Selected Thermal and Hydraulic Experimentation in Support of the Advanced Neutron Source Reactor

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Outline

- Thermal Hydraulic Limit Testing
- Fuel Plate Stability Testing
- Flow Blockage Testing

The ANS Reactor Has Unique Thermal-Hydraulic Characteristics in Comparison to Other Research and Commercial Reactors

- Heavy water coolant
- Parallel Rectangular channels (involute)
- Very small channel gap (1.27 mm)
- Very high velocity (25 m/s)
- Very high exit subcooling (110°C)
- Moderately high heat flux (5.9 MW/m^2 average and 12 MW/m^2 maximum)
- High average power density (4.5 MW/L)
- Large L/D (200)

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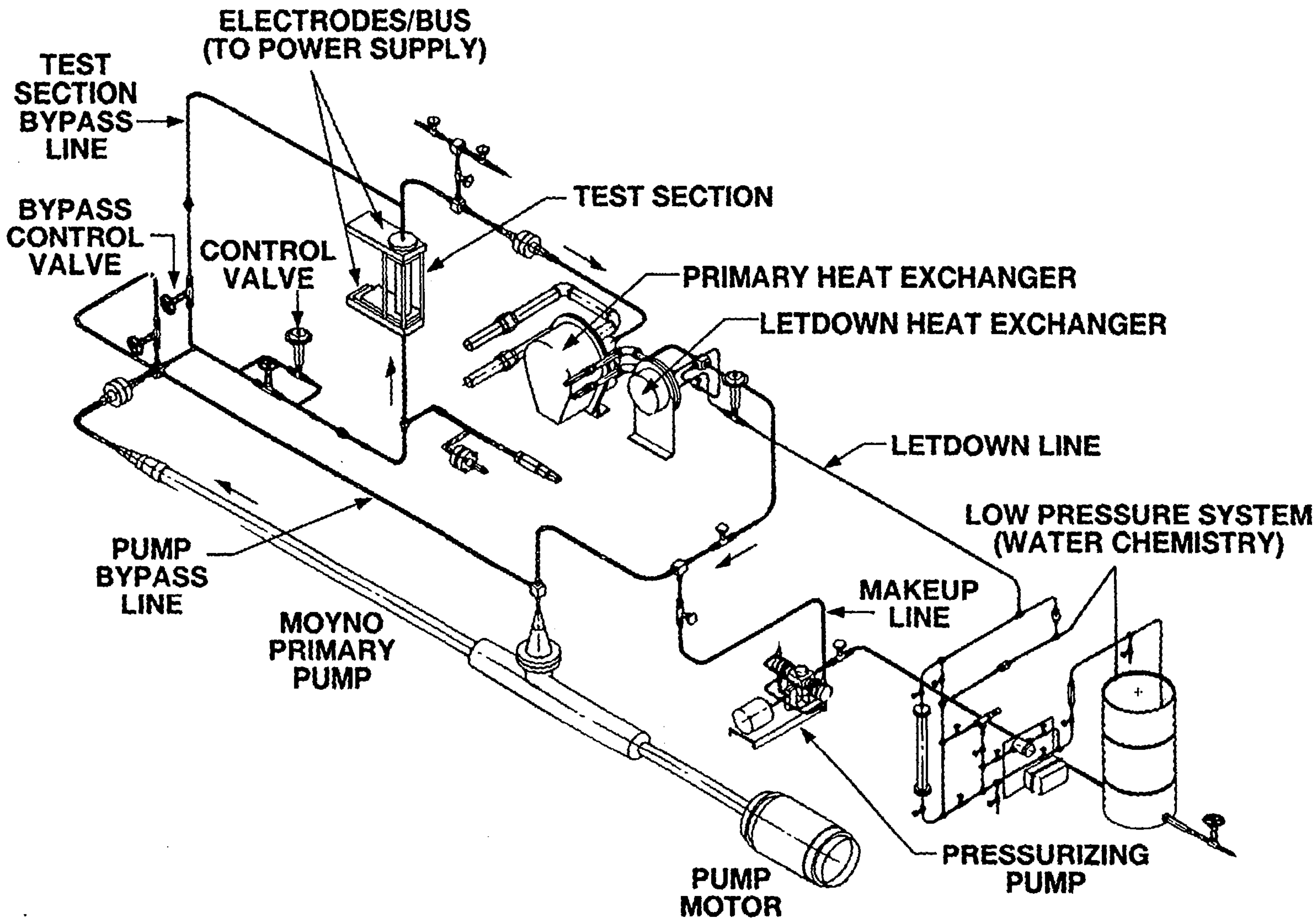
Advanced Neutron Source

Thermal Hydraulic Testing

Objective: To determine experimentally the appropriate core thermal hydraulic limits at ANS conditions.

Advanced Neutron Source (ANS) Thermal Hydraulic Test Loop (THTL) Was Designed to Operate in "Stiff", "Soft" and "Modified Stiff" Modes



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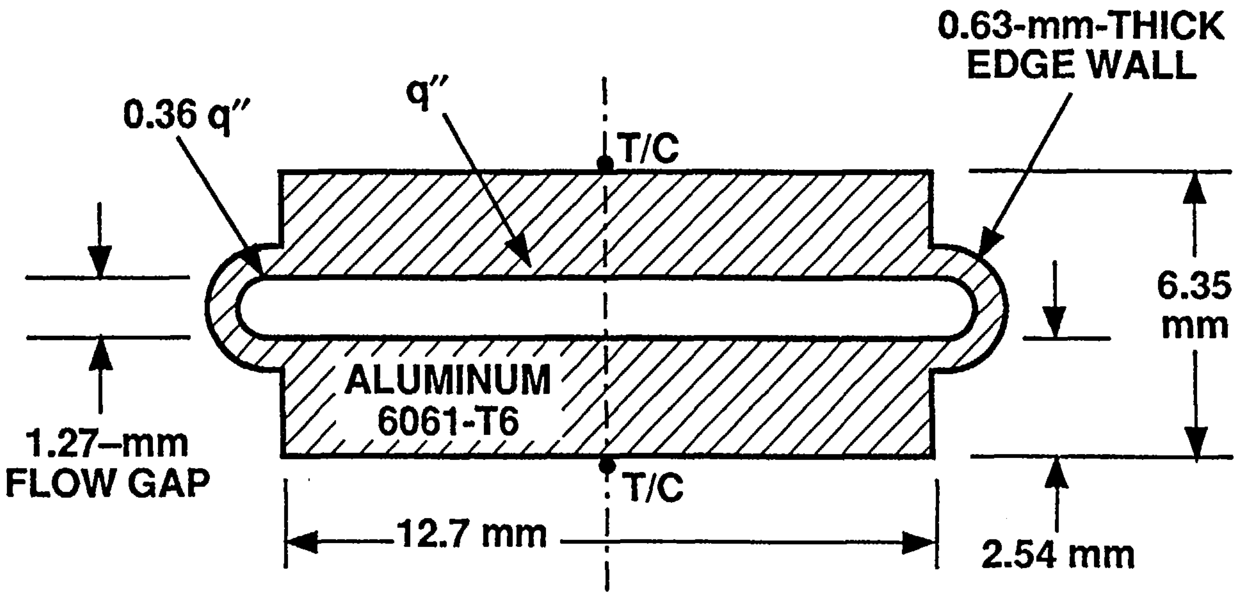
Direct Resistance Heating of the Rectangular Cross-Section of the Channel in the Thermal Hydraulic Test Loop Provided Some Challenges

- 1.27–mm x 12.7–mm rectangular channel
- Full length - 507 mm
- Directly heated using dc current



(WIDE CHANNEL: 24.4 mm)

Range of Flow Excursion Tests Performed Is Beyond Any Data Range Previously Available

- Coolant: Water
- Inlet coolant temperature: 45 and 40°C
- Exit coolant pressure: 1.7 (and 0.45, 0.17) MPa
- Exit heat flux range: 0.7–18 MW/m2
- Corresponding exit velocity range: 2.8 – 28.4 m/s
- Channel configuration: rectangular, 1.27 X 12.7 X 507 mm, aluminum

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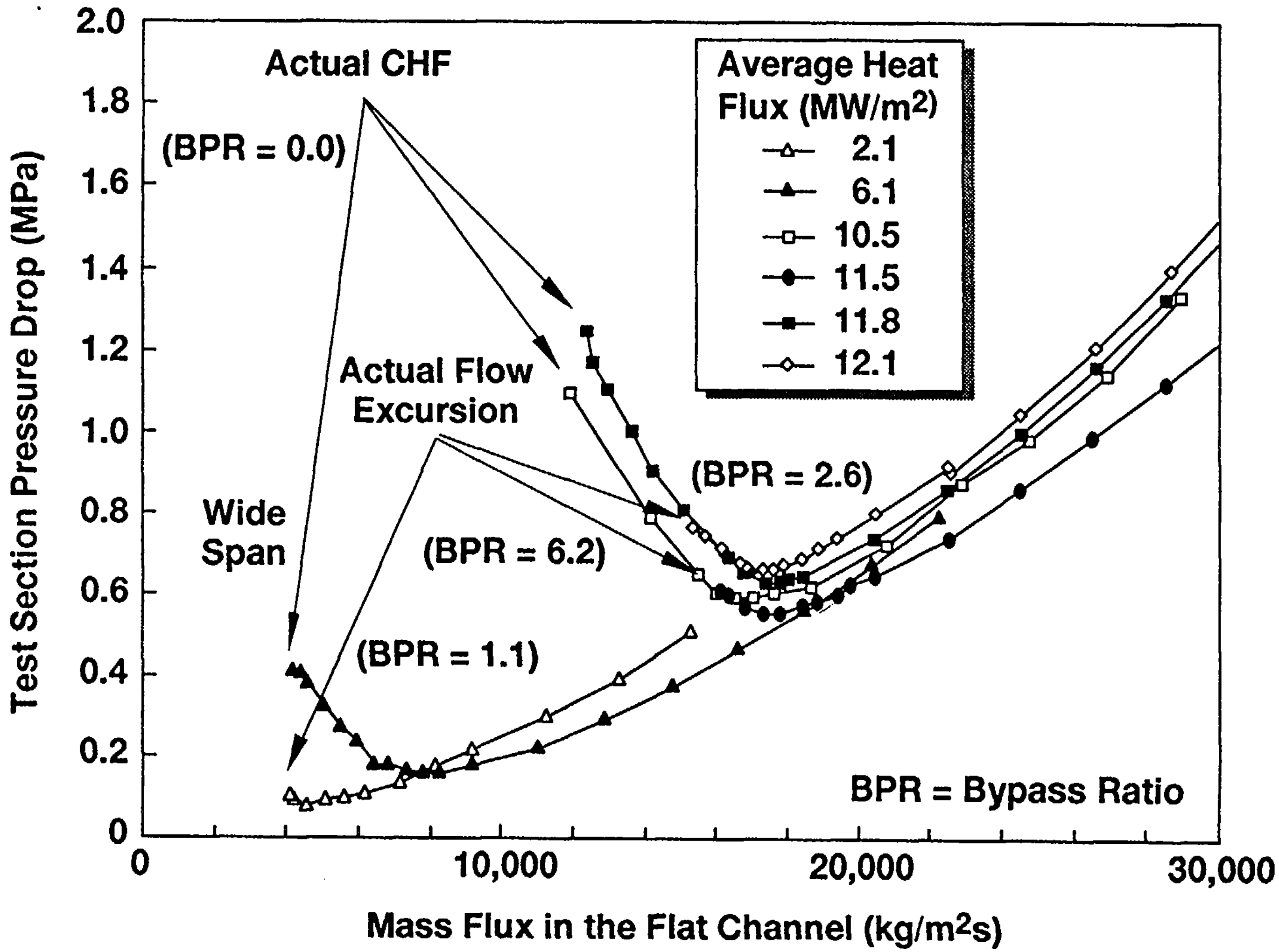
Destructive CHF Tests Performed in a "Stiff" System Showed a 30% Additional Margin in Critical Velocity Compared to the Flow Excursion Velocity (Minimum Pressure Drop). Bypass Flow Ratio (BPR) Does Effect the Point of Destructive Flow Excursion.



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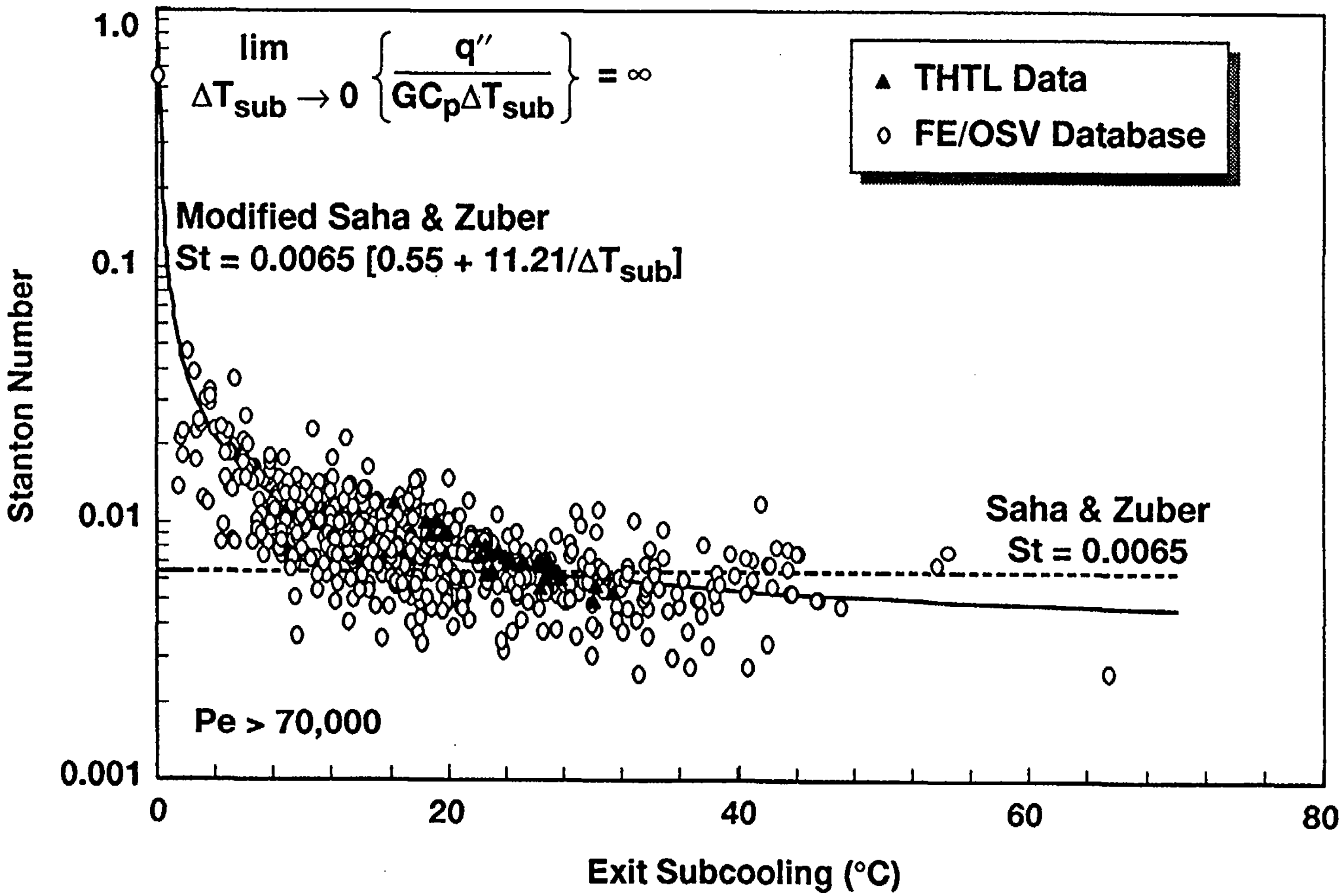
The Modified St Number Correlation Compares Well With the Data Trends and Is Consistent With Its Definition. The Extreme Data Point at Very Low Subcooling Strongly Supports this Conclusion.



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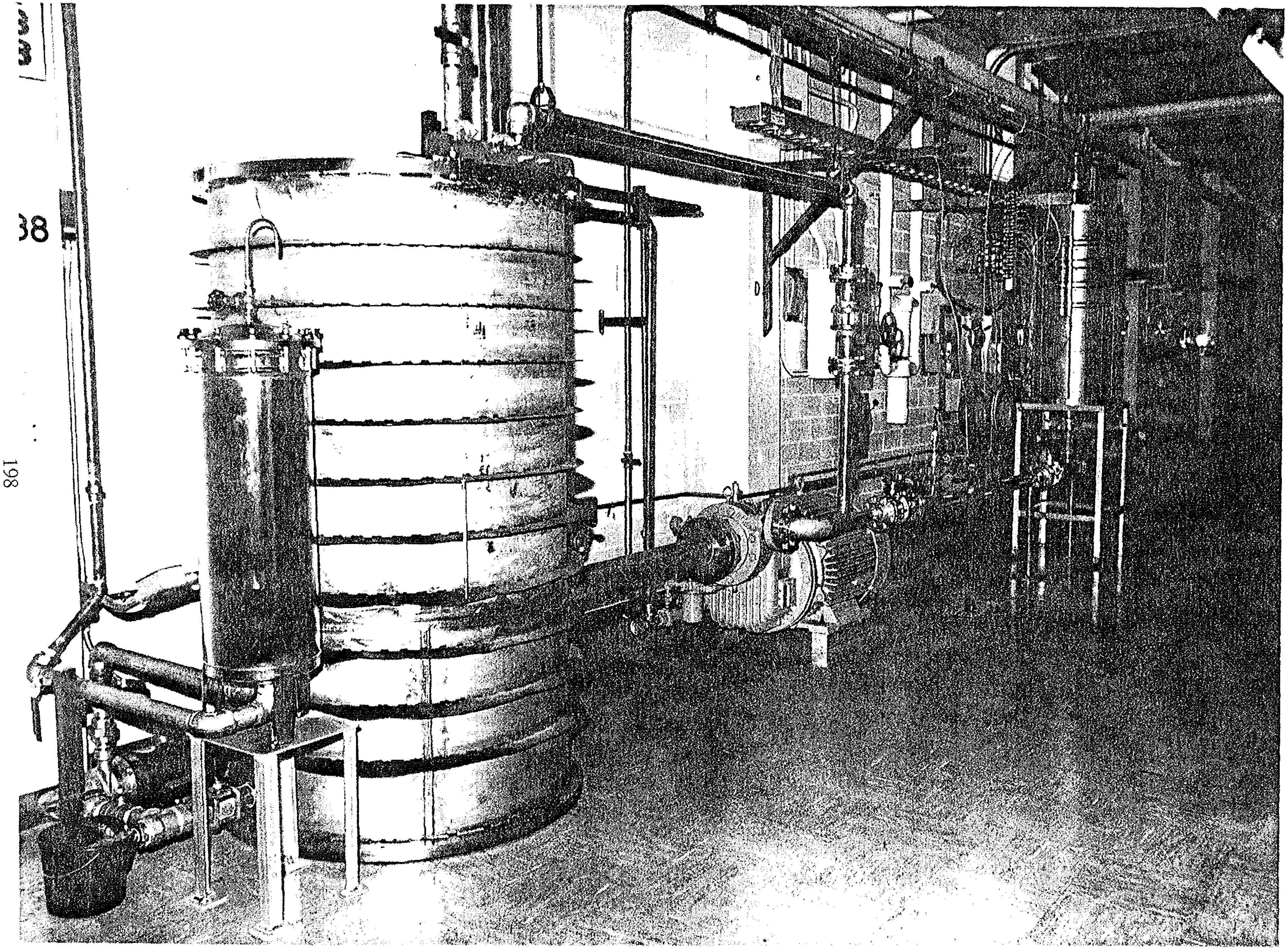
Summary of Thermal Hydraulic Limit Testing and Analysis

- FE data has been acquired at ANS typical flow velocities
- An extensive OSV/OFI data base has been developed with a very broad parameter range
- A modification of the Saha-Zuber correlation was proposed to account for reduced subcooling effects
- Closeout activities include continued investigation of wider span test channels
- Some testing for HFIR will be performed to evaluate the effect of reduced channel gap
- Future plans called for additional testing at 3-core conditions, hot spot testing, etc.

Fuel Plate Stability Testing

Objective: To experimentally evaluate the structural response of ANS fuel plates to hydraulic loads.



EXPERIMENTAL FLOW LOOP

EPOXY INVOLUTE PLATE TEST SECTION

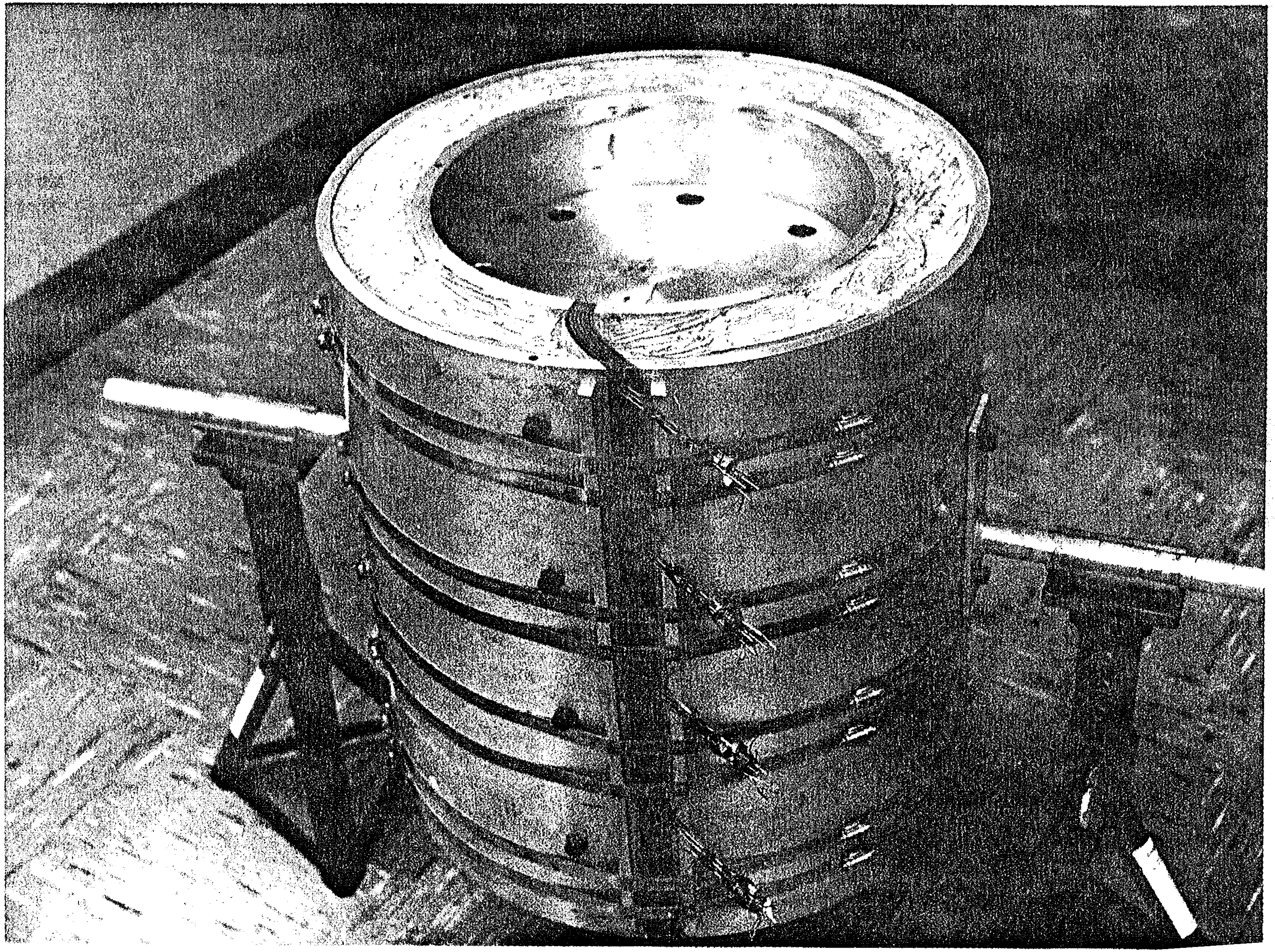
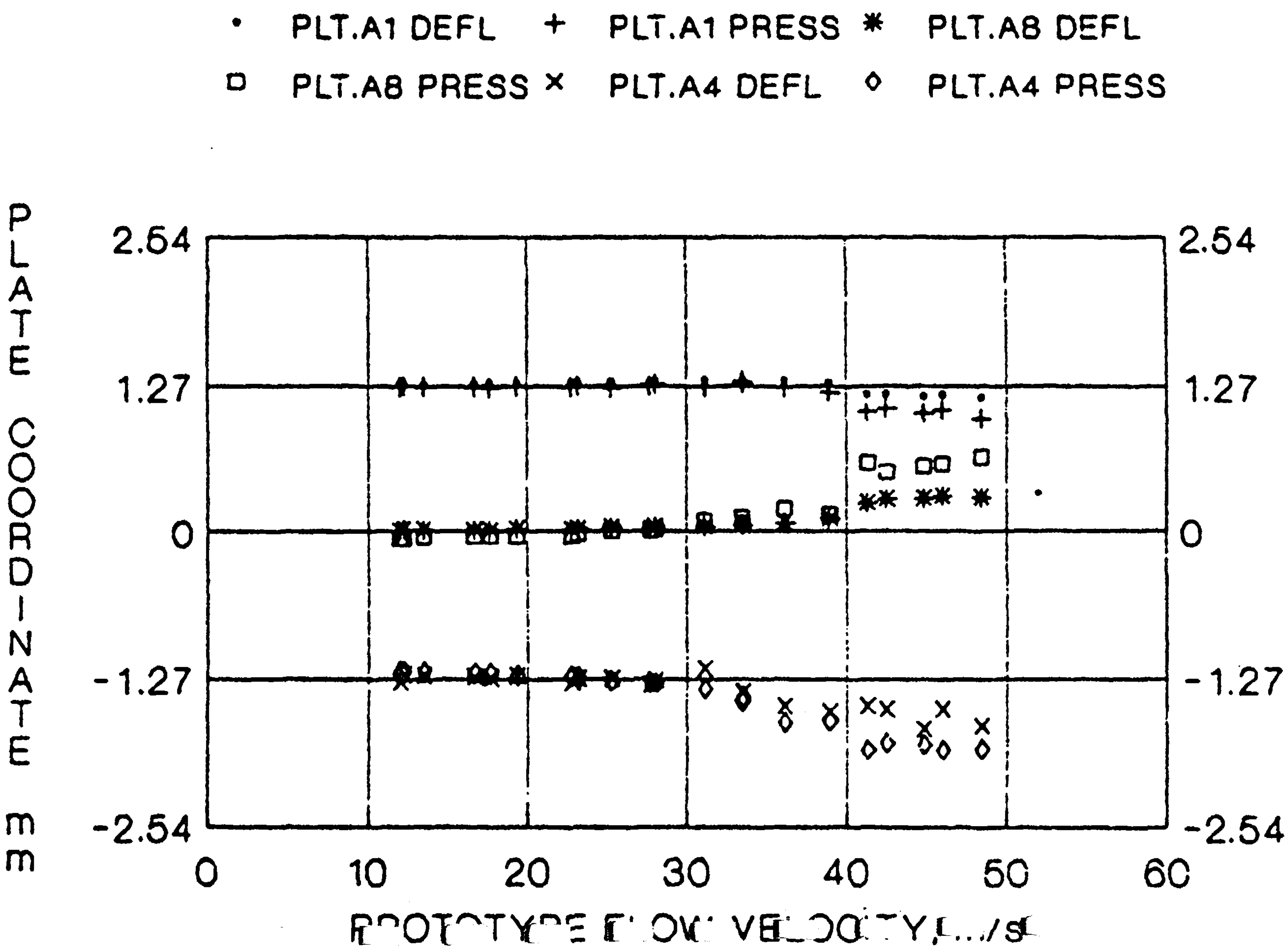


Plate Deflection Was Found to be Proportional to the Pressure Load

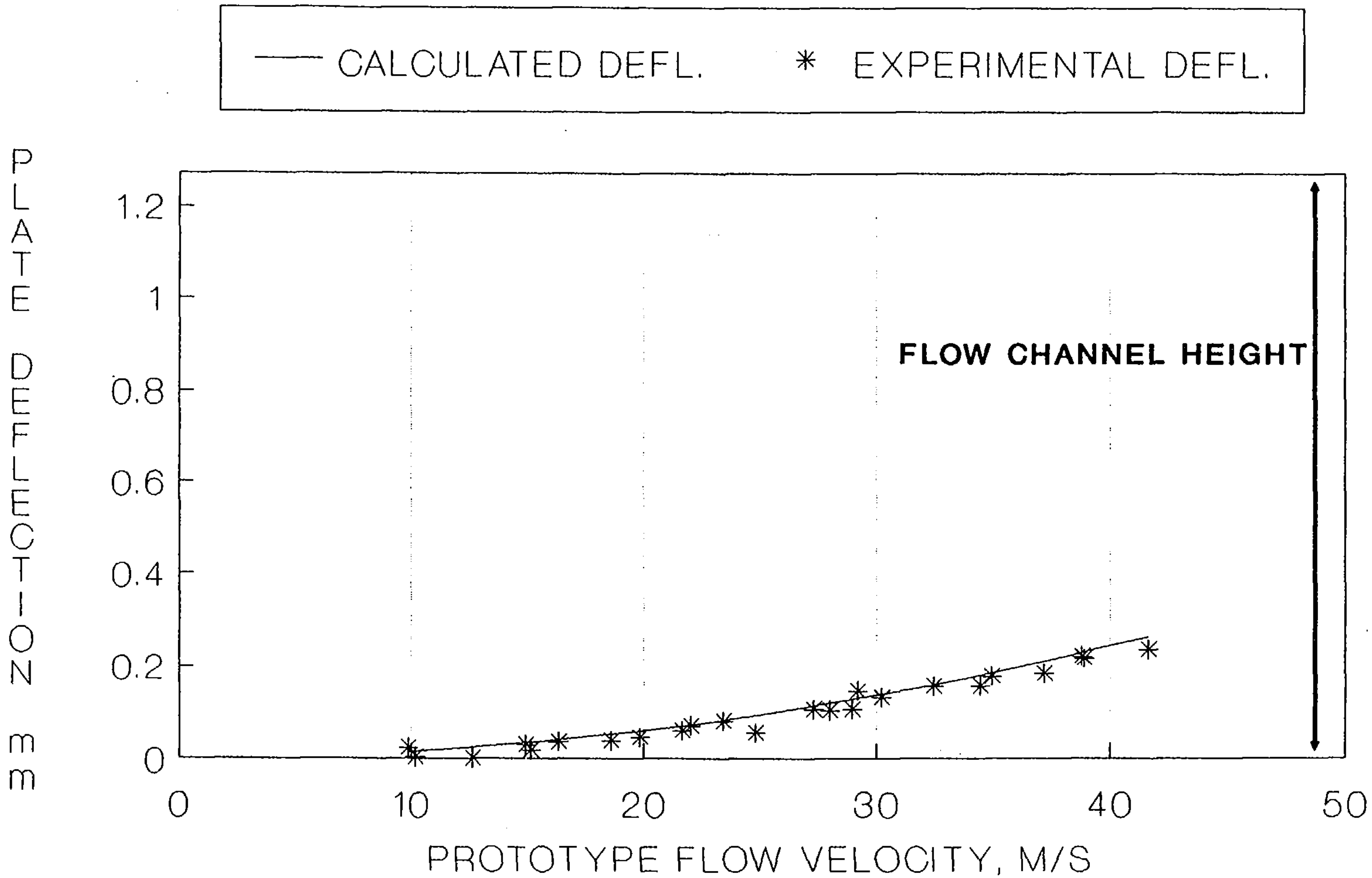


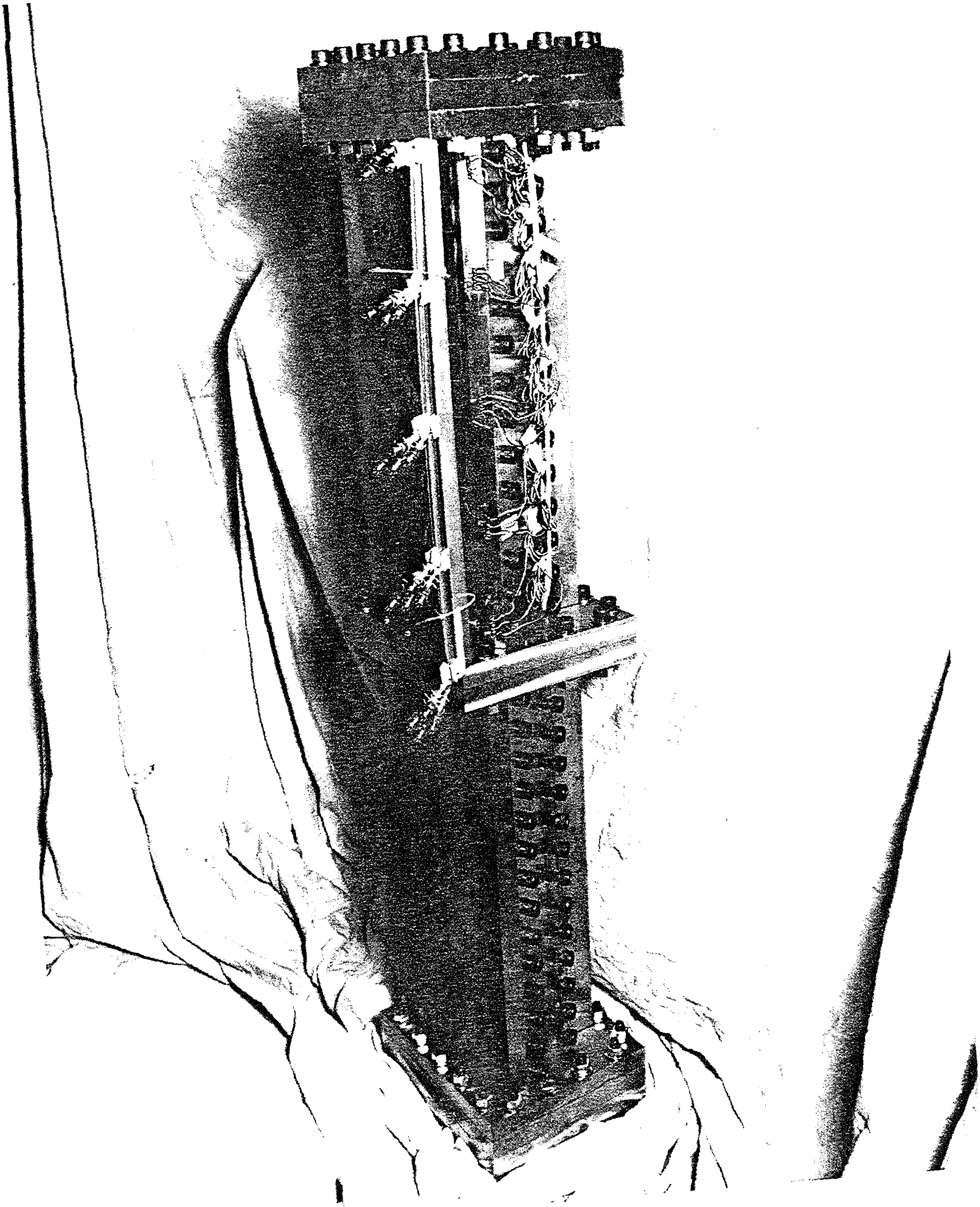
PRESSURE COEFFICIENT AND REYNOLDS' NUMBER RELATED TO YIELD PRESSURE LOAD ON PLATES

$$\frac{\Delta p}{\rho V^2} = 0.040\left(\frac{Vh}{\nu}\right)^{0.177}$$

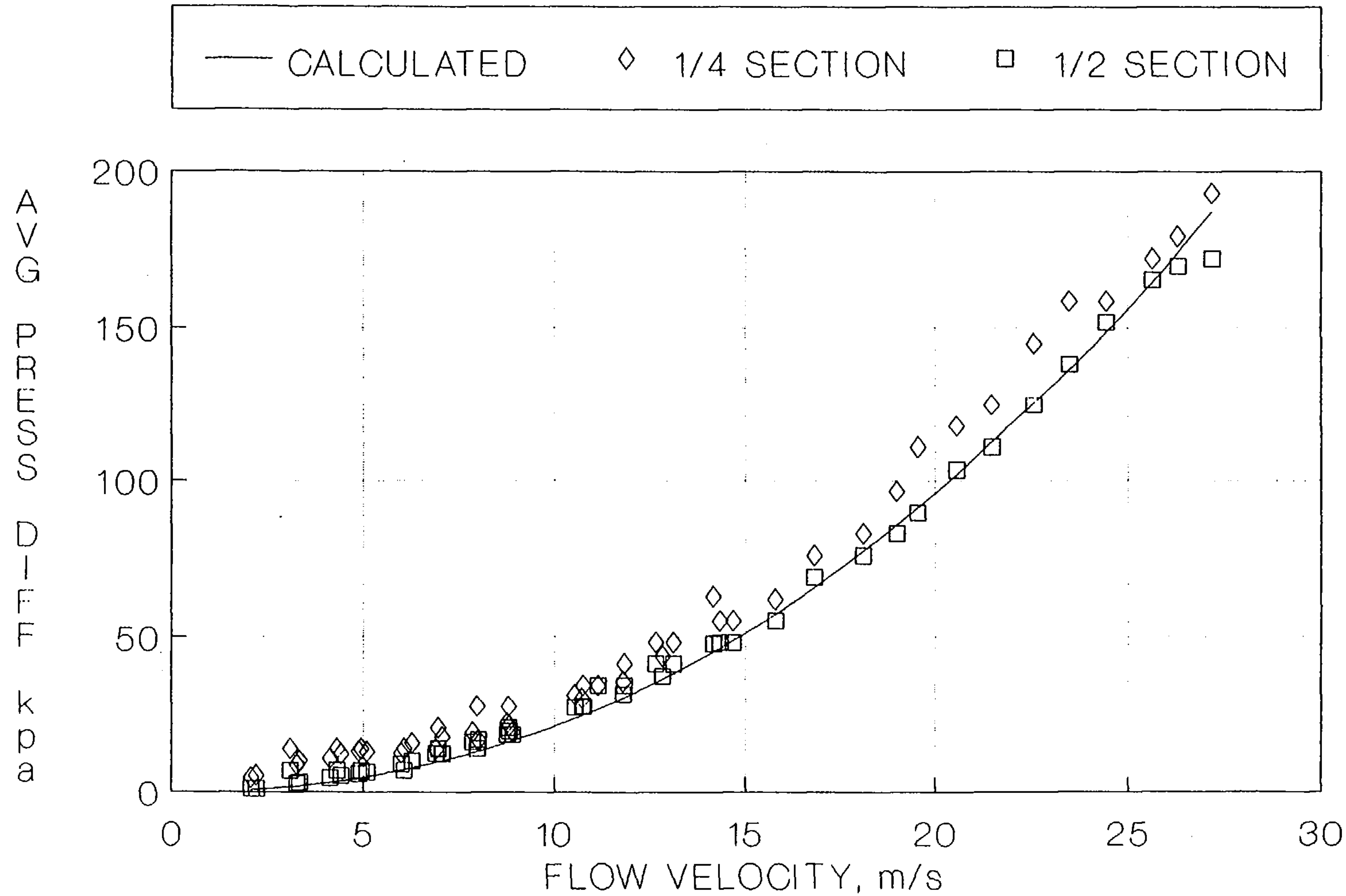
DERIVED FROM EXPERIMENTAL FLOW DATA

LOWER ELEMENT CENTRAL PLATE DEFLECTION CALCULATED VALUES COMPARED WITH EXPERIMENTAL VALUES





AVERAGE PRESSURE DIFFERENCE AS A FUNCTION OF FLOW VELOCITY



Summary of Fuel Plate Stability Testing

(1) A Method Has Been Developed to Predict Structural Response of Fuel Plates to Hydraulic Loading

- Prediction of ΔP across plates
- Determine deflection/stress levels using structural analysis

(2) ANS Specific Conclusions:

- No evidence of potential plate collapse in the coolant velocity range from 0-50 m/s
- No evidence of plate flutter with coolant velocities below 33 m/s
- Local stress levels appear to dictate plate limits as opposed to plate deflection

Flow Blockage Testing

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Objective: To experimentally determine local thermal and fluid behavior downstream of a core inlet blockage.

Flow Blockage Testing

Coolant - H_20

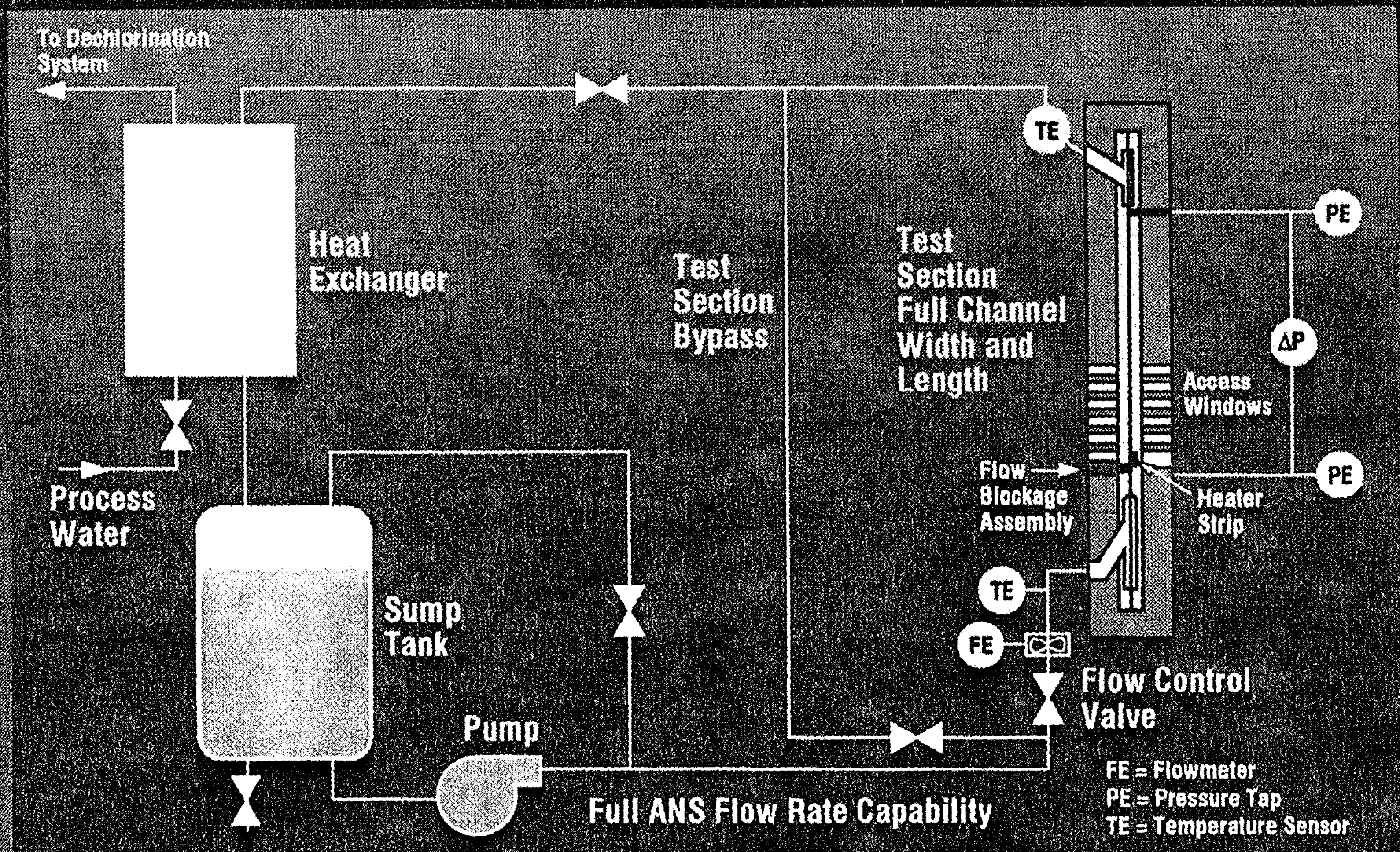
8 — Hydraulic tests using LDV

25 — Thermal tests using TLCs

Flow velocity range : 5 - 25 m/s

Blockage sizes : Center - 15%, 25%, 35%, 40%
Edge - 10%, 25%

Flow Blockage Test Facility Is Designed to Precisely Match Fuel Channel Hydraulic Conditions



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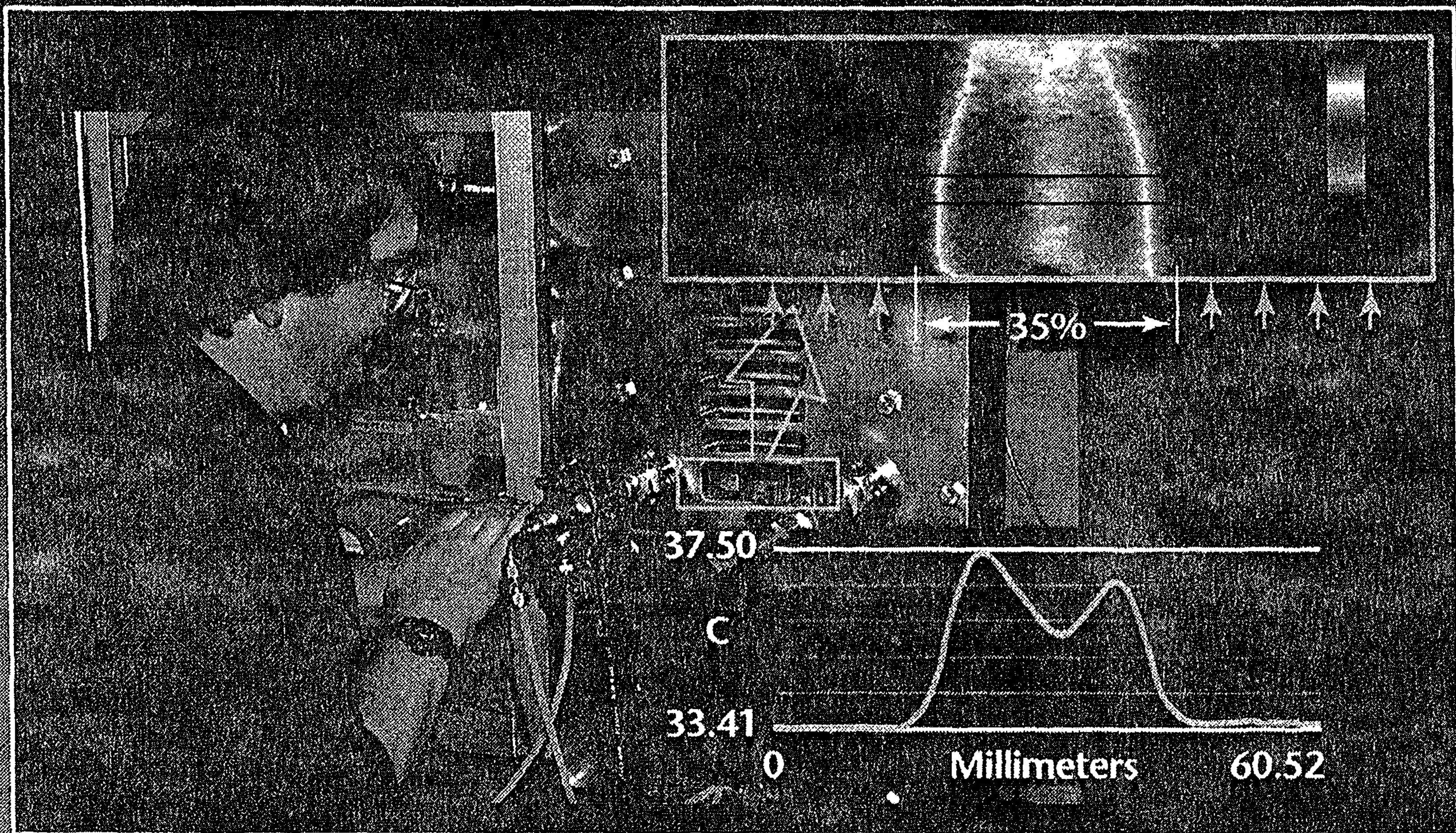
Thermochromic Crystals and Image Processing Techniques Are Used to Experimentally Determine Channel Wall Heat Transfer



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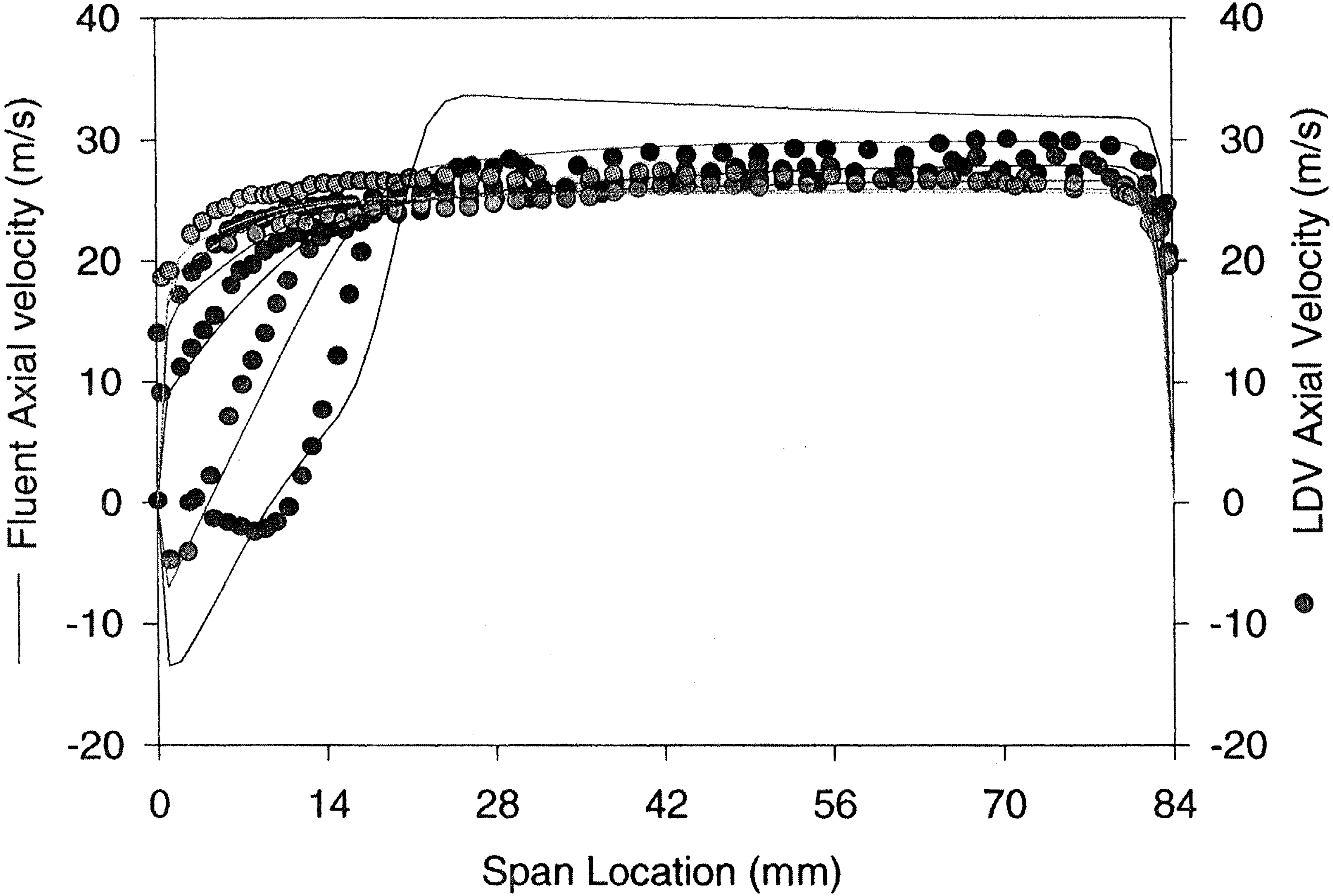
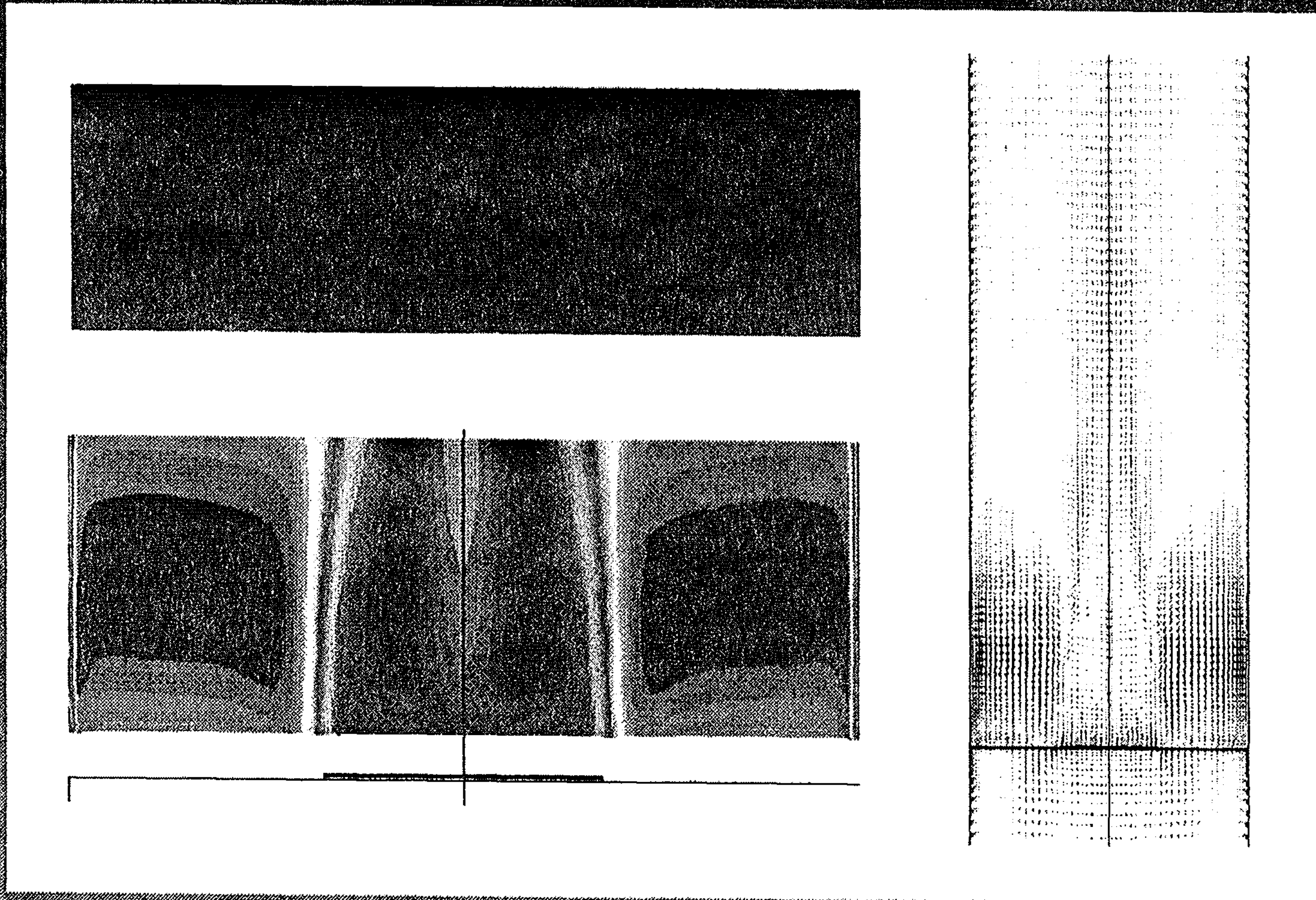
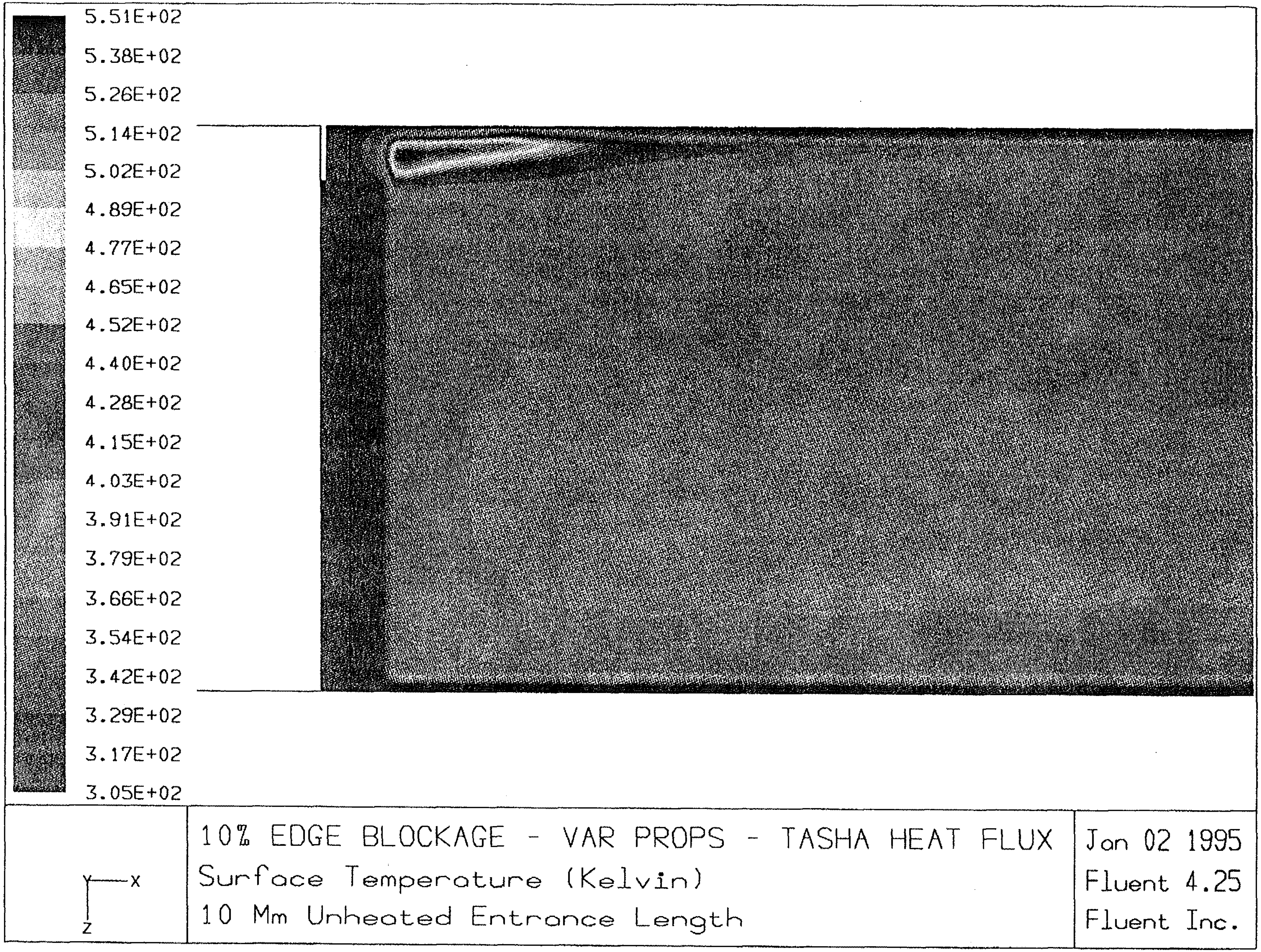
CFD results are in close agreement with experimental data



Computational Fluid Dynamics Improved Our Understanding of the Experimental Results



ORNL-DWG 94M-2609C ETD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5.38E+02
5.26E+02
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4.89E+02
4.77E+02
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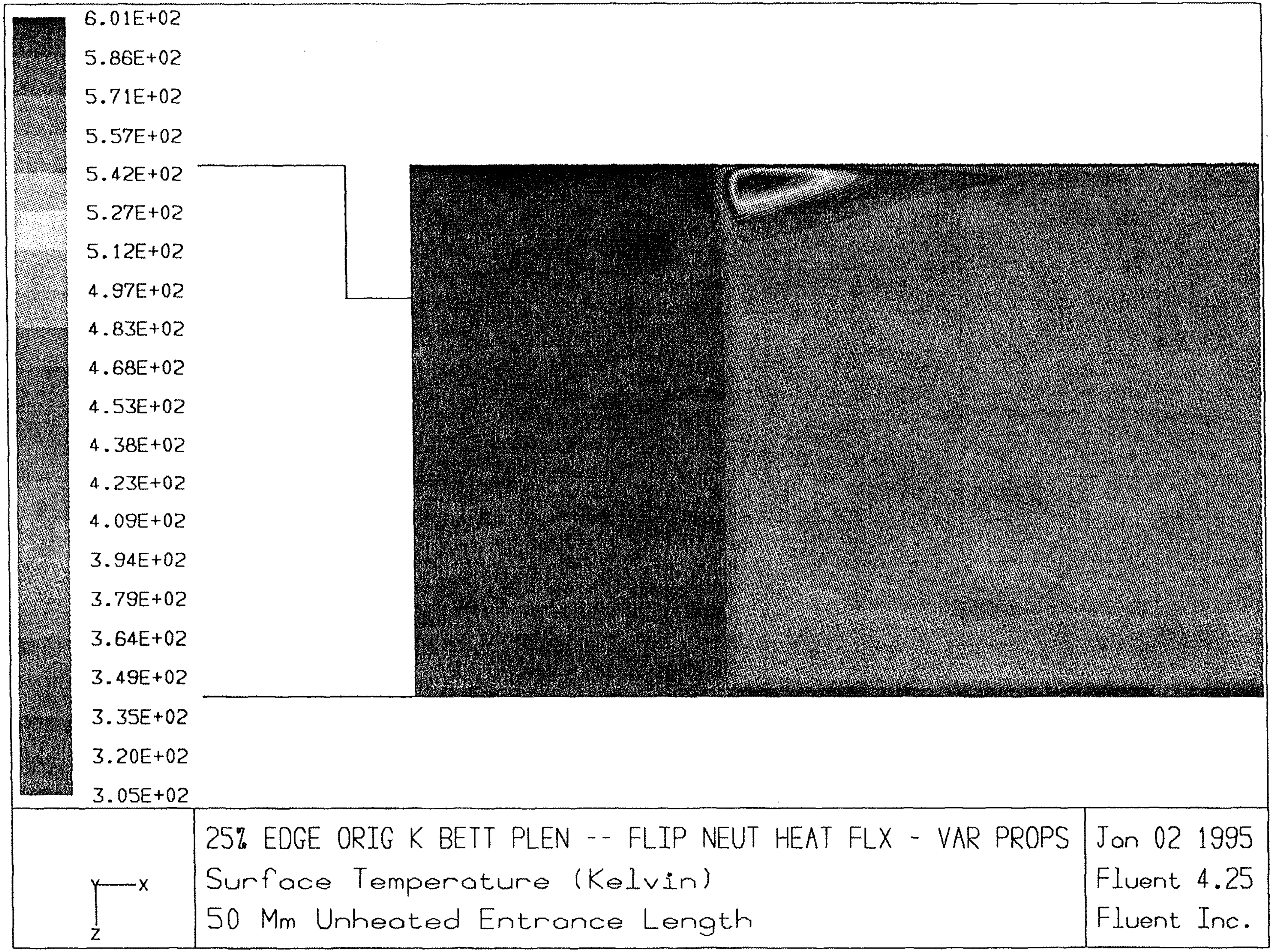
4.52E+02
4.40E+02
4.28E+02
4.15E+02
4.03E+02
3.91E+02
3.79E+02
3.66E+02
3.54E+02
3.42E+02
3.29E+02
3.17E+02
3.05E+02
Y
X
Z
10% EDGE BLOCKAGE - VAR PROPS - TASHA HEAT FLUX
Surface Temperature (Kelvin)
10 Mm Unheated Entrance Length
Jan 02 1995
Fluent 4.25
Fluent Inc.


6.01E+02
5.86E+02
5.71E+02
5.57E+02
5.42E+02
5.27E+02
5.12E+02
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4.83E+02
4.68E+02
4.53E+02
4.38E+02
4.23E+02
4.09E+02
3.94E+02
3.79E+02
3.64E+02
3.49E+02
3.35E+02
3.20E+02
3.05E+02
Y
X
Z
25% EDGE ORIG K BETT PLEN -- FLIP NEUT HEAT FLX - VAR PROPS
Surface Temperature (Kelvin)
50 Mm Unheated Entrance Length
Jan 02 1995
Fluent 4.25
Fluent Inc.

Reattachment Lengths
for 1.4 MPa Pressure Drop (mm)

Blockage Size	Blockage Position	Fluent Model		LDV Data
		Near wall	Channel center	
15%	Center	37	34	x < 27
35%	Center	80	80	x < 27
25%	Edge	74	74	60 < x < 90

Summary of Flow Blockage Testing and Analysis

- CFD code has been benchmarked against prototypic ANS flow conditions and geometry
- CFD analysis appears to be conservative with respect to experimental results
- Unheated entrance length was increased to prevent localized boiling downstream of blockage
- Closeout testing will focus on determining the importance of blockage shapes on local cooling
- Next step would have been to evaluate alternate core inlet designs