Appendix VII

Characterization of Pressurized-Water-Reactor Latent Debris

The U.S. Nuclear Regulatory Commission has recently initiated a study conducted through Los Alamos National Laboratory (LANL) and the University of New Mexico (UNM) to characterize latent debris samples collected at five individual volunteer plants. This work focuses on the physical attributes of dust and dirt, such as particulate-to-fiber mass ratio, size distributions of particulate, material and bulk densities, and hydraulic parameters, including the specific surface area. Because of variations in plant collection methods and sampling schemes, it is not possible to estimate the total latent-debris inventories. This appendix documents preliminary results of that study that are relevant to the supplementary guidance provided by the staff in Section 3.5 of the safety evaluation report.

LANL received a total of five sets of samples, but only totally characterized four. The study did not fully characterize the fifth set because it was dominated by paint chips generated from pressure washing and was therefore deemed to be unrepresentative of pressurized-water reactor containment debris. Material property data collected for the latent-debris samples establish the basis for preparation of a particulate-debris simulant that is suitable for large-scale head-loss testing at UNM. The head-loss testing seeks to quantify the hydraulic properties of latent debris that are needed for the proper application of the NUREG/CR-6224 debris-bed head-loss correlation.

LANL conducted the sample characterization according to the following experimental scope:

- The debris was removed from its shipping container and transferred to plastic laboratory containers for gamma-spectrum counting.
- The fiber and particle fractions were separated from the remaining (or “other“) debris items by manual manipulation, sieving, and water rinsing.
- Particulate size distributions were obtained by graduated sieving.
- The weight of fine particles attached to swiping (Masolin) cloth or filter paper was determined by mass balance and comparisons of clean collection media to soiled collection media.
- The fiber thickness/diameter was determined by scanning electron microscopy (SEM) and microphotographic statistics.
- The material and bulk densities of fibers were estimated by mass measurement combined with volume estimates obtained from water displacement and direct measurement in graduated columns, respectively.
- Particle surface area and density measurements were taken using state-of-the-art nitrogen adsorption techniques.
- Scanning electron microscope/energy-dispersive spectroscopy methods were used to characterize the chemical composition of representative particulate and fiber samples.

Figure VII-1 illustrates a typical variety of composition and proportion between particulate, fiber, and other larger pieces that are assumed to have minimal transport potential. All plants submitted multiple samples ranging from a few grams to several thousand grams that exhibited similar characteristics. For some plants, the samples had to be combined to obtain meaningful measurements; for others, each individual sample could be fully characterized.

Figure VII-1. Representative Latent-Debris Components from a Single Volunteer Plant

Objects larger than a 0.132-in.–mesh size sieve were classified as a debris type other than particulate or fiber. This category of size, composition, and characteristics should be removed from any plant-specific samples that are collected before applying any mass fractions reported in this appendix. Larger latent debris types are not assumed to be transportable at recirculation pool velocities and so do not contribute to long-term increases in sump-screen head loss. Table VII-1 presents the range of particulate and fiber mass fractions that were measured for samples that were characterized after the larger pieces were removed. From these data comes the generic recommendation that 15 percent of the transportable latent debris be assumed to be fiber.

Each volunteer plant used a different collection method and sampling scheme. When separating particulates by wet sieving into fractions (greater than 2 mm, 500 μm to 2 mm, 75 μm to 500 μm, and less than- 75 μm), it became apparent by comparing plants that scraping and bristle-brush collection were not effective at capturing the smaller particulate fractions. The SEM photos of filter papers and cloth swipes that showed significant loadings of particles less than 10 μm in diameter further reinforced this conclusion. High-efficiency particulate air filter vacuuming with the brush attachments or manual swiping with lint-free (Masolin) cloth are recommended collection methods for characterizing plant-specific latent debris loadings.

A suitable surrogate formulation for latent particulate was found using a 28% mass fraction of common sand (ρ=2.6 g/cm^3) sieved between 500 μm and 2 mm, a 35% mass fraction of common sand sieved between 75 μm and 500 μm, and a 37% mass fraction of clay–based soil sieved <75 μm. Clay was used to conservatively incorporate the particulate fraction <10 μm that was observed in the plant samples.

Table VII-1. Particulate and Fiber Mass Fractions for Volunteer Plants A–D

Plant	Particle Weight	Fiber Weight	% Particle	% Fiber
A	5.42	1.04	84	16
B1	214	20	91	9
B2	369	64	85	15
B3	390	37	91	9
B4	592	47	93	7
B5	792	34	96	4
B6	122	50	71	29
B Total	2479	252	91	9
C	13.77	0.76	95	5
D1	2.51	0.47	84	16
D2	0.29	0	100	0
D3	12.45	0.28	97	3
D4	34.34	2.20	94	6
D6	5.56	0.1	98	2
D8	9.15	0.09	99	1
D10	11.98	0.74	94	6
D15	74.92	7.0	91	9
D Total	151.2	10.88	93	7

Sample Range	Total Particulate	71%–100%
	Total Fiber	0%–29%
Plant Range	Particulate	84%–95%
	Fiber	5%–16%

The material density of characterized fibers was found by water displacement measurements of 10 plant samples to range between 1.0 to 1.9 g/cm^3. The mean value of 1.5 g/cm^3 is recommended for use if needed in generic latent-debris assessments. However, a more relevant parameter of fiber is the dry-bed bulk density that can be used to estimate the volume of fiber needed to form a 1/8-in. thick thin bed across the wetted-screen area of a given sump configuration. This property and the suggested application are comparable to the use of the as-manufactured bulk density for fiberglass insulation.

The dry-bed density of latent fiber depends greatly on the amount of compaction applied for the measurement. Several alternatives were tried, but ultimately the staff recommends using the fiberglass density of 2.4 lbm/ft^3 = 38.4 kg/m^3 as a surrogate for dry latent debris. Similarly, fiberglass hydraulic properties should also be used as a surrogate for latent fiber. The following rationale supports these recommendations. First, in cases where fiberglass debris is present on the screen, minor inaccuracies in the latent fiber properties will not affect head-loss calculations. Second, where latent fiber is the dominant fibrous debris source and there is sufficient quantity to form a thin-bed filter, the properties of particulates captured on the fiber bed will dominate maximum head loss. Again, the difference between the actual hydraulic behavior of latent fiber and the presumed properties of fiberglass will not affect head-loss calculations adversely.

Particulate densities for each size fraction and volunteer plant were measured very accurately using the Brunauer-Emmett-Teller nitrogen adsorption method. Densities of particulates in the debris range from 125 to 250 lbm/ft^3 (2 to 4 g/cm^3) with only a few exceptions, and densities for most of the samples range between 156 to 188 lbm/ft^3 (2.5 and 3.0 g/cm^3), regardless of their particle size. These data form the basis of the recommendation for a nominal latent particulate density of 169 lbm/ft^3 (2.7 g/cm^3).

A nominal size distribution of particulates found in the latent debris samples was used as a starting point to develop a formula for surrogate particulate debris that could be tested in a vertical-flow test loop at UNM. This apparatus permits measurement of pressure drop across a debris bed of known composition under a range of water velocities. Hydraulic parameters of the debris bed can then be inferred from differential pressure data by iteratively applying predictive correlations until the model results envelope a range of observed data. Material-specific parameter values, such as the specific surface areas that are inferred in this manner, are only appropriate for use with the particular head-loss formula with which they were derived. In this case, the NUREG/CR-6224 head-loss correlation was applied. Microporous flow-resistance tests were performed on both the latent-debris samples and the surrogate formula to confirm that the surrogate could produce reasonably representative yet conservative hydraulic behavior.

Equivalent mass fractions of common sand and clay-based soil were used to recreate the size distribution of the latent particulate. Over a set of well-conditioned head-loss tests where the surrogate particulate was tested in combination with fiberglass insulation, the specific surface area of the surrogate was estimated to be 106,000 ft^{-1}. The penetration of the debris bed by extremely fine clay silt that continued to circulate in the test loop complicated the analyses of these tests. Within the range of the tests where flow velocities at the screen are less than 0.2 ft/s (uncompressed fiber bed) and the estimated particulate-to-fiber mass ratios cannot exceed 3, the estimated particulate loading on a postulated debris bed can be reduced by 7.5 percent (one-quarter of the less than 75-μm mass fraction) to accommodate realistic debris-bed penetration of latent fine particulates.

The surrogate debris formula was further refined by eliminating the latent-debris fraction with nominal dimensions greater than 2 mm because the particles (sand grains) are not likely to transport at the pool velocities of less than 0.5 ft/s that may exist near the screen under recirculation conditions. This size fraction represents approximately 22 percent of the particulate mass on average that can be discounted from the particulate inventory that is available for long-term transport under recirculation. This size fraction may be subjected to high-velocity transport during fillup, and so the fractional decrease was only recommended for latent-particulate inventories residing above the flood level.