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TMI-2 CORE DEBRIS-CESIUM

RELEASE/SETTLING TEST

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ACKNOWLEDGMENT

ABSTRACT

Cesium release, turbidity and airborne potential tests were conducted on 50 grams of TMI-2 core debris materials. The tests were performed on the debris in two conditions: on the as-received core debris specimen, and after crushing the debris to alter the particle size distribution. The crushing was intended to simulate the breakup of TMI-2 core material that may occur during reactor defueling. These tests are intended to assist GPU Nuclear in predicting the effect of defueling on the reactor environment.

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SUMMARY

In this study there were three types of tests: uncrushed debris test, crushed debris test, and an airborne evaporation tests. In both the uncrushed and crushed debris tests, samples were mixed in a simulated reactor coolant solution. Turbidimetry and radionuclide analysis were performed on samples taken at specified times.

The tests involved approximately 50 grams of debris in a liter of water. This would constitute approximately one volume percent of suspended solids, i.e. approximately a one centimeter layer of the debris bed suspended in one meter of reactor coolant water.

A brief summary of the analysis results are as follows.

o   Stirring debris in simulated reactor coolant resulted in an opaque suspension. The turbidity of the simulated coolant was 1.4 NTU prior to mixing in the debris material. During both tests (144 h), the turbidity never fell back to this level; after 144 h the uncrushed sample was 7.4 NTU; the crushed sample was 2.5 NTU.

o   Crushing the debris has minimal impact on turbidity. In general, the opacity of both solutions decreased at about the same rate (within a factor of 2).

o   Crushing the debris increased the soluble ^{137}Cs concentrations a factor of 4 to 5.

o   For most radionuclides <1% of the total inventory in solution was transported by air during the evaporation process.

o   Most of the airborne activity occurred near the end of the evaporation process, just prior to dry out. The increase in airborne concentration at this time is two to three orders of magnitude higher than at any other time.

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TMI-2 CORE DEBRIS-CESIUM
RELEASE/SETTLING TEST

INTRODUCTION

The cesium release and settling tests were incorporated into the core debris examination program to support data requirements of General Public Utilities (GPU) Nuclear for reactor recovery. Reactor recovery issues that are addressed by these tests are:

o   What are the release rates of radioisotopes from existing and freshly created surfaces.

o   Will the core debris in its present state (or altered by the action of defueling tools) cause a significant reduction in water clarity when it is handled.

o   What is the potential for airborne radioactivity during evaporation of reactor coolant.

During these tests the physical and radiological characteristics of the core debris have been evaluated and the results of these evaluations are presented in this report. These evaluations provided information necessary for planning TMI-2 defueling.

Approximately 50 grams of debris, taken from Sample Number 6, were used for the tests. Sample Number 6 was taken from core location E9, 22 inches into the debris bed. For a more complete description of this sample see Reference 1. Three types of tests were conducted as summarized below:

o   Uncrushed Debris Test--Approximately 50 grams of debris were mixed in a simulated reactor coolant solution and allowed to settle. Samples were removed at specified intervals and turbidimetry and radionuclide analysis were performed. The samples were filtered and analyses performed on both solid and liquid sample fractions.

o   Crushed Debris Test--This test was similar to the uncrushed
    debris test except that the core debris was crushed to expose
    freshly fractured surface areas. The newly crushed core debris
    was then mixed with simulated reactor coolant solution. The
    50 grams of debris used in the uncrushed debris test were also
    used for this test.

o   Airborne Evaporation Test--The airborne evaporation test was
    performed on the simulated reactor coolant solution residual of
    both the uncrushed and crushed debris tests. The simulated
    reactor coolant solutions ($\sim$500 mL each) were transferred to an
    enclosed evaporation chamber where an airstream of 3048 cm/min
    (100 linear ft/min) was passed over the surface of the solution.
    The airstream was passed through a 0.45 μm HEPA filter which
    was analyzed for radionuclide content.

DESCRIPTION OF MATERIALS AND EXPERIMENTAL PROCEDURES

Uncrushed Debris Test

Materials and Equipment

o   **Core debris**--48.75 grams of material taken from Sample 6 (core position E9, 22-in. into the debris bed). Approximately 35% of the sample was used (see Table 1).

o   Simulated reactor coolant water--deionized water containing 5000 ppm boron, 1500 ppm sodium at a pH of 7.6 (composition recommended by GPU).

o   One liter plastic bottle(~8 in. high).

o   25 mL high volume syringe.

o   Glass curvettes, 25 mL.

o   Turbidimeter, H.F. Instruments Co., Model DRT-100D.

o   High volume filtration system with a HEPA filter, 0.45 μm size.

Procedure

The core debris (48.75 grams) and 1 liter of liquid (simulated reactor coolant) were placed in a 1 liter plastic bottle. The bottle was inverted several times to mix the contents. At predetermined time intervals, 25 mL samples of the solution were withdrawn from a specific depth (~5 cm, near the top surface of the solution) using a syringe. Approximately 250 mL of solution was removed during the sampling process, reducing the height of water in the bottle by ~10 cm. The syringe was flushed before taking each sample by partially filling and emptying it with the simulated coolant

TABLE 1. PARTICLE SIZE DISTRIBUTION FOR THE UNCRUSHED AND CRUSHED DEBRIS TESTS

Particle Size Range (μm)	Original Bulk Sample Size Distribution (grams)	Uncrushed Debris Test[a] (grams)	Crushed Debris Test[b] (grams)
4000	57.99	20.25	0.30
1680-4000	49.39	17.26	10.99
1000-1680	13.88	4.94	10.44
707-1000	8.93	3.36	6.38
297-707	5.99	2.26	8.08
149-297	0.97	0.37	3.32
74-149	0.67	0.24	1.82
30-74	0.22	0.072	0.53
<30	0	0	0.87
Total	138.04	48.75[c]	42.73[c]

a. Amount removed from the various size fractions of Sample 6.

b. Quantities reflect the "after crushing" distribution. The same debris was used for the crushed debris as for the uncrushed debris test.

c. The difference of six grams between the two tests was due to loss either during the evaporation test or the crushing process.

solution. Each sample was then transferred into a 25 mL glass curvette which was placed in the turbidimeter; the turbidity of the solution was then measured.

Following turbidimetry measurements, each sample was filtered to separate the solid and liquid sample fractions. Two filters in series were used. The first filter was for particulate material retention and the second filter was used to measure the radionuclide content of water retained on a filter. This measurement was subtracted from the particulates content of the first filter. Both fractions were analyzed for radionuclide content using a calibrated Ge(Li) gamma spectrometer system. The measurements continued for approximately six days until the turbidity of the solution stabilized and the radionuclide concentrations leached into the filtrate portion of the sample fraction had stabilized.

Airborne Evaporation Test (uncrushed debris)

Materials and Equipment

o   Solution--~500 mL of the core debris simulated reactor coolant solution.

o   Evaporation Chamber--1.85 in. high x 4 in. wide x 18 in. long with controlled airflow of 100 linear ft/min (see Figure 1).

o   Air sampling system with 0.45 μm HEPA filters.

o   Graduated cylinder, 500 mL.

Procedure

Immediately following the ~144 h uncrushed debris test, ~500 mL of the simulated reactor coolant supernate, containing both dissolved and suspended particulate material, was decanted from the solid core debris material and transferred to an enclosed chamber with air inlet and outlet
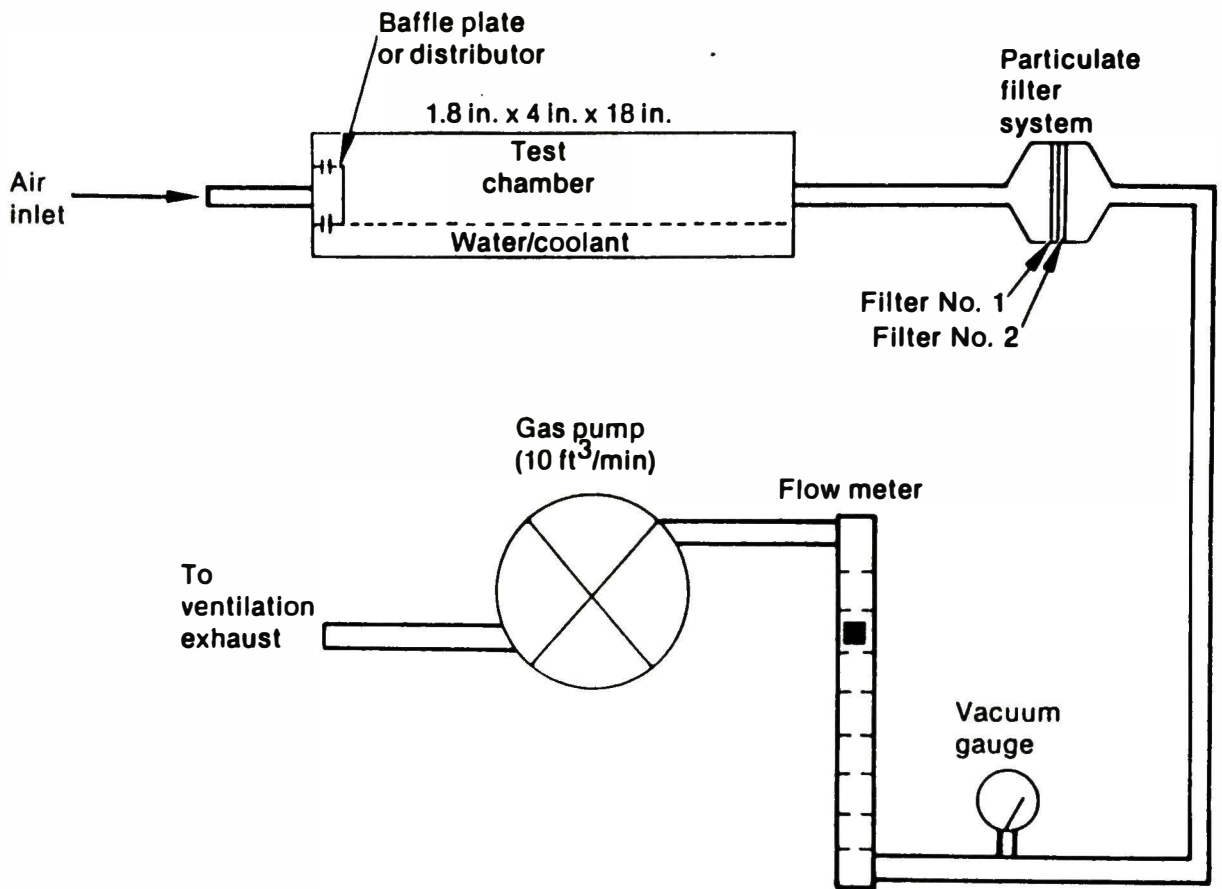
Figure 1. Schematic of the evaporation chamber measurement system.

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tubes (see Figure 1). The chamber contained a baffle plate near the front (upstream side) to equalize the velocity across the surface of the simulated reactor coolant. For radionuclide inventory purposes, the concentrations listed in Table 4 for the 144 h sample were used. These concentrations are considered representative of the simulated reactor coolant used in this test. The solution was evaporated by passing air over the solution surface at a controlled velocity of ∿3000 cm/min (100 linear ft/min) at a total flow rate of 8.49 (+4) cm^3/min (∿3.0 ft^3/min). The 0.45 μm HEPA filters were replaced at intervals and were analyzed to determine the radionuclide airborne concentrations at different times during the evaporation process. The filters are being archived for potential future analyses.

Each filter was analyzed in a calibrated geometry by gamma ray spectrometry and the radionuclide content on the filters converted to microcuries (μCi) of individual radionuclides evaporated per cm^3 of air.

During the evaporation process the solution was intermittently poured from the evaporation chamber and the volume measured to determine the quantity of water evaporated. Solution volume measurements were performed at the times listed in Table 7. Solution loss during the volume measurements was minimal and constituted a small fraction of the total volume. All operations were performed at an ambient temperature of ∿70°F.

Crushed Debris Test

Materials and Equipment

o   Core Debris--The debris collected from the uncrushed debris test (42.75 grams) was dried and weighed.

o   Crusher--A small cylinder and cup apparatus combined with a 2-ton hydraulic jack (see Figure 2).

o   All equipment previously used in the uncrushed debris test.
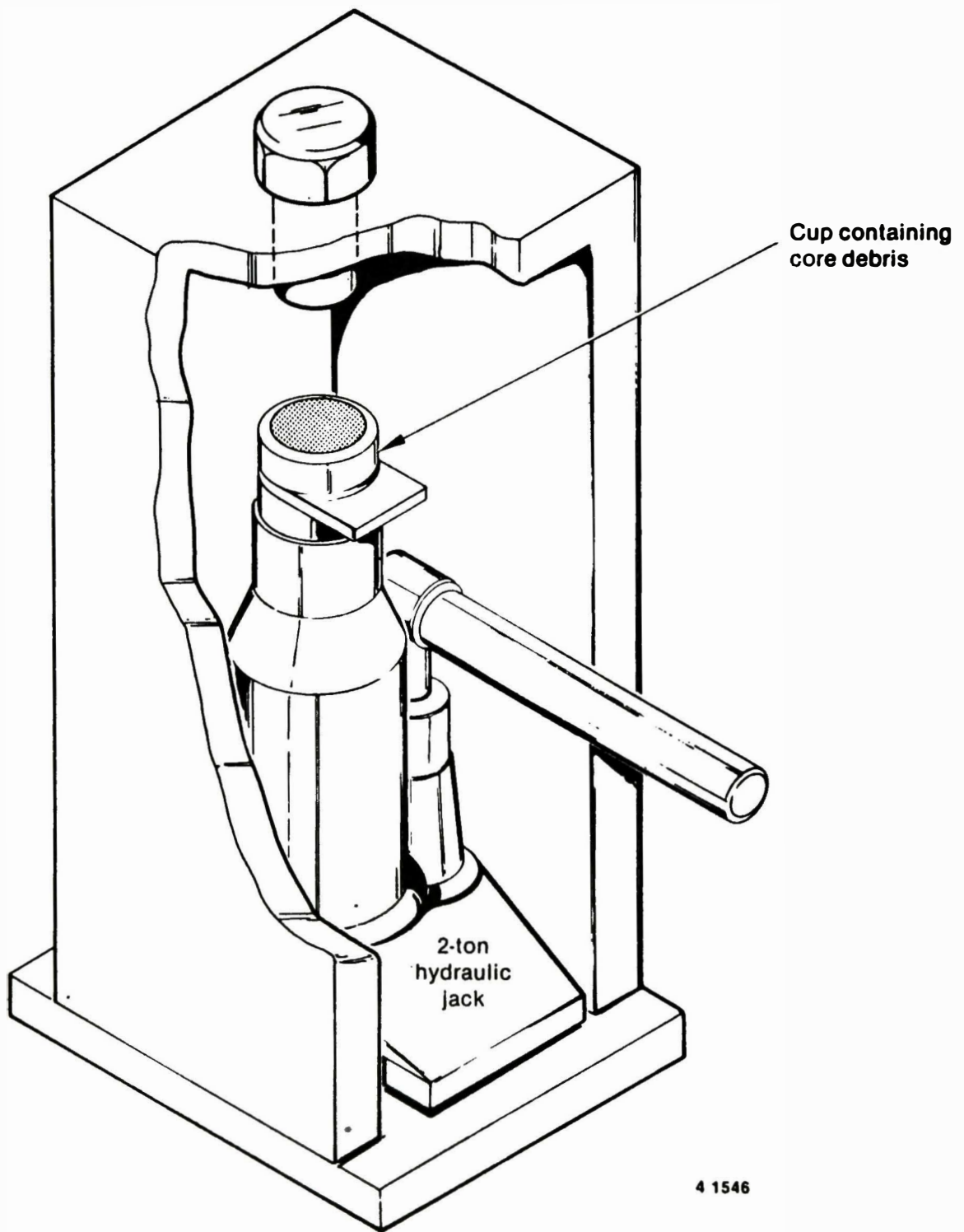
Figure 2. Core debris crushing device.

o   SST sieves, W. S. Tyler, mesh sizes 5, 10, 16, 24, 48, 100, 200, and 325. Sieving was performed using a freon wash.

Procedure

The steps listed for the uncrushed debris test were repeated using the same core debris sample with the following exceptions:

o   The core debris material was first crushed using the device shown in Figure 2 to generate freshly fractured surfaces.

o   The crushed debris was sieved and weighed to determine the new particle size distribution.

Airborne Evaporation Test (crushed debris)

Materials and Equipment

Same as for the uncrushed airborne evaporation test except that the supernate was decanted from the crushed debris test solution.

Procedure

Following the uncrushed debris test, the supernate was transferred to the evaporation chamber and the airborne evaporation test repeated. This test was performed using fresh simulated reactor coolant. The suspended particulate and dissolved material from the first test were not in the solution as they were expended during the uncrushed debris test, as is discussed in the following section.

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RESULTS AND DISCUSSION

Uncrushed and Crushed Debris Tests

Turbidity Measurements[a]

The analytical results for the uncrushed and crushed debris tests are
discussed jointly to evaluate the effects of crushing the core debris.
Table 1 lists the particle size distribution for (a) the original bulk
sample, (b) the sample removed for analysis (~35% of the original
sample), and (c) the crushed sample (particle analysis performed after
uncrushed debris test). A significant reduction in the quantity of the
large particle size core debris, with a corresponding increase in the
weights of the smaller sized fractions, resulted from the crushing
process. Figure 3 is a histogram showing the particle size distribution
for the original bulk sample, the 50 gram uncrushed sample, and the crushed
sample.

Table 2 lists the results of the turbidity measurements. It includes
sample removal times and associated turbidity measurements. The simulated
reactor coolant solution had a turbidity reading of 1.4 NTU before adding
the core debris material. Since the accident, the TMI-2 reactor coolant
turbidity has been ranging between 1 & 5 NTU.

Figure 4 shows the turbidity analysis results listed in Table 2. The
data indicate that concentration of suspended material decreased fastest
during the first hour for both tests. The reduction in turbidity is a
logarithmic function based on time for both the uncrushed and crushed
debris. The crushed debris solution was more turbid initially, but was
equal to the minor disturbance solution after about 60 min. It then became
less turbid. In general, the opacity of both solutions decreased at about
the same rate. Crushing the debris had minimal impact on turbidity (within
a factor of 2).

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a. Appendix A contains a brief description of the turbidity and the method
used to measure it.
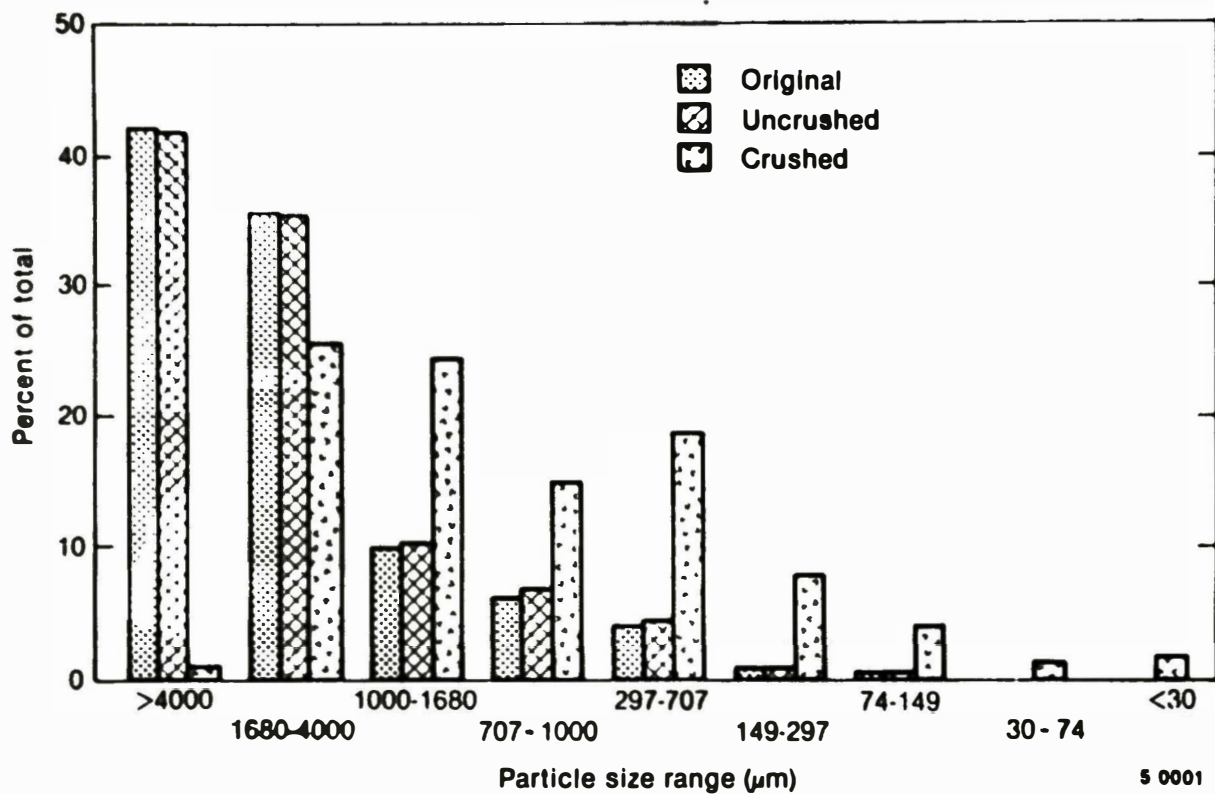
Figure 3. Histogram of the debris particle size distributions for uncrushed and crushed debris.

TABLE 2. TURBIDITY ANALYSIS RESULTS[a]

Uncrushed Debris Test[b]		Crushed Debris Test[b]	
Time After Shaking	Turbidity (NTU)	Time After Shaking	Turbidity (NTU)
1 min	94.7	1 min	115.6
5 min	89.0	5 min	114.0
20 min	72.4	20 min	83.6
1 h	69.0	1 h	60.0
4.90 h	42.0	4.90 h	25.4
24 h	30.1	24 h	12.2
96 h	12.6	48 h	5.5
120 h	8.8	72 h	4.1
144 h	7.4	144 h	2.5

a. Turbidity is listed in Nephelometric Turbidity Units (NTU) and is a measure of the light scattering ability of a solution. By definition a formazin polymer solution is equivalent to one NTU. (See Appendix A)

b. The measured background turbidity reading of the coolant simulant was 1.4 prior to mixing with the core debris material.

Figure 4.   Uncrushed and crushed debris turbidity results.

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Suspended Solids Concentration

The weight of solid materials suspended in the simulated reactor coolant solution was not measured; it was calculated by ratioing the measured radionuclide solids content on the filters (μCi) to the radionuclide concentrations from the smaller particle size fractions of core debris Sample 6.[1] The number of grams of solid material present in each 25 mL of solution is listed in Table 3. The 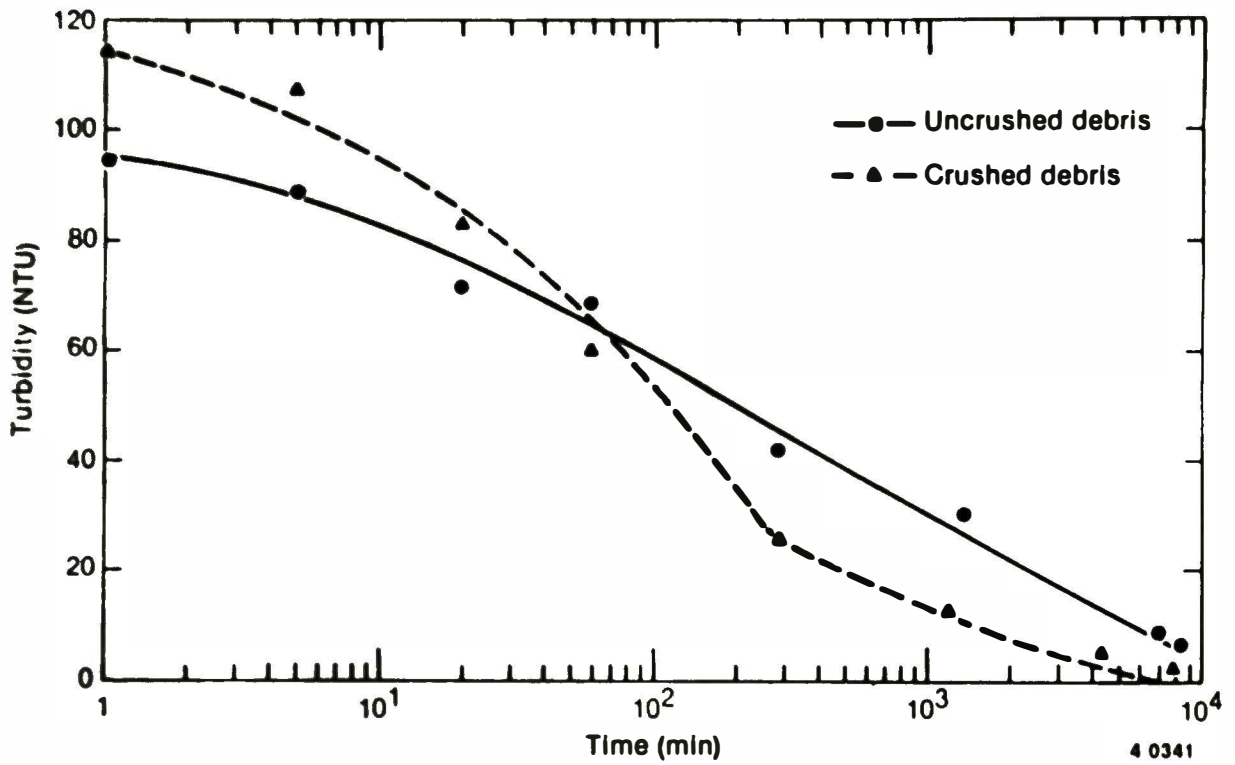uncertainty in this analysis is at least a factor of 2, resulting from the uncertainties in the radionuclide concentrations of particles deposited on the surface of the filter and/or the possible presence of particles smaller than 0.45 μm.

An attempt was made to correlate the turbidimeter analysis results with the calculated solids content. A logarythmic correlation of the data is indicated. However, further laboratory work would be required to adequately define a correlation between turbidimeter readings and solid concentrations for the core debris samples.

The weights of solid materials suspended in the simulated reactor coolant solutions were calculated as a function of time. The data are listed in Table 3. The data range from 49 μ grams/mL at 1 min for the crushed debris test to 0.17 μ grams/mL at 144 h for the uncrushed debris test. Settling was rapid-only; small concentrations of solids were present immediately following agitation of the solution.

Radionuclide Concentrations

Tables 4 and 5 list the radionuclide concentrations (μCi/sample) for the solid and liquid portions of the uncrushed and crushed debris tests. The data show the radionuclide content of the suspended solid fractions decreased at a relatively constant rate for all radionuclides measured in the uncrushed debris test. The crushed debris test radionuclide concentrations followed a similar pattern.

TABLE 3. CESIUM SETTLING TEST SUSPENDED SOLIDS CONCENTRATIONS[a]

Time	Uncrushed Debris (grams/mL)	Crushed Debris (grams/mL)
1.0 min	8.6(-6)	4.9(-5)
5.0 min	6.05(-6)	1.9(-5)
20.0 min	2.4(-6)	4.9(-6)
1.0 h	7.0(-6)	2.0(-6)
4.9 h	8.7(-7)	6.9(-7)
24 h	6.9(-7)	2.24(-7)
48 h	--[b]	5.0(-7)
72 h	--[b]	8.8(-7)
96 h	2.6(-7)	--[b]
120 h	1.2(-7)	--[b]
144 h	1.6(-7)	1.1(-6)

a. Calculation based on the ^{137}Cs concentrations of particles larger than 0.45 μm. The average ^{137}Cs concentration used for calculation purposes is 1.07(+3) μCi/gram.

b. Not measured.

TABLE 4. UNCRUSHED DEBRIS RADIONUCLIDE CONCENTRATIONS
(μCi/sample)

Filtration Number / Time	Filter Number/ Filtrate	Radionuclide				
		^{60}Co	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
1 1.0 min	Filter 1	5.1 + 0.1E-3	1.83 + 0.02E-2	8.6 + 0.1E-3	2.31 + 0.01E-1	1.14 + 0.09E-1
	Filter 2	3.8 ∓ 1.0E-5	2.9 ∓ 0.3E-4	3.9 ∓ 0.9E-5	9.9 ∓ 0.4E-4	--[a]
	Filtrate	3.9 ∓ 0.2E-2	7.84 ∓ 0.08E-1	6.2 ∓ 0.2E-2	2.01 ∓ 0.01E0	--[a]
2 5.0 min	Filter 1	4.2 + 0.1E-3	1.54 + 0.03E-2	6.2 + 0.1E-3	1.61 + 0.01E-1	8.2 + 0.8E-2
	Filter 2	2.3 ∓ 0.8E-5	3.3 ∓ 0.3E-4	4.2 ∓ 0.9E-5	8.7 ∓ 0.4E-4	--[a]
	Filtrate	6.9 ∓ 0.3E-2	8.4 ∓ 0.1E-1	9.9 ∓ 0.3E-2	2.48 ∓ 0.01E0	--[a]
3 20.0 min	Filter 1	2.3 + 0.8E-3	8.8 + 0.2E-3	2.46 + 0.07E-3	6.38 + 0.03E-2	4.1 + 0.5E-2
	Filter 2	2.4 ∓ 0.8E-5	2.6 ∓ 0.3E-4	2.7 ∓ 0.8E-5	7.8 ∓ 0.4E-4	--[a]
	Filtrate	7.3 ∓ 0.3E-2	8.9 ∓ 0.1E-1	1.39 ∓ 0.03E-1	2.58 ∓ 0.01E0	--[a]
4 1.0 h	Filter 1	3.4 + 0.1E-3	1.34 + 0.02E-2	5.3 + 0.4E-3	1.86 + 0.01E-1	9.0 + 0.8E-2
	Filter 2	2.6 ∓ 0.8E-5	3.0 ∓ 0.3E-4	8.1 ∓ 0.7E-5	8.1 ∓ 0.3E-4	--[a]
	Filtrate	8.0 ∓ 0.3E-2	9.7 ∓ 0.1E-2	1.12 ∓ 0.03E-1	2.81 ∓ 0.01E0	--[a]
5 4.9 h	Filter 1	1.01 + 0.05E-3	4.8 + 0.1E-3	9.3 + 0.4E-4	2.24 + 0.02E-2	1.14 + 0.03E-2
	Filter 2	2.7 ∓ 0.7E-5	3.2 ∓ 0.3E-4	5.3 ∓ 0.7E-5	8.0 ∓ 0.3E-4	--[a]
	Filtrate	8.1 ∓ 0.3E-2	9.5 ∓ 0.1E-1	1.08 ∓ 0.03E-1	2.70 ∓ 0.01E0	--[a]
6 24.0 h	Filter 1	6.2 + 0.4E-4	3.4 + 0.1E-3	6.8 + 0.4E-4	1.77 + 0.02E-2	7.6 + 0.2E-3
	Filter 2	2.5 ∓ 0.7E-5	3.7 ∓ 0.3E-4	4.1 ∓ 0.9E-5	8.8 ∓ 0.4E-4	--[a]
	Filtrate	8.0 ∓ 0.3E-2	9.9 ∓ 0.1E-1	1.04 ∓ 0.03E-1	2.54 ∓ 0.01E0	--[a]
7 96 h	Filter 1	3.8 + 0.3E-4	1.49 + 0.08E-3	2.6 + 0.2E-4	6.1 + 0.1E-3	2.8 + 0.8E-3
	Filter 2	2.7 ∓ 0.8E-5	4.5 ∓ 0.3E-4	3.2 ∓ 0.8E-5	8.9 ∓ 0.4E-4	--[a]
	Filtrate	1.24 ∓ 0.04E-1	1.70 ∓ 0.01E0	1.41 ∓ 0.04E-1	3.56 ∓ 0.01E0	--[a]
8 120 h	Filter 1	1.75 + 0.08E-4	7.8 + 0.2E-4	1.05 + 0.05E-4	2.65 + 0.02E-3	6.2 + 0.2E-4
	Filter 2	5.1 ∓ 0.5E-5	3.2 ∓ 0.1E-4	2.6 ∓ 0.3E-5	6.3 ∓ 0.1E-4	--[a]
	Filtrate	1.15 ∓ 0.04E-1	1.51 ∓ 0.01E0	1.27 ∓ 0.03E-1	3.13 ∓ 0.01E0	--[a]
9 144 h	Filter 1	2.8 + 0.3E-4	1.20 + 0.06E-3	1.6 + 0.2E-4	3.72 + 0.08E-3	1.3 + 0.5E-3
	Filter 2	2.5 ∓ 0.3E-5	3.2 ∓ 0.1E-4	2.3 ∓ 0.3E-5	6.1 ∓ 0.1E-4	--[a]
	Filtrate	1.17 ∓ 0.04E-1	1.60 ∓ 0.01E0	1.24 ∓ 0.3E-1	3.14 ∓ 0.01E0	--[a]

a. Not detected.

TABLE 5. CRUSHED DEBRIS RADIONUCLIDE CONCENTRATIONS
(uCi/sample)

Filtration Number/[a] Time	Filter Number/ Filtrate	^{60}Co	^{125}Sb	^{134}Cs	^{137}Cs	^{144}Ce
1 1.0 min	Filter 1	9.1 ± 0.6E-3	5.7 ± 0.2E-2	4.4 ± 0.1E-2	1.30 ± 0.05E0	1.03 ± 0.09E0
	Filter 2	--b	--b	2.3 ± 1.2E-4	7.0 ± 0.1E-3	--b
	Filtrate	9.6 ± 1.9E-3	1.1 ± 0.2E-1	6.4 ± 0.1E-1	1.97 ± 0.08E+1	--b
2 5 min	Filter 1	3.1 ± 0.2E-3	4.3 ± 0.1E-1	3.95 ± 0.04E-1	5.09 ± 0.02E-1	3.7 ± 0.3E-1
	Filter 2	--b	--b	2.6 ± 0.2E-4	7.8 ± 0.1E-3	--b
	Filtrate	7.2 ± 1.2E-3	5.5 ± 1.5E-2	6.5 ± 0.1E-1	2.05 ± 0.05E+1	--b
3 20 min	Filter 1	1.26 ± 0.07E-3	9.0 ± 0.2E-3	4.3 ± 0.1E-3	1.30 ± 0.01E-1	1.2 ± 0.1E-1
	Filter 2	--b	--b	1.8 ± 0.2E-4	5.58 ± 0.09E-3	--b
	Filtrate	6.3 ± 1.3E-3	--b	5.09 ± 0.09E-1	1.58 ± 0.05E+1	--b
4 1 h	Filter 1	6.72 ± 0.05E-4	4.9 ± 0.2E-3	1.58 ± 0.06E-3	4.84 ± 0.03E-2	4.9 ± 0.6E-2
	Filter 2	--b	--b	1.7 ± 0.2E-4	4.96 ± 0.09E-3	--b
	Filtrate	4.3 ± 0.9E-3	5.7 ± 1.5E-2	5.06 ± 0.08E-1	1.54 ± 0.04E+1	--b
5 4.9 h	Filter 1	2.1 ± 0.3E-4	1.5 ± 0.1E-3	5.6 ± 0.4E-4	1.71 ± 0.02E-2	1.3 ± 0.3E-2
	Filter 2	--b	--b	2.2 ± 0.2E-4	6.6 ± 0.1E-3	--b
	Filtrate	6.1 ± 1.3E-3	5.2 ± 1.6E-2	5.0 ± 0.1E-1	1.54 ± 0.05E+1	--b
6 24 h	Filter 1	6.9 ± 1.3E-5	3.3 ± 0.4E-4	1.9 ± 0.2E-4	5.26 ± 0.09E-3	2.4 ± 0.5E-3
	Filter 2	--b	--b	2.4 ± 0.2E-4	6.8 ± 0.1E-4	--b
	Filtrate	8.3 ± 1.4E-3	1.6 ± 0.2E-1	6.7 ± 0.1E-1	2.06 ± 0.05E+1	--b
7 48 h	Filter 1	7.4 ± 1.5E-5	6.0 ± 0.7E-4	4.8 ± 0.3E-4	1.32 ± 0.02E-2	4.1 ± 0.2E-3
	Filter 2	6.8 ± 2.5E-6	--b	8.0 ± 0.1E-3	2.5 ± 0.2E-4	--b
	Filtrate	1.3 ± 0.2E-2	2.7 ± 0.2E-1	7.3 ± 0.1E-1	2.24 ± 0.06E+1	--b
8 72 h	Filter 1	8.9 ± 1.7E-5	6.3 ± 0.5E-4	5.1 ± 0.3E-4	1.6 ± 0.2E-2	5.4 ± 0.9E-3
	Filter 2	--b	1.4 ± 0.4E-4	2.4 ± 0.2E-4	7.6 ± 0.1E-3	--b
	Filtrate	1.5 ± 0.2E-2	3.2 ± 0.3E-1	7.6 ± 0.1E-1	2.25 ± 0.07E+1	--b
9 144 h	Filter 1	1.3 ± 0.2E-4	6.9 ± 0.6E-4	6.6 ± 0.3E-4	2.00 ± 0.02E-2	7.8 ± 1.0E-3
	Filter 2	1.2 ± 0.5E-5	1.9 ± 0.4E-4	3.1 ± 0.2E-4	9.0 ± 0.1E-3	--b
	Filtrate	2.1 ± 0.4E-2	4.2 ± 0.4E-1	7.7 ± 0.2E-1	2.27 ± 0.01E+1	--b

a. Only 18 mL were obtained for filtration Samples 1 and 2, therefore, the data are extrapolated to 25 mL for comparison with the remaining samples where 25 mL was recovered.

b. Not detected.

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Figure 5 shows the ^{137}Cs radionuclide content for the suspended solids and solution filtrate. The data are plotted in total µCi per 25 mL of sample. The filterable solids data are not reported in µCi/gram as the amounts of solid material present were very small (micrograms per filter). Weight measurements at this level would have a large associated uncertainty and would be significantly affected by the constituents of the simulated reactor coolant. The explanation for the high concentration at the 1 h time period in the uncrushed debris test is not known. However, after the first hour, the solid radionuclide content is within a factor of 2 for both tests. Crushing appears to have little affect on radionuclide content present as suspended solids.

Table 6 lists the percentage of the core debris radionuclide inventory released into the simulated coolant for the uncrushed and crushed debris tests. These data indicate only a small fraction of the debris inventory (<1%) is made available for release into the coolant either as suspended particulate or dissolved radionuclides. The simulated coolant radionuclide concentrations used for this analysis were for a homogeneous solution 144 h after agitation by which time most settling had occurred. These data were used because the settling rate is quite rapid as previously discussed.

Figure 5 also shows the total radionuclide concentrations in the 25 mL filtrate solution. The data indicate that soluble ^{137}Cs goes into solution within 5 min with little subsequent leaching. Crushing the uncrushed debris sample resulted in a release of ^{137}Cs (~ a factor of 5) which goes into solution immediately with little subsequent leaching into the solution. The total amount of soluble ^{137}Cs is much greater (1 to 2 orders of magnitude) than the suspended solids content.

Airborne Evaporation Tests

Tables 7 and 8 list the radionuclide concentrations resulting from the airborne evaporation tests conducted on the simulated reactor coolant solutions retained from the uncrushed and crushed debris tests. Some general observations and comparisons are:
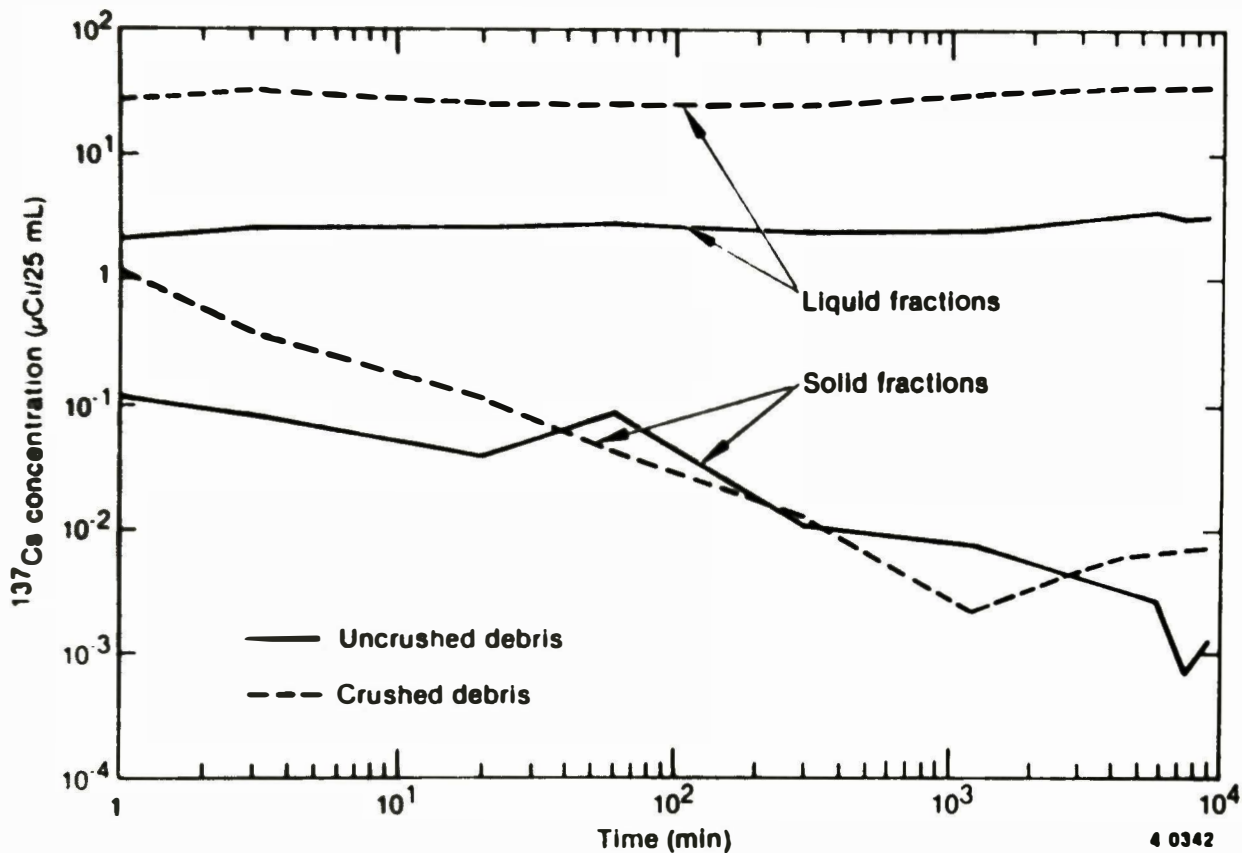
Figure 5. ^{137}Cs concentration in the suspended solids and filtrate (μCi/25 mL of solution).

TABLE 6. FRACTION OF RADIONUCLIDE INVENTORY RELEASED TO COOLANT

Radionuclide	Uncrushed Debris		Crushed Debris	
	Debris Inventory[a] (μCi)	Percent Inventory In Solution	Debris Inventory[b] (μCi)	Percent Inventory in Solution
^{60}Co	5.1 E+3	4.6E-2	4.4E+3	9.6E-3
^{125}Sb	6.73E+3	4.8E-1	5.9E+3	1.4E-1
^{134}Cs	2.6E+3	9.5E-2	2.3E+3	6.7E-1
^{137}Cs	5.2E+4	1.2E-1	4.6E+4	9.9E-1
^{144}Ce	8.0E+4	3.8E-5	7.0E+4	2.3E-4

a. A conservative Debris inventory calculated from Reference 1 for 48.75 gm core debris. Uncertainty is within a factor of 2.

b. A conservative debris inventory calculated for 42.73 gm of debris material.

TABLE 7. AIRBORNE RADIONUCLIDE CONCENTRATIONS - UNCRUSHED DEBRIS TEST ($\mu Ci/cm^3$)

Radionuclide	Filter 1 Time: 1 hour Total: 1 hour	Filter 2 Time: 1 hour Total: 2 hours	Filter 3 Time: 1 hour Total: 3 hours	Filter 4 Time: 1 hour Total: 4 hours	Filter 5 Time: 1 hour Total: 5 hours	Filter 6 Time: 1 hour Total: 6 hours	Filter 7 Time: 1 hour Total: 7 hours
^{60}Co	--a	--a	6.8 ± 1.5E-11	--a	--a	8.9 ± 1.9E-11	--a
^{125}Sb	--a	--a	1.04 ± 0.05E-9	--a	--a	1.1 ± 0.4E-9	--a
^{134}Cs	--a	--a	7.9 ± 1.2E-11	--a	7.3 ± 4.3E-12	8.9 ± 1.3E-11	--a
^{137}Cs	9.4 ± 3.3E-12	4.9 ± 2.7E-12	2.31 ± 0.06E-9	3.3 ± 0.6E-11	2.2 ± 0.2E-10	2.36 ± 0.08E-9	4.6 ± 0.8E-11
^{144}Ce	--a	--a	--a	--a	--a	1.1 ± 0.2E-10	--a
Solution Volume (mL)	--b	470	--b	450	--b	400	--b

Radionuclide	Filter 8 Time: 1 hour Total: 8 hours	Filter 9 Time: 1 hour Total: 9 hours	Filter 10 Time: 2 hours Total: 11 hours	Filter 11 Time: 2 hours Total: 13 hours	Filter 12 Time: 2 hours Total: 15 hours	Filter 13 Time: 2 hours Total: 17 hours	Filter 14 Time: 8 hours Total: 25 hours
^{60}Co	--a	--a	--a	--a	3.9 ± 0.6E-11	--a	4.1 ± 0.3E-10
^{125}Sb	--a	1.1 ± 0.7E-11	1.1 ± 0.3E-11	--a	5.6 ± 2.3E-10	1.2 ± 0.7E-9	5.7 ± 0.2E-9
^{134}Cs	--a	--a	--a	--a	4.8 ± 0.6E-11	--a	5.3 ± 0.4E-10
^{137}Cs	2.2 ± 0.4E-11	4.. ± 1.0E-11	4.6 ± 0.4E-11	7.1 ± 0.7E-11	1.15 ± 0.04E-9	6.2 ± 0.7E-10	1.28 ± 0.05E-8
^{144}Ce	--a	--a	--a	--a	--a	--a	3.0 ± 0.8E-11
Solution Volume (mL)	370	--b	--b	350	290	--b	150

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TABLE 7. (continued)

Radionuclide	Filter 15 Time: 8 hour Total: 33 hours	Filter 16 Time: 4 hour Total: 37 hours	Filter 17 Time: 4 hours Total: 41 hours	Filter 18 Time: 4 hours Total: 45 hours	Filter 19 Time: 4 hours Total: 49 hours	Filter 20 Time: 4 hours Total: 53 hours	Filter 21 Time: 2 hours Total: 55 hours
^{60}Co	1.1 ± 0.7E-11	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]
^{125}Sb	1.4 ± 0.2E-10	2.4 ± 0.2E-10	3.4 ± 1.5E-11	3.4 ± 1.3E-11	4.0 ± 1.6E-11	2.3 ± 1.3E-11	--[a]
^{134}Cs	1.6 ± 0.5E-11	1.8 ± 0.5E-11	--[a]	--[a]	--[a]	--[a]	--[a]
^{137}Cs	3.2 ± 0.3E-10	3.2 ± 0.3E-10	5.2 ± 1.1E-11	7.8 ± 1.2E-11	9.1 ± 1.4E-11	4.2 ± 0.9E-11	7.1 ± 1.7E-12
^{144}Ce	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]	--[a]
Solution Volume (mL)	--[b]	10	--[b]	No measurable solution	Dry	Dry	Dry

a. Not detected.

b. Not measured.

TABLE 8. AIRBORNE RADIONUCLIDE CONCENTRATIONS - CRUSHED DEBRIS TEST
(μCi/cm^3)

Radionuclide	Filter 1	Filter 2	Filter 3[a]	Filter 4	Filter 5
	Time: 18 hours Total: 18 hours	Time: 24 hours Total: 42 hours	Time: 4 hours Total: 46 hours	Time: 2 hours Total: 48 hours	Time: 2 hours Total: 50 hours
^{60}Co	4.2 ± 1.9E-12	--[c]	1.9 ± 0.3E-10	5.3 ± 2.1E-11	2.3 ± 1.8E-11
^{125}Sb	1.4 ± 0.6E-11	2.5 ± 1.5E-12	3.2 ± 0.2E-9	9.4 ± 4.3E-11	--[c]
^{134}Cs	--[c]	--[c]	2.9 ± 0.1E-9	--[c]	--[c]
^{137}Cs	9.9 ± 0.7E-11	7.6 ± 1.5E-12	9.23 ± 0.06E-8	9.6 ± 1.1E-10	4.9 ± 0.4E-10
^{144}Ce	4.7 ± 0.6E-11	--[c]	1.2 ± 0.21E-9	2.0 ± 0.5E-10	1.0 ± 0.5E-10
Solution[b] Volume (mL)	220	-0-	30	Dried out	-0-

a. Reconstituted sample with 100 mL simulated reactor coolant.

b. Initial volume (approximately 500 mL).

c. Not detected.

o   Most of the airborne radionuclide release occurred near the end
     of the evaporation process, prior to dry out. The increase in
     airborne concentrations at this time is 2 to 3 orders of
     magnitude higher than at any other time. This may be due to the
     increased wetted surface to volume ratio.

o   Increased airborne concentrations occurred each time the solution
     volume was measured. By pouring the solution from and back into
     the chamber, some of the chamber surfaces were wetted. As these
     surfaces dried, airborne concentrations increased, perhaps as a
     result of the increased wetted surface to volume ratio.

o   Airborne activities significantly decreased, as soon as all
     liquid had evaporated indicating the probable mode of transport
     is with water droplets.

o   After drying, the ^{137}Cs airborne concentrations were a factor
     of 4 to 5 higher for the crushed debris test than for the minor
     disturbance test. The larger fractions of crushed, smaller
     particles present in the major disturbance test may be the cause
     of the higher airborne concentrations.

The length of time between filter changes was increased during the
crushed debris evaporation test because, as shown by our experience with
the uncrushed debris test, long evaporation periods were required to reduce
the volume of samples; except during dryout, only low airborne
concentrations were measured. However, the solution evaporated more
rapidly than expected and the evaporation chamber dried out during use of
the second filter. An additional 100 mL of liquid was added to the chamber
and the solution was again evaporated. The filters used during evaporation
of the additional 100 mL of solution (3 through 5) were changed at shorter
time intervals. The data indicate high radionuclide concentrations were
produced after the dried surfaces were wetted and the airborne
concentrations subsequently decreased following evaporation dryout by ~2
orders of magnitude.

A comparison of the measured airborne concentrations inventories obtained from Table 7 indicates that for most radionuclides <1% of the total radionuclide inventory in the evaporation chamber went airborne during the dryout process. A higher percentage, <20% was measured for ^{144}Ce. The reason for the higher release fraction for this radionuclide is not known; however, the smallest measurable inventory was present in solution for this radionuclide.

REFERENCE

1. D. W. Akers and B. A. Cook, <u>Preliminary Report: TMI-2 Core Debris Grab Samples, Analysis of First Group of Samples</u>, GEND-INF-60, Volume 1, (to be published).

APPENDIX A
TURBIDITY MEASUREMENT VIA NEPHELOMETRY

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TURBIDITY MEASUREMENT VIA NEPHELOMETRY

Turbidity is an expression of the optical properties that cause light to be scattered or absorbed through a liquid sample and is largely a function of the refractive index, the size and the shape of the particles suspended in solution. As a result, turbidimeters do not produce an "absolute" measurement, but one that is "relative" to the optical nature of the solids suspended in a solution. Formazin polymer is accepted as the turbidity reference standard because when carefully prepared it is uniform in the number, size and shape of its particles. The calibration standard used for these tests was a 0.1 Nephelometric Turbidity Unit (NTU) standard.

This reference standard supplied with the turbidimeter has been compared to a known formazin suspension and it serves as a starting point for "zeroing" the instrument. Calibration is performed by placing a carefully prepared formazin suspension in a sample curvette. Measurement is then made at each end of the instrument's range and adjustments made to display correct values. This sets a linear scale of measurement for any value of turbidity between the end points of the scale. However, it is not possible to characterize a nephelometer's sensitivity as the response is nonlinear and is affected by the individual sample matrix of the turbid material.