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# Summary Report on Performance of

# Performance Contracting, Inc.'s

# Sure-Flow ™ Suction Strainer

# with Various Mixes of

# Simulated Post-LOCA Debris

Revision 0

Written by
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February 14, 1997

PROFORMANCE
Performance By Professionals

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## SUMMARY OF THE PERFORMANCE EVALUATION

The **Sure-Flow$^{TM}$ Suction Strainer** has been designed and developed specifically for attachment to the Emergency Core Cooling System lines on Boiling Water Reactor nuclear plants. The strainer is intended to reduce the post-LOCA Head Loss across the entrance to the ECCS line with the purpose of maintaining ECCS pump flow at the design value. To accomplish this, these strainers are also designed to be installed on the ends of the ECCS lines, in the suppression pool and upstream of the ECCS pumps. High performance strainers such as these have been determined to be necessary on BWR plants because it has been found that the collection of LOCA generated debris and other materials can easily block existing small, passive strainers. The **Sure-Flow Strainers** can alleviate that problem and thereby keep water flow at design values through the ECCS lines.

To evaluate the **Sure-Flow Strainer's** performance, a prototype was fabricated by PCI and tested at the Electric Power Research Institute by the US Boiling Water Reactor Owners' Group in December, 1995 as part of their strainer testing program (Ref. 1). Those tests used shredded NUKON® fiberglass insulation to simulate post-LOCA fibrous debris and they used iron oxide particulate to simulate suppression pool sludge. However, in these 1995 tests, the quantities of fibrous debris were limited to relatively low quantities. Therefore, to evaluate the performance of this strainer with larger quantities of fibrous debris, additional tests were conducted at EPRI in October, 1996. In addition, one additional test was conducted with stainless steel foil, shredded to simulate foil debris from Reflective Metallic Insulation (RMI), and then combined with fibrous debris and particulate.

Combined, these two sets of Head Loss performance tests showed the following behavior of the **Sure-Flow Strainer** prototype with this debris mixture:

- The bare strainer (i.e., with no debris) showed a very low Head Loss behavior and that Head Loss is linearly dependent on the square of the entrance (i.e., at the strainer's nozzle) water velocity.
- its Head Loss behavior is essentially linearly dependent on both Mass of Fibrous Debris and Water Flow Rate,
- the addition of 100 lbs. of CP particulate increases Head Loss across the strainer by about 60%,
- the Head Loss behavior can be accurately modeled with regression equations, developed from the test data, and applied over the tested range of those variables, namely Mass of Fibrous Debris and Water Flow Rate.
- addition of stainless steel foil fragments, which simulate Reflective Metallic Insulation debris, increased the Head Loss across the **Sure-Flow Strainer** by about 20%, an increase of less than 0.5 ft of water.

- thick fibrous debris beds exhibited an effective filtration efficiency that approached unity (i.e., acted almost as a perfect filter).
- on this strainer prototype, the fibrous debris beds exhibited an apparent bed compaction of approximately 24% (using the as-fabricated insulation density as a reference).
- the **Sure-Flow Strainer**, mounted in a horizontal position, did not cavitate, even when the tank was drained so that the strainer was about half exposed above the water level.

The particular strainer prototype was tested on a 24 inch NPS line and it had certain geometric features:

- 170 $ft^2$ total surface area of perforated plate
- 24 inch NPS attachment flange and Internal Core Tube
- 40 inch outer diameter
- 48 inch active length and a 54 inch total length
- 56 $ft^2$ of circumscribed cylindrical surface area, including the ends
- thirteen disks with a width of 1.85 inches each
- twelve gaps (between the disks)with a 2.00 inch width and a tota vol me of about 10.3 $ft^3$
- holes in the Internal Core Tube that are smallest at the flange end a largest at the opposite end; these are sized with a linear distribution, over the length of the Internal Core Tube, so as to provide equal Water Flow Rate from disk to disk and hence uniform water flow over the strainer's length.

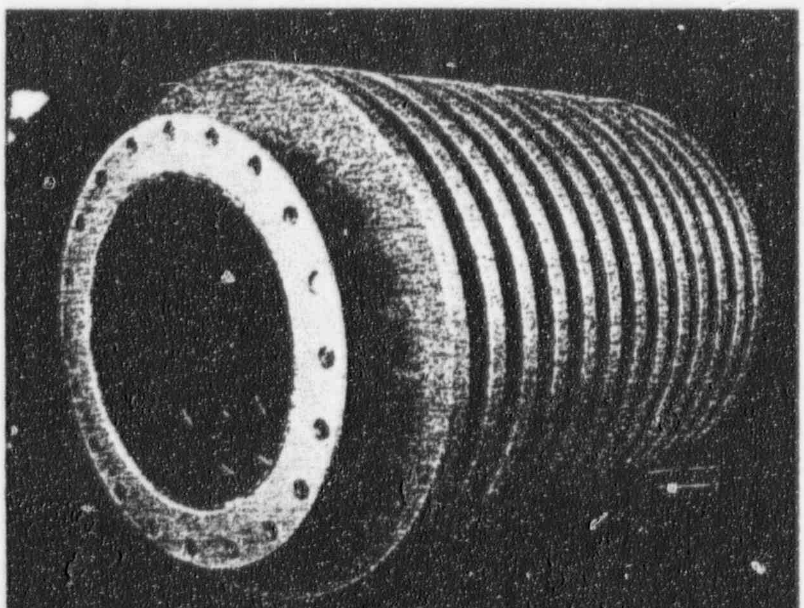
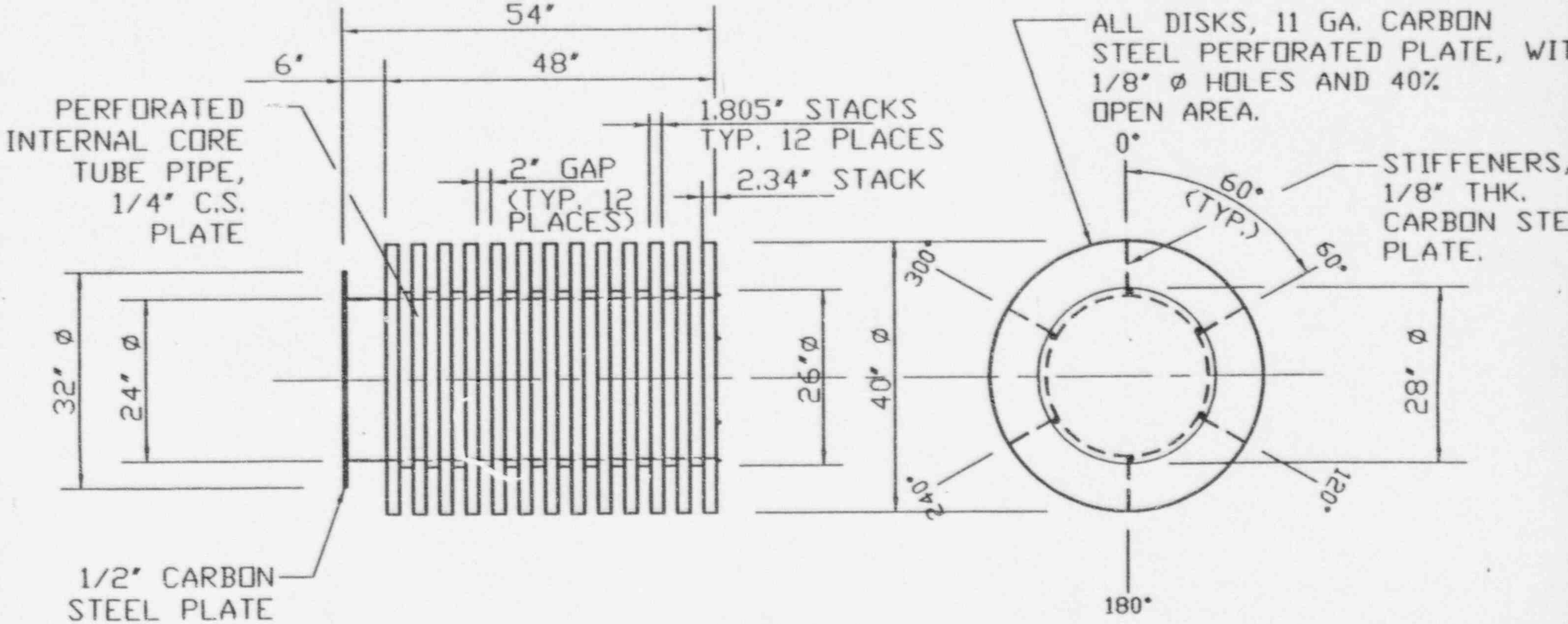


**Figure 1a - Photograph of the Sure-Flow™ Strainer**

| REV | DESCRIPTION | DWN | DATE | CHK | APP |
|---|---|---|---|---|---|
| | | | | | |

## FIGURE 1b




SIDE VIEW

END VIEW

| ITEM NO. | PART NO. | NO. REQ'D | DESCRIPTION |
|---|---|---|---|

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# SURE-FLOW™ STRAINER

**FULL SCALE TEST STRAINER**
**PROTOTYPE NO. 2**

| | | |
|---|---|---|
| Scale: None | Job No. | Drawing Number: ECCS-2 |
| Date: 01-31-96 | Chkd: | |
| Drawn: PMD | Appd: | |

Re

While only one strainer prototype was tested at EPRI as part of the reported testing program, the results of the testing program can be used to verify a general predictive model that can then be used to predict the behavior for other sizes, with other Water Flow Rates and debris quantities. One such model, for predicting Head Loss across a fibrous and particulate debris bed, has been developed by Science and Engineering Associates (SEA) for the United States Nuclear Regulatory Agency. It is based on the one-dimensional, flat plate filtration equations for flow resistance (i.e., for Head Loss) and is developed in Appendix B of NUREG/CR-6224 (Ref. 2). This PCI report suggests how these equations can be modified to account to the three-dimensional shape of the **Sure-Flow Strainer** which is cylindrical in outer shape and is made up of a number of stacked disks. This can to be done to analytically to account for the gaps, between the disks, that fill with fibrous debris and thereby change the disks and gaps to a single, large cylinder which increases in diameter and length with increasing quantities of fibrous debris. Nevertheless, these equations, modified for three-dimensionality, are still based on the one-dimensional, flat plate filtration model that is the basis of those NUREG Head Loss equations.

## I. DESCRIPTION OF THE TESTED SURE-FLOW STRAINER PROTOTYPE

The tested **Sure-Flow Strainer** prototype consists of a series of coaxial stacked disks that are equally spaced and mounted on an Internal Core Tube. **Figure 1a** is a photograph of the tested strainer prototype and **Figure 1b** is a mechanical drawing. The Internal Core Tube is a pipe with holes in it. These holes are spaced so as to line up with the disks and the gaps (between the disks). They have a varying size: those holes closest to the flange end of the strainer are smallest and those at the far end of the strainer are largest, with those inbetween sized linearly so as to provide approximately equal water flow from disk to disk and from gap to gap. In addition, the Internal Core Tube is designed to keep all turbulent water flow (and thereby all high velocities) in the tube itself, away from the disks and the debris. PCI believes that this feature helps prevent compaction of the collected fibrous debris, thereby preventing an even greater increase in Head Loss.

For structural reinforcement, each disk on the prototype has six (6) internal stiffener plates. These plates are radially oriented and are welded to both the core tube and the inside of the disks. The disks are all fabricated on their exterior from perforated metal plate. For this prototype, that material is 11 gauge steel with 1/8 inch diameter holes, spaced so as to give a 40% free area. Fabrication is such that each disk consists of two sheets of perforated plate welded to the Internal Core Tube and one strip of perforated plate welded to the outside of the two sheets like the edge of a wheel, thereby creating a disk. Each disk is 1.85 inches wide and each gap is 2.00 inches wide. The outside shape of the strainer is that of a cylinder that is 48 inches long and 40 inches in diameter, all mounted around a 24 inch outer diameter Internal Core Tube with ¼ inch thickness. The 24 inch NPS flange is welded onto the end of the Internal Core Tube, six (6) inches from the first disk. Therefore, the overall strainer length is 54 inches (i.e., 48 inches of active strainer plus 6 inches of attachment pipe). See **Figure 1b**.

Duke Engineering and Services, Inc. (DE&S) performed a structural evaluation of this strainer prototype and determined that its structural integrity was adequate for the Head Loss tests up to, but not above, about 19 feet of water. When that Head Loss limit was reached during a test, in some cases the water flow rate was reduced to keep the pressure differential across the strainer to less than or equal to that value and thereby allow us to collect data. It is noteworthy to point out that this pressure differential limit of 19 feet is actually approximately equal to the specified post-LOCA maximum hydrodynamic pressure for strainers at many BWR plants. PCI is currently supplying strainers to several BWR nuclear plants and, for structural robustness, these have been designed with greater thickness steel for the Internal Core Tube , the addition of longitudinal stiffeners for the Internal Core Tube, and the addition of more internal disk stiffeners. These additional structural reinforcements will not interfere with either the internal water flow or with the external debris collection and that has been a very important design consideration is reinforcing the **Sure-Flow Strainers** for these nuclear plants.

It is important to point out that the tested prototype is a *bolt-on, cantilever strainer*, designed to be supported by a BWR's attachment ECCS pipe in a radial orientation. Different plants may require other structural mechanisms, depending on the strainer size. For example, one nuclear utility has ordered two seventeen (17) foot long strainers, each containing three tee pipe connections. These long strainers are designed to be supported like a beam, at each end, by a pair of ring girders. The ECCS pipe connections will connect to the tees such that these pipe are oriented at 90 degrees with the strainer axis rather than in line with it. Nevertheless, the Internal Core Tube remains the basic structural "backbone" of this long strainer and each disk must be internally reinforced, just as it would be for a bolt-on, cantilever design strainer.

## II. DESCRIPTION OF THE TEST FACILITY

The tests at EPRI were all conducted by Continuum Dynamics, Inc. (CDI). The 1995 testing, sponsored jointly by the BWROG and PCI, is summarized in the BWROG's Utility Resolution Guidance, or URG (Ref. 1). The CDI test report, Performance Contracting, Inc. ECCS Sure-Flow™ Strainer Data Report, Revision 0 (Ref. 3), gives the results of those tests sponsored by PCI and conducted in 1996. Chapter 2 provides a description of the test facility and the test procedures. The same facility was used and the same procedures were followed for both the 1995 and the 1996 performance tests at EPRI. There was no control over water temperature so that temperature fluctuated and was therefore a little different on different days.

It is significant to point out that the test configuration and strainer mounting at EPRI included a 180° tee, a 90° long radius elbow, and several feet of straight pipe between the two pressure transducers used to measure Head Loss across the strainer. Therefore, the Head Loss measurements for the bare (i.e., with no debris) strainer, while relatively low, still included a pressure drop across these piping components. In this paper, a correction is made to determine the Corrected Head Loss across the bare strainer (i.e., the Corrected Head Loss is the pressure drop across the strainer only, without losses associated with these piping components).

## III. TEST RESULTS

The 1995 test results are provided in the PCI report, *The Development and Testing of Performance Contracting, Inc.'s Sure-Flow™ Stacked Disk Suction Strainer for BWR ECCS Lines*, February 1, 1996 (Ref. 4). Those 1995 test results are also contained in Appendix B of the BWR Owners' Group's Utility Resolution Guidance, Rev. 0 (Ref. 1). The 1996 tests results are provided both in the CDI test report (Ref. 3) and in the PCI Memo for Record, *QA Dedication of Strainer Testing at EPRI*, November 11, 1996 . Note that the water temperature for these 1995 tests was 58° to 60° F and that it was 69° to 70° F for the 1996 tests. Because water viscosity is dependent on water temperature, and since viscosity is about 20% lower for the higher water temperature, a correction will be made for those Head Loss values across debris beds.

PCI performed a QA dedication of both series of tests and therefore documented the results separately from CDI. These results and those reported by CDI were very close in value. For the purposes of this report, PCI has used their own readings rather than those reported by CDI. All were performed under a nuclear Quality Assurance Program.

### A. Bare Strainer Head Loss

**Table 1a: Experimental values of Water Flow Rates, Water Velocity, and Head Loss for the Bare Sure-Flow Strainer prototype tested at EPRI, October 28, 1996**

| WATER FLOW RATE GPM | INTERNAL WATER VELOCITY FT/SEC | WATER VELOCITY SQUARED $FT^2 / SEC^2$ | MEASURED HEAD LOSS FEET WATER |
|---|---|---|---|
| | | | |
| 0 | 0 | 0 | 0 |
| 1250 | 0.925 | 0.855 | 0.017 |
| 2500 | 1.849 | 3.42 | 0.083 |
| 3750 | 2.774 | 7.69 | 0.250 |
| 5000 | 3.699 | 13.7 | 0.500 |
| 6250 | 4.623 | 21.4 | 0.833 |
| 7500 | 5.548 | 30.8 | 1.250 |
| 8750 | 6.472 | 41.9 | 1.667 |
| 10000 | 7.397 | 54.7 | 2.000 |

Bare strainer Head Loss values, as measured in 1996, are given above as Table 1a. These include the pressure drops across the bare strainer, the tee, the 90° long radius elbow, and several feet of straight pipe. These measured values of Bare Strainer Head Loss, can be calculated as a function of Water Flow Rate in gallons per minute. This has been done in **Figure 2** and clearly shows a relationship best described as a parabola, suggesting a flow rate, or water velocity, squared relationship. For further analysis, the Water Flow Rate was converted to Water Velocity, in feet per second, by dividing by the cross-sectional area of the inside of the 24 inch NPS, Schedule 30 pipe, an area of about 3.0 $ft^2$. These values are also shown in Table 1a.

A regression analysis was then performed to determine a regression equation that best fits this test data. This was done as follows: Equation 1 was used in the regression analysis to determine the values of A and B:

Equ. 1 $$\mathbf{HL\ (measured) = A + B * V^2}$$

where the value of coefficient A is very small since theoretically there is no head loss with no water velocity. Table 1b shows the results of the regression analysis of the Bare Strainer Head Loss data measured at EPRI on October 28, 1996 (Ref. 3).

**Table 1b: Results of a regression analysis of Data in Table 1a of Measured Head Loss and Water Velocity for the Bare Strainer in the EPRI test configuration**

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.997496 |
| **R Square** | **0.994998** |
| Adjusted R Square | 0.994284 |
| Standard Error | 0.056796 |
| Observations | 9 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 4.491864 | 4.491864 | 1392.462 | 2.58E-09 |
| Residual | 7 | 0.022581 | 0.003226 | | |
| Total | 8 | 4.514444 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| **Intercept** | **-0.01257** | 0.027532 | -0.45651 | 0.661853 | -0.07767 | 0.052533 | -0.07767 | 0.052533 |
| **X Variable 1** | **0.03849** | 0.001031 | 37.31571 | 2.58E-09 | 0.036051 | 0.04093 | 0.036051 | 0.04093 |

The regression analysis determined the following values for the coefficients: **A = -0.01257** and **B = 0.03485** where **V** has units of ft/sec and **HL** has units of feet of water. Since this relationship has correlation coefficient ($R^2$) of 0.9950, this equation, of a squared dependence of Bare Strainer Head Loss on Water Velocity, appears to be a good fit. And, since Head Loss depends on Velocity squared, the flow is obviously turbulent over most of the velocities, therefore Head Loss is independent of water viscosity and hence independent of water temperature. (Note: this is not true of Head Loss across fibrous and particulate debris for large strainers; this flow through a debris bed is predominantly laminar and therefore linearly dependent on water viscosity).

A plot for calculated Head Loss values, referred to as Regression Head Loss and generated by using this regression equation fit of the test data, is given as the dashed (upper) curve in **Figure 2**.

These Regression Head Loss values included the Head Loss contributions of a 24" NPS, 90° elbow, a 24" NPS, 180° tee connection, and several (less than ten) LF of straight pipe. See the BWROG's URG (Ref. 1) for a description of the piping arrangement at EPRI and for the measurement locations. Therefore, a Corrected Head Loss, across only the bare strainer, by itself, without these piping components, should be calculated. The values of Corrected Head Loss should be less than the values of Regression Head Loss at corresponding values of Water Velocity (and Water Flow Rate) since Corrected Head Loss does not include the pressure losses associated with the piping components. This can be done by using the following general equation to calculate Head Loss across various piping components (see Ref. 2):

Equ. 2 $\mathbf{HL = K * V^2 / 2 * g}$ where **V** = water velocity, ft/sec
**K** = loss factor for the particular fitting
**g** = gravitational constant = 32.2 ft/sec$^2$
**HL** = Head Loss, feet of water

and $\mathbf{K_{90\ elbow}}$ = 0.6 for a 90° standard elbow (such as on the EPRI installation) and
$\mathbf{K_{str\ tee}}$ = 0.5 for a straight, 180° tee (this is estimated).

To calculate the Corrected Head Loss, the pressure drop contribution from the several LF of straight pipe can be ignored since it is such a short length. The Regression Head Loss values can then be corrected for Head Losses across the bare strainer alone, without the piping components, using Equation 3 below:

Equ. 3 $\mathbf{Corrected\ HL = Regression\ HL - HL_{90\ elbow} - HL_{str\ tee}}$

FIGURE 2
MEASURED, CALCULATED, AND CORRECTED VALUES OF HEAD LOSS ACROSS THE BARE STRAINER TESTED AT EPRI, OCTOBER 28, 1996

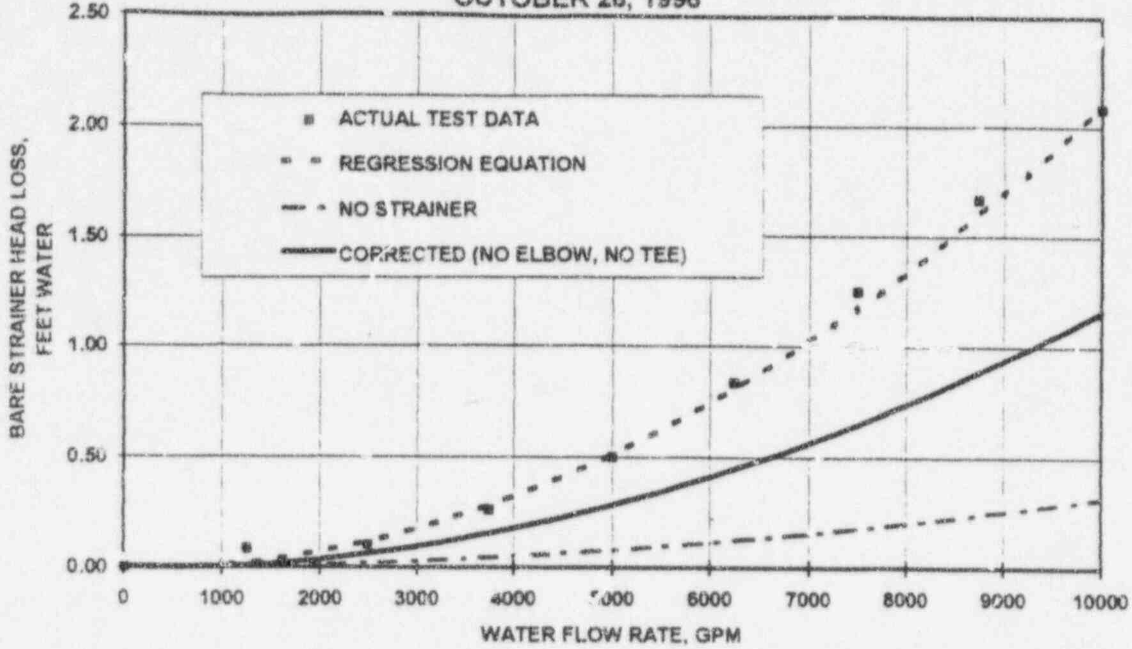



**Figure 2** above can be used to select values for both Regression Head Loss (the heavy dashed line) and Corrected Head Loss (the solid dark line) for a desired water flow rate. For example, at 10,000 gpm (V = 7.43 ft/sec), the Corrected Head Loss = 1.16 feet of water, about 45% less than the measured value of 2.08 feet of water.

It is interesting to compare the Corrected Head Loss to the estimated pressure drop or head loss were no strainer attached to the end of a 24 inch NPS pipe. Equations in Ref. 6 can be used to calculate a coefficient for a sudden contraction of water, from a pool into a pipe. Using Ref. 6, PCI determined that this Coefficient of Contraction, $C_c$, is equal to about 0.62. This value can then be input into Equation 4 below to calculate what we will refer to as the No Strainer Head Loss:

Equ. 4 $$\mathbf{HL = ( 1/C_C - 1)^2 V^2 /2g = 0.37 V^2 /2g}$$

The light dashed curve on **Figure 2** above shows the prediction for the No Strainer Head Loss, or that resulting only from entrance losses of flow being drawn into a 24 inch NPS pipe. It can be seen that these entrance losses are responsible for about 27 % of the head loss across the bare strainer by itself, namely the Corrected Head Loss. That suggests that the remainder, representing 73% of the Corrected Head Loss, results from the strainer itself.

## B. Strainer Head Loss with Simulated Debris

Table 2 below summarizes all the results for the testing conducted at EPRI on this **Sure-Flow Strainer** prototype. For the purposes of distinguishing between the 1995 and the 1996 tests, PCI has used the prefix of "95-" or "96-" to designate the corresponding data. In both cases, the Clean Strainer Measured Head Losses, referred to in Section A above, were first subtracted so that the values reported on Table 2 are for Head Loss across the debris bed only.

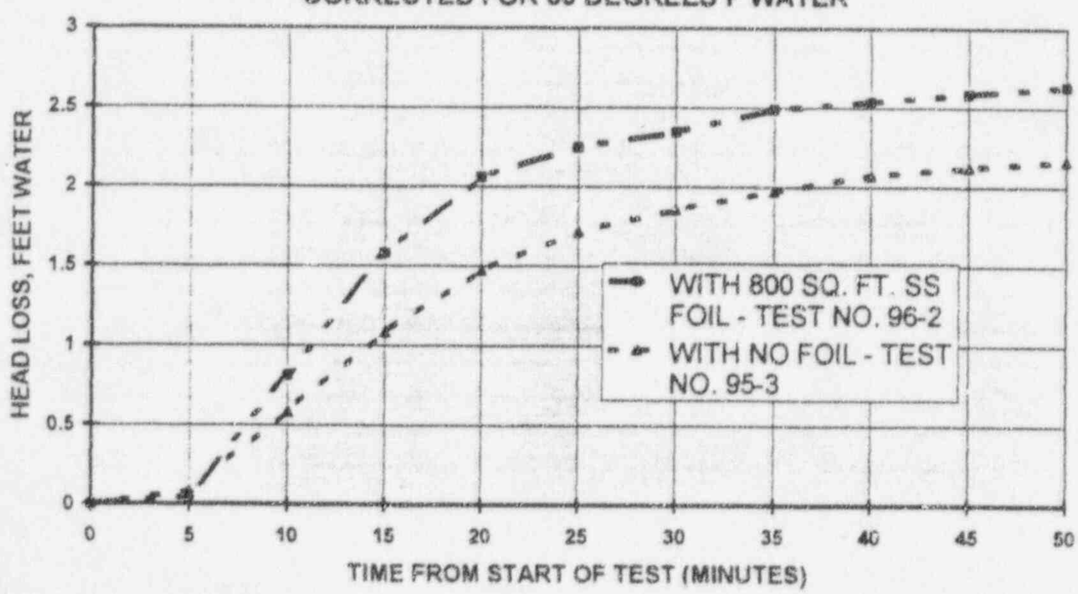
**TABLE 2**
**Summary of Actual Head Loss Test Data from EPRI**
**1995 and 1996 Measured Data**
**All Head Loss Values in Feet of Water**

| TEST NO.: | 95-2 | 95-3 | 95-4 | 95-5 | 96-2 | 96-3A | 96-3B | 96-3C | 96-3D | 96-3E | 96-4 | 96-5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MASS FIBERS (LBS.) | 17 | 25 | 3 | 50 | 25 | 100 | 150 | 200 | 250 | 300 | 100 | 200 |
| MASS CP (LBS.) | 85 | 100 | 100 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 100 | 100 |
| AREA OF FOIL ($FT^2$) | 0 | 0 | 0 | 0 | 800 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WATER TEMP, °F | 57 | 58 | 59 | 58 | 69 | 69 | 70 | 71 | 72 | 73 | 69 | 70 |
| 2500 gpm | 0.58 | 0.83 | 0.00 | 2.29 | 0.96 | | 4.65 | 6.15 | 8.32 | 9.65 | 5.40 | 10.73 |
| 3000 gpm | | | | | | | | | | | | 13.00 |
| 3500 gpm | | | | | | | | | | | | 15.67 |
| 3750 gpm | 1.01 | 1.46 | 0.01 | 3.81 | 1.60 | | 7.58 | 10.58 | 13.66 | 16.16 | 8.66 | |
| 4000 gpm | | | | | | | | | | 16.58 | | 19.17 |
| 5000 gpm | 1.53 | 2.13 | 0.16 | 5.42 | 2.33 | 6.08 | 10.00 | 13.83 | 17.75 | | 12.25 | |
| 6250 gpm | | | | | | | | | | | 14.75 | |
| 7500 gpm | 1.67 | 2.42 | 0.27 | 8.08 | 2.95 | | | | | | | |
| 10000 gpm | 1.67 | 2.58 | 0.00 | 10.17 | 4.34 | | | | | | | |

In most of the tests, the debris was collected on the strainer using a constant 5000 gpm Water Flow Rate, then after its collection, the Water Flow Rate was varied to allow the generation of Head Loss data for other values. However, for Test No. 96-3E (300 lbs. of Fibrous Debris and no CP Particulate) and for Test No. 96-5 (200 lbs. of Fibrous Debris and 100 lbs. of CP Particulate), the Water Flow Rate was reduced to 4000 gpm to keep the total Head Loss below about 19 feet of water, judged by PCI's structural consultants (i.e., Duke Engineering & Services, Inc.) to be the maximum allowable pressure differential across this strainer prototype. In fact, for all of the 1996 tests, this upper limit of 19 feet of water was observed by PCI as the maximum allowable Head Loss, thereby preventing the collection of Head Loss data at higher than 5000 gpm Water Flow Rates for all but Test No. 96-2.

**Figure 3** below shows the results of the debris collection, as Head Loss vs. Time, for Tests Nos. 95-3 and 96-2. For the first of these two tests, 25 lbs. of Fibrous Debris and 100 lbs. of CP Particulate were added; in the second, those same quantities of Fibrous Debris and CP Particulate were added but also 800 square feet of stainless steel foil, simulating debris from Reflective Metallic Insulation, was added. As can be seen, both sets of data followed the same time constant and the Head Loss results, at particular times, are close in value, with the addition of the RMI foil increasing Head Loss by about ½ feet of water, representing about 20% after correction for water temperature. It can also be seen that for this test configuration, using 5000 gpm and a 50,000 gallon tank, that it took approximately 50 minutes to reach an equilibrium Head Loss. This pattern was found for all the debris collection tests, for which debris collection was performed at 4000 or 5000 gpm, as is clearly shown in the transient plots included in Reference 4. The 1996 test data, collected using about 70° F water, was corrected for 60° F water temperature in order to compare it to the 1995 test data which was collected with about 60° F water. This same correction, to 60° F, will also be made for other Head Loss data presented in this paper unless noted otherwise.

FIGURE 3:
EPRI TESTS WITH AND WITHOUT SS FOIL:
HEAD LOSS VS. TIME WITH 5000 GPM OF ROOM
WITH 25 LBS. SHREDDED NUKON & 100 LBS. CP PARTICULATE
CORRECTED FOR 60 DEGREES F WATER



**Figures 4 and 5** (following) show the results taken from the series of Tests 96-3A through -3E. In these tests, no CP Particulate was added to the tank. Instead, fibrous debris was added to the test tank in increasing quantities, starting out with 100 lbs., then increased in 50 lbs. increments till 300 lbs. was added in total. **Figure A-3** from the CDI report (Ref. 3) shows the sequencing clearly in the transient Head Loss graph. **Figure 4** below shows that Head Loss is roughly linearly dependent on Water Flow Rate, for a given quantity of Fibrous Debris. **Figure 5** below shows clearly that Head Loss is approximately linearly dependent on Mass of Fibrous Debris for a given Water Flow Rate through the strainer.

In both cases, there was no CP particulate and the linear behavior can only be considered for the range of the tested variables. However, the essentially linear dependence of Head Loss on Water Flow Rate is expected, per the USNRC NUREG/CR-6224 Equations, for predominantly laminar flow through a fibrous bed collected on the strainer. For Head Loss dependence on Mass of Fibrous Debris, the dependence can be expected to be essentially logarithmic with very large quantities of Fibrous Debris. This logarithmic behavior will be explained later in this report. For the range over which these tests were conducted (i.e., up to 300 lbs. of Fibrous Debris on this particular strainer prototype), the dependence of Head Loss on Mass of Fibrous Debris is, as expected from the Head Loss equations in Reference 2, also essentially linear.

For those tests with 100 lbs. of CP Particulate, graphs similar to **Figures 4 and 5** can be plotted. The four Tests 95-3, 95-5, 96-4, and 96-5 all used the same quantity of CP particulate, namely 100 lbs., and 25, 50, 100, and 200 lbs. of Fibrous Debris, respectively. The Head Loss dependence on Water Flow Rate, for the four different quantities of Fibrous Debris, is shown graphically in **Figure 6**. Again, the dependence on Water Flow Rate is essentially linear. The Head Loss dependence on Mass of Fibrous Debris, for several different Water Flow Rates, is shown in **Figure 7**. Again in this case, the dependence is essentially linear, as was the case without any CP Particulate.

Other than Test No. 95-2, only two different quantities of CP Particulate were used for all of these tests: either 0 lbs. or 100 lbs.

FIGURE 4:
HEAD LOSS VS. FLOW RATE FOR THE SURE-FLOW STRAINER WITH FIBROUS DEBRIS AND NO CP PARTICULATE
HEAD LOSS VALUES CORRECTED FOR 60 DEGREES WATER

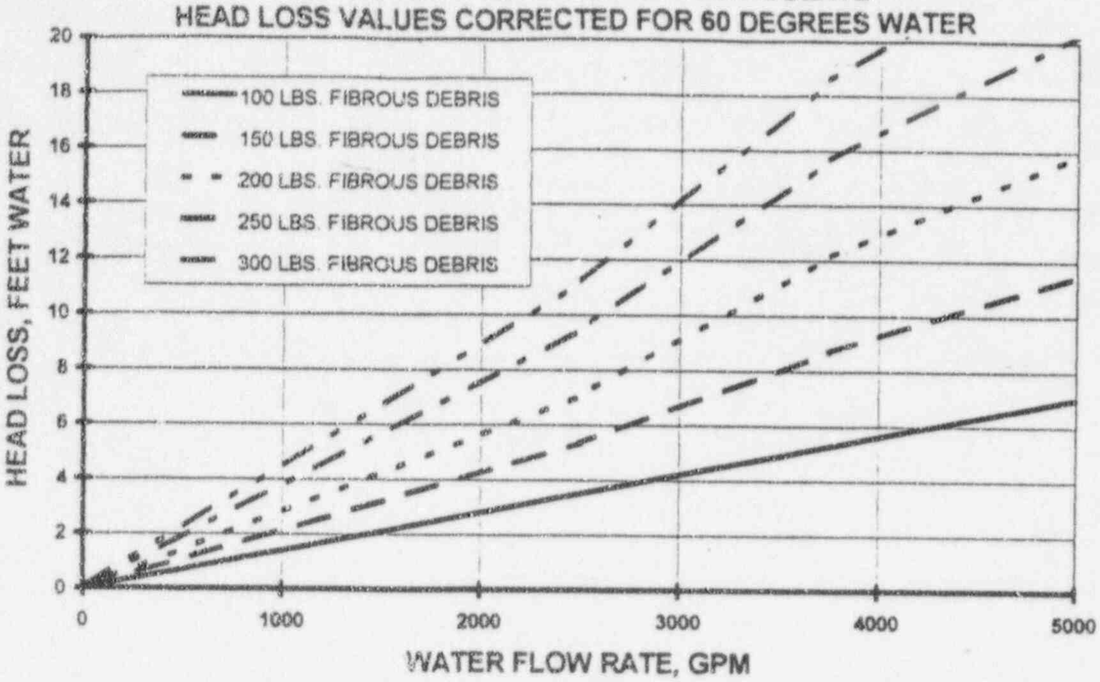



FIGURE 5:
HEAD LOSS VS. MASS FIBROUS DEBRIS FOR THE SURE-FLOW STRAINER WITH FIBROUS DEBRIS AND NO CP PARTICULATE
HEAD LOSS VALUES CORRECTED FOR 60 DEGREES WATER

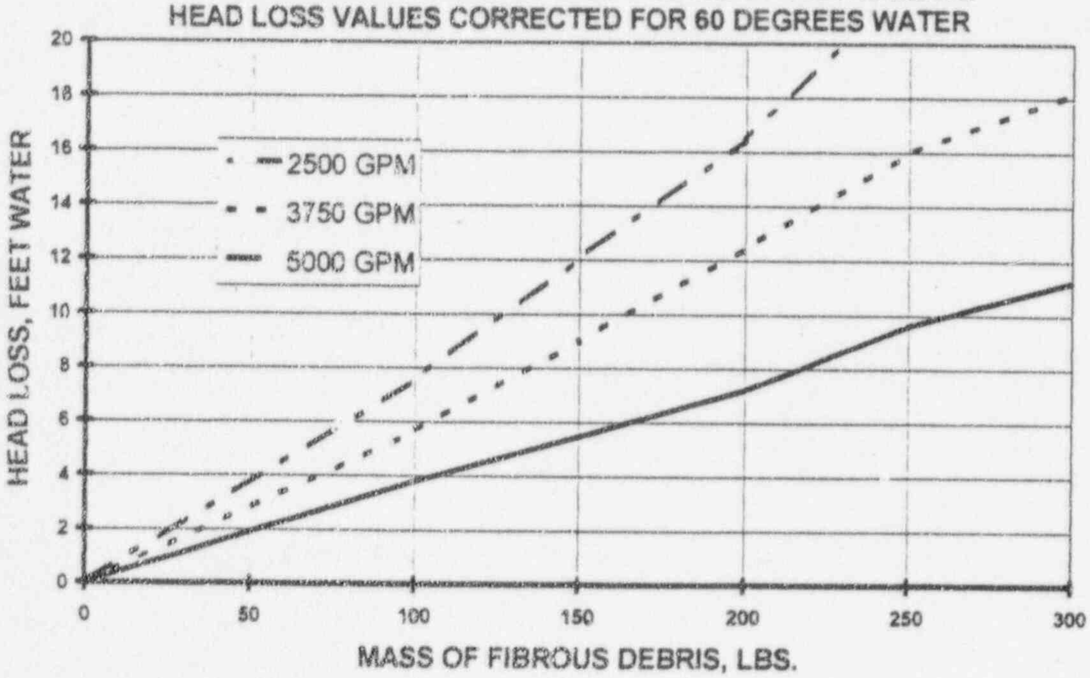


FIGURE 6:
TEST DATA ON PCI'S SURE-FLOW STRAINER AT EPRI:
HEAD LOSS VS. FLOW RATE FOR SEVERAL QUANTITIES OF FIBROUS DEBRIS, WITH 100 LBS. OF CP AND 60 F WATER

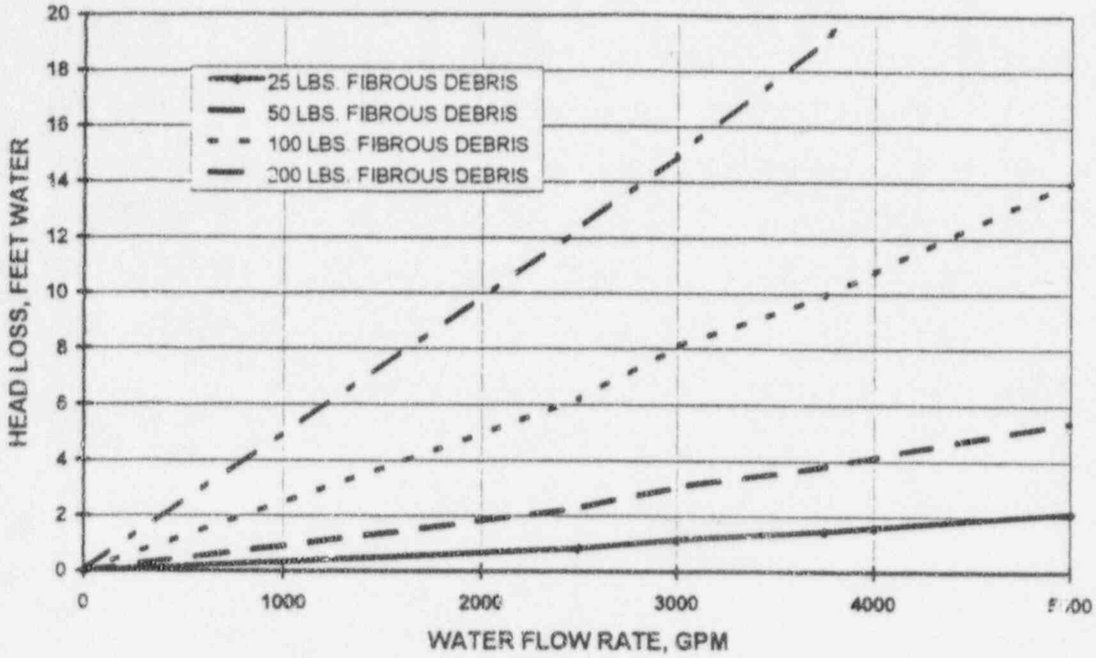
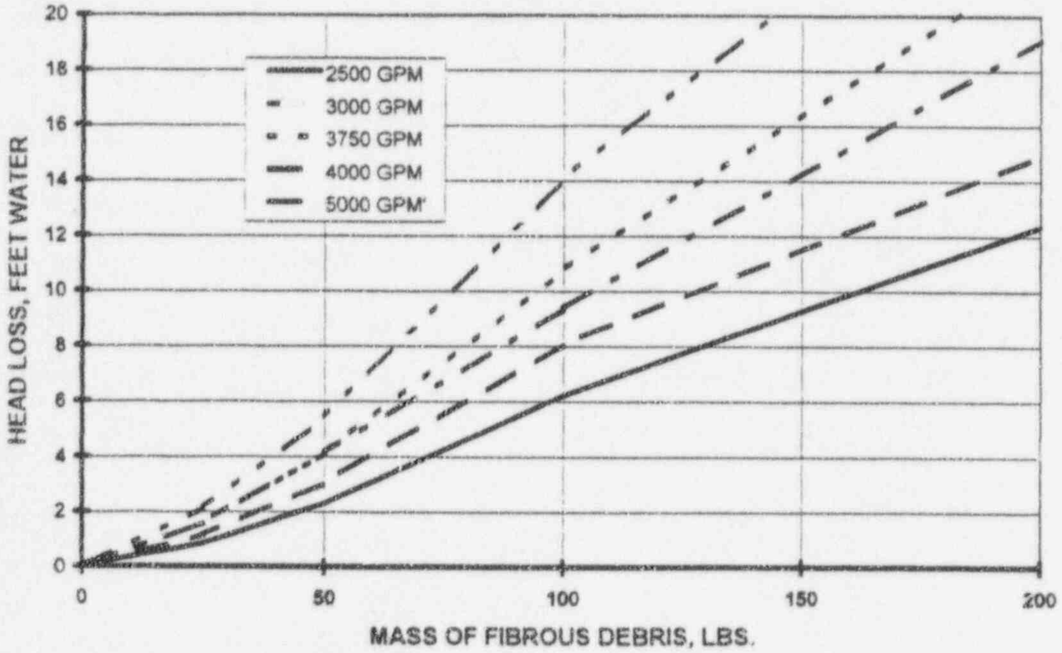



FIGURE 7:
TEST DATA ON PCI'S SURE-FLOW STRAINER TESTED AT EPRI :
HEAD LOSS VS. MASS OF FIBROUS DEBRIS, 100 LBS. OF C.P., AND 60 F WATER



## C. Apparent Filtration Efficiency

After the completion of all the tests, PCI took water samples to be analyzed for per cent solids. A comparison of these were used to calculate the Apparent Filtration Efficiency of the fiber bed on the strainer. The per cent solid at the beginning of each test can be determined by taking the total quantity of CP particulate and assume it is uniformly distributed throughout the approximately 50,000 gallons of water in the EPRI tank and piping system. Table 5 gives the results of tests for Apparent Filtration Efficiency. It is worth noting that these values ranged from a low of 41%, for a very thin layer test, Test No. 95-4, up to almost unity for the thickest layers in Tests No. 96-4 And 96-5.

**Table 5: Estimated Values of Apparent Filtration Efficiency for Tests with Combined NUKON Fibrous Debris and CP Particulate**

| Test No. | 95-2 | 95-3 | 95-4 | 95-5 | 96-2 | 96-4 | 96-5 |
|---|---|---|---|---|---|---|---|
| Mass CP at t=0 | 180* mg/l | 180* mg/l | 180* mg/l | 180* mg/l | 170 mg/l | 160 mg/l | 180 mg/l |
| Mass CP at test end | 51 mg/l | 41 mg/l | 107 mg/l | 35 mg/l | 30 mg/l | 5 mg/l | 12 mg/l |
| Mass CP removed | 129 mg/l | 139 mg/l | 73 mg/l | 145 mg/l | 140 mg/l | 155 mg/l | 168 mg/l |
| Apparent Filtration Efficiency | 72% | 77% | 41% | 81% | 82% | 97% | 98% |

* Indicates a value calculated by using measured weight of CP and estimated volume of water in the tank and piping system.

## D. Fibrous Bed Compaction

A factor which affects head loss across a fibrous bed is the effective bed compaction. This compaction probably results from the viscous effects of water flowing past the fibers collected on the surface of the strainer. For the purposes of most of the calculations, we use the "as fabricated" insulation density which is 2.4 lbs./ft$^3$ for NUKON Base Wool, the insulant used in the fabrication of NUKON Insulation blankets. To determine the effective bed compaction, PCI measured the bed thickness following Test No. 96-05. This was done using a long pole and inserting it into the wet bed, following the draining of the tank. Figure 10 is a photograph of this being done. This measurement technique gave an approximate thickness, from the outer edge of a disk to the outer edge of the bed, of 8 ½ inches. A hand calculation can show that the bed volume was approximately 56 ft$^3$ whereas it would have been approximately 73 ft$^3$ were there no compaction. This allows for 10.3 ft$^3$ of fibers to collect first in the gaps between the disks. Taking the quotient of the actual and the theoretical gives a ratio of 0.76, or a compaction of (1 - 0.76 ) = 24%.

## IV. REGRESSION ANALYSIS OF TEST DATA

Head Loss across the debris bed: Calculations for Head Loss across the debris (i.e., combination of NUKON fibers and corrosion product particulate) on the strainers are performed by first developing a regression equation for some of the data given in Table 1. For the purposes of predicting behavior of this strainer for different water flow rates, different diameters and lengths and hence different surface areas, PCI developed a couple of MS Excel spreadsheet programs. To do this, several assumptions were made:

1. Results from Tests Numbers 95-3, 95-5, 96-4, and 96-5 can be analyzed by regression to determine the Head Loss dependence on Water Flow Rate and Strainer Surface Area. The prototype strainer's tested behavior can then be accurately scaled by dividing its water flow rate and its mass of fibrous (NUKON) debris by its circumscribed surface area, namely 56 $ft^2$ where this strainer had a 40" diameter, a 48" active length, and a 24" Internal Core Tube (Note: for Test No. 96-5, a circular disk was bolted onto the test strainer's end disk, reducing the circumscribed surface area to53 $ft^3$). This assumption is conservative since as more debris buildup occurs, the strainer's surface area actually grows, thereby not remaining at 56 $ft^2$.
2. A given strainer's behavior can be accurately predicted by treating the strainer as a large cylinder that has similar behavior, based on its cylindrical surface area, as the tested prototype. As shown in the EPRI tests, the NUKON fibrous debris will collect all over the strainer and fill all the voids, gaps, etc. This should be valid when the strainer has disks that are 1.85" wide and are separated by 2.00" wide gaps, the same as the tested strainer prototype.
3. The tested corrosion product particulate used in the EPRI Head Loss tests accurately simulates all the specified particulate in a particular plant's specification.
4. Calculated Head Losses at 70° F can be recalculated for other, higher temperatures by simply multiplying by the ratio of the kinematic viscosities at each of the two temperatures. This is based on the derivation of Equ. B-32a in NUREG/CR-6224 (Ref. 1). This also assumes that the Head Loss across a fibrous debris bed is dominated by the laminar, viscosity dependent portion of that equation; this assumption can be validated by calculations which show that the turbulent, non-viscosity portion of the equation contributes little to the calculated Head Loss at some other water flow rate and some other quantity of fibrous debris.
5. The debris build-up on the new strainers is uniform over its length and the Head Loss is uniform across any part of the strainer.
6. To calculate Head Losses at other values of mass ratio values than those encompassed by the tests, namely 4:1 to 1:2, one can use the portion of Equ. B-32a (Ref. 1) that includes the mass ratio:

$$\text{Mass Ratio Correction Factor} = ((1 + 0.54\ (\text{new ratio}))/(1 + 0.54\ (\text{ref. ratio})))^{1.5}.$$

Table 2 gives the results of setting up a regression analysis for Head Loss as a function of Flow Rate and Mass of NUKON Fibrous Debris. As explained in the Assumption 1 above, each of these two independent variables is first divided by the test strainer's surface area, then a new independent variable that is the product of those first two, and then use the Excel regression program to generate coefficients for the following equation:

Equ. 5 $$\mathbf{HL} = \mathbf{A} + \mathbf{B} * (Q/A_s) + \mathbf{C} * (M_f/A_s) + \mathbf{D} * (Q/A_s)(M_f/A_s)$$

where **Q** = strainer flow rate, gpm
**$A_s$** = strainer's cylindrical surface area, sq. ft.
**$M_f$** = mass of NUKON fibers, lbs.
**HL** = strainer head loss, feet of water

Table 2 shows the results of the regression analysis using the test data:

**A = 0.7696**
**B = -0.02292**
**C = -0.5406**
**D = 0.08916**

where value of $R^2$ = 0.9828 for this analysis, indicating an excellent correlation fit over the range of these tests.

Table 3: EPRI Head Loss Test Data Used for a Regression Analysis

EPRI HEAD LOSS DATA WITH 100 LBS. CP AND 25, 50, 100, AND 200 LBS. NUKON, WATER FLOW RATES 0 TO 10,000 GPM HEAD LOSS VALUES CORRECTED FOR 60 DEGREES F WATER

| | FLOW RATE | MASS CP | MASS NUKON | MASS CP/ MASS NUK | MASS X FLOW RATE | HEAD LOSS | FLOW RATE PER AREA | MASS NUKON PER AREA, | MASS/AREA X FLOW RATE/AREA |
|---|---|---|---|---|---|---|---|---|---|
| | GPM | LBS | LBS | LBS/LBS | GPM-LBS | **FEET WATER** | GPM/SQ FT | LBS/SQ FT | GPM-LBS/FT(4) |
| **TEST NO.** | | | | | | | | | |
| **95-3** | 0 | 100 | 25 | 4 | 0 | **0.00** | 0 | 0.446 | 0 |
| | 2500 | 100 | 25 | 4 | 62500 | **0.83** | 44.6 | 0.446 | 19.93 |
| | 3750 | 100 | 25 | 4 | 93750 | **1.46** | 67.0 | 0.446 | 29.89 |
| | 5000 | 100 | 25 | 4 | 125000 | **2.13** | 89.3 | 0.446 | 39.86 |
| | 7500 | 100 | 25 | 4 | 187500 | **2.42** | 133.9 | 0.446 | 59.79 |
| | 10000 | 100 | 25 | 4 | 250000 | **2.58** | 178.6 | 0.446 | 79.72 |
| **95-5** | 0 | 100 | 50 | 2 | 0 | **0.00** | 0.0 | 0.893 | 0.00 |
| | 2500 | 100 | 50 | 2 | 125000 | **2.29** | 44.6 | 0.893 | 39.86 |
| | 3750 | 100 | 50 | 2 | 187500 | **3.81** | 67.0 | 0.893 | 59.79 |
| | 5000 | 100 | 50 | 2 | 250000 | **5.42** | 89.3 | 0.893 | 79.72 |
| | 7500 | 100 | 50 | 2 | 375000 | **8.08** | 133.9 | 0.893 | 119.58 |
| | 10000 | 100 | 50 | 2 | 500000 | **10.17** | 178.6 | 0.893 | 159.44 |
| **96-4** | 0 | 100 | 100 | 1 | 0 | **0.00** | 0.0 | 1.786 | 0.00 |
| | 2500 | 100 | 100 | 1 | 250000 | **6.20** | 44.6 | 1.786 | 79.72 |
| | 3750 | 100 | 100 | 1 | 375000 | **9.95** | 67.0 | 1.786 | 119.58 |
| | 5000 | 100 | 100 | 1 | 500000 | **14.08** | 89.3 | 1.786 | 159.44 |
| | 6250 | 100 | 100 | 1 | 625000 | **16.97** | 111.6 | 1.786 | 199.30 |
| **96--5** | 0 | 100 | 200 | 0.5 | 0 | **0.00** | 0.0 | 3.774 | 0.00 |
| | 2500 | 100 | 200 | 0.5 | 500000 | **12.33** | 47.2 | 3.774 | 178.00 |
| | 3000 | 100 | 200 | 0.5 | 600000 | **14.94** | 56.6 | 3.774 | 213.60 |
| | 3500 | 100 | 200 | 0.5 | 700000 | **19.15** | 66.0 | 3.774 | 249.20 |
| | 4000 | 100 | 200 | 0.5 | 800000 | **22.03** | 75.5 | 3.774 | 284.80 |

## Table 4: Results of Regression Analysis of Data in Table 3 and Using Equation 5 for a Regression Fit

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.991381 |
| **R Square** | **0.982837** |
| Adjusted R Square | 0.979976 |
| Standard Error | 0.975788 |
| Observations | 22 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3 | 981.4552 | 327.1517 | 343.5886 | 4.5185E-16 |
| Residual | 18 | 17.1389 | 0.952161 | | |
| Total | 21 | 998.5941 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| **Intercept** | **0.769632** | 0.605264 | 1.271563 | 0.219713 | -0.5019821 | 2.041246 | -0.50198 | 2.041246 |
| **X Variable 1** | **-0.02292** | 0.006621 | -3.46179 | 0.002783 | -0.0368284 | -0.00901 | -0.03683 | -0.00901 |
| **X Variable 2** | **-0.54061** | 0.317771 | -1.70126 | 0.106104 | -1.208226 | 0.127001 | -1.20823 | 0.127001 |
| **X Variable 3** | **0.089155** | 0.004913 | 18.14504 | 5.13E-13 | 0.07883243 | 0.099478 | 0.078832 | 0.099478 |

Using this Equation 5, Head Loss values, for a particular plant's strainers, can be generated for a case where the suppression pool has water temperature T, the strainers a constant Water Flow Rate Q, a total of $M_f$ pounds of shredded NUKON Fibers and $M_{CP}$ pounds of CP Particulate reach the strainers, the strainers have diameters D and lengths L, and an infinite period of ECCS pump operation. The following example problem shows how this can be accomplished:

**Example Head Loss Problem Using the Regression Equation 5:**

Suppose a plant has four equal sized strainers on a common ring header which draws a total of 20,000 gpm. Each strainer is a Sure-Flow stacked disk strainer, with all disks of the same size, each strainer is 4 feet long and 45 inches in diameter, and each is mounted on a 20 inch NPS pipe. Assume, for the purposes of design conditions, that the water temperature is 180° F, that 800 lbs. of CP particulate and other particulate are in the suppression pool, and that 333 cubic feet of shredded NUKON insulation are transported to the pool. Ignore any particulate or fiber sedimentation and assume 100% filtration efficiency of the particulate by the fibers on the strainers. Also, assume that NUKON insulant has an as-fabricated density of 2.4 lbs./cubic foot.

**Solution:**

First, calculate the cylindrical surface area of each strainer. Including the end disks, this works out to be about 70 ft². Therefore,

$$Q/A = (20{,}000 \text{ gpm total} / 4 \text{ strainers}) / 70 \text{ ft}^2 \text{ cyl. Area} = 71.4 \text{ gpm/ft}^2$$

and $$M_f/A = ((333 \text{ ft}^3 \text{ fibers} / 4 \text{ strainers}) * (2.4 \text{ lbs./ft}^3) / 70 \text{ ft}^2 = 2.85 \text{ lbs./ ft}^3$$

Putting these into Equation 5, the Head Loss can be calculated for ambient water:

$HL_{60}$ = 15.7 feet of water at 60° F water, which has a kinematic viscosity of $1.217 \times 10^{-5}$ ft²/sec.

This Head Loss can now be corrected for 180° F water, which has a kinematic viscosity of $3.85 \times 10^{-6}$ ft²/sec:

$$HL_{180} = 15.7 * 3.85 \times 10^{-6} / 1.217 \times 10^{-5} = \mathbf{5.0 \text{ feet of water}}.$$

This can now be corrected for the Mass Ratio of CP to fibers:

$$\text{Mass Ratio CP : Fibers} = 800 \text{ lbs.} / (333 \text{ ft}^3 * 2.4 \text{ lbs/ft}^3) = 1.00$$

This compares to the range of the tested values. For EPRI Test No. 96-4, the Mass Ratio was also 1.00. Therefore, no correction will be made for mass ratio. Hence, the predicted Head Loss across each strainer, which is 45 inches in diameter and 4 feet long, is 5.0 feet of water at 180° F. This problem is solved.

## V. THEORETICAL ANALYSIS OF STRAINER BEHAVIOR

**Figures 8, 9, and 10** are photographs taken of the strainer following Tests Nos. 95-3, 95-5, and 96-5, respectively (and following the draining of the tank). These were tests conducted with 100 lbs. of CP Particulate and 25, 50, and 200 lbs. of Fibrous Debris respectively. **Figure 8** shows that the gaps, between the disks, have become partially filled with fibrous debris and the disks themselves have also become more or less covered with debris when 25 lbs. were added in Test 95-3. Note that 25 lbs. of fibrous debris corresponds to about 10.3 $ft^3$ of debris volume (based on the as-fabricated insulation density of 2.4 lbs./$ft^3$), which approximately equals the volume of the twelve gaps between the thirteen disks. **Figure 9** shows that the twelve gaps have become completely filled with fibrous debris when 50 lbs. of fibrous debris (corresponding to a volume of about 20.7 $ft^3$ using the as-fabricated insulation density of 2.4 lbs./$ft^3$) was added in Test 95-5. **Figure 10** looks similar to **Figure 9** except that the thickness of the debris bed is even thicker, which it should since 200 lbs of fibrous debris was added for this Test 96-5.

The debris collection behavior is evident: for the first 25 lbs. (10.3 $ft^3$) of fibrous debris, and possibly a little more, the strainer behaves as one that has the 170 $ft^2$ of flat plate surface area, the actual surface area of perforated metal plate on the strainer prototype. For fibrous debris quantities greater than that, the strainer starts to behave like a simple cylindrical shaped strainer after the gaps are filled. The surface area of the circumscribing cylinder, including the ends of the disks, is about 56 $ft^2$, significantly less than the 170 $ft^2$ of perforated plate. With the addition of greater quantities of fibrous debris (i.e., greater than a volume of at least 10.3 $ft^3$ which is what fills the gaps) , the effective surface area will increase due to the increasing effective outer strainer diameter resulting from the increasing Fibrous Debris thickness. This was noted following Test 96-5 when a measurement of the debris bed showed that it had a thickness between 8 and 9 inches. Assuming an 8 ½ inch thick debris bed over the entire strainer, its outer surface area was then about 91 $ft^2$.

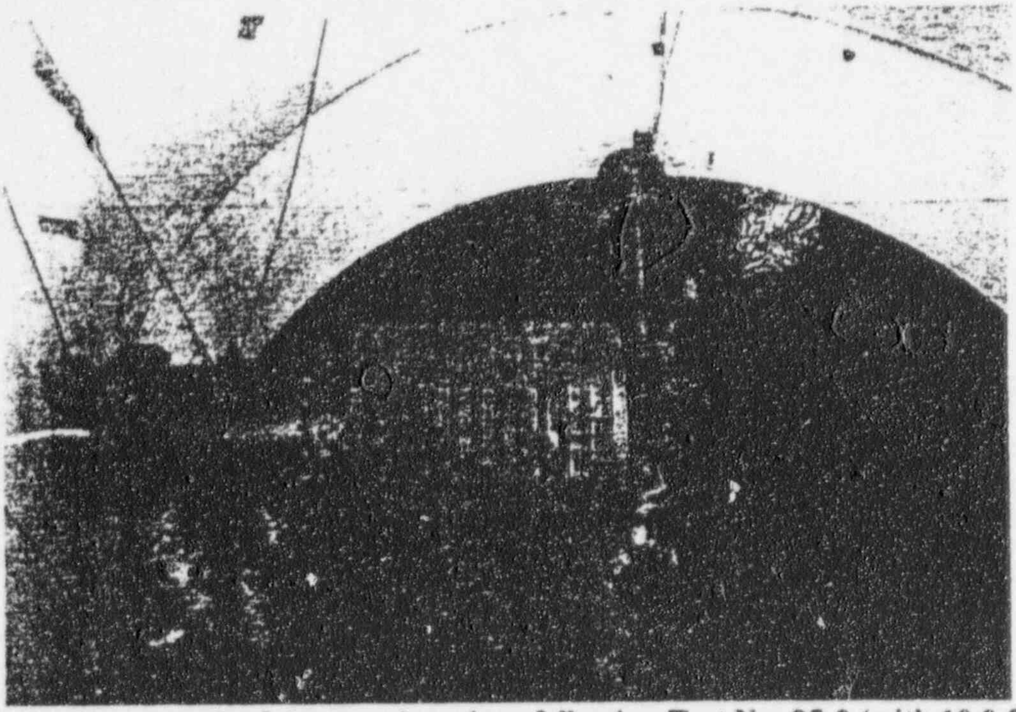


Figure 8 - Photograph of the tested strainer following Test No. 95-3 (with 10.3 $ft^3$ of shredded fibrous debris and 100 lbs. of CP particulate)

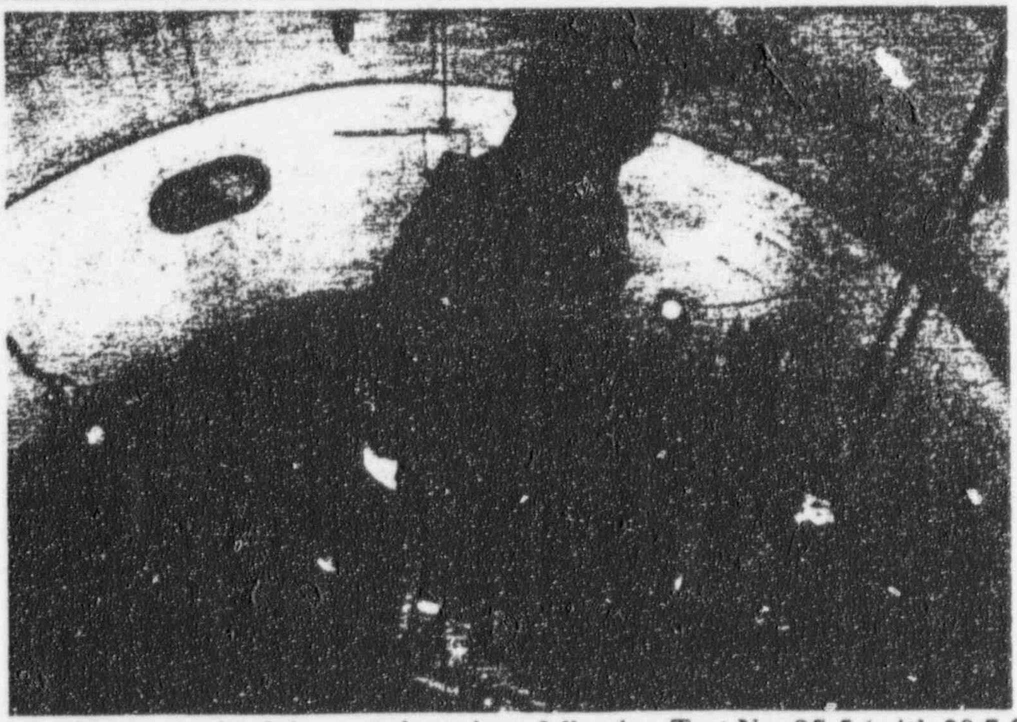


Figure 9 - Photograph of the tested strainer following Test No. 95-5 (with 20.7 $ft^3$ of shredded fibrous debris and 100 lbs. of CP particulate)

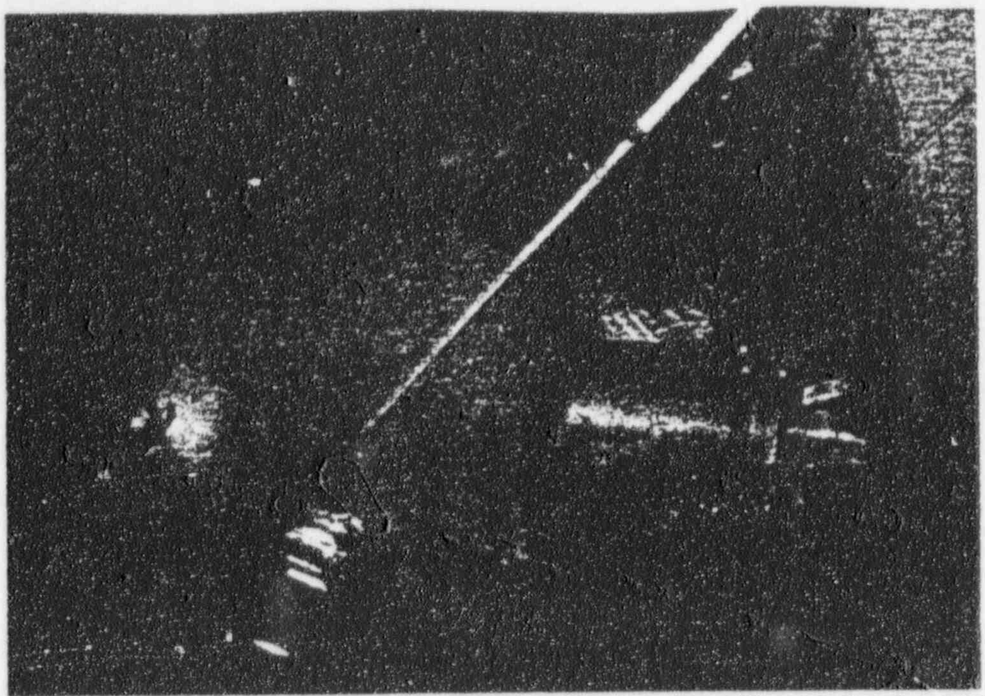


**Figure 10 - Photograph of the tested strainer following Test No. 96-5 (with 83.3 $ft^3$ of shredded fibrous debris and 100 lbs. of CP particulate)**

When behaving like a strainer with 170 $ft^2$ of surface area, this prototype follows the one-dimensional, flat plate NUREG equations for Head Loss. This can be seen from Table 2, for Test No. 95-3 (i.e., 25 lbs. of Fibrous Debris), which gives a good comparison between predicted and experimental results following the NUREG filtration equations. However, for Test No. 95-5 (i.e., 50 lbs. instead of 25 lbs.), the actual measured Head Loss was about twice that predicted assuming flat plate behavior with the full 170 $ft^2$ of perforated metal plate. Also, of course, for Tests Nos. 96-4 and 96-5, which used 100 lbs and 200 lbs., of fibrous debris respectively, the use of 170 $ft^2$ of surface area and the one-dimensional NUREG filtration equations underpredicts Head Loss. With this behavior, it was realized that some modification to the NUREG filtration equations would be necessary. To account for the cylindrical shape of the strainer, one-dimensional, flat plate equations for a cylindrical strainer were developed starting with the NUREG equations. Further modification, accounting specifically for the filling of the gaps with fibrous debris, can be performed to account for the more complex three-dimensional behavior of the strainer and its impact of debris collection patterns.

For comparison, **Figure 11** shows a lower, straight curve for the predicted Head Loss of a one-dimensional, flat plate, 170 $ft^2$of surface area and also an upper curve for a simple cylindrically shaped strainer that has no disks or gaps. The cylindrical strainer is assumed to have the same length and diameter as the tested prototype strainer. **Figure 11** also shows a third curve for the three-dimensional strainer which first acts like a 170 $ft^2$ strainer, then, after the gaps are filled with Fibrous Debris, behaves like a cylindrically shaped strainer. It should be noted that the simple cylindrical prediction is overly conservative for the tested prototype. This is because it does not account for the firs 25 lbs. of the debris becoming trapped by the gaps between the disks and then becoming, essentially, a cylindrical strainer.

A comparison of the equations used in **Figure 11** for the 170 $ft^2$ surface show how the Head Loss values were generated for one-dimensional debris collection on a flat plate strainer. Letting:

$M_{CP}/M_f$ = CP Particulate: Fibrous Debris Mass Ratio collected on the strainer
th = thickness of the Fibrous Debris bed, inches (this accounts for bed compaction described in Section III.D above)
$A_s$ = strainer surface area, $ft^2$
Q = Water Flow Rate, $ft^3$ / sec
HL = Head Loss across the strainer, feet of water

we can write Equation B-32a from NUREG/CR-6224 for 60° F water and modify it for 70° F water by multiplying the coefficient 10 by the ratio of kinematic viscosities at 70° and 60° F:

Equ. 6
$$HL = 8.7 * (1 + 0.54 * M_{CP}/M_f)^{1.5} * th * Q/A_s + 4 * (1 + 0.54 * M_{CP}/M_f) * th * (Q/A_s)^2$$

This one-dimensional flat plate equation (written in Cartesian coordinates) can then be modified for one-dimensional cylindrical surfaces (using cylindrical coordinates) by means of integrating Head Loss as a function of strainer diameter. Because the surface area, $A_s = pi * D_s * L$, we can derive the modified equation for cylinders:

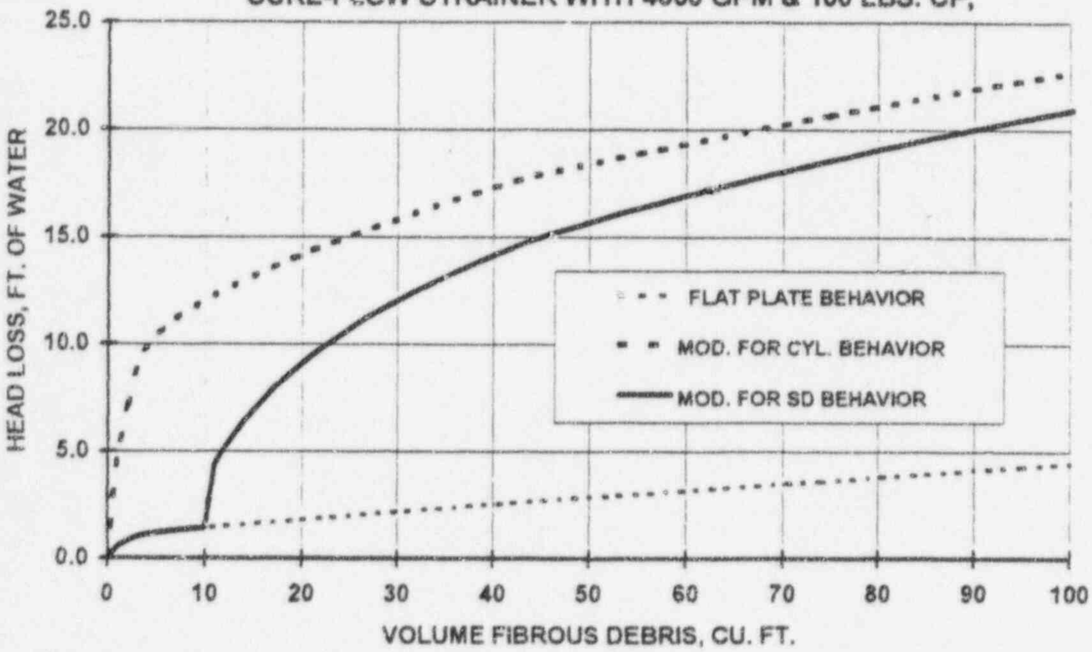
$D_s$ = actual diameter of the strainer, inches
$D_f$ = total diameter of the strainer plus the Fibrous Debris bed, inches (accounting for bed compaction described in Section IV.D above)
$L_f$ = effective strainer length, including the debris bed, ft.

Equ. 7
$$HL = 8.7 * (1 + 0.54 * M_{CP}/M_f)^{1.5} * Q * \ln (D_f /D_s) /(2 * pi * L_f) + 4 * (1 + 0.54 * M_{CP}/M_f) * (Q / (2 * pi * L)^2 ) * (2/D_s - 2/D_f)$$

There are some details required to calculate the values of $D_f$ and L, based on some of the collected fibrous debris becoming trapped in the gaps and the rest collecting on a simple cylindrical surface. In essence, however, the calculated Head Loss will follow the unmodified NUREG Equation, given as Equation 6 above, till the volume of fibers approximately equals the volume of the gaps between the disks, call this volume $V_{fo}$, after which the remaining added fibers will build up on the strainer surface as if it were a simple cylinder. At that point, the Head Loss will be given by the logarithmic Equation 7 plus a correction added to this Equation 7 Head Loss, namely that of the Head Loss with only $V_{fo}$ $ft^3$ of fibers, as given by Equation 6.

**Figure 11** below shows a prediction for this logarithmic behavior with a strainer of the same outer dimensions (i.e., length and diameter) as the tested prototype with 4000 gpm of 70° F water flow. There are three curves: 1) one for the simple flat plate, as given by Equa6ion 6 above, b) a second for a simple cylinder, as given by Equation 7 above, and c) a third which describes the stacked disk behavior, where a volume of fibers = $V_{fo}$ first fills the gaps between the disks and afterwards the strainer behaves like a simple cylinder. This last curve, for the stacked disk, is conservative when compared to the test data and obviously would not have the strong discontinuity resulting from the simple model described above. More work is needed to make it less conservative and hence more accurate in describing the behavior of the **Sure-Flow Strainer** tested. This work is being performed by Innovative Technologies, Inc. and will not be described here.

FIGURE 11
HEAD LOSS VS. VOLUME OF FIBERS USING 70 F WATER
AND THREE DIFFERENT MODELS FOR HEAD LOSS ON THE TESTED
SURE-FLOW STRAINER WITH 4000 GPM & 100 LBS. CP,



## VI. CONCLUSIONS

A stacked disk strainer prototype was tested to determine its Head Loss performance over a wide range of Water Flow Rates and Mass of Fibrous Debris and for one quantity of Corrosion Product particulate. Mass of Fibrous Debris was varied from zero to 300 lbs., Mass of Corrosion Product Particulate was varied between 0 and 100 lbs., and Water Flow Rate was varied between zero and 10,000 gpm for this single strainer prototype. From these tests, the following conclusions could be reached about the behavior of the **Sure-Flow Strainer** prototype tested:

- the bare strainer (i.e., with no debris) showed a very low Head Loss behavior and that Head Loss is linearly dependent on the square of the entrance (i.e., at the strainer's nozzle) water velocity.
- its Head Loss behavior is essentially linearly dependent on both Mass of Fibrous Debris and Water Flow Rate,
- the addition of 100 lbs. of CP particulate increases Head Loss across the strainer by about 60%,
- the Head Loss behavior can be accurately modeled with regression equations, developed from the test data, and applied over the tested range of those variables, namely Mass of Fibrous Debris and Water Flow Rate.
- addition of stainless steel foil fragments, which simulate Reflective Metallic Insulation debris, increases the Head Loss across the **Sure-Flow Strainer** by about 20%.
- thick fibrous debris beds exhibited an effective filtration efficiency that approached unity (i.e., acted almost as a perfect filter).
- on this strainer prototype, the fibrous debris beds exhibited an apparent bed compaction of approximately 24% (using the as-fabricated insulation density as a reference).
- the **Sure-Flow Strainer**, mounted in a horizontal position, did not cavitate, even when the tank was drained so that the strainer was about half exposed above the water level.

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