TESTING WASTE FORMS CONTAINING HIGH RADIONUCLIDE LOADINGS[a]

J. W. McConnell, Jr., R. M. Neilson, Jr., R. D. Rogers
Idaho National Engineering Laboratory
EG&G Idaho, Inc.
Idaho Falls, ID 83415

ABSTRACT

The Low-Level Waste Data Base Development--EPICOR-II Resin/Liner Investigation Program funded by the U.S. Nuclear Regulatory Commission (NRC) is obtaining information on radioactive waste during NRC-prescribed tests and in a disposal environment. This paper describes the resin solidification task of that program, including the present status and results to date. An unusual aspect of this investigation is the use of commercial grade, ion exchange resins that have been loaded with over five times the radioactivity normally seen in a commercial application. That dramatically increases the total radiation dose to the resins. The objective of the resin solidification task is to determine the adequacy of test procedures specified by NRC for ion exchange resins having high radionuclide loadings.

INTRODUCTION

The 28 March 1979 accident at Unit 2 of the Three Mile Island Nuclear Power Station (TMI-2) released approximately 2,120,000 L (560,000 gal.) of contaminated water to the Auxiliary and Fuel Handling Buildings. The water was decontaminated using a three-stage demineralization system called EPICOR-II, containing organic and inorganic ion exchange media. The first stage of the system was designated the prefilter. Fifty EPICOR-II prefilters with high concentrations of radionuclides were transported from TMI-2 to the Idaho National Engineering Laboratory (INEL) for interim storage before final disposal at the commercial disposal facility in the State of Washington. EG&G Idaho, Inc. is examining materials from several of those prefilters, under the Low-Level Waste Data Base Development--EPICOR-II Resin/Liner Investigation Program funded by the U.S. Nuclear Regulatory Commission (NRC).

The investigation is divided into four tasks which address different aspects of waste disposal, as discussed in the program plan[1] and a companion paper at Waste Management '86.[2] Those tasks are resin degradation, resin solidification, field testing, and liner integrity. Resin solidification studies are being conducted at INEL using resins removed from EPICOR-II prefilters PF-7 and -24, with several interim and annual reports available.[3-8] Emphasis is placed on investigating the requirements of 10 CFR 61 "Licensing Requirements for Land Disposal of Radioactive Waste,"[9] using the methods specified in the "Branch Technical Position (TP) on Waste Form"[10] of the NRC Office of Nuclear Materials Safety and Safeguards.

Resin materials are being examined to (a) develop a low-level waste data base and (b) obtain information on survivability of waste forms composed of ion exchange media loaded with radionuclides and solidified in matrices of Portland cement and Dow polymer. This paper describes the resin solidification task and gives the status and results of the work to date.

WASTE FORM FABRICATION

EPICOR-II Prefilter Wastes

Highly loaded ion exchange resin wastes were obtained from EPICOR-II prefilters PF-7 and -24. PF-7 contains three types of synthetic organic ion exchange resins: phenolic cation, strong acid cation, and strong base anion. PF-24 contains two types, strong acid cation and strong base anion, as well as inorganic zeolite. The ion exchange media were layered in the prefilters. Resin wastes were obtained from the prefilters in a coring operation, during which a coring tool was inserted vertically through the resin layers, closed, and withdrawn, thereby removing a representative portion of the waste.

Solidification Agents

Two types of solidification agents (binders) were used in preparing waste forms for the resin solidification task: Portland Type I-II cement and vinyl ester-styrene (VES).[b]

Formulation Development Studies

Formulation development studies were conducted based on previous work,[11-13] using unirradiated, simulated EPICOR-II prefilter wastes supplied by Epicor, Inc. The unirradiated resins were representative of the ion exchange media in PF-7 and -24 and were used in the proper ratios to simulate the actual EPICOR-II wastes.[14,15] Those studies were conducted to determine appropriate formulations for solidifying the actual prefilter wastes.

A range of formulations was investigated in which resin water content, resin pretreatment, waste/binder ratio, and addition of supplemental water (cement formulations only) were considered. The simulated EPICOR-II wastes were prepared in decanted form (ion exchange resin beads saturated with water and the interstitial void space between resin beads filled with water). Determining the water content of the resin was important because the cement formulations subsequently required adjusting the amount of

[a] Work supported by the U.S. Nuclear Regulatory Commission, Office of Nuclear Materials Safety and Safeguards, under DOE Contract No. DE-AC07-76ID01570.

[b] A proprietary, thermosetting polymer solidification agent of the Dow Chemical Co., Midland, MI.

supplemental water added to compensate for the actual water content of the EPICOR-II prefilter wastes.

The cement formulations were hand mixed with a stainless steel spatula. VES formulations were mixed with a cowles-type dispersion blade attached to a high-speed drill motor. The simulated waste forms were prepared in polyethylene vials, 4.76 cm in diameter by 10.2 cm high. The vials had snap-on lids to prevent evaporation of water while the waste forms were curing. The simulated waste forms had an average height of 5.6 cm and were cured at approximately 20°C.

Each of the cement formulations solidified within one day, with no evidence of free-standing liquid. However, formulations having high resin content and formulations containing pretreated (pH adjusted) resins exhibited severe mechanical degradation during subsequent immersion testing. A formulation containing 24-wt% decanted resin, 63-wt% cement, and 13-wt% supplemental water passed all evaluation tests and was selected for the solidification of actual EPICOR-II prefilter wastes.

Each of the VES formulations solidified within one day, with no evidence of free-standing liquid. No mechanical degradation was evident after immersion testing. A formulation containing 61-wt% decanted resin and 39-wt% binder was chosen for the solidification of actual EPICOR-II prefilter wastes. While the VES formulation contains slightly more than twice the decanted resin of the cement formulation by weight, it contains only approximately 25% more resin waste by volume. More detailed information on developing formulations for the resin solidification task is available in Ref. 3.

Solidification of EPICOR-II Prefilter Wastes

The actual EPICOR-II prefilter wastes were homogenized by mixing in 5-gal. buckets for 10 min, using a low speed dough mixer. That operation was performed in a hot cell. Individual samples (approximately 20 g each) of PF-7 and -24 resin wastes were removed from the hot cell after homogenization to determine water and activity contents. Water content measurements were obtained, using ASTM D2187-77,[16] with 5-g subsamples of resin. Then, water was added to measured quantities of the actual EPICOR-II wastes to prepare decanted resins for solidification. Reference 3 gives the water content and grams of dry resin/gram decanted waste, as determined for both the simulated and actual EPICOR-II wastes.

Aliquots (0.1 to 0.3 g) of dried EPICOR-II resin wastes were analyzed by gamma spectroscopy and Sr-90 analysis to determine the activity contents. The resins contained Cs-134, -137, and Sr-90. The average resin activities are given in Table I. The activity content data were used to calculate the activity contents of the waste forms for leachability testing.

Radioactive EPICOR-II waste forms were prepared in a hot cell, using specially designed, remotely operated solidification equipment (Fig. 1). For each batch prepared, 36 vials were filled. Sufficient mixture was added to each vial to produce waste forms with an average height of 7.6 ± 0.6 cm. Snap-on lids were placed on the vials after filling, and the waste forms were cured at approximately 20°C.

Four batches of cement waste forms were prepared, two batches for each waste type (PF-7 and -24). Four batches of VES waste forms were prepared, also two batches for each waste type. Table II gives the formulations used for the cement batches, and Table III gives those for the VES batches. A total of 267 waste forms was prepared. This total includes 136 cement waste forms (72 containing prefilter PF-7 waste and 64 with PF-24 waste) and 131 VES waste forms (71 containing PF-7 waste and 60 with PF-24 waste).

All waste forms were weighed. Contact gamma dose measurements also were obtained (Ref. 3) for each waste form (within the preparation vial). Those measurements were obtained at the mid-height of the waste form, with the center of the ion chamber located approximately 3.2 cm from the side of the waste form.

WASTE FORM TESTING

Baseline/qualification testing of radioactive EPICOR-II waste forms was conducted to determine the (a) presence of any free-standing liquid, (b) as-prepared compressive strength, and (c) homogeneity. Environmental tests are being conducted to determine (a) thermal stability, (b) leachability, (c) immersion stability, (d) radiation stability, and (e) biodegradability. All of the tests are being conducted to determine the adequacy of test procedures specified in the TP.

Baseline/Qualification Tests

Baseline/qualification tests were performed on eight cement and eight VES waste forms. Four of the cement waste forms contained prefilter PF-7 waste, and four contained PF-24 waste. Similarly, half the VES waste forms contained PF-7 waste, and the remainder PF-24 waste. Because of the high activity contents of the waste forms, these and subsequent tests were performed in such a manner so as to limit radiation exposure to personnel and contamination of the test environment, as shown in Fig. 2.

Free-standing liquid determinations were made with the method of ANS 55.1.[17] The lid of each preparation vial was removed, and the waste form inspected to determine if free-standing liquid was present on its top surface. A pointed plunger then was inserted through the bottom of the vial to push the waste form out, and the waste form and vial were inspected for presence of any free-standing liquid.

Compression testing (Fig. 2) was conducted in accordance with ASTM C39-72.[18] The waste forms were capped using a sulfur base mortar and compression tested using an Instron Model TTCLM1-4 Tension/Compression Tester, operated at a crosshead speed of 0.05 in./min. The cure times of the waste forms that were compression tested ranged from 30 to 49 days.

The compressive strength data and visual observations of the waste forms after failure were used to determine homogeneity of the waste forms.

Thermal Stability

Sixteen EPICOR-II waste forms were selected for thermal stability testing. They included eight cement waste forms (four containing PF-7 waste and four with PF-24 waste) and eight VES waste forms (four with PF-7 waste and four with PF-24 waste). The cure time of the waste forms tested was approximately 17 months. Thermal stability testing was conducted in accordance with Sections 5.4.1 through 5.4.4 of ASTM B553-79.[19] That procedure specifies a maximum temperature limit of 60°C and a

TABLE I

Activity Content of EPICOR-II Resin Wastes

Waste Type	Nuclide	Activity Content[a] ± 1σ (Ci/g dry resin)
PF-7	Cs-134	7.73 E-05 ± 2.83 E-07
	Cs-137	1.17 E-03 ± 9.90 E-05
	Sr-90	6.92 E-05 ± 7.21 E-06
PF-24	Cs-134	3.30 E-04 ± 5.80 E-05
	Cs-137	4.99 E-03 ± 3.04 E-04
	Sr-90	1.18 E-05 ± 6.36 E-07

a. Cs-134 and -137, as of Sept. 20, 1983; Sr-90, as of Oct. 25, 1983.

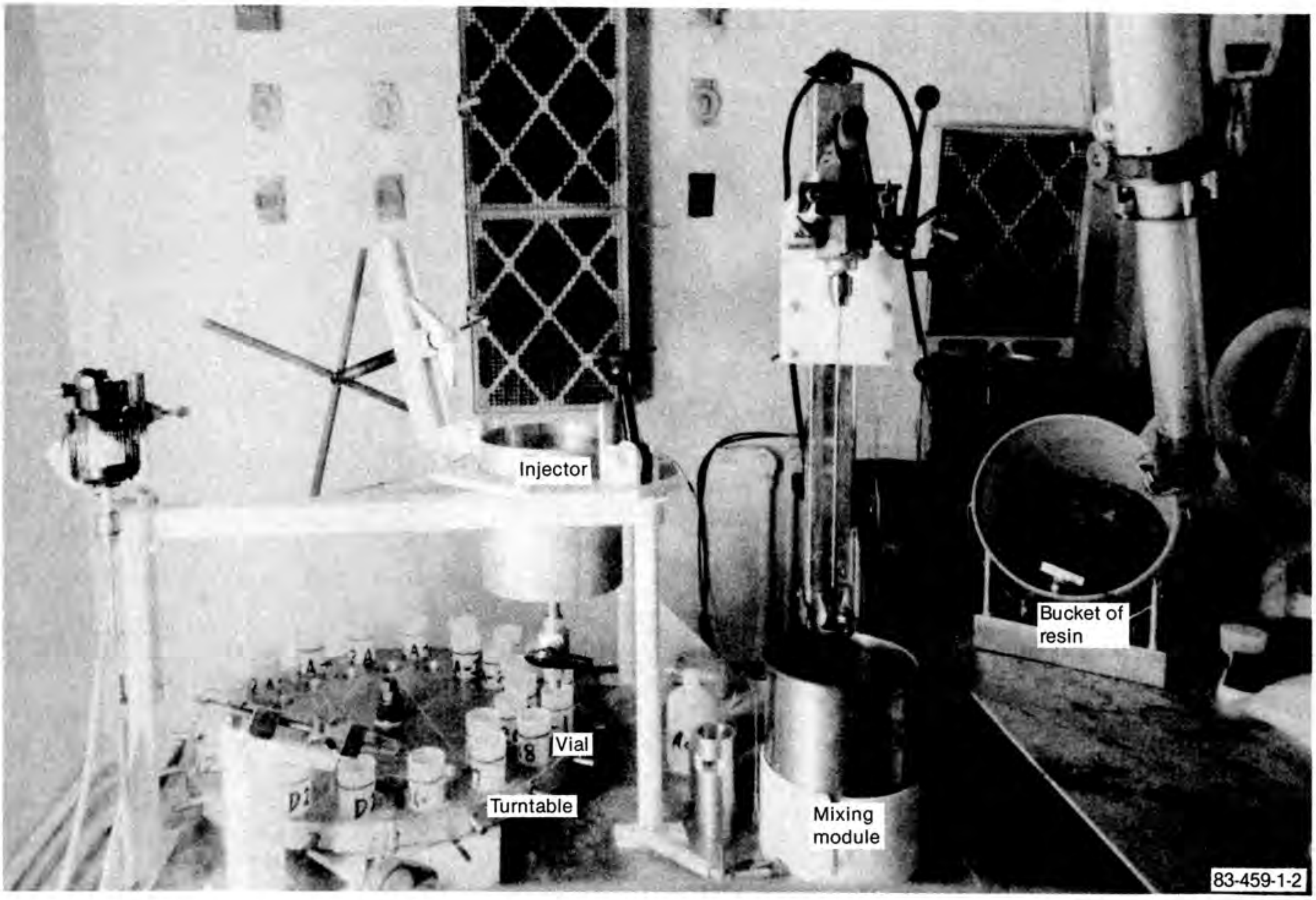

Fig. 1. Photograph of the remotely operated equipment used to produce Portland cement and vinyl ester-styrene waste forms incorporating actual EPICOR-II ion exchange resin wastes.

minimum temperature limit of -40°C. One complete thermal cycle consisted of the following steps:

1. Increasing the temperature of the waste forms to 60 ± 3°C and holding that temperature for at least 1 h
2. Decreasing the temperature of the waste forms to 20 ± 3°C and holding for at least 1 h
3. Decreasing the temperature of the waste forms to -40 ± 3°C and holding for at least 1 h
4. Increasing the temperature of the waste forms to 20 ± 3°C and holding for at least 1 h.

The waste forms (in their preparation vials) were double bagged in individual "zip lock" type polyethylene bags to prevent spread of radioactive contamination. Eight waste forms each were placed in a larger "zip lock" type polyethelene bag and placed on a plastic tray. The tray containing the eight waste forms also was placed in a polyethelene bag. The bag containing the second set of eight waste forms also contained a dummy cement waste form and a

TABLE II

Formulations for Portland Cement Waste Form Batches Containing EPICOR-II Wastes

Batch	Waste Type	Formulation Weight Percentage				
		As-Received Waste	Added Water	Decanted Waste Total[a]	Portland Type I-II Cement	Additional Water
C1	PF-7	15.6	8.5	24.1	62.7	13.2
C1A	PF-7	15.6	8.5	24.1	62.7	13.2
C2A	PF-24	16.8	7.1	24.0	62.5	13.5
C2B	PF-24	16.5	7.1	23.6	61.4	15.1

a. Decanted waste total is the as-received waste plus added water.

TABLE III

Formulations for Vinyl Ester-Styrene Waste Form Batches Containing EPICOR-II Wastes

Batch	Waste Type	Formulation Weight Percentage[a]			
		As-Received Waste	Added Water	Decanted Waste Total[b]	Vinyl Ester-Styrene
D1	PF-7	40.9	20.3	61.3	38.7
D1A	PF-7	38.9	22.6	61.5	38.5
D2	PF-24	43.1	18.3	61.4	38.6
D2A	PF-24	34.9	14.9	49.8	50.2

a. Does not include catalyst and promoter, which constitutes a total of approximately 1 wt%.

b. Decanted waste total is the as-received waste plus added water.

dummy VES waste form, each containing an axial thermocouple. The thermocouples were used to determine how long the waste forms were at the desired temperatures. [Note that equilibration to the test temperatures (as opposed to exposure to the test temperatures) represents the most restrictive interpretation of the test method.]

The trays containing the 16 test waste forms and 2 dummy waste forms were placed in a Statham Model SD51-1 Environmental Chamber for thermal cycling. Because of the extensive bagging of the waste forms, and resultant detrimental effect on heat transfer, one complete thermal cycle required approximately 42 hours. The waste forms were exposed to 30 complete thermal cycles.

After thermal cycling, the waste forms were removed from the polyethelene bags and preparation vials. Compression testing was conducted, as described earlier, using ASTM C39-72.

Leachability

Sixteen waste forms were selected for leachability testing, including eight cement waste forms and eight VES waste forms. Four of each type of waste form contained PF-7 waste, and four contained PF-24 waste. The elapsed time between preparation of the waste forms and leachability testing was approximately 20 months. The test was conducted in accordance with the procedures of ANS 16.1[20]

The 16 waste forms were removed from their preparation vials and weighed and measured (dimensionally). They were placed in individual Teflon netting "baskets," which were suspended from the lids of leachant containers. The leachant containers (Fig. 3) consisted of wide-mouthed, polyethylene bottles, 2-L in volume, with screw-top lids. Leachant volumes ranged from 1420 to 1590 mL (depending on the dimensions of the waste forms) to provide a leachant volume to waste form external geometric surface area ratio (V_L/S) of 10 ± 0.2 cm. Both demineralized and synthetic sea water leachants were used. Two waste forms of each type were tested in each leachant.

Before beginning leachability testing, the waste forms were rinsed by immersing in demineralized water for 30 seconds. Leachability testing was conducted for a total of 89 days. During testing, the leachate was replaced after each of ten specified, incremental leach time intervals. Because of the high radiation dose rate associated with handling the waste forms, separate leachant containers were used for each time interval. This permitted removing and processing the leachate aliquots in a low radiation environment. Each leachate was stirred, and four 25-mL aliquots were removed and placed in individual, 30-mL polyethylene containers. One aliquot was used in measuring the pH of the leachate, one was used for gamma spectroscopy, and two aliquots were reserved for other potential uses. All aliquots, with the exception of those obtained for determining the pH of the leachate, were acidified with nitric acid. After leachability testing, the 16 waste forms were compression tested under the immersion testing procedure.

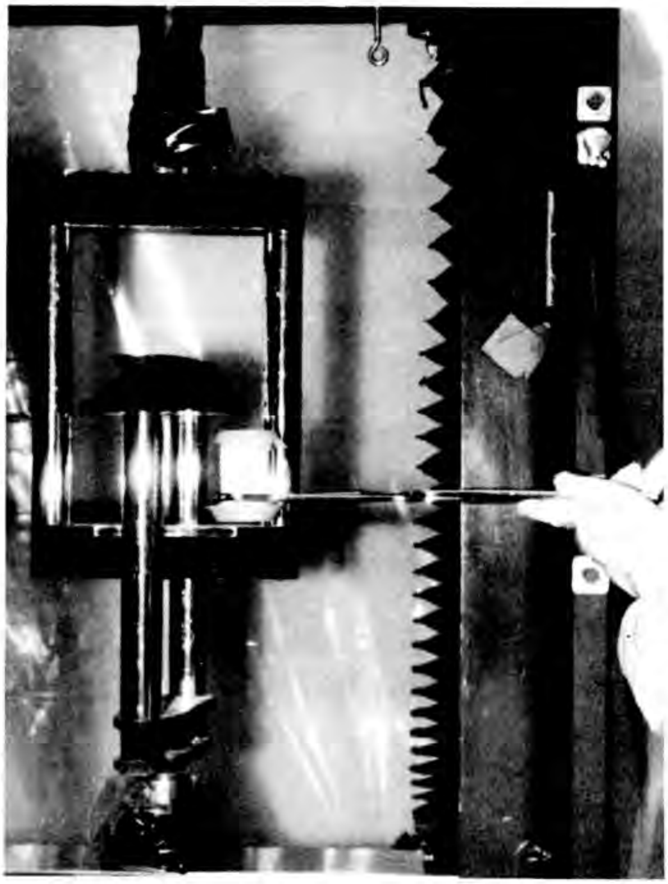

Fig. 2. Photograph of an EPICOR-II waste form being placed in the Instron compression testing machine.

Fig. 3. Photograph of EPICOR-II waste forms in the leachate containers during leachability testing. [Note the lead brick shielding required to reduce radiation exposure to personnel.]

Immersion Stability

Part of the leachability testing procedure served as the immersion portion of this test procedure, using the same 16 waste forms. The waste forms were capped with a sulfur base mortar and compression tested, using ASTM C39-72, as described previously.

Radiation Stability

Sixteen waste forms, eight cement and eight VES, were subjected to gamma irradiation for the radiation stability test. Four of the waste forms prepared from each binder contained PF-7 waste, and four contained PF-24 waste. The elapsed time between preparation of waste forms and gamma irradiation was 26 months.

The 16 waste forms were irradiated in the fuel storage pool of the Gamma Irradiation Facility at the Advanced Test Reactor of INEL. A total intended gamma irradiation dose of 5×10^8 R was selected for all waste forms, based on requirements of the TP. During the irradiation procedure, the positioning equipment in the Gamma Irradiation Facility failed and the cement waste forms received an actual, average gamma irradiation dose of 4.4×10^8 R; and the VES waste forms received 3.9×10^8 R.

After gamma irradiation, the waste forms were placed in a storage cask (Fig. 4) to await compression testing. The ASTM C39-72 procedure will be used, as described previously.

Fig. 4. Photograph showing an EPICOR-II waste form being placed in a plastic bag after the gamma irradiation portion of the irradiation stability testing. [Note the anti-contamination precautions taken by the technician.]

Biodegradability

The TP states that waste forms should be tested for resistance to biodegradation in accordance with both ASTM G21, "Determining Resistance of Synthetic Polymeric Materials to Fungi"[21] and ASTM G22, "Determining Resistance of Plastics to Bacteria."[22] Initial work was conducted, exposing unirradiated waste forms (powdered, wafered, and whole) to both fungi and bacteria. Subsequent work was conducted per ASTM G21 and G22, using irradiated, whole waste forms. Twenty waste forms, ten cement and ten VES, were subjected to biodegradability testing. Five of the waste forms prepared from each binder contained PF-7 waste, and five contained PF-24 waste. Two of each type of waste form prepared from each binder (8 total) were exposed to fungi, and two of each (8 total) were exposed to bacteria. The four remaining waste forms were placed in nutrient agar and used as control specimens.

RESULTS AND CONCLUSIONS

Baseline/Qualification Tests

The TP states that "specimens should have less than 0.5 percent by volume of the waste specimen as free liquids as measured using the method described in ANS 55.1." During the baseline/qualification tests, no free-standing liquid was observed on any of the waste forms.

Data from compression testing of waste forms are given in Table IV. The average compressive strengths for cement and VES waste forms containing the same waste type (PF-7 or -24) are approximately equal. Waste forms containing PF-24 waste (organic resin with zeolite) exhibited a higher average compressive strength (3,600 psi) than those prepared with PF-7 waste (2,900 psi). The compressive strengths of all the waste forms tested greatly exceeded the 50 psi minimum strength required by the TP.

The high compressive strengths and the appearance of the waste forms after failure indicated that the waste forms were homogeneous. No pockets of free-standing liquid were observed.

The baseline/qualification tests indicated that both cement and VES waste forms containing resin wastes from PF-7 and -24 met the free-standing liquid, compressive strength, and homogeneity requirements specified in the TP. The testing and results obtained also confirmed the general applicability of the test methods specified.

Thermal Stability

Average compression test data for the thermally cycled waste forms also are given in Table IV. The TP requires that waste forms should have compressive strengths greater than 50 psi, after thermal cycling. All of the thermally cycled waste forms had compressive strengths in the range of from 2,200 to 6,400 psi. The compressive strengths of the cement waste forms were higher than those of the VES waste forms. Waste forms containing PF-24 waste had higher compressive strengths than those containing PF-7 waste. The compressive strengths of the thermally cycled, cement waste forms were significantly higher than the corresponding, as-prepared waste forms. That was probably caused by additional cement hydration occurring during the long cure time before thermal cycling and subsequent compression testing. The procedure of ASTM C39-72 was applicable for determining compressive strengths of the waste forms after thermal cycling.

Thermal instability of waste forms containing low-level radioactive waste during storage and transport before disposal usually results from freezing and thawing of chemically uncombined water in the waste form. Consequently, degradation of the waste forms is caused by expansion of the water upon freezing. Therefore, it is recommended that the thermal stability test procedure require that waste forms be sealed in containers immediately after preparation and throughout thermal cycling to prevent evaporative water loss. It also is recommended that the test procedure require that centerline temperatures of the waste forms attain the temperatures specified in the procedure and remain at those temperatures for the specified times. Thermocouples should be used during testing to monitor centerline temperatures of the waste forms.

Leachability

Leachability of the waste forms was calculated in the manner detailed in ANS 16.1. Average data from the leachability test are given in Table V for Cs-134 and -137. The leachability of cement waste forms generally was higher than that of comparable VES waste forms in the same leachant, as indicated by the lower leachability indexes for the cement waste forms. Both cement and VES waste forms containing PF-7 waste exhibited higher leachability than those containing PF-24 waste. Using sea water as the leachant resulted in higher leachability than using demineralized water. The Cs-137 and -134 leachability indexes, trends, and ranges are comparable for individual waste forms. Seven of the 16 waste forms have trend values greater than $\pm 5\%$. Trends associated with cement waste forms are negative (decreasing leachability index with time); while trends associated with VES waste forms are positive. None of the waste forms tested produced a leachability index range exceeding 25%, although two waste forms have ranges greater than 20%. All of the

TABLE IV

Compressive Strengths of EPICOR-II Waste Forms

		Compressive Strength $\pm 1\sigma$ (psi)		
Binder	Waste Type	As-Prepared	Thermal Cycled	Immersion Tested
PC	PF-7	2,930 ± 480	4,740 ± 91	2,670 ± 560
PC	PF-24	3,620 ± 720	5,670 ± 650	3,850 ± 1,200
VES	PF-7	2,900 ± 150	2,770 ± 330	2,770 ± 300
VES	PF-24	3,580 ± 190	4,060 ± 43	3,270 ± 320

PC = Portland Type I-II cement
VES = vinyl ester-styrene

TABLE V

Cesium-134 and -137 Leachability from EPICOR-II Waste Forms

Binder	Waste Type	Radionuclide	leachant	Leachability Index	Trend (%)	Range (%)
PC	PF-7	Cs-134	DI	10.3	-4	21
PC	PF-7	Cs-134	SW	9.6	-6	14
PC	PF-7	Cs-137	DI	10.1	-4	22
PC	PF-7	Cs-137	SW	9.5	-6	16
PC	PF-24	Cs-134	DI	10.6	-2	9
PC	PF-24	Cs-134	SW	10.4	-1	5
PC	PF-24	Cs-137	DI	10.4	-2	9
PC	PF-24	Cs-137	SW	10.3	-2	6
VES	PF-7	Cs-134	DI	12.3	+11	13
VES	PF-7	Cs-134	SW	9.4	+13	19
VES	PF-7	Cs-137	DI	12.2	+11	18
VES	PF-7	Cs-137	SW	9.3	+13	19
VES	PF-24	Cs-134	DI	14.0	+ 3	6
VES	PF-24	Cs-134	SW	11.0	+ 3	8
VES	PF-24	Cs-137	DI	13.8	+ 3	6
VES	PF-24	Cs-137	SW	10.8	+ 3	9

PC = Portland Type I-II cement
VES = vinyl ester-styrene
DI = demineralized water
SW = synthetic sea water

waste forms tested have leachability indexes greater than 6, as required by the TP.

The test procedures and calculation of leachability indexes, as specified by ANS 16.1, were applicable for determining leachability of the waste forms. The cement and VES waste forms containing wastes from PF-7 and -24 were found to be resistant to leaching.

Immersion Stability

Immersion of the waste forms was conducted satisfactorily as part of the leachability test. The waste forms then were compression tested to determine if their compressive strengths had been degraded by immersion. Compressive strength data for immersion tested waste forms are given in Table IV. For each type of waste form, the average compressive strengths after immersion are approximately the same as those determined for as-prepared waste forms. The average compressive strengths measured for waste forms immersed in sea water are somewhat higher than for waste forms immersed in demineralized water. However, the number of waste forms tested and the differences noted are too small to suggest any significant effect of leachant type on compressive strength after immersion.

All immersion tested waste forms exhibited compressive strengths far in excess of the 50 psi required by the TP. The ASTM C39-72 test procedure was applicable for determining compressive strengths of the waste forms. It is suggested that the TP state more positively whether other fluid(s) in addition to demineralized water are required for immersion testing.

Radiation Stability

The total gamma irradiation dose received by the waste forms was larger than the total beta plus gamma self-irradiation dose that the waste forms would have received by the end of 300 years. [The calculated, self-irradiation doses ranged from 2.9×10^8 R for cement waste forms containing PF-24 waste to 4.2×10^8 R for VES waste forms containing PF-7 waste.]

Compression testing of gamma irradiated waste forms has not been completed. The appearance of the waste forms after irradiation does not suggest significant mechanical degradation. Implementation of the procedure used for irradiating waste forms indicates that this portion of radiation stability testing can be used successfully to obtain the desired results, as well as to limit personnel exposure and contamination of the test area.

Biodegradability

The cement waste forms gave no indication of being affected by, or offering support for, growth of applied species of fungi and bacteria, as specified in ASTM G21 and G22. However, cement waste forms placed in nutrient-rich media did not chemically or radiologically prevent the growth of fungi. Thus, while the waste forms did not support microbial growth, neither did they prevent it.

The VES waste forms supported fungal growth (Fig. 5), but not bacterial. Tests with unirradiated, powdered or wafered material showed that fungi would grow on the growth media surrounding the material, and a close visual inspection showed at least 10 to 30% of the waste form surface had fungi growing on it. Whole, irradiated VES waste forms had fungal growth on the surrounding media, but close inspection of the waste form surfaces was not possible with available facilities, because of the high radiation levels.

Cement waste forms are not affected by plastic-degrading fungi or bacteria, while the VES waste forms apparently support fungal growth. Long-term effects

Fig. 5. Photograph of a VES waste form containing PF-7 wastes exposed to fungi in an agar-filled Petri dish during biodegradability testing.

of the growth of fungi were not determined in this task. While the methodology of ASTM G21 and G22 seems to be applicable to this type of testing, longer exposure times and use of fungi known to attack concrete are recommended changes.

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