6/28/77

PROPERTIES OF RADIOACTIVE WASTES AND WASTE CONTAINERS

QUARTERLY PROGRESS REPORT
OCTOBER - DECEMBER 1976

P. COLOMBO AND R.M. NEILSON, JR.

Date Published - June 1977

PROCESS TECHNOLOGY DIVISION
DEPARTMENT OF APPLIED SCIENCE
BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
UPTON, NEW YORK 11973

MASTER

PREPARED FOR THE UNITED STATES NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH
UNDER CONTRACT NO. EY 76-C-02-0016

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

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, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

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, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

PROPERTIES OF RADIOACTIVE WASTES AND WASTE CONTAINERS

**QUARTERLY PROGRESS REPORT
OCTOBER - DECEMBER 1976**

P. COLOMBO AND R.M. NEILSON, JR.

**Manuscript Completed - April 1977
Date Published - June 1977**

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

**MEYER STEINBERG, Head
PROCESS TECHNOLOGY DIVISION
DEPARTMENT OF APPLIED SCIENCE
BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
UPTON, NEW YORK 11973**

MASTER

**PREPARED FOR THE UNITED STATES NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH
UNDER CONTRACT NO. EY-76-C-02-0016**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Nuclear Regulatory Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America

Available from

National Technical Information Service

U.S. Department of Commerce

5285 Port Royal Road

Springfield, VA 22161

Price: Printed Copy \$5.50; Microfiche \$3.00

June 1977

260 copies

Table of Contents

	<u>Page</u>
Summary	vii
I. Determination of Free Standing Water for Solidified Radioactive Waste Formulations	1
A. Urea-Formaldehyde (UF)	1
B. Portland Type II Cement	6
II. Urea-Formaldehyde Decontamination Factors for Free Standing Water	12
III. Release of Cesium from Urea-Formaldehyde in Static Leaching	15
IV. Properties of the Dow Solidification Agent	32
A. Weight Loss from Dow Solidification Agent Specimens upon Exposure to Ambient Air	32
B. Thermogravimetric Analysis	35
C. Thermal Conductivity	35
D. Compressive Strength	41
E. Unnotched Izod Impact Strength	41
V. Freeze-Thaw Resistance	43
References	44
Appendix A	45
Appendix B	49
Appendix C	57
Distribution List	88

List of Tables

1. Free Standing Water in Waste-UF Formulations Catalyzed by the Addition of 2.0 Volume % of a 25 Wt.% Sodium Bisulfate Solution	2
2. Free Standing Water in Waste-UF Formulations Catalyzed by the Addition of Sufficient 25 Wt.% Sodium Bisulfate Solution to Achieve a Waste-UF Mixture pH of 1.5 ± 0.5	4

List of Tables (Continued)

	<u>Page</u>
3. Decrease in Diameter (Shrinkage) of Selected Waste-UF Formulations	8
4. Free Standing Water in Waste-Portland Type II Cement Formulations (No Waste Pretreatment)	10
5. Free Standing Water in Waste-Portland Type II Cement Formulations (Waste pH Adjusted to 10.0)	11
6. Urea-Formaldehyde Decontamination Factors for Free Standing Water	14
7. Thermal Conductivity at 100°F of the Dow Solidification Agent	40
8. Compressive Strength of Dow Solidification Agent Specimens	42
9. Unnotched Izod Impact Strength of Dow Solidification Agent Specimens	42

List of Figures

1. Cumulative Free Standing Water as a Function of the Waste/UF Weight Ratio for Selected Wastes.	5
2. Cumulative Free Standing Water as a Function of the Water/UF Weight Ratio.	7
3. $(\Sigma a_n/A_0) \times (V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Twice Per Day with $(V_L/S) = 20\text{cm}$.	17
4. $(\Sigma a_n/A_0) \times (V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Once Per Day with $(V_L/S) = 20\text{cm}$.	18
5. $(\Sigma a_n/A_0) \times (V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Twice Per Week with $V_L/S = 20\text{cm}$.	19

List of Figures (Continued)

	<u>Page</u>
6. $(\Sigma a_n/A_0)x(V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Once Per Week with $(V_L/S) = 20\text{cm}$.	20
7. $(\Sigma a_n/A_0)x(V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Twice Per Day with $(V_L/S) = 10\text{cm}$.	21
8. $(\Sigma a_n/A_0)x(V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Once Per Day with $(V_L/S) = 10\text{cm}$.	22
9. $(\Sigma a_n/A_0)x(V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Twice Per Week with $(V_L/S) = 10\text{cm}$.	23
10. $(\Sigma a_n/A_0)x(V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Once Per Week with $(V_L/S) = 10\text{cm}$.	24
11. $(\Sigma a_n/A_0)x(V/S)$ Versus Σt_n for Cesium Removal from Urea-Formaldehyde by Static Leaching in Distilled Water.	25
12. $(\Sigma a_n/A_0)x(V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Interval is Once Per Day with $(V_L/S) = 2.5\text{cm}$.	26
13. $(\Sigma a_n/A_0)x(V/S)$ Versus Σt_n as a Function of (V_L/S) for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Once Per Day.	27
14. $(\Sigma a_n/A_0)x(V/S)$ Versus Σt_n as a Function of Leachant Renewal Frequency for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. $V_L/S = 10\text{cm}$.	28
15. $(\Sigma a_n/A_0)x(V/S)$ Versus Σt_n as a Function of Leachant Renewal Frequency for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. $V_L/S = 20\text{cm}$.	29

List of Figures (Continued)

	<u>Page</u>
16. Percentage Initial Weight Versus Time in Ambient Air for Dow Solidification Agent Specimens (72°F, 57% RH). Specimen Surface Area = 52.0cm ² .	33
17. Thermogravimetric Weight Loss for Dow Solidification Agent Specimens.	36
18. Thermogravimetric Weight Loss for Dow Solidification Agent (Volume Ratio H ₂ O/Binder = 1.0).	37
19. Thermogravimetric Weight Loss for Dow Solidification Agent (Volume Ratio H ₂ O/Binder = 1.5).	38
20. Thermogravimetric Weight Loss for Dow Solidification Agent (Volume Ratio H ₂ O/Binder = 2.0).	39

SUMMARY

The cumulative quantities of free standing water resulting from the solidification of simulated wastes with urea-formaldehyde (UF) and portland type II cement were determined. The effect of the waste/solidification agent ratio on the cumulative free standing water for selected wastes solidified with UF is reported and was found to be related to sample shrinkage. Urea-formaldehyde decontamination factors for free standing water were determined with ^{137}Cs , ^{85}Sr , ^{60}Co , and ^{59}Fe . With the exception of ^{85}Sr for which UF was shown to have a decontamination factor of 1.6-1.9, the specific activity of the free standing water was essentially equal to that of the waste prior to solidification.

The release of cesium from UF in distilled water was measured by a static leaching technique. The effect of the leachant renewal interval and the ratio of the leachant volume (V_L) to the sample external geometric surface area (S) was examined. The proposed leachant renewal interval of once/day and $V_L/S = 10\text{cm}$ was found to be satisfactory for leaching of these samples.

Samples of a proprietary polymer agent developed by the Dow Chemical Company were tested to determine water loss with exposure to ambient air, weight loss with temperature (TGA), thermal conductivity, compressive strength and impact strength. Property measurements were made for water/binder volume ratios of from 1.0 to 2.0.

No deterioration was observed for a portland type II cement sample with a water/cement ratio of 0.5 by weight subjected to fifty freeze-thaw cycles.

I. DETERMINATION OF FREE STANDING WATER FOR SOLIDIFIED RADIOACTIVE WASTE FORMULATIONS

A. Urea-Formaldehyde (UF)

Work was continued to investigate the effect of the waste to UF weight ratio on the quantity of free standing water observed for selected wastes solidified with urea-formaldehyde. The wastes selected were generally those which had been shown in a previous report⁽¹⁾ to exhibit substantial free standing water. This additional work utilized formulations in which polymerization was achieved by the addition of 2.0 volume percent of a 25 weight percent sodium bisulfate catalyst solution since it had been observed that the addition of sufficient catalyst to attain a waste-UF mixture pH of 1.5 ± 0.5 tends to minimize free standing water for most wastes. Triplicate twenty gram samples of each waste-UF formulation (waste compositions are given in Appendix A) were prepared using Borden Casco-Resin 2 and poured into one inch diameter plastic vials for curing. These vials were sealed to prevent water loss by evaporation. Daily, the vial caps were removed and the free standing water poured out for weighing. It was observed that using this procedure all appreciable free standing water was removed from the sample. For completeness in this report, free standing water data obtained for UF formulations are tabulated in their entirety. Table 1 lists the cumulative free standing water observed for waste-UF mixtures to which 2.0 volume percent of a 25 weight percent sodium bisulfate catalyst solution was added while Table 2 gives corresponding data for formulations to which sufficient catalyst solution was added to achieve a waste-UF mixture pH of 1.5 ± 0.5 .

As shown in Figure 1, the cumulative free standing water observed is not a monotonic function of the waste/UF weight ratio for the wastes examined. Typically, as the waste/UF ratio is increased from zero, the cumulative free standing water observed increases, reaches a maximum, and subsequently decreases. Observations suggested that this behavior was related to sample shrinkage. An experiment was performed to determine the cumulative free standing water for a range of water/UF ratios. Triplicate samples were prepared for water/UF weight ratios of from zero to

TABLE 1

Free Standing Water in Waste-UF Formulations Catalyzed by the Addition of
2.0 Volume % of a 25 Wt.% Sodium Bisulfate Solution

CUMULATIVE WEIGHT PERCENTAGE FREE STANDING WATER (Based on Total Formulation Weight)							
Waste Type	1 Day	2 Days	3 Days	4 Days	7 Days	Free Standing Water pH	Weight Ratio of Waste to UF
1. Bead Resin	0.5±0.2	0.5±0.2	0.5±0.2	0.5±0.2	0.5±0.2	--	2.2
2. BWR Precoat Filter Cake							
a. Powdered Resin	0.3±0.2	0.3±0.2	0.3±0.2	0.3±0.2	0.3±0.2	--	2.0
b. Diatomaceous Earth	2.8±0.3	5.5±0.3	7.3±0.3	8.8±0.3	8.8±0.3	2.8	2.0
	3.1±0.3	3.1±0.3	3.1±0.3	3.1±0.3	3.1±0.3	--	1.0
3. Forced Recirculation Evaporator Concentrates							
a. BWR Chemical Regenerative Waste	0.8±0.1	1.3±0.2	1.3±0.5	1.6±0.4	1.6±0.4	2.3	1.2
b. PWR Chemical Regenerative Waste	1.5±0.1	1.7±0.3	1.7±0.3	1.8±0.3	1.8±0.3	1.5	1.2
c. Boric Acid Waste	0.0	0.0	0.0	0.0	0.0	--	2.0
	1.2±0.1	1.2±0.1	1.2±0.1	1.2±0.1	1.2±0.1	--	1.5
	6.3±4.0	8.0±4.0	8.0±4.0	8.0±4.0	8.0±4.0	1.7	1.0
	6.1±0.5	7.9±0.5	8.1±1.0	8.1±1.0	8.1±1.0	--	0.8
	7.3±1.0	7.4±1.0	7.4±1.0	7.4±1.0	7.4±1.0	--	0.5
	10.0±0.5	11.3±0.5	11.3±0.5	11.3±0.5	11.3±0.5	--	0.3
d. Decontamination Waste	7.5±0.5	12.5±1.0	14.3±1.0	15.4±1.0	15.5±1.0	--	2.0
	14.0±0.5	15.5±0.5	15.5±0.5	16.0±0.5	16.0±0.8	--	1.5
	14.0±4.0	20.0±6.0	20.0±6.0	21.3±6.3	22.2±6.4	3.7	1.1
	5.0±0.5	12.0±0.5	24.0±0.5	26.0±0.6	26.1±0.6	--	0.6
	5.0±0.3	12.5±0.5	24.5±0.5	26.0±0.5	26.4±0.5	--	0.5
	0.5±0.1	3.0±0.5	5.0±0.5	5.0±0.5	5.8±0.8	--	0.2

TABLE 1 (Cont.)

CUMULATIVE WEIGHT PERCENTAGE FREE STANDING WATER
(Based on Total Formulation Weight)

<u>Waste Type</u>	<u>1 Day</u>	<u>2 Days</u>	<u>3 Days</u>	<u>4 Days</u>	<u>7 Days</u>	<u>Free Standing Water pH</u>	<u>Weight Ratio of Waste to UF</u>
4. Thin Film Evaporator Concentrates							
a. BWR Chemical Regenerative Waste	0.0	0.0	0.0	0.0	0.0	--	1.0
b. PWR Chemical Regenerative Waste	0.6±0.4	2.0±0.4	3.0±0.4	3.0±0.4	4.0±0.4	2.0	0.7
c. Boric Acid Waste	1.1±0.1	1.1±0.1	1.1±0.1	1.1±0.1	1.1±0.1	2.0	1.0
d. Decontamination Waste	10.0±0.8	14.0±0.8	15.0±0.8	15.5±1.0	16.0±1.0	--	2.0
	17.5±2.5	21.6±2.5	23.9±2.5	24.7±2.5	25.4±2.5	3.8	1.5
	9.7±0.1	20.2±1.0	24.6±1.0	25.0±1.4	25.5±1.4	--	1.0
	10.0±0.1	20.0±0.5	21.0±0.5	21.5±0.5	21.8±0.5	--	0.5
	5.5±0.5	10.0±0.5	11.5±0.5	12.0±0.5	13.0±0.8	--	0.2

TABLE 2

Free Standing Water in Waste-UF Formulations Catalyzed by the Addition of Sufficient 25 Wt.% Sodium Bisulfate Solution to Achieve a Waste-UF Mixture pH of 1.5 ± 0.5

CUMULATIVE WEIGHT PERCENTAGE FREE STANDING WATER (Based on Total Formulation Weight)					Volume Percent Catalyst Soln. Added	pH of Free Standing Water	Weight Ratio of Waste to UF
	1 Day	2 Days	3 Days	6 Days			
1. Bead Resin	0.45±0.05	0.45±0.05	0.45±0.05	0.45±0.05	1.80	--	2.2
2. BWR Precoat Filter Cake							
a. Powdered Resin	0.25±0.15	0.25±0.15	0.25±0.15	0.25±0.15	1.90	--	2.0
b. Diatomaceous Earth	0.0	0.0	0.0	0.0	2.96	--	2.0
3. Forced Recirculation Evaporator Concentrates							
a. BWR Chemical Regenerative Waste	0.23±0.03	0.23±0.03	0.23±0.03	0.23±0.03	3.13	1.6	1.3
b. PWR Chemical Regenerative Waste	0.4 ±0.2	0.55±0.25	0.80±0.25	0.80±0.25	2.94	1.5	1.3
c. Boric Acid Waste	1.4 ±0.2	1.5 ±0.2	1.5 ±0.2	1.5 ±0.2	0.80	1.6	1.2
d. Decontamination Waste	3.3 ±0.1	3.6 ±0.2	3.9 ±0.3	4.0 ±0.3	10.5	2.0	1.2
4. Thin Film Evaporator Concentrates							
a. BWR Chemical Regenerative Waste	0.0	0.0	0.0	0.0	1.48	--	1.5
b. PWR Chemical Regenerative Waste	4.0 ±2.0	5.2 ±2.2	5.2 ±2.2	7.2 ±2.6	1.74	1.6	1.0
c. Boric Acid Waste	0.55±0.05	0.55±0.05	0.55±0.05	0.55±0.05	1.44	1.4	1.2
d. Decontamination Waste	5.4 ±0.2	9.2 ±0.2	9.9 ±0.3	11.0 ±0.3	13.3	2.6	1.5

Figure 1. Cumulative Free Standing Water as a Function of the Waste/UF Weight Ratio for Selected Wastes.

3.0 in incremental steps of 0.5 by the technique described in the preceding paragraph and analyzed for free standing water content. The sample vials were sealed to prevent water loss by evaporation. This data is shown in Figure 2. For water/UF weight ratios of from 1.5 to 3.0, no observable sample shrinkage occurred and the cumulative free standing water increased slowly as the water/UF ratio was increased. At a ratio of 1.0, two specimens did not shrink appreciably, while the third specimen shrank such that it could be removed from its vial by inversion. The respective quantities of free standing water were 1.5 wt.% for the specimens which did not shrink appreciably and 10.5 wt.% for the third. This formulation is in the transition region indicated in Figure 2.

At water/UF ratios of 0.5 and zero, all samples exhibited appreciable shrinkage, although the cumulative free standing water was less for a weight ratio of zero than 0.5. The shrinkages in the diameter of these specimens at water/UF weight ratios of 0.0, 0.5 and 1.0 were 6.7%, 9.1% and 5.5% respectively, corresponding to volume decreases of 18.8%, 24.9% and 15.6%, assuming an identical change in specimen length occurred. Similar behavior was found for the boric acid formulations shown in Figure 1; above a waste/UF weight ratio of 1.0, no appreciable shrinkage occurred, however, at ratios of from 0.3 to 1.0, an average decrease in specimen diameter of 6.3% was measured. Decreases in specimen diameter were largely independent of the waste/UF ratio over this range. Decontamination waste specimens exhibited shrinkage over the entire range of waste/UF ratios tested. For decontamination wastes from both forced recirculation and thin film evaporators, the maximum shrinkage occurred at waste/UF ratios of 0.5 and was 13.4% and 10.6% of the initial diameter respectively. Shrinkage data for these specimens is shown in Table 3.

B. Portland Type II Cement

BWR and PWR wastes (formulations listed in Appendix A) were solidified with portland type II cement to determine the amount of free standing water present after solidification. The cement and waste were combined in the desired ratios and mixed thoroughly. Triplicate twenty gram aliquots of each waste/cement mixture were poured into individual one inch diameter plastic vials for curing; the sample vials were sealed to prevent

Figure 2. Cumulative Free Standing Water as a Function of the Water/UF Weight Ratio.

TABLE 3

Decrease in Diameter (Shrinkage) of Selected Waste-UF Formulations

<u>Waste Type</u>	<u>Weight Ratio Waste/UF</u>	<u>Percentage Decrease in Diameter</u>
3c, Boric Acid Waste (forced recirculation evaporation)	1.0	5.5 ^(a)
	0.8	6.7
	0.5	6.7
	0.3	6.3
3d, Decontamination Waste (forced recirculation evaporator)	2.0	6.7
	1.5	8.3
	1.0	7.1
	0.5	13.4
	0.2	3.9
4d, Decontamination Waste (thin film evaporator)	2.0	6.7
	1.5	9.1
	1.0	8.7
	0.5	10.6
	0.2	8.3
Distilled Water	1.0	5.5 ^(a)
	0.5	9.1
	0.0	6.7

(a) formulation in the transition region, data reported only for samples in which appreciable shrinkage occurred.

evaporative water loss. Daily, the vial caps were removed and any free standing water poured out for weighing. This procedure was observed to remove all appreciable free standing water from the sample. Free standing water determinations were made for waste/cement formulations for which the waste had no pretreatment and for wastes whose pH was adjusted to approximately ten by the addition of a saturated sodium hydroxide solution prior to solidification. These results are given in Tables 4 and 5 respectively.

Free standing water was not encountered for most waste types tested. Decreasing the waste to cement ratio eliminated free standing water from the majority of the formulations in which it was observed. Further decreases in the waste/cement ratio are expected to eliminate free standing water from those remaining formulations. Pretreatment of the wastes prior to solidification by adjusting the waste pH to approximately ten does not appear to decrease the subsequent amount of cumulative free standing water. However, the free standing water in some waste formulations (such as boric acid waste) is notably increased by pretreatment as a result of the substantial quantity of water which was added to the waste in the sodium hydroxide solution. This addition exceeded the amount of free standing water observed for boric acid waste formulations.

TABLE 4

Free Standing Water in Waste-Portland Type II Cement Formulations
(No Waste Pretreatment)

CUMULATIVE WEIGHT PERCENTAGE FREE STANDING WATER (Based on Total Formulation Weight)				
Waste Type	7 Days	9 Days	11 Days	Weight Ratio of Waste to Cement
1. Bead Resin	4.3±1.0	5.5±2.5	5.5±2.5	1.8
	0.0	0.0	0.0	1.6
	0.0	0.0	0.0	1.5
2. BWR Precoat Filter Cake				
a. Powdered Resin	0.0	0.0	0.0	1.8*
b. Diatomaceous Earth	1.0±0.3	1.0±0.3	1.0±0.3	1.6*
3. Forced Recirculation Evaporator Concentrates				
a. BWR Chemical	8.0±1.0	8.0±1.0	8.0±1.0	1.7
Regenerative Waste	4.0±1.0	4.0±1.0	4.0±1.0	1.0
b. PWR Chemical	2.5±0.8	2.5±0.8	2.5±0.8	1.0
Regenerative Waste	0.0	0.0	0.0	0.6
c. Boric Acid Waste	0.0	0.0	0.0	0.6
d. Decontamination Waste	4.0±1.5	4.0±1.5	4.0±1.5	1.0
	0.0	0.0	0.0	0.6
4. Thin Film Evaporator Concentrates				
a. BWR Chemical				
Regenerative Waste	0.0	0.0	0.0	1.5
b. PWR Chemical				
Regenerative Waste	0.0	0.0	0.0	1.0
c. Boric Acid Waste	0.0	0.0	0.0	0.7
d. Decontamination Waste	0.0	0.0	0.0	1.4

* Water content of these wastes were increased to 70 wt.% to provide sufficient water for mixing.

TABLE 5

Free Standing Water in Waste-Portland Type II Cement Formulations
(Waste pH Adjusted to 10.0)

CUMULATIVE WEIGHT PERCENTAGE FREE STANDING WATER
(Based on Total Formulation Weight)

Waste Type	7 Days	9 Days	11 Days	Weight Ratio of Waste to Cement
1. Bead Resin	1.0±0.5 0.0	1.0±0.5 0.0	1.0±0.5 0.0	1.8 1.5
2. BWR Precoat Filter Cake				
a. Powdered Resin	0.0	0.0	0.0	1.8*
b. Diatomaceous Earth	1.2±0.1	4.9±0.7	4.9±0.7	1.6*
3. Forced Recirculation Evaporator Concentrates				
a. BWR Chemical Regenerative Waste	13.5±3.0 3.2±3.0	13.5±3.0 3.2±3.0	13.5±3.0 3.2±3.0	1.7 1.0
b. PWR Chemical Regenerative Waste	0.0	0.0	0.0	1.0
c. Boric Acid Waste	3.5±1.0 0.0	3.5±1.0 0.0	3.5±1.0 0.0	0.6 0.5
d. Decontamination Waste	0.0	0.0	0.0	1.0
4. Thin Film Evaporator Concentrates				
a. BWR Chemical Regenerative Waste	0.0	0.0	0.0	1.5
b. PWR Chemical Regenerative Waste	0.0	0.0	0.0	1.0
c. Boric Acid Waste	2.0±0.5 0.0	2.0±0.5 0.0	2.0±0.5 0.0	0.7 0.5
d. Decontamination Waste	0.0	0.0	0.0	1.4

* Water content of these wastes were increased to 70 wt.% to provide sufficient water for mixing.

II. UREA-FORMALDEHYDE DECONTAMINATION FACTORS FOR FREE STANDING WATER

Amounts of acidic free standing water may result from the solidification of wastes with urea-formaldehyde. The radionuclide content of the free standing water is of interest particularly as it relates to the specific content of the original waste. Experiments were performed to determine the decontamination factors of urea-formaldehyde for ^{137}Cs , ^{85}Sr , ^{60}Co , and ^{59}Fe as measured from the free standing water where the decontamination factor (DF) is defined as:

$$\text{DF} = \frac{\text{specific radionuclide content of initial waste, mCi/ml}}{\text{specific radionuclide content of free standing water, mCi/ml}} \quad (1)$$

Cylindrical specimens with a diameter of 1-7/8 inches and 2-1/8 inches in length were prepared using Borden Casco-Resin 2 and distilled water at water/UF volume ratios of 2.0 and 3.0. One milliliter aliquots of one of three radioisotope solutions were added to the distilled water for each sample prior to incorporation with UF. These solutions were:

Solution 1	^{137}Cs , 1.98×10^{-3} mCi/ml
	^{85}Sr , 2.56×10^{-3} mCi/ml
Solution 2	^{60}Co , 1.00×10^{-2} mCi/ml
Solution 3	^{59}Fe , 1.37×10^{-2} mCi/ml

These isotopes represent a range of valence states of from +1 to +3. The radioisotopes were divided among three solutions to allow subsequent analysis using a NaI detector. The ^{137}Cs and ^{85}Sr peaks could be adequately resolved by inclusion of a small factor to correct for Compton scattering and peak overlap such that a solution containing both isotopes could be used. Triplicate UF samples were prepared using each radioisotope solution at water/UF volume ratios of 2.0 and 3.0. Counting standards were also prepared for each of these solutions by taking one milliliter of the solution and diluting it to 10 ml. The distilled water to which the aliquot of radioisotope solution had been added was mixed thoroughly with urea-formaldehyde to obtain the desired water/UF ratio. Two volume percent of a saturated sodium bisulfate solution was added as a polymerization catalyst. The specimens were allowed to cure for three days in individual plastic vials which were sealed to prevent evaporative water

loss. At this time, the quantity of free standing water was measured and one milliliter taken and diluted to 10 ml for counting by a Searle Model 1185 automatic gamma counter with a three inch diameter NaI well crystal. Comparison of the counting rate for the free standing water with that for the respective standard solutions allowed calculation of the decontamination factors.

The urea-formaldehyde decontamination factors determined for free standing water are given in Table 6. These decontamination factors represent the average from triplicate specimens and in the case of ^{60}Co and ^{59}Fe were measured for two individual photopeaks. A decontamination factor of 1.0 indicates that the specific activity of the free standing water (mCi/ml) is the same as that of the waste (water in this case) prior to solidification and that the urea-formaldehyde polymer does not adsorb, combine with, or entrap the incorporated activity. Within the accuracy of the experiment, decontamination factors of 1.0 were obtained for ^{137}Cs and ^{60}Co at water/UF volume ratios of 2.0 and 3.0. Decontamination factors of 1.9 and 1.6 were observed for ^{85}Sr at water/UF volume ratios of 2.0 and 3.0 respectively. A small decontamination factor of 1.1 was obtained with ^{59}Fe specimens at a water/UF volume ratio of 2.0, but no decontamination effect was noted at the higher ratio. Any decontamination factor provided by urea-formaldehyde might be expected to decrease with increasing water/UF ratios since less urea-formaldehyde is present in the formulation. Decontamination factors greater than 1.0 as measured by the free standing water could also result from dilution with water produced during UF polymerization or condensation of water during the solidification of thermally hot wastes from evaporators. This relatively activity free condensate forms on cool inner surfaces of the solidification container, but ultimately moves to the surface of the solid and is found as free standing water.

TABLE 6Urea-Formaldehyde Decontamination Factors for Free Standing Water

<u>Water/UF Volume Ratio</u>	<u>Radioisotope</u>	<u>Gamma Energy, MeV</u>	<u>Decontamination Factor</u>
2.0	¹³⁷ Cs	0.662	0.96
	⁸⁵ Sr	0.514	1.93
	⁶⁰ Co	1.17	0.97
		1.33	0.97
	⁵⁹ Fe	1.10	1.10
		1.29	1.13
3.0	¹³⁷ Cs	0.662	0.93
	⁸⁵ Sr	0.514	1.60
	⁶⁰ Co	1.17	1.00
		1.33	1.00
	⁵⁹ Fe	1.10	1.00
		1.29	1.03

III. RELEASE OF CESIUM FROM UREA-FORMALDEHYDE IN STATIC LEACHING

The leachability of cesium from urea-formaldehyde was determined by use of the static method described in Appendix B. The effect of the leachant renewal interval and the ratio of the leachant volume (V_L) to the sample external geometric surface area (S) on the release of cesium was examined. This and previously reported leach data⁽²⁾ utilized atomic adsorption spectrophotometry for leachant analysis. Further leaching experiments will be performed with radiotracers using recently procured counting equipment for leachant analysis. This procedure will provide more rapid leachant analyses with lower detectability limits while largely avoiding the matrix effects inherent with the analyses of low species concentration by atomic adsorption.

Urea-formaldehyde leach specimens were prepared by solidifying distilled water with Borden Casco-Resin 2 at a water/UF volume ratio of 2.0. Specimens were prepared in 0.50 inch I.D. lucite tubes which were sealed with a removable teflon plug at one end. The amount of water and urea-formaldehyde to provide a cylindrical sample approximately one inch in length at the desired water/UF volume ratio had been previously determined. An addition of 0.50 gram of cesium as cesium chloride was made to each specimen by dissolution in distilled water prior to the addition of UF. After the urea-formaldehyde was added, the contents of each specimen tube were thoroughly mixed. Two volume percent of a saturated aqueous sodium bisulfate solution was added as a polymerization catalyst, after which the water-UF mixture was again stirred and the specimen tube sealed to prevent water loss by evaporation. The urea-formaldehyde specimens were allowed to cure for three days before leach testing was begun.

Screw closure wide mouth polymethylpentene leachant solution containers with a nominal capacity of 1,000cm³ were employed. Any free standing water present in the specimen preparation tube as the specimen was removed was added to the leachant solution container. Specimen mass and dimensions were recorded. Each specimen was placed on a small lucite support in its leachant container which allowed the entire surface of the

specimen to be exposed to the leachant. Sufficient distilled water leachant was added without impinging directly on the leach specimen to provide the desired ratio of the leachant volume (V_L) to the external geometric surface area (S) of the specimen. Ratios of (V_L/S) of from 2.5cm to 20cm were utilized. At specified intervals, the specimens were removed from their leach containers and an aliquot of stirred leachant solution taken for analysis by a Perkin-Elmer model 306 atomic adsorption spectrophotometer. The leachant containers and specimen stands were rinsed in distilled water, the specimens replaced and a fresh volume of distilled water leachant added.

Figures 3-6 illustrate the cesium release at $V_L/S = 20\text{cm}$ with leachant renewal periods of twice/day, once/day, twice/week and once/week respectively. Corresponding data is shown in Figures 7-10 for $V_L/S = 10\text{cm}$. Figures 11 and 12 give data for the cesium release at $V_L/S = 5.0\text{cm}$ and 2.5cm respectively for a leachant renewal period of once/day. The once/day leachant renewal period is specified in the leach test procedure found in Appendix B and includes leachant renewal after ten minutes, one hundred minutes and six hours of leaching during the first day. The twice/day leachant renewal period could not be provided at twelve hour intervals due to the length of the working day; leachant renewal occurred twice/day but after alternating incremental time intervals of eight and sixteen hours. No leachant sampling and renewal took place during weekends. Triplicate specimens were utilized for each experiment shown in Figures 3-12. Average curves were calculated and combined in Figures 13-15. Figure 13 illustrates the effect of the V_L/S ratio on cesium release for once/day leachant renewal, while Figures 14 and 15 show the effect of the various leachant renewal intervals on cesium release for V_L/S ratios of 10cm and 20cm respectively. Leach rates are reported in these figures as $[(\text{cumulative fraction cesium release}) \times (\text{specimen volume to exposed surface ratio})]$ or $(\sum a_n/A_0) \times (V/S)$ versus $\sum t_n$ where,

a_n = amount of the species of interest removed during leaching
period n

$\sum a_n$ = cumulative amount of the species of interest during all
leaching periods

Figure 3. $(\Sigma a_n/A_0) \times (V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Twice Per Day with $(V_L/S) = 20 \text{ cm}$.

Figure 4. $(\sum a_n/A_0) \times (V/S)$ Versus $\sum t_n$ for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Once Per Day with $(V_L/S) = 20 \text{ cm}$.

Figure 5. $(\Sigma a_n/A_0) \times (V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Twice Per Week with $V_L/S = 20$ cm.

Figure 6. $(\sum a_n/A_0) \times (V/S)$ Versus $\sum t_n$ for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Once Per Week with $(V_L/S) = 20 \text{ cm}$.

Figure 7. $(\sum a_n/A_0)x(V/S)$ Versus $\sum t_n$ for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Twice Per Day with $(V_L/S) = 10 \text{cm}$.

Figure 8. $(\Sigma a_n/A_0)x(V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Once Per Day with $(V_L/S) = 10 \text{ cm}$.

Figure 9. $(\Sigma a_n/A_0) \times (V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Twice Per Week with $(V_L/S) = 10 \text{ cm}$.

Figure 10. $(\Sigma a_n/A_0)x(V/S)$ Versus Σt_n for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Once Per Week with $(V_L/S) = 10 \text{cm}$.

Figure 11. $(\Sigma n/A_0) \times (V/S)$ Versus Σt_n for Cesium Removal from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Once Per Day with $V_L/S = 5.0 \text{ cm}$.

Figure 12. $(\sum a_n/A_0) \times (V/S)$ Versus $\sum t_n$ for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Interval is Once Per Day with $(V_L/S) = 2.5 \text{ cm}$.

Figure 13. $(\Sigma a_n/A_o) \times (V/S)$ Versus Σt_n as a Function of (V_L/S) for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. Leachant Renewal Frequency is Once Per Day.

Figure 14. $(\Sigma a_n/A_0)x(V/S)$ Versus t_n as a Function of Leachant Renewal Frequency for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. $V_L/S = 10 \text{cm}$.

Figure 15. $(\Sigma a_n/A_0) \times (V/S)$ Versus Σt_n as a Function of Leachant Renewal Frequency for Cesium Release from Urea-Formaldehyde by Static Leaching in Distilled Water. $V_L/S = 20\text{cm}$.

A_0 = amount of the species of interest initially present in the specimen

V = volume of the specimen, cm^3

S = exposed geometric surface area of the specimen, cm^2

t_n = leachant renewal period, days

Σt_n = cumulative leach time, days

The factor (V/S) is included so that the cesium release as expressed is independent of specimen geometry and size for leach times which are short relative to total release of the species of interest. The ordinate in Figures 3-15 is also expressed as cumulative fraction release cesium. This value is dependent upon the value of the ratio V/S which does vary somewhat between specimens. As a result the expressed cumulative fraction release is approximate. Accurate values are obtained by dividing the value of $(\Sigma a_n/A_0) \times (V/S)$ by (V/S) . Appendix C contains sample descriptions and leach data for individual samples.

As shown in Figures 3-12, there is good agreement between the triplicate leach specimens. Figure 13 indicates that $(\Sigma a_n/A_0) \times (V/S)$ is not highly dependent upon the (V_L/S) ratio employed for cesium release from urea-formaldehyde with a once/day leachant renewal frequency. This may, however, result from the rapidity with which cesium is lost from the specimens. Figures 14 and 15 illustrate that the leach rate expressed is dependent upon the leachant renewal period. Because the majority of the initially contained cesium is removed from the specimen in the first day of leaching, leach rates expressed as a result of the first sampling at twice/week or once/week intervals average this release over a considerable time interval. These figures also indicate the insensitivity of the cesium release to (V_L/S) ratios of 10cm and 20cm for all leachant renewal intervals used.

The static leaching results obtained here for cesium removal considered with those reported earlier for strontium release from cement imply that the leachant renewal interval of once/day and (V_L/S) ratio of 10cm which are proposed for use appear satisfactory over a fairly wide range of leachability.

Leachability expressed as $(\Sigma a_n/A_0) \times (V/S)$ with time is independent of sample geometry and size for cumulative leach times which are short relative to a total release of the species of interest, i.e., times for which a finite specimen can be approximately treated as a semi-infinite medium. When this condition is satisfied, the fraction release for a given leach time can be compared for specimens of different geometry and/or size by use of the respective (V/S) ratios as follows:

$$(\Sigma a_n/A_0)_1 (V/S)_1 = (\Sigma a_n/A_0)_2 (V/S)_2 \quad (2)$$

$$\frac{(\Sigma a_n/A_0)_1}{(\Sigma a_n/A_0)_2} = \frac{(V/S)_2}{(V/S)_1} \quad (3)$$

The (V/S) ratios for the leach specimens reported here are approximately 0.51cm. However, the (V/S) ratios for waste forms solidified in containers typically used for radwaste disposal are significantly different. For example, the (V/S) ratios for waste forms solidified in 55 gallon drums and one supplier's 300ft³ vaults are approximately 10.8cm and 36cm respectively. Thus, the cumulative fraction release of the species of interest for a given leach time from such a waste form is expected to be considerably lower than that described in this report for a comparable waste formulation. If $(\Sigma a_n/A_0) \times (V/S)$ is proportional to $t^{1/2}$ such as in a simple diffusion model (and the proportionality constant is equal for similar waste form formulations), the time required for a given fraction release of the species of interest for similar formulations of different geometry and/or size can be expressed as:

$$t_2 = \left[\frac{(V/S)_2}{(V/S)_1} \right]^2 t_1 \quad (4)$$

After the accumulation of sufficient leach data in this program for UF and other waste forms, this data will be employed in predictive modeling efforts.

IV. PROPERTIES OF THE DOW SOLIDIFICATION AGENT

Dow Industrial Service (DIS), a division of Dow Chemical Company, has developed a proprietary organic polymer agent for the solidification of radioactive wastes. Polymerization is achieved by an addition mechanism using a promoter-catalyst system which permits curing without the application of external heat. Wastes are entrapped in the polymer matrix; no chemical reaction between the waste and the solidification agent takes place. DIS has successfully applied this agent to the solidification of a number of simulated and some actual waste streams using waste/binder volume ratios of from 1.0 to over 2.0. Arrangements were made to receive samples of water solidified with this agent at water/binder ratios of 1.0, 1.5, and 2.0 by volume. These samples were right circular cylinders with a diameter of approximately 1.8 inches and 3.1 inches in length. Efforts are currently being directed at obtaining the necessary materials and formulations required for the preparation of additional samples and/or the acquisition of samples as required for further testing.

A. Weight Loss from Dow Solidification Agent Specimens Upon Exposure to Ambient Air

Samples of the Dow solidification agent produced at water/binder volume ratios of 1.0, 1.5, and 2.0 were examined for weight loss versus time with exposure to ambient air. Specimens tested were cylindrical disks with a diameter of 4.68cm and a thickness of 1.20cm cut from the samples supplied by DIS. The external geometric surface area of these specimens as tested was 52.0cm². Figure 16 shows the percentage initial weight of these specimens as a function of time with exposure to ambient air at 72°F and 57% relative humidity. Weight loss occurred most rapidly in the first days of testing and was greater for increasing water/binder ratios. After 70 days, the percentage weight losses observed were 17.5%, 28.0%, and 41.6% for water/binder volume ratios of 1.0, 1.5, and 2.0 respectively. Weight loss is due to the loss of water from the specimens by evaporation; this loss was not complete after seventy days as indicated by the continuing although decreasing loss of weight with time. The

Figure 16. Percentage Initial Weight Versus Time in Ambient Air for Dow Solidification Agent Specimens (72°F, 57% RH). Specimen Surface Area = 52.0cm².

specific gravity of the polymer is not reported by Dow, but is said to be slightly greater than 1.0. If the specific gravity is assumed to be 1.1, the weight loss after seventy days corresponds to the removal of 36.8 wt.%, 48.5 wt.%, and 64.4 wt.% of the contained water for water/binder ratios of 1.0, 1.5, and 2.0 respectively. The percentage of contained water removed per unit time was found to increase as the ratio of the water to binder is increased. Specimens placed in air tight containers showed no weight loss over a period of seventy days. This data may be compared to that reported for the weight loss of urea-formaldehyde specimens upon exposure to ambient air.⁽²⁾

While prolonged exposure to ambient air is not expected during the interim storage, transportation, or burial it may occur through such means as inadequate sealing of drum covers or as a result of an accident. In such cases, the rate at which water is lost would be dependent on the exposed surface area of the waste form and its volume in addition to environmental factors such as temperature and humidity. The relative water loss from specimens tested under similar conditions (where weight loss is due predominantly to water loss by evaporation) may be compared by considering the product of the (fractional water or weight loss) $\times (V/S)$ where V is the specimen volume and S is its external geometric surface area. The loss of water by evaporation from a waste form may affect its mechanical properties possibly resulting in a reduction or loss of integrity but is not, with some exceptions, e.g., tritium, expected to lead to a removal of activity. No obvious losses in sample integrity such as friability or cracking were observed in the Dow specimens although substantial weight losses did occur. Additional testing to quantify the effects of water loss on important mechanical parameters is desirable. For solidification agents in which water is not chemically combined, the water loss occurring on exposure to ambient air is related to the permeability of the material. As such, if contained radionuclides are not adsorbed on additives, do not react chemically with the solidification agent itself, and/or are not physically entrapped particles of low solubility, the leachability of the waste form may be related to its

water loss on exposure to ambient air.

B. Thermogravimetric Analysis

A Perkin-Elmer TGS-2 thermogravimetric analyzer was used to study the weight loss of Dow solidification agent specimens with water/binder ratios of 1.0, 1.5, and 2.0 by volume over a temperature range of 25°C-600°C. A scanning rate of 10°C per minute was employed with a nitrogen sample atmosphere. The average percentage initial weight loss as a function of temperature is shown in Figure 17 for the average of triplicate samples at each water/binder ratio. The data for individual water/binder ratios with the associated data spread is given in Figures 18-20. These curves indicate two temperature regimes over which the majority of the weight loss takes place. Weight losses occurring from 50°C-200°C correspond to the loss of water by evaporation. The onset of polymer decomposition begins at approximately 350°C and is essentially complete at 500°C. The rate of weight loss during polymer decomposition is a maximum at 447°C. The loss of weight due to water evaporation below 200°C increases as the water/binder volume ratio increases. Note that the percentage initial weight at 200°C-350°C is approximately equal for water/binder volume ratios of 1.5 and 2.0, while relatively little weight loss occurs to this temperature for a ratio of 1.0. These water losses may not accurately depict the behavior of the polymer at these water/binder ratios because the composition of the small samples used for TGA analysis may not be representative of the average composition of the specimens from which they were taken.

C. Thermal Conductivity

The thermal conductivity at 100°F of the Dow solidification agent at water/binder volume ratios of 1.0, 1.5, and 2.0 was determined with a Dynatech Model TCHM-G unidirectional heat flow thermal conductance analyzer. Cylindrical test samples with a diameter of 1.8 inches and a thickness of 0.50 inch were prepared from the specimens supplied by Dow. Table 7 is a summary of the measured thermal conductivities of these specimens which is shown to vary with the percentage initial weight

Figure 17. Thermogravimetric Weight Loss for Dow Solidification Agent Specimens.

Figure 18. Thermogravimetric Weight Loss for Dow Solidification Agent (Volume Ratio H_2O /Binder = 1.0).

Figure 19. Thermogravimetric Weight Loss for Dow Solidification Agent (Volume Ratio H_2O /Binder = 1.5).

Figure 20. Thermogravimetric Weight Loss for Dow Solidification Agent (Volume Ratio H_2O /Binder = 2.0).

TABLE 7

Thermal Conductivity at 100°F of the Dow Solidification Agent

<u>Water/Binder Volume Ratio</u>	<u>Percentage Initial Weight</u>	<u>Thermal Conductivity Btu/(hr-ft-°F)</u>
2.0	100.0	0.55
	94.5	0.56
	90.5	0.49
	81.7	0.42
	70.9	0.32
1.5	100.0	0.56
	93.0	0.54
	88.0	0.45
	80.0	0.35
1.0	100.0	0.55
	94.1	0.47
	91.8	0.35

(water loss) of the test specimens. The thermal conductivity is seen to decrease as water is lost from the specimens.

D. Compressive Strength

Compressive strength measurements were made using Dow solidification agent samples at water/binder ratios of 1.0, 1.5, and 2.0. Test samples were cylindrical with a diameter of 1.81 inches and a length of 3.1 inches. Compressive strength data listed in Table 8 represent an average of three specimens tested at a water/binder volume ratio of 1.5 while one specimen each was tested at ratios of 1.0 and 2.0. The number of samples tested was limited due to availability. After compressive failure, small quantities of water were observed as droplets on the fracture fragments, apparently squeezed out of the test specimens.

E. Unnotched Izod Impact Strength

The unnotched Izod impact strength of Dow solidification agent specimens at water/binder volume ratios of 1.0, 1.5, and 2.0 were determined by the method described in ASTM D-256-73 Method C using a Tinius-Olsen Model 66 impact tester. Rectangular prisms specimens with dimensions of 0.5 inches x 0.5 inches x 2.5 inches were cut from the samples supplied by Dow. Fifteen specimens with a water/binder volume ratio of 1.5 were tested with seven specimens tested at ratios of 1.0 and 2.0. The data obtained are shown in Table 9.

TABLE 8

Compressive Strength of Dow Solidification Agent Specimens

<u>Water/Binder Volume Ratio</u>	<u>Sample Diameter, in</u>	<u>Sample Length, in</u>	<u>Compressive Strength lbs/in²</u>
1.0	1.81	3.13	2920
1.5	1.81	3.09	2140±40
2.0	1.81	3.07	1280

TABLE 9

Unnotched Izod Impact Strength of Dow Solidification Agent Specimens

<u>Water/Binder Volume Ratio</u>	<u>Impact Strength (in-lbs/in)</u>	<u>Standard Deviation (in-lbs/in)</u>
2.0	5.06	0.57
1.5	6.84	1.43
1.0	8.60	1.13

V. FREEZE-THAW RESISTANCE OF PORTLAND TYPE II CEMENT

The resistance of portland type II cement at a water/cement ratio of 0.5 by weight to deterioration by freeze-thaw cycling was investigated. A cylindrical specimen with a diameter of 1.0 inch and 2.0 inches in length with a thermocouple placed axially in the center of the specimen was prepared. The specimen was allowed to cure for three weeks in a sealed container, after which it was removed, set on a small test stand, sealed in a plastic bag and placed into a freezer. The specimen was cycled through fifty freeze-thaw cycles with no apparent deterioration. The duration of freeze-thaw cycles was varied from six minutes to five days. A 1.3% decrease in weight due to water loss from the specimen was observed.

References

1. Colombo, P. and Neilson, R.M., Jr., "Properties of Radioactive Wastes and Containers", July-September 1976, BNL-NUREG-50617, Brookhaven National Laboratory, Upton, New York, 1976.
2. Colombo, P. and Neilson, R.M., Jr., "Properties of Radioactive Wastes and Containers", April-June 1976, BNL-NUREG-50571, Brookhaven National Laboratory, Upton, New York, 1976.

Appendix A
Waste Formulations

The following are the chemical formulations of the waste types to be included in the experimental program. The temperature and pH reported are typical values prior to solidification at reactor sites. Actual reactor wastes exhibit substantial variations in composition both between reactors and at a given reactor with time.

1. BEAD RESIN WASTE

<u>Material</u>	<u>Weight Percent, %</u>
Water ^a	50.
Bead Resin (IRN-150) ^b	50.
Temperature	70°F
pH	7

2a. BWR PRECOAT FILTER CAKE (WITH POWDERED RESIN)

<u>Material</u>	<u>Weight Percent in Filter Cake, %</u>
Water ^a	50.
Anion Powdered Resin (PAO) ^c	20.
Cation Powdered Resin (PCH) ^c	20.
Crud ^c	5.
Sodium Chloride	5.
Temperature	70°F
pH	7

2b. BWR PRECOAT FILTER CAKE (WITH DIATOMACEOUS EARTH)

<u>Material</u>	<u>Weight Percent in Filter Cake, %</u>
Water	50.
Diatomaceous Earth	40.
Crud ^d	10.
Temperature	70°F
pH	7

3a. BWR CHEMICAL REGENERATIVE WASTE OF A FORCED RECIRCULATION EVAPORATOR

<u>Material</u>	<u>Weight Percent in Evaporator Bottoms, %</u>
Water	75.
Sodium Sulfate	22.9
Sodium Chloride	2.0
Crud ^d	0.1
Temperature	170°F
pH	6

3b. PWR CHEMICAL REGENERATIVE WASTE OF A FORCED RECIRCULATION EVAPORATOR

<u>Material</u>	<u>Weight Percent in Evaporator Bottoms, %</u>
Water	73.4
Sodium Sulfate	14.9
Ammonium Sulfate	9.6
Sodium Chloride	2.0
Crud ^d	0.1
Temperature	170°F
pH	2.5 to 4.0

3c. BORIC ACID WASTE OF A FORCED RECIRCULATION EVAPORATOR

<u>Material</u>	<u>Weight Percent in Evaporator Bottoms, %</u>
Water	87.9
Boric Acid	12.0
Crud ^d	0.1
Temperature	170°F
pH	3.5

3d. DECONTAMINATION WASTE OF A FORCED RECIRCULATION EVAPORATOR

<u>Material</u>	<u>Weight Percent in Evaporator Bottoms, %</u>
Water	80.
Nutek NT-700 ^e	9.4
EDTA	5.
Citric Acid	5.
Crud ^d	0.2
Hydraulic Oil No. 2	0.2
Lubricating Oil No. 20	0.2
Temperature	170°F
pH	5

4a. BWR CHEMICAL REGENERATIVE WASTE OF A THIN FILM EVAPORATOR

<u>Material</u>	<u>Weight Percent in Evaporator Bottoms, %</u>
Water	50.
Sodium Sulfate	45.8
Sodium Chloride	4.0
Crud ^d	0.2
Temperature	150 to 250°F
pH	6

4b. PWR CHEMICAL REGENERATIVE WASTE OF A THIN FILM EVAPORATOR

<u>Material</u>	<u>Weight Percent in Evaporator Bottoms, %</u>
Water	50.
Sodium Sulfate	29.
Ammonium Sulfate	16.8
Sodium Chloride	4.0
Crud ^d	0.2
Temperature	150 to 250°F
pH	1.8 to 4.0

4c. BORIC ACID WASTE OF A THIN FILM EVAPORATOR

<u>Material</u>	<u>Weight Percent in Evaporator Bottoms, %</u>
Water	50.
Boric Acid	49.8
Crud ^d	0.2
Temperature	150 to 250°F
pH	2.5 to 3.5

4d. DECONTAMINATION WASTE OF A THIN FILM EVAPORATOR

<u>Material</u>	<u>Weight Percent in Evaporator Bottoms, %</u>
Water	50.
Nutec NT-700 ^e	20.
EDTA	9.8
Citric Acid	19.
Crud ^d	0.2
Hydraulic Oil No. 2	0.5
Lubricating Oil No. 20	0.5
Temperature	150 to 250°F
pH	5

- ^a additional to water contained in resin as received
- ^b as received, Rohm and Haas Co., Philadelphia, Pa. 19105
- ^c as received, Ecodyne Corp., Union, N.J. 07083
- ^d fine air cleaner test dust no. 1543094, AC Spark Plug Division,
General Motors Corp., Flint, Michigan 48556
- ^e Nuclear Technology Corp., Amston, Conn. 06231

Appendix B

Proposed Standard Static Leach Test Procedure for Solidified Radioactive Wastes

(This procedure is based on that proposed by the IAEA with minor modifications)

I. INTERCOMPARISON METHOD

1. Requirements for Specimen and Leachant Containers

1.1 Materials of Construction

1.1.1 Specimen Container

The specimen container shall be constructed of a material which:

- (a) will not react chemically with the specimen
- (b) is not sorbent towards the ions extracted from the sample by the leachant

- (c) will withstand the conditions involved in sample preparation

If the leach test is performed with the specimen in the specimen container, the material from which the specimen container is constructed must meet these additional criteria:

- (d) it will not react chemically with the leachant
- (e) it will not be affected by the radiation dose received during testing
- (f) it is not sorbent towards the ions originally present in the leachant

It is recommended, whenever possible, that the specimen not be leach tested in its specimen container.

1.1.2 Leachant Container

The container for the leachant shall be constructed of a material which:

- (a) will not react chemically with the leachant
- (b) is not sorbent towards the ions extracted from the sample by the leachant
- (c) will not be affected by the radiation dose received during the test

1.1.3 A blank run will be made to determine the leach rate of the apparatus.

1.2 Dimensions and Form

- 1.2.1 The specimen container shall be of cylindrical form open at one end, or in the form of a support or envelope with sufficient openings and so shaped that maximum contact between the leachant and all exposed specimen surfaces is achieved. The specimen container dimension and specimen size may vary and will be selected so that the procedure being used for analyzing the leached material in the leachant will have satisfactory accuracy. In the event that a granulated specimen is required for a material of very low leachability, the size of the individual granules must be large enough so that an appreciable portion of each specimen particle will maintain its original composition throughout the tests. This requirement will be assumed to be met if the data from replicate analyses agree.
- 1.2.2 The dimensions of the leachant (outer) container shall be such that the exposed surface of the sample be covered by at least 2.54cm of leachant. If the specimen is not covered to this depth with leachant, the depth used along with the reason for deviation shall be reported.

2. Requirements for Specimen Preparation

2.1 Sampling

Suitable precautions shall be taken to ensure that the sample is representative of the process material, and that the homogeneity of the test specimen is the same as that of the process material.

2.2 Sample Preparation

2.2.1 Cement or Concrete/Waste Mixtures

The mixtures shall be cast in a convenient form which facilitates surface area and volume calculations. The specimen shall be cured in a manner representative of the conditions expected to be used in actual waste processing. The history of the specimen during preparation and between the time of preparation and leaching

shall be recorded, including temperature, humidity, storage atmosphere, and cure time. It is preferable that the specimen be removed from its container for leaching, although it may be leached in the container in which it was cast. If desired, new surfaces may be exposed by sawing or other techniques, or part of the surface may be coated with a waterproofing material. In any case, the surface area exposed to the leachant shall be known. Whenever possible representative specimens should be obtained from actual waste forms.

2.2.2 Urea-Formaldehyde Waste Mixtures

The mixtures shall be cast in a convenient form which facilitates surface area and volume calculations. The specimen shall be prepared in a manner representative of the conditions expected to be used in actual waste processing. The history of the specimen during preparation and between the time of preparation and leaching shall be recorded, including temperature, humidity, storage atmosphere, and elapsed time. It is preferable that the specimen be removed from its container for leaching, although it may be leached in the container in which it was cast. If desired, new surfaces may be exposed by sawing or other techniques, or part of the surface may be coated with a waterproofing material. In any case, the surface area exposed to the leachant shall be known. Whenever possible representative specimens should be obtained from actual waste forms.

2.2.3 Bitumen Waste Mixtures

The mixtures shall be cast in a convenient form which facilitates surface area and volume calculations. The specimen shall be prepared in a manner representative of the conditions expected to be used in actual waste processing. The history of the specimen during preparation and between the time of preparation and leaching shall be recorded, including temperature, humidity, storage atmosphere, and elapsed time. It is preferable that the specimen be removed from its container for leaching, although it may be leached

in the container in which it was cast. If desired, new surfaces may be exposed by sawing or other techniques, or part of the surface may be coated with a waterproofing material. In any case, the surface area exposed to the leachant shall be known. Whenever possible representative specimens should be obtained from actual waste forms.

3. Test Method

3.1 Leachant

The leachant shall be distilled or deionized water.

3.1.1 The pH of the leachant shall be determined and recorded.

3.2 Temperature of the Test

The leaching shall be performed at a temperature of $25^{\circ}\pm 5^{\circ}\text{C}$ and the temperature of the test recorded to the nearest degree.

3.3 Procedure

3.3.1 Prior to placing in the leachant solution container, all fines and dust, such as might result from sawing or crushing a granulated sample shall be removed from the specimen by a technique that is not expected to result in a removal of the species of interest from the specimen. Free standing water, if present, will be added to the leachant solution container.

3.3.2 The specimen shall be placed in the leachant container and sufficient leachant added to ensure that the specimen is covered by at least 2.54cm. The ratio of the volume of leachant to the external geometric surface area of the specimen exposed to the leachant shall not be less than 2.5cm or exceed a ratio which results in an appreciable decrease in leachant analysis accuracy. The leachant shall be added carefully so as not to impinge directly on the exposed face of the specimen.

3.3.3 The leachant container shall be lightly covered and allowed to stand undisturbed until sampling is necessary.

3.3.4 At sampling the specimen shall be removed from the leachant container and the leachant thoroughly mixed. During sampling of the leachant, care will be taken to prevent any solid residue from following the solution.

A sample of the leachant sufficient for replicate analysis shall be taken and the remainder discarded.

Leachant shall be allowed to drain off the specimen; however, the specimen will not be rinsed.

The leachant container will be rinsed after which the specimen will be replaced and covered with a fresh portion of leachant of the same volume and the test shall proceed.

3.4 Sampling Frequency

3.4.1 At ten minutes after the start of the test

3.4.2 After one hundred minutes of leaching

3.4.3 After six hours of leaching

3.4.4 After twenty-four hours of leaching

3.4.5 After each successive twenty-four hour period during the work week for at least the first four weeks. Leaching should begin on Monday whenever possible.

3.4.6 Once per week during the following five months.

3.4.7 Once per month for the following six months and then,

3.4.8 Twice per year for as long as is considered necessary.

3.4.9 Sampling may be performed more frequently than expressed in this section.

3.5 Analysis

3.5.1 The leachant sample shall be mixed and allowed to settle

3.5.2 On the clear supernatant solution the following determinations shall be made and recorded:

3.5.2.1 pH value

- 3.5.2.2 Analysis of the desired constituents leached from the specimen by the best available means.
- 3.5.3 The methods of analysis used, together with the standard deviation and the rated accuracy and precision of the method shall be reported.
- 3.5.4 The same analytical methods shall be used to determine the concentrations of specific elements in the mixture of waste/immobilizing material and in the sample of the leachant. Should this not be practical, an assessment should be made of the effect on the results of the use of different methods and reported with the results.

4. Reporting of Results

- 4.1 Information concerning the specimen tested when reporting the results of leaching tests, the following information concerning the specimen tested shall be reported:
 - 4.1.1 The proportion by weight or volume of waste incorporated in the mixture;
 - 4.1.2 The type, chemical and radioisotopic composition, and specific activity of the waste incorporated in the mixture;
 - 4.1.3 The type and composition of the immobilizing material including any additives or catalyzing agent;
 - 4.1.4 Any departures from the specified methods for specimen preparation.
 - 4.1.5 The history of the specimen between preparation and leaching.
- 4.2 Information concerning the test procedure.
 - 4.2.1 The volume of leachant shall be reported.
 - 4.2.2 Any departures from the specified testing procedure shall be reported together with the reasons for the departure.
- 4.3 Reporting the leach results.

4.3.1 The amount of each element leached or radioactivity proportional to the amount leached (a_n), during each leachant renewal period (n) shall be presented in tabular form along with the duration, in days, of the leachant renewal period (t_n). The following information shall accompany the tabulated leach data:

A_0 = total amount, or radioactivity proportional to the total amount, of the element initially present in the specimen.

S = exposed geometric surface area of the specimen (cm^2).

V = volume of the specimen (cm^3).

M = mass of the specimen (g).

The method used to determine the surface area and volume of the specimen shall be described.

The intent of the foregoing is to assure that the "raw" data are made available in an accessible and unambiguous form.

It is recommended that the data be tabulated as (a_n/A_0) (V/S) ($1/t_n$) with the units of (fraction leached) (cm) (day^{-1}). It is suggested that ($\Sigma a_n/A_0$) (V/S) also be tabulated.

4.3.2 The results may, in addition, be expressed graphically, by, for instance, ($\Sigma a_n/A_0$) (V/S) as a function of the total time of leaching.

II. ENVIRONMENTAL METHOD

The leach test described here is not meant to predict the actual performance of the immobilized waste in the conditions of the disposal environment. It is intended to provide information which will permit a reasonably realistic assessment of the hazards associated with the disposal of a specific waste form in a specific environment.

1. Requirements for Specimen and Leachant Containers

The same requirements apply as specified for the intercomparison method.

2. Requirements for Specimen Preparation

The same requirements apply as specified for the intercomparison method.

3. Test Method

The same procedure applies as specified for the intercomparison method, except that:

- 3.1 The water of the disposal environment shall replace distilled or deionized water as the leachant.
- 3.2 The chemical composition, pH, and other leachant parameters deemed significant shall be determined and recorded before the test commences.

Appendix C

Experimental Leach Data

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 36-1

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.49g
Volume	- 25.84cm^3
Exposed Surface Area	- 50.83cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 1014cm^3
Leachant Replacement Interval	- daily

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.00694	6.94×10^{-3}	2.90	8.50×10^{-2}	8.50×10^{-2}
0.0625	6.94×10^{-2}	3.11	2.04×10^{-1}	2.89×10^{-1}
0.181	2.50×10^{-1}	3.41	1.10×10^{-1}	4.00×10^{-1}
0.75	1	3.56	1.09×10^{-1}	5.08×10^{-1}
1	2	4.22	2.83×10^{-3}	5.11×10^{-1}
1	3	5.34	3.26×10^{-4}	5.12×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 36-2

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 30.60g
Volume	- 27.36cm^3
Exposed Surface Area	- 53.23cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 1014cm^3
Leachant Replacement Interval	- daily

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.00694	6.94×10^{-3}	2.78	8.39×10^{-2}	8.39×10^{-2}
0.0625	6.94×10^{-2}	3.00	1.76×10^{-1}	2.67×10^{-1}
0.181	2.50×10^{-1}	3.22	2.09×10^{-1}	4.82×10^{-1}
0.75	1	3.54	4.07×10^{-2}	5.07×10^{-1}
1	2	4.41	2.80×10^{-3}	5.12×10^{-1}
1	3	4.71	2.04×10^{-4}	5.12×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 36-3

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 30.58g
Volume	- 27.40cm^3
Exposed Surface Area	- 53.23cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 1014cm^3
Leachant Replacement Interval	- daily

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.00694	6.94×10^{-3}	2.78	9.27×10^{-2}	9.27×10^{-2}
0.625	6.94×10^{-2}	3.01	2.67×10^{-1}	3.60×10^{-1}
0.181	2.50×10^{-1}	3.26	9.47×10^{-2}	4.55×10^{-1}
0.75	1	3.64	5.58×10^{-2}	5.11×10^{-1}
1	2	4.38	2.62×10^{-3}	5.12×10^{-1}
1	3	4.66	2.67×10^{-4}	5.12×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 36-4

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.80g
Volume	- 26.86cm^3
Exposed Surface Area	- 52.43cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 1014cm^3
Leachant Replacement Interval	- once a week

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
7	7	2.83	4.95×10^{-1}	4.95×10^{-1}
8	15	4.29	1.16×10^{-2}	5.07×10^{-1}
6	21	6.27	6.55×10^{-4}	5.08×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 36-5

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.10g
Volume	- 25.34cm^3
Exposed Surface Area	- 50.03cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 1014cm^3
Leachant Replacement Interval	- once a week

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
7	7	2.86	4.93×10^{-1}	4.92×10^{-1}
8	15	4.24	1.47×10^{-2}	5.07×10^{-1}
6	21	6.32	7.52×10^{-4}	5.08×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 36-6

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 28.92g
Volume	- 25.34cm^3
Exposed Surface Area	- 50.03cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 1014cm^3
Leachant Replacement Interval	- once a week

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
7	7	2.73	4.94×10^{-1}	4.94×10^{-1}
8	15	4.47	1.33×10^{-2}	5.07×10^{-1}
6	21	6.41	6.84×10^{-4}	5.08×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM

UREA-FORMALDEHYDE SPECIMEN 36-7

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 28.65g
Volume	- 24.83cm^3
Exposed Surface Area	- 49.23cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 1014cm^3
Leachant Replacement Interval	- twice a week

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
3.31	3.31	2.82	4.84×10^{-1}	4.91×10^{-1}
3.69	7.00	3.59	2.04×10^{-2}	5.04×10^{-1}
3.31	10.31	4.64	6.44×10^{-4}	5.04×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 36-8

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.12g
Volume	- 25.34cm^3
Exposed Surface Area	- 50.03cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 1014cm^3
Leachant Replacement Interval	- twice a week

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
3.31	3.31	2.78	4.83×10^{-1}	4.83×10^{-1}
3.69	7.00	3.71	2.00×10^{-1}	5.03×10^{-1}
3.31	10.31	4.88	8.89×10^{-4}	5.04×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 36-11

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.20g
Volume	- 25.84cm^3
Exposed Surface Area	- 50.83cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 1014cm^3
Leachant Replacement Interval	- twice a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
3.31	3.31	2.76	4.91×10^{-1}	4.84×10^{-1}
3.69	7.00	3.73	1.33×10^{-2}	5.04×10^{-1}
3.31	10.31	5.18	4.61×10^{-4}	5.04×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 36-9

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 27.75g
Volume	- 24.32cm^3
Exposed Surface Area	- 48.43cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 1014cm^3
Leachant Replacement Interval	- twice a week

Leach Time (days)		Final pH of Leachant	(Fraction Release) $\times(V/S)$, cm	
Incremental t_n	Cumulative Σt_n		Incremental $(a_n/A_0)\times(V/S)$	Cumulative $(\Sigma a_n/A_0)\times(V/S)$
0.33	3.33×10^{-1}	2.86	4.37×10^{-1}	4.36×10^{-1}
0.67	1	3.65	6.58×10^{-2}	5.02×10^{-1}
0.33	1.33	4.67	3.24×10^{-3}	5.05×10^{-1}
0.67	2	4.65	2.30×10^{-3}	5.06×10^{-1}
0.33	2.33	5.69	6.33×10^{-5}	5.06×10^{-1}
0.67	3	4.65	6.33×10^{-5}	5.06×10^{-1}
0.33	3.33	5.14	1.27×10^{-4}	5.07×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 36-10

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 28.25g
Volume	- 24.82cm^3
Exposed Surface Area	- 49.23cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 1014cm^3
Leachant Replacement Interval	- twice a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.33	3.33×10^{-1}	2.82	4.30×10^{-1}	4.30×10^{-1}
0.67	1	3.62	7.35×10^{-2}	5.03×10^{-1}
0.33	1.33	3.96	2.81×10^{-3}	5.05×10^{-1}
0.67	2	4.47	9.16×10^{-4}	5.07×10^{-1}
0.33	2.33	5.01	1.81×10^{-4}	5.07×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 36-12

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.0g
Volume	- 25.84cm^3
Exposed Surface Area	- 50.83cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 1014cm^3
Leachant Replacement Interval	- twice a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.33	3.33×10^{-1}	2.82	4.67×10^{-1}	4.66×10^{-1}
0.67	1	3.64	3.80×10^{-2}	5.04×10^{-1}
0.33	1.33	3.93	1.72×10^{-3}	5.06×10^{-1}
0.67	2	4.42	8.05×10^{-4}	5.07×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 40-1

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.73g
Volume	- 26.60cm^3
Exposed Surface Area	- 52.03cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 507cm^3
Leachant Replacement Interval	- once a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.00694	6.94×10^{-3}	3.73	4.58×10^{-2}	4.58×10^{-2}
0.0625	6.94×10^{-2}	3.24	2.26×10^{-1}	2.71×10^{-1}
0.181	2.50×10^{-1}	3.17	1.67×10^{-1}	4.38×10^{-1}
0.75	1	3.55	6.69×10^{-2}	5.05×10^{-1}
1	2	4.35	3.57×10^{-3}	5.09×10^{-1}
1	3	4.95	4.65×10^{-4}	5.10×10^{-1}
3	6	6.94	6.23×10^{-5}	5.10×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 40-2

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.46g
Volume	- 26.35cm^3
Exposed Surface Area	- 51.63cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 507cm^3
Leachant Replacement Interval	- once a week

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.00694	6.94×10^{-3}	3.55	6.77×10^{-2}	6.77×10^{-2}
0.0625	6.94×10^{-2}	3.17	1.67×10^{-1}	2.34×10^{-1}
0.181	2.50×10^{-1}	3.21	1.97×10^{-1}	4.31×10^{-1}
0.75	1	3.55	6.90×10^{-2}	5.00×10^{-1}
1	2	4.35	8.95×10^{-3}	5.09×10^{-1}
1	3	5.09	5.58×10^{-4}	5.10×10^{-1}
3	6	5.40	8.95×10^{-5}	5.10×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 40-3

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 28.70g
Volume	- 26.10cm^3
Exposed Surface Area	- 51.15cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 507cm^3
Leachant Replacement Interval	- once a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.00694	6.94×10^{-3}	3.42	6.78×10^{-2}	6.77×10^{-2}
0.0625	6.94×10^{-2}	3.14	1.90×10^{-1}	2.58×10^{-1}
0.181	2.50×10^{-1}	3.25	2.03×10^{-1}	4.61×10^{-1}
0.75	1	3.55	4.53×10^{-2}	5.06×10^{-1}
1	2	4.55	2.88×10^{-3}	5.09×10^{-1}
1	3	5.21	3.73×10^{-4}	5.10×10^{-1}
3	6	5.58	4.54×10^{-5}	5.10×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 40-4

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 28.43g
Volume	- 25.84cm^3
Exposed Surface Area	- 50.83cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 507cm^3
Leachant Replacement Interval	- once a week

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
6	6	2.83	4.92×10^{-1}	4.92×10^{-1}
7	13	4.38	1.45×10^{-2}	5.07×10^{-1}
7	20	7.03	9.00×10^{-4}	5.08×10^{-1}
9	29	6.15	8.66×10^{-5}	5.08×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 40-5

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 28.43g
Volume	- 25.84cm^3
Exposed Surface Area	- 50.83cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 507cm^3
Leachant Replacement Interval	- once a week

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
6	6	2.68	4.86×10^{-1}	4.86×10^{-1}
7	13	3.97	2.06×10^{-2}	5.07×10^{-1}
7	20	6.99	1.06×10^{-3}	5.08×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 40-6

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 28.43g
Volume	- 25.84cm^3
Exposed Surface Area	- 50.83cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 507cm^3
Leachant Replacement Interval	- once a week

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
6	6	2.73	4.87×10^{-1}	4.86×10^{-1}
7	13	4.01	2.02×10^{-2}	5.07×10^{-1}
7	20	6.78	1.04×10^{-3}	5.08×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 40-7

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.26g
Volume	- 26.60cm^3
Exposed Surface Area	- 52.03cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 507cm^3
Leachant Replacement Interval	- twice a week

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
2.31	2.31	2.67	4.99×10^{-1}	4.98×10^{-1}
3.69	6	4.20	1.09×10^{-2}	5.09×10^{-1}
3.31	9.31	5.25	1.07×10^{-3}	5.11×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 40-8

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.54g
Volume	- 26.86cm^3
Exposed Surface Area	- 52.43cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 507cm^3
Leachant Replacement Interval	- twice a week

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)x(V/S), cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)x(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)x(V/S)$</u>
2.31	2.31	2.68	5.03×10^{-1}	5.04×10^{-1}
3.69	6	3.85	5.94×10^{-3}	5.10×10^{-1}
3.31	9.31	5.47	1.13×10^{-3}	5.11×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 40-9

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.26g
Volume	- 26.60cm^3
Exposed Surface Area	- 52.03cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 507cm^3
Leachant Replacement Interval	- twice a week

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
2.31	2.31	2.72	4.92×10^{-1}	4.92×10^{-1}
3.69	6	3.83	1.75×10^{-2}	5.10×10^{-1}
3.31	9.31	5.67	1.11×10^{-3}	5.11×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 40-10

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 27.87g
Volume	- 25.34cm^3
Exposed Surface Area	- 50.03cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 507cm^3
Leachant Replacement Interval	- twice a day

Leach Time (days)		Final pH of Leachant	(Fraction Release) $\times(V/S)$, cm	
Incremental t_n	Cumulative Σt_n		Incremental $(a_n/A_0)\times(V/S)$	Cumulative $(\Sigma a_n/A_0)\times(V/S)$
0.33	3.33×10^{-1}	2.84	4.09×10^{-1}	4.09×10^{-1}
0.67	1	3.40	8.77×10^{-2}	4.97×10^{-1}
0.33	1.33	4.33	5.78×10^{-3}	5.02×10^{-1}
0.67	2	4.79	2.45×10^{-3}	5.049×10^{-1}
0.33	2.33	5.54	2.72×10^{-4}	5.057×10^{-1}
0.67	3	6.75	2.59×10^{-4}	5.059×10^{-1}
0.33	3.33	6.96	4.12×10^{-5}	5.059×10^{-1}
0.67	6	6.95	3.30×10^{-5}	5.059×10^{-1}
0.33	6.33	7.22	1.65×10^{-5}	5.059×10^{-1}
0.67	7	7.19	1.24×10^{-5}	5.059×10^{-1}
0.33	7.33	7.08	4.12×10^{-6}	5.059×10^{-1}
0.67	8	6.00	4.12×10^{-6}	5.06×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 40-11

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 26.75g
Volume	- 24.32cm^3
Exposed Surface Area	- 48.44cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 507cm^3
Leachant Replacement Interval	- twice a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.33	3.33×10^{-1}	2.79	4.21×10^{-1}	4.22×10^{-1}
0.67	1	3.51	7.88×10^{-2}	4.99×10^{-1}
0.33	1.33	4.42	3.32×10^{-3}	5.03×10^{-1}
0.67	2	4.82	1.39×10^{-3}	5.046×10^{-1}
0.33	2.33	5.63	1.91×10^{-4}	5.053×10^{-1}
0.67	3	5.91	2.66×10^{-4}	5.053×10^{-1}
0.33	3.33	6.51	4.43×10^{-4}	5.055×10^{-1}
0.67	6	6.33	--	5.055×10^{-1}
0.33	6.33	7.17	1.78×10^{-5}	5.058×10^{-1}
0.67	7	7.11	1.33×10^{-5}	5.058×10^{-1}
0.33	7.33	7.12	4.43×10^{-6}	5.058×10^{-1}
0.67	8	6.43	2.13×10^{-4}	5.06×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 40-12

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 27.87g
Volume	- 25.34cm^3
Exposed Surface Area	- 50.03cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 507cm^3
Leachant Replacement Interval	- twice a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.33	3.33×10^{-1}	2.82	4.65×10^{-1}	4.65×10^{-1}
0.67	1	3.56	3.35×10^{-2}	5.00×10^{-1}
0.33	1.33	4.45	3.57×10^{-3}	5.035×10^{-1}
0.67	2	4.89	1.42×10^{-3}	5.05×10^{-1}
0.33	2.33	5.11	2.18×10^{-4}	5.056×10^{-1}
0.67	3	5.43	4.18×10^{-5}	5.056×10^{-1}
0.33	3.33	5.52	1.76×10^{-4}	5.058×10^{-1}
0.67	6	6.03	1.67×10^{-5}	5.059×10^{-1}
0.33	6.33	6.20	1.67×10^{-5}	5.059×10^{-1}
0.67	7	6.45	1.25×10^{-5}	5.059×10^{-1}
0.33	7.33	6.76	1.25×10^{-5}	5.059×10^{-1}
0.67	8	6.26	2.09×10^{-5}	5.06×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 41-1

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 27.87g
Volume	- 25.34cm^3
Exposed Surface Area	- 50.03cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 127cm^3
Leachant Replacement Interval	- once a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.00694	6.94×10^{-3}	2.69	9.73×10^{-2}	9.73×10^{-2}
0.0625	6.94×10^{-2}	2.71	1.42×10^{-1}	2.39×10^{-1}
0.181	2.50×10^{-1}	2.85	2.34×10^{-1}	4.73×10^{-1}
0.75	1	3.30	1.64×10^{-2}	4.90×10^{-1}
1	2	3.85	1.45×10^{-2}	5.04×10^{-1}
1	3	6.14	2.37×10^{-3}	5.06×10^{-1}
3	6	7.28	5.63×10^{-4}	5.07×10^{-1}
1	7	8.86	1.49×10^{-4}	5.07×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 41-2

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.26g
Volume	- 26.60cm^3
Exposed Surface Area	- 52.03cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 127cm^3
Leachant Replacement Interval	- once a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.00694	6.94×10^{-3}	2.91	1.27×10^{-1}	1.27×10^{-1}
0.0625	6.94×10^{-2}	2.82	1.27×10^{-1}	2.54×10^{-1}
0.181	2.50×10^{-1}	2.86	1.58×10^{-1}	4.11×10^{-1}
0.75	1	3.25	7.70×10^{-2}	4.89×10^{-1}
1	2	3.92	1.45×10^{-2}	5.03×10^{-1}
1	3	4.70	2.34×10^{-3}	5.06×10^{-1}
3	6	7.22	7.28×10^{-4}	5.06×10^{-1}
1	7	8.48	1.54×10^{-4}	5.07×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 41-3

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 27.31g
Volume	- 24.83cm^3
Exposed Surface Area	- 49.23cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 127cm^3
Leachant Replacement Interval	- once a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.00694	6.94×10^{-3}	3.07	1.02×10^{-1}	1.02×10^{-1}
0.0625	6.94×10^{-2}	2.99	1.93×10^{-1}	2.95×10^{-1}
0.181	2.50×10^{-1}	2.70	1.18×10^{-1}	4.13×10^{-1}
0.75	1	3.15	7.95×10^{-2}	4.93×10^{-1}
1	2	3.80	1.19×10^{-2}	5.04×10^{-1}
1	3	4.44	1.94×10^{-3}	5.06×10^{-1}
3	6	7.23	4.31×10^{-4}	5.07×10^{-1}
1	7	8.11	9.05×10^{-5}	5.07×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 41-4

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 28.70g
Volume	- 26.10cm^3
Exposed Surface Area	- 51.23cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 253cm^3
Leachant Replacement Interval	- once a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.00694	6.94×10^{-3}	3.15	4.59×10^{-3}	4.59×10^{-2}
0.0625	6.94×10^{-2}	3.43	2.00×10^{-1}	2.47×10^{-1}
0.181	2.50×10^{-1}	3.23	1.27×10^{-1}	3.74×10^{-1}
0.75	1	3.36	1.27×10^{-1}	5.01×10^{-1}
1	2	4.17	1.01×10^{-2}	5.11×10^{-1}
1	3	4.92	1.21×10^{-3}	5.11×10^{-1}
3	6	5.35	1.89×10^{-4}	5.12×10^{-1}
1	7	8.23	2.03×10^{-5}	5.12×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 41-5

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.54g
Volume	- 26.90cm^3
Exposed Surface Area	- 52.43cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 253cm^3
Leachant Replacement Interval	- once a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.00694	6.94×10^{-3}	3.15	6.20×10^{-2}	6.20×10^{-2}
0.0625	6.94×10^{-2}	3.35	1.90×10^{-1}	2.52×10^{-1}
0.181	2.50×10^{-1}	3.27	1.71×10^{-1}	4.23×10^{-1}
0.75	1	3.36	8.24×10^{-2}	5.07×10^{-1}
1	2	4.21	7.11×10^{-3}	5.12×10^{-1}
1	3	4.94	8.06×10^{-4}	5.12×10^{-1}
1	6	5.41	1.34×10^{-4}	5.12×10^{-1}
1	7	7.89	2.06×10^{-5}	5.12×10^{-1}

EXPERIMENTAL RESULTS FOR THE LEACHING OF CESIUM FROM
UREA-FORMALDEHYDE SPECIMEN 41-6

A. Description of Specimen

Waste Type	- water
Waste to Solidification Agent Ratio	- 2:1 by volume
Catalyst	- 2.0 vol.% saturated aqueous NaHSO_4
Cesium Added	- 0.5g (stable)
Mass	- 29.54g
Volume	- 26.90cm^3
Exposed Surface Area	- 52.43cm^2
Curing Time	- 3 days

B. Leach Test Procedure

Leach Test	- static
Leachant	- distilled water
Leachant Volume	- 253cm^3
Leachant Replacement Interval	- once a day

<u>Leach Time (days)</u>		<u>Final pH of Leachant</u>	<u>(Fraction Release)$\times(V/S)$, cm</u>	
<u>Incremental t_n</u>	<u>Cumulative Σt_n</u>		<u>Incremental $(a_n/A_0)\times(V/S)$</u>	<u>Cumulative $(\Sigma a_n/A_0)\times(V/S)$</u>
0.00694	6.94×10^{-3}	3.10	7.78×10^{-2}	7.78×10^{-2}
0.0625	6.94×10^{-2}	3.57	1.23×10^{-1}	2.00×10^{-1}
0.181	2.50×10^{-1}	3.36	2.54×10^{-1}	4.54×10^{-1}
0.75	1	3.45	5.02×10^{-2}	5.06×10^{-1}
1	2	4.25	5.20×10^{-3}	5.12×10^{-1}
1	3	5.34	6.28×10^{-4}	5.12×10^{-1}
3	6	5.73	8.96×10^{-5}	5.12×10^{-1}
1	7	7.80	4.56×10^{-4}	5.12×10^{-1}

DISTRIBUTION LIST

Copies

NUCLEAR REGULATORY COMMISSION

- 1 Director, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555
- 8 C.B. Bartlett, Chief of the Fuel Cycle Research Branch, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555
- 6 W.P. Bishop, Chief, Waste Management Programs, 7735 Old Georgetown Road, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555
- 1 J.T. Collins, Chief, Effluent Treatment Branch, Division of Site Safety & Environmental Analysis (P-932), U.S. Nuclear Regulatory Commission, Washington, D.C. 20555
- 1 Robert F. Barker, Chief, Transportation & Product Standards Branch, Office of Standards Development, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555
- 4 Lake Barrett, Environmental Evaluations Branch, Division of Operating Reactors, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555
- 1 H.D. Thornberg, Division of Inspection and Enforcement (EW-359), U.S. Nuclear Regulatory Commission, Washington, D.C. 20555
- 2 Margaret Cunningham, Library, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

- 3 G.H. Daly, ERDA, Chief, Waste Management Branch, Washington, D.C. 20545
- 1 R.W. Ramsey, Jr., ERDA, Chief, Waste Processing Branch, Washington, D.C. 20545

Copies

LABORATORIES, CONTRACTORS, OTHERS

- 1 W.M. Necoechea, Aerojet Energy Conversion Company, P.O. Box 13222, Sacramento, California 95813
- 1 H.O. Thrash, Alabama Power Company, 600 North 18th Street, P.O. Box 2641, Birmingham, Alabama 35291
- 1 C.M. Slansky, Allied Chemical Corporation, Idaho Falls, Idaho 83401
- 1 Lynn Godfrey, Allied-General Nuclear Services, P.O. Box 847, Barnwell, South Carolina 29812
- 1 W. Clark, American Cyanamid Company, Berdan Avenue, Wayne, New Jersey 07470
- 1 Yoshito Nagai, American Electric Power Service Corporation, 2 Broadway, New York, New York 10004
- 1 R. Russell, Vice-President Marketing, AMETEK, Inc., Power Systems Group, Station Square Two, Paoli, Pennsylvania 19301
- 1 John Murphy, ANEFCO, Inc., 151 East Post Road, White Plains, New York 10601
- 1 M.J. Steindler, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439
- 1 A. Carter Rogers, Arizona Nuclear Power Project, P.O. Box 21666, Phoenix, Arizona 85036
- 1 F.W. Hartley, Arizona Public Service Company, P.O. Box 21666, Phoenix, Arizona 85036
- 1 L. Rutland, Atcor, Inc., Park Mall, Peekskill, New York 10566
- 1 Philip M. Garrett, Atomic Industrial Forum, Inc., 7101 Wisconsin Avenue, Washington, D.C. 20014
- 1 L.F. Grantham, Atomics International, 8900 DeSoto Avenue, Canoga Park, California 91304
- 1 H. Babad, Atomics International Hanford Company, Richland, Washington 99352
- 1 Stephen Lamanna, Babcock & Wilcox, P.O. Box 1260, Lynchburg, Virginia 24505

Copies

LABORATORIES, CONTRACTORS, OTHERS

- 1 A.M. Platt, Battelle Pacific Northwest Laboratories, Richland, Washington 99352
- 1 Lowell Lepisto, Bechtel Power Corporation, P.O. Box 60860, Terminal Annex, Los Angeles, California 90060
- 1 Valentine Malafeew, Bechtel Power Corporation, P.O. Box 607, 15740 Shady Grove Road, Gaithersburg, Maryland 20760
- 1 Charles R. Martin, Bechtel Power Corporation, P.O. Box 2166, Houston, Texas 77001
- 1 Boris Pavelka, Bechtel Power Corporation, 50 Beale Street, San Francisco, California 94119
- 1 M.J. Dunn, Black & Veatch, 1500 Meadow Lane Parkway, Kansas City, Missouri 64114
- 1 Thomas Duncan, Borden Chemical Company, Structural Adhesives Division, 14 Johnson Street, Bainbridge, New York 13733
- 1 Vincent Stagliola, Boston Edison Company, Pilgrim Nuclear Power Station, RFD #1 Rocky Hill Road, Plymouth, Massachusetts 02360
- 1 J.G. Munisteri, Group Vice President, Power Division, Brown & Root, Inc., P.O. Box 3, Houston, Texas 77001
- 1 Otis Jenkins, Information Center, Burns & Roe, Inc., 700 Kinderkamack Road, Oradell, New Jersey 07649
- 1 Francis Patti, Chief Nuclear Engineering, Burns & Roe, Inc., 185 Crossways Park Drive, Woodbury, New York 11797
- 1 Jesse R. Conner, The Carborundum Company, 505 McNeilly Road, Pittsburgh, Pennsylvania 15226
- 1 L. Newhart, Vice President Power Projects, Catalytic, Inc., Suntac Power Division, Centre Square West, 1500 Market Street, Philadelphia, Pennsylvania 19102
- 1 Lloyd J. Andrews, Chem-Nuclear Systems, Inc., P.O. Box 1866, Bellevue, Washington 98009
- 1 Kenneth H. Dufrane, Chem-Nuclear Systems, Inc., 3623 Eggert Road, Orchard Park, New York 14127

Copies

LABORATORIES, CONTRACTORS, OTHERS

- 1 T.J. McCord, Chem-Nuclear Systems, Inc., P.O. Box 726,
Barnwell, South Carolina 29812
- 1 Carl D. Banks, Cleveland Electric Illuminating Company,
P.O. Box 5000, Cleveland, Ohio 44101
- 1 James P. Donohue, Supervisor Radwaste Systems, Combustion
Engineering, Inc., 1000 Prospect Hill Road, Windsor, Connecticut 06095
- 1 Larry Katonak, Commonwealth Associates, 209 E. Washington Avenue,
Jackson, Michigan 49201
- 1 Dennis M. Budzik, Consumers Power Company, 1945 W. Parnall Road,
Jackson, Michigan 49201
- 1 J. Tappen, Dames & Moore, 20 Haarlem Street, White Plains,
New York 10603
- 1 John F. Hayes, Delaware Custom Material, Inc., 21380 Lorain Road,
Cleveland, Ohio 44126
- 1 John L. Jennings, Jr., Delmarvia Power & Lighting Company,
800 King Street, Wilmington, Delaware 19899
- 1 Norbert Dernbach, Dernbach Associates, Box 405, Miller Place,
New York 11764
- 1 M. Sacid Ozker, Detroit Edison Company, 2000 Second Avenue,
Detroit, Michigan 48226
- 1 J. Bruce Owen, Dow Industrial Service, 47 Building, Midland,
Michigan 48640
- 1 S.K. Blackley, Jr., Chief Engineer Mechanical & Nuclear Division,
Design Engineering Department, Duke Power Company, 422 South
Church Street, Charlotte, North Carolina 28242
- 1 Tony B. Owen, Duke Power Company, McGuire Nuclear Station,
P.O. Box 488, Cornelius, North Carolina 28031
- 1 E. Albenesius, E.I. du Pont de Nemours & Company, Inc., Savannah
River Plant, Aiken, South Carolina 29801
- 1 R.M. Wallace, E.I. du Pont de Nemours & Company, Inc., Savannah
River Plant, Aiken, South Carolina 29801

Copies

LABORATORIES, CONTRACTORS, OTHERS

- 1 Simon I. Glassman, Ebasco Services, Inc., 2 Rector Street,
New York, New York 10006
- 1 R.F. Williams, Electric Power Research Institute, P.O. Box 10412,
Palo Alto, California 94303
- 1 G.W. Leddicotte, Florida Power & Light Company, P.O. Box 3100,
Miami, Florida 33101
- 1 K. Yoshitani, Nuclear Systems Department, Fluor Pioneer Inc.,
200 W. Monroe Street, Chicago, Illinois 60606
- 1 Manager, Nuclear Waste Management Systems, General Atomic Company,
P.O. Box 81608, San Diego, California 92138
- 1 Art Carson, General Electric Company, Nuclear Energy Division,
175 Curtner Avenue, San Jose, California 95125
- 1 Eugene E. Voiland, General Electric Company, Morris Operation,
Route 1, Box 219-B, Morris, Illinois 60450
- 1 George F. Head, Manager, Production, Georgia Power Company,
P.O. Box 4545, Atlanta, Georgia 30302
- 1 Herbert A. Schlesinger, Assistant Chief Chemical Engineer,
Gibbs & Hill, Inc., 393 Seventh Avenue, New York, New York 10001
- 1 Dennis P. Ferrigno, Gilbert Associates, Inc., P.O. Box 1498,
Reading, Pennsylvania 19603
- 1 James A. Flynn, Gilbert Associates, Inc., R&D Division,
340 Morgantown Road, Reading, Pennsylvania 19603
- 1 Steven P. Kraft, GPU Service Corporation, 260 Cherry Hill Road,
Parsippany, New Jersey 07054
- 1 Charles Hackney, Gulf States Utilities, P.O. Box 2951, Beaumont,
Texas 77704
- 1 R.E. Lerch, Hanford Engineering Development Laboratory, P.O. Box 1970,
Richland, Washington 99352
- 1 Peter Tuite, Hittman Nuclear and Development Corporation,
9190 Red Branch Road, Columbia, Maryland 21045
- 1 David F. Villacres, Houston Lighting & Power Company, Electric
Tower, P.O. Box 1700, Houston, Texas 77001

Copies

LABORATORIES, CONTRACTORS, OTHERS

- 1 R.E. Harris, Illinois Power Company, 500 South 27th Street,
Decatur, Illinois 62525
- 1 George A. Kuehn, Jr., Iowa Electric Light and Power Company,
Duane Arnold Energy Center, P.O. Box 351, Cedar Rapids, Iowa 52406
- 1 Edward S. Scalsky, Jersey Central Power & Light Company, Nuclear
Generating Station, P.O. Box 388, Forked River, New Jersey 08731
- 1 David Clark, Kentucky Department for Human Resources, Radiation
Control Branch, 275 East Main Street, Frankfort, Kentucky 40601
- 1 L.A. Emelity, Los Alamos Scientific Laboratory, Los Alamos,
New Mexico 87544
- 1 Howard L. Freese, Luwa Corporation, P.O. Box 16348, Charlotte,
North Carolina 28216
- 8 Gerald Parker, Assistant to the Commissioner of Radiological
Health, Massachusetts Department of Health, 80 Bryston Street
(Room 835), Boston, Massachusetts 02116
- 1 D. Cyrus Klingsber, National Academy of Sciences, Committee of
Radioactive Waste Management, National Research Council, 2101
Constitution Avenue, Washington, D.C. 20418
- 1 Terry R. Lash, Natural Resources Defense Council Inc., 2345 Yale
Street, Palo Alto, California 94306
- 1 Ronald Sanacore, NEL-PIA MAELU, The Exchange, Farmington Avenue,
Farmington, Connecticut 06032
- 1 W.G. Keltner, New York State Electric & Gas Corporation,
Binghamton, New York 13202
- 1 N. Richard Werthamer, New York State Energy Research and
Development Authority, Room 2425, 230 Park Avenue, New York,
New York 10017
- 1 Thomas J. Cashman, Director, Bureau of Radiation, New York State
Department of Environmental Conservation, 50 Wolf Road, Albany,
New York 12233
- 1 J.E. McCarthy, Niagara Mohawk Power Corporation, Building Code D-3,
300 Erie Boulevard, West, Syracuse, New York 13202

LABORATORIES, CONTRACTORS, OTHERS

- 1 Mary Meehan, Niagara Mohawk Power Corporation, East 1st & Bridge Street, Oswego, New York 13126
- 1 David Striawson, NPR Associates, 1140 Connecticut Avenue, N.W., Washington, D.C. 20036
- 1 B. Roberts, Nuclear Engineering Company, Inc., P.O. Box 7246, Louisville, Kentucky 40207
- 1 J.P. Duckworth, Nuclear Fuel Services, Inc., P.O. Box 124, West Valley, New York 14171
- 1 C.R. Moore, Nuclear Fuel Services, Inc., Suite 600, 600 Executive Boulevard, Rockville, Maryland 20852
- 1 Larry J. Hansen, Nuclear Packaging, Inc., 1733 South Fawcett, Tacoma, Washington 98402
- 1 W. Rodgers, Nuclear Safety Associates, 5101 River Road, Bethesda, Maryland 20016
- 1 W.L. Pearl, Nuclear Water and Waste Technology, P.O. Box 6406, San Jose, California 95150
- 1 T.A. Russell, NUS Corporation, 4 Research Place, Rockville, Maryland 20850
- 1 R. Jon Stouky, NUS Corporation, 4 Research Place, Rockville, Maryland 20850
- 1 H.W. Godbee, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tennessee 37830
- 1 J.G. Moore, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tennessee 37830
- 1 D.L. Morin, Offshore Power Systems, Reactor and Containment Systems Engineering, 8000 Arlington Expressway, Box 8000, Jacksonville, Florida 32211
- 1 Andrew Rushok, Ohio Edison Company, Nuclear Engineering Department, 76 S. Main Street, Akron, Ohio 44308
- 1 A.J. Hogan, Philadelphia Electric Company, 2301 Market Street, N-2-1, Philadelphia, Pennsylvania 19101
- 1 Herbert Morawetz, Polytechnic Institute of New York, Department of Chemistry, 333 Jay Street, Brooklyn, New York 11201
- 1 Jack W. Lentsch, Portland General Electric Company, Electric Building, 621 S.W. Alder Street, Portland, Oregon 97205

Copies

LABORATORIES, CONTRACTORS, OTHERS

- 1 Ken Gablin, Protective Packaging Inc., 328 Production Court,
Louisville, Kentucky 40299
- 1 Lawrence A. Reiter, Public Service Gas & Electric Company,
Room 412 MP, 80 Park Place, Newark, New Jersey 07101
- 1 T.R. Burns, Public Service Indiana, 1000 East Main Street,
Plainfield, Indiana 46168
- 1 Linda L. Phillips, Rochester Gas and Electric Corporation,
89 East Avenue, Rochester, New York 14649
- 1 L.R. Hill, Supervisor Nuclear Waste Technology Division 1141,
Sandia Laboratories, Albuquerque, New Mexico 87115
- 1 L.C. Oyen, Sargent & Lundy, 55 E. Monroe Street, Chicago,
Illinois 60603
- 1 Dallas T. Pence, Science Applications, Inc., 1200 Prospect Street,
P.O. Box 2361, La Jolla, California 92037
- 1 Heyward G. Shealy, Director, Division of Radiological Health,
South Carolina Board of Health, J. Marion Sims Building,
2600 Bull Street, Columbia, South Carolina 29201
- 1 Paul C. Williams, Stock Equipment Company, 16490 Chillicothe Road,
Chagrin Falls, Ohio 44022
- 1 Burt Coplan, Stone & Webster Engineering Corporation, 245 Summer
Street, Boston, Massachusetts 02210
- 1 Paul Mayo, Stone & Webster Engineering Corporation, 245 Summer
Street, Boston, Massachusetts 02210
- 1 Thomas B. Lewis, Jr., Stone & Webster Engineering Corporation,
3 Executive Plaza, Cherry Hill, New Jersey 08109
- 1 George Kniazewycz, Teknekron Energy Resource Analysts Corporation,
2118 Milvia Street, Berkeley, California 94704
- 1 Chuck K. Feist, Texas Utilities Services Inc., 2001 Bryan Tower,
Dallas, Texas 75201
- 1 Eugene Novak, Toledo Edison Company, Edison Plaza, 300 Madison
Avenue, Toledo, Ohio 43652

Copies

LABORATORIES, CONTRACTORS, OTHERS

- 1 Terry L. Chinn, Union Electric Company, P.O. Box 149, St. Louis, Missouri 63166
- 1 John H. Crowley, Manager, Advanced Engineering Department, United Engineers & Constructors, Inc., 30 S. 17th Street, Philadelphia, Pennsylvania 19101
- 1 C.S. Kang, United Engineers & Constructors, Inc., Nuclear Technical Staff Library, 30 S. 17th Street, Philadelphia, Pennsylvania 19101
- 1 H.W. Heacock, United Nuclear Industries, Inc., 1201 Jadwin Avenue, Richland, Washington 99352
- 1 Stan Cosgrove, University of Cincinnati, Department of Chemical and Nuclear Engineering, Cincinnati, Ohio 45221
- 2 D. Smith, Director, Technology Assessment Division (AW-459), Office of Radiation Programs, U.S. Environmental Protection Agency, 401 M Street S.W., Washington, D.C. 20460
- 1 W. Holcomb, Technology Assessment Division (AW-459), Office of Radiation Programs, U.S. Environmental Protection Agency, 401 M Street S.W., Washington, D.C. 20460
- 1 G.L. Meyer, Office of Radiation Programs, U.S. Environmental Protection Agency, 401 M Street S.W., Washington, D.C. 20460
- 1 Joseph R. Sipp, Vermont Yankee Nuclear Power Corporation, P.O. Box 157, Vernon, Vermont 05354
- 1 R.V. Subramanian, Washington State University, Department of Materials Science, Pullman, Washington 99164
- 1 J.L. Mahloch, Waterways Experiment Station, Office for Environmental Services, P.O. Box 631, Vicksburg, Mississippi 39180
- 1 John E. Stewart, Werner & Pfleiderer Corporation, 160 Hopper Avenue, Waldwick, New Jersey 07463
- 1 Arnold S. Kitzes, Westinghouse Electric Corporation, P.O. Box 2728, Pittsburgh, Pennsylvania 15230
- 1 L.E. Brown, Wisconsin Michigan Power Company, Point Beach Nuclear Plant, Postal Route 3, Two Rivers, Wisconsin 54241

Copies

LABORATORIES, CONTRACTORS, OTHERS

- 1 Virginia Perkins, Wisconsin Electric Power Company, Room 433,
231 W. Michigan Avenue, Milwaukee, Wisconsin 53201
- 1 A. Purdy, Witco Chemical Corporation, Pioneer Division,
1000 Convery Boulevard, Perth Amboy, New Jersey 08862
- 1 Edmund C. Tarnuzzer, Yankee Atomic Electric Company, 20 Turnpike
Road, Westboro, Massachusetts 01581

BROOKHAVEN NATIONAL LABORATORY DISTRIBUTION

J.M. Hendrie
B. Manowitz
M. Steinberg
P. Colombo
R.M. Neilson, Jr.
C.H. Lai
L. Milian
L. Belkin
D. Schweller