HEAD LOSS TESTS WITH BLAST GENERATED NUKON™ INSULATION DEBRIS

By

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PERFORMANCE CONTRACTING, INC.

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NOTE: The test results included in this report are applicable to the NUKON™ Insulation System only. Other insulation systems and materials may look similar but, due to different mechanical properties, will have different behavior when heated to a high temperature, then subjected to a high pressure blast, and subsequently tested for head loss. For data on those other systems and materials, similar tests should be conducted.

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ABSTRACT

In the event of a loss of coolant accident (LOCA) in a nuclear power plant, it is possible that insulation covering pipes and equipment in the containment building could be dislodged and fragmented. Insulation debris, if carried by the flow for the emergency core cooling system (ECCS), could collect on the screens or strainers surrounding the pump suction, creating head loss. Excessive loss could possibly lead to insufficient available NPSH with resultant pump cavitation.

Previous tests at ARL have addressed various factors affecting the head loss across insulation debris, but all tests were conducted with manually shredded insulation collected on a woven wire screen. The tests described herein were conducted using insulation debris generated (by others), on NUKON™ Insulation System blanket (first temperature exposed), from an air jet blast to produce random sized debris similar to material that would actually occur in a LOCA. Head loss tests were conducted using this NUKON insulation debris by ARL over an increased range of thicknesses and approach velocities. Samples were allowed to collect in flowing water on a woven wire screen, which is commonly used in PWR plants, and on a perforated plate, which is usually used on BWR strainers. The resulting head loss data were used in a multiple regression analysis to develop a best fit expression relating nominal thickness and approach velocity to head loss. This equation, for NUKON Insulation debris generated by a high pressure blast, is

$$H = 173V^{1.94}e^{1.46} \qquad (1993)$$

where H is in ft, the approach velocity, V, is in ft/sec, and the as manufactured bed thickness, e, is in ft. The analysis indicated that 95% of the data was within an error band of +87% and -47% of this equation. A comparison of the 1993 equation with a previous regression equation developed by ARL on NUKON Insulation fragments in 1989 indicated that losses with the blast

generated insulation debris would be less than for the NUKON insulation manually pulled apart into shreds, with the latter loss having been predicted by

$$H = 410V^{1.62}e^{1.45} \qquad (1989)$$

The losses indicated by the 1993 equation were also compared to results of experimental work done by ARL in 1983 with cut-up NUKON Insulation fragments and lower approach velocities, which had led to the following equation.

$$H = 68\ V^{1.79}e^{1.07} \qquad (1983)$$

The comparison of the 1993 with the 1983 equation gave closer results than between the 1983 and 1989 equation.

These results should be used for NUKON Insulation only. For a predictive equation on other fibrous insulation materials, similar high temperature exposure, blast exposure, and head loss tests should be conducted.

HEAD LOSS TESTS WITH BLAST GENERATED NUKON™ INSULATION DEBRIS

INTRODUCTION

A Loss of Coolant Accident (LOCA) in a nuclear power plant would generate debris from various sources within the containment vessel. Thermal insulation used for piping and equipment located close to a pipe break may be fragmented, resulting in the generation of insulation debris. During the cool down period after a LOCA, an Emergency Core Cooling System (ECCS) would draw water from the containment sump or suppression pool. The ECCS sump or pipe suction includes screens or perforated plate, respectively, to protect the system from debris ingestion, which could degrade the ECCS pump performance. However, collection of insulation debris on the screens or strainers may cause excess head loss relative to the required NPSH for the pumps.

Quantifying the head loss due to accumulated insulation debris is complicated by the numerous variables that must be considered. Some of these variables are: insulation type, approach velocity, insulation mass, size of debris fragments, distribution of debris on the screen, water temperature, alkalinity, time, and the effects of prior insulation exposure to heat. Previous tests have been conducted by ARL (see References) to determine the transport and head loss of fragmented NUKON insulation as influenced by velocity, water temperature and pH, and size of the fragments. In all of the previous tests, the NUKON Base Wool was either manually cut or pulled apart. The combination of maximum velocity and thickness for tests reported on herein (1993) generally exceeds earlier ARL tests in 1983, where the maximum velocity was 0.5 ft/sec and few tests had head losses that exceeded 14 ft. The 1983 tests were conducted with fragments and shreds. The ARL tests of 1989, conducted on NUKON fragments, were limited to nominal thicknesses equal to or less than 1 1/8" and with velocities up to approximately 2 ft/sec, but the insulation was manually pulled apart to small shreds of fibers. For both the 1989 and 1993 tests, the NUKON insulation was exposed first to in-service temperature conditions of at least 550° F.

To better approximate the size characteristics of NUKON insulation debris that would be generated by a LOCA, a sudden pipe break was simulated by the Colorado Engineering Experiment Station, Inc. (CEESI) (Reference 3). For the CEESI tests, a 3 inch layer of heat treated NUKON™ insulation (in three individual NUKON blankets) was wrapped around a 12.75 inch OD pipe, and a burst of high pressure air, caused by rupturing a disk at about 1,550 psig, was directed at the insulation from various distances. The resulting NUKON insulation fragments were collected and shipped to ARL for head loss testing.

NUKON MATERIAL PREPARATION

Two NUKON debris test samples were received from CEESI. Sample #1 resulted from a 4 inch diameter nozzle downstream of the rupture disk, with the nozzle origin 11.75 inches from the pipe wall. Sample #2 resulted from a 6 inch nozzle 26.75 inches from the pipe wall. Essentially all of the fragmented material came from the center insulation segment directly in line with the break nozzles. As discussed later, all ARL tests except one were conducted on the debris from CEESI Sample #1.

After the CEESI tests, some of the debris was vacuum collected and some was collected by hand. The heat treated insulation fragments, shown in Figure 1, included pieces varying from a few shreds of fibers to fragments having an area of 8 square inches or greater. Some fiber mesh and threads were included. The pack density of the as manufactured NUKON Base Wool was about 2.4 lb/ft^3.

A goal of the ARL testing described herein was to determine the head loss due to a random sample of the shredded NUKON insulation debris. To accomplish this, CEESI Sample 1 was shaken in a plastic bag, and ten large handfuls of insulation debris were distributed into ten piles. From each pile, an approximately equal amount was taken and combined in another plastic bag. From this bag, after shaking, NUKON debris was randomly taken and weighed on a scale accurate to 0.001 lb. The amount of debris required for each test was calculated based on the nominal thickness of "as manufactured" NUKON debris desired on the test screen, knowing its area and the pack density of the material.

TEST FACILITY DESCRIPTION

A closed flow loop was used as the basic test facility, with two centrifugal pumps providing the range of approach velocities. Each pump had an electronic speed control to vary flow, allowing valves to be in the fully open position so that air would not come out of solution in the high velocity, low pressure region at a partially open valve. A schematic of the testing facility is shown in Figure 2, and Figure 3 is a photograph of the facility.

For low approach velocities, the 1 HP brass centrifugal pump supplying the 3 inch line was used. For higher velocities, the 3 HP pump supplying a parallel 4 inch line was used. Internals of the 3 HP pump were thoroughly cleaned prior to installation. The loop was fabricated of CPVC piping to avoid the introduction of rust particles. The test section was eight inches in diameter and was oriented vertically such that the insulation fragments could be introduced from above into flowing water, and so that the insulation fragments would distribute themselves naturally over the retention screen or perforated plate.

The stainless steel test screen, chosen to be typical of ECCS installations in PWR's, was a woven wire screen with four wires of 1/16 inch diameter per inch, resulting in a 56% open area. The perforated plate, chosen to be typical of strainers in BWR's, consisted of 14 gauge, 304 stainless steel, with 1/8" diameter holes, 3/16" center to center, having 40% open area. A 10 inch long portion of the test section immediately above the screen was fabricated of plexiglass for visual evaluation of the sample distribution and compression on the screen.

Flow in both lines was measured by orifice meters fabricated to American Society of Mechanical Engineers (ASME) standards. Flow rate calculations used ASME standard orifice meter coefficients, resulting in an estimated flow measurement uncertainty of 2.5 percent. Orifices having diameters of 1.50 and 3.00 inches were used in the 3 inch and 4 inch lines, respectively. Water temperature was measured by a thermistor thermometer. Town water having a constant pH of approximately 7.0 was used. The water temperature was uncontrolled, but generally did not vary more than 10° F during any test.

The head difference across the test sample was measured using two pairs of piezometers, one pair 32 inches upstream and the other 6 inches downstream of the screen (Figure 2). An air over water differential manometer was used during tests for head differentials less than approximately 5 ft. For most tests, a 250 inch differential pressure transducer was manifolded into the same lines as for the air over water differential manometer. The transducer was connected to a hand-held data readout system that indicated the head drop (in feet of w approximately one second intervals. The head loss from the pressure transducer was compared to measurements with the differential manometer before and after each test, and at all values when the differential was less than about 5 ft. In this way, there was a continuous check of the head drop across the insulation.

TEST PROCEDURES

Prior to the beginning of testing, the entire system was flushed out. Then a sample of other insulation was used to further filter out any debris or grit in the facility.

The dry NUKON insulation debris from the CEESI tests was weighed to achieve the nominal thickness to be tested. The test facility was filled with tap [illegible] and all manometer lines and the pressure transducer were bled to remove any air. All lin[illegible] were checked to insure initial values of zero differential at zero flow.

The facility was then started at a flow cor[illegible]ponding to an approach velocity of approximately 0.1 ft/sec. Water was recirculated while the blast generated debris was dropped piece by piece from above through a 4 inch diameter port on the top of the vertical pipe section. There was no special order of introducing large or small pieces, as a random distribution on the screen was to be achieved. Usually, each piece was allowed to become saturated before the next piece was dropped in, although sometimes two or three small shreds were added in close succession. Each piece sank and was transported at its own rate to the screen or perforated plate. The total time required to drop in all the insulation was a function of the nominal thickness and the number of pieces. For a thickness of 4 inches, twenty five minutes was required to add all the NUKON debris. Ten to fifteen minutes was more typical for the thinner layers. Figure 4A shows a 4 inch sample after the entire amount was dropped into the test section, but before the approach velocity was increased, while Figure 4B shows a 4 inch sample after testing.

Differential heads across the test sample and the orifice meter were recorded after a few minutes settling time. The approach velocity was then incremented by the appropriate amount and the data acquisition procedure repeated. The head loss across the debris for a given approach velocity was recorded versus time, and the stabilized head loss is reported herein. Typically, 10 to 15 minutes was required to attain a nearly constant reading. The approach velocity was then increased until either a maximum of 2 feet per second was reached or the maximum flow (head) capacity of the system was reached. The test apparatus was then disassembled for removal of the test sample. After reassembly, the test procedure was repeated for another nominal thickness. Generally, photographs were taken of the NUKON debris in the test facility at the beginning and end of each test, and of the compacted debris on the screen after removal from the facility.

TEST RESULTS

Head Loss Measurements (1993):

Head loss tests were conducted on five thicknesses of blast generated NUKON insulation debris, 0.25, 0.50, 1.5, 2.5, and 4 inches, over a range of velocities up to approximately 2 ft/sec or a differential head loss of up to approximately 14 ft. To evaluate the consistency of the data, repeat tests were conducted for nominal thicknesses of 0.5" and 1.5". All of these tests were conducted on CEESI Sample 1. One head loss test simulating a nominal thickness of 1.5" was conducted with CEESI Sample 2.

The head loss data using the air blast generated NUKON debris and the woven wire screen is shown in Table 1. The head loss data recorded with the perforated plate is presented in Table 2. Hereafter, Table 1 and Table 2 data is designated 1993 head loss data, and the earlier ARL data is also designated by year, 1983 and 1989.

Experimental scatter of the 1993 data is indicated by comparing the three tests of insulation head losses for CEESI Sample 1 for nominal thicknesses 0.5 and 1.5 inches with woven wire in Table 1. The scatter in the data may be attributable to the distribution of debris on the screen and to the size of the individual debris pieces. It appeared that smaller debris shreds tended to compact more than larger ones. If a portion of the screen remained relatively unblocked, observations indicated that flow was diverted to the more open area. Figure 5 shows the distribution of NUKON debris for one of the 0.5 inch tests. Due to the relative consistency of Tests 3 and 6 for 0.5 inch, and to be conservative (that is, to use the higher head losses), Test 8 was omitted from the regression analysis discussed below.

Based on the test data in Table 1 (except Test 8) and Table 2, a multiple regression analysis was performed. The relationship between head loss and both approach velocity and bed thickness is of the form:

$$H = a\, V^{b} e^{c} \qquad (1)$$

where

H	=	head loss, feet
e	=	bed thickness, feet (as fabricated volume divided by screen area)

V	=	approach velocity, feet per second
a, b, c	=	regression coefficients and exponents, dimensionless

A measure of the error associated with using the regression formula to characterize the test data may be obtained by calculating the standard deviation of the data set with respect to the regression formula.

$$S = \text{square root (sum } (\ln H_M - \ln H_R) / (n-l)) \tag{2}$$

where

S	=	standard deviation
H_M	=	measured head loss
H_R	=	calculated head loss
n	=	number of measured data points

For data normally distributed from the mean, which may be assumed as a first approximation for this data set, 95 percent of the data points can be expected to fall within two standard deviations (2S) of the regression formula.

The resulting regression formula for the blast generated NUKON insulation debris, with the woven wire screen or perforated plate, is:

$$H = 173\ V^{1.94}\ e^{1.46} \tag{3}$$

The 95 percent confidence limits, in percent of the predicted value, are +87% and -47%. This implies that almost all data points are within those variations from the value calculated from the regression equation, as shown in Figure 6.

Figure 7 shows the measured head losses with the regression formula superimposed. Head losses with the perforated plate were somewhat higher than with the screen for the 0.5 inch thickness, as shown in Figure 8. The same figure shows that no such trend existed for larger thicknesses. The loss for the perforated plate alone (no insulation debris) is shown on Figure 9.

Comparison of 1993 Equation With Earlier Equations for NUKON Fragments:

Head loss regression equations were developed in 1983 and 1989 for NUKON insulation fragments based on each respective set of conditions and resulting data. The 1983 tests had "as fabricated", non-heat treated NUKON insulation manually cut into fragments (1" x 1" x 1/8") and shreds (the fragments pulled into 4 pieces). The maximum velocity tested in 1983 was 0.5 ft/sec, and the thicknesses varied from 1/8" through 10". Because the data for the fragments and shreds were similar, the 1983 equation included all of that data.

$$H = 68\ V^{1.79} e^{1.07} \qquad (1983) \qquad (4)$$

To better represent NUKON debris from a LOCA, where the insulation may be disintegrated into aller "fibers", and to consider heat exposed insulation, additional tests were conducted in 1989, and these tests included approach velocities up to approximately 2 ft/sec. For those tests, heat treated NUKON insulation was manually pulled apart into very fine shreds. The regression equation developed from those tests was:

$$H = 410\ V^{1.62} e^{1.45} \qquad (1989) \qquad (5)$$

The head loss predicted by equation 3 (1993), using the blast generated NUKON insulation debris, is less than predicted by the 1989 equation. The 1989 equation also predicts sses greater than the equation developed in 1983, which was based on a lower range of approach velocities. The comparison of the 1993 with the 1983 equation gave closer results than between the 1983 and 1989 equation.

REFERENCES

1. Transport And Head Loss Tests of Owens - Corning NUKON™ Fiberglas Insulation, by Dominique N. Brocard, for Owens-Corning Fiberglass Corporation, ARL Report 110-83/M489F.

2. NUKON™ Insulation Head Loss Tests, by James B. Nystrom, for Performance Contracting, Inc., ARL Report No. 124-89/M670F.

3. Air Blast Destructive Testing of NUKON™ Insulation-Simulation of a Pipe Break LOCA, Colorado Engineering Experiment Station, Inc. (CEESI), October, 1993.

TABLES

[redacted]

TABLE 1: HEAD LOSS - BLAST GENERATED NUKON INSULATION DEBRIS (1993)
WITH WOVEN WIRE SCREEN
(feet of water)

ARL Test #	Thickness (Inches)	Approach Velocity (ft/sec) 0.2	0.4	0.62	0.7	0.76	0.8	0.87	1.00	1.16	1.26	1.50	1.72	1.83	1.93	2.0
CEESI Sample 1 Debris																
2	1.5	0.47	1.95	4.1			5.88			11.2						
3	0.5	0.03	0.17				0.72					2.50		4.50		
4	4.0	1.63	5.60		14.1											
5	0.25	0.02	0.12				0.46					1.47			2.22	
6	0.5	0.05	0.22				0.99					3.09	3.94	4.35		
7	2.5	0.79	3.40				11.4	13.1								
8	0.5	0.01	0.08				0.33					1.14				2.1
17	1.5	0.32	1.08				4.38			7.73						
19	1.5	0.41	1.55			4.80					10.2					
CEESI Sample 2 Debris																
9	1.5	0.60	2.60				8.75		12.3							

Note: Tests (numbers) not shown were voided due to operational problems.

TABLE 2: HEAD LOSS - BLAST GENERATED NUKON INSULATION DEBRIS (1993) WITH PERFORATED PLATE
(feet of water)

ARL Test #	Thickness (Inches)	Approach Velocity (ft/sec) 0.2	0.4	0.77	0.80	0.85	1.22	1.4	1.5	1.65
CEESI Sample 1 Debris										
10	0.5	0.08	0.37	1.55					5.43	6.50
12	2.5	0.83	3.17		11.5	13.2				
13	0.5	0.10	0.48		1.82				5.66	6.70
14	1.5	0.37	1.38		5.04		10.6			
15	1.5	0.28	0.95		3.65			9.39		
16	Void									

Note: Tests (numbers) not shown were voided due to operational problems.

FIGURES

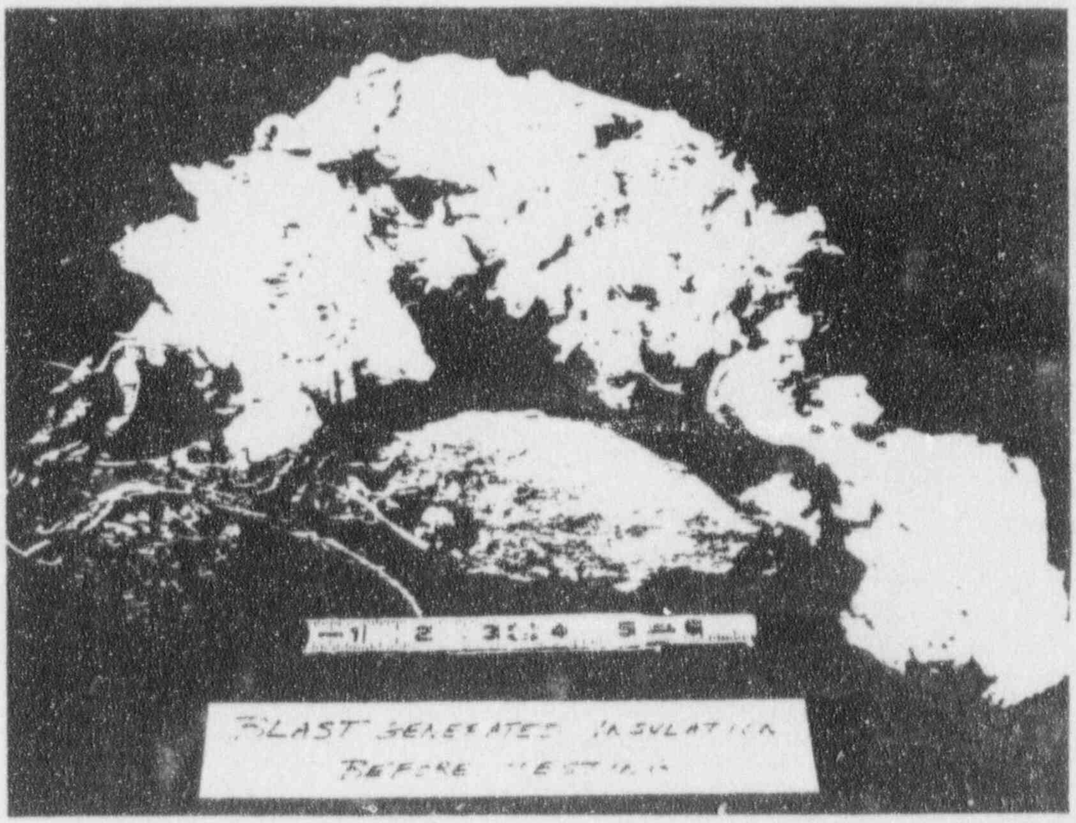

FIGURE 1 BLAST GENERATED NUKON INSULATION DEBRIS
BEFORE TESTING

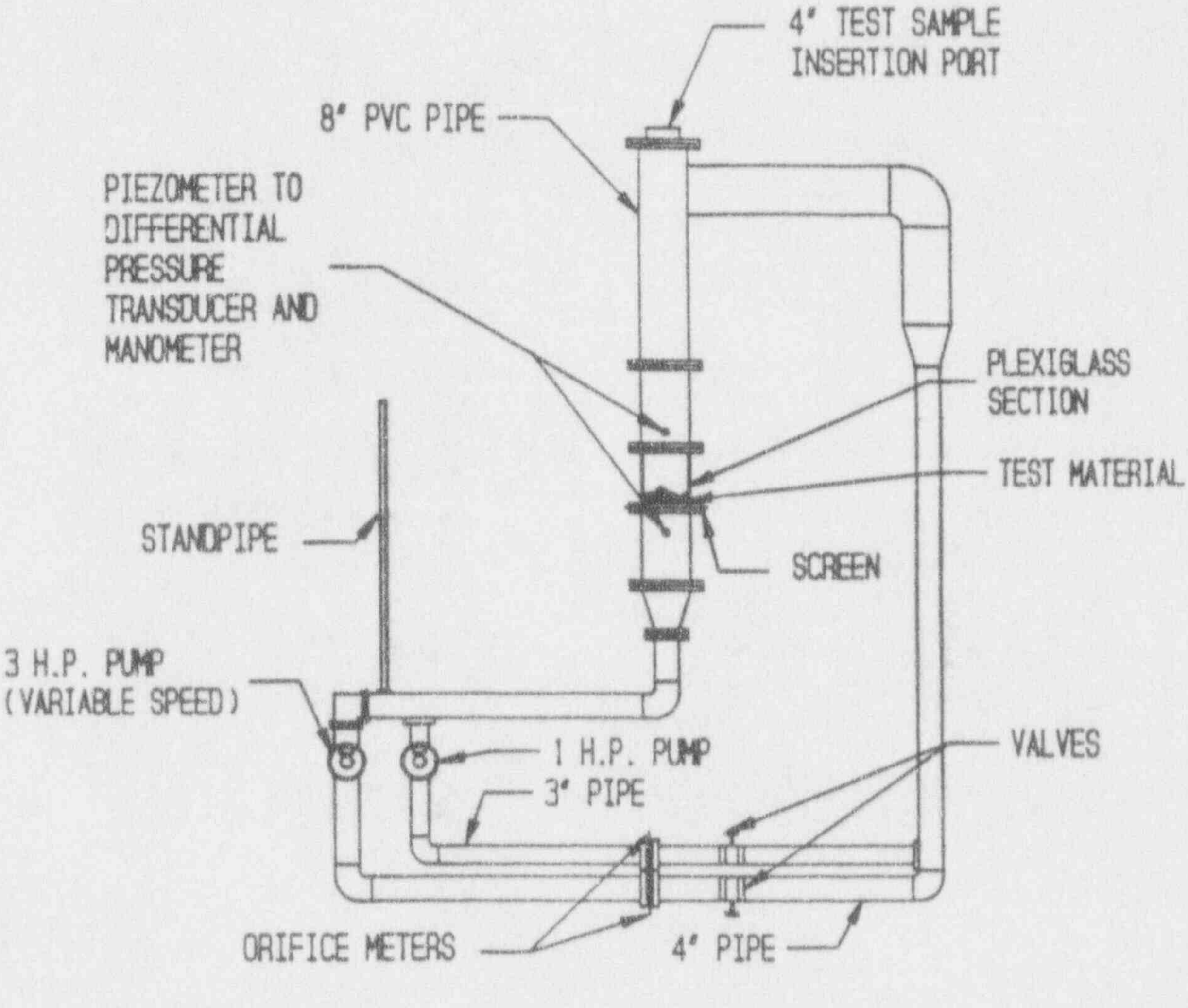

FIGURE 2 TEST FACILITY SCHEMATIC FOR NUKON INSULATION HEAD LOSS TESTS

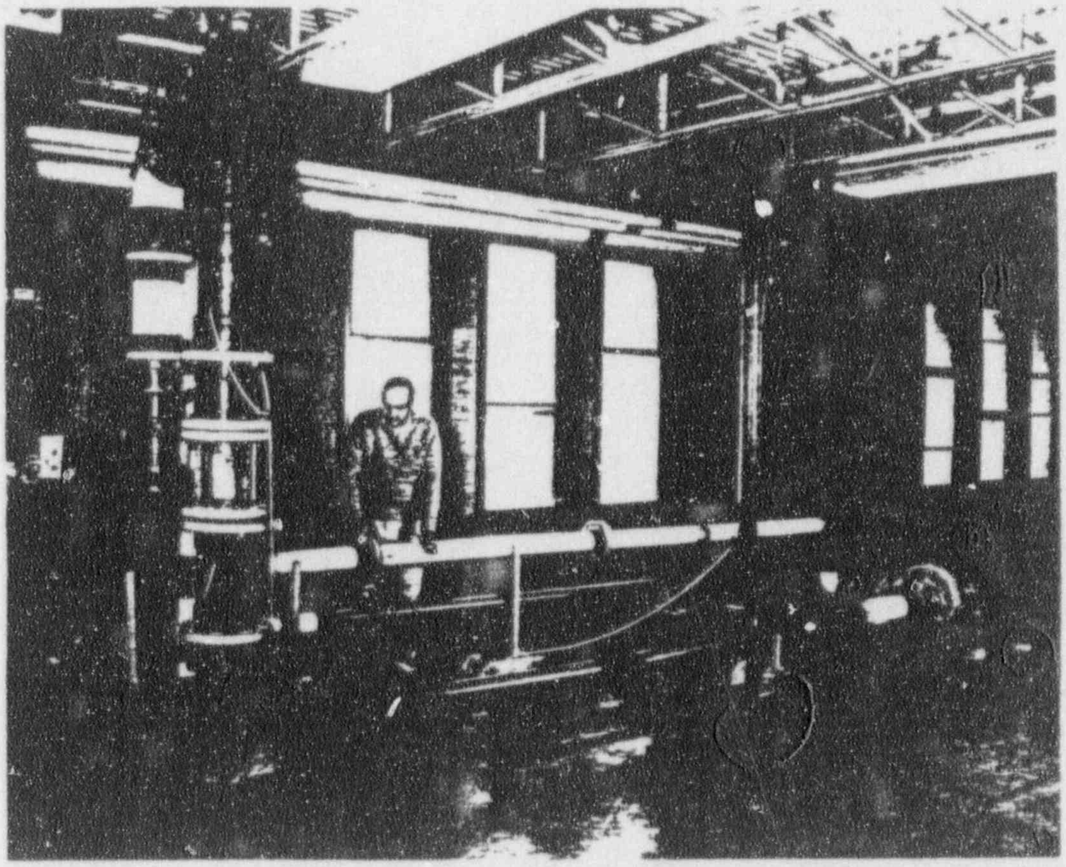

FIGURE 3 VIEW OF TEST FACILITY

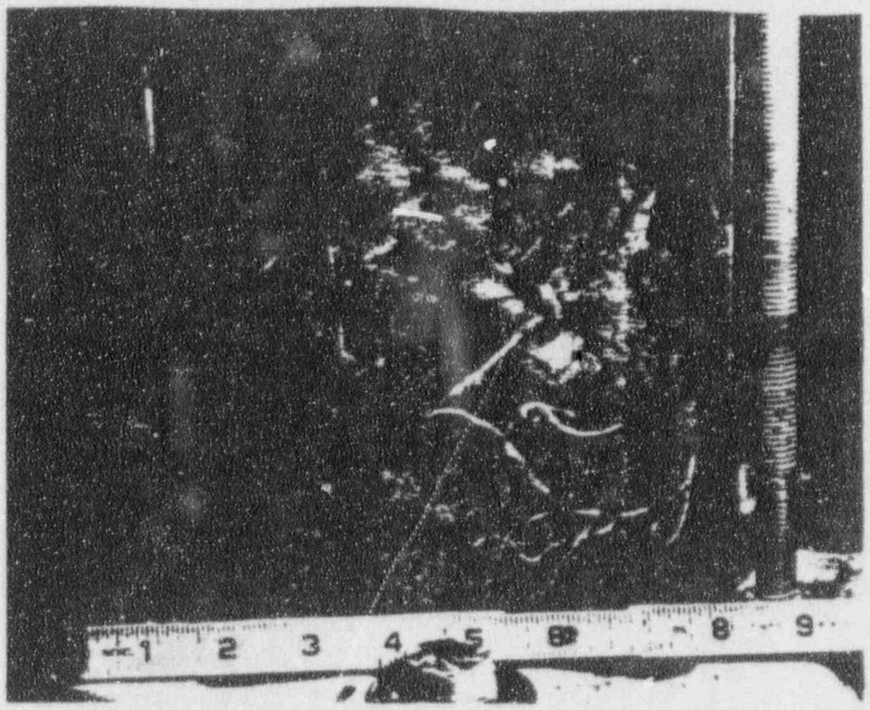

FIGURE 4A NOMINAL 4 INCH NUKON DEBRIS SAMPLE ON SCREEN PRIOR TO SETTING APPROACH VELOCITY

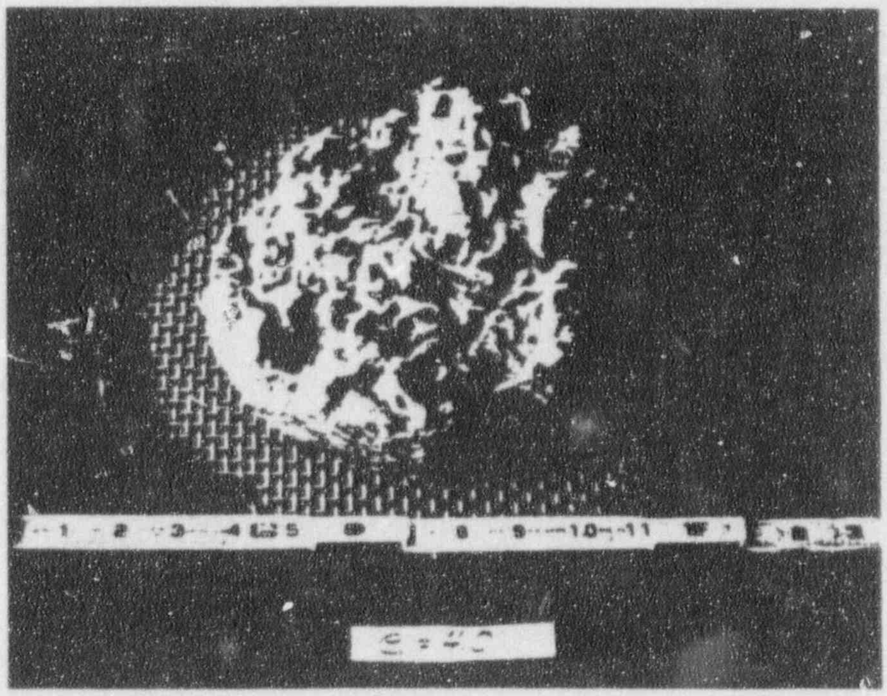

FIGURE 4B NOMINAL 4 INCH NUKON DEBRIS SAMPLE ON SCREEN AFTER TESTING

ARL

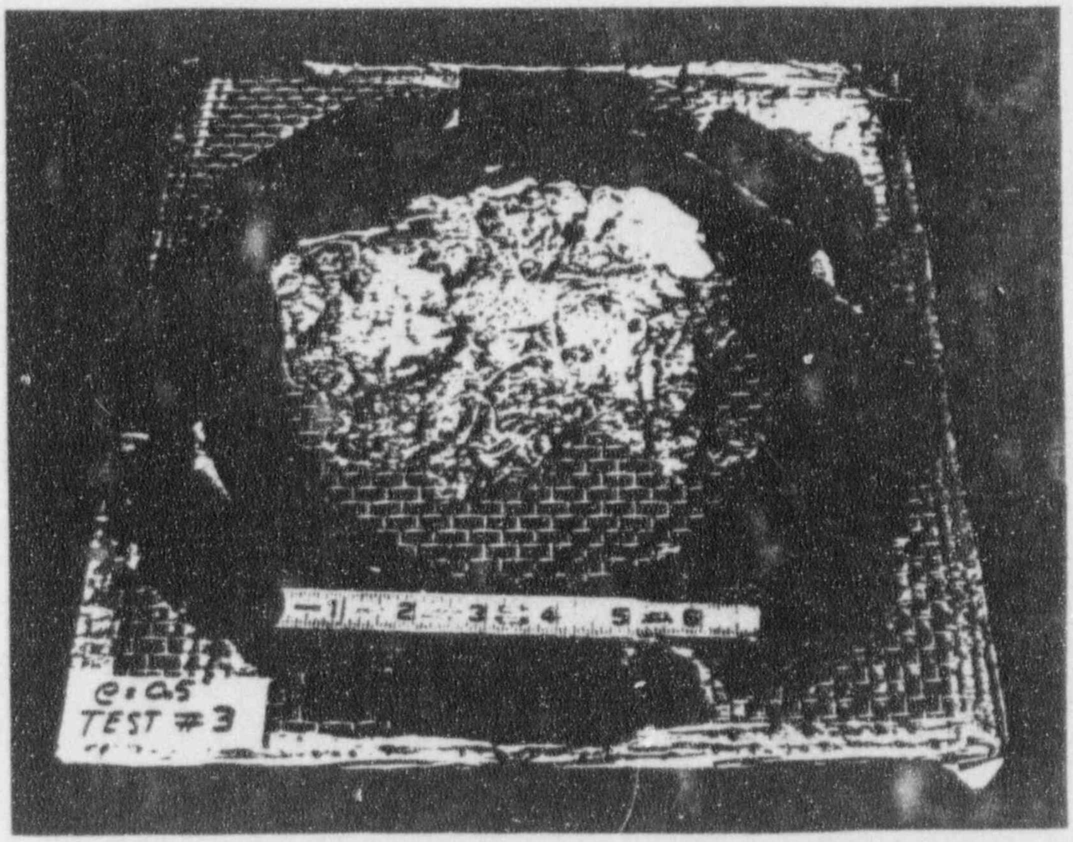

FIGURE 5 DISTRIBUTION OF NUKON INSULATION DEBRIS ON SCREEN FOR 0.5 INCH NOMINAL THICKNESS

ARL

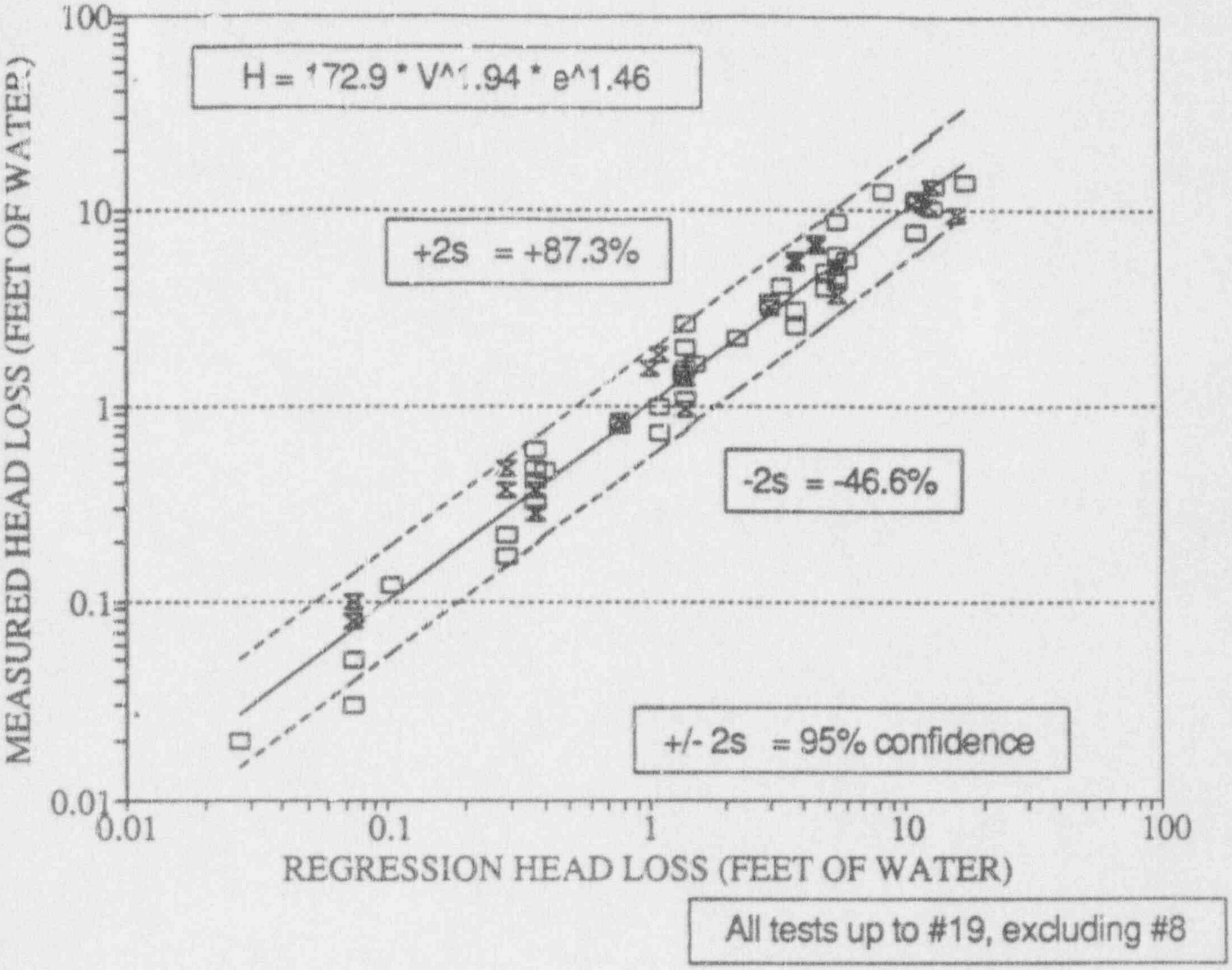

FIGURE 6 CONFIDENCE LIMITS OF REGRESSION ANALYSIS
NUKON INSULATION HEAD LOSS TESTS (1993)

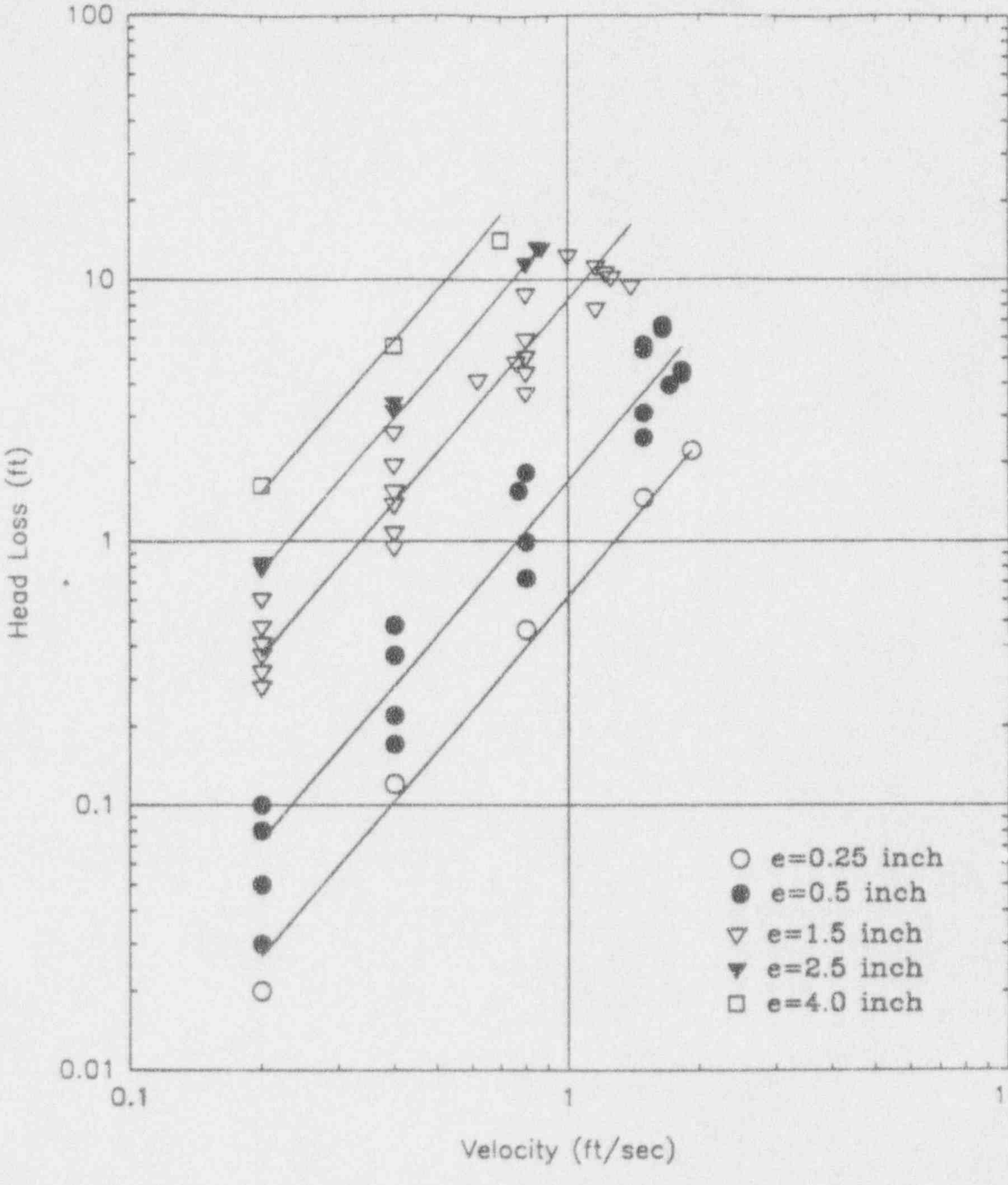

FIGURE 7 MEASURED HEAD LOSS AND REGRESSION EQUATION 3
NUKON INSULATION HEAD LOSS TESTS (1993)

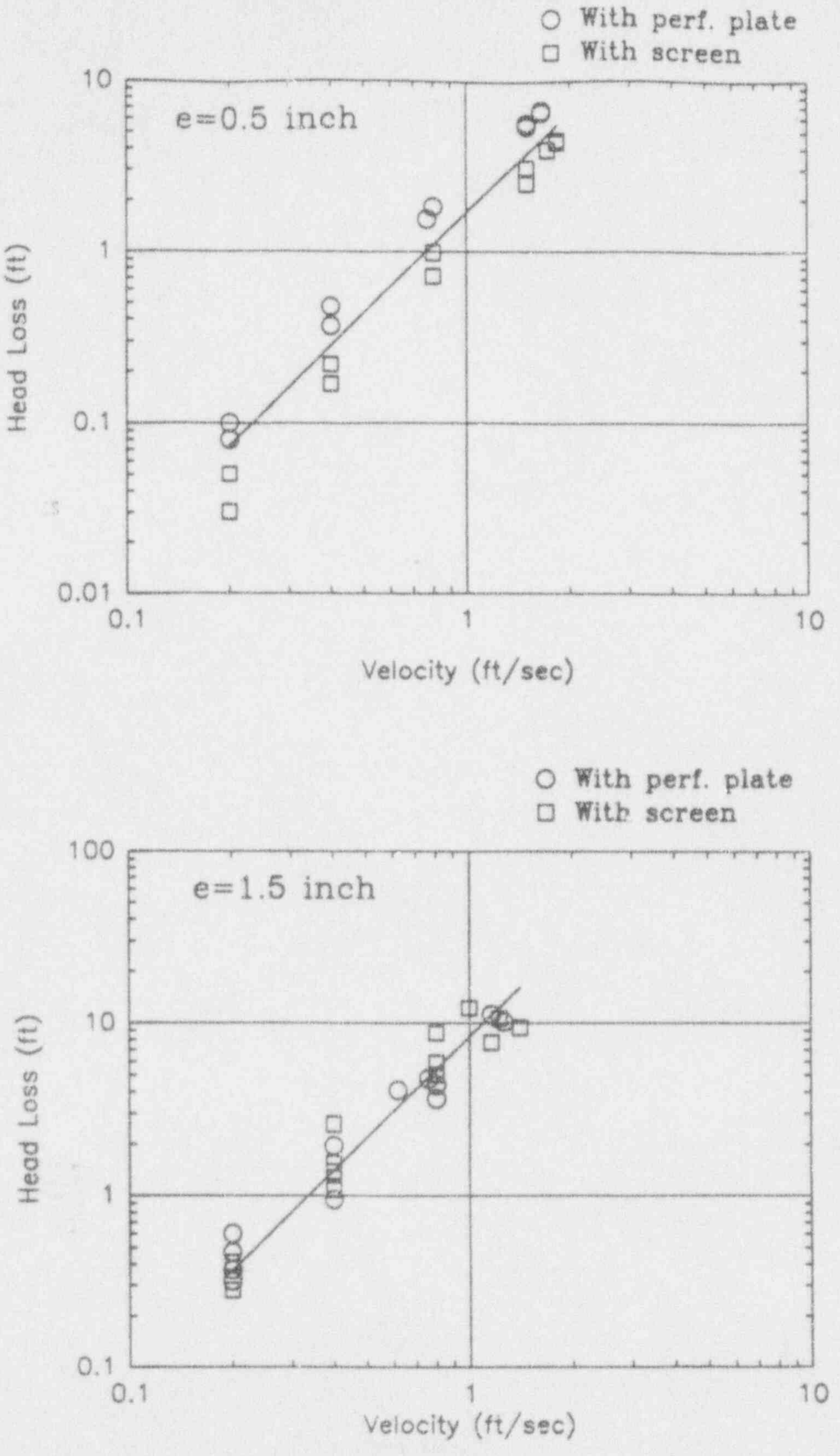

FIGURE 8 COMPARISON BETWEEN SCREEN AND PERFORATED PLATE STRAINERS NUKON INSULATION HEAD LOSS TESTS (1993)

ARL

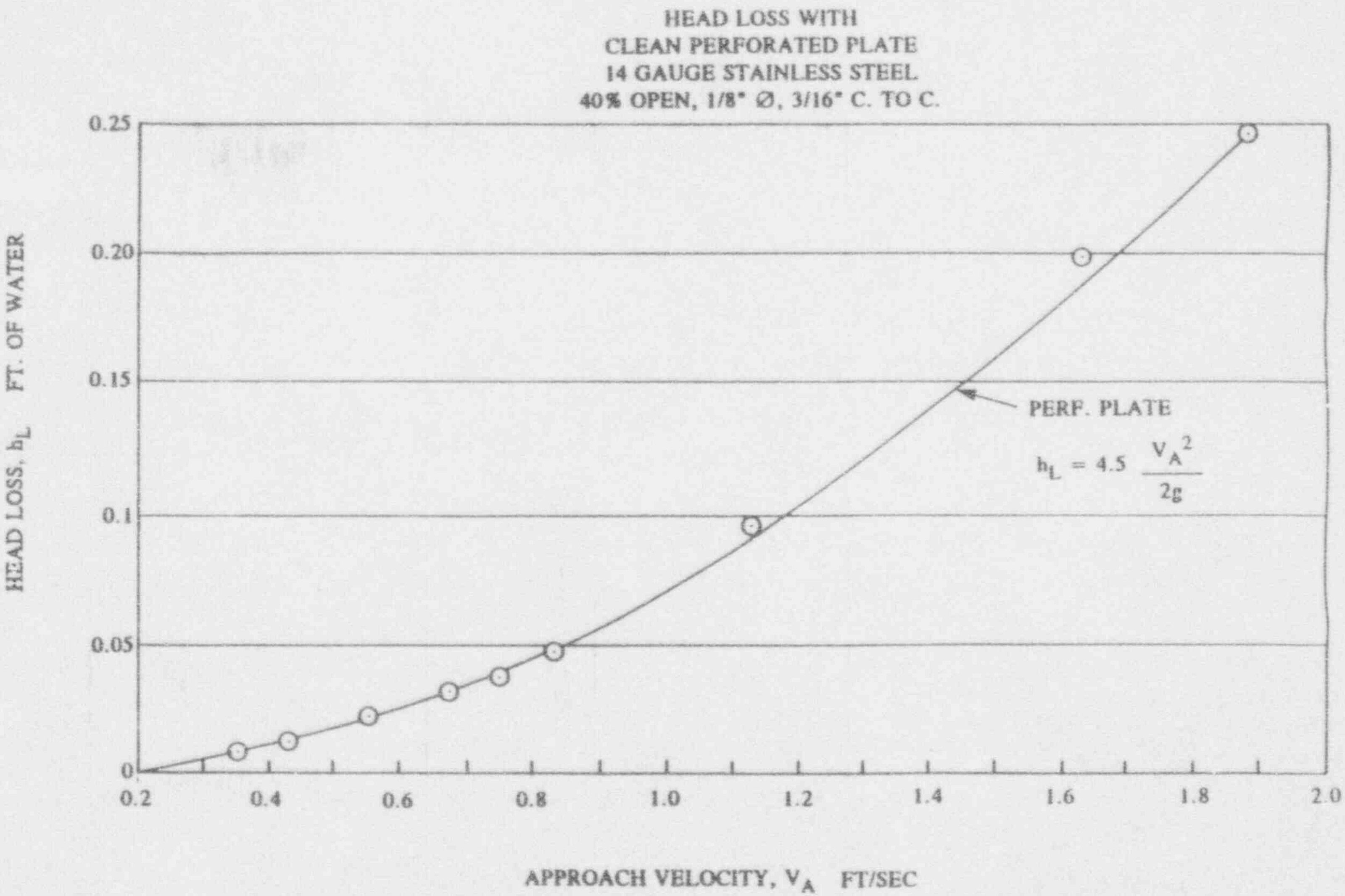

FIGURE 9 HEAL)SS FOR CLEAN PERFORATED PLATE

ARL

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