CHARACTERISATION OF LATENT DEBRIS FROM PRESSURISED WATER REACTOR CONTAINMENT BUILDINGS

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Executive summary

When accounting for the total amount of debris that may be present in a pressurised water reactor (PWR) containment pool during operation of the emergency core cooling system (ECCS), it is important to include a reasonable estimate of the latent dirt and foreign material that can be found in containment in addition to the debris generated by a high-pressure pipe rupture. Past and recent testing has shown that even small volumes of fibrous debris present on an ECCS sump screen can very effectively filter particulates that are present in the sump pool, leading to significant pressure losses across the composite debris bed. Debris present during routine operations that is subjected to containment spray and pool transport may contribute a significant source of particulate and perhaps fiber material. Because the PWR industry is working to estimate the quantity of latent debris present in containment, Los Alamos National Laboratory (LANL) is working, under the direction of the United States Nuclear Regulatory Commission (USNRC), to characterise the material composition and the hydraulic flow properties of actual plant debris samples. Beginning in August 2003 and ending in March 2004, this study is expected to quantify particulate and fiber debris parameters, such as the specific surface area and flow porosity that are critical to the proper application of the NUREG 6224[1] head-loss correlation. Microfiltering, optical microscopy, and organic dissolution chemistry tests are being used to fractionate the fibrous and particulate components. All tests are being performed at the geochemistry laboratory at the Isotope and Nuclear Chemistry Facility, Chemistry Division (C-INC), LANL, which has the necessary analytic equipment to make direct measurements of the hydraulic flow properties and to handle low-level radioactive PWR latent debris material. The success of this study is dependent on the participation and cooperation of the US PWR industry, the NRC, and LANL. Approximately six volunteer PWR plants are expected to contribute samples collected during their recent condition assessment surveys.

1. Zigler, G., J. Brideau, D.V. Rao, C. Shaffer, F. Souto and W. Thomas, “Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris”, United States Nuclear Regulatory Commission final report NUREG/CR-6224, Science and Engineering Associates, Inc., report SEA-93-554-06-A:1 (October 1995).

1. Introduction

This paper presents the results of a United States Nuclear Regulatory Commission (USNRC)-sponsored project focused on characterising debris resident in pressurised water reactor (PWR) containment buildings. Information is provided to establish the background and purpose for the work, as well as details associated with the experimental protocol being employed at Los Alamos National Laboratory (LANL) to collect the desired characterisation data. This paper presents preliminary results associated with this ongoing project. Much of the information that follows reflects the work-in-progress associated with this project.

2. Background and purpose

The USNRC is interested in evaluating accident scenarios at commercial PWR nuclear power plants in which "latent" debris is washed into reactor containment sumps during loss of coolant accidents (LOCAs). This "latent" or "pre-LOCA" debris potentially could clog screens upstream of pumps that supply cooling water to a reactor core that is experiencing a loss of cooling.[2,3,4,5] "Latent" refers to debris that is already present and that resides inside the containment structure before the accident (as opposed to debris that is generated by the accident). Examples of latent debris include ordinary dust and dirt, insulation fibers, clothing fibers, paper fibers, chunks of plastic, metal filings, paint chips, human hair, or just about anything else that might end up on a floor or other surface inside an industrial building.

A primary safety concern related to long-term recirculation cooling following a LOCA is LOCA-generated and pre-LOCA debris material that is transported to debris interceptors (i.e. sump strainers or screens), which results in strainer blockage and degraded emergency core-cooling (ECC) pump performance. Draft Regulatory Guide DG-1107 "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident"[6,7] suggests that the cleanliness of the reactor containment during plant operation (i.e. pre-LOCA or latent debris) be considered when estimating the amount and type of debris available to block the ECC sump screens. The potential for this material to impact the head loss across the ECC sump screens should be considered. This study focuses on characterising this latent debris material and assessing its potential to contribute to sump-strainer blockage.

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2. Lochbaum, D., "Pressurized Water Reactor Containment Sump Failure", Union of Concerned Scientists, internet issue brief (20 August 2003).

3. Wald, M.L., "Safety Problem at Nuclear Plants is Cited", *The New York Times* (8 September 2003).

4. Rawlins, Wade, "Harris Plant Has Design Flaw", *News Observer* (14 September 2003).

5. Matthiessen A., and D. Lochbaum, Indian Point Energy Center, Petition Pursuant to 10 CFR 2.206, "PWR Containment Sump Failure", letter to W.D. Travers, Executive Director for Operations, US Nuclear Regulatory Commission (8 September 2003).

6. Draft Regulation Guide DG-1107, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident", United States Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (February 2003).

7. Bonaca, M.V., Draft final revision 3 to Regulatory Guide 1.82, "Water Sources for Long-Term Recirculation Cooling Following a Loss-of-Coolant Accident", letter to N.J. Diaz, Chairman, United States Nuclear Regulatory Commission (30 September 2003).

Past and recent testing has shown that even small volumes of fibrous debris present on an ECC sump screen can very effectively filter particulates that are present in the sump pool, leading to significant pressure losses across the composite debris bed and resulting in degraded pump performance. Debris present during routine operations or pre-LOCA or resident debris that is subjected to containment spray (or wash-down from a coolant-pipe rupture) and pool transport may contribute a significant source of particulate and perhaps fiber material. The USNRC and its contractors are carefully studying pressure drop across "filter beds" as a function of the physical properties of the filter bed and the linear flow velocity through the bed.[8] Semi-empirical equations have been developed to predict pressure drop across filter beds using a combination of fluid-flow theory and experimental results. Some of the most important parameters in these correlations are the density of the filter bed and the surface area per unit volume within the bed. The relative volume of "fibers" and "particles" in the bed is also important because the compressibility of the bed depends on this ratio.

This study, funded by the USNRC, focuses on characterising the pre-LOCA or latent debris resident in a PWR containment building. Specifically, the focus of this effort is to collect representative pre-LOCA debris from PWR containments and to characterise this debris consisting of dust and dirt samples; characterising will support the material property determination of the loosely dispersed resident debris constituents. The PWR industry has informally agreed to provide the samples of resident debris that are needed to complete this effort, and six PWR operators have agreed to provide samples. To date, three sets of samples have been received at LANL and are in various stages of characterisation. The material property data are needed to support the application of the NUREG/CR-6224[1] debris-bed head-loss correlation. In addition, the material property data to be collected for resident debris are expected to establish the basis for debris simulant for additional head-loss tests.

Previous work has focused on filter-bed materials that would be generated during an accident, not on debris that is already present in the containment structure. For this project, latent debris will be collected from within PWR containment buildings and shipped to LANL for physical characterisation. This characterisation will include, but not necessarily be limited to, qualitative separation of "fiber" and "particle" fractions from the rest of the latent debris, microphotographic classification of fibers, determination of average particle density of the debris measurement of the surface area per unit weight of the debris particles using the N_2-BET method, and possibly determination of filtration properties of the materials (pressure drop vs. flow rate) in small-scale experiments. LANL's Geochemistry Laboratory is being enlisted for this work because the latent debris typically contains very low levels of radioactivity (primarily gamma-emitting activation products) and therefore must be handled in a radiological or nuclear facility.

3. Experimental protocol

Shipment of radioactive debris samples from candidate PWRs and the associated receipt and inspection at LANL required the establishment of a simple protocol to enable work to begin in the Geochemistry Laboratory. After the debris is collected at the plant site, its radionuclide content is determined by gamma spectroscopy to satisfy shipping requirements. This information must be provided to LANL so that a radioactive material receipt request can be filed through established LANL Geochemistry Laboratory protocols. To date, five PWRs have provided gamma spectra results of latent debris collected, and the results indicate that the debris contains radionuclide inventory less

8 United States Nuclear Regulatory Commission, "Transient ECCS Strainer Blockage Model, Appendix B", NUREG/CR-6224 (October 1995).

than the “sum-of-fractions” barcode limit for a radionuclide inventory in the Geochemistry Laboratory. The quantities of latent debris received from these five PWRs vary from grams to kilograms. Thus, the total activity of debris samples expected from all six PWRs is unlikely to exceed the Hazard Category 3 nuclear facility limit.

When the material is received at the Geochemistry Laboratory site, it is taken first to the laboratory count room for gamma counting and spectral analysis before being unpackaged (the gamma spectroscopic report from the nuclear plant also is provided). The count room personnel will determine if they can detect any radionuclides to which national security programs in the building might be sensitive. To date, this has not been the case because the samples have not contained any debris from fuel elements (the radioactivity is generally attributable to activation products). Alpha and beta counting has not been conducted on the samples because the radioactivity in the samples is very heterogeneous (contained in only a few particles) and it is not possible to prepare the samples for alpha or beta counting without incurring greater risk of contamination than simply proceeding with the work after gamma counting.

Once the debris material has been received into the laboratory, experimental work can begin. The experimental scope is as follows:

1. determine qualitatively the composition of debris collected from each plant;
2. characterise particulate and fiber fractions using microscopic examination;
3. determine physical properties of particulate and fiber fractions; and
4. conduct small-scale filtration experiments.

The experimental debris characterisation proceeds as follows.

3.1 Removal of debris from its shipping container to laboratory containers

The debris from the first three plants arrived in two different types of containers. Two sets of samples consisted of small quantities (a few grams) of debris in double-contained baggies, e.g. Ziploc® bags. The debris either was loose in the bags or adhered to masolin cloth, paper “swipes”, or vacuum filters. Debris was removed from each bag and placed into a small Tupperware® tray. Filter/swipe papers were shaken gently to remove any loose debris. Wet filter/swipe papers are used to wash the debris adhered to the bags. Next, the swipes were gently agitated in a water bath to remove the debris. Another sample consisted of six HEPA filters with the quantity of debris ranging from 160 to 750 grams. Because of its greater quantity, transfer of this second debris sample to the Laboratory container was carried out in a glove bag to prevent potential spill and inhalation of the debris particles and fibers.

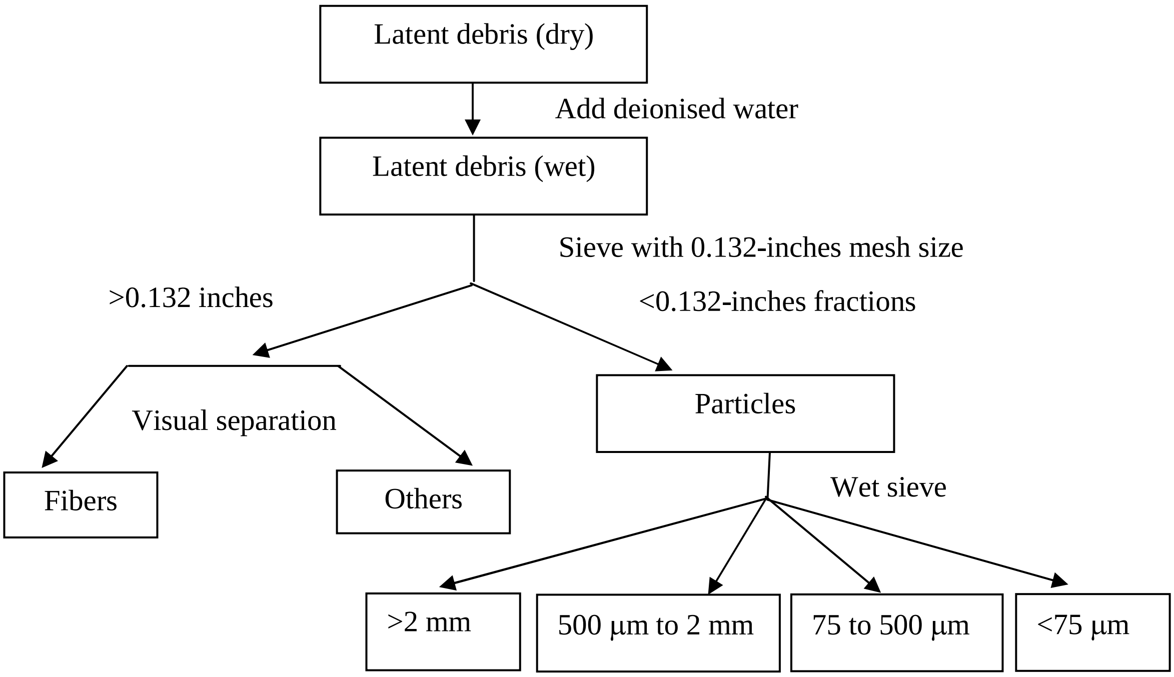
3.2 Separation of “fiber” and “particle” fractions from the remaining debris

Wet sieving was employed to separate “fiber” and “particle” fractions from the remainder of the debris by using a 0.132-in.-mesh-size sieve. The particle-size fraction less than 0.132 in. was further separated by wet sieving into four fractions, i.e. >2 mm; 500 μm to 2 mm; 75 μm to 500 μm, and <75 μm. Once acceptable separation was achieved, the water was allowed to evaporate in a hood overnight or over the weekend. Figure 1 demonstrates the wet separation scheme employed to segregate the latent debris.

3.3 *Surface area and density measurement of particles*

The surface areas of subtractions of the debris particles were measured by nitrogen adsorption. The subtractions were dried, weighed, and then loaded into a glass sample cell for measuring. The samples were loaded inside a hood to prevent spill and inhalation. The nitrogen adsorption BET surface area was measured using a Quantachrone Nova 1200 instrument. This technique also provided estimates of volume and thus densities of samples.

Figure 1. Latent debris qualitative separation flow scheme



3.4 *Microphotographic classification of fibers*

Fibrous debris varied in size and quantity for each sample. A metallurgical microscope with a 20X objective lens was used to identify the size/shape of the fibrous debris separated from the above procedures. The sample was loaded onto a microscope slide using glue.

3.5 *Scanning electron microscope (SEM)/energy-dispersive spectroscopy characterisation (EDAX)*

Fiber and particle sub samples that either appeared to be very representative or were of special interest because of an unusual characteristic (e.g. shape and colour) were selected for SEM/EDAX characterisation to show the surface topography and to qualitatively determine elemental composition.

3.6 *Settling measurements*

Settling measurements on different particle-size fractions were performed to provide information on settling velocities so that calculations could be conducted to determine fractions (or sizes) of particulate debris that would reach sump screens.

3.7 Small-scale filtration experiments

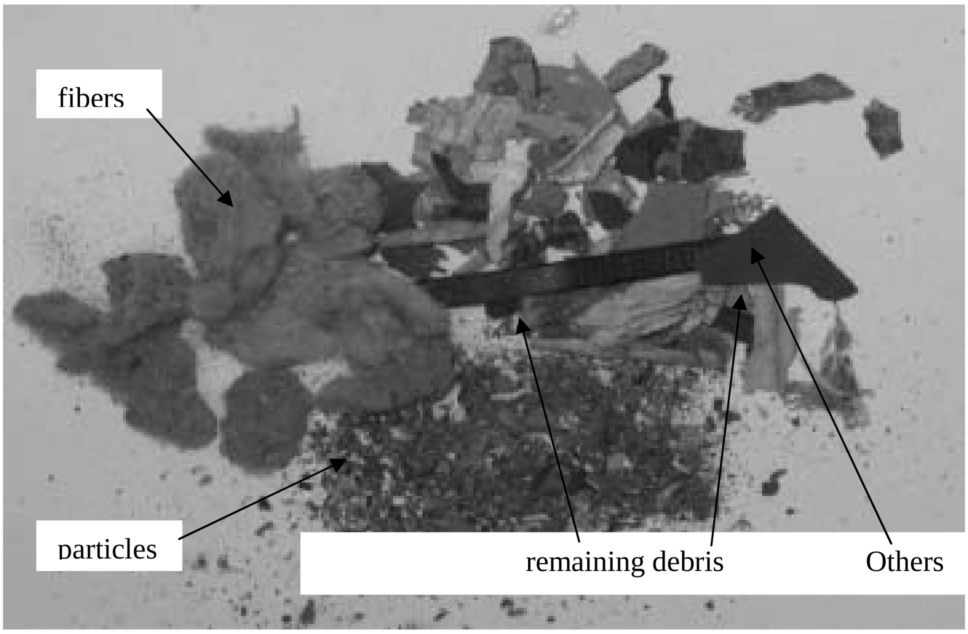
If sufficient quantities of material are available, bench-top experiments may be conducted to measure pressure drop as a function of filter-bed thickness, material mix (fiber vs. particle), and flow rate through the filter bed. Some of these experiments may be conducted in conjunction with the debris density measurements mentioned previously (density would be measured first, then water flow through the bed to measure pressure drop as a function of time and flow rate). All such experiments will be conducted with wet debris, and gravity will always be the preferred driving force for flow so that pressures will be relatively low. Double containment (spill trays) will be used to prevent the potential spread of contamination by leaks. Debris from settling measurements will be recovered and recombined with other debris to conduct filtration experiments. Linear flow velocities similar to those in nuclear plant sump strainers will be employed in a small test loop similar to the loop employed at the University of New Mexico. Meshes or screens of different sizes will be employed at the end of columns to initiate filter bed build-up. Once a filter bed has been built up, the bed density would be measured by measuring the length (and thus the volume) of the bed, weighing the column, and then removing and drying the material and column to get the dry weights of both the material and column. In addition to bed density, the filter-bed porosity also will be measured, which is another important parameter in the filter-bed head-loss correlations.

4. Results and discussion

4.1 Composition of debris

Debris samples from three PWRs, namely plants A, B, and C, have been received and have undergone characterisation. The quantity of debris received from these three plants is significantly different, varying from less than 10 grams to about a few hundred grams. In general, the debris consists of three major fractions, as illustrated in Figure 2.

Figure 2. Composition of debris (pictured from plant A debris)



Determining the composition of debris starts with the initial separation of debris into fibers, particles, and remaining debris, i.e. “other”. The weight percentage of each fraction of every sample is different, depending on where and how the sample was collected. Table 1 lists the initial separation results of debris from the three plants. At times, separation is difficult because very small particles adhere to the fibers and are nearly impossible to completely separate.

Table 1. Weight fraction of latent debris from plants A, B, and C

Plant A				**Plant B**				**Plant C**			
	Weight (g)				***Weight (g)***				***Weight (g)***		
ID	P[a]	F[b]	O[c]	ID	P[a]	F[b]	O[c]	ID	P[a]	F[b]	O[c]
1	0.32	0.02	0.02	B1	111	12	41	C1	4.42	0.05	0.66
2	0.45	0.06	0.12	B2	225	42	59	C2	NA[d]	0.30	NA
3	0.06	0.07	NA	B3	290	29	82	C3	0.77	<0.01	1.90
4	1.18	0.41	0.04	B4	267	23	51	C4	0.23	NA	0.13
5	0.15	NA	0.24	B5	474	24	255	C5	1.23	0.02	1.90
6	0.54	0.02	0.18	B6	74	40	121	C6	0.16	0.04	0.37
7	0.24	NA	0.06		***Weight (wt %)***			C7	4.20	0.35	7.59
8	0.05	0.01	NA	B1	68	7	25	C8	3.76	NA	0.19
9	0.76	0.21	0.12	B2	69	13	18				
10	0.38	0.11	0.07	B3	72	7	20				
11	0.23	0.01	0.39	B4	78	7	16				
12	0.2	NA	NA	B5	63	3	34				
13	0.1	0.08	NA	B6	31	17	51				
14	0.4	0.04	0.01								
total	**5.06**	**1.04**	**1.25**					**total**	**13.77**	**0.76**	**12.74**
	Weight (wt %)								***Weight (wt %)***		
A	**69**	**14**	**17**					**C**	**50.50**	**2.79**	**46.72**

[a] P = particles.

[b] F = fibers.

[c] O = others.

[d] NA = not applicable.

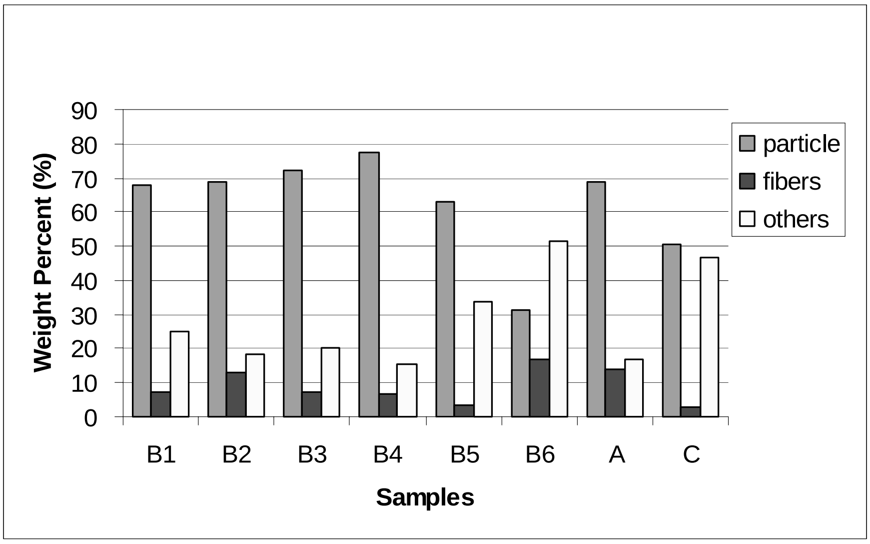
The quantity of debris in the individual debris samples from plant A was determined to be insufficient to conduct further characterisation tests. To enable further testing, all of the individual debris samples were combined to represent plant A.

In contrast to plant A, the quantities of debris in each sample from plant B were large enough to allow further characterisation.

Similar to plant A, the quantity of debris in the individual debris samples from plant C was not enough to conduct further characterisation tests for all samples. However, the character of each sample from plant C seemed quite different when compared with plants A and B. Individual sample characterisation will be completed on the samples with sufficient quantity.

Figure 3 summarises the results of the initial separation of debris for plants A, B, and C. In Figure 3, the six individual samples from plant B are shown, whereas the combined results for plants A and C are presented. The results are shown by weight percent; not surprisingly, particulate fractions significantly exceed fiber or “other” fractions for most samples.

Figure 3. Composition of latent debris from plants A, B, and C



To characterise the particulate in more detail, the debris sample particle fraction was further separated into four particle-size categories using sieves with mesh sizes >2 mm, 500 µm, and 75 µm. Table 2 lists the particle-size distribution results for plants A, B, and C.

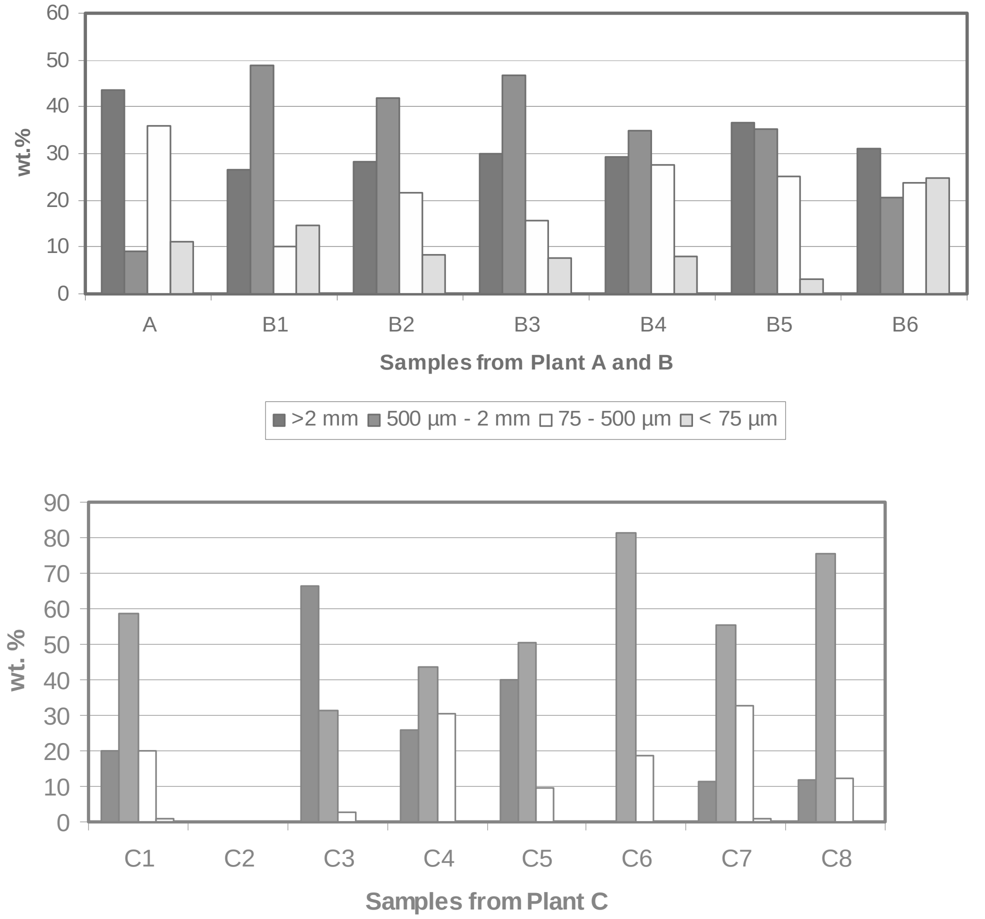
Table 2. Particle-size distributions of plants A, B, and C debris

Sample ID	Particle size							
	>2 mm		500 µm to 2 mm		75 to 500 µm		<75 µm	
	g	wt %	g	wt %	g	wt %	g	wt %
A	1.5	43.73	0.32	9.19	1.24	36.01	0.38	11.08
B1	26.03	26.49	48.04	48.88	9.97	10.14	14.24	14.50
B2	53.25	28.11	79.48	41.95	41.15	21.72	15.57	8.22
B3	77.76	29.95	121.03	46.62	40.15	15.60	20.30	7.82
B4	54.73	29.44	65.13	35.03	51.55	27.73	14.50	7.80
B5	134.51	36.49	130.44	35.39	92.23	25.02	11.44	3.10
B6	10.21	31.19	6.72	20.53	7.74	23.64	8.07	24.65
C1	0.69	20.18	2.01	58.77	0.69	20.18	0.03	0.88
C2	NA	NA	NA	NA	NA	NA	NA	NA
C3	0.51	66.23	0.24	31.17	0.02	2.6	NA	NA
C4	0.06	26.09	0.10	43.48	0.07	30.43	NA	NA
C5	0.49	39.84	0.62	50.41	0.12	9.77	NA	NA
C6	NA	NA	0.13	81.25	0.03	18.75	NA	NA
C7	0.47	11.19	2.33	55.48	1.37	32.62	0.03	0.71
C8	0.45	11.97	2.84	75.53	0.47	12.50	NA	NA

[a] NA = not applicable.

Figure 4 presents the particle-size distribution results for plants A, B, and C. As indicated in Figure 4, particles with a size ranging between 500 µm and 2 mm constitute the major fraction of the debris, followed by particles with a size range >2 mm. The quantity of particles with a size ranging between 75 and 500 µm is also significant for almost all of the samples. Particles <75 µm constitute the smallest fraction of almost all of the samples, especially in samples from plant C, in which the amount of particles <75 µm is barely detectable. The fraction of very small particles, i.e. <75 µm, is highly dependent on the debris-collection method at each plant, which may help to explain the lack of very small particles in the plant C debris sample.

Figure 4. Particle-size distribution of plants A, B, and C debris



4.2 Classification of fibers

Several samples that were separated from the debris shipments from different plants were viewed under an optical microscope using a 20X objective lens. Figures 5, 6, and 7 show several selected microscopic images of “fibrous” samples from Plants A, B, and C, respectively. Because of the large variation in the fiber shapes and dimensions, these images are not necessarily fully representative of the original samples. This variation is not surprising considering the difference in sample collection locations within the plant, the dominant materials present in the plant at the time of sample collection, the methods used to collect the samples, and the techniques we used to separate the samples. However, several useful observations can be drawn from these images.

As these images depict, the fibers are between about 1 and 20 μm in diameter (or thickness), with the majority being closer to the upper range. The larger fibers (>>5 μm in diameter or thickness) appear to be almost straight cylinders, single tortuous and flexible strands, or twisted, flat ribbon-like strips. Some of these strands appear to be interwoven to form larger clusters of multiple fibers attached at different points and have random orientations. The smaller fibers (<<5 μm in diameter or thickness) appear to be interwoven together to form larger clumps. The size of these clumps ranges between a few microns to more than a millimetre (not shown in these images). The images also indicate that these clumps tend to attach (or clamp) to neighbouring fibers.

Another important observation from these images is that almost all of the fibers have particles attached to them. This attachment is apparently physiochemical rather than mechanical. The size of these particles is comparable to the diameter (or thickness) of the hosting fiber in most instances but can be much larger in other instances. However, because of the limited resolution of optical microscopy, it is not obvious whether these attached particles are single particles or clusters of smaller individual particles. These attached particles (or clusters) can have a significant effect on the overall transport behaviour of the debris, not only because they induce additional physical roughness to the fiber surfaces, but also because they can act as seeds that stimulate further attachment of other particles or further clustering of the fibers themselves.

Overall, the fiber characteristics qualitatively reflect the fiber-debris classification by shape, as summarised in Table B-3 of NUREG/CR-6224.[8]

Figure 5. Photo images of plant A fiber

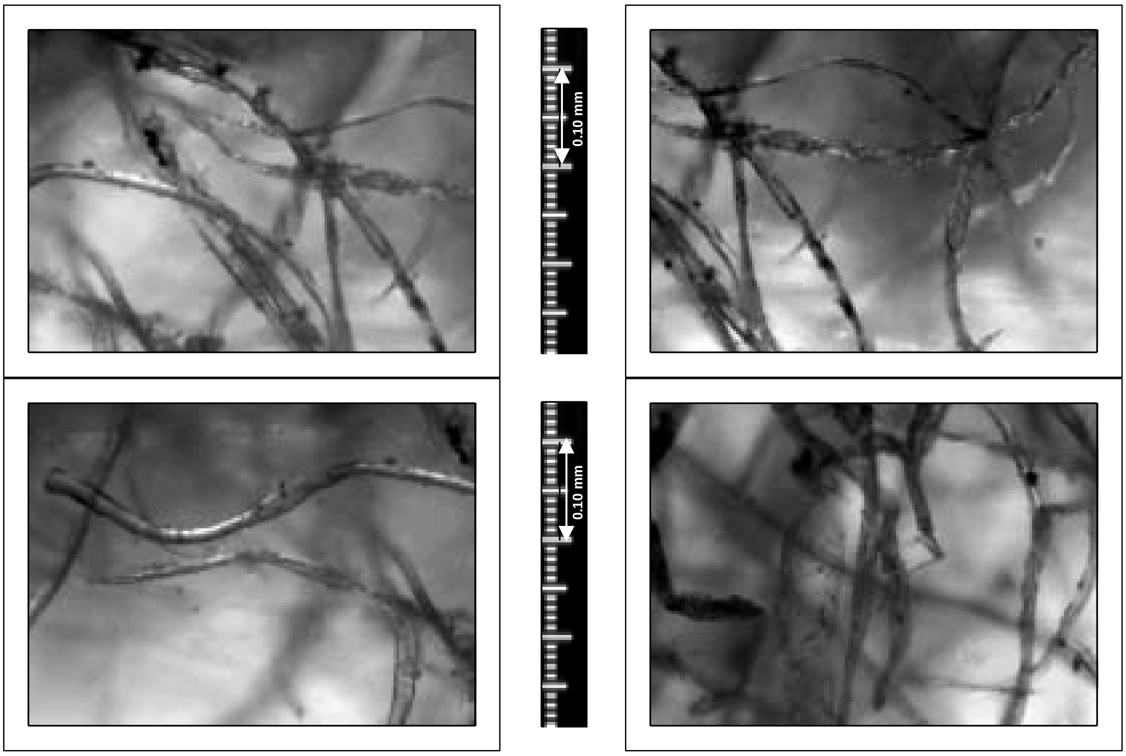


Figure 6. Photo images of plant B fiber

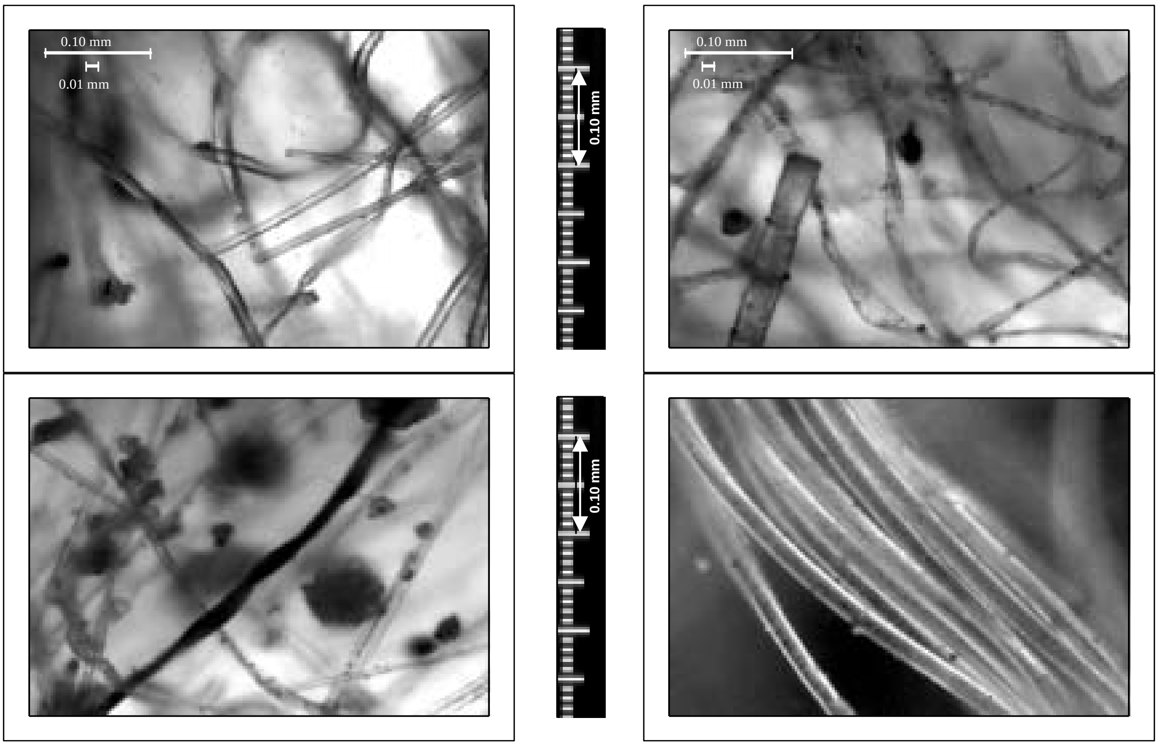
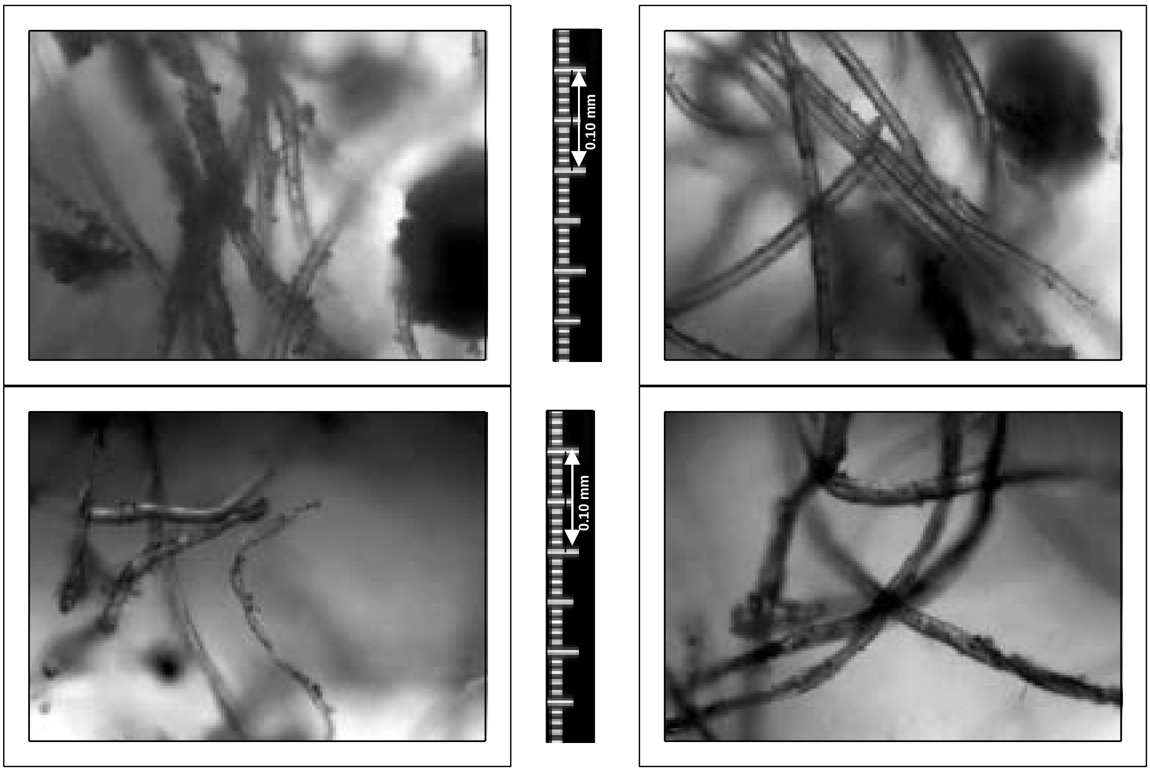


Figure 7. Photo images of plant C fiber



4.3 Specific surface area and density of particles in latent debris

According to the ECCS Strainer Blockage Model,[8] the formation of a debris layer on the strainer surface results in pressure drops across a fibrous bed. The extent of the pressure drop depends largely on the character of the debris, including its specific surface area and density. To that end, one of the primary purposes of this study was to conduct specific surface-area measurements on various-sized particles of latent debris from plants A, B, and C. The average results of these measurements are listed in Table 3.

Table 3. Specific surface area and density of particles in debris from plants A, B, and C

Sample ID	<75 µm		75 to 500 µm		500 µm to 2 mm	
	Specific surface area (m^2/g)	Density (g/cm^3)	Specific surface area (m^2/g)	Density (g/cm^3)	Specific surface area (m^2/g)	Density (g/cm^3)
A	0.48	2.25	0.80	2.22	1.96	1.48
B1	0.66	2.80	0.11	2.51	0.05	2.69
B2	0.81	2.67	0.38	2.38	0.18	2.40
B3	0.68	2.88	0.43	2.87	0.99	2.10
B4	0.28	3.27	0.16	3.60	0.10	2.89
B6	0.42	3.31	0.29	2.65	0.89	2.46
C1	NA	NA	0.29	1.95	0.28	2.38
C8	NA	NA	0.01	3.04	0.02	2.95

The relationship between particle size, specific surface area (m^2/g), and density (g/cm^3) for all measurements completed to date is depicted in Figure 8; the densities of the particles in the debris range from 2 to 4 g/cm^3. The plant A data point for particles sized between 500 µm and 2 mm is not shown in Figure 8. The densities for most of the samples, regardless of their particle-size and surface-area differences, range between 2.5 to 3.0 g/cm^3. Interestingly, the surface areas of particles sized between 75 to 500 µm are generally smaller than the surface areas of particles sized <75 µm. Two ranges of surface areas appear for the large particle sizes shown in Figure 8. One set clusters around a low surface area of about 0.2 m^2/g, whereas the other clusters around a large surface area of about 1 m^2/g. Thus, it seems that the average density of debris does not depend on its particle size; however, the surface area of debris does seem to depend on its particle size. In general, the smaller the particle size of the debris, the larger the surface area. Exceptions do occur in which larger particles also have larger surface areas, thus reflecting the stochastic variability in the physical and chemical characters of the debris.

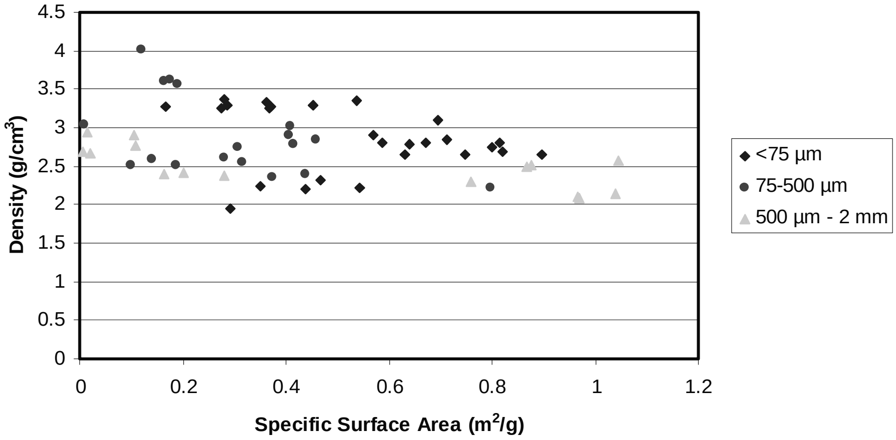
4.4 Characteristics of pores in latent debris

As discussed above, the surface area of particles depends not only on the particle size but also on the character of the porosity, the pore distributions, and the shape of the pores on the particles. Representative data for latent particle debris with the particle size of 75 to 500 µm were analysed using software AS1 Autosorb 1, provided by Quantachrone Instruments. The HK[9] method was applied

9. Horvath, G. and K. Kawazoe (1983), "Method for the Calculation of Effective Pore Size Distribution in Molecular Sieve Carbon", *Journal of Chemical Engineering Japan* **16**:5, pp. 470-475.

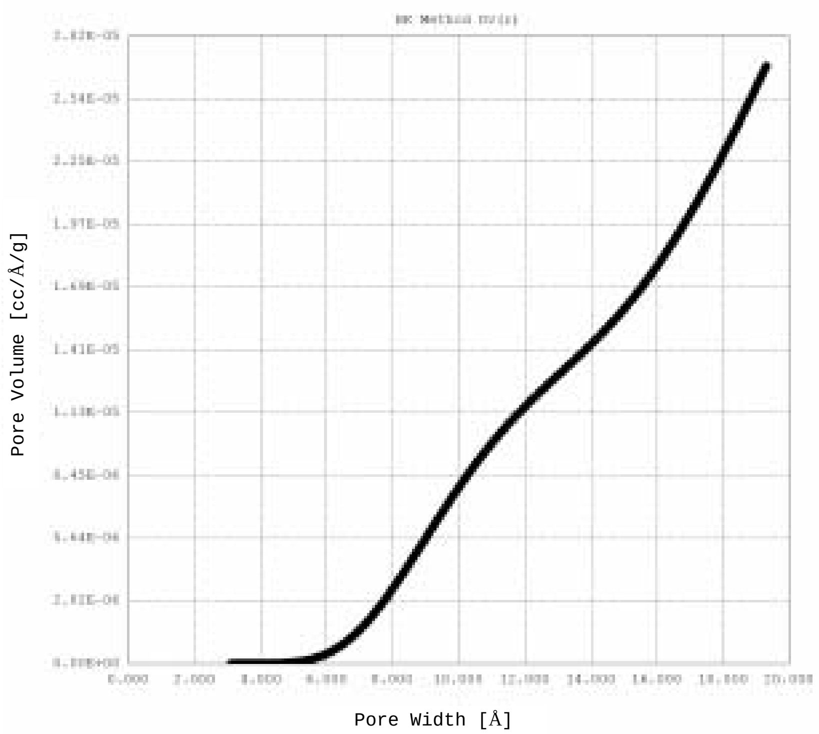
to the determination of pore distributions of micropores (<20 Å), whereas the BJH[10] method was applied to the determination of pore distribution of mesopores (20 to 500 Å).

Figure 8. Specific surface area and density of latent debris as function of its particle size.



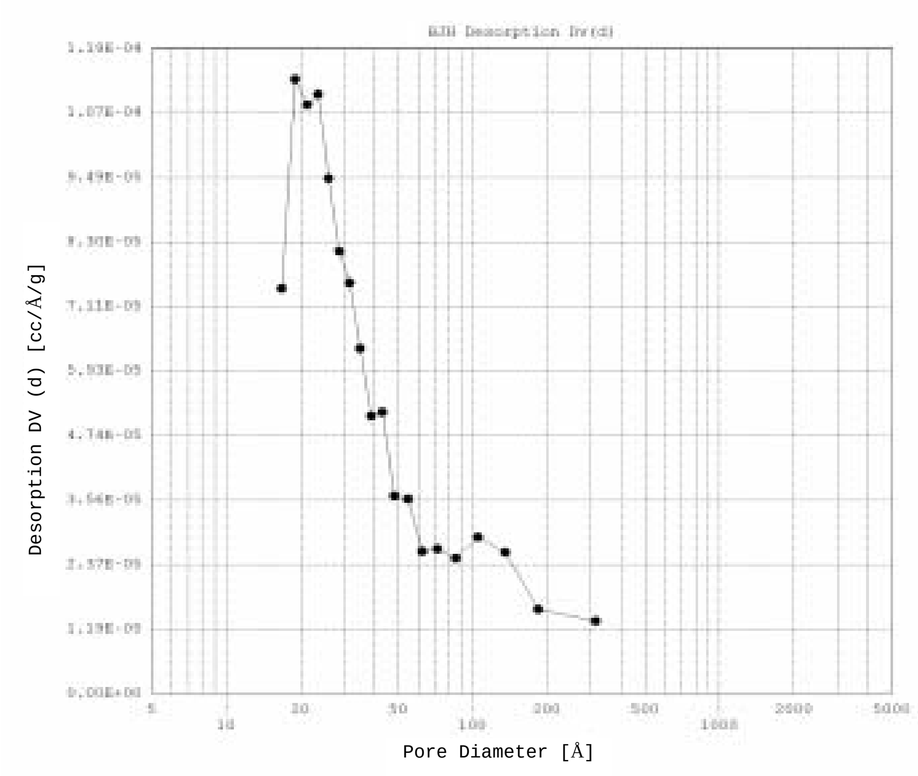
Figures 9 and 10 present the results of the HK and BJH methods when applied to determine the precise pore distribution of representative particle debris samples. These results are typical of the particle debris samples analysed to date. As shown in Figures 9 and 10, the pore diameters range from 10^{-3} µm to 3×10^{-2} µm for particles in the range of 75 to 500 µm.

Figure 9. Micropore distributions in the representative particle debris



10. Barrett, E.P., L.G. Joyner and P.P. Halenda (1951), *Journal of the American Chemical Society* **73**:373.

Figure 10. Mesopore distributions in the representative particle debris



5. Conclusions

Latent debris from three PWRs has been characterised to date. Debris samples from the three plants show particle distributions ranging from 31 to 78 wt %, fiber distributions from 3 to 17 wt %, and other materials present in the debris from 16 to 51 wt %. The particle-size distribution appears to be highly dependent on the method used to collect debris samples within the plant; however, the results for the samples thus far analysed show the following distribution: >2mm, 11 to 66 wt %; 500 µm to 2 mm, 10 to 81 wt %; 75 to 500 µm, 3 to 36 wt %; and <75 µm, 1 to 25 wt %. Particle densities were observed to range from 1.5 to 4 g/cc, with a median density of about 2.7 g/cc. The specific surface areas of the debris particles ranged from 0.01 m^2/g to 2.0 m^2/g. Smaller diameter particles exhibited larger specific surface areas.

Qualitative photomicrograph observations of fibers show fiber diameters ranging from 1 to 20 µm, with shapes including straight cylinders, single tortuous flexible strands, and twisted flat ribbon-like strips. Some fibers appear to be interwoven, forming large clusters similar to the fibrous debris shape classification shown in NUREG/CR-6224.[8] Most of the fibers, regardless of their shape and size, appear to have debris particles attached to them. The attached particle diameters range from about 1 µm to greater than 50 µm.

Additional work is needed to finish characterisation of the latent debris received at LANL to date. SEM/EDAX characterisation of the debris will provide information on surface topography and composition. Planned settling velocity measurements and small-scale filtration experiments will also provide further insight into the character of plant latent debris.

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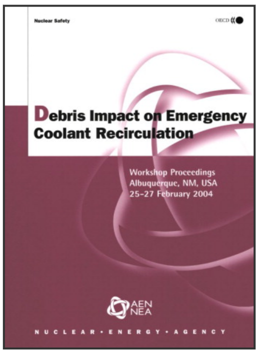

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