, at temperatures below 0°C, the lead should essentially become stronger but also more brittle and thus more susceptible to cracking. In the burial trench, the lower temperatures to which the package will be subjected (~10°C) should serve mainly to increase the ability of the lead to withstand pressure and, given the improbability of sudden stresses, there should be little likelihood of negative structural effects.

In summary, independent consideration of the 3M container components leads to the conclusion that there should be little thermal effect in regard to the carbon steel and also in regard to the lead so long as it is not significantly stressed at temperatures below its recrystallization temperature.

---

*Telephone conversation between M. Reich and R. E. Barletta, February 10, 1984.

Ideally, 3M should consider the effects of low temperature recrystallization in its analysis of the container stability.

5.2.2.7 Radiation Effects on Containers and Wastes

The materials and components of the 3M wastes packaged in the 2-inch and 3-inch lead-lined drums which might yield radiolysis products of concern are the polymer/plastics and cellulosics. This means that the types of packages for which radiolysis products must be taken into consideration would be those containing Nalgene-emplaced wastes. The approximate composition of these hot cell wastes has been given (by volume) as 50% polymer/plastic, 10% HEPA filters and 40% glass, paper, metal and waste microspheres (see Section 3.2.1).(7)

The 3M hot cell waste packages containing polymers/plastics have been stated to contain 10% or less by volume polymer/plastic material. The remaining volume is void space. Since void space is not to be included in waste classification, this means that the Class C activity limit for such a package would, at most, be that corresponding (for a 3-in. lead-lined drum) to a volume of 2.6 ft^3 (lining volume plus 10% internal volume) or ~340 Ci. In addition, assuming a waste material density of 1 g/cm^3, the mass of polymer/plastic material present in such a package would be 4.5×10^3 g (10% of 4.5×10^4 cm^3 internal volume).

Packages of waste cellulosic materials and having greater than 30 Ci of Cs-137 hold 1×10^3 g of cellulosics. It has been assumed that void space is minimized in such packages. For the purposes of the radiolysis calculations in this section, the cellulosics have been taken as occupying the total internal volume and the upper Class C limit Cs-137 activity for a 30-gallon container, ~520 Ci, is assumed.

Packages containing HEPA filters have been stated to contain activities that do not exceed 30 Ci of Cs-137 and, given that a worst case calculation for radiolysis of cellulosics can be made based on the information pertaining to the cellulosic-containing packages of activities >30 Ci, these HEPA filter packages will not be considered further.

The information used in the radiolysis calculations for the two types of Nalgene-emplaced waste packages is summarized in Table 5.3. It should be noted that, for the purposes of waste package classification and activity assumptions in this section, the total waste package volume has been used exclusive of void space, i.e., the lead-lining has been included with the pertinent waste volume to yield the total "package" volume. For the activity density values, i.e., the radioactivity distribution throughout the waste material (C_i in Table 5.3), a homogeneous distribution has been assumed and only the waste-occupied internal volume of the package has been included.

Table 5.3

3M Nalgene-Emplaced Waste Package Summary
(3-in. Lead-Lined Drum)

	Package Volume (void space excluded) ft^3	cm^3	Internal Volume ft^3	cm^3	Total Activity (Ci)	Mass of Material (g)	$\frac{C_i}{(\text{mCi/cm}^3)}$
(1) polymers/ plastics	2.6	$7.4\text{x}10^4$	1.6	$4.5\text{x}10^4$	340	$4.5\text{x}10^3$	7.6
(2) cellulosics	4.0	$1.1\text{x}10^5$	1.6	$4.5\text{x}10^4$	520	$1\text{x}10^3$	12

The accumulated dose for 300 years has been calculated according to the method given in Dougherty and Adams.(18) The pertinent value of the geometric g factor was based on extrapolation of g values from Hine and Brownell.(19)

The gamma (γ) dose can be calculated from the general equation:

$$D_i^\gamma(t) = D_i^\gamma(\infty)\ (1-e^{-\lambda_i t})$$

where

$D_i^\gamma(t)$ is the absorbed gamma dose at time t due to decay of the ith radionuclide

and

$D_i^\gamma(\infty)$ is the total absorbed gamma dose due to decay of the ith radionuclide and is equal to

$$\frac{C_i \Gamma_i g \times 8.76 \times 10^3 \text{ h} \cdot \text{yr}^{-1}}{\lambda_i}$$

where C_i is the ith radionuclide activity density (mCi/cm^3), Γ_i is the gamma ray constant of the ith radionuclide (rad cm^{2}h mCi^{-1}), g is a geometric factor which assumes tissue equivalency (cm), and λ_i is the decay constant of the ith radionuclide (yr^{-1})

or, in this case,

$$D^{\gamma}_{Cs-137}\ (300\ yr) = \frac{C_{Cs-137}\ \Gamma_{Cs-137}\ g \times 8.76 \times 10^3\ h \cdot yr^{-1}\ (1-e^{-\lambda_{Cs-137}t})}{\lambda_{Cs-137}}$$

For the types of packages considered, i.e., (1) the polymer/plastics and (2) the cellulosics, the activity densities, C_i, are 7.6 (mCi/cm^3) and 12 (mCi/cm^3), respectively. Other pertinent parameter values are:

$\Gamma_{Cs-137} = 3.3$ (rad cm^2 h mCi^{-1})

$g = 101$ (cm)

$\lambda_{Cs-137} = 0.023$ (yr^{-1})

$t = 300$ yr

Substitution yields 9.6×10^8 rad accumulated γ dose for the polymer/plastics and 1.5×10^9 rad accumulated γ dose for the cellulosics.

The β^- dose for these two package types can be calculated from the general equation:

$$D_i^{\beta}(t) = D_i^{\beta}(\infty)\ (1 - e^{-\lambda t})$$

where

$D_i^{\beta}(t)$ is the absorbed beta dose at time t due to decay of the ith radionuclide.

$D_i^{\beta}(\infty)$ is the total absorbed beta dose due to decay of the ith radionuclide and is equal to

$$\frac{A\ C_i\ \overline{E}_i \times 8.76 \times 10^3\ h \cdot yr^{-1}}{\lambda_i}$$

where

C_i is the activity density of the ith radionuclide (mCi/cm^3), $\overline{E}_i$ is the average beta energy of the ith radionuclide (MeV), and A is a proportionality constant which equals 2.1×10^3 rad cm^3 MeV^{-1}h^{-1}mCi^{-1} when C_i and E_i have the units given. Finally, λ_i is the decay constant of the ith radionuclide (yr^{-1})

or, in this case,

$$D^{\beta}_{Cs-137}(300\ yr) = \frac{A\ C_{Cs-137}\ \overline{E}_{Cs-137} \times 8.76 \times 10^{3}\ h\ .\ yr^{-1}}{\lambda_{Cs-137}} \left(1-e^{-\lambda_{Cs-137}t}\right)$$

Again, the Cs-137 concentrations have been taken as 7.6 mCi/cm and 12 Ci/cm^3 for the polymer/plastics and the cellulosics, respectively. The values of the other parameters are:

$A = 2.1 \times 10^{3}$ (rad cm^3 MeV^{-1}h^{-1}mCi^{-1})

$\overline{E}_{Cs-137} = 0.195$ (MeV)

$\lambda = 0.023$ (yr^{-1})

$t = 300$ (yr)

Substitution yields 1.2×10^{9} rad accumulated β dose for the polymer/plastics and 1.9×10^{9} rad accumulated β dose for the cellulosics.

The plastics fraction of these wastes (see Table 3.2) would be expected to generate gas, predominantly hydrogen, in a radiation field(1). The gaseous products expected to be produced at the total γ and β accumulated dose (2×10^{9} rad) based on the G-value for polyethylene (3.7 molecules per 100 eV absorbed)(20) should amount to approximately 200 mL of gas (STP) per gram of plastic. Assuming a waste density of 1 g/cm^3, for a 3-inch lead-lined drum and total accumulated dose absorbed by the plastics, this would result in 9×10^{2} liters of gas (STP).

Hydrogen, carbon dioxide, and carbon monoxide total gas production from radiolysis of the cellulosic component of the wastes has been calculated based on a G (total gas) of 0.63 molecule/100 eV.(21) Given this G value, the total gas production (over 300 years) for the cellulosic waste fraction is 50 L of a mixture of H_2, CO_2, and CO gases.

Were the lead-lined drums sealed, these volumes of gas produced over the 300-year period would result in a pressurization equivalent to ~21 atm inside the polymer/plastics drum and ~2 atm inside the cellulosics drum (all gases taken as originally at STP). The lack of a seal on the 3M lead-lined waste drums allows the gases produced by radiolysis to escape the container and, thus, no such pressurization is expected to occur. Thus, there are no deleterious effects anticipated due to radiolytic gas production.

The other radiolysis products that might be of concern with respect to the 3M wastes are the organic acids produced from the radiolysis of cellulosics. The G value for organic carboxylic acid group-containing molecules is 3.6. The major acids reported for radiolysis of cellulosics are: formic (G = 2.3, 64%), glucuronic, 2-ketohexanoic and 3 unspecified "5-ketohexanoic or uronic acids".(22) There is a potential for acceleration of container corrosion by these compounds. For the cellulosic waste package, with the γ dose calculated earlier, 1.5×10^9 rad, there should be a production of ~6 moles of organic acids, of which 64% or approximately 4 moles, would be formic acid.

Assuming this G value (3.6) holds for β radiolysis as well, the β dose (2×10^9 rad) should result in production of ~8 moles of organic acids, of which ~5 moles would be formic acid. The total organic acid production from β and γ radiolysis of cellulosics might thus be expected to produce up to 14 moles of organic acid of which ~9 moles would be formic acid.

In order to illustrate the magnitude of effect that such an amount of organic acid could produce, the following assumptions have been made:

(1) the inner carbon steel liner used for the 3M lead-lined drums has been taken to be composed totally of iron,

(2) in the primary metal dissolution/oxidation step, i.e., the iron-acid interaction, it has been assumed (as a conservative case) that iron is taken from the zero oxidation state to the +2 state, i.e., two acidic groups are utilized per iron atom,

and

(3) the acid has been assumed to contain only one carboxylic functional group per molecule, and to interact as in (2) above independent of the presence of water.

Given these assumptions, for 14 moles of acid ~7 moles of iron should be consumed. This corresponds to ~420 g of iron. Given the density of iron as 7.86 g cm^{-3}, and the thickness of the carbon steel liner (11 gauge) as 0.3 cm, this amount of acid could, as a worst case, result in dissolution of ~175 cm^2 of liner. The drum inner bottom area has been calculated as ~800 cm^2 (3-in. wall thickness lead-lined drum). Were the organic acid localized at the drum bottom, this would mean that ~20% of the liner bottom area could be effectively corroded. It would be expected that the lead could also be attacked by the acid once the carbon steel liner is breached. If it is assumed that ~50% of the organic acid is consumed in penetrating the carbon steel liner and 50% remains available to attack the lead, a estimate of potential damage may be made. Given assumptions similar to those made above [(2) and (3)] except that it is lead that is corroded by reaction with acid, 4 moles of lead should be corroded. This amount of lead would correspond to a circular area ~9 cm^2 (1% of the total bottom area) and 3-inches thick (for the 3-inch wall thickness lead-lined drum), and ~13 cm^2 (~2% of the total bottom area) and 2-inches thick (for the 2-inch wall thickness lead-lined drum).

It should be noted (see also Section 5.2.2.3) that, given the relative difference in electrode potentials for lead and iron, there is a possibility that galvanic protection of the lead liner may occur at the expense of the carbon steel.

In summary, given all the assumptions made earlier, the organic acids produced by radiolysis of the cellulosic fraction of these wastes could corrode part of the bottom area of the carbon steel liner used in the 30-gallon lead-lined drums. In addition, there is conceivably enough acid present to corrode through ~1-2% of the lead drum bottom for the 3-inch and 2-inch wall thicknesses.

The interaction behavior of formic acid with the three main waste package materials of concern can be summarized as follows:

(1) with lead, corrosion due to formic acid (10-100% concentration, 25-100°C) is so significant that it is recommended lead not be used for any component parts where there may be contact with formic acid.(23)

(2) with carbon steel, formic acid enhances corrosion (see above) such that carbon steel is "not recommended" as a lining material for use with formic acid.(24)

(3) with polyethylene (the Nalgene container material, which is low density polyethylene, has been assumed to behave similarly to polyethylene), formic acid (anhydrous) interacts in a nondestructive manner at least over the temperature range 60-140°F (15-60°C). Also polyethylene is resistant to attack by formic acid in 10-85% aqueous solution (considered because of the water influx potential of the package; water has not been given as a major γ-radiolysis product of the materials considered) over the temperature range 60-160°F (15-71°C).(23)

The procedure for packaging the Nalgene-emplaced wastes has the effect that all cellulosic materials are contained in Nalgene. Thus, radiolysis production of formic acid from the cellulosics should occur inside the Nalgene vessels. At the same time, the Nalgene itself (being low density polyethylene) is undergoing radiolysis to give off gas (mainly hydrogen) as discussed earlier. There is a possibility, depending on the condition and behavior/stability of the Nalgene vessels, that the formic acid produced in the interior may find its way to the carbon steel inner liner and, eventually to the lead itself.

Even though the Nalgene containers may not be damaged either during handling, packaging or by any waste components (e.g., a piece of glass), the potential damage due to irradiation of the Nalgene is of concern. King et al.(25) have tabulated absorbed radiation doses that may damage polyethylene. For what has been termed "threshold damage" to tensile strength and shear strength, polyethylene can have absorbed a total dose of 1.7×10^9 ergs$\cdot$g^{-1} or 1.7×10^7 rad. Changes in other properties such as elongation, elastic modulus, and impact strength do not occur until higher absorbed doses (between 2.1×10^9 and 3.6×10^{10} ergs g^{-1} or 2.1×10^7 to 3.6×10^8 rad). The calculated total cumulative doses to the 3M (Class C upper limit assumed) Nalgene-emplaced cellulosic wastes has been given earlier as 3 x 10^9 rad or 3 x 10^{11} erg g^{-1}. This accumulated dose is two orders of magnitude higher than that required to produce threshold damage to the polyethylene and it is thus expected that over the 300 year period, the polyethylene (Nalgene) material could suffer mechanical damage due to irradiation from the Cs-137.

Summary

Radiolysis has been considered for the plastic and cellulosic components of the 3M wastes. It is assumed that the radiolysis effects on metals, glass and ceramics that may be present are minimal. Hydrogen gas is the principal radiolysis product of polyethylene and the total amount of gas produced has been calculated for the polyethylene component of the 3M waste package containing Nalgene-emplaced wastes (contaminated with Cs-137 at the upper Class C activity limit) as totalling approximately 900 liters (STP) over the 300 year period. Hydrogen, carbon dioxide and carbon monoxide gas production from radiolysis of the cellulosic component of these wastes totals approximately 50 liters of gas (STP) over the 300 year period. The lack of a gas-tight seal on the lead-lined drum leads to the expectation that this gaseous material will escape the container and, consequently no pressurization is anticipated. Were the drum sealed such that all the radiolysis gas products were retained, pressures of ~21 and ~2 atm (0°C), for the polymer/plastics and cellulosics containers, respectively, would be expected to build up over the 300-year period.

Liquid radiolysis products include several organic acids which result from radiolysis of cellulosics. The total organic acid production expected over 300 years is ~14 moles of which formic acid comprises 64% or ~9 moles. The polyethylene-formic acid interaction behavior is not destructive and there is a potential for containment of this acid by the Nalgene if no damage has occurred in packaging/handling and until the irradiation damage to the Nalgene compromises its ability to contain. However, should the formic acid be able to contact the carbon steel liner, and/or the lead itself, enhancement of container corrosion from within may occur. This could affect the lifetime estimates for the lead-lined containers such that a 300-year lifetime could not be guaranteed.

5.2.2.8 Biodegradation Effects

Biodegradation of the 3M lead-lined package container materials has been considered from two points of view (1) outside the container, i.e., in the trench soil environment, and (2) inside the container, i.e., in the waste themselves. In neither case is biodegradation expected to be a primary problem, i.e., direct biodegradation of the lead and carbon steel is not expected since neither material supplies a carbon source. From both viewpoints, however, biodegradation by-products (e.g., organics acids) may be of concern with respect to corrosion of the container. A discussion of the complexity of the composition and behavior of a system of microorganisms which may exist either in the soil or in the wastes and also of the different chemicals they may consume or produce has been given in Gause et al.(1) For the case at hand, it should be noted that:

(1) from the soil environment, the consideration of corrosion of the container from outside (Section 5.2.2.3) has been based on published measured corrosion rates for metals in soils which contained microorganisms (i.e., not sterilized) and thus the effect of microbial activity on corrosion is reflected in the soil corrosion data of Romanoff discussed above. Romanoff has stated that organic acid-rich soils are more corrosive to lead than inorganic soils. It was concluded that this behavior was a consequence of the lack of protective film formation due to the high solubility of certain organic salts of lead. Lead acetate was cited as an example.

and

(2) from the point of view of biodegradation of the wastes, there is the potential for self-sterilization within ~3 months for 3M wastes (in 30-gallon lead-lined drums) that have Cs-137 contamination levels of ~200 Ci per package.

The consideration of sterilization of the wastes by radiation from waste radioisotopes must include several factors as summarized below.

(1) Sterilization has been shown to occur at accumulated doses up to 5×10^6 rad (that necessary for sterilization of sporulating bacteria);(26) the dose rate effect has not yet been totally established.

(2) At dose rates greater than 10^4 rad/h, it appears that the sterilization effect is independent of the dose rate,(26) and the exact lower bound on dose rate has not been set.

(3) For the Class C limit Cs-137 activity considered for the 3M 3-inch wall thickness lead-lined drum (~520 Ci), the initial dose rate (β^- and γ) has been calculated as 3×10^3 rad/h. This dose rate will decrease exponentially at a rate dependent on the Cs-137 decay constant.

The times to accumulated sterilization dose independent of dose rate effects have been calculated (Table 5.4). Both the γ and β^- dose contributions have been included in these calculations. Inclusion of the β^- dose implies the assumption that the β^- emitting activity and the microbes are homogeneously distributed throughout the wastes.

Since the lower limit for sterilization to have dose rate independence has not been definitively set, it is possible that those Cs-137 activities which produce a dose rate within an order of magnitude of the known 10^4 rad/h upper threshold may also effectively sterilize the wastes once the necessary accumulated dose has been reached. Those activities in Table 5.4 for which the initial dose rate is of the order of 10^3 rad/h are 260, 500, and ~520 Ci. The lower activity limit for this type of container at which the 10^3 rad/h dose rate can be achieved is ~200 Ci. Thus, for waste packages

Table 5.4

Time to Sterilization Dose Accumulation for Different Cs-137 Package Activity Levels

30-Gallon Drum Cs-137 Package Activity[b] (Ci)	Time[a] to Sterilization Dose 5×10^6 rad[c] (yrs)
5	14
26	2
50	1
260	0.2
500	~1 month
(~520)[d]	~1 month[d]

[a] Determined by extrapolation of plot of $e^{-\lambda t}$ vs time for set accumulated dose, geometry, distribution, and Cs-137 activity.

[b] Values taken over the entire Class B and C ranges for this type of package.

[c] Maximum dose published for sterilization of sporulating bacteria.(26)

[d] Upper Class C limit values for this size container.

(in 30-gallon lead-lined drums) containing >200 Ci of Cs-137, it should be expected that self-sterilization may occur in less than 3 months. Self-sterilization of those packages whose activities are such that 1 to 14 years elapse before the necessary accumulated dose has been reached (50 to 5 Ci in Table 5.4) must be viewed with skepticism. Based upon the analysis presented, no 3M waste package will remain self-sterilizing after ~50 years, the time required for the dose rate of a 3M package containing the upper class C limit concentration of Cs-137 (~520 Ci) to fall below 10^3 rad/hr.

Implicit in the generalization that a self-sterilizing package should experience minimal effects from biodegradation of the wastes themselves are the assumptions that:

(1) There is no inoculation from outside the wastes such as might occur with water influx into the packages,

and,

(2) There is no significant (from the standpoint of corrosive or degradative chemical production) biodegradation occurring in the wastes prior to the time at which the self-sterilization is complete.

Both of these assumptions require careful consideration in the case of the 3M lead-lined drum waste package. First, there is, as mentioned in other sections (5.2.2.4,-7-,12), no seal on this container such that there is a guarantee of no water influx. Rainwater containing microorganisms could thus, potentially, enter this type of package (at any time, but particularly significant times with respect to changes in container degradation behavior would be subsequent to the self-sterilization period) and thereby replenish the microoganism population responsible for biodegradation. Second, the rates of biodegradation are dependent on a great number of factors including the particular types of microorganisms, the ambient gas conditions (anaerobic vs aerobic), the amount of water present, the type and amounts of nutrients present, etc.

Summary

It would be very difficult to indicate whether biodegradation processes going on in the wastes could contribute significantly to the degradation of the container prior to the self-sterilization time. It might be that those packages containing activities at levels such that the self-sterilization interval is much shorter than the time to expected water influx have a greater chance of experiencing extended container integrity simply because, for some unspecified time, the container is not subjected to the effects of biodegradation from within.

5.2.2.9 Department of Transportation (DOT) Type A Requirements

The high integrity container should be capable of meeting the requirements for a Type A package as specified in 49 CFR Section 173.411 and 412. According to a statement from the manufacturer of the 30-gallon 2- and 3-inch wall thickness lead-lined drums, these containers are constructed to meet DOT Type A requirements.

5.2.2.10 Lifting Loads to Which the Container May be Subjected

The high integrity container and the associated lifting devices should be designed to withstand the forces applied during lifting operations. As a minimum, the container should be designed to withstand a 3-g vertical lifting load.

The vertical lifting load which the 30-gallon lead-lined drums are designed to support corresponds to approximately 3500 lb.(27) Since the empty 2-in. and 3-in. lead-lined drums weigh 1700 and 2100 lbs, additional handling support is needed for containers to withstand a 3-g vertical lifting load. Such a lifting load would be equivalent (for empty drums) to 5100 and 6300 lbs for these two container types, respectively.(28) As indicated in the RSRs, typical waste loads for these packages weigh ~300 lbs. Essentially, then, a waste-filled 30-gallon, 3-inch lined drum would weigh ~2400 lbs. The container in this package would then need to be capable of withstanding a lifting load of 7200 lbs. This is 3700 lbs in excess of the lifting load these containers are designed to withstand.

5.2.2.11 Design for Avoidance of Water Retention on Container Surfaces

The 30-gallon lead-lined drums, being cylindrical structures, have flat surfaces on the top and bottom. There is also a raised ring around the top of the outer carbon steel drum where the drum lid sits, and a similar ring on the bottom. Thus, if placed vertically, this container would be expected to collect and retain water on its upper surface. The lead lining itself also has flat upper and lower surfaces so that it is expected that water collection and retention would occur on its upper and lower surfaces as well. In addition, the lead liner has an opening around its lid which allows water essentially free access to the drum contents.

5.2.2.12 Container Closure

The 30-gallon lead-lined drums as shipped by 3M have a closed outer carbon steel drum. There is a standard ring-bolt seal which is not designed to be gas tight. The inner lead-lining is not sealed, the lid has a step design and the lining is closed by simple emplacement of the lid (see Section 4). This design should allow for relief of internal pressures, but no guarantee could be given that influx of moisture could not occur (especially once the outer carbon steel drum has corroded away).

In addition to the possibility of material (water, soil, microbes, etc.) influx to this container and to the wastes, there is the possibility of physical displacement of some of the wastes themselves. This could be a consequence of the dislodgement of the drum's lead-lining lid which may occur when the drum is placed in any position beyond the horizontal (i.e., such that the drum cylinder axis and the line of the trench bottom from an included angle between 90 and 180°). This possibility was discussed in Section 4. The significance of this lid-dislodgement increases with time as the outer drum corrodes away.

5.2.2.13 Prototype Testing of Containers

Prototype testing should be performed on high integrity container designs to demonstrate the container's ability to withstand the proposed conditions of waste preparation, handling, transportation, and disposal.

At this time, no prototype testing to demonstrate this container's ability to withstand the proposed conditions of waste preparation, handling, transportation and disposal has been performed.

5.2.2.14 Quality Assurance Program

High integrity containers should be fabricated, tested, inspected, prepared for use, filled, stored, handled, transported, and disposed of in accordance with a quality assurance program. The quality assurance program should also address how wastes which are detrimental to high integrity container materials will be precluded from being placed into the container. Special emphasis should be placed on fabrication process control for those high integrity containers which utilize fabrication techniques such as polymer molding processes.

The type of quality assurance program followed by 3M personnel is dependent on the activity of the wastes: (1) one program is followed for DOT Type A quantities and, (2) another program is followed for wastes of activities greater than DOT Type A quantities. The Cs-137 activity for Type A packages (10 CFR Part 71) is $\leq$3 Ci. According to 10 CFR Part 61, 3 Ci of Cs-137 in one of the 30-gallon lead-lined drums would correspond to Class B waste. For 3M wastes, this would fall into the category of wastes which (given their non-stabilized condition) have been evaluated as needing to be disposed of in a high integrity container. 3M therefore has, at this time, no unified quality assurance program for application to their Class B and C wastes. They could possibly be processing some Class B wastes along with Class A wastes if both were to be categorized as DOT Type A. With respect to the higher activity packages, it is known that as a part of a quality assurance procedure, 3M personnel inspect all lead-lined drums for discontinuities in the lead linings prior to use.(7) These inspections involve inserting a radiation source in the lining center and monitoring of the outside for any radiation that would escape through openings (were they present) in the lining.

5.2.2.15 Summary of Recommendation Conclusions in Evaluation of Lead-Lined Drums as High Integrity Containers

The 3M lead-lined package has been evaluated for consistency with the high integrity container guidelines in the Technical Position on Waste Form. It should be noted 3M has not claimed that the lead-lined drums they use for these wastes are high integrity containers.

- The guidelines in the TP (letters refer to the order in the TP) for a HIC that are met by the 3M lead-lined drum waste package are:

  (a) that referring to <1% free liquid volume and the need for a process control system, and

  (i) that stating the need for the HIC to fulfill DOT Type A package requirements.

- TP guidelines that may require more analysis, testing, modification of structure, etc. to be met by the 3M lead-lined drum waste packages follow.

  (b) The recommendation for a design goal of 300-year maintenance of structural integrity - the 3M lead-lined drum, as presently represented, has not been specifically designed to maintain structural integrity for 300 years. To meet this guideline, 3M should provide an analysis of container stability based upon the container design and contents as well as anticipated burial site conditions.

  (c) The recommendation that the corrosive and chemical effects of wastes and environment be considered in regard to their impact on the performance of the HIC - the corrosive effects of the environment (which include soil corrosion and all that it entails) have the potential to compromise the 300-year container performance objective. It may be necessary to modify the container design to minimize and/or counteract these effects.

Several points which are of note with respect to package performance are:

(1) The wooden overpacks that are currently part of the 3M waste package will be expected to contribute, through their biodegradation, to the corrosive effects of the environment on the HIC and, potentially, to adversely affect site performance as well;

(2) The lifetime of carbon steel outer drums is expected to be in the range of 10 to 120 years;

(3) The lead lined drums themselves are subject to corrosion from the outside. The effects of this corrosion should be considered in a design and structural analysis.

(j) The guideline that the HIC be able to withstand a 3-g lifting load - as presently constructed, the lead-lined drum is able to support approximately 3500 lbs. For the empty two- and three-inch lead-lined drums, a 3-g lifting load would correspond to 5100 and 6300 lbs, respectively. According to the drum manufacturer these loads (and of course, waste-loaded package loads as well) are in excess of the weight limit that can be supported by the present lead-lined drum package design. Any proposed modification in drum design should ensure that the 3-g lifting load can be supported by this package.

(k) The recommendation that the HIC design be such that water retention on the container surface is avoided - the lead-lined drums, as presently constructed, may allow for water retention; additionally, the lead lining, in not being sealed, is vulnerable to water influx. A design modification may be required to minimize water contact time with the container.

(ℓ) The recommendation that the container be sealed over the lifetime of the container - the 3M lead-lined drums have two closures: (1) the outer carbon steel drum, and (2) the inner lead liner. As these waste packages are presently constructed, (1) is sealed and (2) is not. A package design meant to provide for a seal over the lifetime of the container would have to include some design modifications resulting from analysis of the expected behavior and lifetimes of the container components. As gas generation is expected from the package components, the effects of radiolytic and biogenic gases on seals should be considered by 3M in their design analysis.

(m) The recommendation that prototype testing of the container be performed. 3M should conduct such tests on a final package design.

- TP recommendations about which only qualified conclusions can be drawn with respect to the 3M lead-lined drums include areas of concern and areas about which additional information is necessary. These are given below.

(d) The recommendation that the mechanical strength of the HIC be sufficient to withstand the loads expected in the trench environment - the outer carbon steel drum is expected to have sufficient mechanical strength, but is <u>not</u> expected to last the entire required package lifetime. The strength of the lead liners may be sufficient. 3M should provide a mechanical strength analysis which includes consideration of bending and/or buckling pressures in conjunction with consideration of effects of corrosion and/or long-term creep on specific portions of the container design.

(f) The recommendation that the HIC withstand thermal load effects - these effects are not expected to be significant, however the mechanical strength analysis discussed in (d) above should include evaluation of the effects of low temperature recrystallization in lead.

(g) The recommendation that radiation effects on the HIC be considered - the radiation effects on the HIC materials themselves are expected to be minimal. However, the radiolysis of the wastes leads to gas and liquid (organic acid) production. The gases expected to be generated over a 300-year period could lead to pressurization of the drum (up to 21 atm for the Cs-137 Class C limit polymer/plastics package), were it sealed. The liquid organic acids produced in radiolysis of cellulosics could, were they to come in contact with the HIC materials, contribute to the overall package corrosion and, hence, to a decrease in expected package lifetime. For quantitative estimation of these effects, 3M should provide an analysis of the expected waste package behavior over time with respect to radiolytic degradation.

(h) The recommendation that biodegradation effects on the HIC package be taken into account - what have been termed "secondary" biodegradation effects, i.e., those relating to biodegradation by-products, may be influential in corrosion of the drum from within [such effects are expected to have contributed to the corrosion effects of soil as discussed earlier, see (c) above], but for quantitative estimates of these effects to be made, further information on the 3M waste and soil biodegradation by-products and rates may be needed. Self-sterilization of some high activity packages is possible and this may lead to inhibition of biodegradation effects unless the material is re-inoculated.

(n) The recommendation that a quality assurance program be instituted to apply to all HIC packages - the quality assurance program currently used by 3M may or may not be adequate to ensure packaging consistent with the stability requirements. A detailed quality assurance and process control program to ensure that the objectives of the waste classification and stability objectives of 10 CFR 61 are being met for each package should be provided by 3M.

5.2.3 3M Concrete-Lined Drums - 10 CFR Part 61 Requirements

As noted in Section 3.2.2, concrete-lined drums have generally been used for wastes which require more shielding than that provided by a regular carbon steel drum, but less than that provided by a lead-lined drum. In the RSRs surveyed for this report, the concrete-lined drums were considered to be those with weights between the weight of an empty concrete-lined drum (425 lb) and an empty lead-lined drum (2100 lb). (The weights of the empty drums are taken from Table 4.1). It was found that the only wastes with specific activities above the Class A range which were disposed of in concrete-lined drums were lead, glass, paper, and plastic containing Cs-137 with specific activities in the Class B range. For example, the concrete-lined drums have been used for disposing of the residuals from cleaning sources after fabrication. This type of waste packaged in concrete-lined drums will, in general, meet the minimum requirements of 10 CFR Part 61, Section 56(a) for all classes of waste but, as discussed below, does not necessarily meet the structural stability requirements of Section 61.56(b). (See Appendix A for these requirements).

5.2.4 3M Concrete-Lined Drums - Technical Position Recommendations for High Integrity Containers

The 3M concrete-lined package has been evaluated for consistency with the high integrity container guidelines in the Technical Position on Waste Form. It should be noted that 3M has made no claims to the effect that the concrete-lined drum is a high integrity container.

The guidelines for high-integrity containers (HICs) as outlined in the Technical Position on waste form are considered in the following sections individually as they pertain to the 3M Class B wastes packaged in 30-gallon concrete-lined drums. Where the analysis is the same as that given in the preceding discussion of 3M lead-lined drums, reference is made to the appropriate section.

5.2.4.1 Free Liquid Fraction and Process Control

As in the case of the wastes packaged in lead-lined drums (Section 5.2.2.1), the 3M staff have indicated that no free liquids have been disposed of in the concrete-lined packages.

5.2.4.2 Design Goal of Minimum 300-year Container Lifetime

As in the case of the lead-lined drum, the concrete-lined drum was not designed with a goal of 300-year maintenance of structural integrity. As already noted, the purpose of the concrete is to shield wastes which do not require the greater amount of shielding provided by lead. Factors influencing the container lifetime will be considered again as the remaining Technical Position recommendations for HICs are addressed in the discussions below.

5.2.4.3 Consideration of Corrosion and Chemical Effects - Wastes and Environment

The non-radiolytic corrosive and chemical effects of the wastes and the external environment are similar to those discussed in Section 5.2.2.3 in connection with the lead-lined drum. The chemical nature of the wastes in the concrete-lined drums is, in general, similar to that in the lead-lined drums and would thus be expected to have a minimal degradative effect on the inner wall of the container. The effects of radiolysis are discussed in Section 5.2.4.7.

The lifetime of the carbon steel outer drum wall cannot be accurately estimated from existing data on carbon steel corrosion in soil. In the discussion in Section 5.2.2.3 of corrosion of the carbon steel outer drum wall of the lead-lined container, pitting time estimates of 2.5 to 9.6 years and container lifetime estimates of 10 to 120 years were noted for this component. Biodegradative corrosion is implicitly included in these estimates. The galvanic acceleration of the carbon steel corrosion by lead (which is not included in these lifetime estimates) does not apply to the concrete-lined drum. Even without this galvanic effect, the carbon steel drum is unlikely to provide either stability or containment for a length of time on the order of the 300 years specified as a design goal for the container lifetime.

The deterioration of concrete as a result of exposure to aggressive chemicals has been reviewed in an NRC report by Gause et al.(2) Three factors were considered to be significant in the corrosion of concrete:

1) the type of cement,

2) the kinds of aggressive chemical agents, in particular, sulfates and the products of biodegradation, and

3) the availability of water in the burial environment.

It was concluded that at a dry site such as Hanford, to which 3M's waste is currently being shipped, it is likely that buried concrete will remain dry and, consequently, not subject to degradation by corrosion. At a wetter burial site, however, the long-term stability of the concrete component of a waste package is likely to be compromised, although without site-specific data, it is not possible to accurately estimate the lifetime of a 3-inch concrete annulus.

Both waste-specific and disposal site-specific corrosion and chemical tests need to be performed in order to confirm the suitability of the proposed container materials to meet the 300-year design lifetime goal.

5.2.4.4 Mechanical Strength

The concrete-lined drum, like the lead-lined drum, must have a mechanical strength sufficient to withstand the load of a 45-ft column of soil with a density of 120 lb/ft^3, equivalent to a load of 5400 lb/ft^2 (0.25 MPa). As in Section 5.2.2.4, the loads were calculated for each component individually and a vertical orientation of the drum, the most conservative case, was assumed. The whole-package vertical load on the 3-inch concrete annulus is about 70 psi (~0.5 MPa), the same as that on the 3-inch lead annulus. The whole-package vertical loads on the 26 gauge (0.014 in) carbon steel inner liner and on the 18-gauge (0.048 in) outer drum wall are about ~11000 psi (75 MPa) and 3600 psi (~30 MPa), respectively. These calculated loads and the maximum loads allowed on the materials making up these components are summarized in Table 5.5. It may be concluded that the mechanical strength of each component individually is sufficient to withstand the severe whole-package load in a vertical orientation.

Table 5.5

Soil Load on Components of Vertically Emplaced Concrete-Lined Drum

Component	Load	Mechanical Strength[a]
3-in concrete annulus	0.5 MPa, 70 psi	2650 to 4000 psi (18-30 MPa) compressive strength at 28 days
18-gauge steel outer drum wall	30 MPa, 3600 psi	30,000 psi (210 MPa) minimum yield strength
26-gauge carbon steel inner liner	75 MPa, 11000 psi	

[a] Data from Reference 29.

While the conclusion of this first order mechanical strength analysis indicated that this package will sustain the soil overburden, a detailed structural analysis should be provided by the waste generator if HIC certification is requested for this container. This analysis should consider all relevant failure modes (e.g., failure due to buckling stress) as well as the impact of any anticipated package degradation (e.g., since carbon steel/soil corrosion rates suggest complete degradation of a carbon steel drum within 120 years, no credit should be given to the outer carbon steel drum at 300 years).

5.2.4.5 Polymeric Material Creep Test Data Extrapolation

As in the case of the lead-lined drum (Section 5.2.2.5), this recommendation is not applicable since the drum is not constructed of a polymeric material.

5.2.4.6 Thermal Load Effects

The effects of the thermal loads of processing, storage, and transportation on the concrete-lined drums, unlike lead-lined drums, could potentially be significant because of possible detrimental effects on the concrete. As noted by Lea(30), in wet concrete, the water enclosed in the pores of the material will, on freezing, expand and thereby set up severe internal stresses and force the particles of mortar apart. Freezing and thawing will have no significantly damaging effects on any concrete not sufficiently saturated with water. (The quantitative meaning of "sufficiently saturated" will not be discussed here. See Lea(30), pp. 611 to 621). According to the 3M staff, the concrete-lined drums generally sit for weeks or months after the concrete is poured, allowing sufficient time for "set up" prior to use.(8) Because of the absence of significant free liquid in the wastes when packaged, as well as the presence of the inner carbon steel lining, the concrete is not likely to absorb water during processing, storage and transport. It is therefore expected that no significant changes in the material design properties of the concrete will result from thermal cycling testing as specified in Sections C4(g) and C4(f) of the Technical Position. After burial, water may come in contact with the concrete because of corrosion of the outer drum container, but the depth of burial will preclude freeze-thaw degradation since the temperature of the trench will remain above freezing.(2) In order to verify the resistance of the package to thermal cycling damage, it is recommended that thermal cycling testing in accordance with the TP be conducted on concrete with a composition and curing history like that used in the drums. Alternatively, equivalent data, if available, should be obtained about such concrete.

5.2.4.7 Radiation Effects on Containers and Wastes

The products of the radiolysis of plastics and paper are of concern. Since simulated concrete waste forms have been γ-irradiated to 10^{10}rad with no adverse effect on their compressive strength,(31) direct radiation damage to the concrete is not considered a problem. As in Section 5.2.2.7, two principal types of waste packages will be considered, polymer/plastics and cellulosics, for assessment of the radiation effects on wastes.

The dose at 300 years is calculated in the same manner as in Section 5.2.2.7. Packages have been assumed to contain the same types of materials with only the Cs-137 cocentration changed. The only pertinent parameter with a value different from that in the earlier dose calculations is thus C_i, the radionuclide activity concentration, which, for the Class B Cs-137 concentration limits leads to 0.07 mCi/cm^3 and 0.11 mCi/cm^3 for the (1) polymers/plastics, and (2) cellulosics, respectively. Accumulated γ doses would be: (1) polymers/plastics ~9 x 10^6 rad and (2) cellulosics ~1.5 x 10^7 rad. Also accumulated β^-doses would be: (1) polymers/plastics ~1 x 10^7 rad and (2) cellulosics ~1.7 x 10^7 rad. Total γ and β^-accumulated doses are then: (1) 2 x 10^7 rad and (2) 3 x 10^7 rad. The resulting gas production (STP) over 300 years is expected to be ~9L for the polymer/plastics packages and ~0.5L for the cellulosics packages. If confined to the drums, there could result a pressurization of 1.2 atm for the polymer/plastics packages (there would be no significant pressurization for the cellulosics packages). However, as in the case of the lead-lined drums, the lack of a long-term gas-tight seal precludes any such pressurization.

As a result of the radiolysis of the cellulosics, it is expected that 1 x 10^{-4} moles of carboxylic acid will be produced per gram of cellulosic material of which 64% or about 7 x 10^{-5} moles per gram or ~0.1 moles per container will consist of formic acid. Because of the lack of a positive seal, water intrusion may occur prior to failure of the outer drum. With the same conservative assumption used in Section 5.2.2.7 for the dissolution of iron by an organic acid, it is found that up to 20 cm^2 of the carbon steel inner lining may be destroyed. (This number is obtained by assuming that all of the radiolytic acid reacts with the carbon steel inner lining and none is consumed by reaction with the waste or with the concrete. This might occur, for example, if the drum were emplaced in the disposal trench horizontally.)

On the other hand, it may be assumed that all the radiolytic acid reacts with the concrete (e.g., vertical emplacement of the drum). The quantitative effect of low-molecular-weight organic acids on concrete does not seem to have been quantitatively documented but acids such as acetic, citric, malic, and lactic, but not oxalic, have been found to attack concrete, often having "a marked action" within a few months to a year.(30) When compared to acetic acid in its effect on concrete, formic acid has been described both as corroding concrete more slowly,(32) and as being more destructive.(30)

Corrosion of concrete by acids generally occurs as a result of exchange reactions between the hydrogen ions of the acid and the cationic components of the concrete, especially the Ca^{2+} in $Ca(OH)_2$.(32) The $Ca(OH)_2$ in the concrete generally reacts with the attacking acids to form water-soluble salts which may subsequently be leached.(32) An estimate of the effect on the concrete could be made if the $Ca(OH)_2$ content of the concrete were known. If 64 weight percent of CaO(30) in Portland cement is taken as typical (changes in the percentage composition of the cement as a result of hydration during curing have been neglected), and it is assumed that all of the CaO is potentially available as $Ca(OH)_2$ [which is consistent with experimental concrete waste from leach studies in which very basic (~ pH 12) solutions resulted from immersion of concrete samples in distilled water],(33) then ~3 g of CaO could be converted to a leachable form by reaction with the 0.1 mole of organic acid that may be radiolytically generated, thus affecting 4.4 g of cement in the concrete. If the density of the concrete is about 2.3 g/cm^3(30) then (neglecting the presence of aggregate) it may be estimated that about 2 cm^3 of concrete may be affected by reaction with the radiolytically generated organic acid and by the subsequent leaching of the soluble reaction products. This represents much less than 1% (3×10^{-3}%) of the total concrete lining volume and may thus be considered insignificant.

The most likely situation is attack by the radiolytically generated acids on both the steel and concrete components of the drum since both steel and concrete are initially exposed to the wastes in the drum. (There is no steel barrier between the 3-inch concrete base at the bottom of the drum and the contents of the drum.)

There is thus the possibility of damage to the inner carbon steel and concrete drum components as a result of attack by radiolytically generated organic acids. However, the magnitude of the damage is expected to be quite small.

It may be concluded that pressurization of the container by radiolytically generated gas will not be a problem because of the lack of a gas-tight seal. The corrosive and chemical effects of the radiolytic waste degradation products may cause some damage to the components of the drum, but only a very crude quantitative assessment is possible at the present time. Based on this assessment however, the effect of these products on the concrete is expected to be minimal. Compatibility testing of the container materials with the radiolytic waste degradation products may be required.

5.2.4.8 Biodegradation Effects

Much of the discussion of biodegradation of lead-lined drum materials is applicable to the concrete-lined drum materials, i.e., direct biodegradation of the concrete and carbon steel is not expected to be significant but the by-products of the biodegradation of other materials may be of concern with respect to corrosion of the container. The corrosion rates for metals in soils discussed in Sections 5.2.2.3 and 5.2.4.3 include the effects of biodegradation by-products. The indirect effects of biological processes on the chemical corrosion of concrete have been summarized in another NRC report by Gause et al.(1) Self-sterilization of the waste package will not be significant for Cs-137 in the concrete-lined drum, in particular in the lower concentration Class B range. The cellulosics, largely paper, are likely to be the most significant of the biodegradable waste components in the drum, but their biodegradation products are not likely to contribute to internal corrosion of the drum prior to susceptibility of the drum to intrusion of groundwater. In the absence of site-specific data for external corrosion of the drum and of both site- and waste-specific data for internal corrosion of the drum, a quantitative assessment of the effects of biodegradation on container stability is not possible at this time.

The nature of the 3M waste biodegradation products and their effects on the container materials must be determined for such an assessment. The biodegradation products of the cellulosic waste components are of particular concern in this respect. In order to quantify these effects, the compatibility of the container materials with the biodegradation products of the waste may need to be tested.

5.2.4.9 DOT Type A Requirements

It is not clear whether, as recommended in the TP, the concrete-lined drums meet DOT Type A requirements and, in particular, whether the concrete liner will maintain its physical integrity as a result of the required free drop test. Such information is necessary for the assessment of the concrete-lined drum as a HIC.

5.2.4.10 Lifting Loads on Containers

There is no information on the design lifting load, if any, for the concrete-lined drum. It is, therefore, unclear whether the recommendation that containers be designed to withstand a 3-g vertical lifting load is followed. Such a lifting load would be equivalent to 1275 lb for an empty concrete-lined drum and 2721 lb for the heaviest filled concrete-lined drum. (An empty concrete-lined drum weighs 425 lbs and, based on the RSRs, the heaviest filled concrete-lined drum weighs 907 lbs.) Design lifting load information must be supplied in order to determine whether this container is in accord with the TP guideline.

5.2.4.11 Water Retention on Container Surface

The outer carbon steel drum of the concrete-lined container is assumed to be similar to that of the lead-lined container. Thus, if emplaced vertically in the trench, this container would also be expected to retain water on its upper surface. The concrete-lined container would thus not be in accord with this TP recommendation.

5.2.4.12 Container Closure

The concrete-lined drum, like the lead-lined drum discussed in Section 5.2.2.12, is not designed to be gas tight or water tight (the porosity of concrete would prevent its being gas tight), thus allowing for relief of internal pressure, but also allowing for the influx of water and the subsequent loss of waste materials through gaps between the concrete lid and the concrete liners. In addition, as a result of the concrete drum fabrication process (Section 4), there may be a seam separating the bottom 3 inches of concrete from the concrete annulus. This seam may also allow the entry of water and the release of waste materials. It has been noted(34) that special procedures (e.g., sandblasting) may be required where bonding and water-tightness are desired at construction joints, i.e., the contacts between newly placed concrete and existing concrete surfaces. At 3M no such special procedures are used. Cracks in the concrete, if any exist or occur, may provide similar pathways for water and waste material. The drum design does allow for inspection of the contents without compromising container integrity.

It may be concluded that the concrete-lined container is in accord with the recommendations of the TP regarding inspectability and passive venting, but the entry of moisture and loss of waste materials is not minimized in the present design of the drum.

5.2.4.13 Prototype Testing

See Section 5.2.2.13, above.

5.2.4.14 Quality Assurance Program

See Section 5.2.2.14, above.

5.2.4.15 Summary of Conclusions in Evaluation of 3M Concrete-Lined Drum as a HIC

The 3M concrete-lined package has been evaluated for consistency with the guidelines in the Technical Position for high integrity containers. As in the case of the lead-lined drums, 3M has not claimed that the concrete-lined drums which they use for disposal of radioactive wastes are HICs. The evaluation is summarized below (letters refer to order in the TP):

- The 3M concrete-lined drum is in accord with the following guidelines given in the TP for a HIC:

  (a) Free Liquid Fraction and Process Control

  (d) Mechanical Strength

- Further analysis and possible modification of the drum design may be required because the 3M concrete-lined drum is not in accord with the following TP HIC guidelines:

  (b) Design Goal of Minimum 300-year Lifetime:

  The 3M concrete-lined drum has not been specifically designed to maintain structural integrity for 300 years. Such a design goal would require an analysis and evaluation of the container stability, based upon design, and contents, as well as anticipated burial site conditions.

  (h) Water Retention on Container Surface

  A design modification may be necessary to minimize water retention on the surface of the drum.

  (ℓ) Container Closure

  Some changes in the design of the drum may be necessary to provide for a seal over the lifetime of the container (see lead-lined drum section).

(m) Prototype Testing

Such testing should be performed in a final package design.

- Present information is insufficient to determine whether the 3M concrete-lined drum is in accord with the following guidelines:

(c) Corrosive and Chemical Effects of Waste Containers and Trench Environment

The corrosive effects of the environment have the potential to compromise the 300-year container performance objective. It may be necessary to modify the container design to minimize and/or counteract these effects. This is very dependent on the type of burial environment (see Section 5.2.4.3) and given the dryness of the Hanford site, the 3M package may be minimally affected by the environment.

(f) Thermal Load Effects

In order to verify the resistance of the concrete to thermal cycling damage, it is recommended that thermal cycling testing be conducted on the package.

(g) Radiation Effects on Container and Waste

Quantitative estimation of the corrosive and chemical effects on the container materials of the radiolytic waste degradation products needs to be improved through an analysis of the expected waste package behavior over time. Based on the first order assessment performed here, these effects are not expected to compromise this container integrity.

(h) Biodegradation Effects.

Corrosive and chemical effects on the container materials of the biodegradative products of the wastes need to be quantitatively assessed.

(i) DOT Type A Requirements.

The concrete-lined drum should be tested in accord with the DOE Type A package qualification as specified in the DOT regulations.

(j) Lifting Load.

The container needs to be made capable of withstanding a 3-g vertical lifting load.

(n) Quality Assurance Program

As for the lead-lined drums, it is unclear whether the quality assurance program currently used by 3M addresses the concerns of the TP. The 3M quality assurance program needs to be concerned with appropriate packaging of wastes in accordance with waste classification and stability objectives of 10 CFR 61.

The following TP HIC recommendation is not applicable to the 3M concrete-lined drum:

(e) Polymeric Material Creep Test Data Extrapolation.

6. CONCLUSIONS

The waste generated by 3M during the production of sources and radiopharmaceuticals has been characterized. It was found that 3M produces wastes which can be classified as Class A, Class B, and Class C according to the waste classification system of 10 CFR Part 61. The wastes generated by 3M may represent a significant contribution of activity to wastes shipped for shallow land burial. For example, it has been estimated that 3M's wastes accounted for 89% of the Cs-137 and 88% of the Sr-90 buried in eight trenches at the Sheffield site. Even for those trenches, however, 3M's contributions varied enormously by trench.

A review of RSRs for waste shipped by 3M to Hanford spanning the period from February 1982 to August 1983 indicates that 3M shipped its wastes in four types of packages. These are wooden crates, carbon steel drums (30-gallon and 55-gallon), 30-gallon concrete-lined drums and 30-gallon lead-lined drums (either 2-inch or 3-inch linings). Class A wastes have been packaged in each of the container types with the exception of the lead-lined drums. For the most part, Class B and C wastes are packaged in either concrete- or lead-lined drums. A total of 20 radioisotopes were identified in the RSRs reviewed. Of these, the major radioisotopes in the Class A wastes were Po-210, Cs-137, Sr-90, and H-3. The Class B and C wastes contain mainly Cs-137 and Sr-90.

Each of the waste packages used by 3M was evaluated with respect to the appropriate sections of 10 CFR Part 61 on waste characteristics, as well as the Technical Position on Waste Form. In addition, the components of the 3M waste packages were reviewed to determine if materials were present which were hazardous or which could compromise burial site performance. The results of these evaluations, as well as concerns and needs for additional information, are summarized below.

6.1 Class A Waste Packages

The largest volume of waste shipped by 3M is Class A waste. The radioisotopes contained in this waste generally have half-lives of less than 5 years although isotopes of longer half life are present. These wastes appear to meet the minimum requirements for Class A wastes. Some concerns exist about potential Class A wastes which could be generated by 3M. These are:

- Future disposal of wastes associated with the production of radiopharmaceuticals may necessitate that 3M identify wastes that contain any chelating agents in excess of 0.1% by weight, e.g., DTPA in Yb-169 wastes.

- Kr-85 wastes should be packaged in a manner consistent with 10 CFR Part 61 requirements. Since no Kr-85 waste is currently being shipped by 3M, it could not be determined if these requirements would be met by 3M packages.

6.2 Class B and Class C Waste Packages

3M currently ships its Class B and C wastes in lead- or concrete-lined drums. The waste itself consists of miscellaneous components from hot cell operations. These include plastic containers with waste paper and plastics, microspheres, glass, outsized items such as contaminated furnaces and equipment, and returned or reject sources. These wastes are not monolithic and it appears unlikely that they of themselves could be relied upon to be stable and recognizable for 300 years. Since it is possible that the container used to package these wastes could provide stability, the containers used by 3M for its Class B and C wastes were evaluated for consistency with the guidelines given in the TP for HICs. In addition, the waste packages were evaluated to see if they met the minimum requirements for wastes given in 10 CFR Part 61.

6.2.1 Minimum Requirements

The Class B and C waste packages evaluated appear, in general, to meet the minimum requirements for waste given in 10 CFR Part 61 Section 56.

6.2.2 Stability Requirements

As stated above, the contents of the 3M packages do not meet the stability requirements for Class B and C wastes. They thus require stabilization in the event that a suitable HIC for these wastes is not used. Conclusions regarding the acceptability of the containers currently being used by 3M with respect to the HIC recommendations are summarized below.

6.2.2.1 Lead-Lined Drums

The areas of the TP guidelines that may require more analysis, testing, modification of structure, etc., to be met by the 3M lead-lined drum waste packages follow.

- The lead-lined drum, as presently represented, has not been specifically designed to maintain its structural integrity for 300 years. It should be noted that the soil corrosion data reviewed indicate lead has the potential of meeting this design goal as a material of construction. However, organic acids produced by radiolysis of the drum contents could reduce the container lifetime due to corrosion from within. To meet this guideline, 3M should provide an analysis of container stability based upon the container design and contents as well as anticipated burial site conditions.

- Wooden overpacks used by 3M are subject to biodegradation and are not expected to be stable for the design life. It is expected that there would be a decrease in container volume resulting from degradation of the overpack. Such degradation could lead to the production of natural chelating agents which could affect buried waste. It is recommended that these overpacks be removed prior to burial.

- The container, as presently designed, does not meet the 3-g lift recommendation. Additional handling supports may be necessary to make the container capable of supporting the 3-g lifting load.

- The container design is such that water can accumulate on the top of the container. After corrosion of the outer carbon steel drum, it is possible that, due to the present design of the container, water may accumulate on the top of the inner lead liner. Additionally, the lead lining, in not being sealed, is vulnerable to water influx. A design modification may be required to minimize water contact time with the container.

- The container does not have a seal which is designed to last the lifetime of the container. Such a design would need to include some modifications resulting from analysis of the expected behavior and lifetimes of the container components. As gas generation is expected from the package contents, the effects of radiolytic and biogenic gases on seals should also be considered by 3M in their design analysis.

- Prototype testing has not as yet been performed. Such testing should be conducted on a final package design.

Beyond the areas listed above, the following four concerns exist with regard to the lead-lined drum. Should the earlier deficiencies be remedied by 3M, the following would probably require further effort and information. They are:

- Since the carbon steel lining will probably not last 300 years, the lead lining should be capable of supporting the soil overburden for the design life of the container. The strength of the lead liners may be sufficient. 3M should provide a mechanical strength analysis which includes consideration of bending and/or buckling pressures in conjunction with consideration of effects of corrosion and/or long-term creep on specific portions of the container design.

- The thermal guideline of the TP recommends a temperature range for testing which includes a transition through the recrystallization temperature of lead. It should be determined that temperature cycling through the temperature range of 60°C to -40°C will not affect container stability.

- Insufficient information exists to determine quantitatively the effects of biodegradation on container stability. The effect of biodegradation of the drum contents on container corrosion as well as the effects of self-sterilization should be considered in 3M's package analysis.

- It could not be determined if the quality assurance procedures employed by 3M are adequate to ensure that each Class B or C waste package will meet the requirements of 10 CFR Part 61 for these wastes. This is because current procedures may vary for packages of the same waste class.

The lead-lined drum packages do conform to two of the guidelines given in the TP.

- There appears to be <1% free liquid in the waste.
- Based upon information provided by the manufacturer of the container, the lead-lined drum fulfills DOT Type A package requirements.

6.2.2.2 Concrete-Lined Drums

The areas in which the concrete-lined container may require modifications in order to conform to the TP guidelines are as follows:

- The container, as presently represented, has not been designed to maintain its structural integrity for 300 years. To meet this guideline, 3M should provide an analysis of container stability based upon the container design and contents as well as anticipated burial site conditions.
- The present container design is such that water may accumulate on the top of the container. After corrosion of the outer carbon steel drum, it is possible that, due to the present design of the container, water may accumulate on the top of the inner concrete liner. Additionally, the concrete lining, in not being sealed, is vulnerable to water influx. A design modification may be required to minimize water contact time with the container.
- The container does not have a seal which is designed to last the lifetime of the container. Such a design would need to include some modifications resulting from analysis of the expected behavior and lifetimes of the container components. It should be noted that this design does allow for inspection of the contents and passive venting.
- Prototype testing has not as yet been performed. Such testing should be conducted on a final package design.
- A quality assurance program is required for container fabrication and waste packaging. A program to ensure that the objectives of the waste classification and stability objectives of 10 CFR 61 are being met for each package should be provided by 3M.

Further information is required in six areas to determine whether the concrete-lined package conforms to TP guidelines. These are:

- Testing of the effects of the waste package contents on the long-term stability of the container materials of construction (steel and concrete) should be performed.
- Data are needed on the effects of thermal cycling between 60°C and -40°C. It should be determined that temperature cycling through this range will not affect stability.
- An assessment of the effects of the radiolytic degradation products of the wastes on this container should be performed. This assessment may require that compatibility testing be performed in order to quantify the effects identified in this report as having the potential to affect container performance. Based on the first order assessment performed here, these effects are not expected to compromise this container integrity.
- An assessment of the effects of biodegradation of the wastes contained in the concrete-lined drums should be performed by 3M.
- The container should be tested in accordance with the DOT Type A package qualification.
- The ability of the container to withstand a vertical 3-g lifting load should be demonstrated.

The concrete-lined drums do conform to two of the guidelines given in the TP.

- There appears to be <1% free liquid in the waste.
- The container materials of construction appear to have sufficient strength to support the soil overburden.

6.3 Evaluation of Additional Hazards in the 3M Wastes

Based upon the information obtained from 3M regarding the contents of their wastes, as well as the evaluations performed by BNL, there do not appear to be any materials present in the Class B and C wastes which pose a significant non-radiological hazard. Further, with the exception of concerns noted for the wooden overpacks discussed in Section 6.2 above, there appear to be no materials present in these wastes in sufficient quantity to compromise long-term performance of the burial site.

7. REFERENCES

1. E. P. Gause et al., "Characterization of the Radioactive Large Quantity Waste Package of the Union Carbide Corporation," NUREG/CR-2870, BNL-NUREG-51576, 1982.

2. E. P. Gause et al., "Characterization of the Class B Stable Radioactive Waste Packages of the New England Nuclear Corporation," NUREG/CR-3018, BNL-NUREG-51607, 1982.

3. Memorandum from E. P. Gause and E. Veakis, Brookhaven National Laboratory, to File, "Survey of Low-Level Waste Generators," July 12, 1982.

4. Study of Non-Fuel Cycle Wastes June 1983 Monthly Letter Report, FIN A-3172, p. 3.

5. D. R. Mackenzie et al., "Evaluation of the Radioactive Inventory in and Estimation of Isotopic Release From, the Waste in Eight Trenches at the Sheffield Low-Level Waste Burial Site," Informal Report, BNL-NUREG-34022, 1984.

6. 3M Radiation Therapy Products Price List, F-DB-950, Effective February 1, 1983, Medical Products Division/3M St. Paul, Minnesota.

7. Memorandum from B. Siskind and C. R. Kempf, Brookhaven National Laboratory, to Files, "Trip Report: Visit to Minnesota Mining and Manufacturing (3M) in New Brighton, Minnesota, October 11, 1983," October 13, 1983.

8. Memorandum from C. R. Kempf, Brookhaven National Laboratory, to File, "Information from Minnesota Mining and Manufacturing Company (3M) on Radioactive Wastes and Containers," December 15, 1983.

9. U. S. Nuclear Regulatory Commission, "Licensing Requirements for Land Disposal of Radioactive Waste," Federal Register, Vol. 47, No. 248, 57446-57476, December 27, 1982.

10. Memorandum from C. R. Kempf, Brookhaven National Laboratory, to File, "Information from Minnesota Mining and Manufacturing (3M) Staff about Radioactive Wastes," January, 25, 1984.

11. Memorandum from C. R. Kempf, Brookhaven National Laboratory, to File, "Design Service Life of Allied Metal Manufactured Lead-Lined Drums," January 24, 1984.

12. Study of Fuel Cycle Wastes September 1982 Monthly Letter Report, FIN A-3159, p. 5.

13. M. Romanoff, United States Department of Commerce, "Underground Corrosion," NBS Circular 579, PB-168350, April 1957. Available for purchase from National Technical Information Service, Springfield, Virginia 22161.

14. P. T. Gilbert and F. C. Porter, "Tests on the Corrosion of Buried Aluminum, Copper, and Lead," British Iron and Steel Research Association-Special Report 45, pp. 55-74 (1952).

15. Nuclear Engineering Company, Inc., "The Hanford Commercial Low-Level Waste Disposal Facility," NECO 79-001, February 1979 (Amended through October 28, 1981).

16. Metals Handbook Ninth Edition, Volume 2, Prepared under the direction of the ASM Handbook Committee, American Society for Metals, Metals Park, Ohio 44073.

17. Steels for Elevated Temperature Service," United States Steel Corporation, A Duss 43-1089-04, USSC, 600 Grant St., Pittsburgh, Pennsylvania 15230, June 1972.

18. D. R. Dougherty and J. W. Adams, Brookhaven National Laboratory, "Evaluation of the Three Mile Island Unit 2 Reactor Building Decontamination Process," NUREG/CR-3381, BNL-NUREG-51689, August 1983.

19. G J. Hine and G. L. Brownell, Radiation Dosimetry, p. 858, Academic Press, Inc., New York, 1956.

20. A. Charlesby, "Breakdown of Organic Materials Under Irradiation," IEEE, Trans. Nucl. Soc., 16, 153-159, (1969).

21. N. E. Bibler, Savannah River Laboratory, "Radiolytic Gas Production During Long-Term Storage of Nuclear Wastes," USDOE Report DP-MS-76-51, (Conf. 761002-3), October 1976.

22. B. Bludovsky and V. Duckacek, "Some Aspects of the Mechanism of Cellulose Radiolysis," Radiochem. Radioanal. Letters 38, 21-30 (1979).

23. P. A. Schweitzer, Corrosion Resistance Tables, pp. 473-475, Marcel Dekker, Inc., New York, 1976.

24. I. Mellan, Corrosion Resistant Materials Handbook, Noyes Data Corp., New Jersey, 1976.

25. R. W. King and others, "Polymers," in Effects of Radiation on Materials and Components, J. F. Kircher, and R. E. Bowman, Eds. (Reinhold Publishing Corp., New York, 1964), Chap. 3, pp. 84-166.

26. International Atomic Energy Agency, "Training Manual on Food Irradiation Technology and Techniques," Technical Report Series No. 114, p. 69, Vienna, Austria (July 1970).

27. Memorandum from C. R. Kempf, Brookhaven National Laboratory, to File, "Weight That can be Supported by Lifting Devices on 30-Gallon Lead-Lined Drums Manufactured by Allied Metal," February 15, 1984.

28. P. L. Piciulo, Brookhaven National Laboratory, "Technical Considerations for High Integrity Containers for the Disposal of Radioactive Ion-Exchange Resin Waste," USNRC Report BNL-NUREG-51649, NUREG/CR-3168, October 1983.

29. T. Baumeister, E. A. Avallone, and T. Baumeister III, Eds., Marks' Standard Handbook for Mechanical Engineers, p. 5-3, p, 6-188, McGraw-Hill, New York, 1978.

30. F. M. Lea, The Chemistry of Cement and Concrete, Chemical Publishing Company, Inc., New York, 1971.

31. J. A. Stone, "Evaluation of Concrete as a Matrix for Solidification of Savannah River Plant Waste," DP-1448, 1977.

32. I. Biczok, Concrete Corrosion-Concrete Protection, Akademiai Kiado, Budapest, 1972.

33. N. Morcos and A. J. Weiss, Brookhaven National Laboratory, "Properties of Radioactive Wastes and Waste Containers," Quarterly Progress Report, April-June 1981, USNRC Report BNL-NUREG-51410, NUREG/CR-2193, Vol. 1, No. 2, November 1981.

34. U. S. Department of the Interior, Concrete Manual - A Water Resources Technical Publication, Eighth Edition, Revised Reprint, U. S. Government Printing Office, 1981.

APPENDIX A

10 CFR PART 61 SECTIONS 55 AND 56

disposal site before they leave the site boundary.

§ 61.54 Alternative requirements for design and operations.

The Commission may, upon request or on its own initiative, authorize provisions other than those set forth in §§ 61.51 through 61.53 for the segregation and disposal of waste and for the design and operation of a land disposal facility on a specific basis, if it finds reasonable assurance of compliance with the performance objectives of Subpart C of this part.

§ 61.55 Waste classification.

(a) Classification of waste for near surface disposal.

(1) *Considerations.* Determination of the classification of radioactive waste involves two considerations. First, consideration must be given to the concentration of long-lived radionuclides (and their shorter-lived precursors) whose potential hazard will persist long after such precautions as institutional controls, improved waste form, and deeper disposal have ceased to be effective. These precautions delay the time when long-lived radionuclides could cause exposures. In addition, the magnitude of the potential dose is limited by the concentration and availability of the radionuclide at the time of exposure. Second, consideration must be given to the concentration of shorter-lived radionuclides for which requirements on institutional controls, waste form, and disposal methods are effective.

(2) *Classes of waste.* (i) Class A waste is waste that is usually segregated from other waste classes at the disposal site. The physical form and characteristics of Class A waste must meet the minimum requirements set forth in § 61.56(a). If Class A waste also meets the stability requirements set forth in § 61.56(b), it is not necessary to segregate the waste for disposal.

(ii) Class B waste is waste that must meet more rigorous requirements on waste form to ensure stability after disposal. The physical form and characteristics of Class B waste must meet both the minimum and stability requirements set forth in § 61.56.

(iii) Class C waste is waste that not only must meet more rigorous requirements on waste form to ensure stability but also requires additional measures at the disposal facility to protect against inadvertent intrusion. The physical form and characteristics of Class C waste must meet both the minimum and stability requirements set forth in § 61.56.

(iv) Waste that is not generally acceptable for near-surface disposal is waste for which waste form and disposal methods must be different, and in general more stringent, than those specified for Class C waste. In the absence of specific requirements in this part, proposals for disposal of this waste may be submitted to the Commission for approval, pursuant to § 61.58 of this part.

(3) Classification determined by long-lived radionuclides. If radioactive waste contains only radionuclides listed in Table 1, classification shall be determined as follows:

(i) If the concentration does not exceed 0.1 times the value in Table 1, the waste is Class A.

(ii) If the concentration exceeds 0.1 times the value in Table 1 but does not exceed the value in Table 1, the waste is Class C.

(iii) If the concentration exceeds the value in Table 1, the waste is not generally acceptable for near-surface disposal.

(iv) For wastes containing mixtures of radionuclides listed in Table 1, the total concentration shall be determined by the sum of fractions rule described in paragraph (a)(7) of this section.

TABLE 1

Radionuclide	Concentration curies per cubic meter
C-14	8
C-14 in activated metal	80
Ni-59 in activated metal	220
Nb-94 in activated metal	0.2
Tc-99	3
I-129	0.08
Alpha emitting transuranic nuclides with half-life greater than five years	[1] 100
Pu-241	[1] 3,500
Cm-242	[1] 20,000

[1] Units are nanocuries per gram.

(4) Classification determined by short-lived radionuclides. If radioactive waste does not contain any of the radionuclides listed in Table 1, classification shall be determined based on the concentrations shown in Table 2. However, as specified in paragraph (a)(6) of this section, if radioactive waste does not contain any nuclides listed in either Table 1 or 2, it is Class A.

(i) If the concentration does not exceed the value in Column 1, the waste is Class A.

(ii) If the concentration exceeds the value in Column 1, but does not exceed the value in Column 2, the waste is Class B.

(iii) If the concentration exceeds the value in Column 2, but does not exceed the value in Column 3, the waste is Class C.

(iv) If the concentration exceeds the value in Column 3, the waste is not generally acceptable for near-surface disposal.

(v) For wastes containing mixtures of the nuclides listed in Table 2, the total concentration shall be determined by the sum of fractions rule described in paragraph (a)(7) of this section.

TABLE 2

Radionuclide	Concentration, curies per cubic meter		
	Col. 1	Col. 2	Col. 3
Total of all nuclides with less than 5 year half life	700	(1)	(1)
H-3	40	(1)	(1)
Co-60	700	(1)	(1)
Ni-63	3.5	70	700
Ni-63 in activated metal	35	700	7000
Sr-90	0.04	150	7000
Cs-137	1	44	4600

[1] There are no limits established for these radionuclides in Class B or C wastes. Practical considerations such as the effects of external radiation and internal heat generation on transportation, handling, and disposal will limit the concentrations for these wastes. These wastes shall be Class B unless the concentrations of other nuclides in Table 2 determine the waste to the Class C independent of these nuclides.

(5) Classification determined by both long- and short-lived radionuclides. If radioactive waste contains a mixture of radionuclides, some of which are listed in Table 1, and some of which are listed in Table 2, classification shall be determined as follows:

(i) If the concentration of a nuclide listed in Table 1 does not exceed 0.1 times the value listed in Table 1, the class shall be that determined by the concentration of nuclides listed in Table 2.

(ii) If the concentration of a nuclide listed in Table 1 exceeds 0.1 times the value listed in Table 1 but does not exceed the value listed in Table 1, the waste shall be Class C, provided the concentration of nuclides listed in Table 2 does not exceed the value shown in Column 3 of Table 2.

(6) Classification of wastes with radionuclides other than those listed in Tables 1 and 2. If radioactive waste does not contain any nuclides listed in either Table 1 or 2, it is Class A.

(7) The sum of the fractions rule for mixtures of radionuclides. For determining classification for waste that contains a mixture of radionuclides, it is necessary to determine the sum of fractions by dividing each nuclide's concentration by the appropriate limit and adding the resulting values. The appropriate limits must all be taken from the same column of the same table. The sum of the fractions for the column must be less than 1.0 if the waste class is to be determined by that column. Example: A waste contains Sr-90 in a

concentration of 50 Ci/m^3 and Cs-137 in a concentration of 22 Ci/m^3. Since the concentrations both exceed the values in Column 1, Table 2, they must be compared to Column 2 values. For Sr-90 fraction 50/150=0.33; for Cs-137 fraction, 22/44=0.5; the sum of the fractions=0.83. Since the sum is less than 1.0, the waste is Class B.

(8) *Determination of concentrations in wastes.* The concentration of a radionuclide may be determined by indirect methods such as use of scaling factors which relate the inferred concentration of one radionuclide to another that is measured, or radionuclide material accountability, if there is reasonable assurance that the indirect methods can be correlated with actual measurements. The concentration of a radionuclide may be averaged over the volume of the waste, or weight of the waste if the units are expressed as nanocuries per gram.

§ 61.56 Waste characteristics.

(a) The following requirements are minimum requirements for all classes of waste and are intended to facilitate handling at the disposal site and provide protection of health and safety of personnel at the disposal site.

(1) Waste must not be packaged for disposal in cardboard or fiberboard boxes.

(2) Liquid waste must be solidified or packaged in sufficient absorbent material to absorb twice the volume of the liquid.

(3) Solid waste containing liquid shall contain as little free standing and noncorrosive liquid as is reasonably achievable, but in no case shall the liquid exceed 1% of the volume.

(4) Waste must not be readily capable of detonation or of explosive decomposition or reaction at normal pressures and temperatures, or of explosive reaction with water.

(5) Waste must not contain, or be capable of generating, quantities of toxic gases, vapors, or fumes harmful to persons transporting, handling, or disposing of the waste. This does not apply to radioactive gaseous waste packaged in accordance with paragraph (a)(7) of this section.

(6) Waste must not be pyrophoric. Pyrophoric materials contained in waste shall be treated, prepared, and packaged to be nonflammable.

(7) Waste in a gaseous form must be packaged at a pressure that does not exceed 1.5 atmospheres at 20°C. Total activity must not exceed 100 curies per container.

(8) Waste containing hazardous, biological, pathogenic, or infectious material must be treated to reduce to the maximum extent practicable the potential hazard from the non-radiological materials.

(b) The requirements in this section are intended to provide stability of the waste. Stability is intended to ensure that the waste does not structurally degrade and affect overall stability of the site through slumping, collapse, or other failure of the disposal unit and thereby lead to water infiltration. Stability is also a factor in limiting exposure to an inadvertent intruder, since it provides a recognizable and nondispersible waste.

(1) Waste must have structural stability. A structurally stable waste form will generally maintain its physical dimensions and its form, under the expected disposal conditions such as weight of overburden and compaction equipment, the presence of moisture, and microbial activity, and internal factors such as radiation effects and chemical changes. Structural stability can be provided by the waste form itself, processing the waste to a stable form, or placing the waste in a disposal container or structure that provides stability after disposal.

(2) Notwithstanding the provisions in §§ 61.56(a) (2) and (3), liquid wastes, or wastes containing liquid, must be converted into a form that contains as little free standing and noncorrosive liquid as is reasonably achievable, but in no case shall the liquid exceed 1% of the volume of the waste when the waste is in a disposal container designed to ensure stability, or 0.5% of the volume of the waste for waste processed to a stable form.

(3) Void spaces within the waste and between the waste and its package must be reduced to the extent practicable.

§ 61.57 Labeling.

Each package of waste must be clearly labeled to identify whether it is Class A waste, Class B waste, or class C waste in accordance with § 61.55.

§ 61.58 Alternative requirements for waste classification and characteristics.

The Commission may, upon request or on its own initiative, authorize other provisions for the classification and characteristics of waste on a specific basis, if, after evaluation, of the specific characteristics of the waste, disposal site, and method of disposal, it finds reasonable assurance of compliance with the performance objectives in Subpart C of this part.

§ 61.59 Institutional requirements.

(a) *Land ownership.* Disposal of radioactive waste received from other persons may be permitted only on land owned in fee by the Federal or a State government.

(b) *Institutional control.* The land owner or custodial agency shall carry out an institutional control program to physically control access to the disposal site following transfer of control of the disposal site from the disposal site operator. The institutional control program must also include, but not be limited to, carrying out an environmental monitoring program at the disposal site, periodic surveillance, minor custodial care, and other requirements as determined by the Commission; and administration of funds to cover the costs for these activities. The period of institutional controls will be determined by the Commission, but institutional controls may not be relied upon for more than 100 years following transfer of control of the disposal site to the owner.

Subpart E—Financial Assurances

§ 61.61 Applicant qualifications and assurances.

Each applicant shall show that it either possesses the necessary funds or has reasonable assurance of obtaining the necessary funds, or by a combination of the two, to cover the estimated costs of conducting all licensed activities over the planned operating life of the project, including costs of construction and disposal.

§ 61.62 Funding for disposal site closure and stabilization.

(a) The applicant shall provide assurance that sufficient funds will be available to carry out disposal site closure and stabilization, including: (1) Decontamination or dismantlement of land disposal facility structures; and (2) closure and stabilization of the disposal site so that following transfer of the disposal site to the site owner, the need for ongoing active maintenance is eliminated to the extent practicable and only minor custodial care, surveillance, and monitoring are required. These assurances shall be based on Commission-approved cost estimates reflecting the Commission-approved plan for disposal site closure and stabilization. The applicant's cost estimates must take into account total capital costs that would be incurred if an independent contractor were hired to perform the closure and stabilization work.

(b) In order to avoid unnecessary duplication and expense, the Commission will accept financial sureties that have been consolidated with earmarked financial or surety arrangements established to meet

APPENDIX B

TECHNICAL POSITION ON WASTE FORM

4. High Integrity Containers

   a. The maximum allowable free liquid in a high integrity container should be less than one percent of the waste volume as measured using the method described in ANS 55.1. A process control program should be developed and qualified to ensure that the free liquid requirements in 10 CFR Part 61 will be met upon delivery of the wet solid material to the disposal facility. This process control program qualification should consider the effects of transportation on the amount of drainable liquid which might be present.

   b. High integrity containers should have as a design goal a minimum lifetime of 300 years. The high integrity container should be designed to maintain its structural integrity over this period.

   c. The high integrity container design should consider the corrosive and chemical effects of both the waste contents and the disposal trench environment. Corrosion and chemical tests should be performed to confirm the suitability of the proposed container materials to meet the design lifetime goal.

   d. The high integrity container should be designed to have sufficient mechanical strength to withstand horizontal and vertical loads on the container equivalent to the depth of proposed burial assuming a cover material density of 120 lbs/ft^3. The high integrity container should also be designed to withstand the routine loads and effects from the waste contents, waste preparation, transportation, handling and disposal site operations, such as trench compaction procedures. This mechanical design strength should be justified by conservative design analyses.

   e. For polymeric material, design mechanical strengths should be conservatively extrapolated from creep test data.

f. The design should consider the thermal loads from processing, storage, transportation and burial. Proposed container materials should be tested in accordance with ASTM B553 in the manner described in Section C2(g) of this technical position. No significant changes in material design properties should result from this thermal cycling.

g. The high integrity container design should consider the radiation stability of the proposed container materials as well as the radiation degradation effects of the wastes.

Radiation degradation testing should be performed on proposed container materials using a gamma irradiator or equivalent. No significant changes in material design properties should result following exposure to a total accumulated dose of 10^8 Rads. If it is proposed to design the high integrity container to greater accumulated doses, testing should be performed to confirm the adequacy of the proposed materials. Test specimens should be prepared using the proposed fabrication techniques.

Polymeric high integrity container designs should also consider the effects of ultra-violet radiation. Testing should be performed on proposed materials to show that no significant changes in material design properties occur following expected ultra-violet radiation exposure.

h. The high integrity container design should consider the biodegradation properties of the proposed materials and any biodegradation of wastes and disposal media. Biodegradation testing should be performed on proposed container materials in accordance with ASTM G21 and ASTM G22. No indication of culture growth should be visible. The extraction procedure described in Section C2(d) of this technical position may be performed where indications of visible culture growth can be attributable to contamination, additives, or biodegradable components on the specimen surface that do not affect the overall integrity of the substrate. It is also acceptable to determine biodegradation rates using the Bathta-Pramer Method described in Section C2 (d). The rate of biodegradation should produce less than a 10 percent loss of the total carbon in the container material after 300 years. Test specimens should be prepared using the proposed material fabrication techniques.

i. The high integrity container should be capable of meeting the requirements for a Type A package as specified in 49 CFR 173.398(b). The free drop test may be performed in accordance with 10 CFR 71, Appendix A, Section 6.

j. The high integrity container and the associated lifting devices should be designed to withstand the forces applied during lifting operations. As a minimum the container should be designed to withstand a 3g vertical lifting load.

k. The high integrity container should be designed to avoid the collection or retention of water on its top surfaces in order to minimize accumulation of trench liquids which could result in corrosive or degrading chemical effects.

l. High integrity container closures should be designed to provide a positive seal for the design lifetime of the container. The closure should also be designed to allow inspections of the contents to be conducted without damaging the integrity of the container. Passive vent designs may be utilized if needed to relieve internal pressure. Passive vent systems should be designed to minimize the entry of moisture and the passage of waste materials from the container.

m. Prototype testing should be performed on high integrity container designs to demonstrate the container's ability to withstand the proposed conditions of waste preparation, handling, transportation and disposal.

n. High integrity containers should be fabricated, tested, inspected, prepared for use, filled, stored, handled, transported and disposed of in accordance with a quality assurance program. The quality assurance program should also address how wastes which are detrimental to high integrity container materials will be precluded from being placed into the container. Special emphasis should be placed on fabrication process control for those high integrity containers which utilize fabrication techniques such as polymer molding processes.

APPENDIX C

DESCRIPTION OF THE DATA BASE USED FOR THE 3M RSRs AND SOME EXAMPLES OF ITS USE

As part of a study of the low level radioactive waste generated by 3M, the quantities of such waste shipped for dipsosal during a recent 19-month period (2/05/82 to 8/22/83) were surveyed in terms of volumes, activities, and class breakdown. The six radioactive shipment records (RSRs) contained information about the containers and contents of a total of 620 packages. Because of the need to retrieve subsets of these data defined by parameters such as container type, package weight, radionuclide species, and activity, it was decided to enter and store the data from the RSRs in a computerized data base. As in the case of the data base established for the BNL study of the inventory at the Sheffield disposal site(1), such a data base may be used to generate lists, counts and sums of specified subsets of the data.

The data base was defined using Intel Corporation's System 2000 data base management system(2) on BNL's CDC 6600 computers. A diagram of the hierarchical data base structure is given in Figure 1. It will be noted that the data sets in this data base are arranged into four levels. The first level contains information about the generator, the second about the shipments, the third about the waste packages in these shipments, and the fourth about the radiounuclides in these packages. The data base definition, which consists of component labels, is presented in Figure 2. These labels are essentially identification tags which are used to retrieve the data. The components numbered from 10 to 53, termed data base elements, correspond to the data sets depicted schematically in Figure 1; the hierarchical levels of the data sets are indicated by the degree of indentation of the elements in Figure 2. The components 101 to 104 are user-defined functions, which may be invoked to perform calculations on selected data, e.g., conversion of English to metric units of volume and calculation of specific activity from stored data. Components 201 and 202 are commands invoked during input of data. It will be noted that the data base elements correspond to entries and column headings on the 3M RSRs. (See example in Figure 3.) Not all of the data in the RSRs were loaded into the data base, but for each package the package number, container volume, container weight, radionuclides, and radionuclide activities were entered. The empty data base elements proved to be useful as buffer storage during operations requiring manipulation of the data, such as the determination of waste classification by the sum-of-fractions rule.

After completion of data input it was possible to obtain information useful for the charaterization of 3M wastes. As an example of a fairly simple data base operation, a tally of the number of occurrences of each radionuclide was obtained. (This was reported to the NRC in the January 1984 letter report for FIN A-3172.) As a result of a similar tally, at least three cases of duplicate package numbers were discovered, each of which occurs in different RSRs with different package contents and description; two other such cases may have resulted from poor copies of the RSRs with difficult-to-read entries.

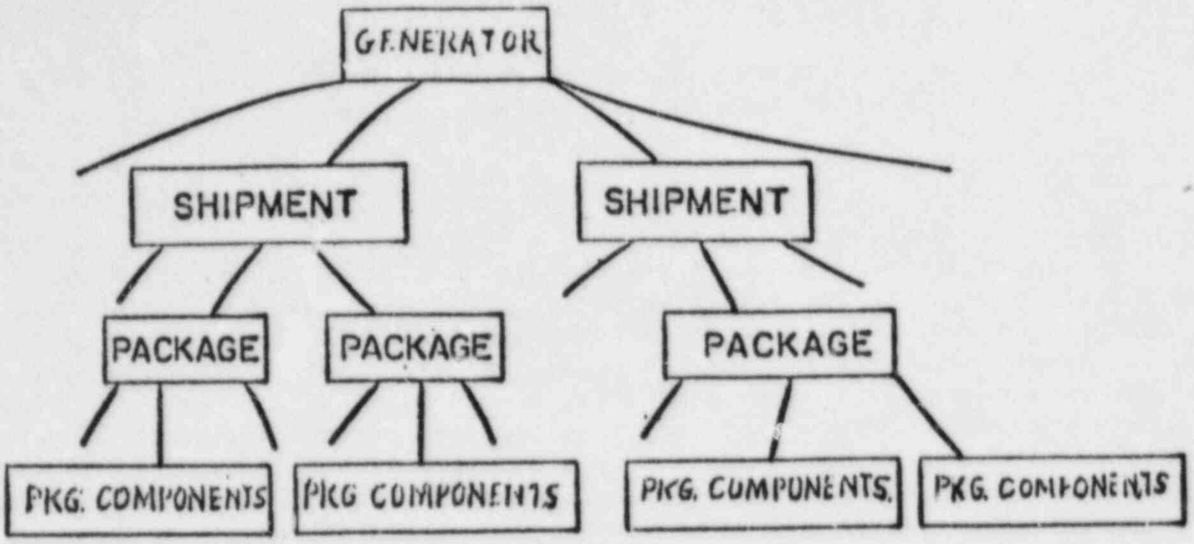
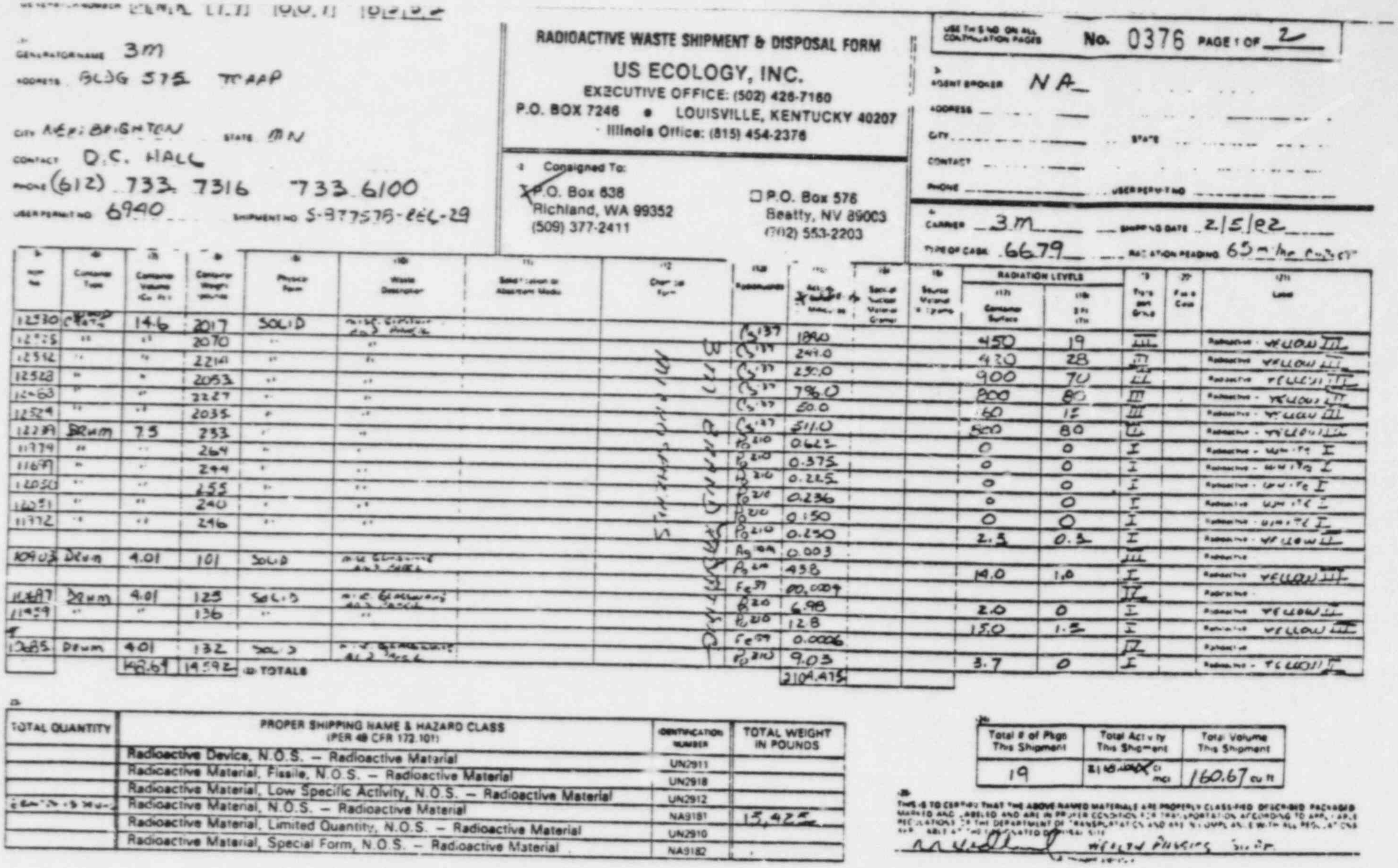


Figure 1 Structure of the data base.

```
SYSTEM RELEASE NUMBER        M2.00D
DATA BASE NAME IS NFCGEN1
DEFINITION NUMBER         4
DATA BASE CYCLE       144
   10*  GENERATOR (CHAR X(15))%
   15* . DESCRIPTION (TEXT X(240))%
   19*  SHIPMENT (RECORD)%
     20*  RSR NO (CHAR X(8) IN 19)%
     21*  INFO (CHAR X(11) IN 19)%
     22*  TOTAL PACKAGES (INTEGER NUMBER 9(5) IN 19)%
     23*  TOTAL CURIES (DECIMAL NUMBER 9(5).999 IN 19)%
     24*  TOTAL VOLUME (DECIMAL NUMBER 9(5).9 IN 19)%
     28*  PACKAGE (RECORD IN 19)%
       30*  PACKAGE NO (CHAR X(8) IN 28)%
       31*  CONTAINER TYPE (CHAR X(8) IN 28)%
       32*  CONTAINER VOLUME (DECIMAL NUMBER 9(5).9 IN 28)%
       33*  CONTAINER WEIGHT (INTEGER NUMBER 9(5) IN 28)%
       34* .PHYSICAL FORM (CHAR X(15) IN 28)%
       35*  WASTE DESCRIPTION (CHAR X(60) IN 28)%
       36*  CHEMICAL FORM (CHAR X(60) IN 28)%
       38*  RADIATION LEVEL SURFACE (DECIMAL NUMBER 9(5).9 IN 28)%
       39*  RADIATION LEVEL 3FT (DECIMAL NUMBER 9(5).9 IN 28)%
       48*  PKG COMPONENTS (RECORD IN 28)%
         50*  RADIONUCLIDE (CHAR X(5) IN 48)%
         51*  CURIES (DECIMAL NUMBER 9(5).9(5) IN 48)%
         52*  TRANSPORT GROUP (CHAR X(5) IN 48)%
         53*  FRACTION (DECIMAL NUMBER 999.999 IN 48)%
  101*  VOLUME CUBIC METERS (DECIMAL FUNCTION '(C32*283.1/10000.0)')%
  102*  SPECIFIC ACTIVITY (DECIMAL FUNCTION '(C51/*C101*)')%
  103*  CAPACITY CU M (DECIMAL FUNCTION '(*1*/264.17)')%
  104*  SPEC ACTIV DRUM (DECIMAL FUNCTION '(C51/*C103(*1*))')%
  201*  ADD RSRS (STRING 'REPEAT/APPEND TREE C19 EQ*DATA*WHERE C10 EQ 3
M*X/%')%
  202*  ADD PACKAGES (STRING 'REPEAT/APPEND TREE C28 EQ*DATA*WHERE C20
EQ*1*%/
%')%
---
```

Figure 2 Computer printout of data base definition.



GENERATOR NUMBER [illegible]

GENERATOR NAME 3M
ADDRESS BLDG 575 TCAAP
CITY NEW BRIGHTON STATE MN
CONTACT D.C. HALL
PHONE (612) 733 7316 733 6100
USER PERMIT NO 6940 SHIPMENT NO S-377575-REG-29

RADIOACTIVE WASTE SHIPMENT & DISPOSAL FORM

US ECOLOGY, INC.
EXECUTIVE OFFICE: (502) 426-7160
P.O. BOX 7246 • LOUISVILLE, KENTUCKY 40207
Illinois Office: (815) 454-2376

Consigned To:
☒ P.O. Box 638
Richland, WA 99352
(509) 377-2411

☐ P.O. Box 578
Beatty, NV 89003
(702) 553-2203

USE THIS NO. ON ALL CONTINUATION PAGES No. 0376 PAGE 1 OF 2

AGENT BROKER NA
ADDRESS
CITY STATE
CONTACT
PHONE USER PERMIT NO

CARRIER 3M SHIPPING DATE 2/5/82
TYPE OF CASK 6679 RADIATION READING 65 mr/hr contact

Item No.	Container Type	Container Volume (Cu. Ft.)	Container Weight (Pounds)	Physical Form	Waste Descriptor	Solidification or Absorbent Media	Chemical Form	Radionuclides	Activity (mCi)	Special Nuclear Material Grams	Source Material Kilograms	Radiation Levels Container Surface	Radiation Levels 3 Ft.	Transport Group	Fissile Class	Label
12530	Crate	14.6	2017	SOLID	misc. glassware and paper			Cs^{137}	1890			450	19	III		Radioactive - Yellow III
12525	"	"	2070	"	"			Cs^{137}	249.0			430	28	III		Radioactive Yellow III
12532	"	"	2214	"	"			Cs^{137}	250.0			900	70	III		Radioactive Yellow III
12528	"	"	2053	"	"			Cs^{137}	796.0			800	80	III		Radioactive - Yellow III
12463	"	"	2227	"	"			Cs^{137}	50.0			60	15	III		Radioactive - Yellow III
12529	"	"	2035	"	"			Cs^{137}	511.0			500	80	III		Radioactive - Yellow III
12239	Drum	7.5	233	"	"			Po^{210}	0.622			0	0	I		Radioactive - White I
11774	"	"	264	"	"			Po^{210}	0.375			0	0	I		Radioactive - White I
11699	"	"	244	"	"			Po^{210}	0.225			0	0	I		Radioactive - White I
12050	"	"	255	"	"			Po^{210}	0.236			0	0	I		Radioactive White I
12051	"	"	240	"	"			Po^{210}	0.150			0	0	I		Radioactive - White I
11772	"	"	246	"	"			Po^{210}	0.250			2.5	0.3	I		Radioactive - Yellow II
								Ag^{110m}	0.003					III		Radioactive
10903	Drum	4.01	101	SOLID	misc. glassware and paper			Ag^{110m}	438			14.0	1.0	I		Radioactive Yellow III
								Fe^{59}	0.0009					II		Radioactive
11897	Drum	4.01	125	SOLID	misc. glassware and paper			Po^{210}	6.98			2.0	0	I		Radioactive Yellow II
11959	"	"	136	"	"			Po^{210}	12.8			15.0	1.5	I		Radioactive Yellow III
								Fe^{59}	0.0006					II		Radioactive
12685	Drum	4.01	132	SOLID	misc. glassware and paper			Po^{210}	9.03			3.7	0	I		Radioactive - Yellow II
	TOTALS	48.64	14592						2104.415							

TOTAL QUANTITY	PROPER SHIPPING NAME & HAZARD CLASS (PER 49 CFR 172.101)	IDENTIFICATION NUMBER	TOTAL WEIGHT IN POUNDS
	Radioactive Device, N.O.S. — Radioactive Material	UN2911	
	Radioactive Material, Fissile, N.O.S. — Radioactive Material	UN2918	
	Radioactive Material, Low Specific Activity, N.O.S. — Radioactive Material	UN2912	
[illegible]	Radioactive Material, N.O.S. — Radioactive Material	NA9181	15,425
	Radioactive Material, Limited Quantity, N.O.S. — Radioactive Material	UN2910	
	Radioactive Material, Special Form, N.O.S. — Radioactive Material	NA9182	

Total # of Pkgs This Shipment	Total Activity This Shipment	Total Volume This Shipment
19	2104.415 Ci mCi	160.67 cu ft

THIS IS TO CERTIFY THAT THE ABOVE NAMED MATERIALS ARE PROPERLY CLASSIFIED, DESCRIBED, PACKAGED, MARKED AND LABELED AND ARE IN PROPER CONDITION FOR TRANSPORTATION ACCORDING TO APPLICABLE REGULATIONS OF THE DEPARTMENT OF TRANSPORTATION AND ARE IN COMPLIANCE WITH ALL REGULATIONS APPLICABLE AT THE DESIGNATED DISPOSAL SITE

Health Physics Supv.

Figure 3 Example of 3M RSR.

An example of a more sophisticated use of the data base is the determination of the class of Cs-137 waste in concrete-lined as opposed to unlined 30-gallon drums. Based on information from 3M, the weight of an empty concrete-lined drum is 425 lb. A listing of all 30-gallon drums containing Cs-137 ordered by container weight was requested. (The container volume used to define the desired data subset was that given for 30-gallon drums in the RSRs, 4.0 cubic feet. Lead-lined 30-gallon drums containing Cs-137 are not listed because their overpack volume, 14.6 cubic feet, is given in the RSR.) The resulting computer printout is presented in Figure 4. A bimodal distribution of container weights is evident: 63 to 292 lb and 502 to 907 lb. It may be reasonably assumed that the containers in the heavier of the two weight ranges are concrete-lined drums. A listing of each mode separately was requested, this time ordered by activity (Figures 5 and 6). The upper limit of Class A for Cs-137 in a 30-gallon drum is approximately 0.11 Ci. Thus, one of the 42 unlined 30-gallon drums containing Cs-137 would be Class B under present regulations. Four of the 16 concrete-lined drums are within present Class A limits. From a similar listing of Sr-90 in 30-gallon drums, it was determined that all seven drums were unlined, but that five of these contained Sr-90 in excess of the present Class A limit. (See Figure 7.)

```
---
LIST BY C20,C33,C50,C51,DB C33 WH C50 EQ CS137 AND C32 EQ 4.0%

  CONTAINER WEIGHT    RADIONUCLIDE           CURIES
***
*                 63   CS137                  0.02400
*                 64   CS137                  0.01200
*                 65   C14                    0.00022
*                      TH232                  0.00000
*                      H3                     0.00000
*                      SR90                   0.00002
*                      TC99                   0.00001
*                      CS137                  0.00005
*                 69   CS137                  0.00300
*                 73   CS137                  0.06000
*                 74   CS137                  0.00800
*                 77   CS137                  0.00500
*                 78   CS137                  0.02700
*                 80   CS137                  0.01000
*                 81   CS137                  0.01000
*                 84   CS137                  0.00200
*                 86   CS137                  0.00500
*                 86   CS137                  0.05000
*                 89   CS137                  0.00300
*                 89   CS137                  0.01000
*                 92   CS137                  0.00500
*                 94   CS137                  0.04500
*                 96   CS137                  0.00010
*                 96   CS137                  0.00300
*                 98   CS137                  0.01000
*                113   CS137                  0.01000
*                124   CS137                  0.00800
*                131   CS137                  0.00500
*                134   CS137                  0.03000
*                134   CS137                  0.00500
*                137   CS137                  0.00450
*                143   CS137                  0.01500
*                144   CS137                  0.05300
*                157   CS137                  0.00100
*                160   CS137                  0.00100
*                167   CS137                  0.00100
*                168   PO210                  0.00090
*                      CS137                  0.00090
*                180   CS137                  0.00500
*                192   CS137                  0.00100
*                208   CS137                  0.01000
*                214   CS137                  0.50000
*                218   CS137                  0.00500
*                230   CS137                  0.00100
*                243   CS137                  0.00100
*                280   CS137                  0.00100
*                284   CS137                  0.00200
*                292   CS137                  0.00100
*                502   CS137                  0.03000
*                530   CS137                  0.10000
*                575   CS137                  0.60000
*                591   CS137                  0.50000
*                627   CS137                  2.00000
*                657   CS137                  0.91000
*                693   CS137                  1.50000
*                704   CS137                  0.60000
*                721   CS137                  0.15000
*                747   CS137                  1.50000
*                760   CS137                  0.42400
*                764   CS137                  2.80000
*                860   CS137                  0.03000
*                882   CS137                  0.00900
*                894   CS137                  2.00000
*                907   CS137                  1.50000
```

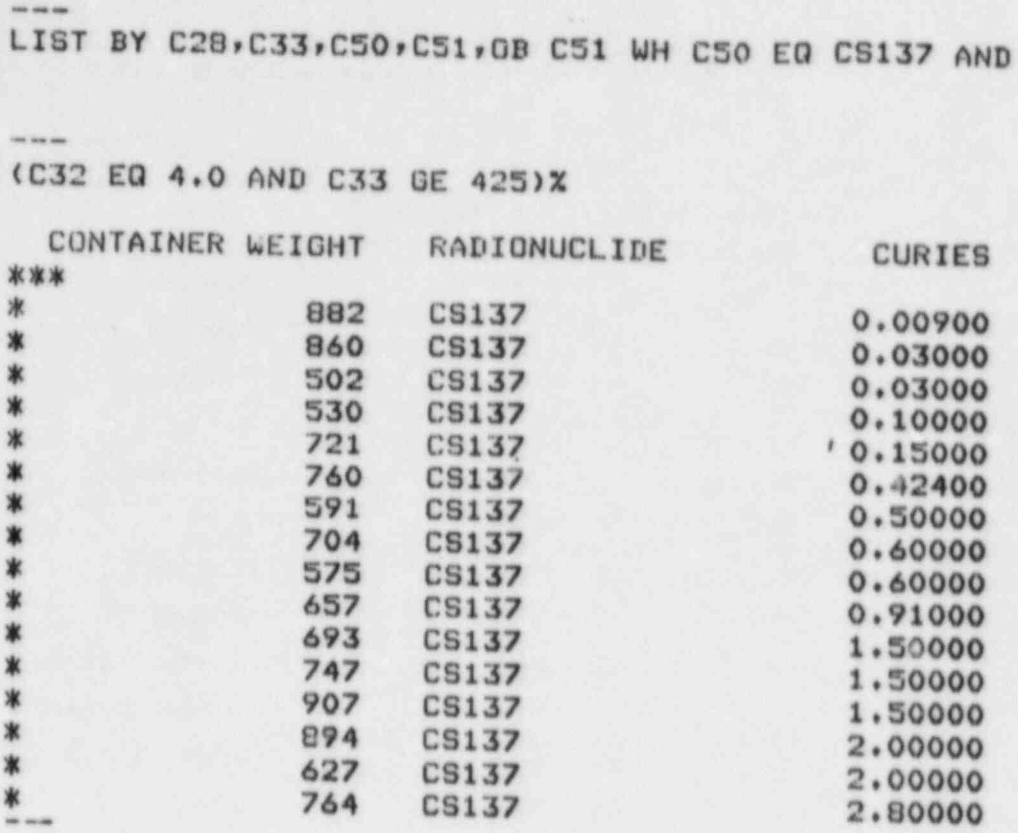
unlined ↓

↑ concrete-lined

Figure 4 Computer printout of 30-gallon drums containing Cs-137 ordered by container weight.

```
   CONTAINER WEIGHT    RADIONUCLIDE           CURIES
***
*                 65   C14                   0.00022
*                      TH232                 0.00000
*                      H3                    0.00000
*                      SR90                  0.00002
*                      TC99                  0.00001
*                      CS137                 0.00005
*                 96   CS137                 0.00010
*                168   PO210                 0.00090
*                      CS137                 0.00090
*                157   CS137                 0.00100
*                230   CS137                 0.00100
*                160   CS137                 0.00100
*                192   CS137                 0.00100
*                292   CS137                 0.00100
*                167   CS137                 0.00100
*                280   CS137                 0.00100
*                243   CS137                 0.00100
*                 84   CS137                 0.00200
*                284   CS137                 0.00200
*                 69   CS137                 0.00300
*                 96   CS137                 0.00300
*                 89   CS137                 0.00300
*                137   CS137                 0.00450
*                131   CS137                 0.00500
*                180   CS137                 0.00500
*                 92   CS137                 0.00500
*                 77   CS137                 0.00500
*                 86   CS137                 0.00500
*                218   CS137                 0.00500
*                134   CS137                 0.00500
*                 74   CS137                 0.00800
*                124   CS137                 0.00800
*                 81   CS137                 0.01000
*                208   CS137                 0.01000
*                 89   CS137                 0.01000
*                 98   CS137                 0.01000
*                113   CS137                 0.01000
*                 80   CS137                 0.01000
*                 64   CS137                 0.01200
*                143   CS137                 0.01500
*                 63   CS137                 0.02400
*                 78   CS137                 0.02700
*                134   CS137                 0.03000
*                 94   CS137                 0.04500
*                 86   CS137                 0.05000
*                144   CS137                 0.05300
*                 73   CS137                 0.06000
*                214   CS137                 0.50000
---
```

Figure 5 Listing of unlined 30-gallon drums containing Cs-137 ordered by Cs-137 activity. Last drum listed is Class B under current regulations. (Diagnostic message blocked out).



```
---
LIST BY C28,C33,C50,C51,OB C51 WH C50 EQ CS137 AND

---
(C32 EQ 4.0 AND C33 GE 425)%

  CONTAINER WEIGHT    RADIONUCLIDE            CURIES
***
*               882   CS137                  0.00900
*               860   CS137                  0.03000
*               502   CS137                  0.03000
*               530   CS137                  0.10000
*               721   CS137                  0.15000
*               760   CS137                  0.42400
*               591   CS137                  0.50000
*               704   CS137                  0.60000
*               575   CS137                  0.60000
*               657   CS137                  0.91000
*               693   CS137                  1.50000
*               747   CS137                  1.50000
*               907   CS137                  1.50000
*               894   CS137                  2.00000
*               627   CS137                  2.00000
*               764   CS137                  2.80000
---
```

Figure 6 Listing of probable concrete-lined 30-gallon drums, containing Cs-137, ordered by Cs-137 activity. First four drums are Class A, the remainder Class B under current regulations. (Diagnostic message blocked out).

```
---
LIST BY C28,C33,C50,C51,C35,OD C51 WH C50 EQ SR90 AND

---
(C32 EQ 4.0 AND C33 LE 425):
 CONTAINER WEIGHT   RADIONUCLIDE          CURIES

***
*               65  C14                   0.00022

*                   TH232                 0.00000

*                   H3                    0.00000

*                   SR90                  0.00002

*                   TC99                  0.00001

*                   CS137                 0.00005

*               70  SC46                  0.00300

*                   SR90                  0.00300

*               87  SR90                  0.00500   CLASS B

*               91  SR90                  0.00500   CLASS B

*               66  SR90                  0.00500   CLASS B

*              109  SR90                  0.00500   CLASS B

*               65  SR90                  0.01000   CLASS B

---
```

Figure 7 Listing of 30-gallon drums containing Sr-90, order by Sr-90 activity. Note, Class B assignment of last five drums. (Diagnostic message blocked out).

References

1. D. R. MacKenzie, C. R. Kempf, and J. F. Smalley, "Evaluation of the Radioactive Inventory in, and Estimation of the Isotopic Releases from, the Waste in Eight Trenches at the Sheffield Low-Level Waste Burial Site," BNL-NUREG-34022, December 1983.

2. Intel Systems Corporation, "System 2000 Reference Manual," UMN-3.

APPENDIX D

AMERICAN NATIONAL STANDARD 55.1

Appendix 2

(This Appendix is not a part of American National Standard Solid Radioactive Waste Processing Systems for Light Water Cooled Reactor Plants ANSI/ANS-55.1-1979) but is included for information only)

The purpose of the free liquid tests is to demonstrate that processed solid waste will not contain free liquid over the expected chemical and physical range of waste processed.

1. These tests shall be performed with non-radioactive solid wastes. Tests shall also include chemical contaminants likely to be encountered during system operation, such as oils, decontamination chemicals, detergents, and solvents.

2. Solidification agents and potential waste constituents should be tested and a set of process parameters established which provide boundary conditions within which reasonable assurance can be given that solidification will be complete.

3. Tests shall use containers identical to those used during normal system operation. Preliminary tests used to establish operating parameters may be performed using smaller containers (but not smaller than 55-gallon drums).

4. After mixing and packaging of each test container, the following procedure should be used to check for free liquid.

4.1 After container filling and closure, the container is stored for a time sufficient to allow for complete solidification.

4.2 After storage, the container is opened and the test material visually examined. There shall be no free liquid within the container as determined from visual inspection after opening.

4.3 After visual inspection, with the container still in the upright orientation, the bottom or low point of the container is breached by drilling or other suitable means to simulate a dropped or punctured container. The minimum area of the opening shall be one square inch. There shall be no free liquid visible flowing or dripping from the breach.

4.4 After the breach tests, the contents of the container are examined by sectioning, axial core sampling, or other suitable means necessary to ensure that no free liquid is within the solidified wastes.

NRC FORM 335
(11 81)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER *(Assigned by DDC)*
NUREG/CR-3844
BNL-NUREG-51787

4. TITLE AND SUBTITLE *(Add Volume No., if appropriate)*
Characterization of the Radioactive Waste Packages of the Minnesota Mining and Manufacturing Company

2. *(Leave blank)*

3. RECIPIENT'S ACCESSION NO.

7. AUTHOR(S)
C. R. Kempf, B. Siskind, R. E. Barletta, and D. Dougherty

5. DATE REPORT COMPLETED

MONTH	YEAR
May	1984

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*

Brookhaven National Laboratory
Department of Nuclear Energy
Upton, New York 11973

DATE REPORT ISSUED

MONTH	YEAR
July	1984

6. *(Leave blank)*

8. *(Leave blank)*

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*

Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

10. PROJECT/TASK/WORK UNIT NO.

11. FIN NO.
A3172

13. TYPE OF REPORT
Technical

PERIOD COVERED *(Inclusive dates)*

15. SUPPLEMENTARY NOTES

14. *(Leave blank)*

16. ABSTRACT *(200 words or less)*

An evaluation of the low-level waste packages generated by Minnesota Mining and Manufacturing Co. (3M) was made on the basis of 10 CFR Part 61 criteria and on the Technical Position on Waste Form and Waste Classification (TP). This evaluation was the result of a study initiated by the U.S. Nuclear Regulatory Commission (NRC), in which 3M participated.

3M produces a variety of radioactive products and wastes. The dominant radioisotopes are Po-210 and Cs-137. The Po-210 packages are generally Class A and meet the requirements in 10 CFR Part 61. The Cs-137 and Sr-90 packages fall into all three waste classifications (A, B, and C). These wastes are packaged by 3M in 30-gallon or 55-gallon carbon steel drums (Class A) or 30-gallon lined drums (Class B and C). The Class B and greater lead- and concrete-lined packages have been evaluated with respect to meeting the stability requirements for waste disposed of in a high integrity container. When so evaluated, eleven areas of concern were identified with respect to the regulations and recommendations in the TP.

17. KEY WORDS AND DOCUMENT ANALYSIS

Low-Level Waste, Cs-137 > Class B,
Lead-Lined/Concrete-Lined Drum,
HIC Evaluation with Respect to Guidance in
Technical Position on Waste Form

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS *(This report)*
Unclassified

21. NO OF PAGES

20. SECURITY CLASS *(This page)*

22. PRICE
$

NRC FORM 335 (11 81)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

120555078877 1 IAN
US NRC
ADM-DIV OF TIDC
POLICY & PUB MGT BR-PDR NUREG
W-501
WASHINGTON DC 20555