UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

February 19, 1997

MEMORANDUM TO: Frank C. Cherny, Acting Chief
Generic Safety Issues Branch
Division of Engineering Technology
Office of Nuclear Regulatory Research

FROM: Aleck W. Serkiz, Senior Task Manager
Generic Safety Issues Branch
Division of Engineering Technology
Office of Nuclear Regulatory Research

AW Serkiz

SUBJECT: ECCS STACKED DISK STRAINERS MEETING

Performance Contracting, Inc. (PCI) and Innovative Technology Solutions Corp. (ITS) staff presented information related to PCI's stacked disk strainer testing and data comparisons with the BLOCKAGE 2 code correlation for estimating head loss across a BWR suction strainer as described in NUREG/CR-6224. Attendees are shown in Table 1, and the attachment "ECCS Stacked Disk Strainers" is the information presented by Messrs. G. Hart, Dr. P. Mast and G. Zigler.

A copy of the attachment is being placed in the PDR to provide an open record of the subject matter discussed.

cc: Attendees - w/o "ECCS Stacked Disk Strainers" attachment
L. C. Shao - w/attachment
M. Marshall, Jr. - w/attachment
PDR - w/attachment

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TABLE 1

Attendee Listing
ECCS Stacked Disk Strainers
Performance Contracting, Inc. & Innovative Technology Solutions, Inc.
February 1[illegible], 1997
USNRC Rockville, MD - Room T9-F5

Participant	Company & Address	Phone No.
Aleck W. Serkiz	USNRC/RES/DET/GSIB	301-415-6563
Robert Elliott	USNRC/NRR/SCSB	301-415-1397
Carl Berlinger	USNRC/NRR/SCSB	301-415-3627
Richard Lobel	USNRC/NRR/SCSB	301-415-2865
Andrew Kaufmann	Continuum Dynamics Inc. Princeton, NJ	609-734-9282
Robert Goss	TRANSCO Products Inc. Chicago, IL	312-427-2818
Bill Houston	Sequoia Consulting Group St. Augustine, FL	904-461-8774
Peter Mast	ITS Corporation Albuquerque, NM	505-254-1005
Gordon Hart	Performance Contracting, Inc. Kansas City, KS	413-441-0100
Gilbert Zigler	Science & Engineering Assoc. Albuquerque, NM	505-259-1005

ECCS Stacked Disk Strainers

PCI Full Scale Stacked Disk EPRI Tests

Modified NUREG/CR-6224 Correlation

Dr. Peter Mast & Gilbert L. Zigler
Innovative Technology Solutions Corporation

Gordon Hart
Performance Contracting Inc

Presented to the USNRC
February 18, 1997

Agenda

- Presentation by Gordon Hart on the full scale PCI stacked disk strainer tests conducted at EPRI
- Presentation by Dr. Peter Mast on a modified NUREG/CR-6224 correlation and comparison with test data
- Discussion

Review of PCI's Sure-Flow Strainer Head Loss Testing

- EPRI in December, 1995
  - conducted as part of the BWROG's strainer testing program
- EPRI in October, 1996
  - sponsored by PCI alone
- both sets of tests conducted by CDI

Features of the Test Strainer

- 24 inch NPS attachment flange and Internal Core Tube
- 40 inch outer diameter
- 48 inch active length and a 54 inch total length
- 170 ft^2 total surface area (of perf plate)
- 56 ft^2 of circumscribed cylindrical area

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Features of the Test Strainer

- thirteen disks, each 1.85" wide
- twelve gaps, each 2.00" wide (between the disks) with a total volume of 10.3 ft^3
- holes in the Internal Core Tube sized so as to provide equal Water Flow Rate from disk to disk.

1995 Strainer Testing Input

Test No.	Mass FG lbs.	Mass CP lbs.
95-1	0	0
95-2	17	85
95-3	25	100
95-4	3	100
95-5	50	100

1996 Strainer Testing Input

Test No.	Mass FG lbs.	Mass CP lbs.
96-1	0	0
96-2	25 + SS RMI	100
96-3	100, 150, 200, 250, and 300	0
96-4	100	100
96-5	200	100

Summary of Test Procedures

- Start with tank of clean water with pump operating at a constant flow rate
- Add dry CP and allow 5 - 10 minutes to mix
- Add fiber slurry, scattering them around the tank top
- Continuously measure Head Loss till its value stabilizes with time, about 50 minutes at 5000 gpm

Summary of Test Procedures (cont.)

- Reduce water flow to 2500 gpm, measure HL, then increase to 3750 gpm, measure HL,….., till we reach the max. value
- Perform add'l testing, such as cutting pump and restarting to determine whether debris drops off passively

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

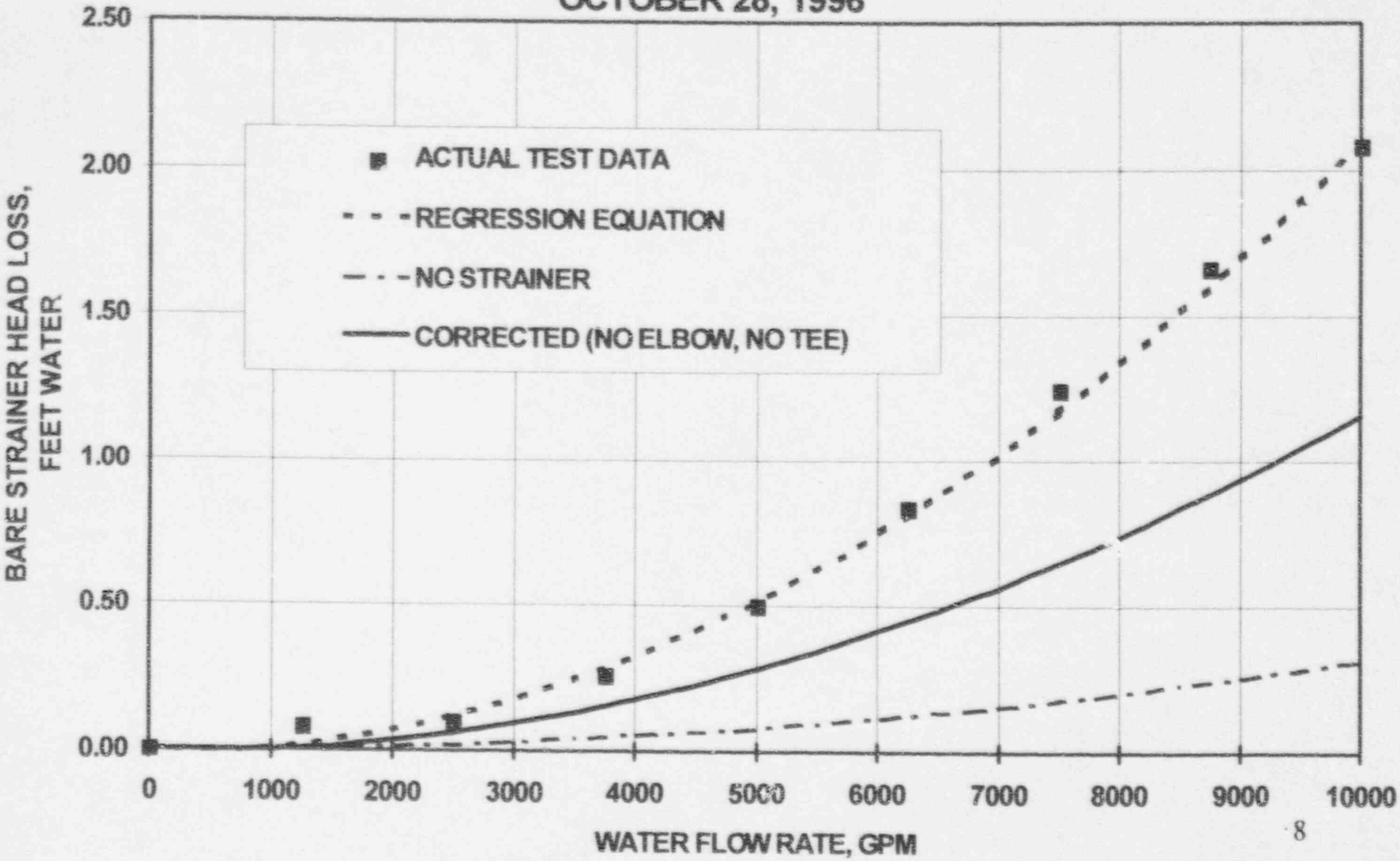

TABLE 2
Summary of Actual Head Loss Test Data from EPRI
1995 and 1996 Measured Data
All Head Loss Values in Feet of Water

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		4.55	6.15	8.32	9.65	5.40	10.73
3000 gpm												13.00
3500 gpm												16.67
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							

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

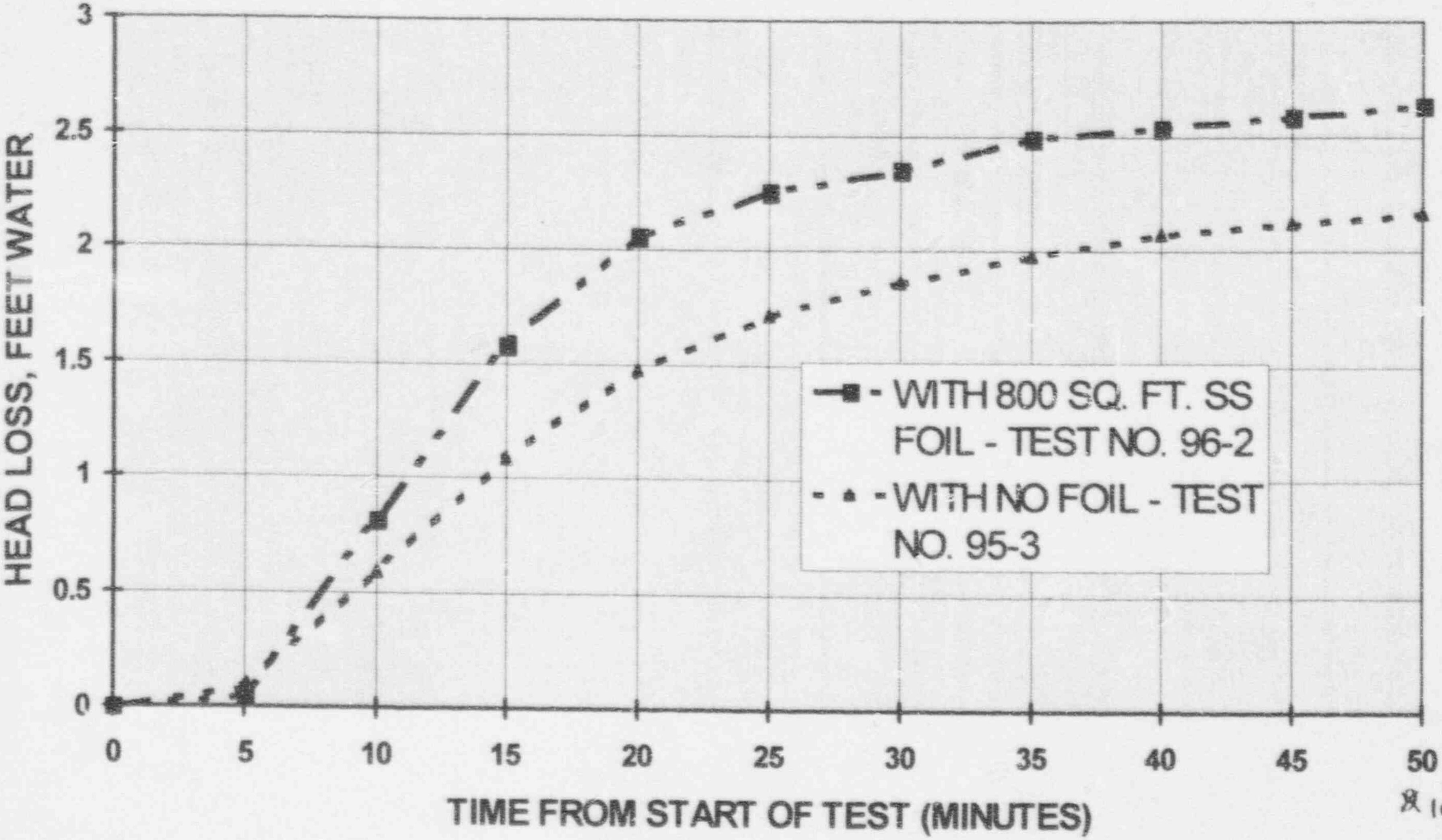

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FIGURE 4:
HEAD LOSS VS. FLOW RATE FOR THE SURE-FLOW STRAINER WITH FIBROUS DEBRIS AND NO CP PARTICULATE
HEAD LOSS VALUES CORRECTED FOR 60 DEGREES WATER

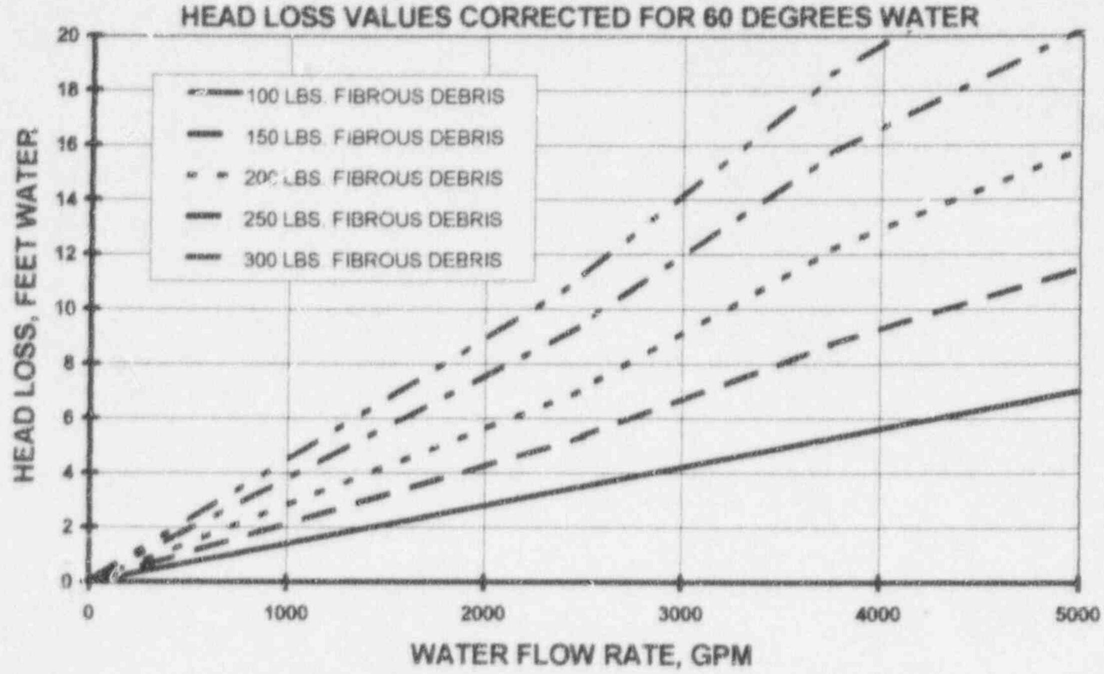


FIGURE 5:
HEAD LOSS VS. MASS FIBROUS DEBRIS FOR THE SURE-FLOW STRAINER WITH FIBROUS DEBRIS AND NO CP PARTICULATE
HEAD LOSS VALUES CORRECTED FOR 60 DEGREES WATER

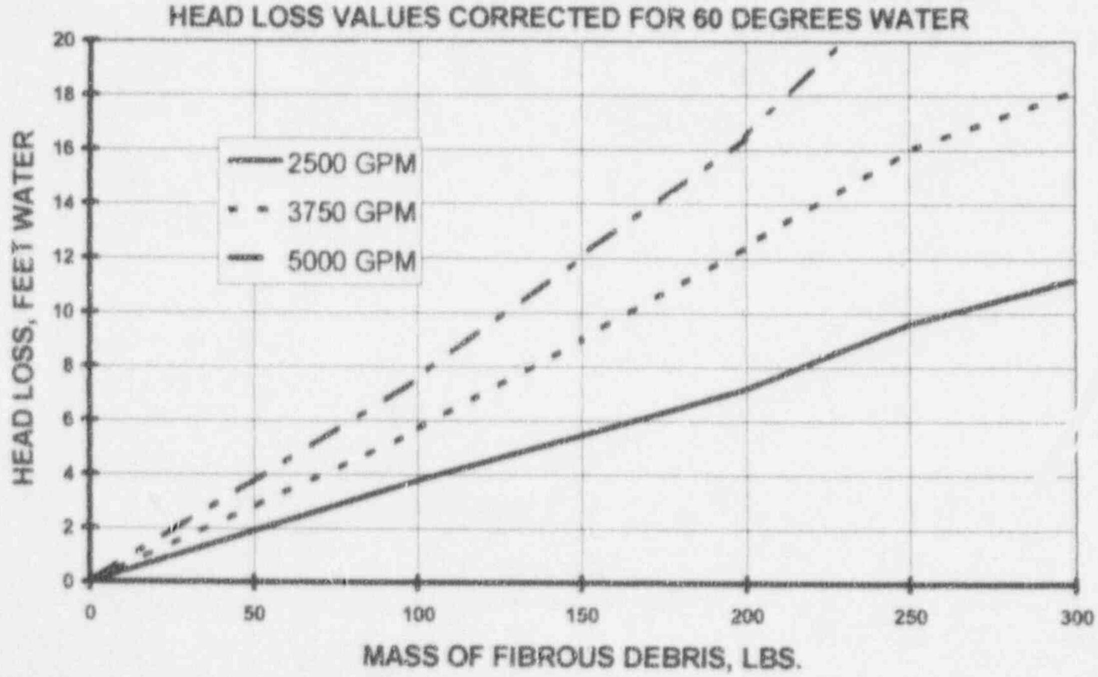


FIGURE 6:
TEST DATA ON PCI'S SURE-FLOW STRAINER AT EPRI:
HEAD LOSS VS. FLOW RATE FOR SEVERAL QUANTITIES OF FIBROUS DEBRIS, WITH 100 LBS. OF CP AND 60 F WATER

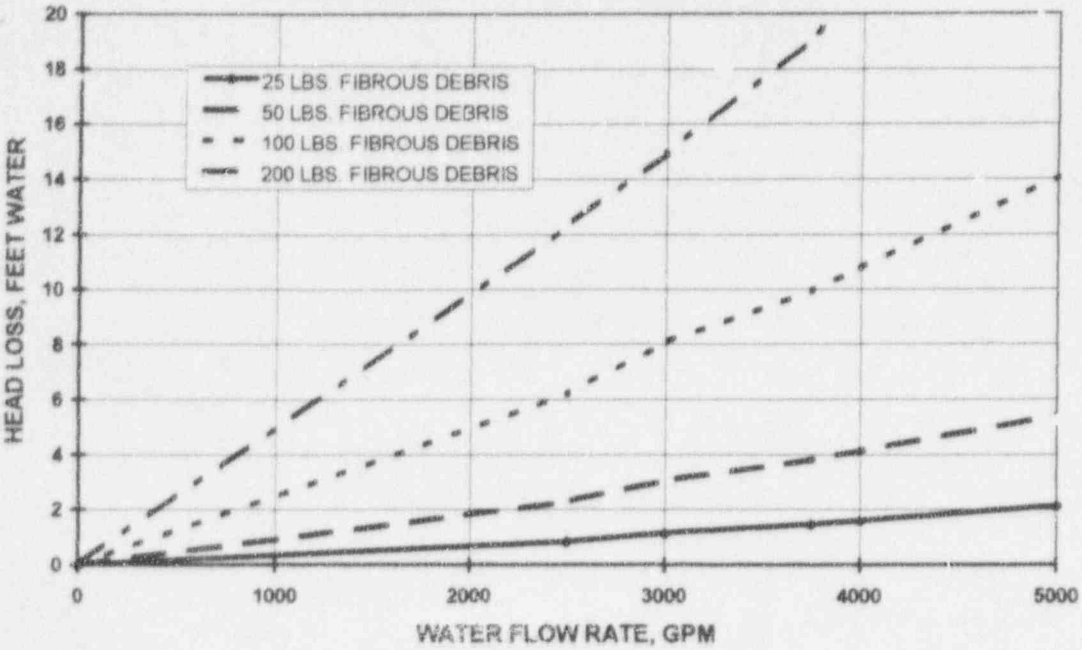
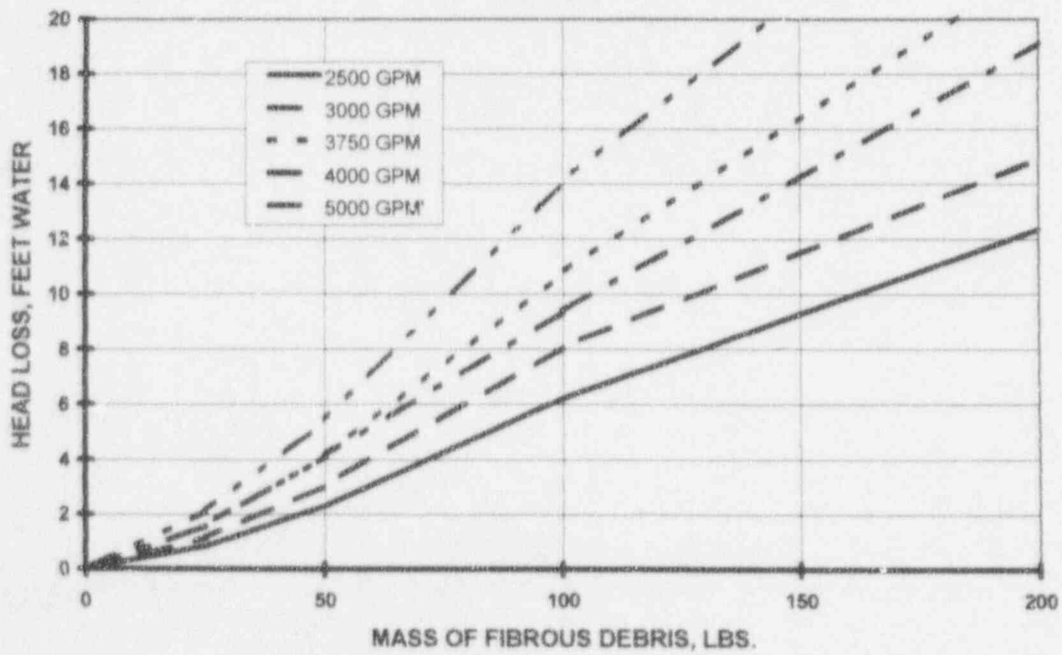


FIGURE 7:
TEST DATA ON PCI'S SURE-FLOW STRAINER TESTED AT EPRI :
HEAD LOSS VS. MASS OF FIBROUS DEBRIS, 100 LBS. OF C.P., AND 60 F WATER



Results of Regression Analysis: Head Loss w/ fibers and CP

$$HL = A + B * (Q/A_s) + C * (M_f/A_s) + D * (Q/A_s)(M_f/A_s)$$

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

where **A = 0.7696**

B = -0.02292

C = -0.5406

D = 0.08916

and $R^2 = 0.9828$ for this analysis

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Conclusions of Test Program

- Bare strainer HL is proportional to V^2 and includes an elbow and a tee
- Between 10 ft^3 and 20 ft^3 of NUKON fibers are needed to fill the gaps, after which thick beds are formed
- HL is essentially linear with Water Flow Rate and Mass Fibrous Debris for a given range of conditions

Conclusions of Test Program (cont.)

- HL behavior can be modeled with regression equations for this strainer geometry
- Thick beds have a filtration efficiency of almost 100%
- Addition of 2.5 mil SS RMI foil increases HL about 0.5 ft. water (20%) at 5000 gpm

Conclusions of Test Program (cont.)

- Fibrous bed showed a compaction of about 24%
- Horizontally mounted strainer would not cavitate, even when half uncovered

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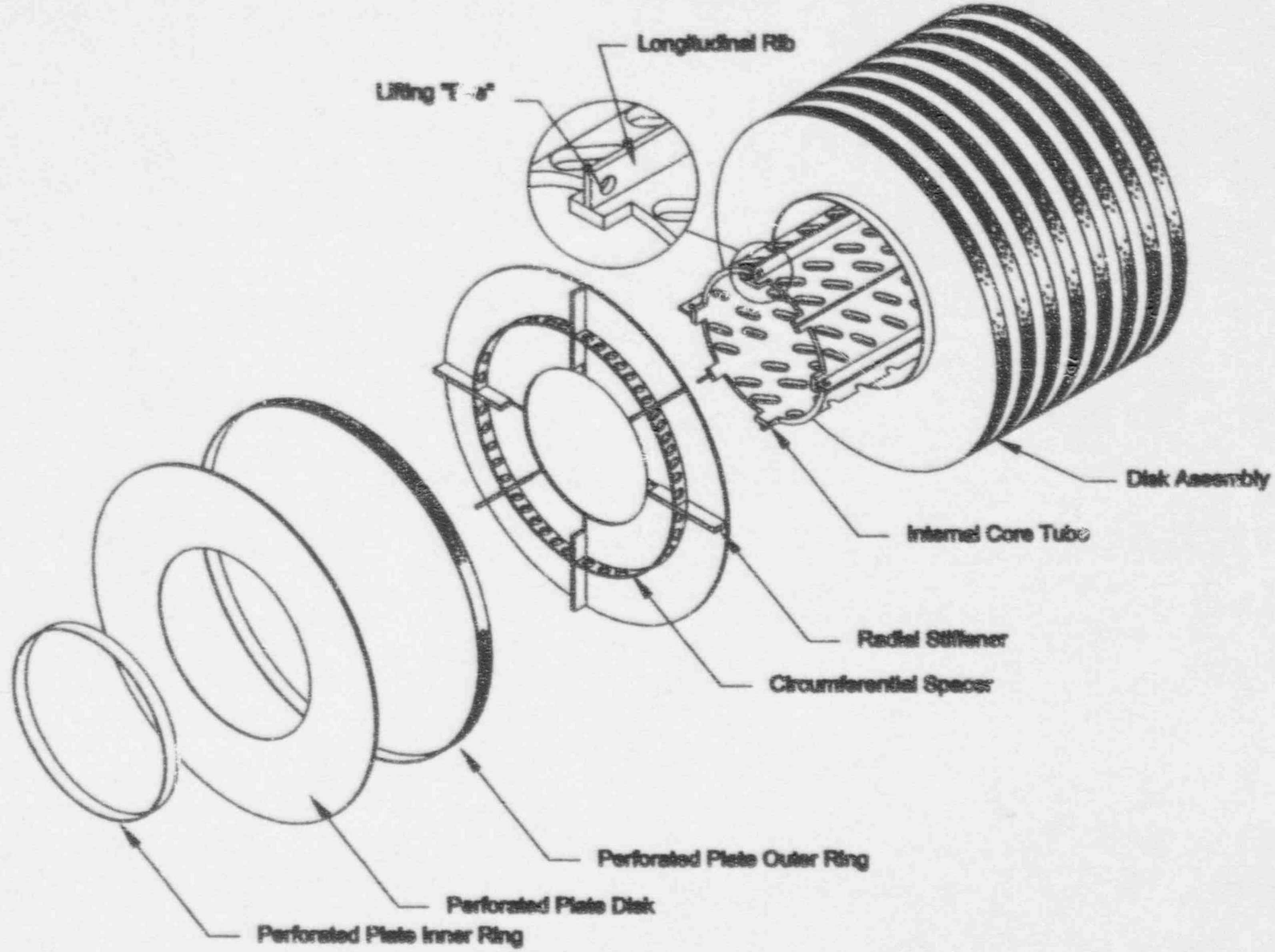
P.C.I.'S SURE-FLOW SUCTION STRAINER BOLT-ON MODEL



Comparison of Head Loss Model Based on NUREG/CR-6224 with PCI Full-Scale Strainer Test Data

Peter Mast & Francisco Souto

Innovative Technology Solutions Corporation

Presented to the US Nuclear Regulatory Commission

February 18, 1997

ITS Corporation

Purpose of Presentation

Present Suggested Approach for Extending Basic Head Loss Methodology Outlined in NUREG/CR-6224 to a Broader Range of Strainer Geometry and Debris Characteristics

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Purpose of Development Effort

Head Loss Model with the Following Attributes:

- Applicable to a variety of strainer geometries
- Applicable for heavy and light fiber loads
- Applicable to a variety of (non-RMI) debris types
- Sufficiently *accurate/conservative* to be acceptable to NRC

Overview

- Background
- Extended Head Loss Model Description
- Criteria for Assessing Head Loss Model Performance
- Validation of Extended Head Loss Model Using EPRI PCI Strainer Data
- Conclusions

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Head Loss Determination Options

- Measure performance of <u>actual</u> strainer under <u>actual</u> conditions expected
- Use strainer-specific "Correlation" to interpolate from within "Prototypic" data
- ***Develop "Model" that combines explicit treatment of key application-specific variables with use of generic "Correlations"***
- 1st principles "Model"

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Conclusions (cont.)

- The extended ITS model **conservatively predicts** the head loss across a stacked disk strainer when subjected to "intermediate" debris loads.

A single, unified model can be used to reliably predict head loss results under a wide range of debris loads for an arbitrary stacked disk strainer.

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ITS Approach

- Use NUREG/CR-6224 "semi-theoretical" correlation as a basis
- Determine shortcomings of "simple" application of that correlation
- Develop model for generic stacked-disk strainer and extend correlation for that application
- Validate new model to EPRI PCI strainer data
- Develop insights into PCI strainer performance

Review of NUREG/CR-6224 Methodology

- Models head loss as a function of debris thickness, debris bed porosity, surface-to-volume ratio
- Models head loss as a function of fluid properties

$$\Delta H = K_1\left[K_2 S_v^2 (1-\varepsilon_m)^{1.5}\left[1+K_3(1-\varepsilon_m)^3\right]\mu U + K_4 S_v \frac{(1-\varepsilon_m)}{\varepsilon_m}\rho_w U^2\right]\Delta L$$

$$\varepsilon_m = f(compression) \quad \Rightarrow \quad compression = 1.3[\Delta H / \Delta L]^{0.38}$$

where: $\Delta L = \dfrac{V_{fiber}}{A_s}$ and $U = \dfrac{Q}{A_s}$

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Advantages of NUREG/CR-6224 Methodology

- Form of correlation, correlation parameters based on years of data, wide variety of applications
- Readily applicable to a variety of debris types
- Only requires debris physical characteristics (size, density, etc.)
- Does not require "application-specific" data

except!

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Limitations of “Simple” Application of NUREG/CR-6224 Methodology

- NUREG/CR-6224 developed for flat disk strainers
- In reality fluid velocity and debris thickness are functions of:
  - Available surface area
  - Strainer geometry
- ‘Blind’ application of the NUREG/CR-6224 head loss model to a stacked disk strainer under heavy fiber loads significantly *underpredicts* strainer head loss.
  - “Discrepancies” as large as 80% were observed and major trends were not predicted.

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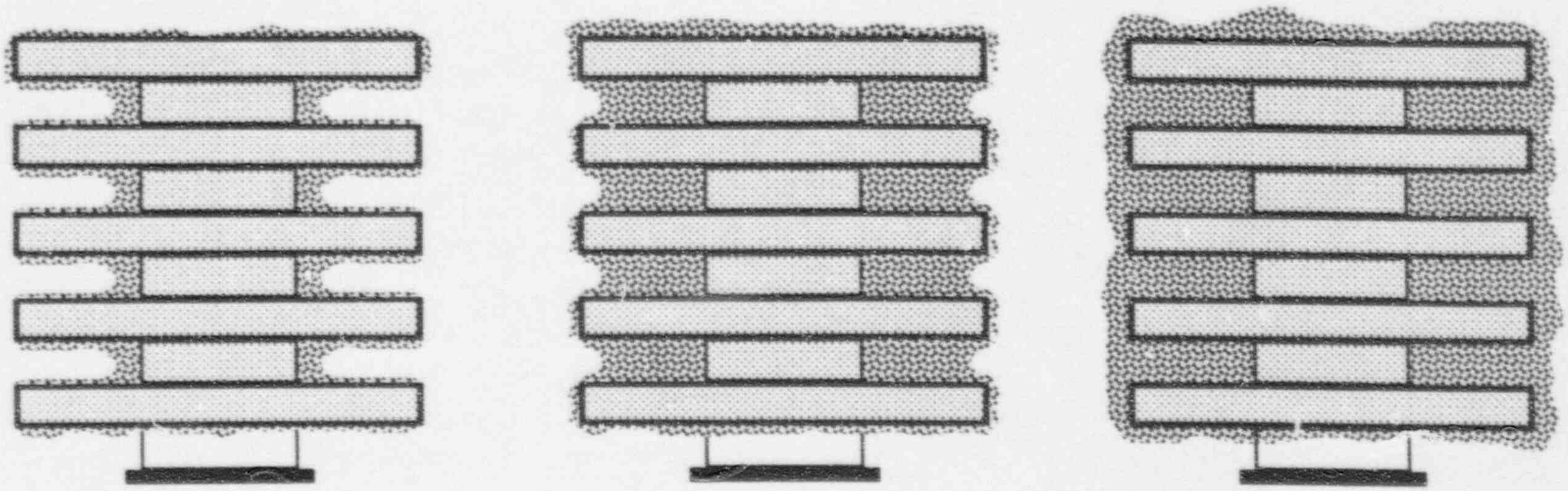
Illustration of Changes in Strainer Area at High Fiber Loads



Stacked-Disk Surface Area

Partial Loss of Inner Surface

Approach to Circumscribed Cylinder

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ITS Extended Head Loss Model
Light Fiber Load

For V_d such that

$$\Delta L(V_d \,.\, A_s) \leq \Delta L_{\max}$$

$$A = full\ strainer\ surface\ area\,,\ A_s$$
$$V = V_d$$
$$\Delta L = \Delta L(V\,,\, A,\, flat\ geometry)$$
$$U = U(\,flow,\, A)$$
$$\Delta H = \Delta H(\Delta L, U\,)$$

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ITS Extended Head Loss Model
Heavy Fiber Load

For V_d such that

$$\Delta L(V_d, A_s) \geq h_{gap} / 2$$

$$A = circumscribed\ surface\ area,\ A_c$$

$$V = V_d - V_{gap}$$

$$\Delta L = \Delta L(V, A, cylindrical\ geometry)$$

$$U = U(flow, A)$$

$$\Delta H = \Delta H(\Delta L, U)$$

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ITS Extended Head Loss Model Intermediate Fiber Load

$$\Delta L_{\max} \geq \Delta L(V_d, A_s) \geq h_{gap} / 2$$

$$V_1 = V_d(\Delta L_{\max})$$

$$\Delta H_1 = \Delta H(\Delta L_{\max}, U_{flat}, flat\ geometry)$$

$$V_2 = V_d(h_{gap} / 2)$$

$$\Delta H_2 = \Delta H(h_{gap} / 2, U_{circ}, cylindrical\ geometry)$$

$$\Delta H = \Delta H_1 + (\Delta H_2 - \Delta H_1)\frac{V_d - V_1}{V_2 - V_1}$$

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Criteria for Assessing Head Loss Correlation Performance

- Variability in measured head loss ranges from ±10% to ±25% depending on the data considered.
  - Variability tends to be smaller in tests repeated in the same facility, and larger for tests of the same conditions conducted in different facilities
- International working group concluded typical measurement variability to be ± 20-30%*
  - » *Correlation performance within 20-30% is acceptable provided results do not consistently under-predict measurements.*

* OECD document NEA/CSNI/R (95) 11, February 1996

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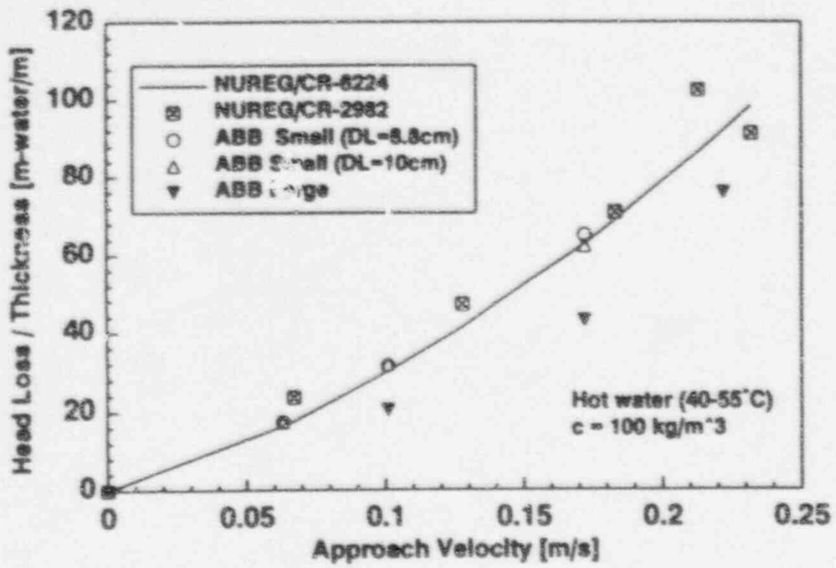
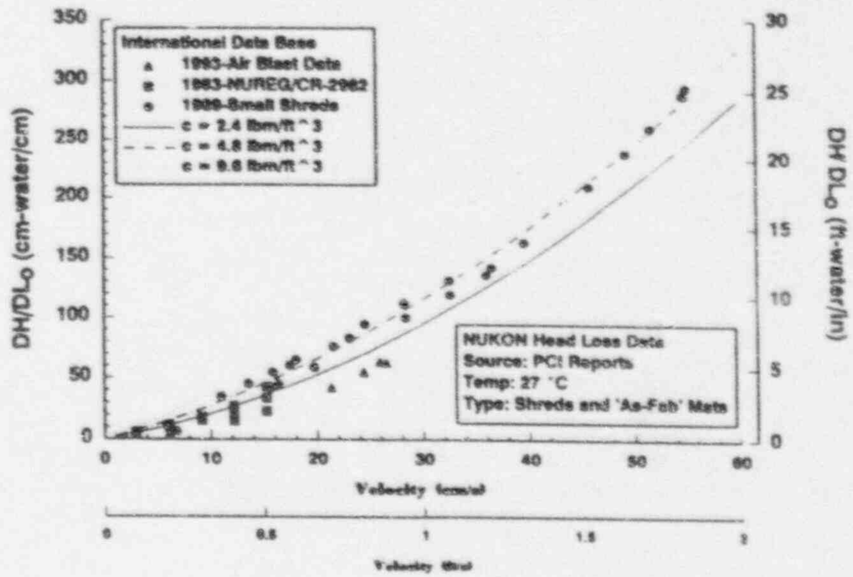
Examples of Test Data Variability



Mineral Wool*



NUKON™**

Refs: * OECD document NEA/CSNI/R (95) 11, February 1996

** NUREG/CR-6224, App. B

Impact of Uncertainties on Model Prediction

- +/- 1 degree F in water temperature

  +/- 1.5% in head loss

- +/- 0.1 lb/cu-ft in insulation density

  +/- 7% in head loss

(Representative values calculated for test 96-3C at 3750 gpm)

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Available EPRI Test Data for PCI Stacked Disk Strainers

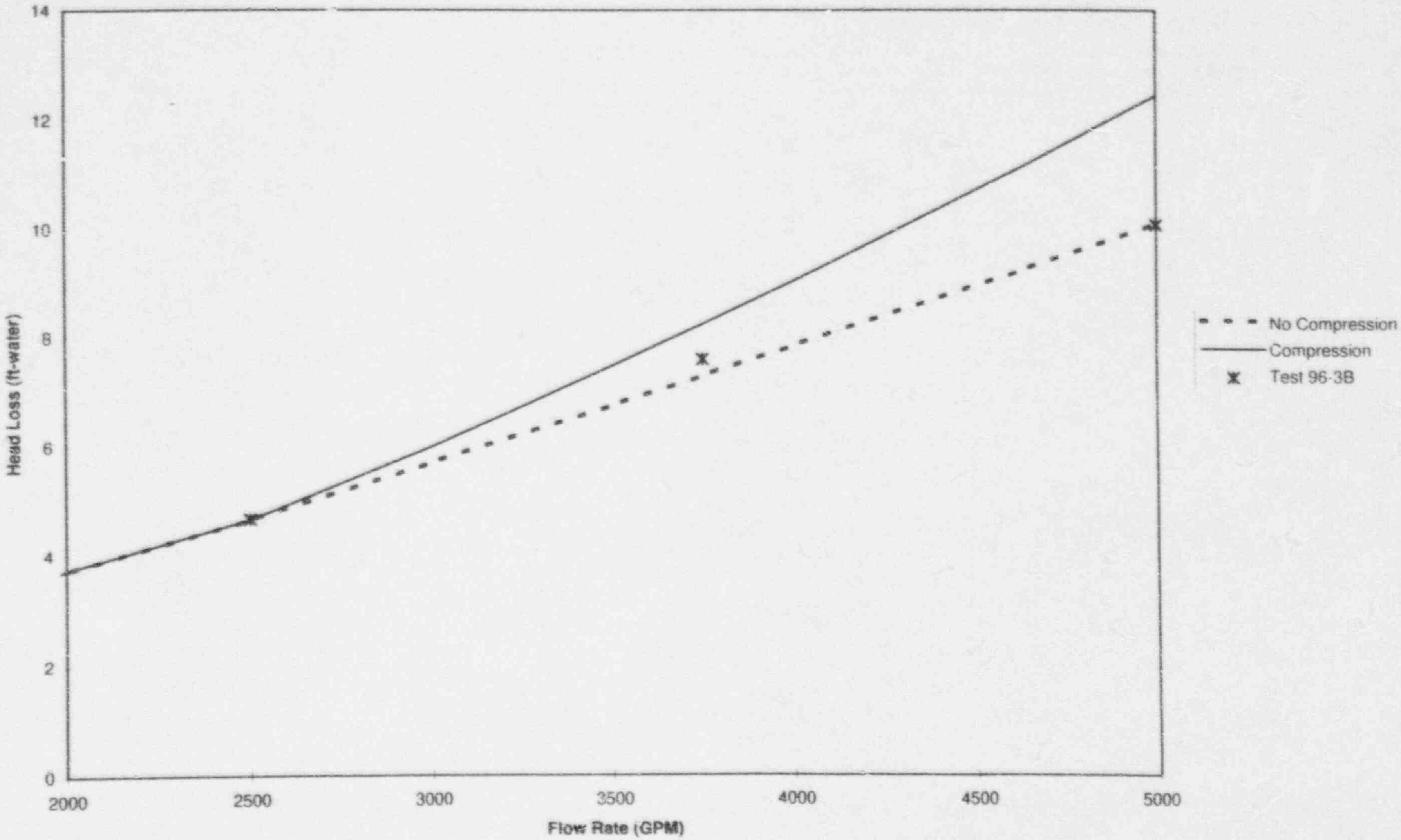
- *December 1995*: Full Scale EPRI Test
  - Test series P2, P3, and P5
  - Fiber mass of 17, 25 and 50 lbs with sludge mass of 85 and 100 lbs
- *October 1996*: Full Scale EPRI Test
  - Test series 3A - D, 4 and 5
  - Fiber mass of 100 to 250 lbs (no sludge)
  - Fiber mass of 100 lbs with 100 lbs sludge
  - Fiber mass of 200 lbs with 100 lbs sludge

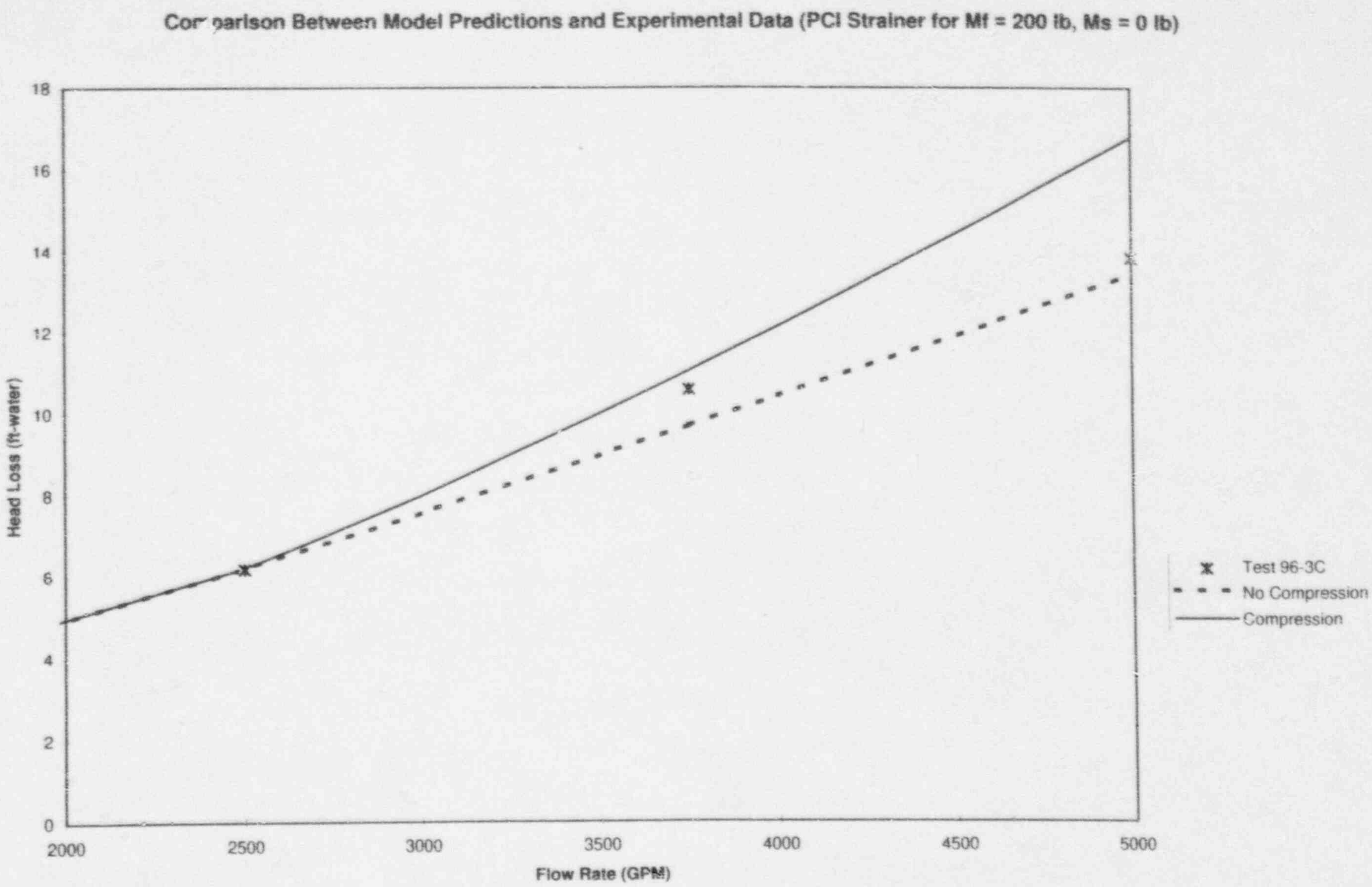
Comparison for Tests 96:3A-D

Heavy Fiber Load w/o Sludge

- Experimental data (*CDI report values*)
- ITS model predictions with NUREG/CR-6224 debris bed compression formulation
- ITS model predictions w/o compression
- No adjustment of correlation parameters to match experimental data!

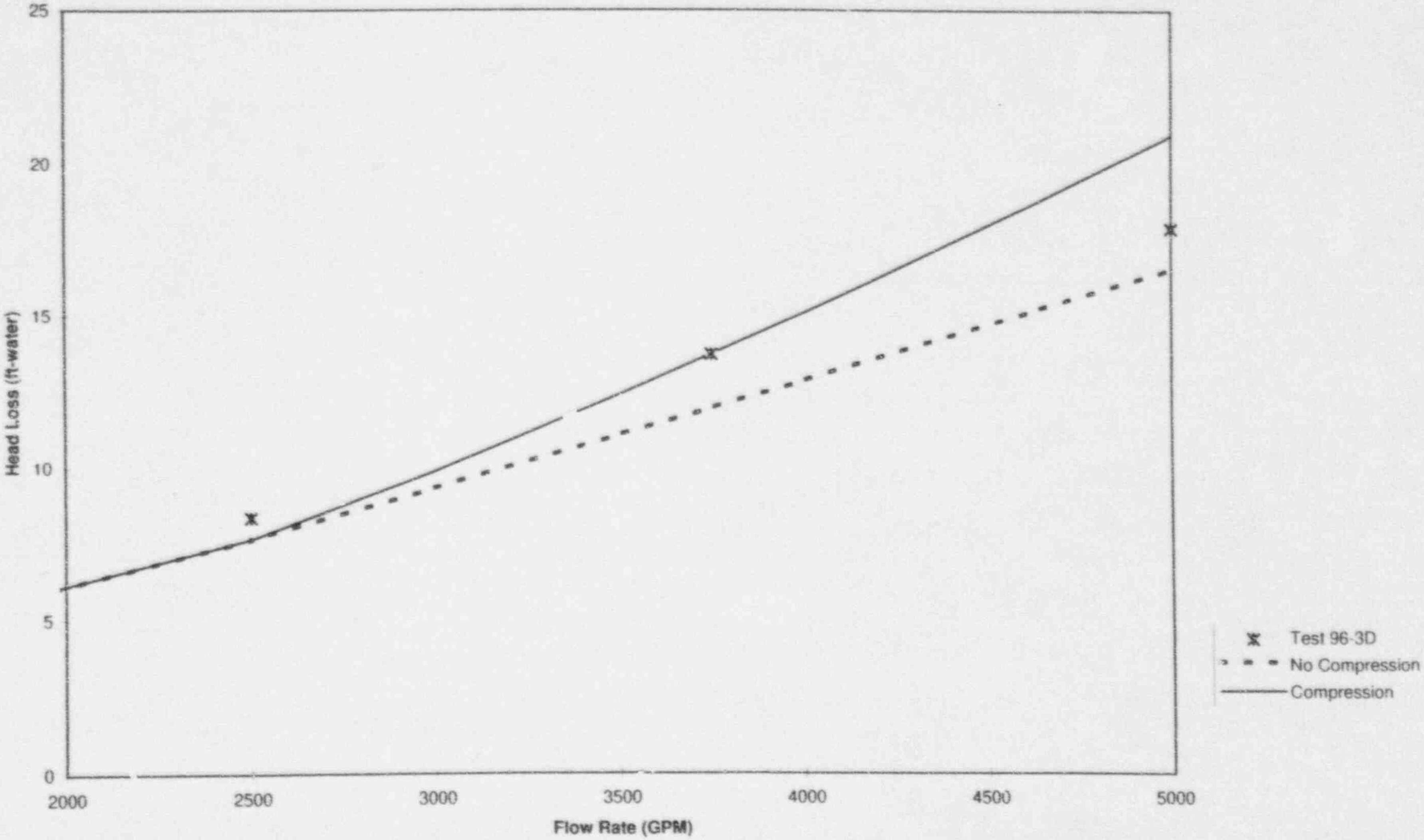
Comparison Between Model Predictions and Experimental Data (PCI Strainer for Mf = 150 lb, Ms = 0 lb)



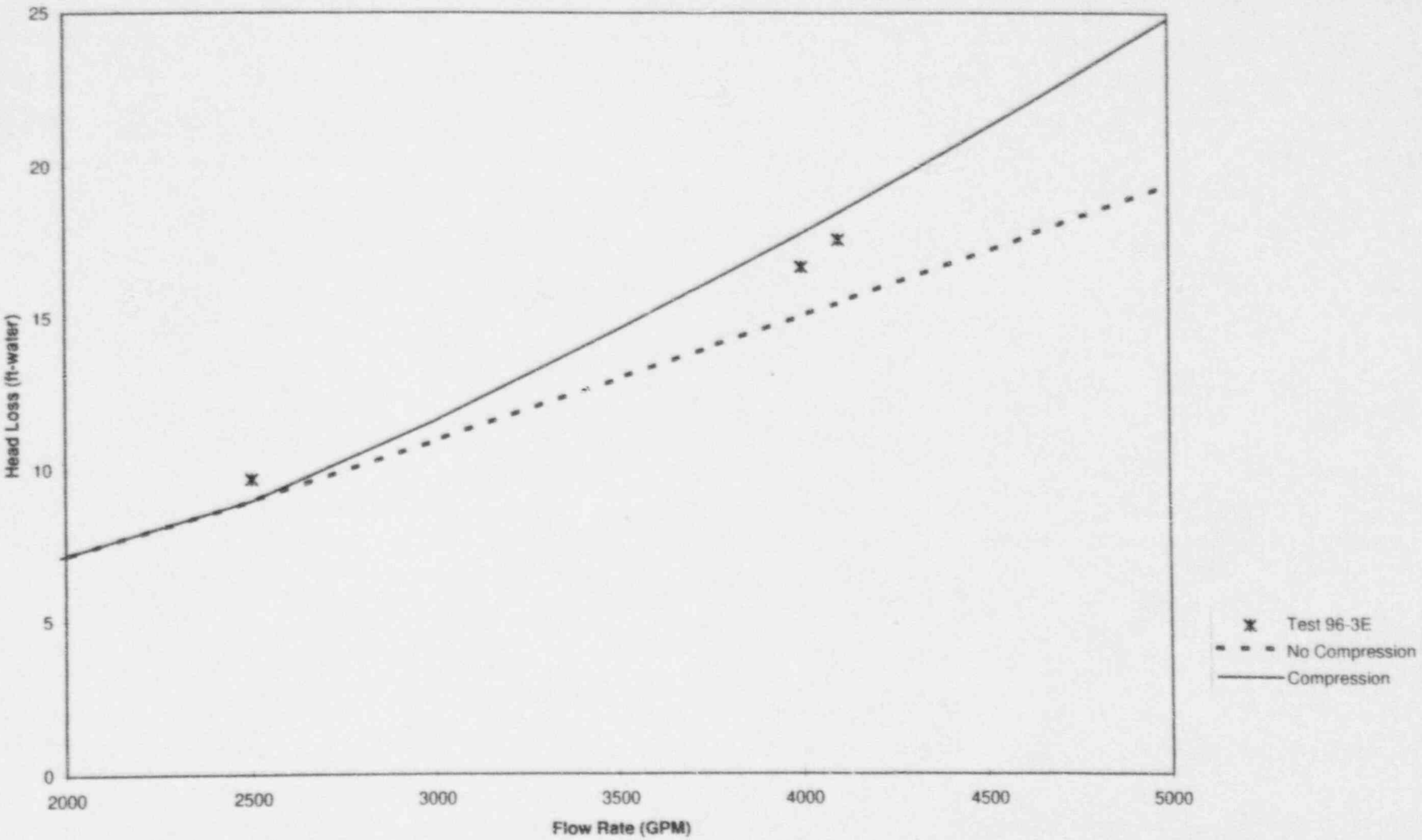


Comparison Between Model Predictions and Experimental Data (PCI Strainer for Mf = 200 lb, Ms = 0 lb)
Head Loss (ft-water)
Flow Rate (GPM)
0
2
4
6
8
10
12
14
16
18
2000
2500
3000
3500
4000
4500
5000
Test 96-3C
No Compression
Compression

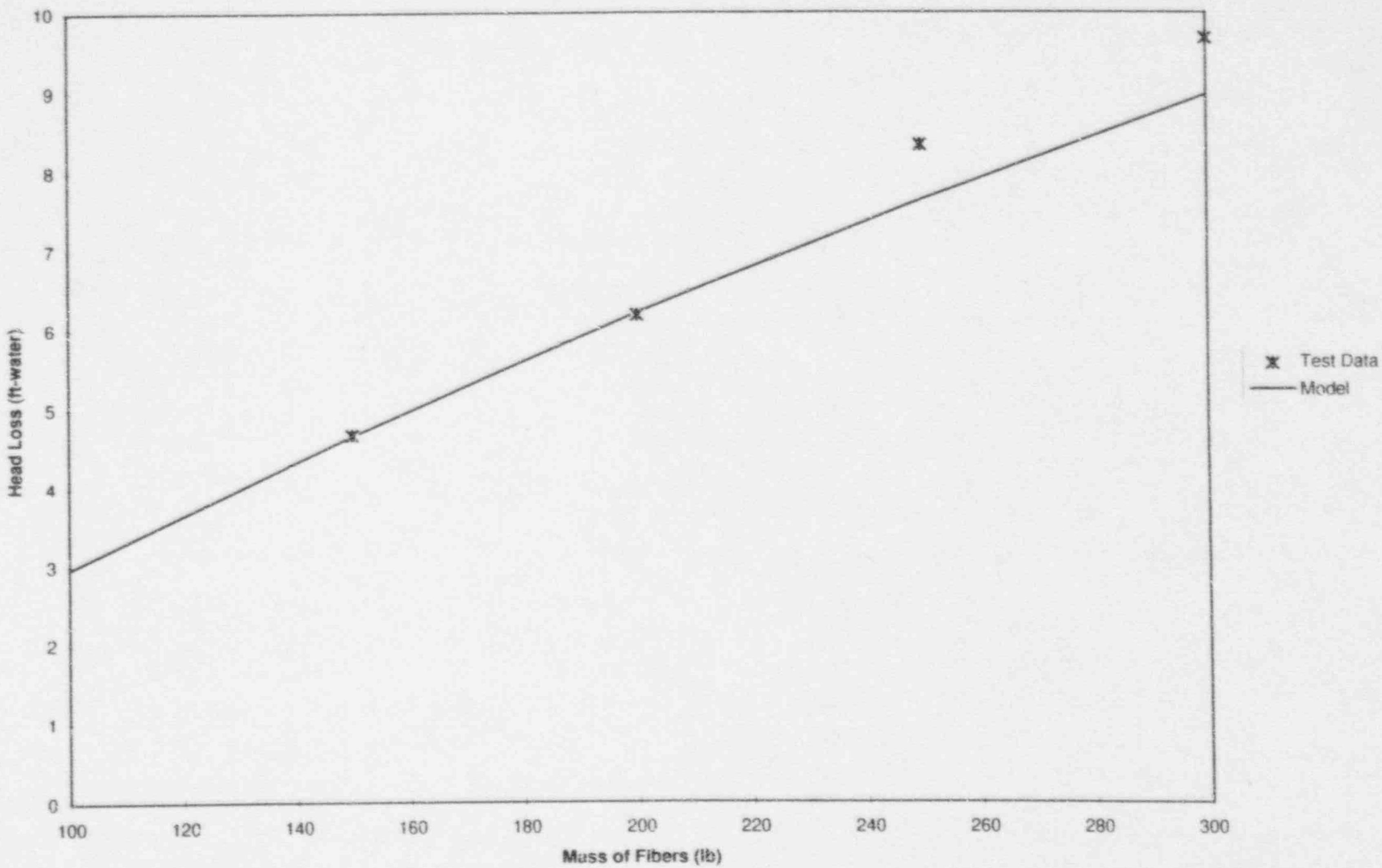
Comparison Bewteen Model Predictions and Experimental Data (PCI Strainer for Mf=250 lb, Ms = 0 lb)



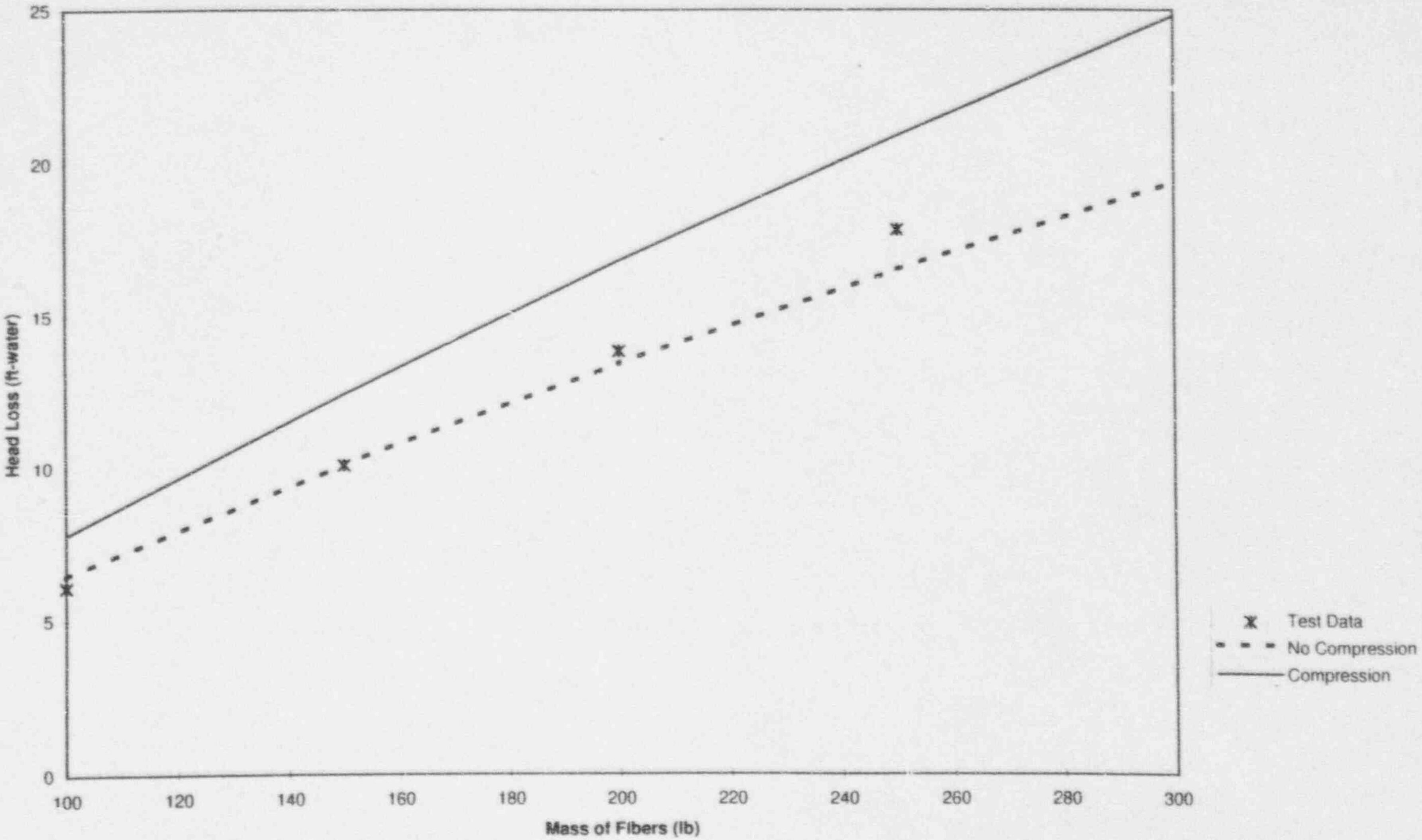
Comparison Between Model Predictions and Experimental Data (PCI Strainer for Mf = 300 lb, Ms = 0 lb)



Comparison Between Model Predictions and Experimental Data (PCI Strainer at 2500 GPM With No Sludge)



Comparison Between Model Predictions and Experimental Data (PCI Strainer at 5000 GPM With No Sludge)



Comparison for Tests 96:4,5

Heavy Fiber Load with Sludge

- Experimental data (*CDI report values*)
- ITS model predictions with NUREG/CR-6224 debris bed compression formulation
- ITS model predictions w/o compression
- No adjustment of correlation parameters to match experimental data!

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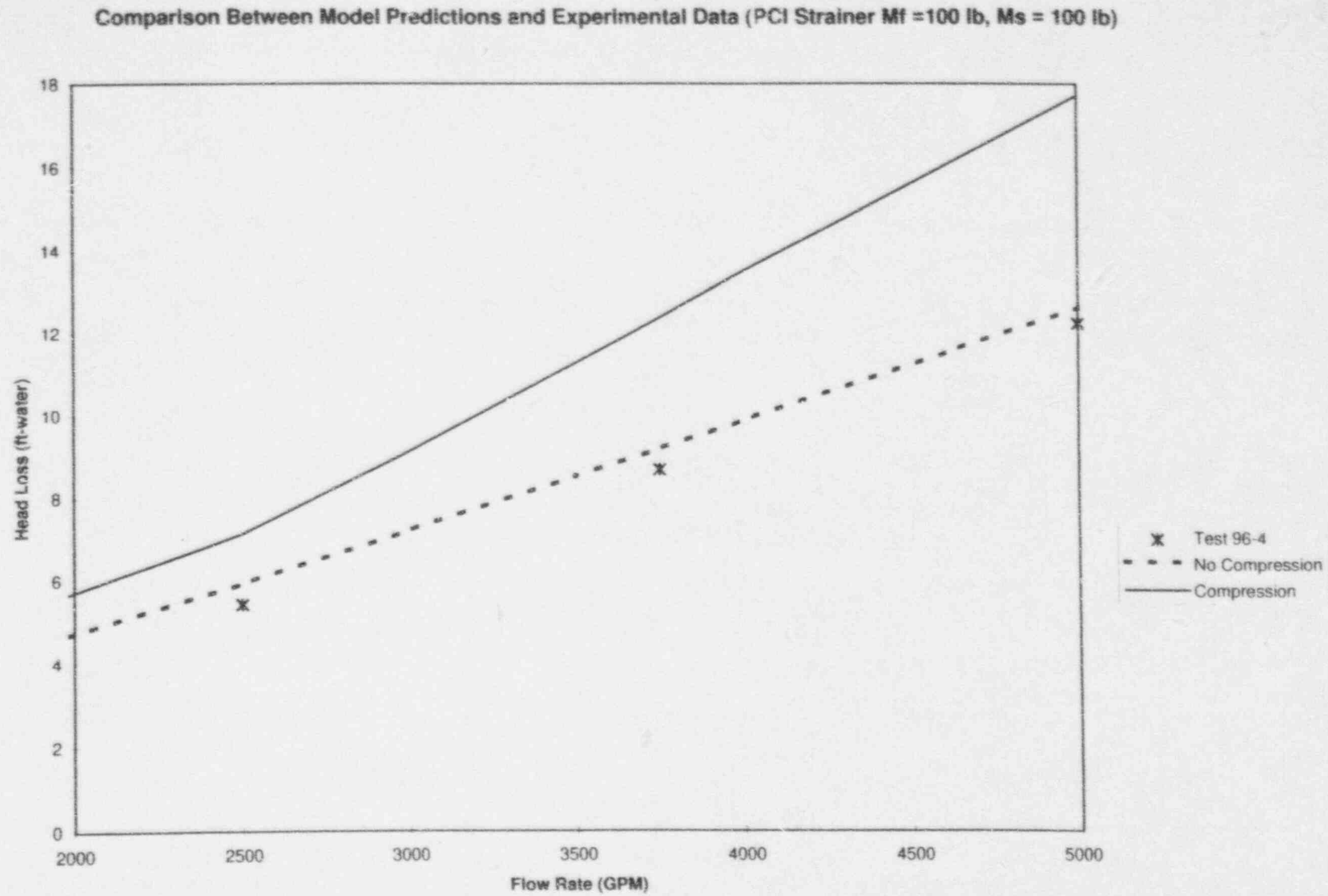
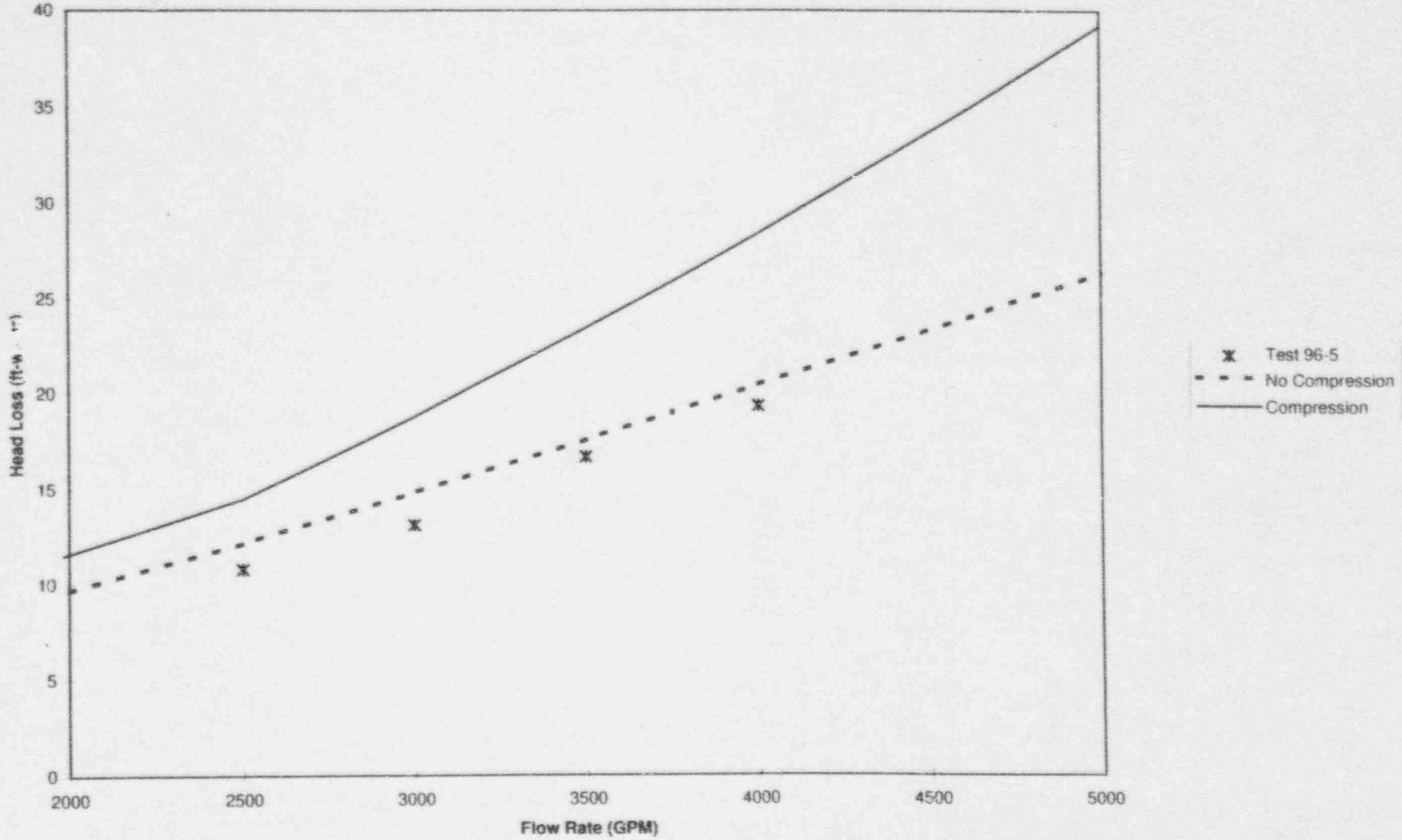

Comparison Between Model Predictions and Experimental Data (PCI Strainer Mf =100 lb, Ms = 100 lb)
Head Loss (ft-water)
Flow Rate (GPM)
0
2
4
6
8
10
12
14
16
18
2000
2500
3000
3500
4000
4500
5000
Test 96-4
No Compression
Compression

Comparison between Model Predictions and Experimental Data (PCI Strainer Mf = 200 lb, Ms = 100 lb)



Comparison for Tests 95:P2,3

Light Fiber Load with Sludge

- Experimental data (*CDI report values*)
- ITS model predictions with NUREG/CR-6224 debris bed compression formulation
- ITS model predictions w/o compression
- No adjustment of correlation parameters to match experimental data!

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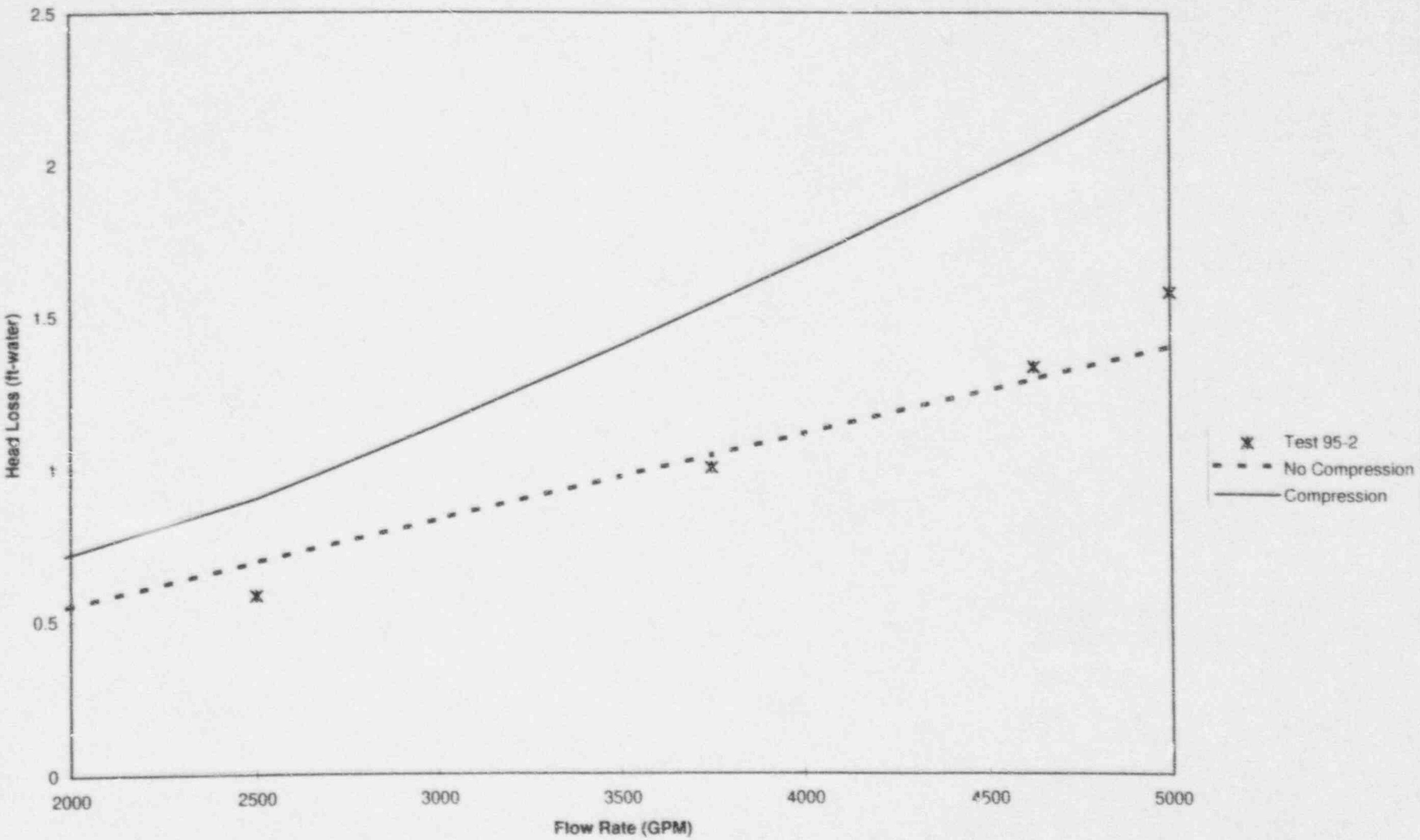
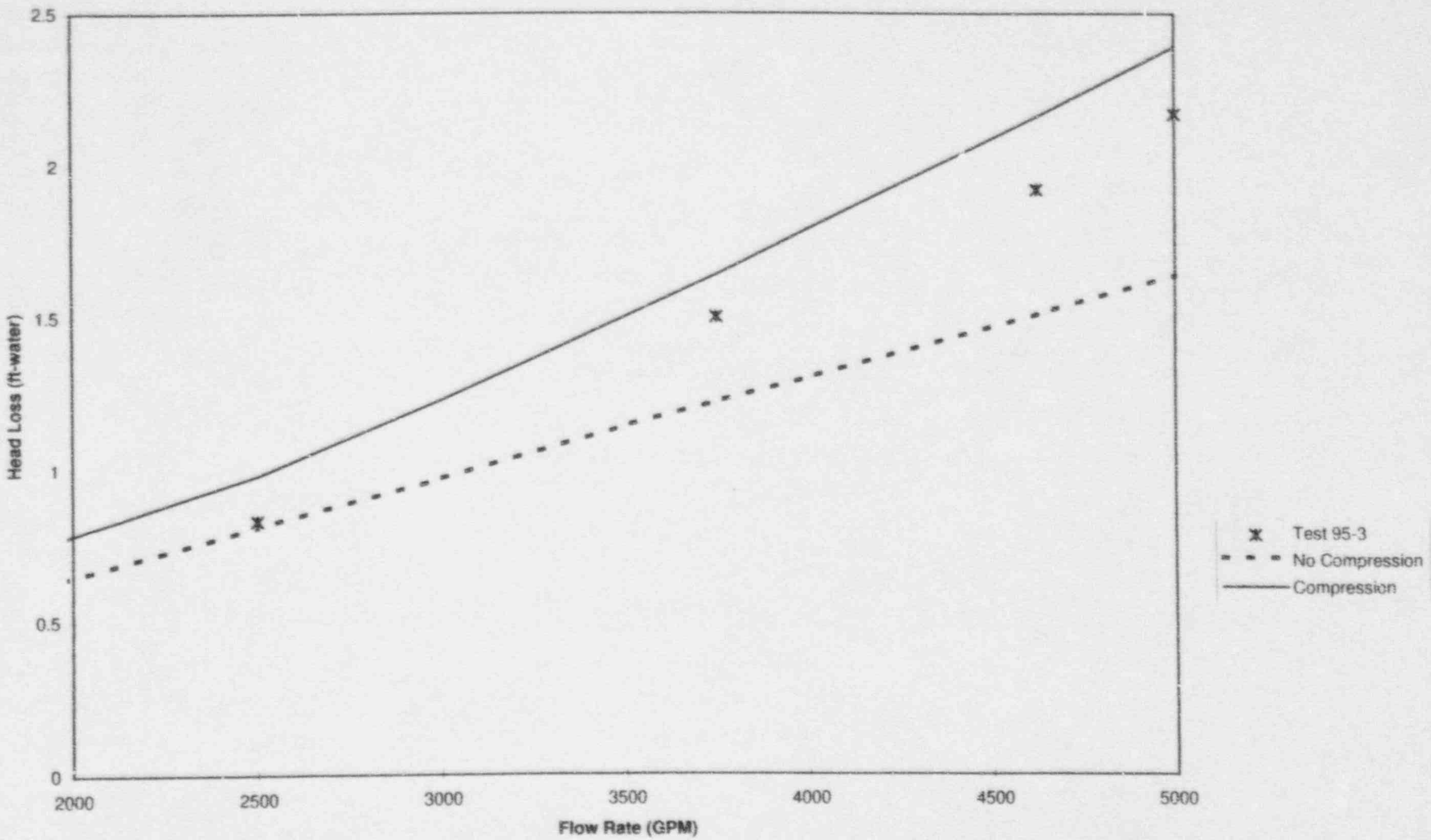
Comparison Between Model Predictions and Experimental Data (PCI Strainer, Mf = 17 lb, Ms = 85 lb)



Comparison Between Model Predictions and Experimental Data (PCI Strainer Mf=25 lb, Ms=100 lb)



Comparison for Tests 95:P2,3
Adjusted Filtration Efficiency

- Experimental data (*CDI report values*)
- ITS model predictions
  - with NUREG/CR-6224 debris bed compression formulation
  - with filtration efficiency of 0.75 for P2
  - with filtration efficiency of 0.90 for P3

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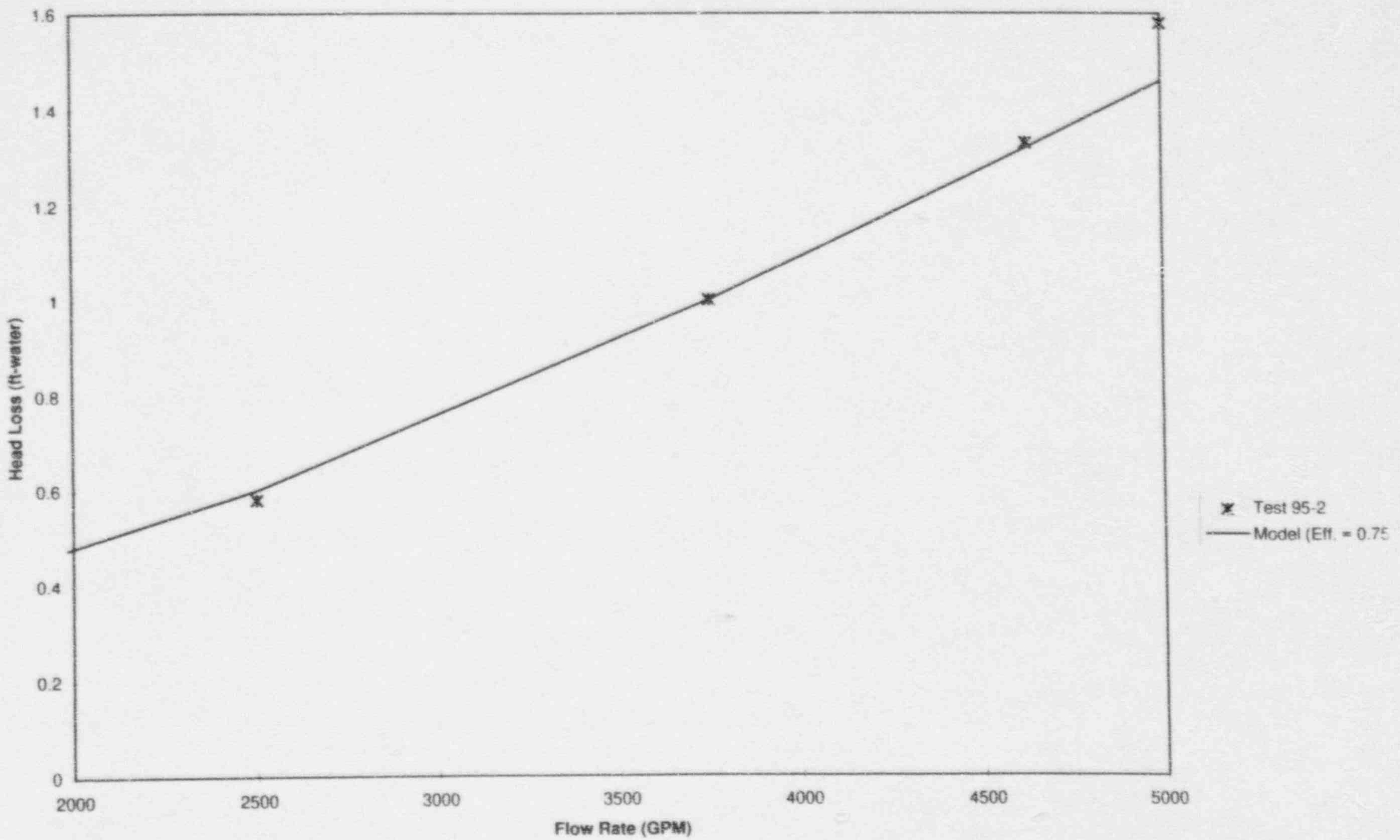
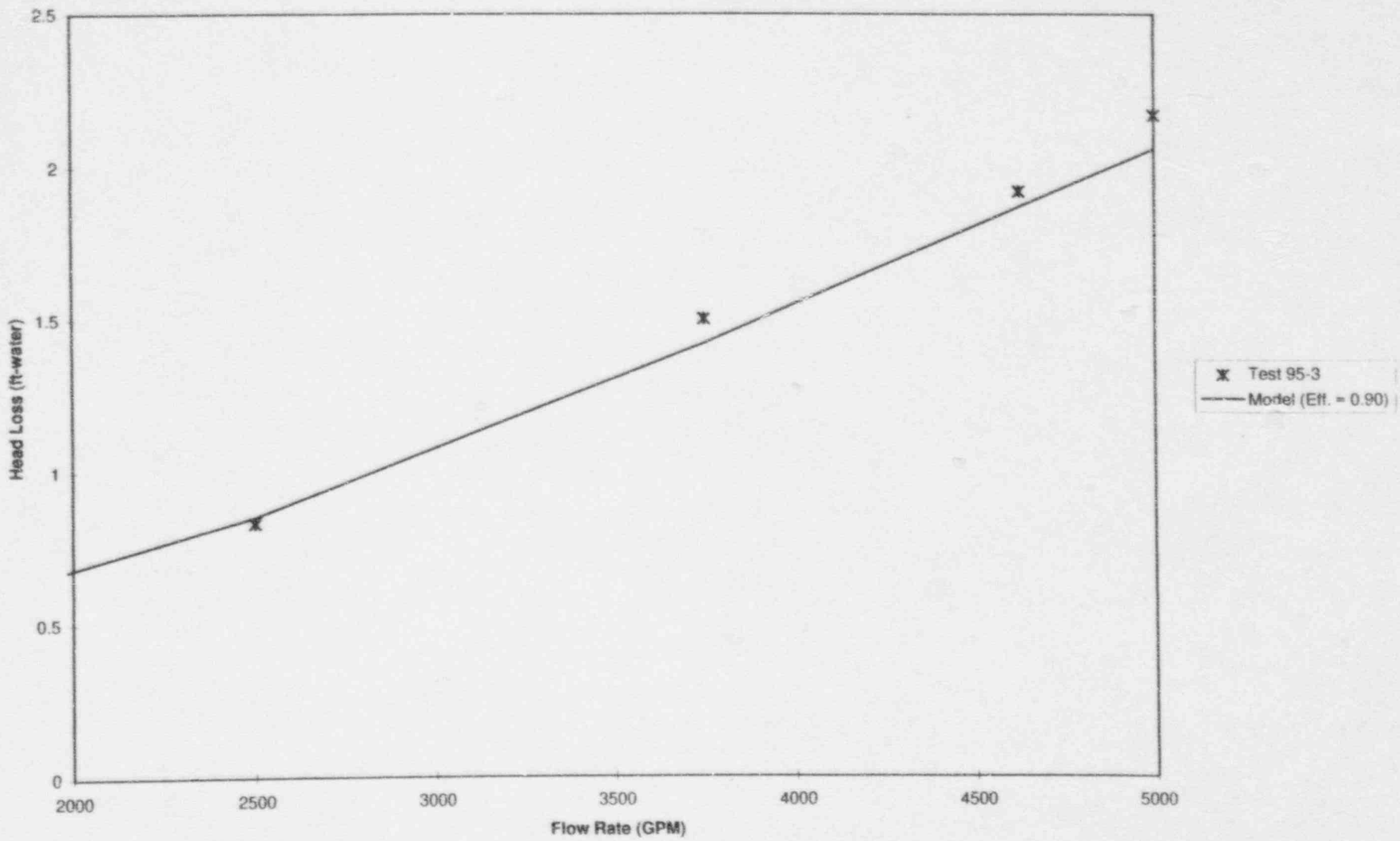
Comparison Between Model Predictions and Experimental Data (PCI Strainer, Mf = 17 lb, Ms = 85 lb)



Comparison Between Model Predictions and Experimental Data (PCI Strainer, Mf = 25 lb, Ms = 100 lb)



Comparison for Tests 95:P5

Moderate Fiber Load with Sludge

- Experimental data (*CDI report values*)
- ITS model predictions with NUREG/CR-6224 debris bed compression formulation
- ITS model predictions w/o compression
- No adjustment of correlation parameters to match experimental data!

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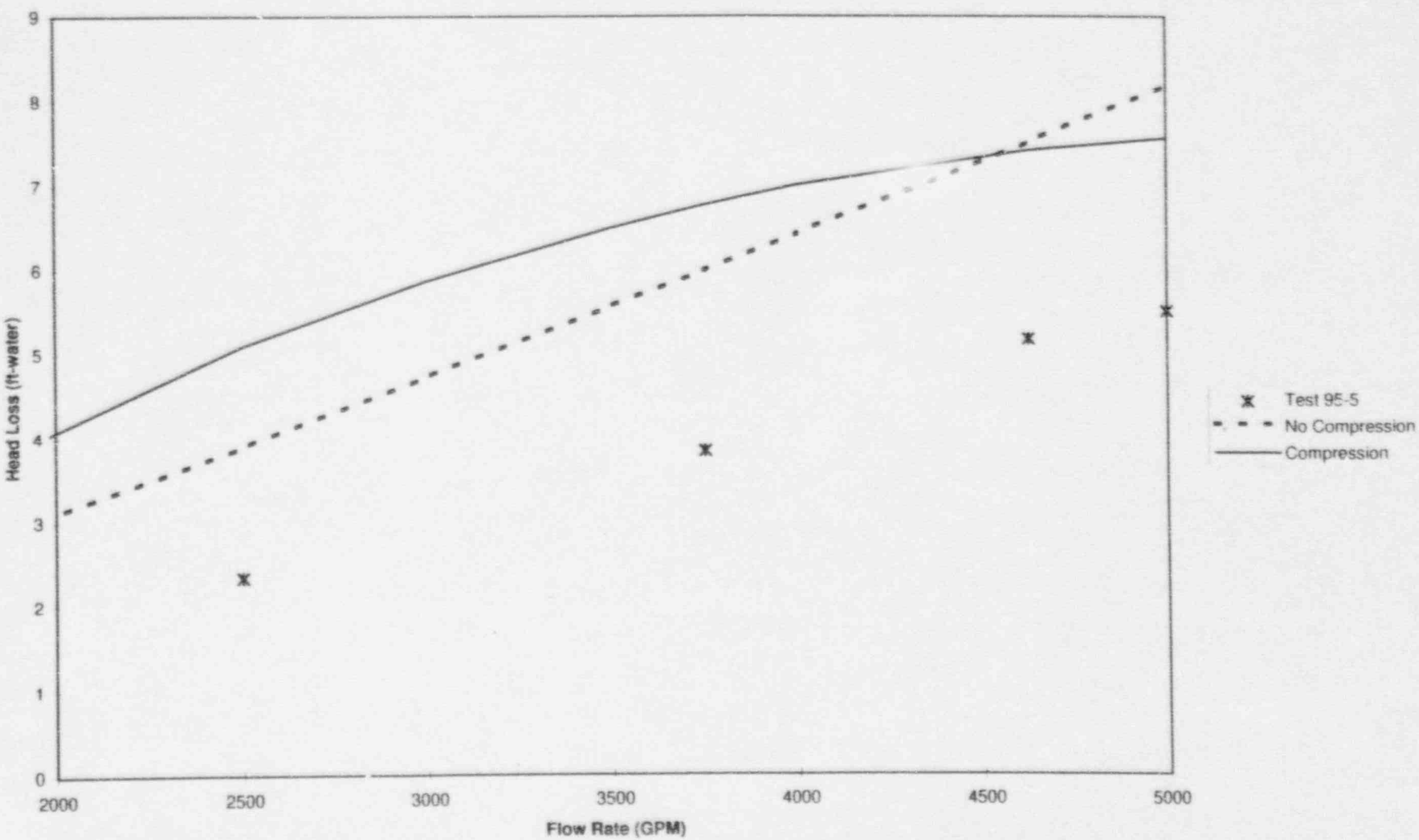
Comparison Between Model Predictions and Experimental Data (PCI Strainer, Mf = 50 lb, Ms = 100 lb)



Conclusions

- The "*un-modified*" NUREG/CR-6224 head loss model **conservatively predicts** the head loss across a stacked disk strainer subjected to small debris loads with varying amounts of sludge.
- The "*un-modified*" NUREG/CR-6224 head loss model provides **excellent** agreement for such conditions when less than perfect filtration efficiency is accounted for.

ITS Corporation

Conclusions (cont.)

- An extended model developed at ITS, which accounts for changes in available strainer area as debris accumulates within the gaps of the stacked disks and which accounts for the strainer cylindrical geometry, provides **excellent** agreement for heavy fiber loads both with and without sludge.