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Experimental Investigation of Sedimentation of LOCA-Generated Fibrous Debris and Sludge in BWR Suppression Pools

Prepared by
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Abstract

Several tests were conducted in a 1:2.4 scale model of a Mark I suppression pool to investigate the behavior of fibrous insulation and sludge debris under LOCA conditions. NUKON™ shreds, manually cut and tore up in a leaf shredder, and iron oxide particles were used to simulate fibrous and sludge debris, respectively. The suppression pool model included four downcomers fitted with pistons to simulate the steam-water oscillations during chugging expected during a LOCA. The study was conducted to provide debris settling velocity data for the models used in the BLOCKAGE computer code, developed to estimate the ECCS pump head loss due to clogging of the strainers with LOCA generated debris. The tests showed that the debris, both fibrous and particulate, remains fully mixed during chugging; they also showed that, during chugging, the fibrous debris underwent fragmentation into smaller sizes, including individual fibers. Measured concentrations showed that fibrous debris settled slower than the sludge, and that the settling behavior of each material is independent of the presence of the other material. Finally, these tests showed that the assumption of considering uniform debris concentration during strainer calculations is reasonable. The tests did not consider the effects of the operation of the ECCS on the transport of debris in the suppression pool.

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Acknowledgements

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Alan Johnson, Mahadevan Padmanabhan, and George Hecker of Alden Research Laboratory, Inc. (ARL) were instrumental in designing the experimental apparatus, defining the experiments, and conducting the experiments described and analyzed in this report. Their work is documented in the ARL report, "NUKON Insulation and Sludge Settling Following a LOCA in a BWR Suppression Pool," Alden Research Laboratory, Inc., May 1995.

From SEA, Gilbert Zigler was the Project Manager for this task, providing technical direction for the study. Together with Jane Brideau, he also performed a technical and editorial peer review of the report. Debbie Rettig was responsible for the typing and layout of the final document.

Other organizations whose efforts contributed to this study include the BWR Owners' Group ECCS Suction Strainer Committee and the University of New Mexico. Rocky Sgarro was the chairman of the BWROG ECCS Suction Strainer Committee, which provided estimates of the size distribution of the sludge particles present in BWR suppression pools. Toivo Kodas of the University of New Mexico performed the sludge simulant size analysis using a scanning electron microscope.

1.0 Introduction

This report describes a set of experiments to investigate the transport properties of the debris materials expected to be in the suppression pool during Loss of Coolant Accidents (LOCA) in Boiling Water Reactors (BWR). The experiments were conducted at the Alden Research Laboratory, Inc. (ARL) under subcontract to Science and Engineering Associates, Inc. (SEA) on behalf of the Nuclear Regulatory Commission (NRC). These experiments are hereinafter referred to as the NRC experiments.

This study was motivated by the need to obtain experimental data to validate some of the key assumptions in the suppression pool transport models used in the BLOCKAGE computer code, developed to estimate the Emergency Core Cooling System (ECCS) pump head loss due to clogging of the suction strainers with LOCA generated debris [1]. In the development of these models, initially it was conservatively assumed that all the debris reaching the suppression pool would remain suspended and would ultimately be transported to the ECCS pump suction strainers. Subsequently, a transient model was developed considering: (1) the amount and size of the debris introduced to the suppression pool, (2) the gravitational sedimentation of the debris in the suppression pool during and after the high-energy phase of a LOCA, (3) the resuspension of the debris contained on the suppression pool floor, and (4) the ECCS flow rate. While developing this transient model, it was recognized that experimental data was required to address these issues. The underlying processes associated with the debris transport phenomena in the suppression pool following a LOCA are, however, too complex to be addressed by a single set of experiments; consequently, several scoping analyses were conducted with a previous version of BLOCKAGE to identify the most important factors influencing the model predictions. Based on these scoping calculations, the set of experiments described in this report were proposed to obtain information in the following specific areas:

- Resuspension of debris contained at the bottom of the suppression pool during the high-energy phase of a LOCA.
- Mixing and fragmentation of fibrous debris when subjected to high levels of turbulence during the high-energy phase of a LOCA.
- Sedimentation characteristics of fibrous and particulate debris during and after the high-energy phase of a LOCA.

The debris generated by a LOCA in a BWR is highly plant specific, including fibrous or metallic thermal insulation of the pipes in the drywell. Similarly, the suppression pool layouts vary from small torus shaped Mark I to Mark III. Therefore, it was decided to limit the scope of the experiments to study the transport of LOCA generated debris in a reference BWR-4 with a Mark I containment, NUKON™ thermal insulation, and suppression pool sludge particles.

A 1:2.4 scale model of a Mark I suppression pool segment with NUKON™ fibrous debris and iron-oxide particles was used to conduct experiments addressing the above areas; the contribution of the ECCS recirculation flow to the transport of debris materials in the suppression pool, however, was not investigated as part of this set of experiments.

This report is structured as follows. Chapter 2 presents a description of the progression of events in a LOCA, emphasizing their effects on the debris transport in the suppression pool, as well as the test model used in this study to simulate these phenomena. The description of the test facility, the debris materials, and the experimental procedures used in these tests are presented in chapter 3. Chapter 4 presents the results and the corresponding analysis; finally, chapter 5 contains the significant findings from this study.

2.0 Technical Approach

In the event of a LOCA due to a pipe break within the containment of a BWR, piping thermal insulation and other materials in the vicinity of the break will be dislodged due to the jet forces caused by the mixture of steam and water ejected from the break. A fraction of this dislodged insulation and some other materials, like paint chips and concrete dust, will be transported to the suppression pool by the steam and water flow discharged from the break. Some of this debris, together with some other particulate materials that may be present in the suppression pool before the LOCA, will eventually be transported and accumulated on the suction strainers of the ECCS pumps, increasing the differential pressure, or head loss, across them. In some cases, this accumulation of debris leads to head losses that can cause the pumps to fail. In the assessment of the potential BWR ECCS strainer blockage due to LOCA generated debris, understanding of the transport phenomena in the suppression pool is a key issue. The following section provides a description of these phenomena in a BWR with a Mark-I containment system.

2.1 Suppression Pool Phenomena During a LOCA

Following a pipe break LOCA, the pressure and temperature of the drywell atmosphere increase rapidly. This increase in drywell pressure accelerates the water initially present in the downcomers into the suppression pool. This vent-clearing process generates a water jet capable of causing turbulent mixing of the suppression pool water. Immediately after the vent-clearing process, non-condensible gases from the inert drywell atmosphere are discharged into the suppression pool through the downcomers, resulting in swelling of the suppression pool. During this initial phase of the accident, the suppression pool flow fields are dominated by large scale turbulence, leading to resuspension of the particulate materials previously contained on the suppression pool floor.

Eventually, the vent downcomer flow will consist primarily of steam and, as the flow of steam continues, pressure oscillations occur in the suppression pool. Experimental data suggest that these oscillations can be divided into two categories: "condensation oscillations", which occur at relatively high vent flow rates and are characterized by continuous oscillations, and "chugging", which occurs at lower steam flow rates and is characterized by a series of pulses, typically a second or more apart.

Chugging occurs when, as a result of reductions in the steam flow, water enters the downcomers and causes steam condensation in the downcomers. During this process, the non-condensible gases form a thin layer that prevents heat transfer between steam and water. This results in a build-up of pressure behind the condensation front, causing the front to move closer to the vent pipe exit, where the non-condensible gases could be vented from the pipe. This mechanism of steam condensation results in a situation where the condensation front (or the water front) moves upwards and downwards in the downcomers, in a cycling process that continues until the drywell and wetwell pressures equalize.

The downcomer water level oscillations during chugging result in addition of kinetic energy to the suppression pool, generating turbulent flow fields. This phase of an accident, commonly referred to as the high-energy phase, typically lasts from a few minutes to up to half an hour depending on the break size, downcomer geometry, and suppression pool temperature. The kinetic energy imparted to the pool during the high-energy phase generates turbulent flow fields which in turn may influence the suppression pool transport. In particular, the turbulence may (1) disintegrate fibrous debris into smaller classes, (2) impede settling resulting in mixed suppression pool conditions, and (3) resuspend the debris that is located at the bottom of the suppression pool.

The ECCS will inject water into the reactor vessel, flooding the core, and ultimately cascading into the drywell through the break. Since the drywell is full of steam at the time of vessel flooding, cascading water from the break causes condensation and rapid decrease in drywell pressure. At this stage, the vacuum breaker valves open to allow the non-condensible gases in the suppression pool to flow back into the drywell, leading to the equalization of drywell and wetwell pressures. Thereafter, vapor flow to the suppression pool will be reduced and the turbulence levels will decay, allowing sedimentation of debris.

In the final stage of the accident, BWRs rely on long-term ECCS cooling for the reactor and containment sprays to control drywell pressure and temperature, and suppression pool cooling for ultimate heat removal from the containment. The actuation of the suppression pool cooling features will result in recirculation flow patterns in the suppression pool, which may affect debris sedimentation; also, if pool recirculation is sufficiently large, resuspension of a fraction of the sediment at the bottom of the suppression pool may occur.

2.2 Phenomena Identified For Study

The condensation oscillations in the suppression pool are expected to occur in a large LOCA during a relatively short period of time (about 30 s), followed by chugging for the remainder of the blowdown phase. For a medium LOCA, condensation oscillations are very unlikely and intense to moderate chugging is more common. Depending on the break size, chugging may last up to 20 minutes in the case of a medium LOCA. The potential for debris sedimentation is minimal during condensation oscillations due to shorter duration, whereas some settling may occur during chugging. Based on these considerations, it was decided to study the behavior of debris in the suppression pool only during chugging.

The transport of debris in the suppression pool due to the operation of the ECCS after the high-energy phase of a LOCA is an important issue that has to be addressed. However, the study of this phenomena was not considered as part of the present set of experiments.

The following section describes the test model used in this set of experiments to simulate the behavior of fibrous debris and particulate matter in the suppression pool during and after chugging.

2.3 Test Model

In this model it is assumed that mixing of the debris in the suppression pool during chugging is caused only by the addition of kinetic energy from the water that moves into and out of the downcomers. Pressure changes in the drywell due to the addition and sudden condensation of steam provide the only driving force for the water motion. This assumption is based on the inference that temperature gradients do not contribute significantly to internal flow or turbulence in the suppression pool.

The Mark-I full scale test facility (FSTF) tests [2] provided some information that can be used to quantify the kinetic energy of interest. In particular, these tests provided pool wall pressure data during chugging following a medium break size LOCA. Test data indicated a total chugging duration of about 4 to 5 minutes. Two types of chugging were observed: Type 1, with synchronized oscillations of neighboring downcomers; and Type 2, with relatively unsynchronized oscillations. Since Type 1 is more representative of a medium LOCA, only this type of chugging is considered in this study.

Three cases of Type 1 chugging were identified from the FSTF data; each case represented different amounts of kinetic energy corresponding to initial, middle, and later stages of chugging. The highest kinetic energy occurred initially, when the rate of energy released from the steam pipe was the greatest.

In this study, the amount of kinetic energy imparted to the suppression pool was computed by an analytic simulation of the suppression pool coupled to the drywell. This analytic model, described in Appendix A of Reference 3, used the pool wall pressure amplitudes from the FSTF data to calculate the period and amplitude of the steam-water interface in the downcomers, and hence, the kinetic energy imparted to the pool. The resulting period and amplitude for each of the three Type 1 chugging cases are:

Case 1: 2.4 seconds, 8.0 feet (high energy, corresponding to the initial stage of a LOCA)

Case 2: 1.9 seconds, 5.0 feet (medium energy, corresponding to the middle stage of a LOCA)

Case 3: 1.6 seconds, 3.8 feet (low energy, corresponding to the final stage of a LOCA)

The steam-water interface oscillations as a function of time for the three chugging cases, obtained from the analytical study, are shown in Figure 2-1.

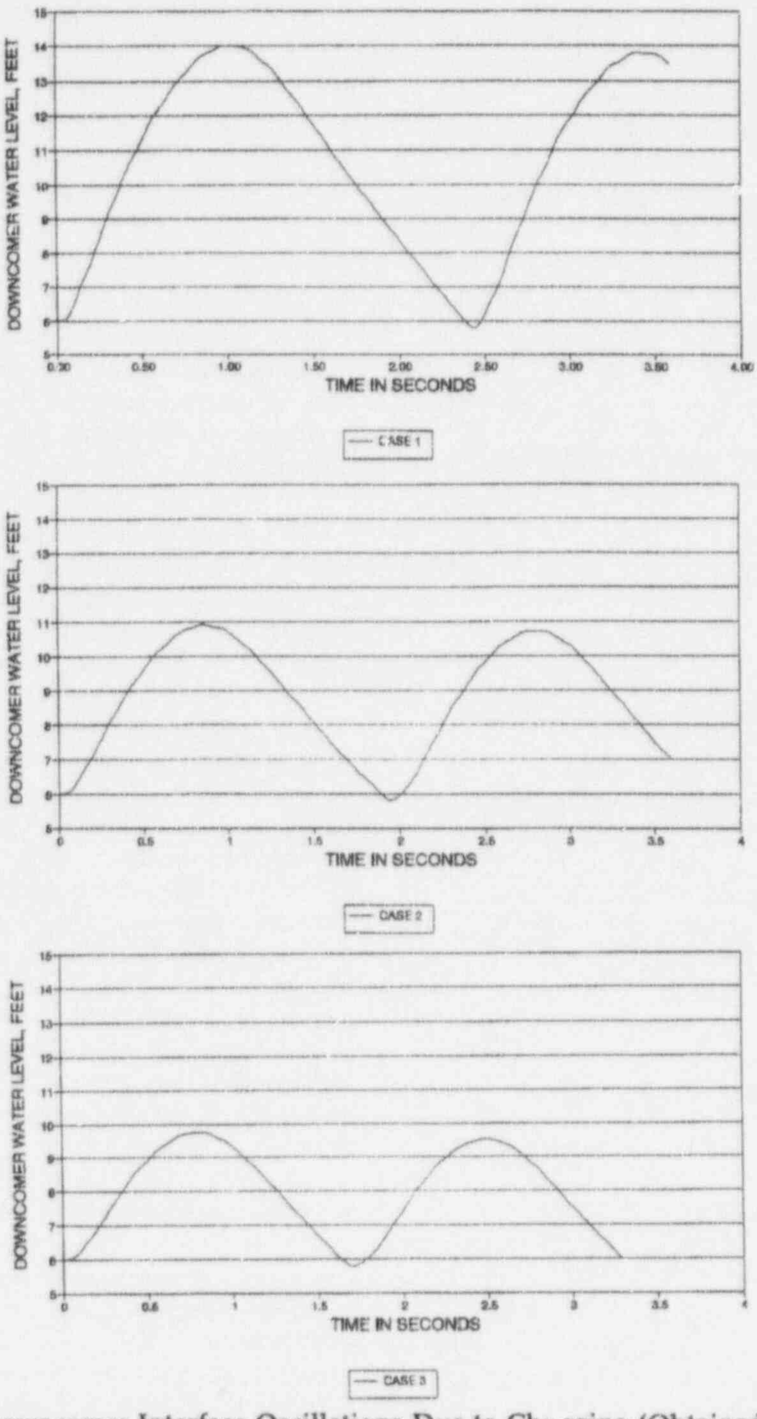


Figure 2-1. Typical Downcomer Interface Oscillations Due to Chugging (Obtained from Analytical Study)

2.4 Model Similitude

Since the experiments used the actual size debris, similitude requires that a) the kinetic energy per unit volume in the test facility be the same as in an actual BWR Mark-I suppression pool, and b) that the mode of turbulence generation in both cases be the same. Practical considerations limited the test facility geometrical scale to be 1:2.4 of the actual BWR Mark-I downcomer and suppression pool geometry. This required scaling the water surface amplitude and period in the model downcomers in such a way as to produce the same kinetic energy per unit pool volume in the test facility as in the actual case. The basis for this scaling is presented in the following discussion.

The kinetic energy per unit volume, E, is given by

$$E = \rho \frac{V^2}{2} \quad \text{(2-1)}$$

where ρ is the density of water and V is a characteristic velocity, such as the interface velocity in the downcomer.

Similitude requires equal E in the model and the actual case, that is

$$\rho_m V_m^2 = \rho_a V_a^2 \quad \text{(2-2)}$$

or

$$\frac{V_m}{V_a} = \sqrt{\rho_a / \rho_m} \quad \text{(2-3)}$$

In the above equations, the subscripts *m* and *a* refer to the model and actual case, respectively. Since water in the model and the actual case have about the same density (within about 1%),

$$V_m = V_a \quad \text{(2-4)}$$

The time scale can be determined from the geometric scale and velocity scale. The time for a particle of water leaving the downcomer to reach the pool floor would be the distance to the pool floor divided by the average velocity. Since the distance is scaled to the geometric scale, the time scale would be equal to the geometric scale, the velocity scale being equal to 1.

$$\frac{T_m}{T_a} = \frac{L_m V_a}{V_m L_a} = \frac{L_m}{L_a} \quad \text{(2-5)}$$

With the time scale and velocity scale known, and assuming a sinusoidal motion of water in the downcomer, it can be shown that the amplitudes of oscillation would scale to the geometric scale. This means that both the period and amplitude of downcomer oscillations should be scaled to the geometric scale.

Based on this model, it was concluded that the similitude criterion is met if the simulated chugging period and amplitude in the test facility are reduced by a factor of 2.4 with respect to the actual case values.

The proposed test model may introduce two types of scale effects: decay of turbulence and surface waves.

Because turbulence decay is inversely proportional to the eddy size, turbulence in the model decays somewhat quicker than in the actual case. Also, the model segment boundaries, which do not exist in the actual case, cause a quicker decay of turbulence. Although the actual case has structures inside the pool which augment turbulence decay, it was decided not to include scaled structures in the model to compensate for the otherwise quicker turbulence decay.

Surface waves generated in the model cannot be scaled, as surface waves, being gravity dominated, require Froude scaling. Their effects are considered secondary, because they do not add energy to the pool. However, if a surface wave resonant condition existed, then the mixing energy could be significant. By performing simulated chugging tests based on Froude similitude, it was confirmed that surface wave resonance does not occur in the actual case, nor did it occur during the tests described herein.

3.0 Test Facility and Experimental Procedures

3.1 Test Facility

A 1:2.4 geometric scale simulation of a segment of a Mark I BWR suppression pool, based on the FSTF program, was constructed with a curved painted steel bottom and two plexiglas side walls for viewing. Figure 3-1 shows the model geometry, while a model photograph is included in Figure 3-2. Four downcomers, each 10" (0.25 m) in diameter, were modeled at the appropriate locations in the tank with scaled spacing and floor clearance. The front and back walls were spaced one half the distance to the next pair of downcomers in either direction. Hence, the water volume per downcomer of the tank was scaled to the volume per downcomer of a typical BWR Mark I suppression pool. Three of the downcomers were aluminum pipes, while the fourth one was a plexiglas pipe to allow visualization of insulation debris movement inside the downcomer during chugging simulation.

The downcomer water-steam interface oscillations were simulated in the model by plungers, mechanically moved to the scaled frequency, amplitude, and position versus time. Figure 3-3 shows the mechanical drive arrangement, and Figure 3-4 is a photograph of the mechanism. All plungers oscillated in phase, which simulated Type 1 chugging as identified in the FSTF tests. The plunger movement was accomplished by a crank disc rotated at the required rpm using a 50 HP (37 KW) electric motor and speed controller, generating the required plunger motion versus time through a cam arrangement. The position of the cam-follower pin determined the motion and maximum amplitude, while the variable speed drive powering the motor determined the frequency. Based on model similitude relations, the downcomer water interface (plunger) amplitudes for the case selected from Figure 2-1 were scaled to the geometric scale of 1:2.4, and the periods or simulated chugging intervals were also scaled to 1:2.4.

Figure 3-5 shows the three cases of scaled downcomer interface oscillations obtained by scaling the corresponding three cases shown in Figure 2-1; Figure 3-6 is a comparison of the desired interface motion and the corresponding velocities for Case 3, determined from the analytical model, versus the actual motion from the physical mechanism. The agreement is sufficient for the purposes of this study.

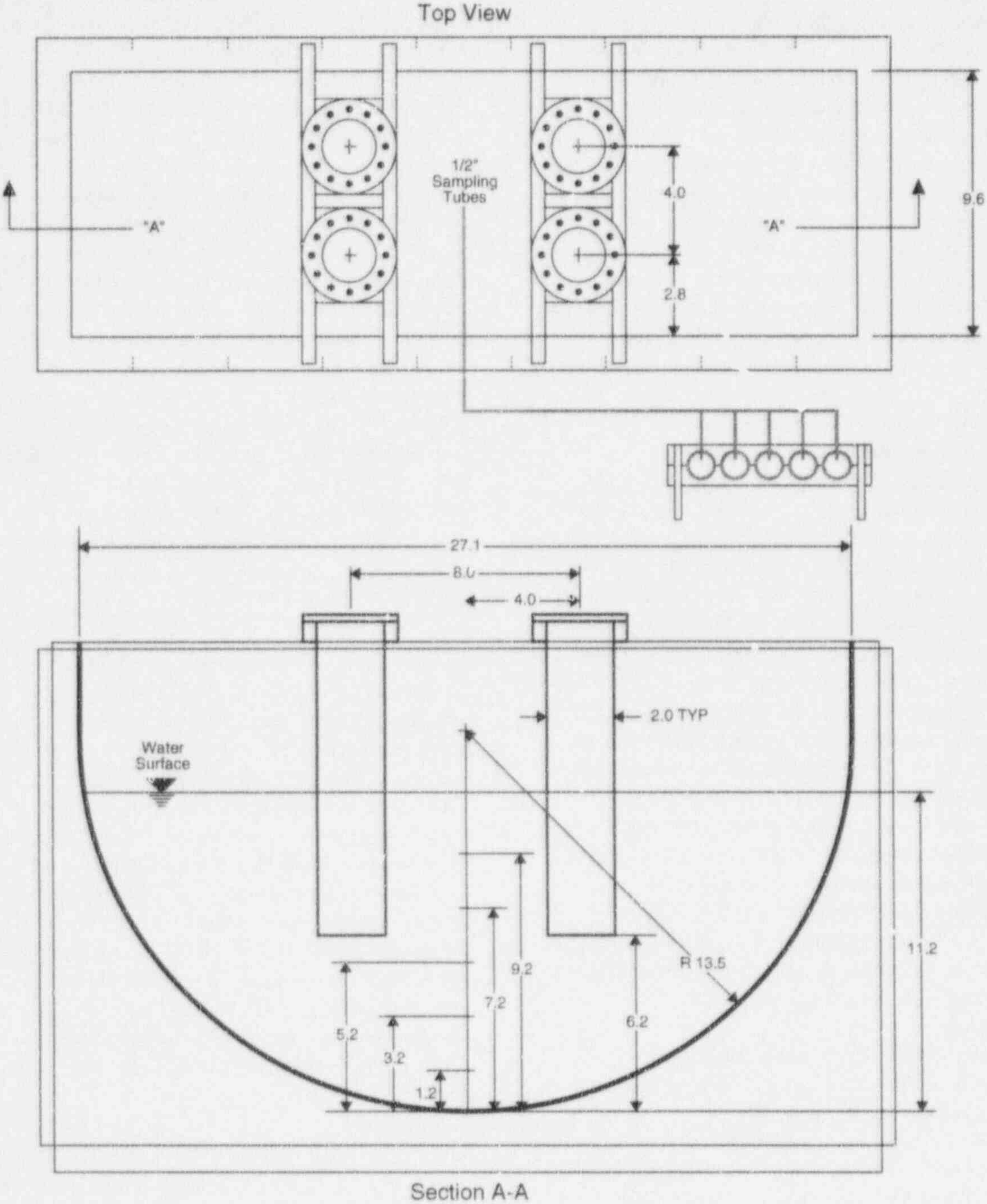
3.2 Test Debris

These experiments considered two types of LOCA generated debris: fibrous and particulate materials. In particular, NUKON™ thermal insulation blankets were used to generate the fibrous debris, whereas iron oxides particles were used to simulate some of the particulate matter commonly found in BWR's suppression pools; these iron oxide particles are hereafter referred to as "sludge". Debris size is known to influence the sedimentation rates; hence, considerable attention was given to the following areas: 1) identification of representative size distributions of the debris likely to reach the suppression pool following a LOCA; 2) acquisition and generation of test debris that closely resemble those identified debris sizes and shapes; 3) implementation of proper controls on debris production for use in the experiments; and 4) characterization of the debris that were used in the tests. This debris characterization was accomplished using scanning electron microscope and sedimentation velocity (sedigraph) analysis [4].

3.2.1 Fibrous Debris

In the case of steel-jacketed NUKON™ thermal insulation , the LOCA generated debris is expected to vary in shape from fines to partially fragmented blankets; Figure 3-7 presents the classification of the fibrous debris that are expected during a LOCA [5]. Various analyses , however, suggested that classes 3, 4 and 5 are more likely to be transported to the suppression pool; in addition, experiments suggest that very small quantities of fibrous debris classes 1 and 2, namely individual fibers of various lengths, would be produced in a LOCA for steel-jacketed NUKON™ insulation. Based on these considerations, it was judged that the more likely fibrous debris reaching the suppression pool in a typical BWR plant would closely resemble classes 3&4 and 5&6.

The NUKON™ thermal insulation blankets, artificially aged by heating in ovens in accordance with ASTM procedures, were provided by Performance Contracting, Inc. (PCI). The method selected to generate the desired fibrous debris



Note: All pool dimensions in feet (actual Mark I suppression pool)

Figure 3-1. Modeled Suppression Pool Geometry [3]

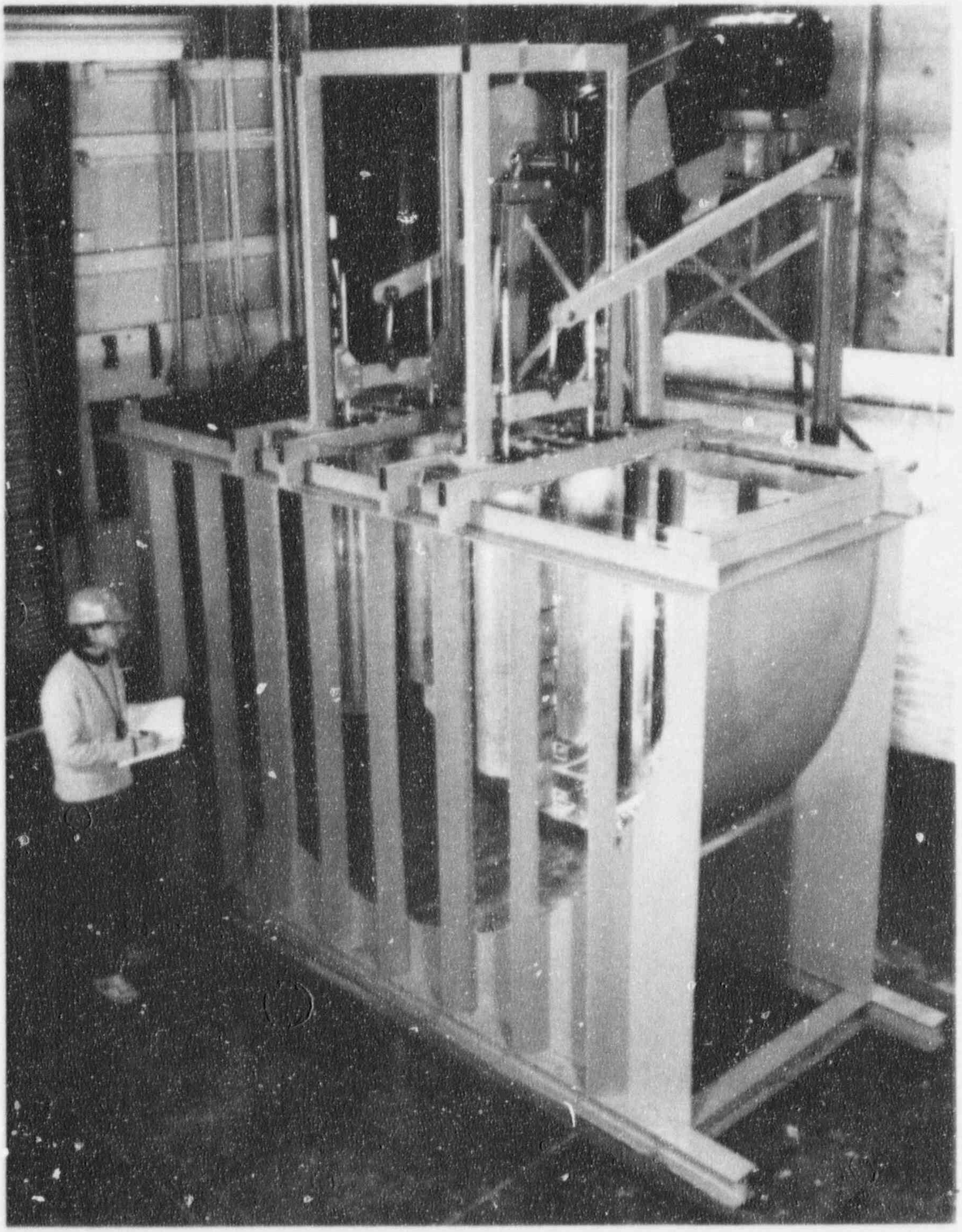


Figure 3-2. 1:2.4 Suppression Pool Segment Model [3]

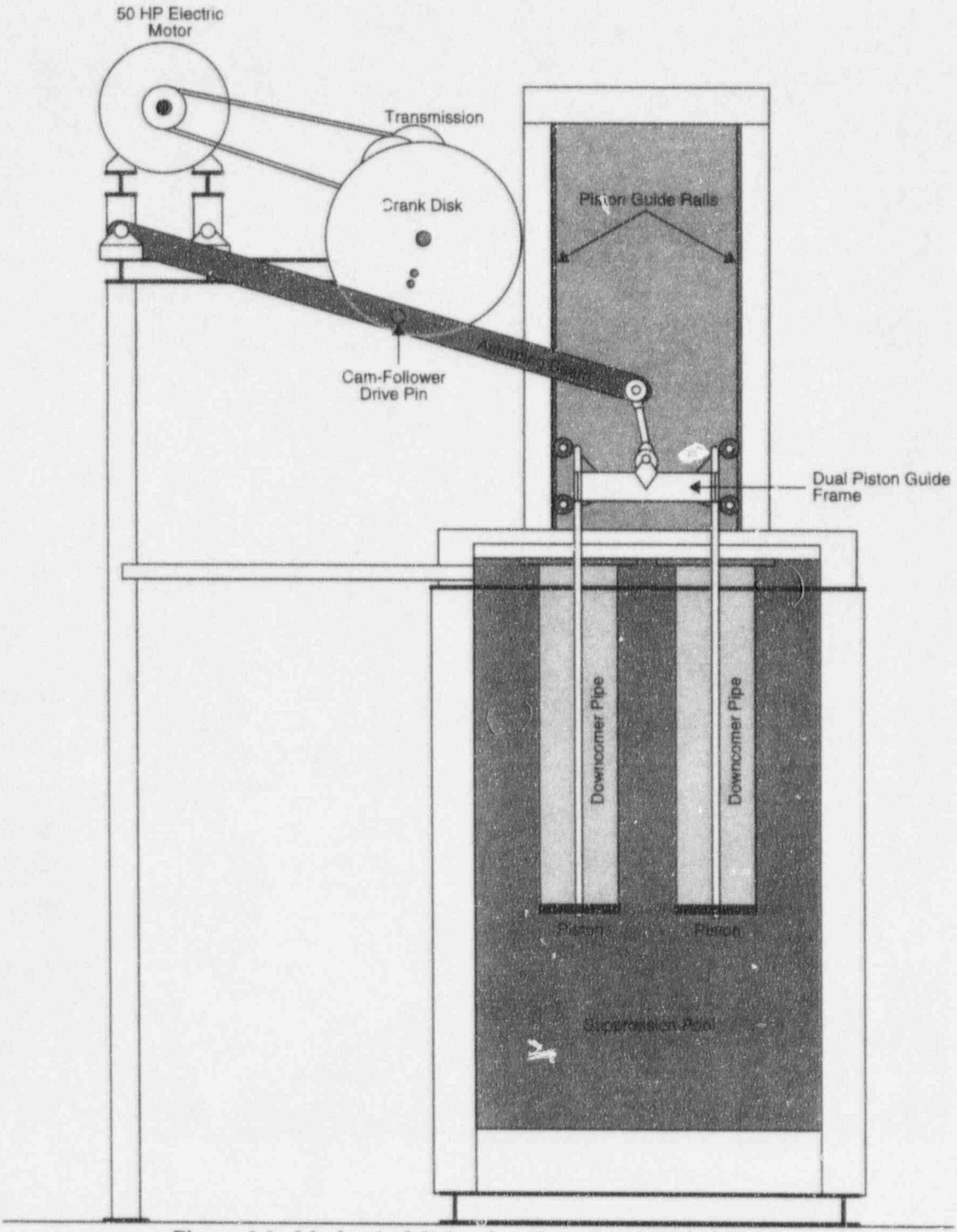


Figure 3-3. Mechanical Drive for Chugging Simulation [3]

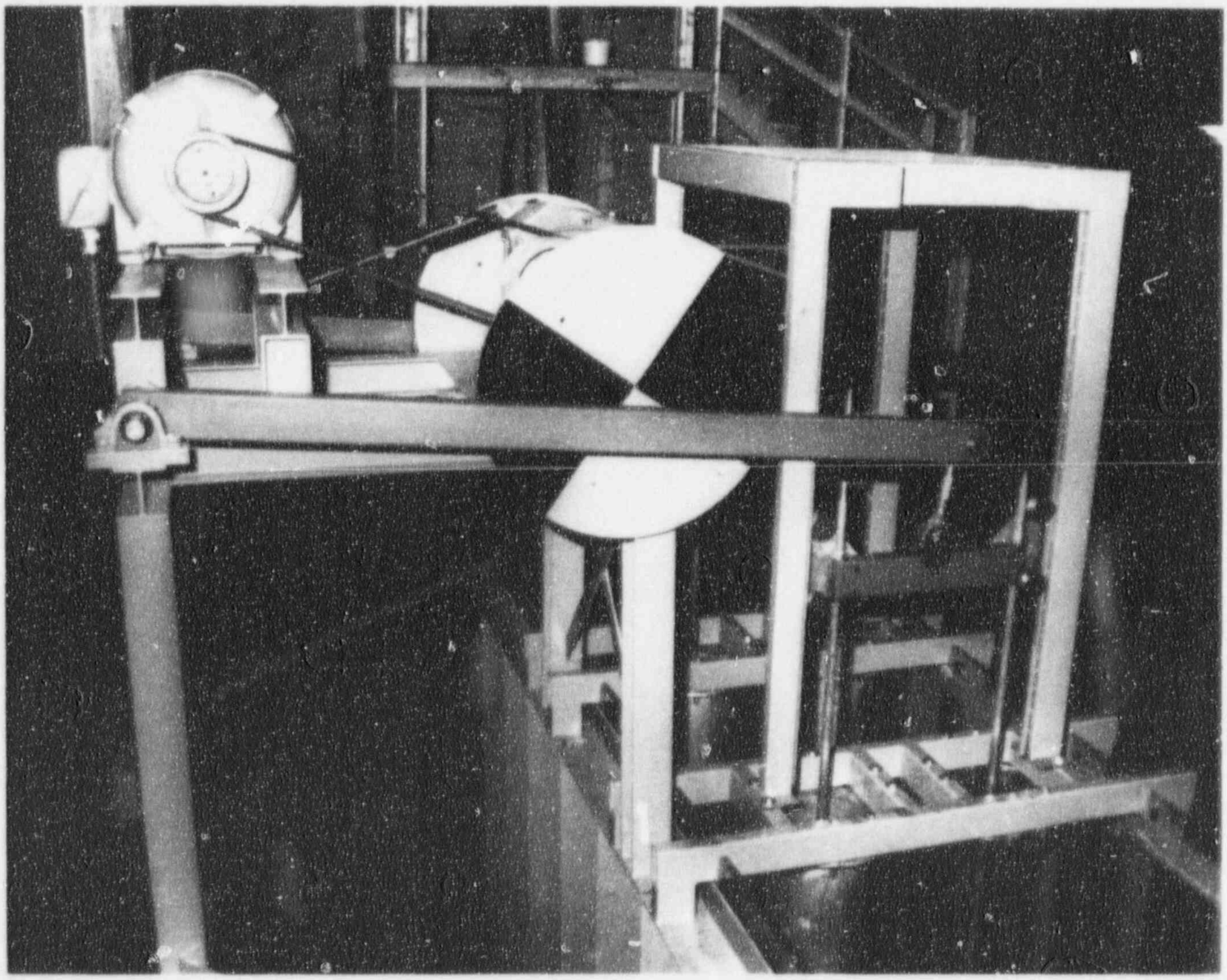


Figure 3-4. Mechanical Drive in Suppression Fool Tests [3]

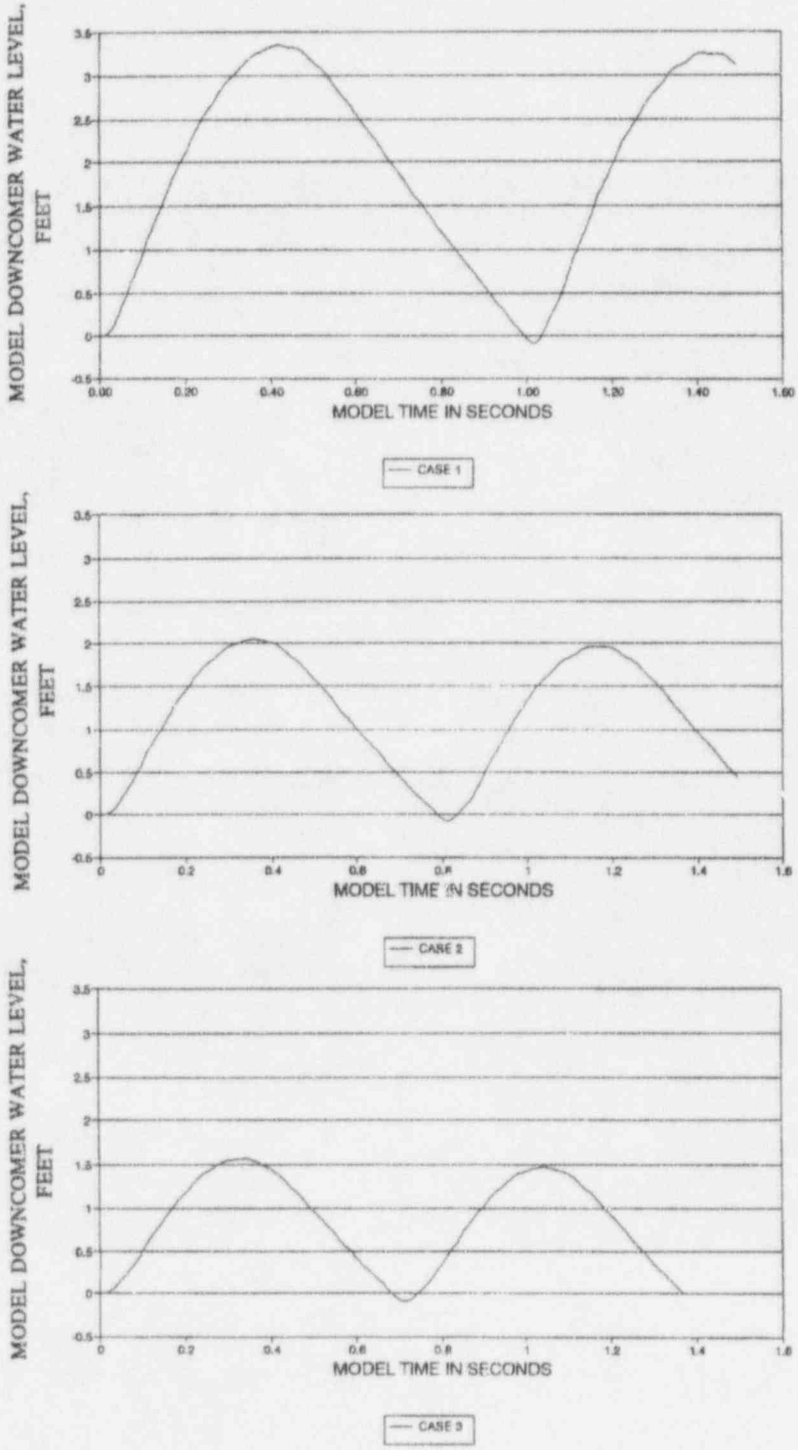
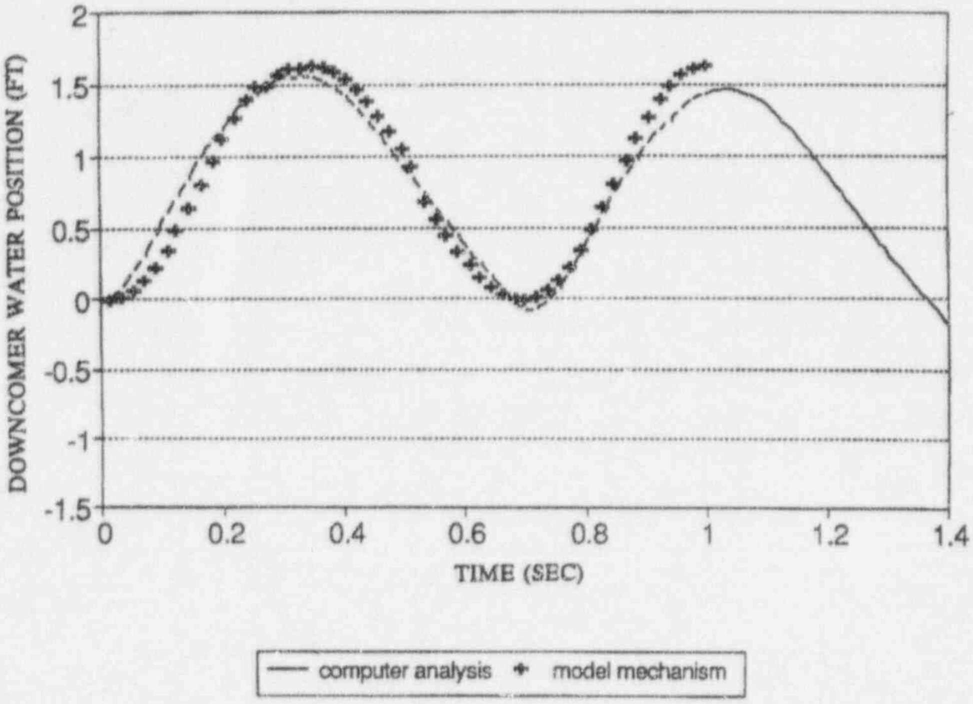
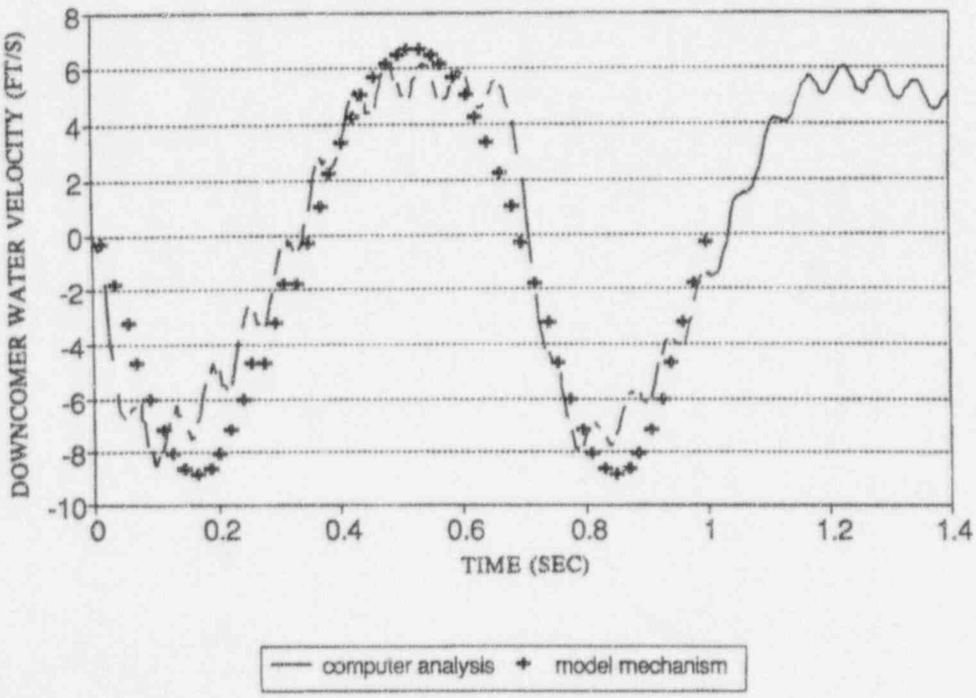


Figure 3-5. Scaled Downcomer Interface Oscillations for the Model Study [3]



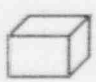
A. DOWNCOMER INTERFACE OSCILLATIONS



B. VELOCITY OF DOWNCOMER FLOW

Figure 3-6. Comparison of Desired and Model Generated Interface Oscillations for Case 3 Chugging Simulation [3]

Figure 3-7. Fibrous Debris Classification

Class No.	Description		Settling Characteristics	Settling Velocity in Calm Pools	Strainer Filtration Efficiency
1		Very small pieces of fiberglass material, "microscopic" fines which appear to be cylinders of varying L/D.	Drag equations for cylinders are well known, should be able to calculate fall velocity of a tumbling cylinder in still water.	1-3.5 mm/s Based on Cal. for 0.5 - 2.54 cm long fibers	Unknown
2		Single flexible strand of fiberglass, essentially acts as a suspended strand.	Difficult to calculate drag forces due to changing orientation of flexible strand.	Same as above	Nearly 1.0
3		Multiple attached or interwoven strands that exhibit considerable flexibility and which due to random orientations induced by turbulence drag could result in low fall velocities.	This category is suggested since this class of fibrous debris would likely be most susceptible to re-entrainment in the recirculation phase if turbulence and/or wave velocity interaction becomes significant.	0.04 ft/s - 0.06 ft/s (measured)	1.0 (measured)
4		Formation of fibers into clusters which have more rigidity and which react to drag forces more as a semi-rigid body.	This category might be represented by the smallest debris size characterized by PCIs air blast experiments.	0.08 - 0.13 ft/s (measured)	1.0 (measured)
5		Clumps of fibrous debris which have been noted to sink. Generated by different methods by various experimenters.	This category was characterized by the PCI air test experiments as comprising the largest two sizes in a three size distribution.	0.13 - 0.18 ft/s (measured)	1.0 (measured)
6		Larger clumps of fibers. Forms an intermediate between Classes 5 and 7.	Few of the pieces generated in PCI air blast tests consisted of these debris types.	0.16 - 0.19 ft/s (measured)	1.0 (measured)
7		Precut pieces (i.e. .25" by .25") to simulate small debris. Other manual/mechanical methods to produce test debris.	Dry form geometry known, will ingest water, should be able to scope fall velocities in still water assuming various geometries.	0.25 ft/s (calculated)	1.0 (estimated)

classes 3&4 and 5&6 was based on several exploratory studies; in this method, the NUKON™ blankets provided by PCI were first cutup manually into large pieces, typically several inches in size. These pieces were then fragmented in a leaf shredder to generate the appropriate fibrous debris classes 3&4 and 5&6. The detailed procedure to generate the fibrous debris is given in Appendix A. Figures 3-8 and 3-9 show photographs of representative fibrous debris fragments used in these experiments.

3.2.2 Suppression Pool Sludge

Several BWR's suppression pools contain corrosion products, primarily iron oxides, produced during routine operations; this particulate matter is commonly referred to as suppression pool sludge. In addition, other miscellaneous debris materials, such as anti-contamination coveralls, plastic bags, used tape and tools, have been found in some suppression pools [6]. In this set of experiments, only the sludge particles were simulated.

The makeup of sludge in BWR's suppression pools is plant specific, but it is generally characterized as iron oxide. By some estimates [7], the amount of sludge may vary from 70 to 5000 lb (30 to 2300 kg), depending on the plant cleanup procedures. The BWR owners' group (BWROG) characterized, using laser light scattering, the particle size distribution of the sludge samples obtained from five BWR suppression pools, including Mark I, II and III containments. Based on this characterization, the BWROG suggested the size distribution given in Table 3-1 [8].

A survey was conducted among some companies capable of providing several powders with the recommended particle size distribution. None of the surveyed companies was able to provide iron oxide powders with the required exact particle size distribution. Although it was recognized that some non-iron oxide powders could be provided with a close match to the BWROG's recommended particle size distribution, it was decided to use iron oxide powders to better simulate the sludge observed in BWR's suppression pools.

Black iron oxide, Fe_3O_4, was supplied by Hansen Engineering, Inc. according to the size distribution specified in Table 3-2. To simulate the BWROG's suggested particle size distribution, it was decided to mix 95% (in mass) of black iron oxide #2008 and 5% of black iron #9109-N, resulting in the so called sludge A; the estimated particle size distribution for this mixture is presented in Table 3-3.

Later scanning electron microscope (SEM) analysis showed that iron oxide particles, in the dry powder state provided by the manufacturer, agglomerated extensively, leading to a broad spread of the size distribution ranging from sub-micron primary particles to about 375 µm agglomerates; in most cases, the particles and agglomerates were nearly spherical; Figures 3-10 and 3-11, SEM photographs of sludge A, clearly show these observations. In addition, the sludge A particle size distribution was characterized using sedimentation velocity (sedigraph) analysis, which provides an indication about the size distribution of the primary particles (i.e., before agglomeration) composing sludge A. The results of this analysis, presented in Table 3-4, suggest a particle size distribution with a mass-median diameter of about 5 µm (i.e., 50% of the sludge A particles, by mass, have an equivalent diameter less than 5 µm). This characterization study revealed that the agglomerated particles were very difficult to disperse using stirring and normal vibrators, suggesting that it is unlikely that the

Table 3-1. BWROG-Provided Size Distribution of the Suppression Pool Sludge

Particle Size Range (µm)	Average Size (µm)	% By Mass
0-5	2.5	81%
5-10	7.5	14%
10-75	42.5	5%

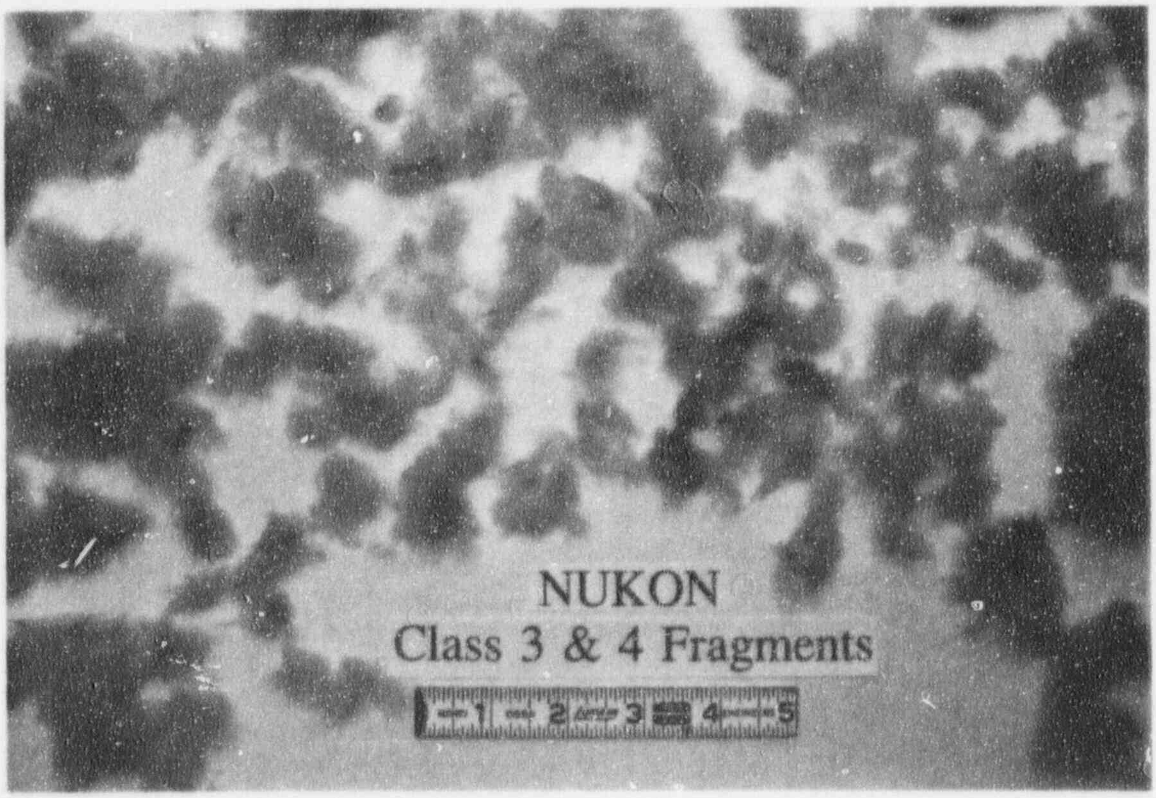


Figure 3-8. Representative Sample of Shredded NUKON™ Fibrous Debris

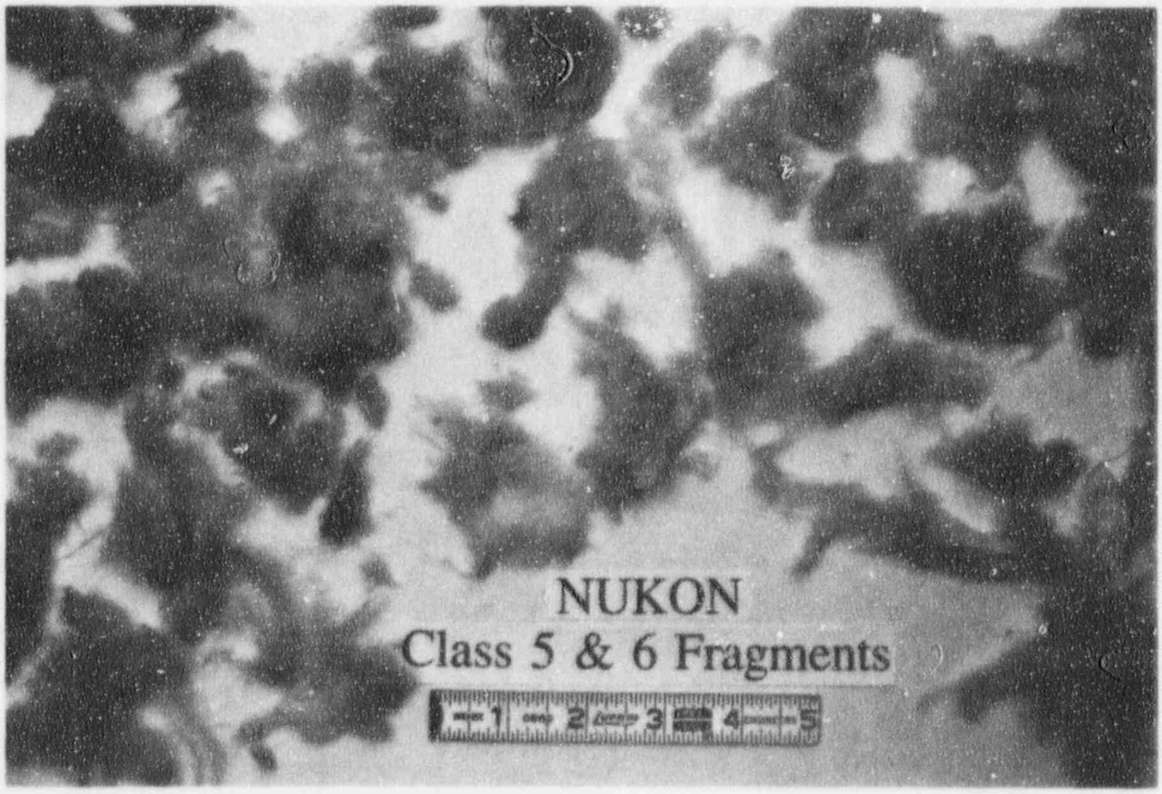


Figure 3-9. Representative Sample of Shredded NUKON™ Fibrous Debris

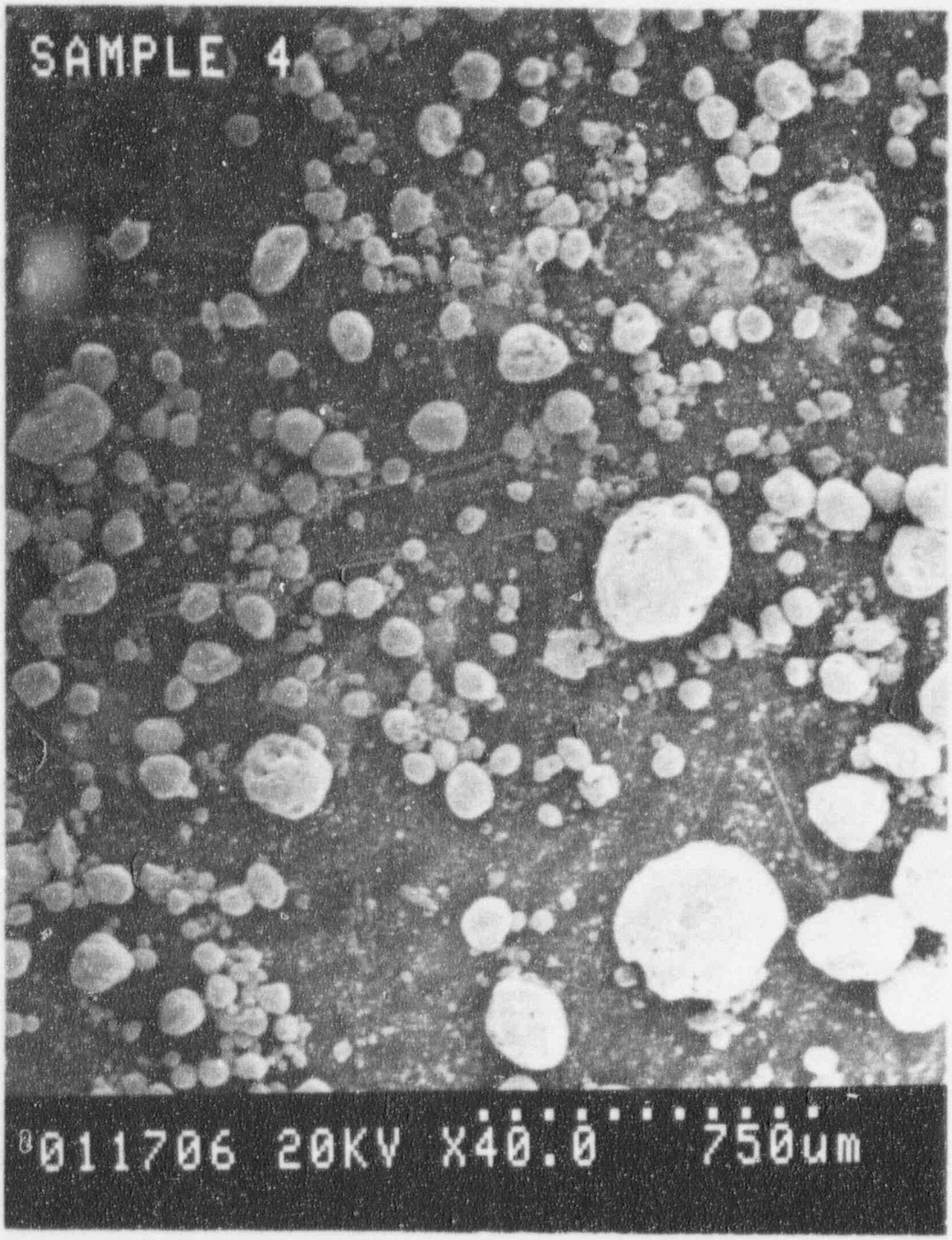


Figure 3-10. SEM of Sludge A (750 μm magnification)

Figure 3-11. SEM of Sludge A (1 μm magnification)

Table 3-2. Iron Oxide Particles Supplied by Hansen Engineering, Inc.

Fe_3O_4 Specification	< 2 µm	2-5 µm	5-10 µm	10-35 µm	>35 µm
#2008	5%	80%	15%	0%	0%
#9101-N	~0%	~0%	~0%	82%	~18%

agglomerates can be broken up by the turbulence created in the test facility.

3.3 Exploratory Tests

Exploratory tests were included in the test plan to optimize hardware and methods for sampling and concentration analysis; to determine if initial (additional) mixing prior to simulated chugging would be required; to determine the test duration and sample frequency (time interval), and to evaluate sample analysis accuracy. No specific matrix was formulated for the exploratory tests. However, the exploratory tests conducted are listed in Table 3-5.

There were a total of 7 exploratory tests, which were labeled Ex-1 through Ex-7. The conditions of each test are listed in Table 3-5. Information obtained from each exploratory test, used in developing a test procedure for parametric tests, is listed below:

Ex-1: The purpose was to take samples during and after simulated chugging to determine sampling rates and expected scatter in the data. Pre-soaked Class 5&6 insulation debris was added during simulated chugging. About half of the insulation floated on the surface of the pool after simulated chugging stopped. Lessons learned were:

- Let the insulation debris settle to the bottom before simulated chugging begins.
- Take more samples over a longer time.
- Develop consistent weight analysis procedure.
- Operate model at frequencies where surface wave resonance is not present.

Ex-2: As Ex-1, but with insulation debris initially on the floor. Oscillation period adjusted to avoid resonance. Most of the insulation sank after simulated chugging stopped.

- Initially, it was believed that adding insulation during simulated chugging and/or that surface resonance were responsible for floating insulation. Later however, parametric test T-17 (see section 3.4) showed that even starting with Class 3&4 insulation debris on the floor, with no surface resonance during testing, some insulation floated to the surface after simulated chugging stopped. No

Table 3-3. Sludge A Particle Size Distribution According to Manufacturer's Specifications

Particle Size Range (µm)	% By Mass
< 2	4.75
2-5	76
5-10	14.25
10-25	4.1
35-75	0.9

Table 3-4. Sludge A Particle Size Distribution. Sedimentation Velocity Analysis with Surfactant.

Equivalent Diameter (μm)	Cumulative Mass Fraction (%)	Mass Fraction (%)
100.00	98.6	1.5
80.00	98.6	0
60.00	98.6	0
50.00	98.4	0.2
40.00	97.5	0.9
30.00	95.4	2.1
25.00	94.2	1.2
20.00	92.9	1.2
15.00	90.2	2.8
10.00	82.7	7.4
8.00	75.9	6.9
6.00	61.4	14.5
5.00	50.5	10.9
4.00	38.4	12.2
3.00	26.1	12.3
2.00	13.2	13.0
1.50	6.5	6.7
1.00	2.7	3.8
0.80	2.4	0.3
0.60	2.4	0
0.50	2.1	0.3
0.40	1.8	0.3

Median Diameter: 4.95 μm
Modal Diameter: 5.42 μm

correlation was found that linked floating insulation debris with insulation size, surface wave resonance, or temperature of the water. Tests Ex-1 and T-17 were the only tests where more than a few percent of the insulation debris floated after simulated chugging stopped. The resulting settling velocities for case T-17 matched the predicted data, assuming all insulation sank; therefore, floating insulation debris was not a major concern. After test Ex-2, the extent of surface resonance was observed as a function of simulated chugging period. Froude scaled tests were conducted, and it was determined that surface wave resonance did not occur in the actual suppression pool. The Case 2 simulated chugging period was adjusted by 1% to avoid surface resonance.

Tests Ex-3 through Ex-6 extended the simulated chugging duration to about 17 minutes to measure more accurately if any settling occurred during simulated chugging and if a fully mixed condition existed.

Table 3-5. Exploratory Tests

Test #	Debris Type	Concentration in Water (% by Weight)	Actual Case Chugging Period; Interface Amplitude in Downcomers
Exploratory Tests			
Ex-1	NUKON Class 5&6	0.0032%	1.6 s; 3.8 ft (Case 3)
Ex-2	NUKON Class 5&6	0.0032%	1.6 s; 3.8 ft (Case 3)
Ex-3	NUKON Class 5&6	0.0032%	1.6 s; 3.8 ft (Case 3)
Ex-4	NUKON Class 3&4	0.0032%	1.6 s; 3.8 ft (Case 3)
Ex-5	Sludge A	0.0213%	1.6 s; 3.8 ft (Case 3)
Ex-6	NUKON Class 5&6 Sludge A	0.0032% 0.0213%	1.6 s; 3.8 ft (Case 3)
Ex-7	NUKON Class 3&4	0.0032%	1.6 s; 3.8 ft (Case 3)

Ex-3: NUKON™ insulation Class 5&6

- Samples indicate fully mixed condition (no settling) during simulated chugging.

Ex-4: NUKON™ insulation Class 3&4

- Fully mixed, no settling during simulated chugging.

Ex-5: Sludge only

- Fully mixed, no settling during simulated chugging.

Ex-6: Sludge and insulation

- Fully mixed, no settling during simulated chugging.

Ex-7: Insulation was introduced by spraying dry insulation debris with a garden hose on a plank held above the suppression pool.

- No difference from results with pre-soaked insulation poured in the tank and allowed to settle.

The conclusions from the exploratory tests are:

- To introduce insulation debris, samples should be pre-soaked in a bucket of water and gently squeezed to remove air bubbles. The air bubbles were removed to help achieve a consistent set of data. However, this step may not have been necessary in view of test Ex-7 where air bubbles were not removed and yet no insulation debris floated after simulated chugging stopped.

- Dry sludge should be poured into the pool. Soaking the sludge prior to introduction caused the sludge to stick to the bucket. Also, if the bucket remained dry, it could be weighed before and after the sludge was poured into the pool, verifying the weight of sludge used in the test.

- The filtering and weighing process was refined so consistent results were obtained. An analysis of sludge concentrations concluded that about 97% ± 3% of a known amount could be recovered by filtering, drying, and weighing the sample.

- Simulated chugging, even at the lowest energy level (Case 3), provided enough energy to fully mix and re-entrain NUKON™ insulation debris (Class 3-6) and Sludge A in the suppression pool.

3.4 Parametric Tests

A test matrix was developed to assess the effect of the following variables on debris mixing and potential settling during simulated chugging, settling after simulated chugging and re-entrainment of particles from the pool floor during simulated chugging:

a. Type of debris (NUKON™ insulation debris Class 3&4, Class 5&6, and sludge);
b. Behavior of sludge only, insulation debris only, and combinations of sludge and insulation debris;
c. Varying sludge to insulation debris mass ratio; and
d. Simulated chugging energy input (different frequency and amplitude).

Table 3-6 is the test matrix developed to address the effect of these variables.

The initial condition for each test was to have the debris fully mixed in the model tank, simulating the mixing produced by the initial gas venting and pool swell immediately following a LOCA. Exploratory tests showed that about one minute of simulated chugging resulted in a fully mixed condition, even at the lowest energy level with the insulation debris and sludge initially at the bottom of the tank. Hence, the initial mixing was completed by the time the first sample was taken at 1 minute after simulated chugging started.

Using the GE FSTF test data as a guide, the total simulated chugging duration was chosen to be about 4 minutes. However, exploratory tests were conducted with a total simulated chugging duration of 7 minutes to allow more samples to be collected for a more accurate evaluation of mixing during simulated chugging.

Debris concentrations were measured in the center of the tank at five equally spaced vertical locations, starting 0.8 ft (0.2 m) below water surface. The distance between sample ports was also 0.8 ft, resulting in the sampling ports being 0.5, 1.33, 2.2, 3.0, and 3.8 ft (0.15, 0.41, 0.76, 0.91 and 1.16 m) off the pool floor. Scaled to an actual Mark I suppression pool, these elevations correspond to 1.2, 3.2, 5.2, 7.2, and 9.2 ft (0.37, 0.98, 1.58, 2.19, and 2.80 m) off the floor. About 2.8×10^{-2} ft^3 or 0.8 liters (8×10^{-4} m^3) were withdrawn simultaneously from each of the five ports at selected time intervals, using the sampling apparatus shown in Figure 3-12. Prior to moving the bottles into position to collect a sample, the valves were open to flush out the sample lines. The samples were filtered, dried, and weighed (see test procedures, Appendix A), and the concentrations were expressed as the mass of debris per unit mass of water. Periodic sampling at 1 minute intervals during simulated chugging and at 2.4 minutes (and longer) intervals after simulated chugging stopped yielded concentration profiles as a function of time. The last sample set was taken about 42 minutes after simulated chugging stopped.

3.5 Test Procedures

A step by step test procedure for parametric tests was developed based on the experience gained in the exploratory tests; the resulting procedure, given in Appendix A, is summarized as follows:

- Fill tank to 56 inches (1.42 m) (actual case height of 11.2 ft or 3.41 m) above the floor level with clear water.
- Add a known quantity of pre-soaked NUKON™ insulation fragments to the tank and allow for the debris to settle to the bottom of the tank.
- Add a pre-determined quantity of sludge to the tank and allow the sludge to settle to the bottom of the tank.
- Set the variable speed pump controller frequency to the pre-determined value and adjust the cam pin position to simulate the chugging conditions on interest. Run the simulated chugging for a total of 4 minutes (or 9.6 actual case minutes).
- Draw water samples at every 60 seconds (or 2.4 actual case minutes) while simulated chugging is continuing.
- Terminate simulated chugging after 4 minutes (or 9.6 actual case minutes) and allow for the turbulence to decay.

- Draw water samples at every 2 minutes (4.8 actual case minutes) over the initial 10 minutes and every 10 minutes over the next 30 minutes.

The water samples were then used to estimate debris concentration using the filtration method described in Appendix A.

Table 3-6. Parametric Tests

Test #	Debris Type	Concentration in Water (% by Weight)	Actual Case Chugging Period; Interface Amplitude in Downcomers
Different Fiber Classes; Sludge Type A			
A-1 R1	NUKON Class 3&4	0.0032%	1.6 s; 3.8 ft (Case 3)
A-2 R1	NUKON Class 5&6	0.0032%	1.6 s; 3.8 ft (Case 3)
A-3 R1	Sludge A	0.0213%	1.6 s; 3.8 ft (Case 3)
A-4 R1	NUKON Class 5&6 Sludge A	0.0032% 0.0213%	1.6 s; 3.8 ft (Case 3)
A-5	NUKON Class 3&4 Sludge A	0.0032% 0.0213%	1.6 s; 3.8 ft (Case 3)
Different Concentrations			
B-6	NUKON Class 5&6 Sludge A	0.0011% 0.0213%	1.6 s; 3.8 ft (Case 3)
B-7	NUKON Class 3&4 Sludge A	0.0011% 0.0213%	1.6 s; 3.8 ft (Case 3)
B-8	Sludge A	0.0638%	1.6 s; 3.8 ft (Case 3)
Different Period & Amplitude (Tests D-12 and D-13 were deleted.)			
D-11 R1	NUKON Class 3&4	0.0032%	1.9 s; 5 ft (Case 2)
D-14 R1	NUKON Class 5&6 Sludge A	0.0032% 0.0208%	1.9 s; 5 ft (Case 2)
Repeat Tests			
D-11	NUKON Class 3&4	0.0032%	2.1 s; 5 ft
D-14	NUKON Class 5&6 Sludge A	0.0032% 0.0213%	2.1 s; 5 ft
Other Concentration Ratios			
T-17	NUKON Class 3&4 Sludge A	0.0032% 0.0032%	1.6 s; 3.8 ft (Case 3)
T-18	NUKON Class 3&4 Sludge A	0.0032% 0.0016%	1.6 s; 3.8 ft (Case 3)

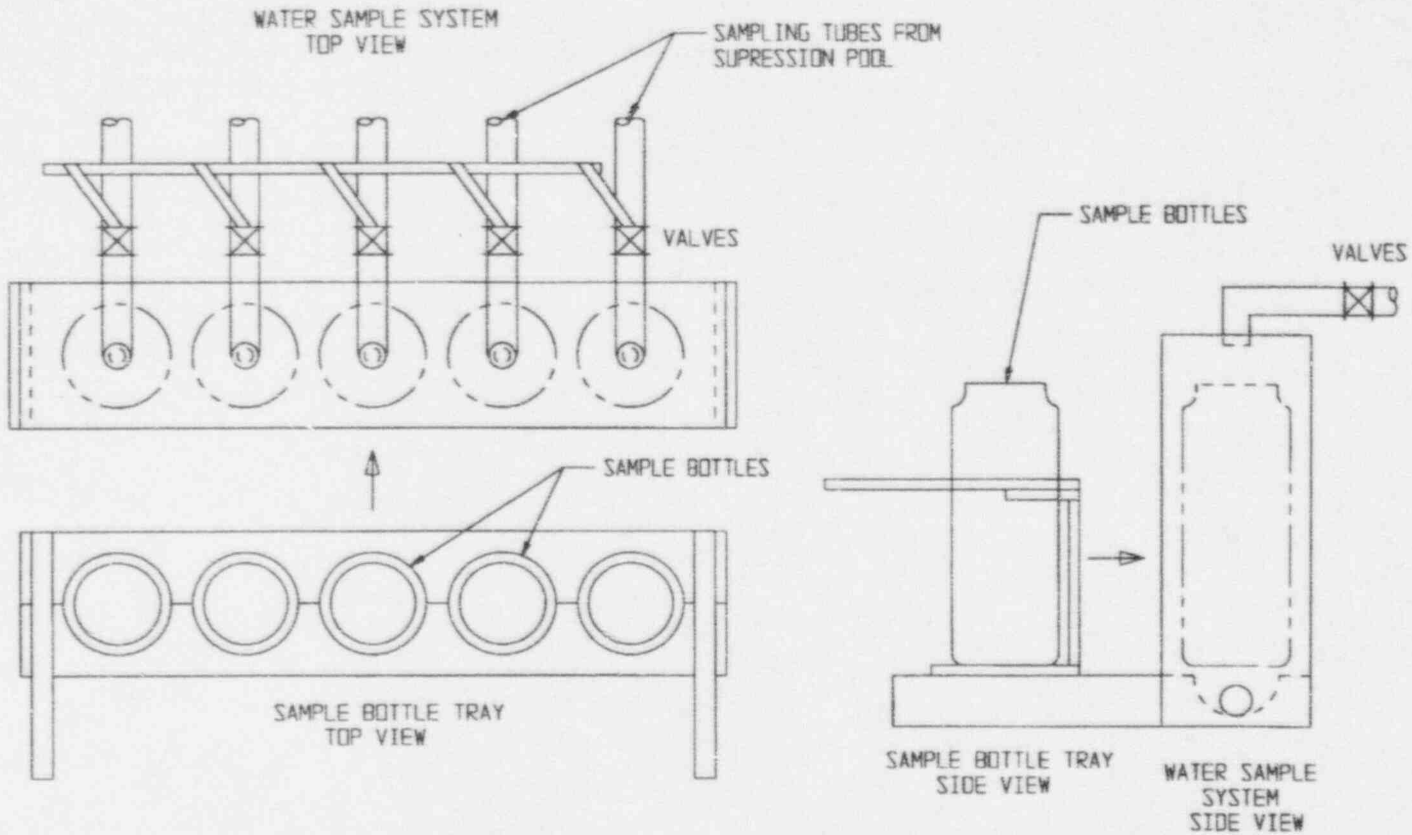


Figure 3-12. Sampling Apparatus for Debris Concentration Measurements

4.0 Analysis of Experimental Results

4.1 Results

Raw data of concentration measurements for the tests in the matrix (see Table 3-6) are included in Appendix B. Plots of test results are presented in Figures 4-1 through 4-12 [3] to allow ready evaluation of settling during and after simulated chugging. Actual case, i.e., full scale, values of the variables are used in all plots. Model values were converted to actual case values using the corresponding model to actual case ratios, namely 1:2.4 for depth (or height) and time, and 1:1 for concentration and velocity.

For each test, an average initial mixed concentration Cav is calculated by dividing the total mass of debris added by the mass of water in the tank. In the figures, measured concentrations C for each test are expressed as a percent of the calculated average initial concentration Cav. Average concentrations during chugging versus height in the tank are plotted in caption a) of Figures 4-1 through 4-12. Individual concentration measurements are plotted as functions of height and as functions of time in captions b) and c), respectively. Settling velocities calculated from concentration measurements are shown in caption d) of Figures 4-1 through 4-12.

Average concentration during chugging, caption a) in Figures 4-1 through 4-12, show the extent of entrainment of debris from the floor of the suppression pool. The data are the average of four measurements for each sample port. To get a measured average close to the true average, seven samples were taken during the exploratory tests to obtain an average with less error. Averages near 100% would indicate that debris is entrained and fully mixed.

Vertical concentration profiles, caption b) in Figures 4-1 through 4-12, show the concentration data versus height at specific times. Random scatter of data near 100% concentration during chugging would suggest that all debris was entrained in the pool and that no settling occurred. As settling occurs after simulated chugging stops, the slope of the concentration profiles shows the concentration gradient in the pool at the time specified. Scatter in the data is expected for the larger insulation fragments, and as those settle and only the finer material remains in suspension, the data become more consistent. More samples could not be taken because the loss of more water from the suppression pool would change the test conditions.

Concentration versus time at each sample elevation, caption c) in Figures 4-1 through 4-12, show how the concentration decreases with time after chugging. The time at which simulated chugging stops is marked on each plot. The steeper the slope, the faster the debris settles.

To allow use of the data in a more general format, including in the code BLOCKAGE, it was desired to evaluate sedimentation after chugging in terms of particle settling velocities. The test data of concentration decay with time, after the end of simulated chugging, were analyzed using a settling column approach, commonly used in the settling analysis of discrete solids of varying sizes in waste water settling chambers [9]. Equating the model pool to a settling column, the measured debris concentration C as a percent of Cav at some time represents the percent of debris with settling velocity less than or equal to a settling velocity $Vs = H/t$, where H is the depth of the sampling port from the water surface, and t is the time elapsed after simulated chugging stops. A plot of (100 - C) versus Vs relates the fraction of total debris with the minimum settling velocity for that fraction. Settling velocity data are included as caption d) in Figures 4-1 through 4-12.

4.2 Debris Behavior During Simulated Chugging

Debris initially on the floor became fully resuspended within the first few seconds after the simulated chugging commenced as observed by visual inspections, both for low and moderate chugging energy levels (Cases 3 and 2, respectively). The debris tested included Class 3&4 and Class 5&6 fibrous debris with and without sludge. As seen from the time averaged vertical concentration profiles, for all practical purposes the debris remained fully mixed and suspended in the pool, even for the lowest energy. Any fluctuations in the vertical concentration profiles are attributable to the randomness in the concentration that is typical of turbulent pools as well as in the sampling techniques. Together, these figures can be used to conclude that turbulence introduced by even very

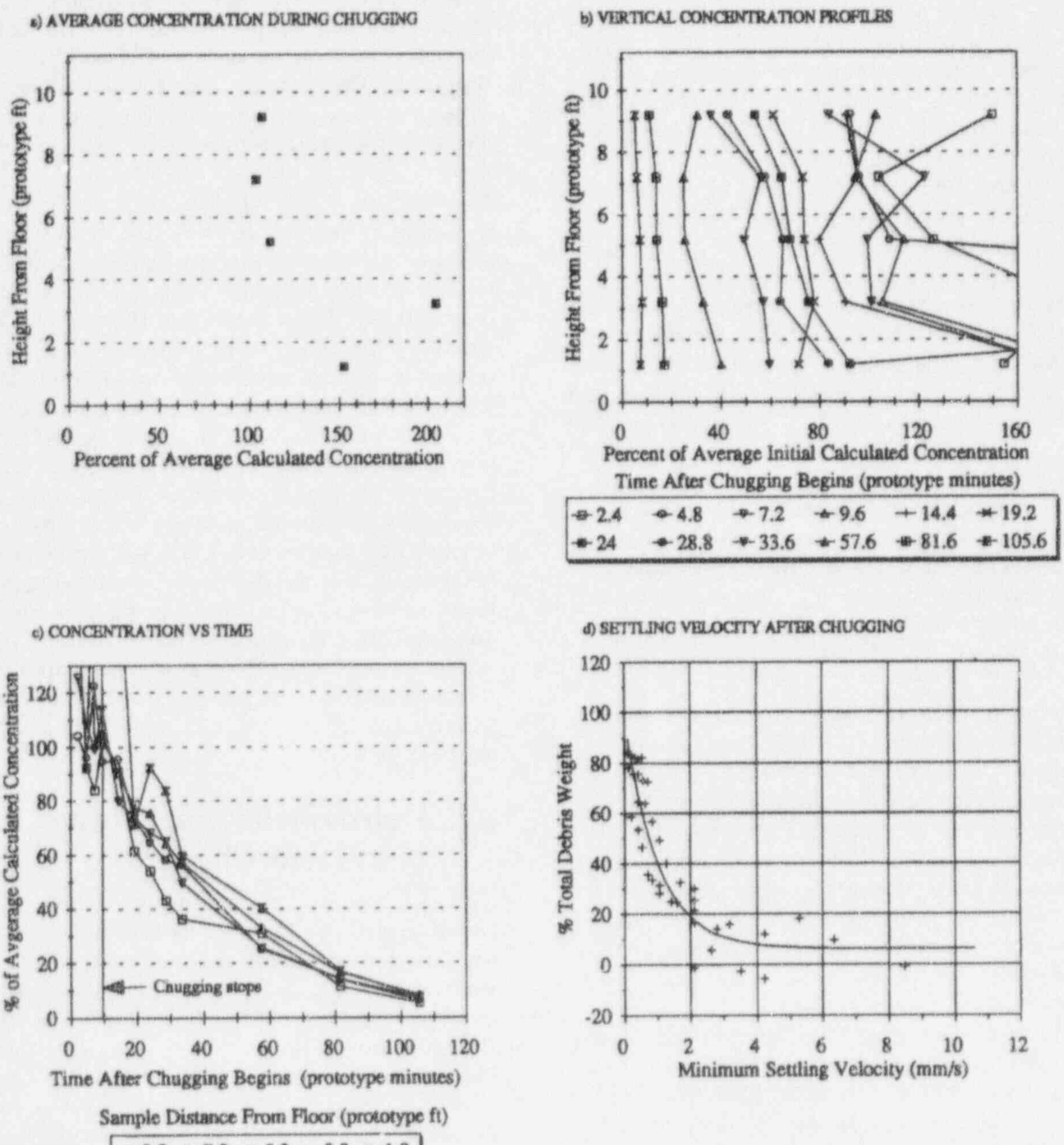


Figure 4-1. Debris Settling in Suppression Pool; Test A-1R1: 3.8 ft amplitude; 1.6 Sec Period (Case 3) NUKON™: 0.0032%. Class 3&4. Sludge A: 0.0% [3]

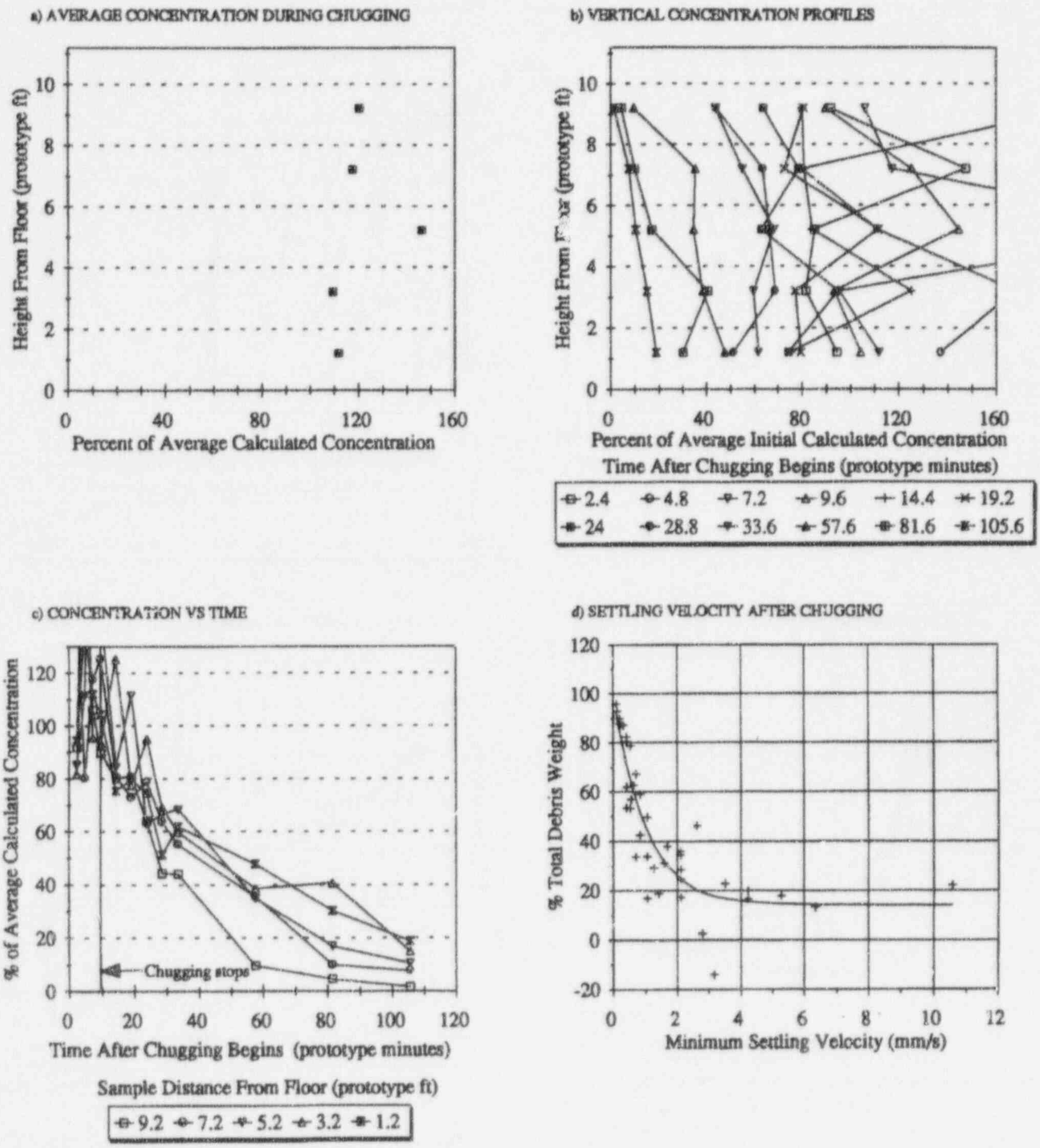


Figure 4-2. Debris Settling in Suppression Pool; Test A-2 R1: 3.8 Ft Amplitude, 1.6 Sec Period (Case 3) NUKON™: 0.0032% Class 5&6. Sludge A: 0.0% [3]

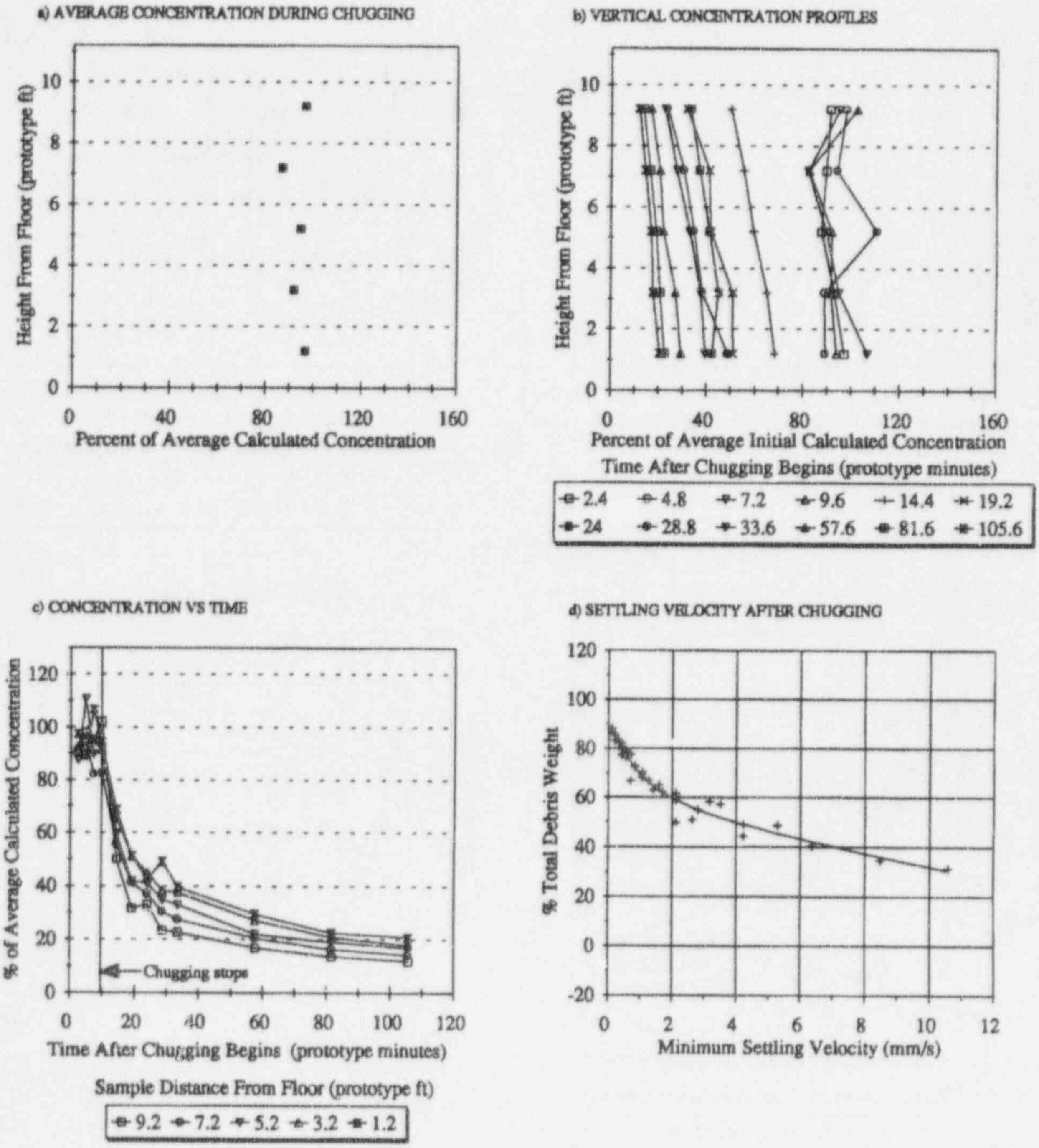


Figure 4-3. Debris Settling in Suppression Pool; Test A-3R1: 3.8 ft amplitude; 1.6 Sec Period (Case 3). NUKON™: 0.0%. Sludge A: 0.0213% [3]

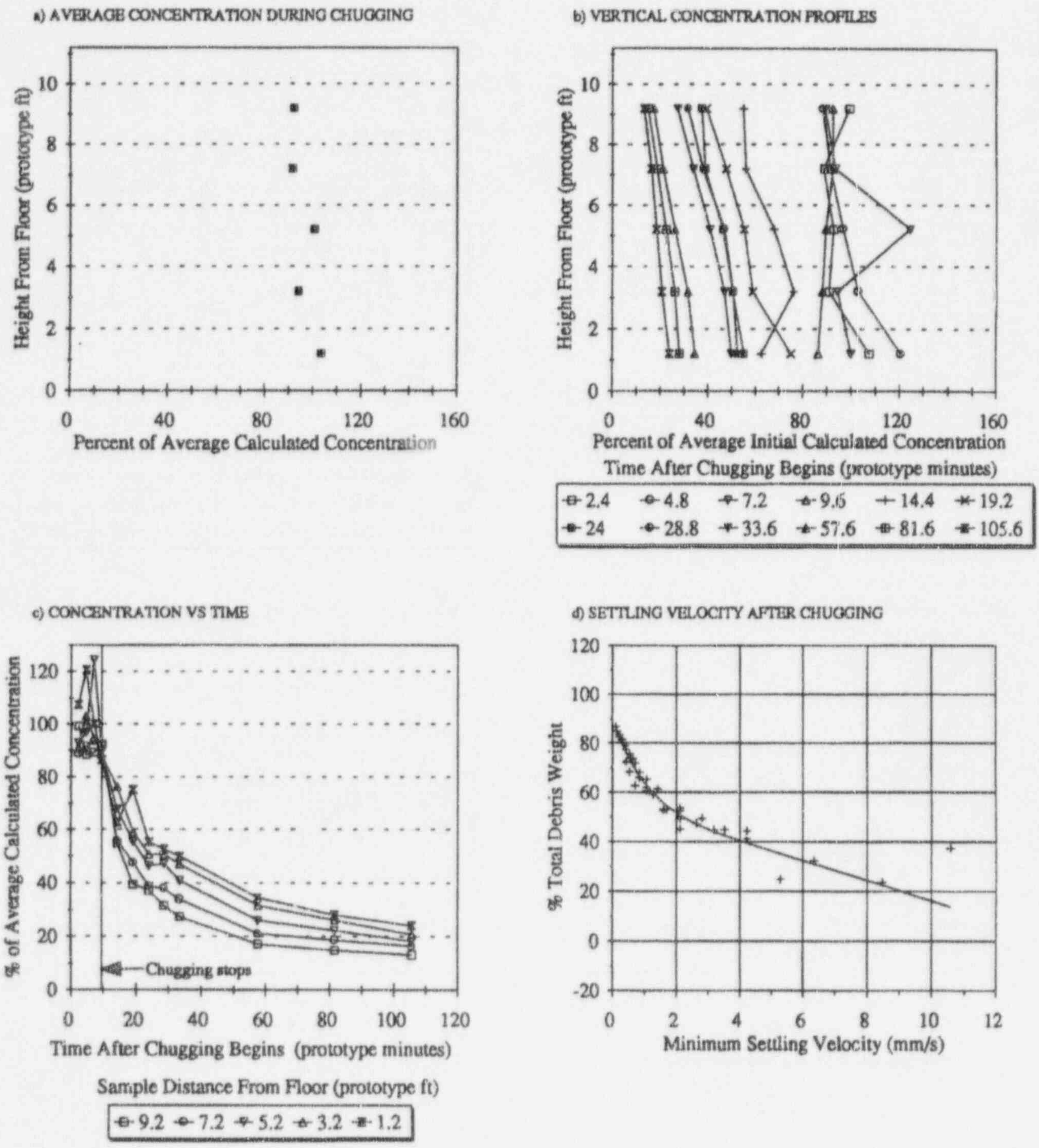


Figure 4-4. Debris Settling in Suppression Pool; Test A-4 R1: 3.8 Ft Amplitude, 1.6 Sec Period (Case 3) NUKON™: 0.0032% Class 5&6. Sludge A: 0.0213% [3]

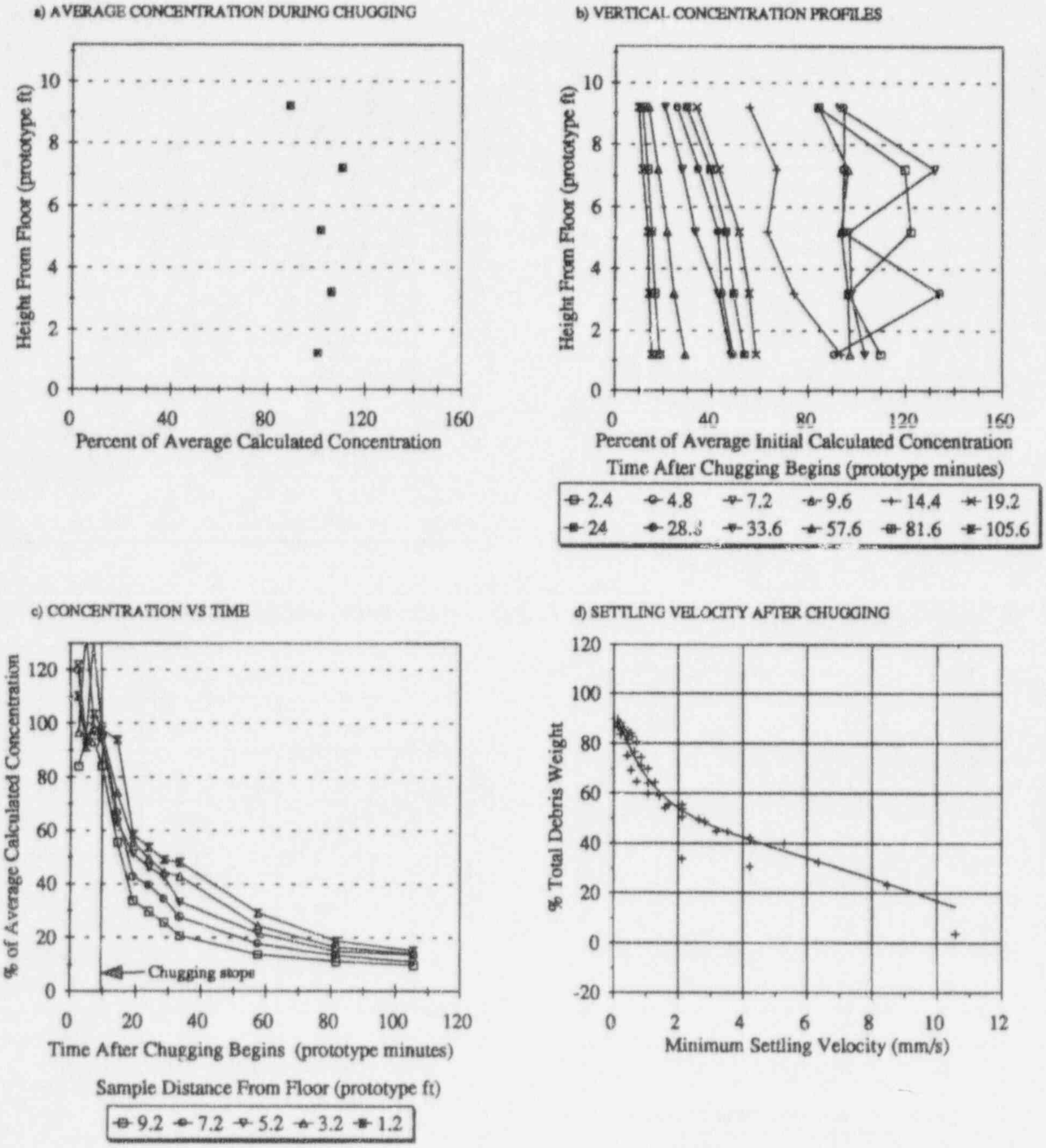


Figure 4-5. Debris Settling in Suppression Pool; Test A-5: 3.8 ft amplitude, 1.6 Sec Period (Case 3). NUKON™: 0.0032%. Class 3 & 4. Sludge A: 0.0213% [3]

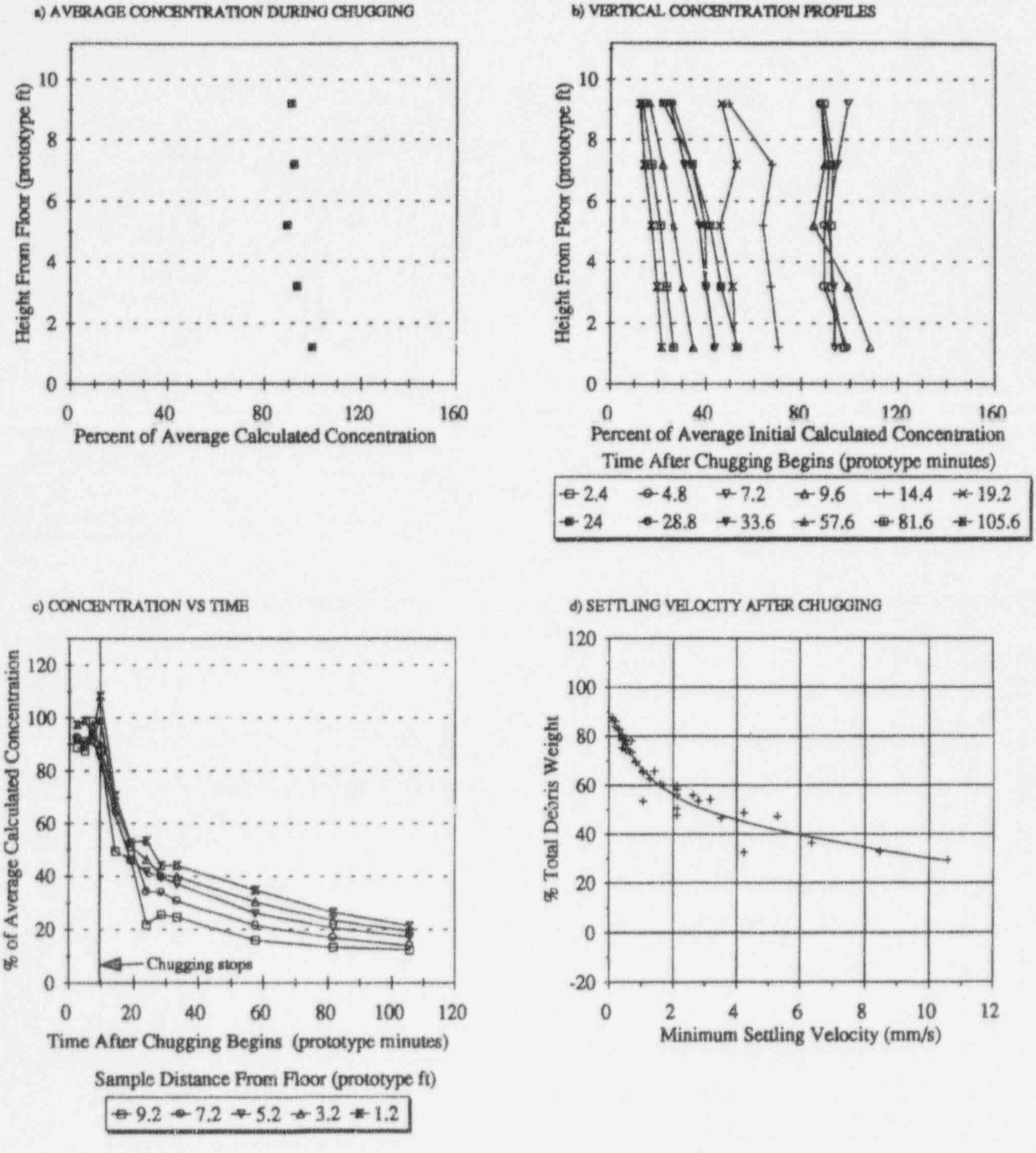


Figure 4-6. Debris Settling in Suppression Pool; Test B-6: 3.8 Ft Amplitude, 1.6 Sec Period (Case 3) NUKON™: 0.0011% Class 5&6. Sludge A: 0.0213% [3]

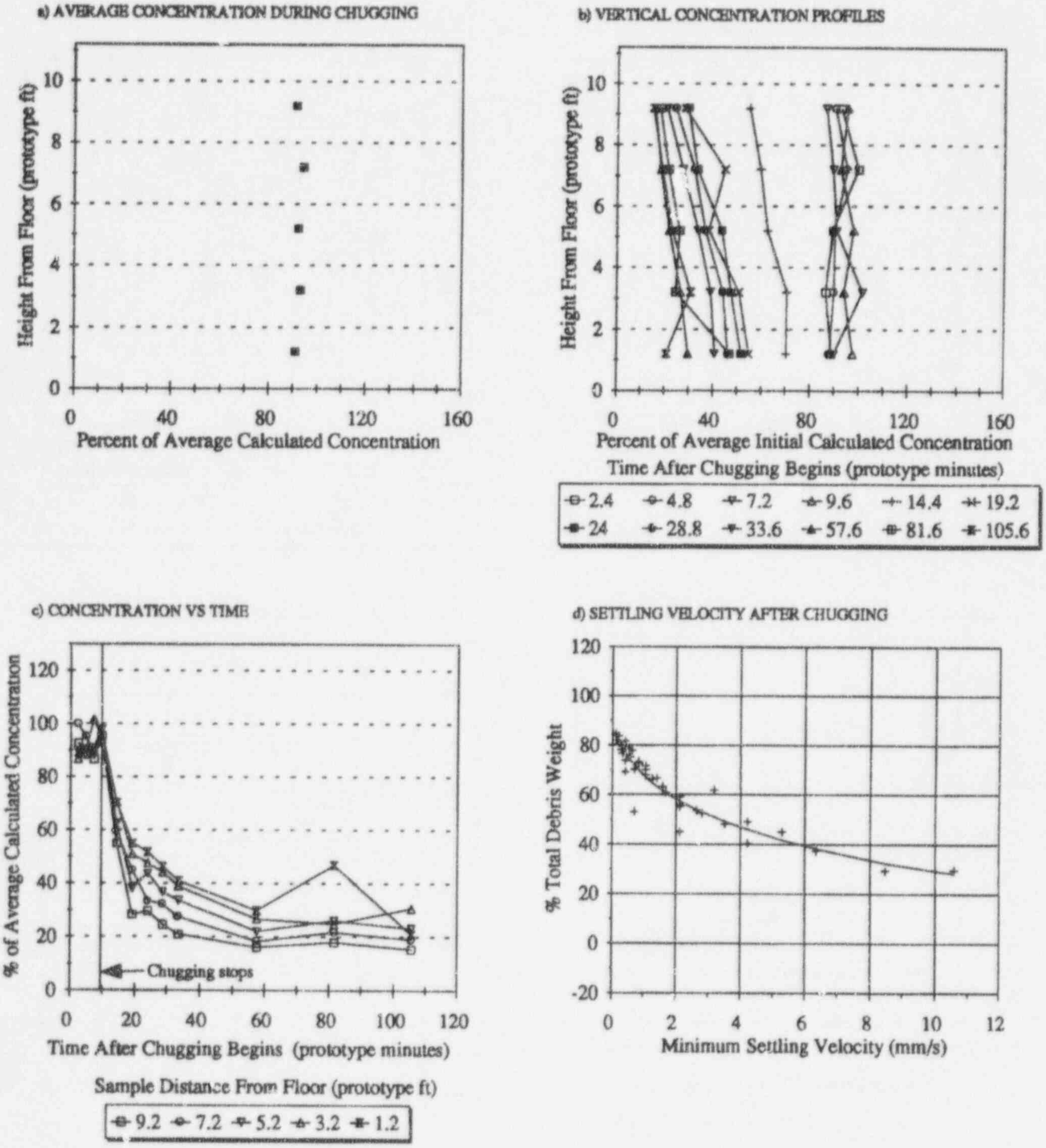


Figure 4-7. Debris Settling in Suppression Pool; Test B-7: 3.8 Ft Amplitude, 1.6 Sec Period (Case 3) NUKON™: 0.0011% Class 3&4. Sludge A: 0.0213% [3]

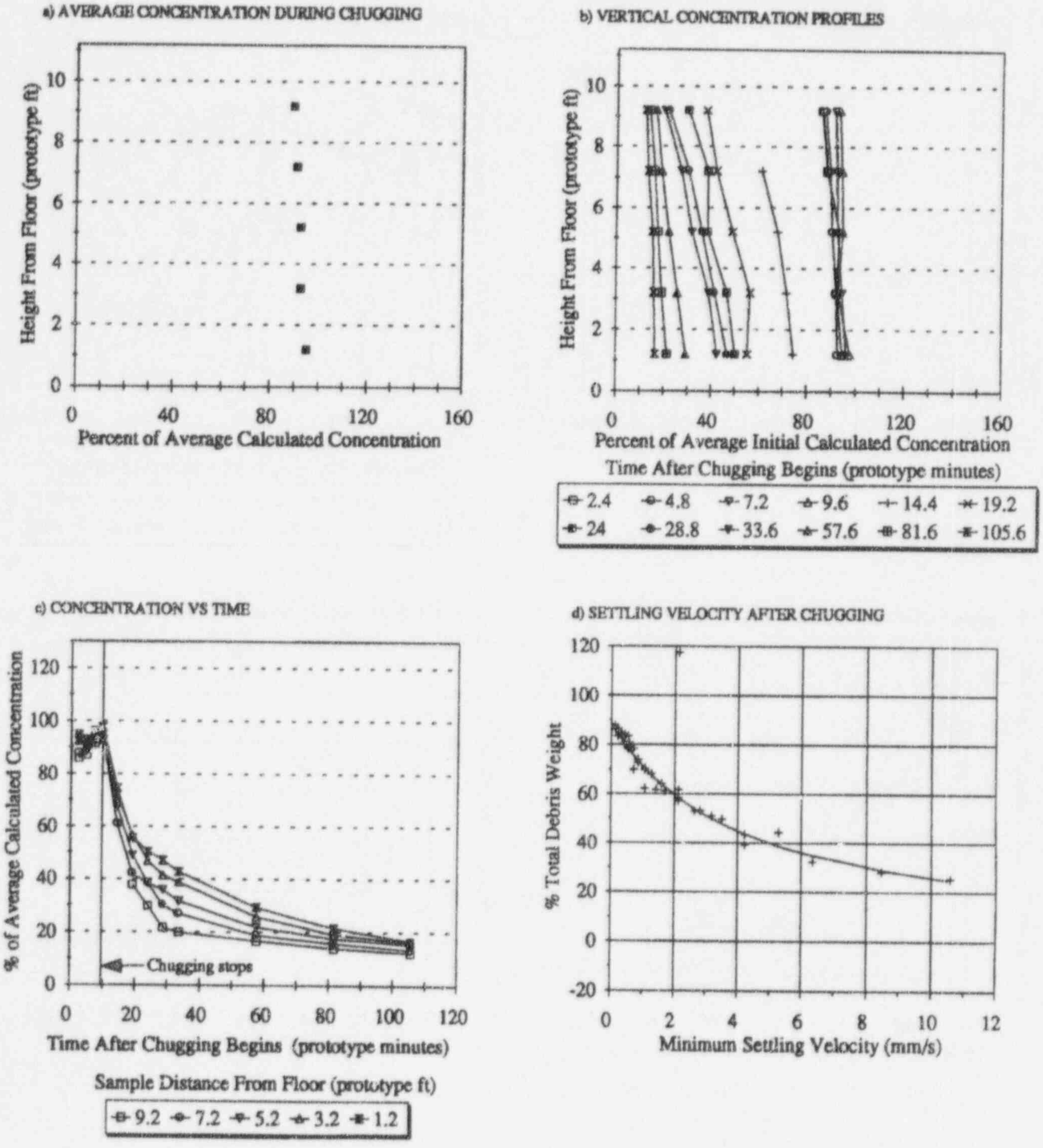


Figure 4-8. Debris Settling in Suppression Pool; Test B-9: 3.8 Ft Amplitude, 1.6 Sec Period (Case 3) NUKON™: 0.0%. Sludge A: 0.0638% [3]

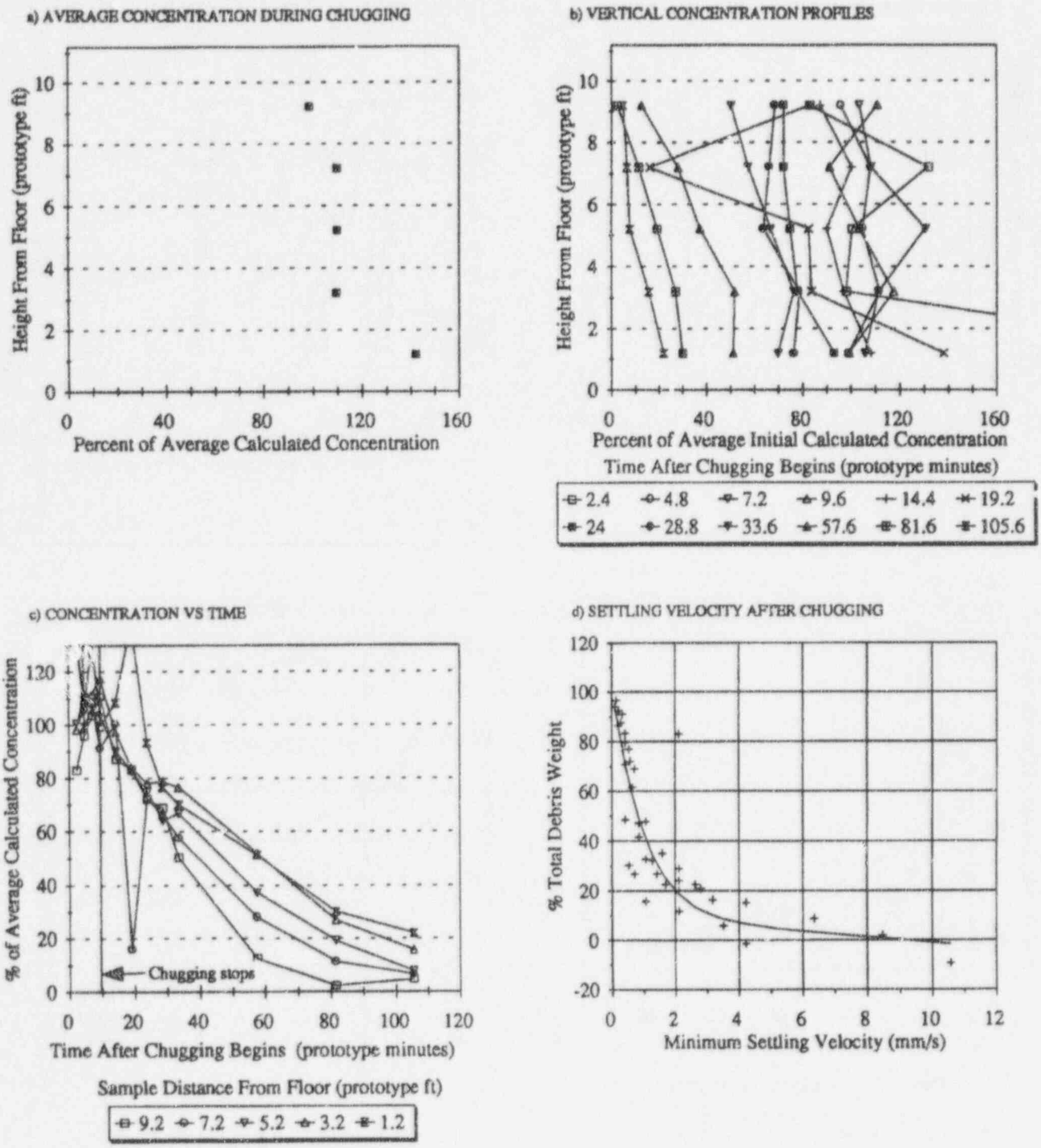


Figure 4-9. Debris Settling in Suppression Pool; Test D-11 R1: 5.0 Ft Amplitude, 1.9 Sec Period (Case 2) NUKON™: 0.0032% Class 3&4. Sludge A: 0.0% [3]

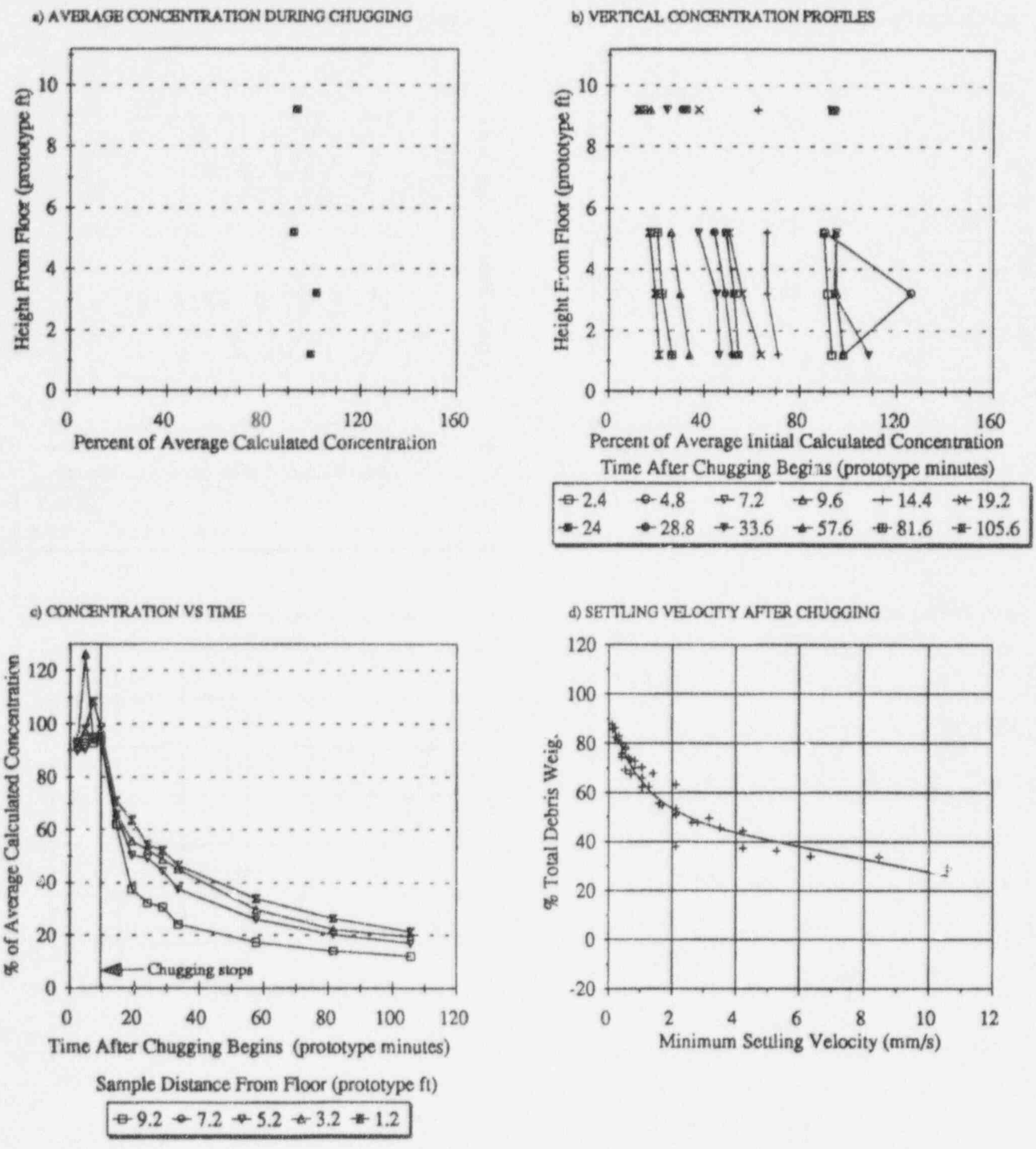


Figure 4-10. Debris Settling in Suppression Pool; Test D-14 R1: 5.0 Ft Amplitude, 1.9 Sec Period (Case 2) NUKON™: 0.0032% Class 5&6. Sludge A: 0.0213% [3]

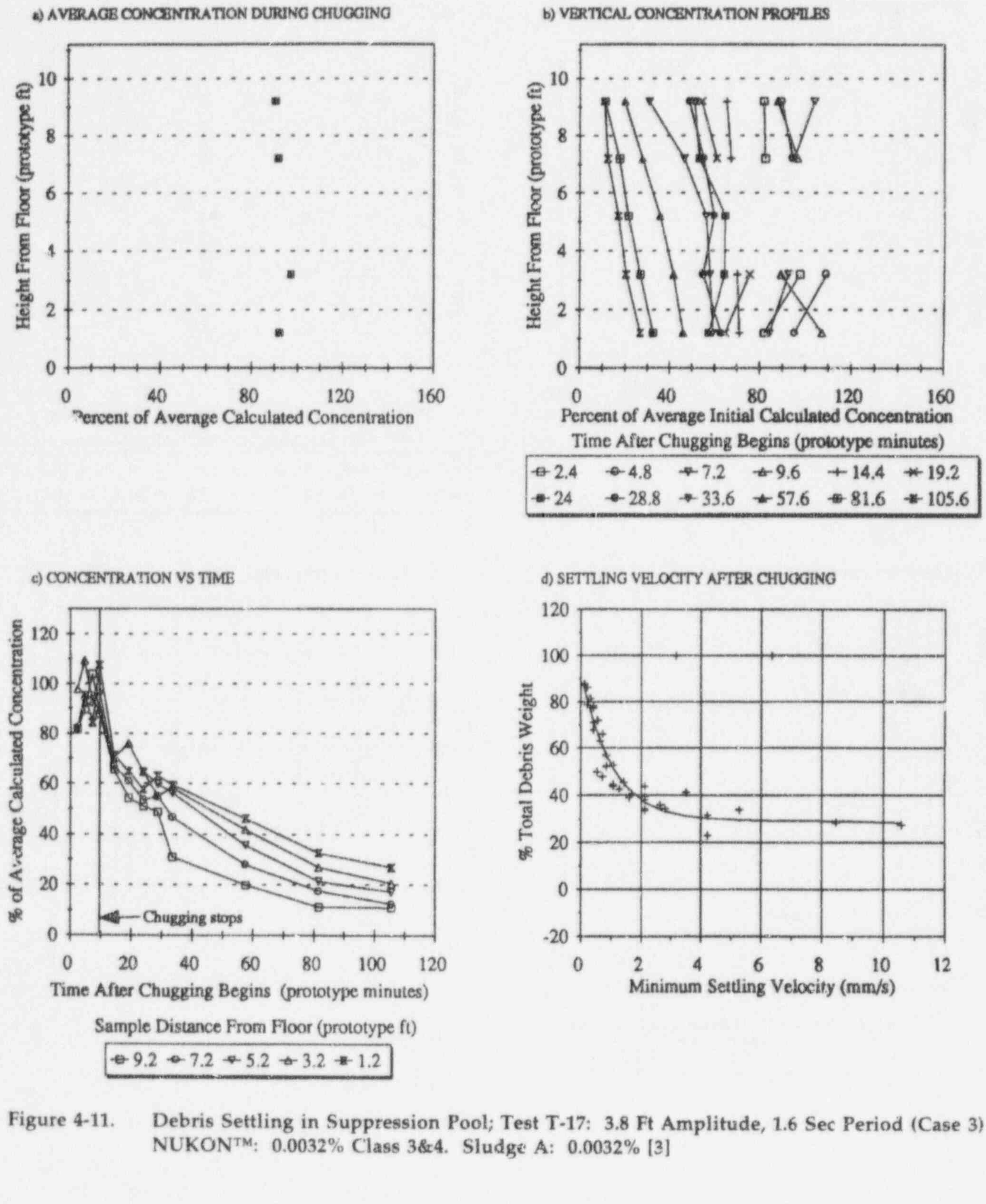


Figure 4-11. Debris Settling in Suppression Pool; Test T-17: 3.8 Ft Amplitude, 1.6 Sec Period (Case 3) NUKON™: 0.0032% Class 3&4. Sludge A: 0.0032% [3]

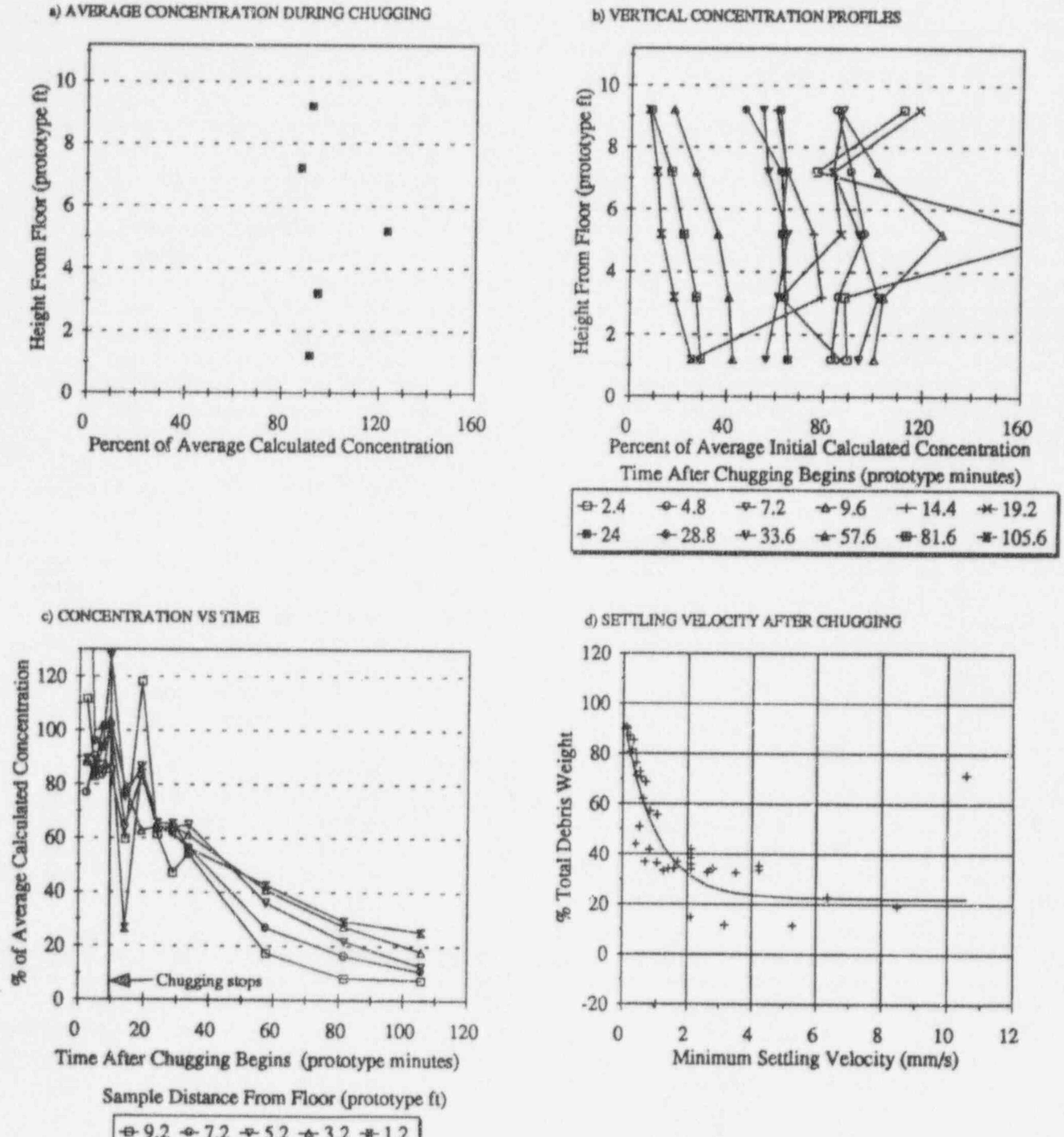


Figure 4-12. Debris Settling in Suppression Pool; Test T-18: 3.8 Ft Amplitude, 1.5 Sec Period (Case 3) NUKON™: 0.0032% Class 3&4. Sludge A: 0.0016% [3]

low energy chugs, such as case 3 chugs, will result in fully mixed conditions soon after the simulated chugging starts, irrespective of where the debris was introduced, i.e., on the floor or near the downcomer. These tests also demonstrate that potential for debris settling is negligible during the chugging phase.

Visual observations during simulated chugging tests with NUKON™ debris, both with classes 3&4 and 5&6, showed further disintegration of fibrous debris into smaller sizes, including a considerable amount of individual fibers. In general, the disintegration occurred close to the downcomer where the shreds are subjected to cyclic forces of downward jet and ingestion into the downcomer. This visual observation is supported by concentration measurements which reveal that more than 10-15% of the debris remains suspended for time periods larger than 100 minutes after termination of simulated chugging, which is only possible if the debris underwent disintegration.

In these tests, the debris were introduced at the bottom of the tank, which is different from the actual BWR suppression pools where the fibrous debris are introduced through the downcomers. Introduction of fibrous debris through the downcomers would heighten the potential for fragmentation of debris.

4.3 Settling After Simulated Chugging

In all tests, simulated chugging was terminated after 4 minutes or 9.6 actual case minutes. Visual observations suggest that debris, especially the sludge particles, start to sediment immediately after termination of simulated chugging, indicating rapid decay in turbulence levels. These observations are confirmed by concentration measurements which were plotted in caption c) of Figures 4-1 through 4-12. As can be seen from these figures, the measured concentration at each sampling position decreases with time due to gravitational settling. In addition, as can be seen from caption b) in these figures, the measured concentration at the lower elevations (e.g., 1.2 ft, or 0.32 m, off the floor) is continually larger than the corresponding at higher elevations (e.g., 9.2 ft, or 2.80 m, off the floor), which is also consistent with the gravitational settling. The concentration data with time were analyzed using a settling column approach to obtain settling velocities as described in Reference [9]. Caption d) in Figures 4-1 through 4-12 plot these settling velocities for the tests, as minimum settling velocities versus the fraction of debris possessing those velocities. Figure 4-13 plots settling velocity versus weight fraction for insulation debris of classes 3&4 and 5&6. Figure 4-14 presents similar curves for sludge and fiber mixtures of different sludge-to-fiber mass ratios, including the case of sludge only. These figures can be used to draw the following insights:

- As a result of fragmentation suffered by the debris during the high energy phase, settling rates are weakly dependent on the class of the fibers (3&4 vs 5&6) initially added to the tank (see Figure 4-13). Two different equations were developed for each for Classes 3&4 and Classes 5&6 and listed on Figure 4-13. The slight differences in the settling velocity suggest that possibly class 5&6 possesses slightly larger pieces at the termination of chugging. However, the differences appear to be negligible.
    - In general, the sludge possesses larger settling velocities, as demonstrated by the fact that 50% of the insulation debris possesses settling velocity less than 1 mm/s, whereas 50% of the tested Sludge A possesses settling velocity in excess of 3 mm/s.
    - The settling velocities for sludge and fiber mixtures can be estimated using the principle of superposition. This suggests that fibrous and non-fibrous species settle independently of each other.

The settling velocity measurements can also be used to draw several insights into size distribution of the debris, especially the particulate debris. From Stokes' law it is known that for spherical particles the settling velocities, V_s, in calm pools can be estimated using the following equation:

$$V_s = \frac{D_p^2 g\ (\rho_p - \rho_w)}{18\mu} \qquad \textbf{(4-1)}$$

where,

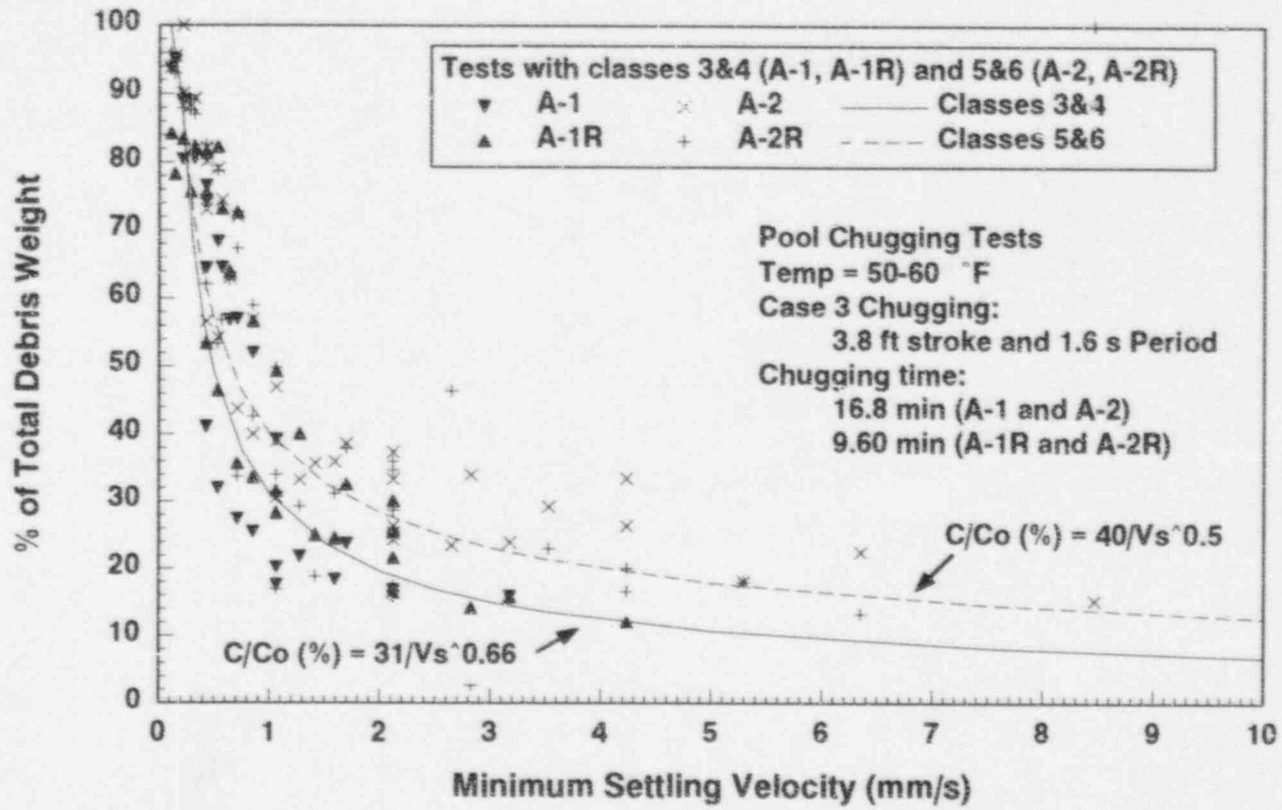


Figure 4-13. Settling Velocity Distribution for Classes 3&4 and 5&6 Shreds After Being Subjected to Simulated Chugging

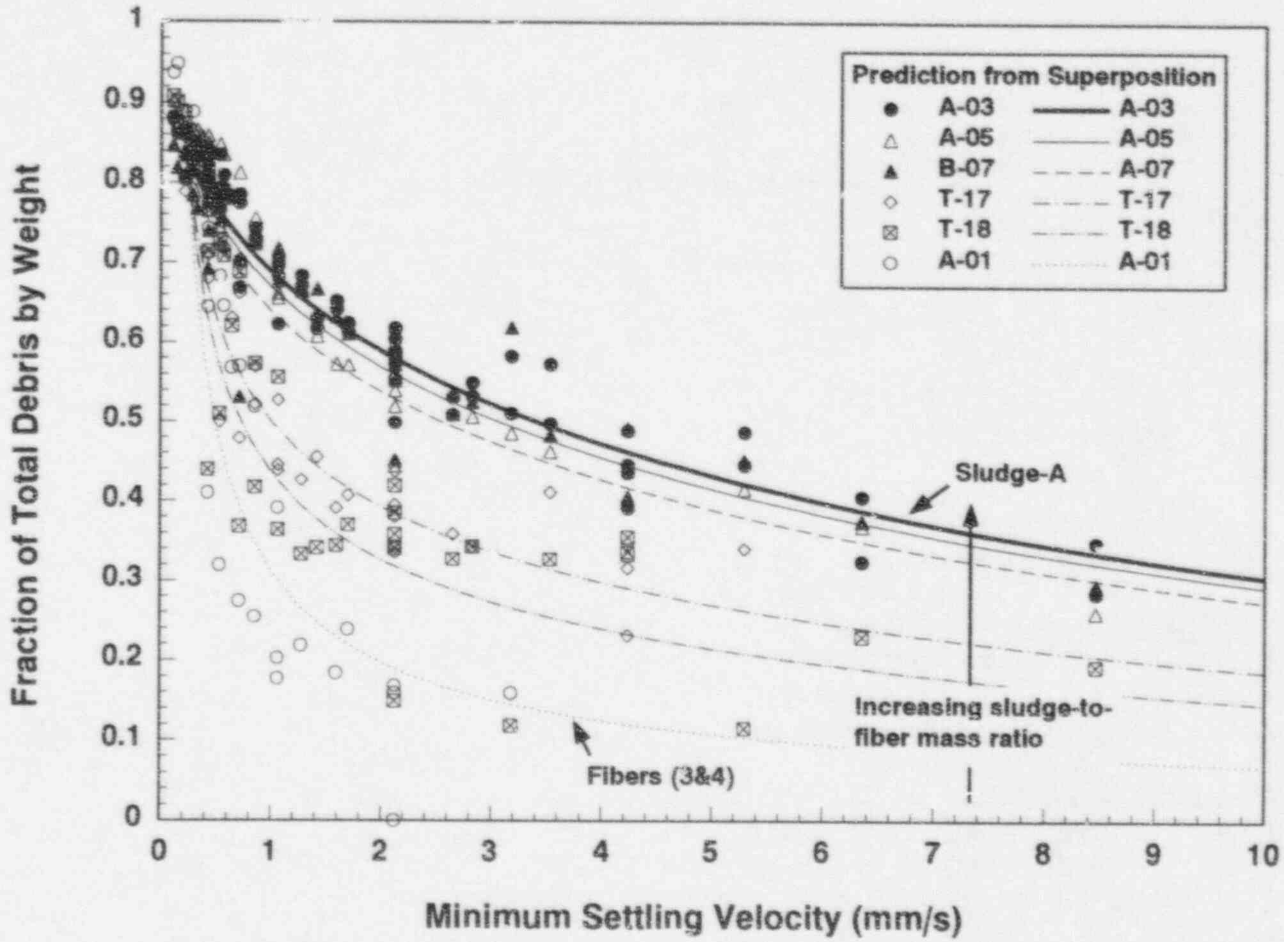


Figure 4-14. Settling Velocities for Various Sludge and Fiber Mixtures Predicting Using the Principle of Superposition (Assumes Independent Behavior)

D_p is the equivalent diameter of the debris particle,
ρ_p is the density of the debris particle,
ρ_w is the density of water,
μ is the viscosity of water,
g is the acceleration of gravity.

This equation can be inversed to estimate the minimum particle diameter once the minimum settling velocity is known as follows:

$$D_p = \sqrt{\frac{18\,\mu\,V_s}{g(\rho_p - \rho_w)}} \tag{4-2}$$

The minimum particle size distribution data obtained in this manner for sludge only is plotted in Figure 4-15. This figure suggests that more than 50% of the Sludge A consists of particles larger than 40 µm, and more than 25% are larger than 70 µm. Clearly, these estimates indicate that sludge particles in the tank are larger than manufacturer's specifications for powder #2008. This observation is also consistent with the SEM pictures (e.g., Figures 3-10 and 3-11) of dry Sludge A samples. This confirms that the iron-oxide sludge particles tend to agglomerate quickly and form large agglomerates that are not easily disintegrated by turbulence.

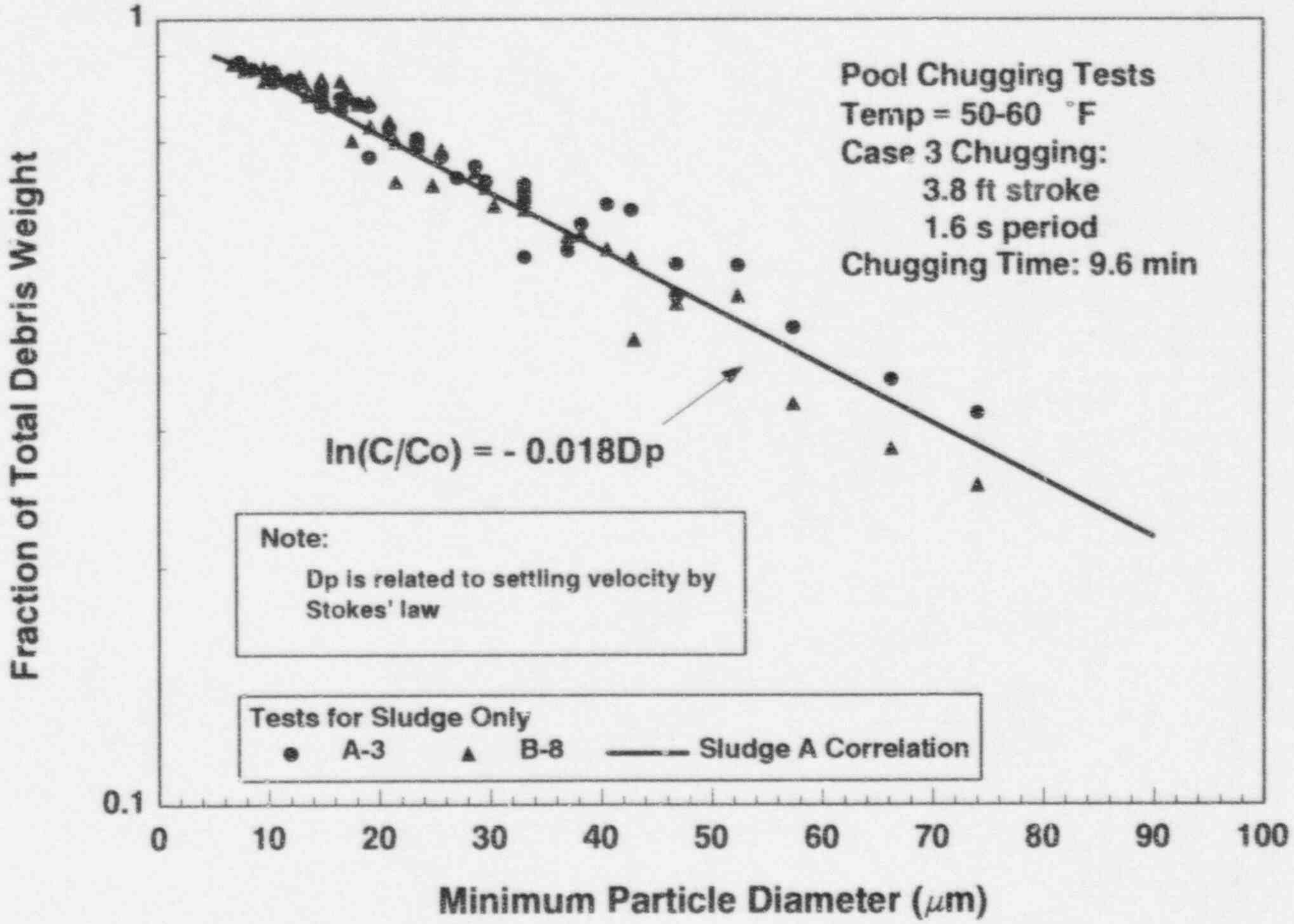


Figure 4-15. Particle Size Distribution Curve for Sludge A

5.0 Significant Findings

The suppression pool tests conducted with a 1:2.4 scale model of a Mark I suppression pool segment with NUKON™ fibrous debris and iron oxide sludge indicate that:

- During simulated chugging, both the fibrous and particulate debris remained fully mixed in the tank, even at the lowest simulated chugging energies (i.e., Case 3). The turbulence created by these low energy simulated chugs was capable of resuspending the debris initially contained at the bottom of the tank and resulted in uniform vertical concentration profiles. Although this data was obtained for the lowest energy simulated chugs, it is believed to be equally valid for other phases of accident progression, including condensation oscillations typical of large LOCA and Case 1 and Case 2 chugging that characterize both medium LOCA and the final stages of a large LOCA.

- Even during the simulated chugging of lowest energy, the fibrous debris underwent further fragmentation into smaller sizes, including individual fibers. In general, the fragmentation occurred near the downcomers where the fibrous debris was subjected to cyclic shear forces from downward jet and ingestion into the downcomer.

- Visual observations suggest that the turbulence decays within few minutes after termination of chugging simulation. This enables settling of the debris in the post-high energy phase. The initial settling rate was more rapid for sludge compared with the fibrous debris. This observation may not be valid for the actual BWRs since in the later case additional turbulence is continually added to the suppression pool by the recirculating ECCS. Higher levels of turbulence may be present in a BWR suppression pool if the Residual Heat Removal system (RHR) is operated in the suppression pool cooling mode. Since these phenomena can not be easily simulated in the test facility, engineering judgement must be employed in estimating the correction factors that account for the effect of such phenomena on the settling velocities.

- The sludge used in the present study (Sludge A) was found to have been made up of large agglomerates that settle quickly in the post-high energy phase. The minimum particle diameters obtained using Stokes' law suggests that more than 50% of the particles are larger than 40 μm. These sizes are considerably larger than BWROG specifications for suppression pool sludge (see Table 3-1). There is a possibility that these agglomerates may have been formed in the present tests because the iron oxide powders were supplied in the dry form, where the individual particles are in physical contact with each other. This potential for agglomeration may be minimized in an actual BWR case, where the particles are in suspension thereby minimizing the chance for collision. Several factors may contribute towards agglomeration in the suppression pool, and all these processes are not very well understood. One possible option for estimating the settling rates for a plant-specific sludge is to use the Stokes' law in conjunction with the actual sludge size distribution.

- In the post-high energy phase, the vertical concentration profiles are slightly non-uniform. However, for strainer blockage analysis, it is reasonable to assume that the concentration profile is uniform near the strainer.

These conclusions related to post high-energy phase do not consider the effect of recirculation flow patterns within the suppression pool established by the ECCS flow. Simulation of such flow may provide additional insights related to horizontal variation of concentration profiles, which is essential to determine near-field concentration.

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[5] Appendix B of Reference 1.

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[7] Reference 1, p. 4-24.

[8] "BWR Owners' Group ECCS Suction Strainer Committee Suppression Pool Sludge Particle Size Distribution", Letter from General Electric to A.W. Serkiz, USNRC, Dated September 13, 1994.

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Appendix A

BWR Pool Simulated Chugging Tests
Step By Step Test Procedures

I. Preparation Procedure

A. Tank

1. Drain tank.
2. Drain water above pistons and clean.
3. Rinse tank with water spray; drain.
4. Mop and wipe tank floor, side walls, and pistons.
5. Rinse tank with water spray; drain.
6. Fill tank at least 1 ft high; drain.
7. Repeat steps 5 and 6 until there is no visible residue.
8. Fill tank to 56 inches above its lowest point (156 ft^3).

B. Insulation Procedure

1. Use established insulation preparation procedure (same as for head loss tests).

C. Sludge A

1. Find the tare of a one gallon plastic pail to ±1 g.
2. Fill with 95% of the desired total weight of fine (2008) sludge.
3. Add to it 5% of the desired total weight of coarse (9101N) sludge.
4. Carefully pour the dry sludge into the tank already filled with water to the required height.
5. Weigh the empty pail to find the amount of sludge adhering to the pail.

D. Sample Bottles

1. Use 1.0 liter glass bottles.
2. Empty bottles should be rinsed clean and contain less than 1 g of residual water.
3. The weight of the empty bottle without the lid should appear on the label of each bottle.
4. Organize twelve sets of bottles in sequence for testing. The sets are numbered from 1 through 12 and within each set, there are five bottles labeled A through E denoting the height from where the sample is drawn.

II. Sampling Procedure

A. Record the water temperature in the tank.
B. Record the water height in the tank.
C. At the designated sample time, open the 5 sample ports and allow to flush for 4 seconds.
D. Place the rack of five sample bottles under the sample ports while the ports are open.
E. When bottles are about 3/4 full, close the sample ports.
F. Cap the bottles and replace with the next set of five empty bottles for the next sample.
G. Sample at the following times (actual times, i.e., not scaled):

1.	During simulated chugging:	1 set of samples per minutes
2.	After simulated chugging:	1 set every 2 minutes for 10 minutes, then
		1 set every 10 minutes for 30 minutes

III. Simulated Chugging Procedure

A. To achieve a given simulated chugging period, set the controller frequency to the corresponding value. The desired controller frequency is determined from the graph of simulated chugging period versus controller frequency. The graph is a curve fit through data points of digital readout of controller frequency and simulated chugging period, as measured by the number of chugs in 10 seconds measured with a stopwatch.

B. Case 3: The motor that drives the pistons is ramped automatically to the required simulated chugging period in 36 seconds (actual case time). The beginning of simulated chugging starts approximately 18 seconds after ramping begins.

C. Case 2: The motor that drives the pistons is ramped automatically to 90% of the required simulated chugging period in 36 seconds (actual case time). The beginning of simulated chugging starts approximately 18 seconds after ramping begins. The speed is increased manually to achieve the required simulated chugging period in less than 24 seconds.

D. Case 1: To be specified later, if Case 1 testing is needed.

IV. Concentration Analysis Procedures

A. Insulation Only Tests

1. Weigh a 1.0 micron pore filter to ±0.1 mg.
2. Place the filter on the filtering assembly.
3. Clean the funnel with a glass cleaner and wipe with a lint-free towel.
4. Screw the funnel to the filtering assembly.
5. Weight the sample bottle ±1g (without the lid) and subtract the weight of the empty bottle (written on the label) to find the weight of water.
6. Carefully pour the sample into the funnel.
7. Open the vacuum line to the filtrate bottle.
8. Rinse the bottle with distilled water and pour into funnel at least three times.
9. Rinse the funnel with distilled water.
10. When no water remains above the filter, disconnect the vacuum line and remove the filter.
11. Place the filter on a clean rack and weight after at least 20 hours of air drying.
12. Save the dried filters for at least six months.

B. Tests With Fine Particulates (and Insulation, if Present)

1. Pour a 0.2% by wt sludge concentration through the funnel.
2. Rinse the funnel with distilled water.
3. Weigh a 0.45 micron pore filter ±0.1 mg.
4. Place the filter on the filtering assembly.
5. Do not clean the funnel between samples.
6. Screw the funnel to the filtering assembly.
7. Weigh the sample bottle without the lid and subtract the weight of the empty bottle (written on the label) to find the weight of water.
8. Carefully pour the sample into the funnel.
9. Open the vacuum line to the filtrate bottle.
10. Rinse the bottle with distilled water and pour into funnel at least three times.
11. Rinse the funnel with distilled water.
12. When no water remains above the filter, disconnect the vacuum line and remove the filter.
13. Place the filter on a clean rack and weigh after at least 20 hours of air drying.
14. Save the dried filters for at least six months.

C. Insulation Debris Generation

1. Heat treated insulation blanket is cut vertically into 6" squares.
2. 2 squares are processed at a time.

3. Each square is peeled into individual layers, about 10 to 12 per square.
4. All these layers are put into leaf shredder (off).
5. Leaf shredder is covered and a bag is placed beneath.
6. Leaf shredder is turned on and run for 60 seconds.
7. Bag beneath shredder is removed; larger pieces of insulation that remain in shredder are removed and kept separate from material that settles into bag. The material in the shredder is considered to represent class 5 and 6. The rest of the material is considered to represent class 3 and 4. Any 6" x 6" squares still intact (not shredded) are removed from either sample.
8. Bag is replaced beneath shredder and steps 1 through 7 are repeated until the required amount of insulation for either size class obtained.

Instrumentation: To weigh the initial amount of sludge and fibrous insulation debris, a 6000 g capacity OHAUS CT6000 class A digital scale (resolution of 1 g) was used; this scale was also used to weigh the water in each sample.

A 180 g capacity A&D electronic balance, model ER180A, was used to weigh the filter papers and sludge in each sample; the resolution for this scale was set to 0.1 mg.

LEAF SHREDDER FLOWTROW LEAF EATER

Setting: Fine

Exposed length of plastic string = 3.4" approximately

Number of strings exposed = 4

Appendix B

Raw Data for the Concentration Measurements

	grams	% by wt of water
Nukon: Class 3&4	142	0.0032%
Sludge A	0	0.0000%
Mix A	0	0.0000%
Total	142	0.0032%

Chugging lasts 9.6 minutes

Time (Full scale minutes)		Sample Bottles (g)		Water (g)	Filters (0.1 mg)		Residue	% of average initial calculated concentration
	Label	empty	full	full-empty	new	used	used-new	
2.4	a1	353	1072	719	987	1358	371	160.3%
	b1	358	1128	770	1264	1547	283	114.2%
	c1	357	1117	760	1193	1526	333	136.1%
	d1	357	1134	777	1252	1731	479	191.5%
	e1	353	1102	749	974	1372	398	165.1%
4.8	a2	353	1119	766	1189	1443	254	103.0%
	b2	357	1172	815	1265	1544	279	106.3%
	c2	357	1157	800	978	1284	306	118.8%
	d2	353	1148	795	1189	2320	1131	441.9%
	e2	353	1142	789	1258	1519	261	102.8%
7.2	a3	352	1037	685	973	1181	208	94.3%
	b3	353	1076	723	1200	1509	309	132.8%
	c3	354	1102	748	1262	1526	264	109.6%
	d3	352	1086	734	972	1235	263	111.3%
	e3	353	1059	706	1195	1617	422	185.7%
9.6	a4	353	1053	700	1189	1444	255	113.2%
	b4	353	1103	750	1270	1523	253	104.8%
	c4	353	1106	753	983	1284	301	124.2%
	d4	353	1104	751	1190	1470	280	115.8%
	e4	353	1179	826	1265	1795	530	199.3%
14.4	a5	353	1000	647	971	1182	211	101.3%
	b5	352	1040	688	1189	1423	234	105.7%
	c5	352	1071	719	1265	1474	209	90.3%
	d5	353	1059	706	973	1202	2[illegible]	100.8%
	e5	353	1025	672	1191	1594	403	186.3%
19.2	a6	352	1036	684	1262	1420	158	71.8%
	b6	352	1085	73[illegible]	969	1166	197	83.5%
	c6	352	1090	738	1153	1353	200	84.2%
	d6	353	1098	745	1258	1469	211	88.0%
	e6	353	1064	711	1211	1398	187	81.7%
24	a7	352	1052	700	1155	1300	145	64.3%
	b7	353	1086	733	1256	1433	177	75.0%
	c7	353	1094	741	1213	1400	187	78.4%
	d7	351	1086	735	1157	1360	203	85.8%
	e7	353	1079	726	1259	1499	240	102.7%
28.8	a8	354	1044	690	1211	1330	119	53.6%
	b8	354	1098	744	1158	1322	164	68.5%
	c8	353	1102	749	1209	1391	182	75.5%
	d8	354	1096	742	1252	1430	178	74.5%
	e8	353	1072	719	1164	1382	218	94.2%
33.6	a9	353	1112	759	1216	1330	114	46.7%
	b9	354	1144	790	1261	1430	169	66.5%
	c9	353	1150	797	1157	1311	154	60.0%
	d9	354	1132	778	1259	1428	169	67.5%
	e9	354	1131	777	1208	1383	175	70.0%
57.6	a10	353	1098	745	1214	1313	99	41.3%
	b10	353	1130	777	1248	1337	89	35.6%
	c10	351	1135	784	1210	1301	91	36.1%
	d10	353	1148	795	1260	1371	111	43.4%
	e10	353	1130	777	1155	1282	127	50.8%
81.6	a11	353	1111	758	1157	1210	53	21.7%
	b11	353	1131	778	1260	1321	61	24.4%
	c11	353	1114	761	1212	1272	60	24.5%
	d11	353	1141	788	1156	1224	68	26.8%
	e11	353	1112	759	1260	1327	67	27.4%
105.6	a12	353	984	631	1221	1253	32	15.8%
	b12	352	1026	674	1153	1189	36	16.6%
	c12	353	1057	704	1259	1299	40	17.6%
	d12	353	1040	687	1213	1254	41	18.5%
	e12	353	1000	647	1163	1200	37	17.8%

Test A-2 R1
1/30/95

	grams	% by wt of water
Nukon: Class 5&6	142	0.0032%
Sludge A	0	0.0000%
Mix A	0	0.0000%
Total	142	0.0032%

Chugging lasts 9.6 minutes

Time (Full scale minutes)	Label	Sample Bottles (g) empty	Sample Bottles (g) full	Water (g) full-empty	Filters (0.1 mg) new	Filters (0.1 mg) used	Residue used-new	% of average initial calculated concentration
2.4	a1	353	1098	745	1207	1433	226	94.2%
	b1	358	1129	771	1259	1631	372	149.9%
	c1	357	1126	769	1157	1374	217	87.7%
	d1	357	1140	783	1209	1421	212	84.1%
	e1	353	1110	757	1260	1496	236	96.8%
4.8	a2	353	1177	824	1155	1676	521	196.4%
	b2	357	1189	832	1206	1427	221	82.5%
	c2	357	1173	816	1251	1550	299	113.8%
	d2	353	1154	801	1158	1597	439	170.2%
	e2	353	1158	805	1219	1581	362	139.7%
7.2	a3	352	1174	822	1259	1546	287	108.5%
	b3	353	1187	834	1155	1477	322	119.9%
	c3	354	1174	820	1220	1871	651	246.6%
	d3	352	1162	810	1260	1515	255	97.8%
	e3	353	1154	801	1153	1448	295	114.4%
9.6	a4	353	1081	728	1214	1430	216	92.2%
	b4	353	1138	785	1262	1585	323	127.8%
	c4	353	1126	773	1159	1525	366	147.1%
	d4	353	1151	798	1161	1407	246	95.8%
	e4	353	1148	795	1214	1487	273	106.7%
14.4	a5	353	1113	760	1265	1467	202	82.6%
	b5	352	1131	779	1256	1465	209	83.3%
	c5	352	1133	781	1157	1375	218	86.7%
	d5	353	1151	798	1218	1546	328	127.7%
	e5	353	1160	807	1257	1459	202	77.8%
19.2	a6	352	1168	816	1156	1374	218	83.0%
	b6	352	1165	813	1211	1408	197	75.3%
	c6	352	1126	774	1258	1542	284	114.0%
	d6	353	1142	789	1157	1360	203	79.9%
	e6	353	1134	781	1160	1366	206	81.9%
24	a7	352	1064	712	1262	1414	152	66.3%
	b7	353	1111	758	1208	1406	198	81.1%
	c7	353	1127	774	1161	1324	163	65.4%
	d7	351	1095	744	1256	1489	233	97.3%
	e7	353	1083	730	1206	1387	181	77.0%
28.8	a8	354	939	585	1161	1249	88	46.7%
	b8	354	984	630	1269	1403	134	66.1%
	c8	353	1007	654	1201	1346	145	68.9%
	d8	354	989	635	1159	1305	146	71.4%
	e8	353	961	608	1211	1316	105	53.6%
33.6	a9	353	1155	802	1153	1273	120	46.5%
	b9	354	1170	816	1206	1357	151	57.5%
	c9	353	1165	812	1257	1442	185	70.8%
	d9	354	1159	805	1155	1316	161	62.1%
	e9	354	1158	804	1209	1375	166	64.1%
57.6	a10	353	1047	694	1258	1285	27	12.1%
	b10	353	1090	737	1153	1243	90	37.9%
	c10	351	1118	767	1163	1255	92	37.3%
	d10	353	1095	742	1211	1309	98	41.0%
	e10	353	1076	723	1158	1275	117	50.3%
81.6	a11	353	1101	748	1152	1169	17	7.1%
	b11	353	1133	780	1209	1240	31	12.3%
	c11	353	1132	779	1251	1300	49	19.5%
	d11	353	1138	785	1157	1266	109	43.1%
	e11	353	1122	769	1212	1293	81	32.7%
105.6	a12	353	1047	694	1253	1262	9	4.0%
	b12	352	1093	741	1155	1179	24	10.1%
	c12	353	1098	745	1270	1301	31	12.9%
	d12	353	1100	747	1205	1247	42	17.5%
	e12	353	1069	716	1215	1264	49	21.3%

Test A-3 R1
1/20/95

	grams	% by wt of water
Nukon: Class 5&6	0	0.0000%
Sludge A	938	0.0213%
Mix A	0	0.0000%
Total	938	0.0213%

Chugging lasts 9.6 minutes

Time (Full scale minutes)		Sample Bottles (g)		Water (g)	Filters (0.1 mg)		Residue	% of average initial calculated concentration
	Label	empty	full	full-empty	new	used	used-new	
2.4	a1	353	1105	752	899	2356	1457	91.1%
	b1	358	1154	796	896	2412	1516	89.6%
	c1	357	1162	805	875	2374	1499	87.6%
	d1	357	1151	794	903	2472	1569	92.9%
	e1	353	1133	780	895	2509	1614	97.3%
4.8	a2	353	1150	797	916	2574	1658	97.8%
	b2	357	1180	823	907	2555	1648	94.2%
	c2	357	1156	799	919	2798	1879	110.6%
	d2	353	1148	795	911	2417	1506	89.1%
	e2	353	1147	794	917	2427	1510	89.4%
7.2	a3	352	1051	699	890	2305	1415	95.2%
	b3	353	1097	744	887	2187	1300	82.2%
	c3	354	1119	765	883	2341	1458	89.6%
	d3	352	1117	765	904	2449	1545	95.0%
	e3	353	1087	734	893	2560	1667	106.8%
9.6	a4	353	1039	686	908	2400	1492	102.3%
	b4	353	1150	797	908	2307	1399	82.5%
	c4	353	1143	790	892	2439	1547	92.1%
	d4	353	1140	787	882	2414	1532	91.5%
	e4	353	1152	799	886	2484	1598	94.1%
14.4	a5	353	1173	820	890	1765	875	50.2%
	b5	352	1154	802	887	1834	947	55.5%
	c5	352	1144	792	889	1891	1002	59.5%
	d5	353	1242	889	886	2119	1233	65.2%
	e5	353	1145	792	900	2053	1153	68.5%
19.2	a6	352	1084	732	896	1391	495	31.8%
	b6	352	1135	783	891	1576	685	41.1%
	c6	352	1140	788	891	1592	701	41.8%
	d6	353	1128	775	893	1736	843	51.2%
	e6	353	1121	768	894	1733	839	51.4%
24	a7	352	1068	716	885	1390	505	33.2%
	b7	353	1123	770	891	1498	607	37.1%
	c7	353	1131	778	879	1561	682	41.2%
	d7	351	1128	777	883	1629	746	45.1%
	e7	353	1102	749	871	1552	681	42.8%
28.8	a8	354	1068	714	878	1234	356	23.4%
	b8	354	1120	766	865	1362	497	30.5%
	c8	353	1118	765	871	1438	567	34.9%
	d8	354	1117	763	875	1497	622	38.3%
	e8	353	1099	746	874	1654	780	49.2%
33.6	a9	353	1163	810	873	1263	390	22.6%
	b9	354	1157	803	877	1348	471	27.6%
	c9	353	1142	789	883	1437	554	33.0%
	d9	354	1156	802	879	1522	643	37.7%
	e9	354	1132	778	883	1540	657	39.7%
57.6	a10	353	1122	769	872	1146	274	16.8%
	b10	353	1149	796	879	1225	346	20.4%
	c10	351	1135	784	876	1242	366	22.0%
	d10	353	1151	798	898	1358	460	27.1%
	e10	353	1149	796	870	1369	499	29.5%
81.6	a11	353	1136	783	874	1100	226	13.6%
	b11	353	1235	882	900	1205	305	16.3%
	c11	353	1144	791	883	1203	320	19.0%
	d11	353	1141	788	894	1242	348	20.8%
	e11	353	1157	804	894	1280	386	22.6%
105.6	a12	353	1148	795	893	1092	199	11.8%
	b12	352	1161	809	898	1143	245	14.2%
	c12	353	1149	796	880	1164	284	16.8%
	d12	353	1147	794	894	1194	300	17.8%
	e12	353	1145	792	884	1233	349	20.7%

Test A-4 R1
1/13/95

	grams	% by wt of water
Nukon: Class 5&6	142	0.0032%
Sludge A	938	0.0213%
Mix A	0	0.0000%
Total	1080	0.0245%

Chugging lasts 9.6 minutes

Time (Full scale minutes)	Label	Sample Bottles (g)		Water (g)	Filters (0.1 mg)		Residue	% of average initial calculated concentration
		empty	full	full-empty	new	used	used-new	
2.4	a1	353	1094	741	788	2588	1800	99.2%
	b1	358	1140	782	790	2488	1698	88.7%
	c1	357	1215	858	781	2730	1949	92.8%
	d1	357	1231	874	784	2733	1949	91.1%
	e1	353	1116	763	784	2792	2008	107.5%
4.8	a2	353	1054	701	795	2311	1516	88.3%
	b2	357	1106	749	782	2458	1676	91.4%
	c2	357	1133	776	782	2619	1837	96.7%
	d2	353	1120	767	785	2719	1934	103.0%
	e2	353	1085	732	785	2947	2162	120.6%
7.2	a3	352	1124	772	796	2483	1687	89.3%
	b3	353	1166	813	794	2653	1859	93.4%
	c3	354	1145	791	787	3198	2411	124.5%
	d3	352	1142	790	777	2605	1828	94.5%
	e3	353	1139	786	785	2711	1926	100.1%
9.6	a4	353	1073	720	779	2407	1628	92.3%
	b4	353	1138	785	779	2554	1775	92.4%
	c4	353	1165	812	778	2559	1781	89.6%
	d4	353	1145	792	775	2484	1709	88.1%
	e4	353	1107	754	778	2375	1597	86.5%
14.4	a5	353	1099	746	784	1785	1001	54.8%
	b5	352	1149	797	786	1874	1088	55.8%
	c5	352	1152	800	793	2120	1327	67.7%
	d5	353	1140	787	842	2312	1470	76.3%
	e5	353	1080	727	821	1937	1116	62.7%
19.2	a6	352	1046	694	844	1513	669	39.4%
	b6	352	1095	743	830	1695	865	47.5%
	c6	352	1108	756	831	1855	1024	55.3%
	d6	353	1109	756	830	1921	1091	58.9%
	e6	353	1140	787	821	2267	1446	75.0%
24	a7	352	1124	772	819	1524	705	37.3%
	b7	353	1148	795	840	1593	753	38.7%
	c7	353	1154	801	829	1737	908	46.3%
	d7	351	1142	791	824	1803	979	50.5%
	e7	353	1155	802	826	1910	1084	55.2%
28.8	a8	354	1088	734	824	1392	568	31.6%
	b8	354	1140	786	819	1548	729	37.9%
	c8	353	1156	803	830	1756	926	47.1%
	d8	354	1136	782	848	1819	971	50.7%
	e8	353	1123	770	839	1829	990	52.5%
33.6	a9	353	1088	735	849	1342	493	27.4%
	b9	354	1132	778	831	1476	645	33.9%
	c9	353	1146	793	845	1639	794	40.9%
	d9	354	1136	782	833	1732	899	47.0%
	e9	354	1123	769	838	1778	940	49.9%
57.6	a10	353	1219	866	843	1210	367	17.3%
	b10	353	1196	843	825	1261	436	21.1%
	c10	351	1165	814	838	1357	519	26.0%
	d10	353	1193	840	844	1495	651	31.7%
	e10	353	1216	863	837	1567	730	34.5%
81.6	a11	353	1153	800	833	1125	292	14.9%
	b11	353	1162	809	839	1209	370	18.7%
	c11	353	1138	785	834	1264	430	22.4%
	d11	353	1163	810	835	1353	518	26.1%
	e11	353	1150	797	850	1398	548	28.1%
105.6	a12	353	1126	773	832	1083	251	13.3%
	b12	352	1145	793	830	1149	319	16.4%
	c12	353	1148	795	843	1200	357	18.3%
	d12	353	1153	800	837	1246	409	20.9%
	e12	353	1153	800	834	1306	472	24.1%

Test A-5
1/9/95

	grams	% by wt of water
Nukon: Class 3&4	142	0.0032%
Sludge A	938	0.0213%
Mix A	0	0.0000%
Total	1080	0.0245%

Chugging lasts 9.6 minutes

Time (Full scale minutes)		Sample Bottles (g)		Water (g)	Filters (0.1 mg)		Residue	% of average initial calculated concentration
	Label	empty	full	full-empty	new	used	used-new	
2.4	a1	353	1064	711	838	2302	1464	84.1%
	b1	358	1101	743	837	3014	2177	119.7%
	c1	357	1092	735	841	3039	2198	122.1%
	d1	357	1069	712	850	2534	1684	96.6%
	e1	353	1066	713	840	2762	1922	110.1%
4.8	a2	353	992	639	834	2314	1480	94.6%
	b2	357	1099	742	832	2549	1717	94.5%
	c2	357	1019	662	831	2361	1530	94.4%
	d2	353	997	644	843	2961	2118	134.3%
	e2	353	1001	648	837	2282	1445	91.1%
7.2	a3	352	1031	679	838	2382	1544	92.9%
	b3	353	1064	711	847	3144	2297	131.9%
	c3	354	1059	705	850	2523	1673	96.9%
	d3	352	1042	690	850	2503	1653	97.8%
	e3	353	1044	691	846	2599	1753	103.6%
9.6	a4	353	1049	696	848	2282	1434	84.1%
	b4	353	1075	722	839	2540	1701	96.2%
	c4	353	1072	719	835	2481	1646	93.5%
	d4	353	1057	704	843	2506	1663	96.5%
	e4	353	1040	687	857	2497	1640	97.5%
14.4	a5	353	1105	752	851	1875	1024	55.6%
	b5	352	1125	773	846	2108	1262	66.7%
	c5	352	1127	775	849	2046	1197	63.1%
	d5	353	1111	758	857	2231	1374	74.0%
	e5	353	1103	750	853	2576	1723	93.8%
19.2	a6	352	1143	791	843	1499	656	33.9%
	b6	352	1141	789	837	1664	827	42.8%
	c6	352	1143	791	841	1838	997	51.5%
	d6	353	1140	787	853	1927	1074	55.7%
	e6	353	1145	792	841	1975	1134	58.5%
24	a7	352	1146	794	847	1424	577	29.7%
	b7	353	1140	787	851	1609	758	39.3%
	c7	353	1141	788	851	1740	889	46.1%
	d7	351	1137	786	854	1805	951	49.4%
	e7	353	1139	786	845	1880	1035	53.8%
28.8	a8	354	1165	811	847	1357	510	25.7%
	b8	354	1128	774	854	1507	653	34.5%
	c8	353	1144	791	843	1671	828	42.8%
	d8	354	1141	787	842	1697	855	44.4%
	e8	353	1143	790	851	1801	950	49.1%
33.6	a9	353	1115	762	851	1238	387	20.7%
	b9	354	1136	782	843	1373	530	27.7%
	c9	353	1130	777	843	1476	633	33.3%
	d9	354	1116	762	842	1642	800	42.9%
	e9	354	1095	741	845	1718	873	48.1%
57.6	a10	353	1164	811	839	1113	274	13.8%
	b10	353	1151	798	857	1202	345	17.7%
	c10	351	1132	781	849	1263	414	21.7%
	d10	353	1160	807	850	1334	484	24.5%
	e10	353	1151	798	849	1422	573	29.3%
81.6	a11	353	1135	782	859	1075	216	11.3%
	b11	353	1144	791	846	1106	260	13.4%
	c11	353	1140	787	845	1136	291	15.1%
	d11	353	1140	787	847	1165	318	16.5%
	e11	353	1124	771	848	1202	354	18.8%
105.6	a12	353	1152	799	844	1035	191	9.8%
	b12	352	1136	784	833	1047	214	11.1%
	c12	353	1134	781	834	1092	258	13.5%
	d12	353	1133	780	848	1119	271	14.2%
	e12	353	1123	770	853	1141	288	15.3%

Test B-6
1/16/95

	grams	% by wt of water
Nukon: Class 5&6	47	0.0011%
Sludge A	938	0.0213%
Mix A	0	0.0000%
Total	985	0.0223%

Chugging lasts 9.6 minutes

Time (Full scale minutes)	Label	Sample Bottles (g) empty	Sample Bottles (g) full	Water (g) full-empty	Filters (0.1 mg) new	Filters (0.1 mg) used	Residue used-new	% of average initial calculated concentration
2.4	a1	353	1116	763	851	2364	1513	88.8%
	b1	358	1164	806	817	2482	1665	92.5%
	c1	357	1150	793	808	2432	1624	91.7%
	d1	357	1155	798	840	2484	1644	92.3%
	e1	353	1145	792	848	2570	1722	97.4%
4.8	a2	353	1146	793	840	2391	1551	87.6%
	b2	357	1167	810	867	2513	1646	91.0%
	c2	357	1172	815	867	2490	1623	89.2%
	d2	353	1159	806	865	2470	1605	89.2%
	e2	353	1149	796	859	2617	1758	98.9%
7.2	a3	352	1130	778	861	2578	1717	98.8%
	b3	353	1170	817	869	2584	1715	94.0%
	c3	354	1156	802	852	2476	1624	90.7%
	d3	352	1143	791	855	2499	1644	93.1%
	e3	353	1162	809	852	2547	1695	93.8%
9.6	a4	353	1125	772	862	2377	1515	87.9%
	b4	353	1168	815	866	2491	1625	89.3%
	c4	353	1164	811	846	2384	1538	84.9%
	d4	353	1164	811	866	2660	1794	99.1%
	e4	353	1158	805	869	2817	1948	108.4%
14.4	a5	353	1163	810	883	1777	894	49.4%
	b5	352	1160	808	883	2100	1217	67.4%
	c5	352	1144	792	876	2001	1125	63.6%
	d5	353	1165	812	875	2093	1218	67.2%
	e5	353	1157	804	884	2152	1268	70.6%
19.2	a6	352	1128	776	879	1683	804	46.4%
	b6	352	1152	800	871	1806	935	52.3%
	c6	352	1114	762	866	1645	779	45.8%
	d6	353	1132	779	876	1767	891	51.2%
	e6	353	1145	792	877	1810	933	52.8%
24	a7	352	1149	797	874	1263	389	21.9%
	b7	353	1159	806	880	1497	617	34.3%
	c7	353	1160	807	876	1628	752	41.7%
	d7	351	1147	796	877	1701	824	46.4%
	e7	353	1146	793	872	1817	945	53.4%
28.8	a8	354	1175	821	876	1346	470	25.6%
	b8	354	1168	814	880	1499	619	34.1%
	c8	353	1147	794	878	1578	700	39.5%
	d8	354	1145	791	877	1590	713	40.4%
	e8	353	1147	794	866	1646	780	44.0%
33.6	a9	353	1111	758	871	1288	417	24.6%
	b9	354	1151	797	882	1428	546	30.7%
	c9	353	1150	797	876	1537	661	37.1%
	d9	354	1121	767	866	1549	683	39.9%
	e9	354	1144	790	872	1647	775	43.9%
57.6	a10	353	1100	747	873	1140	267	16.0%
	b10	353	1139	786	838	1217	379	21.6%
	c10	351	1140	789	826	1285	459	26.1%
	d10	353	1135	782	840	1368	528	30.2%
	e10	353	1132	779	827	1431	604	34.7%
81.6	a11	353	1069	716	843	1057	214	13.4%
	b11	353	1108	755	831	1116	285	16.9%
	c11	353	1141	788	832	1195	363	20.6%
	d11	353	1130	777	834	1240	406	23.4%
	e11	353	1105	752	841	1285	444	26.4%
105.6	a12	353	1095	742	839	1043	204	12.3%
	b12	352	1156	804	833	1084	251	14.0%
	c12	353	1155	802	836	1143	307	17.1%
	d12	353	1116	763	834	1164	330	19.4%
	e12	353	1120	767	830	1197	367	21.4%

Test B-7
1/17/95

	grams	% by wt of water
Nukon: Class 3&4	47	0.0011%
Sludge A	938	0.0213%
Mix A	0	0.0000%
Total	985	0.0223%

Chugging lasts 9.6 minutes

Time (Full scale minutes)	Label	Sample Bottles (g) empty	Sample Bottles (g) full	Water (g) full-empty	Filters (0.1 mg) new	Filters (0.1 mg) used	Residue used-new	% of average initial calculated concentration
2.4	a1	353	1072	719	786	2275	1489	92.7%
	b1	358	1118	760	838	2531	1693	99.8%
	c1	357	1128	771	837	2378	1541	89.5%
	d1	357	1132	775	845	2345	1500	86.7%
	e1	353	1095	742	840	2313	1473	88.9%
4.8	a2	353	1128	775	826	2391	1565	90.4%
	b2	357	1168	811	829	2550	1721	95.0%
	c2	357	1162	805	880	2503	1623	90.3%
	d2	353	1160	807	837	2460	1623	90.1%
	e2	353	1153	800	883	2459	1576	88.2%
7.2	a3	352	1148	796	877	2418	1541	86.7%
	b3	353	1158	805	878	2486	1608	89.5%
	c3	354	1143	789	854	2456	1602	90.9%
	d3	352	1157	805	865	2691	1826	101.6%
	e3	353	1145	792	847	2439	1592	90.0%
9.6	a4	353	1280	927	852	2826	1974	95.4%
	b4	353	1180	827	838	2548	1710	92.6%
	c4	353	1160	807	862	2627	1765	97.9%
	d4	353	1172	819	848	2570	1722	94.2%
	e4	353	1157	804	849	2604	1755	97.8%
14.4	a5	353	1037	684	848	1687	839	54.9%
	b5	352	1080	728	852	1820	968	59.5%
	c5	352	1108	756	859	1914	1055	62.5%
	d5	353	1096	743	854	2024	1170	70.5%
	e5	353	1066	713	872	1991	1119	70.3%
19.2	a6	352	1103	751	862	1336	474	28.3%
	b6	352	1162	810	863	1673	810	44.8%
	c6	352	1157	805	872	1558	686	38.2%
	d6	353	1133	780	857	1743	886	50.9%
	e6	353	1142	789	860	1828	968	54.9%
24	a7	352	1050	698	833	1295	462	29.6%
	b7	353	1095	742	858	1412	554	33.4%
	c7	353	1020	667	884	1535	651	43.7%
	d7	351	1099	748	882	1677	795	47.6%
	e7	353	1075	722	866	1701	835	51.8%
28.8	a8	354	977	623	874	1217	343	24.7%
	b8	354	1017	663	880	1358	478	32.3%
	c8	353	1042	689	828	1395	567	36.9%
	d8	354	1029	675	877	1542	665	44.1%
	e8	353	1001	648	879	1550	671	46.4%
33.6	a9	353	1115	762	870	1226	356	20.9%
	b9	354	1160	806	872	1367	495	27.5%
	c9	353	1155	802	870	1473	603	33.7%
	d9	354	1138	784	845	1528	683	39.0%
	e9	354	1150	796	869	1597	728	41.0%
57.6	a10	353	1146	793	873	1159	286	16.2%
	b10	353	1173	820	873	1210	337	18.4%
	c10	351	1137	786	869	1256	387	22.0%
	d10	353	1165	812	866	1350	484	26.7%
	e10	353	1157	804	877	1413	536	29.9%
81.6	a11	353	1109	756	861	1166	305	18.1%
	b11	353	1153	800	872	1258	386	21.6%
	c11	353	1148	795	862	1326	464	26.1%
	d11	353	1138	785	870	1304	434	24.8%
	e11	353	1135	782	871	1690	819	46.9%
105.6	a12	353	1174	821	867	1149	282	15.4%
	b12	352	1165	813	871	1216	345	19.0%
	c12	353	1140	787	867	1276	409	23.3%
	d12	353	1153	800	881	1431	550	30.8%
	e12	353	1161	808	867	1247	380	21.1%

 Test B-8
1/18/95

	grams	% by wt of water
Nukon: Class 5&6	0	0.0000%
Sludge A	2814	0.0638%
Mix A	0	0.0000%
Total	2814	0.0638%

Chugging lasts 9.6 minutes

Time (Full scale minutes)	Label	Sample Bottles (g) empty	Sample Bottles (g) full	Water (g) full-empty	Filters (0.1 mg) new	Filters (0.1 mg) used	Residue used-new	% of average initial calculated concentration
2.4	a1	353	1053	700	855	4690	3835	85.9%
	b1	358	1111	753	855	5080	4225	88.0%
	c1	357	1131	774	866	5465	4599	93.1%
	d1	357	1123	766	850	5356	4506	92.2%
	e1	353	1145	792	855	5633	4778	94.6%
4.8	a2	353	1120	767	853	5121	4268	87.2%
	b2	357	1179	822	834	5515	4681	89.3%
	c2	357	1159	802	853	5468	4615	90.2%
	d2	353	1150	797	848	5525	4677	92.0%
	e2	353	1094	741	875	5258	4383	92.7%
7.2	a3	352	1093	741	884	5200	4316	91.3%
	b3	353	1148	795	880	5551	4671	92.1%
	c3	354	1142	788	873	5517	4644	92.4%
	d3	352	1136	784	875	5591	4716	94.3%
	e3	353	1123	770	877	5598	4721	96.1%
9.6	a4	353	1132	779	886	5507	4621	93.0%
	b4	353	1150	797	880	5656	4776	93.9%
	c4	353	1154	801	879	5715	4836	94.6%
	d4	353	1145	792	872	5565	4693	92.9%
	e4	353	1151	798	930	5906	4976	97.7%
14.4	a5	353	1131	778	870		-870	-17.5%
	b5	352	1152	800	876	3982	3106	60.9%
	c5	352	1142	790	866	4271	3405	67.6%
	d5	353	1149	796	837	4473	3636	71.6%
	e5	353	1141	788	889	4633	3744	74.5%
19.2	a6	352	1075	723	883	2625	1742	37.8%
	b6	352	1137	785	866	2970	2104	42.0%
	c6	352	1133	781	859	3300	2441	49.0%
	d6	353	1142	789	869	3711	2842	56.5%
	e6	353	1117	764	875	3580	2705	55.5%
24	a7	352	1121	769	883	2352	1469	29.9%
	b7	353	1131	778	876	2780	1904	38.4%
	c7	353	1136	783	864	2781	1917	38.4%
	d7	351	1151	800	850	3238	2388	46.8%
	e7	353	1155	802	849	3423	2574	50.3%
28.8	a8	354	1057	703	867	1844	977	21.8%
	b8	354	1110	756	862	2313	1451	30.1%
	c8	353	1135	782	876	2667	1791	35.9%
	d8	354	1116	762	875	2885	2010	41.3%
	e8	353	1093	740	887	3105	2218	47.0%
33.6	a9	353	1119	766	868	1846	978	20.0%
	b9	354	1160	806	881	2270	1389	27.0%
	c9	353	1139	786	873	2461	1588	31.7%
	d9	354	1154	800	895	2876	1981	38.8%
	e9	354	1148	794	873	3038	2165	42.7%
57.6	a10	353	1092	739	875	1657	782	16.6%
	b10	353	1136	783	893	1836	943	18.9%
	c10	351	1126	775	864	1949	1085	21.9%
	d10	353	1128	775	865	2141	1276	25.8%
	e10	353	1126	773	882	2331	1449	29.4%
81.6	a11	353	1115	762	883	1558	675	13.9%
	b11	353	1098	745	881	1633	752	15.8%
	c11	353	1102	749	877	1715	838	17.5%
	d11	353	1108	755	878	1799	921	19.1%
	e11	353	1073	720	876	1865	989	21.5%
105.6	a12	353	1260	907	885	1592	707	12.2%
	b12	352	1231	879	872	1617	745	13.3%
	c12	353	1194	841	874	1696	822	15.3%
	d12	353	1146	793	866	1674	808	16.0%
	e12	353	1234	881	881	1815	934	16.6%

Test D-11 R1
1/23/95

	grams	% by wt of water
Nukon: Class 3&4	142	0.0032%
Sludge A	0	0.0000%
Mix A	0	0.0000%
Total	142	0.0032%

Chugging lasts 9.6 minutes

Time (Full scale minutes)	Label	Sample Bottles (g) empty	Sample Bottles (g) full	Water (g) full-empty	Filters (0.1 mg) new	Filters (0.1 mg) used	Residue used-new	% of average initial calculated concentration
2.4	a1	353	1145	792	876	1090	214	83.9%
	b1	358	1183	825	877	1230	353	132.9%
	c1	357	1189	832	864	1136	272	101.6%
	d1	357	1171	814	895	1155	260	99.2%
	e1	353	1152	799	905	1588	683	265.5%
4.8	a2	353	1183	830	889	1148	259	96.9%
	b2	357	1181	824	836	1125	289	108.9%
	c2	357	1184	827	826	1108	282	105.9%
	d2	353	1186	833	842	1144	302	112.6%
	e2	353	1165	812	824	1086	262	100.2%
7.2	a3	352	1155	803	831	1101	270	104.4%
	b3	353	1178	825	837	1127	290	109.2%
	c3	354	1152	798	839	1177	338	131.6%
	d3	352	1156	804	836	1127	291	112.4%
	e3	353	1155	802	823	1099	276	106.9%
9.6	a4	353	1117	764	822	1097	275	111.8%
	b4	353	1151	798	825	1062	237	92.3%
	c4	353	1143	790	828	1094	266	104.6%
	d4	353	1163	810	837	1146	309	118.5%
	e4	353	1149	796	825	1082	257	100.3%
14.4	a5	353	1125	772	829	1048	219	88.1%
	b5	352	1131	779	826	1080	254	101.3%
	c5	352	1122	770	831	1057	226	91.2%
	d5	353	1147	794	825	1076	251	98.2%
	e5	353	1124	771	836	1107	271	109.2%
19.2	a6	352	1120	768	841	1049	208	84.1%
	b6	352	1157	805	837	881	44	17.0%
	c6	352	1144	792	834	1047	213	83.5%
	d6	353	1145	792	833	1049	216	84.7%
	e6	353	1146	793	825	1180	355	139.1%
24	a7	352	1130	778	836	1019	183	73.1%
	b7	353	1152	799	834	1022	188	73.1%
	c7	353	1144	791	829	1022	193	75.8%
	d7	351	1142	791	828	1029	201	78.9%
	e7	353	1178	825	827	1077	250	94.1%
28.8	a8	354	1184	830	825	1011	186	69.6%
	b8	354	1176	822	826	1004	178	67.3%
	c8	353	1157	804	823	991	168	64.9%
	d8	354	1165	811	833	1041	208	79.7%
	e8	353	1132	779	828	1022	194	77.4%
33.6	a9	353	1092	739	831	953	122	51.3%
	b9	354	1141	787	830	978	148	58.4%
	c9	353	1155	802	834	1009	175	67.8%
	d9	354	1137	783	833	1028	195	77.4%
	e9	354	1129	775	835	1012	177	70.9%
57.6	a10	353	1089	736	833	865	32	13.5%
	b10	353	1135	782	831	904	73	29.0%
	c10	351	1128	777	837	933	96	38.4%
	d10	353	1147	794	830	965	135	52.8%
	e10	353	1120	767	821	950	129	52.2%
81.6	a11	353	1085	732	825	833	8	3.4%
	b11	353	1135	782	828	859	31	12.3%
	c11	353	1136	783	825	876	51	20.2%
	d11	353	1142	789	822	893	71	28.0%
	e11	353	1122	769	820	897	77	31.1%
105.6	a12	353	1112	759	835	849	14	5.7%
	b12	352	1144	792	837	856	19	7.5%
	c12	353	1138	785	841	863	22	8.7%
	d12	353	1136	783	825	867	42	16.7%
	e12	353	1123	770	830	887	57	23.0%

Appendix B Test D-14 R1
1/24/95

	grams	% by wt of water
Nukon: Class 5&6	142	0.0032%
Sludge A	938	0.0213%
Mix A	0	0.0000%
Total	1080	0.0245%

Chugging lasts 9.6 minutes

Time (Full scale minutes)	Label	Sample Bottles (g)		Water (g)	Filters (0.1 mg)		Residue	% of average initial calculated concentration
		empty	full	full-empty	new	used	used-new	
	a1	353	1013	660	829	2332	1503	93.0%
	b1	358	1053	695	825	2437	1612	94.7%
2.4	c1	357	1076	719	829	2409	1580	89.8%
	d1	357	1063	706	831	2411	1580	91.4%
	e1	353	1035	682	823	2379	1556	93.2%
	a2	353	1091	738	827	2533	1706	94.4%
	b2	357	896	539	839	2051	1212	91.8%
4.8	c2	357	1161	804	830	2609	1779	90.4%
	d2	353	1139	786	837	3264	2427	126.1%
	e2	353	1123	770	840	2688	1848	98.0%
	a3	352	1132	780	828	2600	1772	92.8%
	b3	353	827	474	824	1807	983	84.7%
7.2	c3	354	1140	786	845	2673	1828	95.0%
	d3	352	1144	792	835	2658	1823	94.0%
	e3	353	1144	791	836	2936	2100	108.4%
	a4	353	1074	721	836	2493	1657	93.9%
	b4	353	722	369	838	1574	736	81.5%
9.6	c4	353	1212	859	823	2812	1989	94.6%
	d4	353	1133	780	834	2652	1818	95.2%
	e4	353	1108	755	842	2652	1810	97.9%
	a5	353	1018	665	903	1913	1010	62.0%
	b5	352	673	321	889	1381	492	62.6%
14.4	c5	352	1093	741	886	2082	1196	65.9%
	d5	353	1082	729	891	2074	1183	66.3%
	e5	353	1050	697	888	2098	1210	70.9%
	a6	352	1068	716	881	1540	659	37.6%
	b6	352	667	315	890	1174	284	36.8%
19.2	c6	352	1127	775	882	1837	955	50.3%
	d6	353	1126	773	890	1944	1054	55.7%
	e6	353	1102	749	883	2050	1167	63.6%
	a7	352	1139	787	915	1539	624	32.4%
	b7	353	670	317	913	1163	250	32.2%
24	c7	353	1151	798	906	1867	961	49.2%
	d7	351	1157	806	904	1937	1033	52.3%
	e7	353	1158	805	900	1971	1071	54.3%
	a8	354	954	600	908	1360	452	30.8%
	b8	354	595	241	908	1083	175	29.7%
28.8	c8	353	1023	670	903	1632	729	44.4%
	d8	354	1005	651	889	1667	778	48.8%
	e8	353	978	625	889	1687	798	52.1%
	a9	353	1092	739	887	1325	438	24.2%
	b9	354	590	236	878	1034	156	27.0%
33.6	c9	353	1139	786	880	1604	724	37.6%
	d9	354	1141	787	876	1746	870	45.2%
	e9	354	1132	778	911	1797	886	46.5%
	a10	353	1048	695	899	1195	296	17.4%
	b10	353	591	238	909	1058	149	25.6%
57.6	c10	351	1132	781	894	1391	497	26.0%
	d10	353	1128	775	893	1459	566	29.8%
	e10	353	1095	742	877	1496	619	34.1%
	a11	353	1196	843	892	1185	293	14.2%
	b11	353	608	255	882	998	116	18.6%
81.6	c11	353	1132	779	886	1272	386	20.2%
	d11	353	1140	787	882	1310	428	22.2%
	e11	353	1125	772	900	1401	501	26.5%
	a12	353	1133	780	894	1126	232	12.1%
	b12	352	610	258	884	970	86	13.6%
105.6	c12	353	1139	786	886	1213	327	17.0%
	d12	353	1152	799	897	1278	381	19.5%
	e12	353	1133	780	899	1306	407	21.3%

Test T-17
2/8/95

	grams	% by wt of water
Nukon: Class 3&4	142	0.0032%
Sludge A	142	0.0032%
Mix A	0	0.0000%
Total	284	0.0064%

Chugging lasts 9.6 minutes

Time (Full scale minutes)	Label	Sample Bottles (g) empty	Sample Bottles (g) full	Water (g) full-empty	Filters (0.1 mg) new	Filters (0.1 mg) used	Residue used-new	% of average initial calculated concentration
2.4	a1	353	1177	824	894	1333	439	82.7%
	b1	358	1163	805	883	1315	432	83.4%
	c1	357	357	0	887		-887	
	d1	357	1234	877	898	1456	558	98.8%
	e1	353	1227	874	900	1368	468	83.2%
4.8	a2	353	1056	703	880	1290	410	90.6%
	b2	357	1110	753	875	1337	462	95.3%
	c2	357	357	0	880		-880	
	d2	353	1197	844	878	1478	600	110.4%
	e2	353	1167	814	878	1384	506	96.5%
7.2	a3	352	1019	667	877	1328	451	105.0%
	b3	[illegible]	1065	712	888	1329	441	96.2%
	c3	[illegible]	354	0	881		-881	
	d3	[illegible]	1065	713	885	1315	430	93.7%
	e3	353	1054	701	891	1277	386	85.5%
9.6	a4	353	1102	749	882	1311	429	89.0%
	[illegible]	353	1143	790	880	1376	496	97.5%
	c4	353	353	0	883		-883	
	d4	353	1155	802	876	1343	467	90.4%
	e4	353	1133	780	898	1443	545	108.5%
14.4	a5	353	1105	752	885	1207	322	66.5%
	b5	352	1138	786	882	1228	346	68.4%
	c5	352	352	0	888		-888	
	d5	353	1165	812	884	1257	373	71.3%
	e5	353	1122	769	881	1239	35[illegible]	72.3%
19.2	a6	352	1094	742	884	1149	265	55.5%
	b6	352	1146	794	899	1216	317	62.0%
	c6	352	352	0	865		-865	
	d6	353	1151	798	856	1251	395	76.9%
	e6	353	1129	776	896	1226	330	66.0%
24	a7	352	1149	797	891	1159	268	52.2%
	b7	353	1162	809	886	1170	284	54.5%
	c7	353	1224	871	904	1273	369	65.8%
	d7	351	1167	816	880	1225	345	65.7%
	e7	353	1155	802	929	1233	[illegible]04	58.9%
28.8	a8	354	1108	754	899	1142	[illegible]43	50.1%
	b8	354	1152	798	878	1167	283	56.2%
	c8	353	1217	864	879	1218	339	60.9%
	d8	354	1157	803	904	1195	291	56.3%
	e8	353	1147	794	903	1231	328	64.2%
33.6	a9	353	1049	696	878	1022	144	32.1%
	b9	354	1098	744	872	1101	229	47.8%
	c9	353	1108	755	868	1147	279	57.4%
	d9	354	1111	757	876	1165	289	59.3%
	e9	354	1081	727	869	1152	283	60.5%
57.6	a10	353	1111	758	874	977	103	21.1%
	b10	353	1152	799	870	1019	149	29.0%
	c10	351	1137	786	869	1056	187	37.0%
	[illegible]	353	1161	808	874	1098	224	43.1%
	e10	353	1134	781	867	1105	238	47.3%
81.6	a11	353	1074	721	873	931	58	12.5%
	b11	353	1118	765	864	956	92	1[illegible].7%
	c11	353	1140	787	884	999	115	22.7%
	d11	353	1138	785	875	1017	142	28.1%
	e11	353	1110	757	878	1043	165	33.9%
105.6	a12	353	1106	753	873	932	59	12.2%
	b12	352	1149	797	871	941	70	13.6%
	c12	353	1154	801	874	969	95	18.4%
	d12	353	1153	800	877	989	112	21.7%
	e12	353	1150	797	866	1010	144	28.1%

Appendix B Test T-18
2/9/95

	grams	% by wt of water
Nukon: Class 3&4	142	0.0032%
Sludge A	71	0.0016%
Mix A	0	0.0000%
Total	213	0.0048%

Chugging lasts 9.6 minutes

Time (Full scale minutes)	Label	Sample Bottles (g) empty	Sample Bottles (g) full	Water (g) full-empty	Filters (0.1 mg) new	Filters (0.1 mg) used	Residue used-new	% of average initial calculated concentration
2.4	a1	353	1112	759	862	1278	416	113.5%
	b1	358	1165	807	874	1180	306	78.5%
	c1	357	1161	804	877	1566	689	177.5%
	d1	357	1173	816	872	1227	355	90.1%
	e1	353	1136	783	866	1211	345	91.2%
4.8	a2	353	1183	830	871	1218	347	86.6%
	b2	357	1207	850	864	1243	379	92.3%
	c2	357	1189	832	873	1266	393	97.8%
	d2	353	1186	833	874	1226	352	87.5%
	e2	353	1149	796	865	1191	326	84.8%
7.2	a3	352	1163	811	868	1216	348	88.9%
	b3	353	1157	804	859	1189	330	85.0%
	c3	354	1164	810	855	1229	374	95.6%
	d3	352	1159	807	861	1265	404	103.7%
	e3	353	1241	888	868	1279	411	95.8%
9.6	a4	353	1120	767	871	1195	324	87.5%
	b4	353	1230	877	857	1294	437	103.2%
	c4	353	1121	768	859	1340	481	129.7%
	d4	353	1160	807	854	1266	412	105.7%
	e4	353	1145	792	858	1249	391	102.2%
14.4	a5	353	1030	677	864	1065	201	61.5%
	b5	352	1076	724	857	1089	232	66.4%
	c5	352	1109	757	858	1140	282	77.1%
	d5	353	1097	744	856	1146	290	80.7%
	e5	353	1061	708	883	980	97	28.4%
19.2	a6	352	1148	796	880	1341	461	119.9%
	b6	352	1206	854	865	1216	351	85.1%
	c6	352	1136	784	875	1209	334	88.2%
	d6	353	1120	767	874	1113	239	64.5%
	e6	353	1137	784	871	1206	335	88.5%
24	a7	352	1139	787	877	1117	240	63.2%
	b7	353	1167	814	903	1162	259	65.9%
	c7	353	1166	813	894	1146	252	64.2%
	d7	351	1170	819	903	1163	260	65.7%
	e7	353	1168	815	911	1176	265	67.3%
28.8	a8	354	1093	739	872	1047	175	49.0%
	b8	354	1142	788	884	1126	242	63.6%
	c8	353	1148	795	880	1132	252	65.6%
	d8	354	1142	788	852	1103	251	66.0%
	e8	353	1135	782	898	1152	254	67.3%
33.6	a9	353	1199	846	907	1136	229	56.1%
	b9	354	1193	839	917	1153	236	58.3%
	c9	353	1169	816	906	1169	263	66.7%
	d9	354	1159	805	863	1108	245	63.0%
	e9	354	1167	813	849	1077	228	58.1%
57.6	a10	353	1168	815	865	941	76	19.3%
	b10	353	1163	8[illegible]	850	962	112	28.6%
	c10	351	1152	801	851	998	147	38.0%
	d10	353	1162	809	856	1023	167	42.7%
	e10	353	1159	806	852	1025	173	44.4%
81.6	a11	353	1103	750	906	942	36	9.9%
	b11	353	1144	791	860	930	70	18.3%
	c11	353	1159	806	849	941	92	23.6%
	d11	353	1141	788	845	956	111	29.2%
	e11	353	1136	783	854	972	118	31.2%
105.6	a12	353	1166	813	849	885	36	9.2%
	b12	352	1157	805	890	939	49	12.6%
	c12	353	1170	817	878	935	57	14.4%
	d12	353	1146	793	881	957	76	19.8%
	e12	353	1148	795	893	997	104	27.1%

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M. L. Marshall, Jr., A. W. Serkiz, NRC Project Managers

11. ABSTRACT (200 words or less)

Several tests were conducted in a 1:2.4 scale model of a Mark I suppression pool to investigate the behavior of fibrous insulation and sludge debris under LOCA conditions. NUKON™ shreds, manually cut and tore up in a leaf shredder, and iron oxide particles were used to simulate fibrous and sludge debris, respectively. The suppression pool model included four downcomers fitted with pistons to simulate the steam-water oscillations during chugging expected during a LOCA. The study was conducted to provide debris settling velocity data for the models used in the BLOCKAGE computer code, developed to estimate the ECCS pump head loss due to clogging of the strainers with LOCA generated debris. The tests showed that the debris, both fibrous and particulate, remains fully mixed during chugging; they also showed that, during chugging, the fibrous debris underwent fragmentation into smaller sizes, including individual fibers. Measured concentrations showed that fibrous debris settled slower than the sludge, and that the settling behavior of each material is independent of the presence of the other material. Finally, these tests showed that the assumption of considering uniform debris concentration during strainer calculations is reasonable. The tests did not consider the effects of the operation of the ECCS on the transport of debris in the suppression pool.

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