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"Quench Studies for the SMES/CICC: Simulation and Experimental Verification"

QUENCH STUDIES FOR THE SMES/CICC: SIMULATION AND EXPERIMENTAL VERIFICATION

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Workshop on Stability
and Quench in
Cable-in-Conduit Conductors
NHMFL, May 10, 1993

QUENCH SIMULATION

- **CPED (Coil Protective Energy Dump)**

  Coil thermal model to simulate resistance/temperature evolution and current decay during an energy dump. Energy balance of coil with assumed normal zone propagation velocity.

- **HEDUMP (HElium DUMP)**

  Helium flow model to simulate pressure and normal zone evolution during an energy dump.

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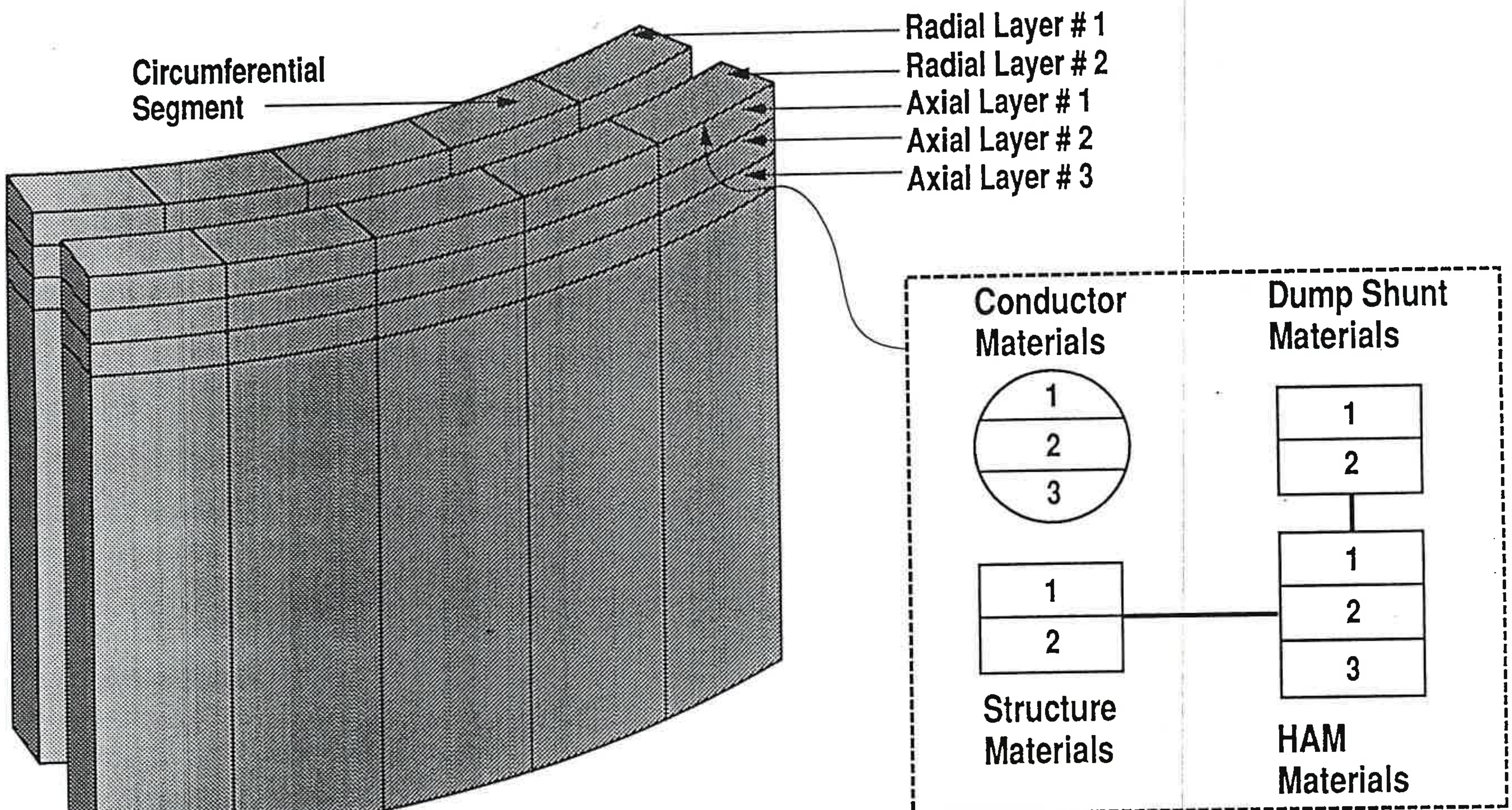
CPED GEOMETRY AND BOOKKEEPING



When used, the dump shunt, HAM, and structure are at the same temperature.

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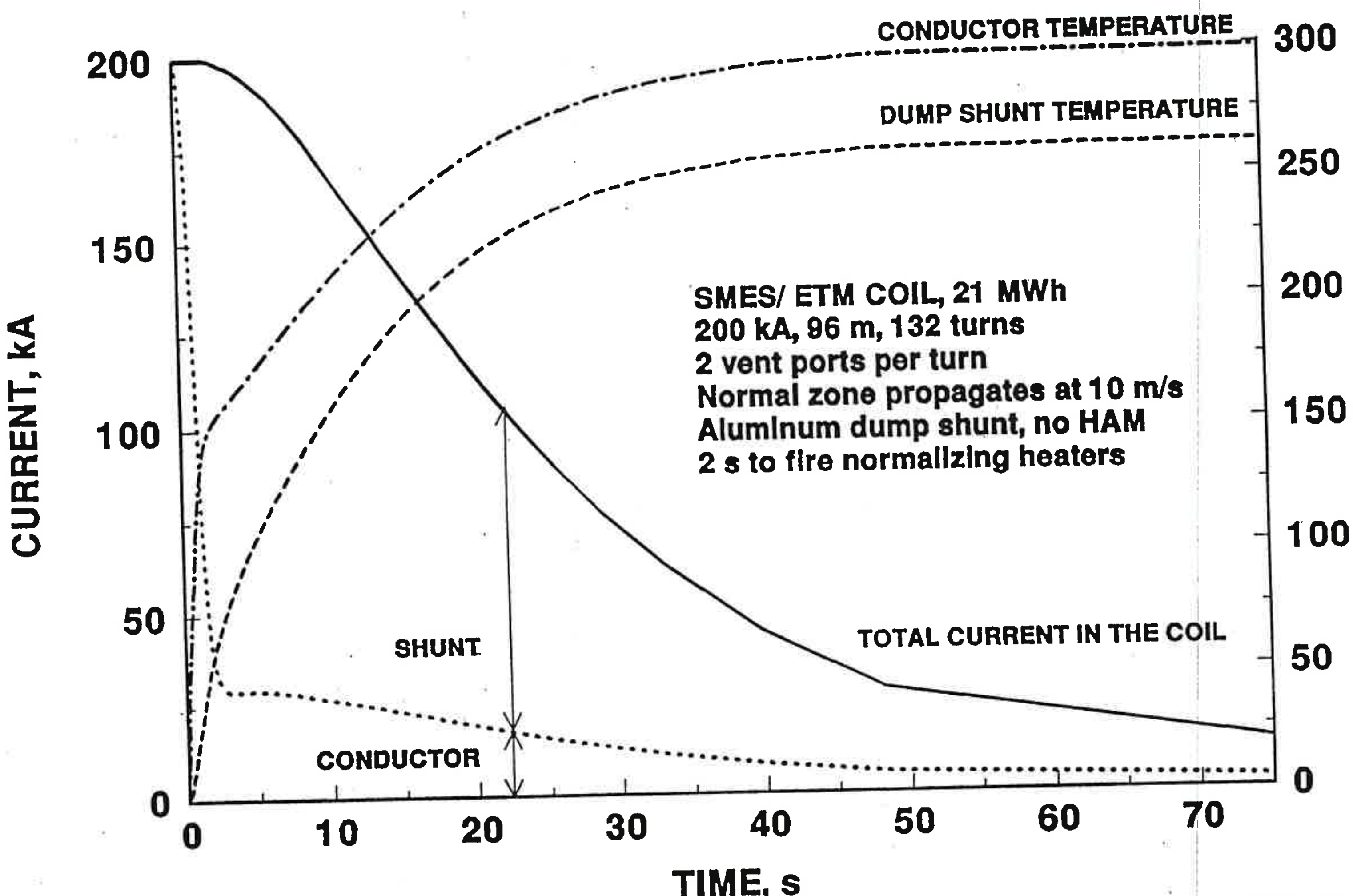
CPED RESULTS FOR THE ETM COIL



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HEDUMP MODEL

- **Phase 1:** Uniform helium/cable metal temperature (1-zone model).
- **Risk Reduction:** Differentiated central tube helium and cable space metal/helium (2-zone model).

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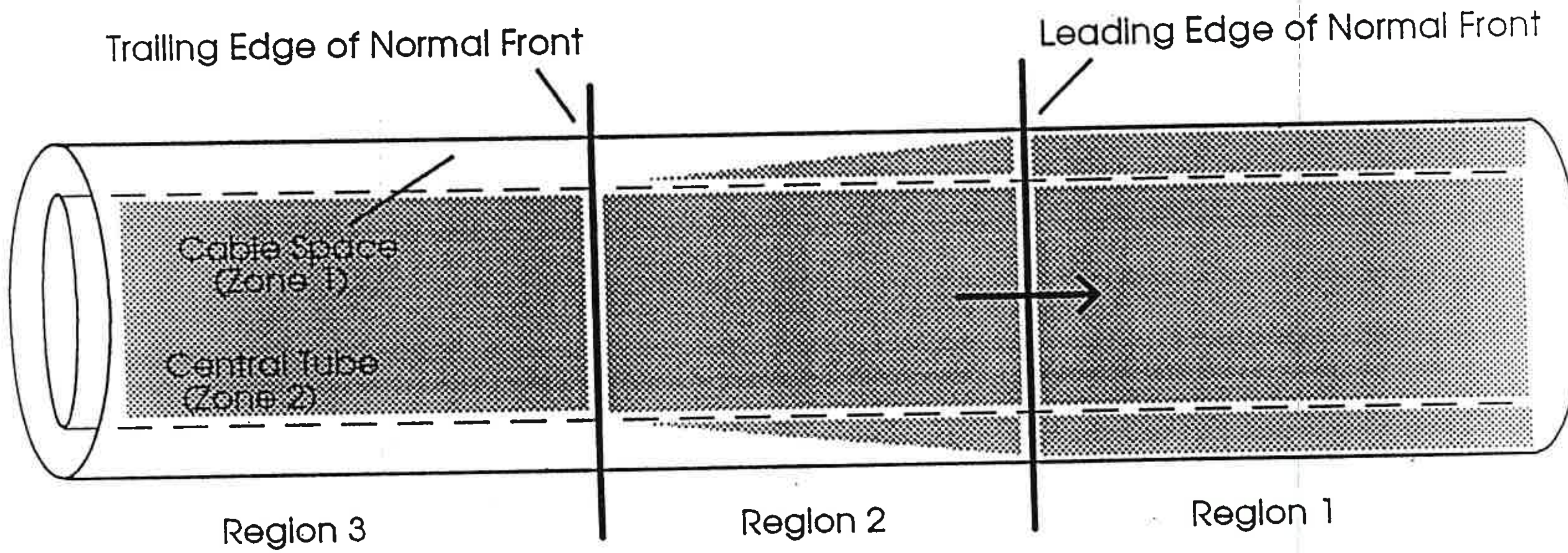
2-ZONE/3-REGION MODEL



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Central Tube Equations

Continuity:

$$\frac{\partial \rho_{ct}}{\partial t} = -\frac{\partial(\rho_{ct} v_{ct})}{\partial x} + \frac{\dot{m}'_{cs}}{A_{ct}}$$

Momentum:

$$\frac{\partial(\rho_{ct} v_{ct})}{\partial t} = -\frac{\partial(\rho_{ct} v_{ct}^2)}{\partial x} - \frac{\partial p_{ct}}{\partial x} - \frac{f}{D_{ct}} \frac{\rho_{ct} v_{ct}^2}{2}$$

Energy:

$$\frac{\partial e_{ct}}{\partial t} = -\frac{\partial\left[v_{ct}(e_{ct} + p_{ct})\right]}{\partial x} + \frac{\pi D_{ct} \tilde{h}}{A_{ct}}(T_{cs} - T_{ct}) + \frac{\dot{m}'_{cs}}{A_{ct}} h_{cs}$$

with:

$$e_{ct} = \rho_{ct}\left(u_{ct} + \frac{v_{ct}^2}{2}\right)$$

$$\dot{m}'_{cs} = A'_h \rho_{cs} \sqrt{\frac{2(p_{cs} - p_{ct})}{\rho_{cs}}}$$

cs = cable space
ct = central tube

Cable Space Equations

Continuity:

$$\frac{\partial \rho_{cs}}{\partial t} = -\frac{\dot{m}'_{cs}}{A_{cs}}$$

Energy:

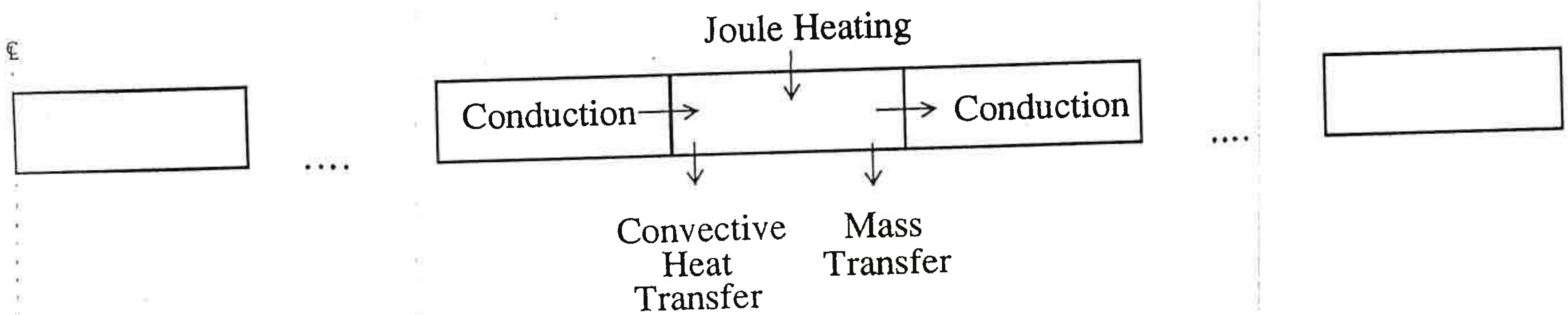
$$\frac{\partial (M'_{He} u_{He} + M'_m u_m)}{\partial t} = \dot{Q}'_J - \dot{m}'_{cs} h_{cs} - \pi D_{ct} \tilde{h} (T_{cs} - T_{ct}) + \\ + A_m \frac{\partial}{\partial x}\left(k \frac{\partial T_{cs}}{\partial x} \right)$$

Equations of State:

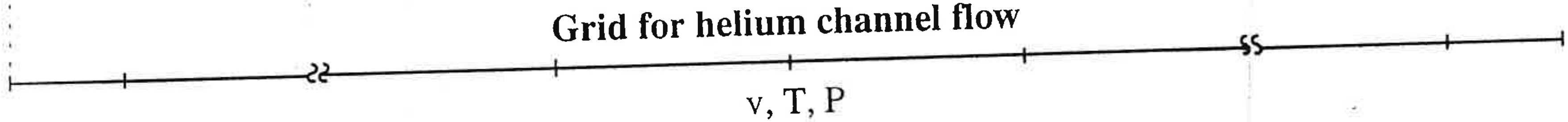
$$p = p(\rho, u_{He})$$
$$T = T(\rho, u_{He})$$
$$h = h(\rho, u_{He})$$
$$u_m = u_m(T_m)$$

Numerical Scheme

Elements for cable space mass/energy balance



Grid for helium channel flow



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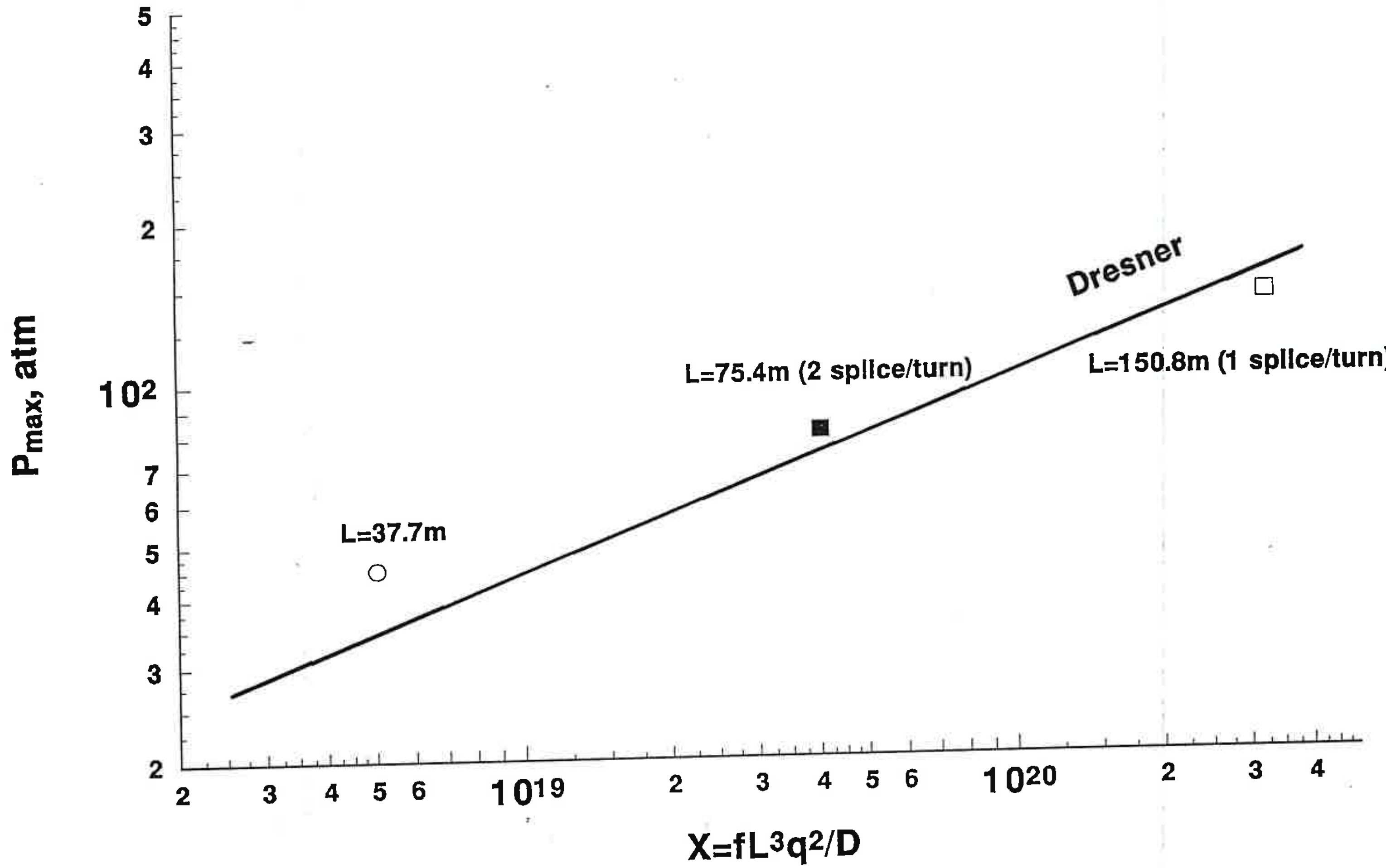
MAXIMUM PRESSURE

Q' = 30 kW/m



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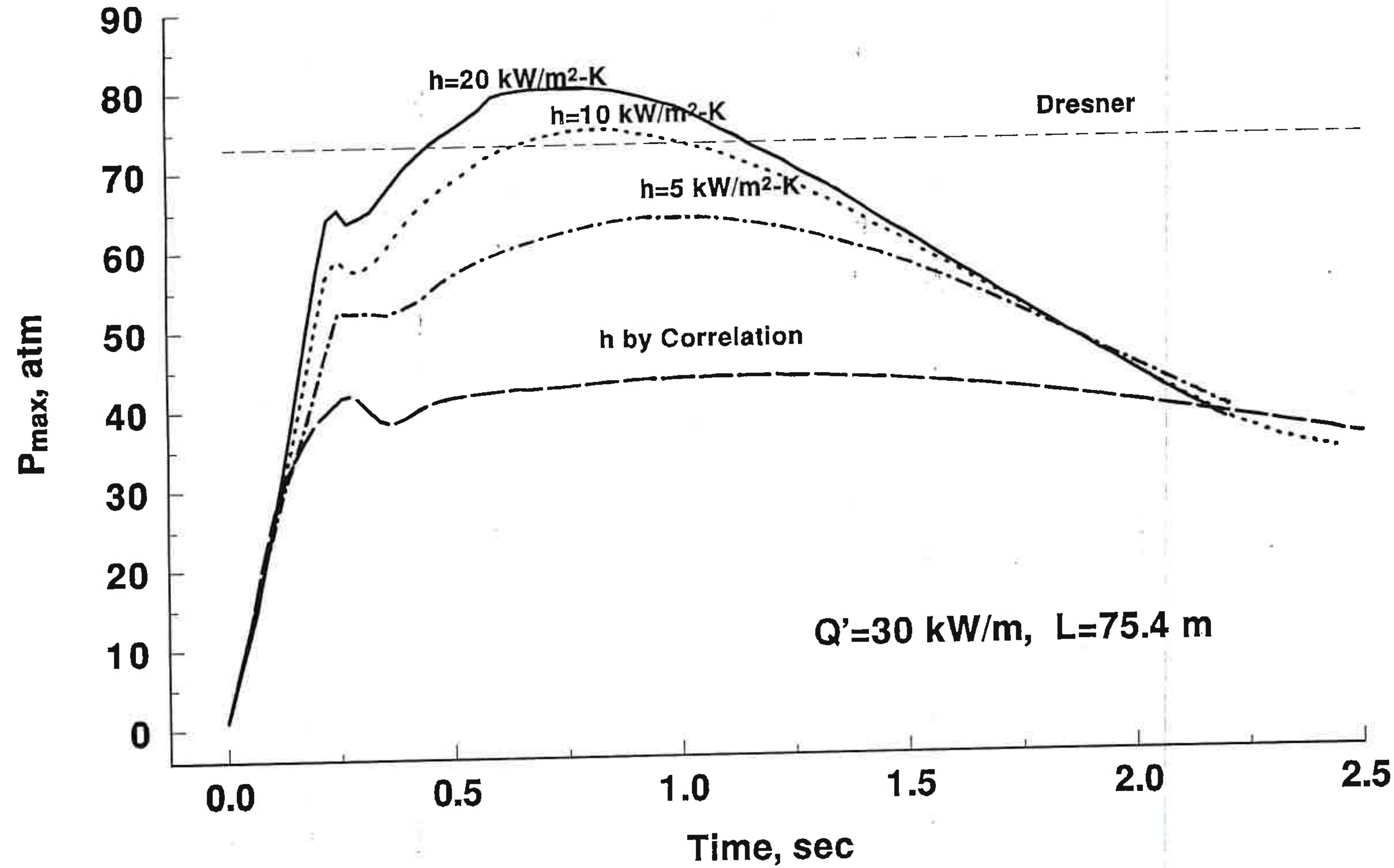
MAXIMUM PRESSURE



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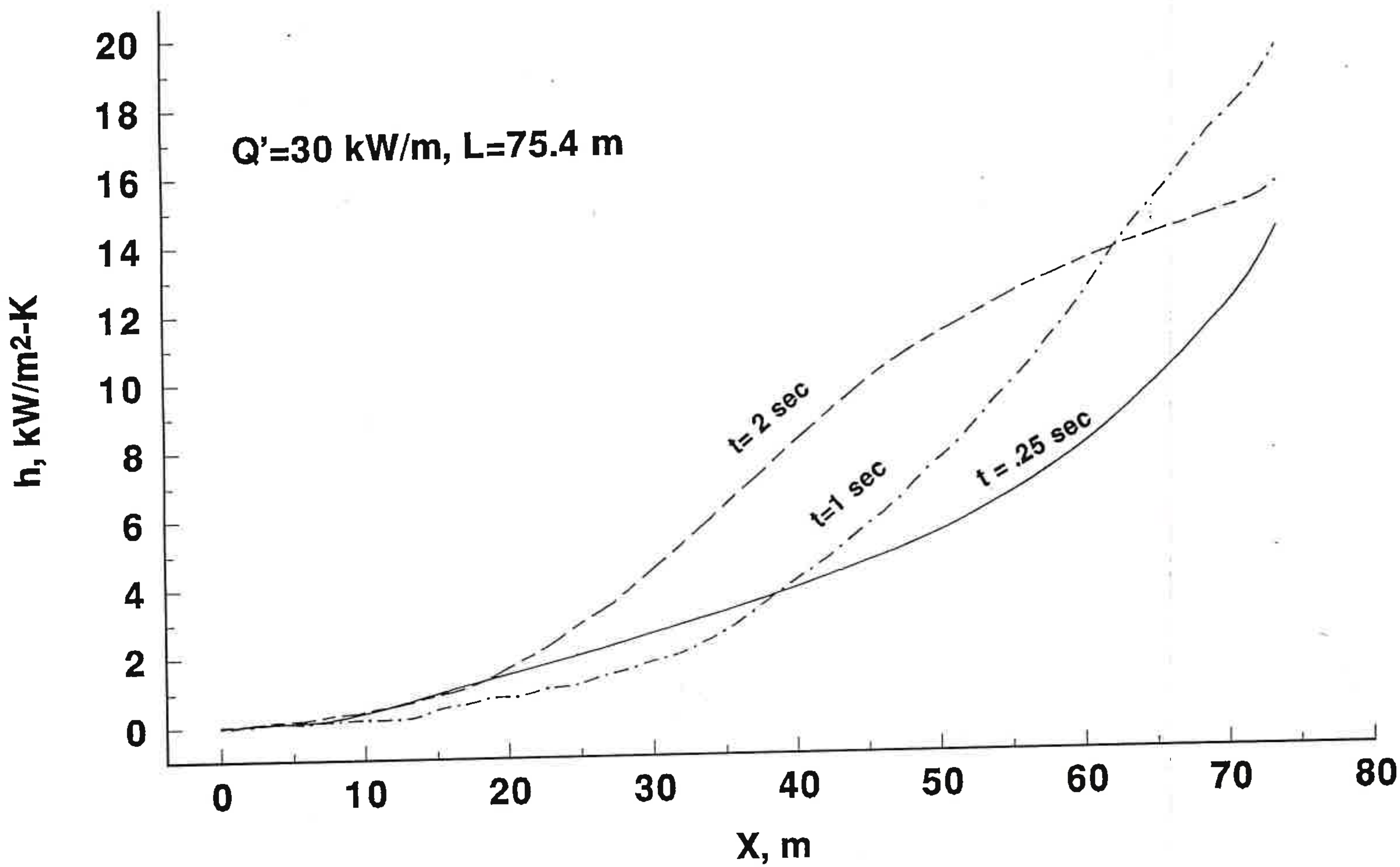
CONVECTIVE HEAT TRANSFER COEFFICIENT PROFILES



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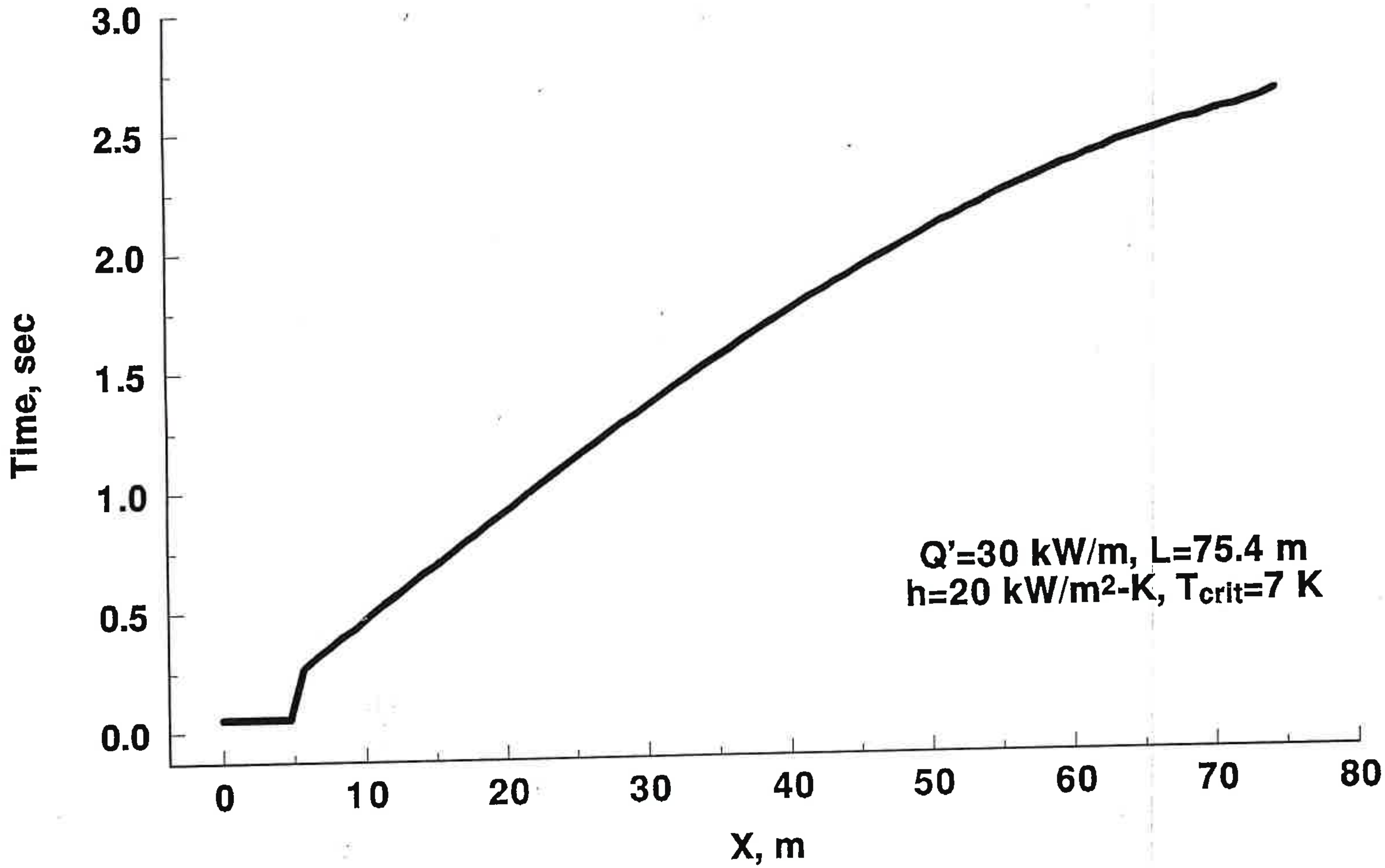
NORMAL FRONT PROPAGATION



QUENCH MODEL/VERIFICATION

- Consistency checks.
- Comparison with analytical results in limiting cases.
- Comparison with experimental results.

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QUENCH INITIATION AND PROPAGATION STUDY (QUIPS)

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QUIPS/OBJECTIVES

- Demonstrate and measure quench propagation in a subscale version of the SMES/CICC.
- Use the quench measurements to validate and benchmark HEDUMP.
- Extend our understanding of quench initiation and propagation in CICC's similar to the SMES conductor.

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QUIPS/LOGISTICS AND SETUP

- Experiment conducted at the NHMFL (Dr. John Miller).
- Power supply at NHMFL allows for quench test at constant current.

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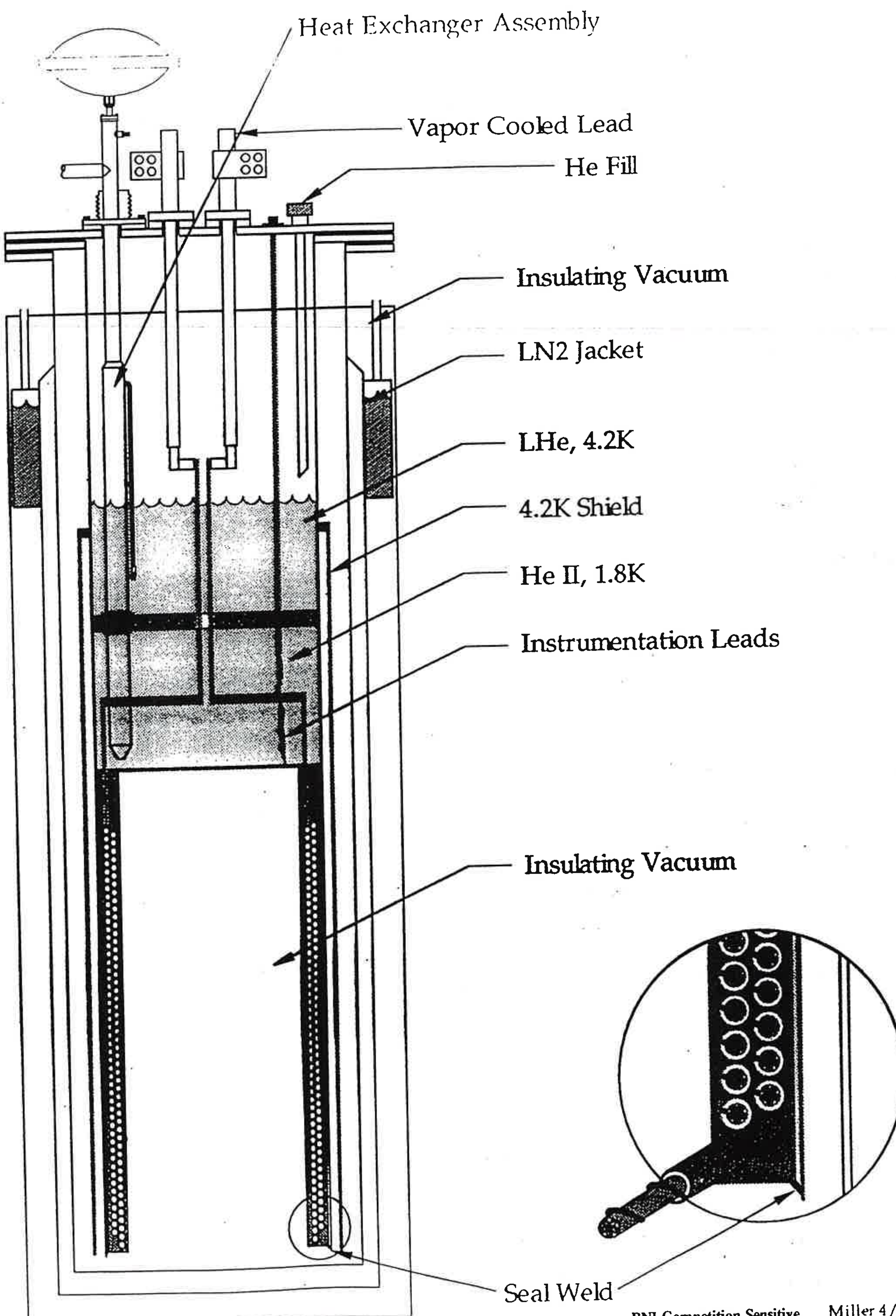
NHMFL Power Supply

4 each 20 kA, 500 V, operable
singly or in any combination
(total 40 MW)

Ripple and noise (0 - 500 Hz)	10 ppm
Stability (including ripple):	100 ppm
Repeatability (including ripple):	100 ppm
Resolution between adjacent steps:	10 ppm
Accuracy (current calibration):	1000 ppm



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Miller 4/93-1 MP

QUIPS/PAYOFFS

- Subscale sample provides model for ETM quench propagation velocity.

- Database for HEDUMP validation and benchmarking. Reduce conservatism of ETM design. Reduce risk and cost.

- Enlarge engineering database on "hybrid" CICCs.

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