J. Winston Lue
ORNL

"Normal Zone Propagation and Thermal Hydraulic Quenchback in a Cable-in-Conduit Superconductor"

NORMAL ZONE PROPAGATION AND THERMAL HYDRAULIC QUENCHBACK IN A CABLE-IN-CONDUIT SUPERCONDUCTOR

J. W. Lue

Oak Ridge National Laboratory

Workshop on Stability and Quench
in Cable-in-Conduit Conductors

National High Magnetic Field Laboratory

May 10, 1993

/

CEC '93 Paper AQ33

NORMAL ZONE PROPAGATION AND THERMAL HYDRAULIC QUENCHBACK IN A CABLE-IN-CONDUIT SUPERCONDUCTOR

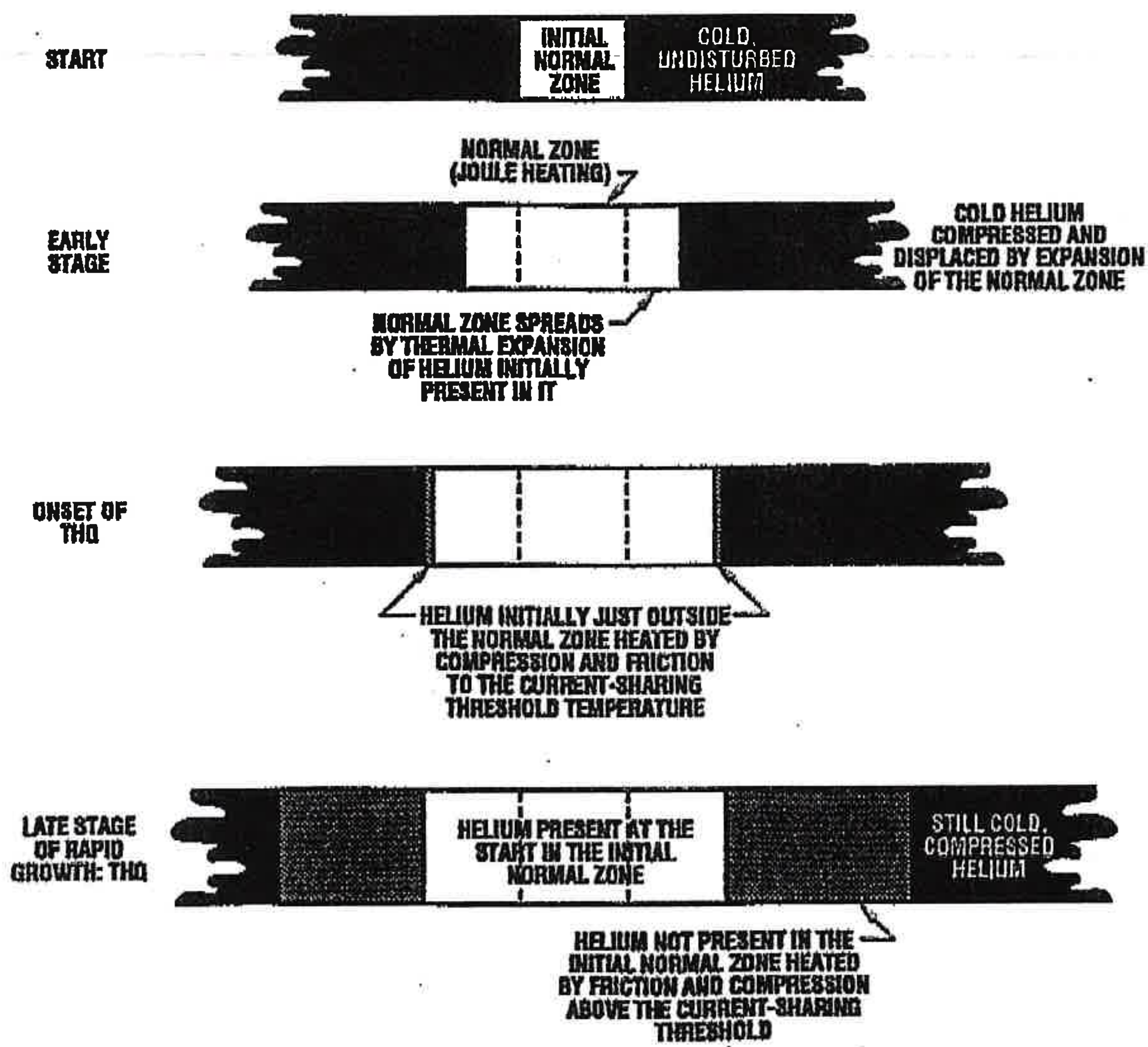
J. W. Lue and L. Dresner

Oak Ridge National Laboratory*
Oak Ridge, TN 37831-8040

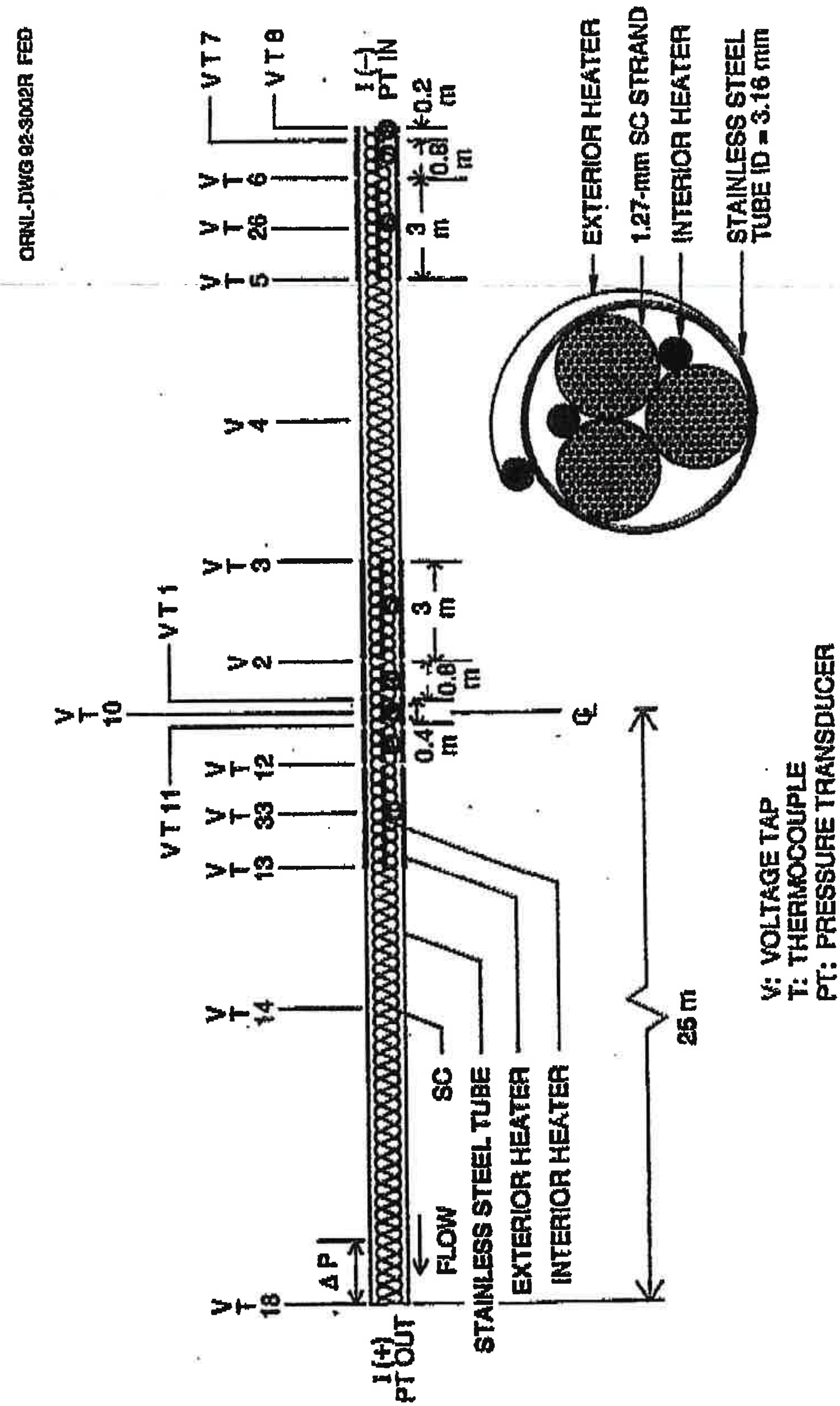
ABSTRACT

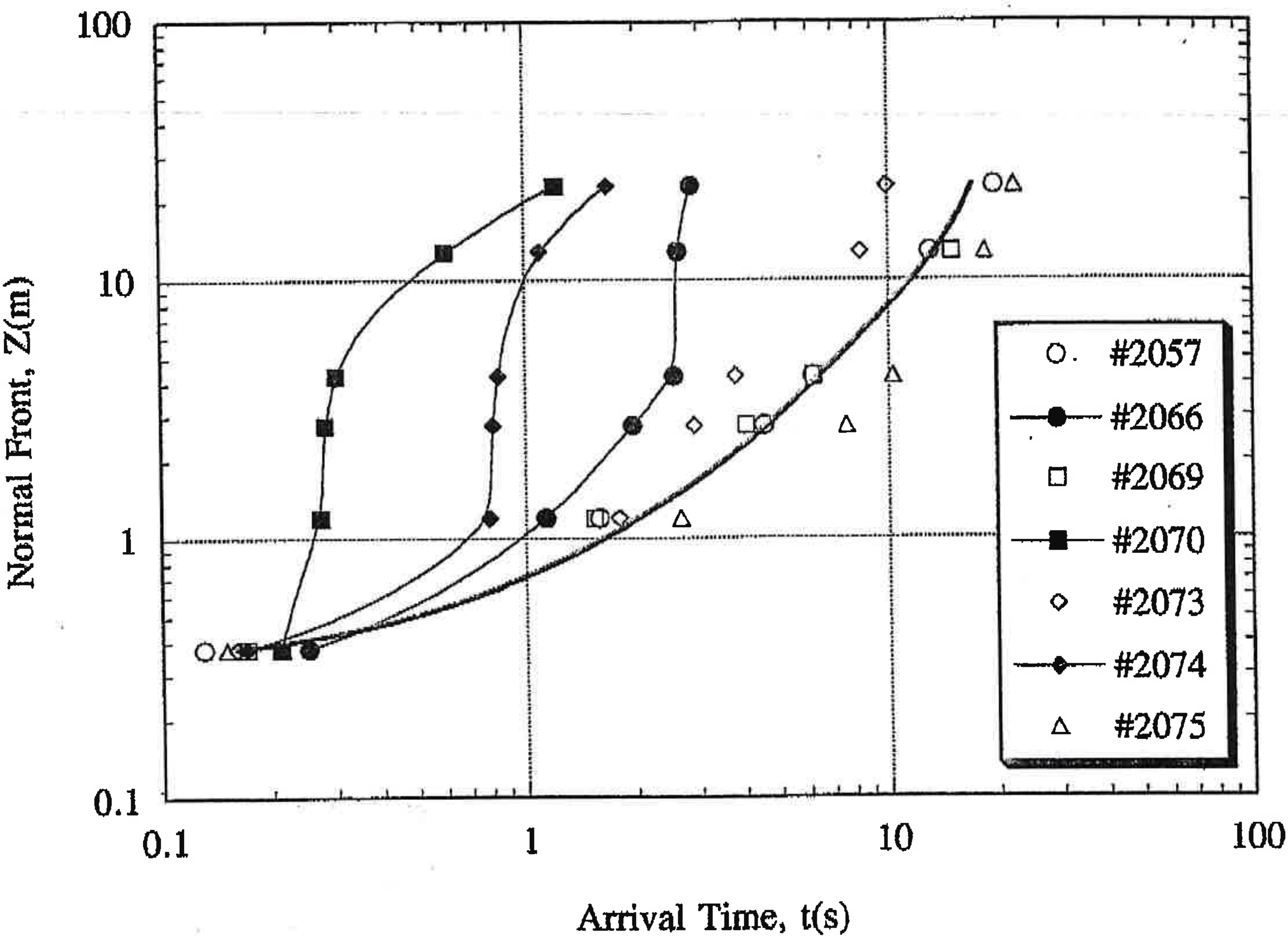
When a local normal zone appears in a cable-in-conduit superconductor, a slug of hot helium is produced. The pressure rises and the hot helium expands. Thus the normal zone propagation in such a conductor can be governed by the hot helium expansion, rather than the heat conduction along the conductor. The expansion of the hot helium compresses the cold helium outside of the normal zone. This raises the temperature of the cold helium. When the temperature rise reaches the current sharing limit, the superconductor in contact goes normal. Thus a rapid increase in normal zone propagation occur. This phenomenon is termed Thermal Hydraulic Quenchback (THQ). An experiment was performed to investigate this process. The existence of THQ was verified. Thresholds of THQ were also observed by varying the conductor current, the magnetic field, the temperature, and the initial normal zone length. When THQ occurred, normal zone propagation approaching the velocity of sound was observed. A better picture of THQ is obtained by a careful comparison of the data with analytical studies.

ORNL-DWG 92M-2589 FED

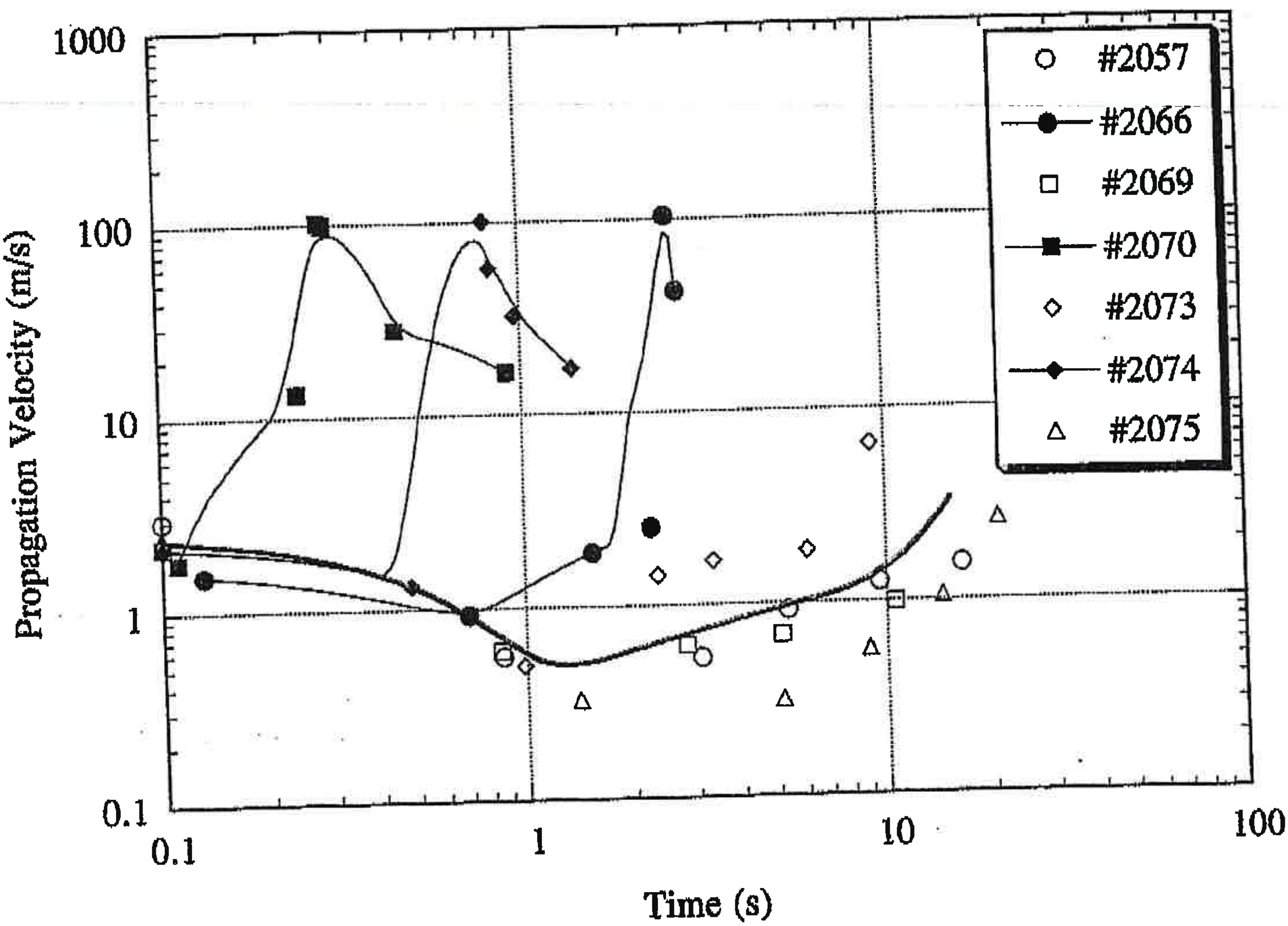


3

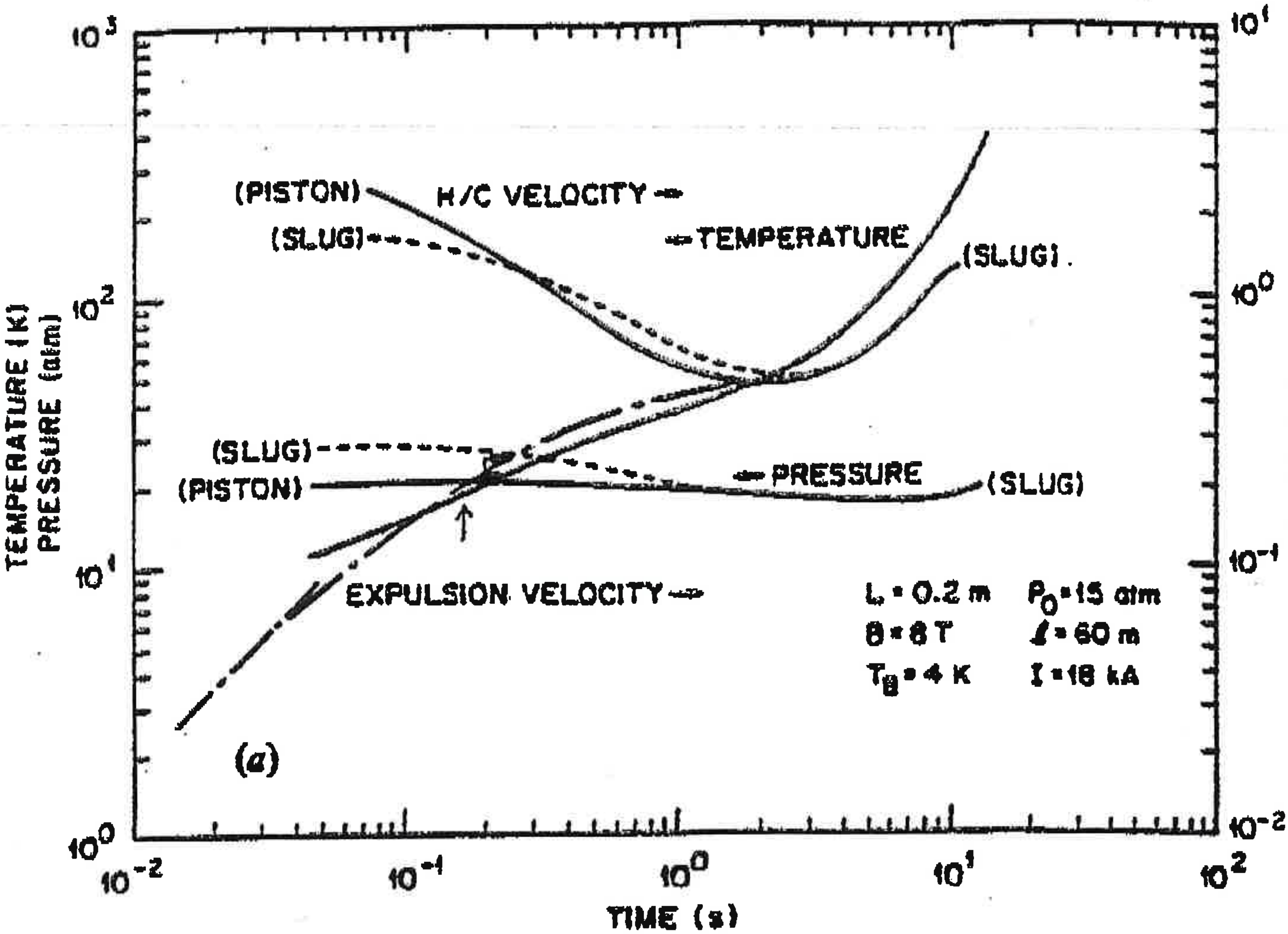

ORNL-DWG 92-3002R FED
VT 7
VT 8
I (−)
PT IN
0.2 m
0.8 m
3 m
V T 6
V T 26
V T 5
V 4
V T 3
VT 1
V 2
3 m
0.8 m
V T 10
0.4 m
℄
VT 11
V T 12
V T 33
V T 13
V T 14
SC
STAINLESS STEEL TUBE
EXTERIOR HEATER
INTERIOR HEATER
FLOW
Δ P
V T 18
I (+)
PT OUT
25 m
EXTERIOR HEATER
1.27-mm SC STRAND
INTERIOR HEATER
STAINLESS STEEL
TUBE ID = 3.16 mm
V: VOLTAGE TAP
T: THERMOCOUPLE
PT: PRESSURE TRANSDUCER



Sharp increases in normal front propagation were observed for shots #2066, 2070, and 2074. A single line was drawn through the other shots that showed the general trend of gradual increase in propagation .



When THQ existed, transient velocities of more than 100 m/s were observed. The sonic velocities were about 130-150 m/s under the present helium test conditions. For shots without THQ there was a trend of slowing down in the hot helium expansion velocity before a gradual increase took place.



L. Dresner, IEEE Trans. Magn., p 1710, March 1989.
Note the drop in H/C velocity in either analysis models.

The temperature rise, ΔT of the cold helium adjacent to the hot helium by the compression of the expanding hot helium and the friction with the cable strands

$$\Delta T = \Delta p \left(\frac{\partial T}{\partial p}\right)_V + \frac{2f}{DC_p} \int_0^t \dot{Z}^3 dt \,, \qquad (1)$$

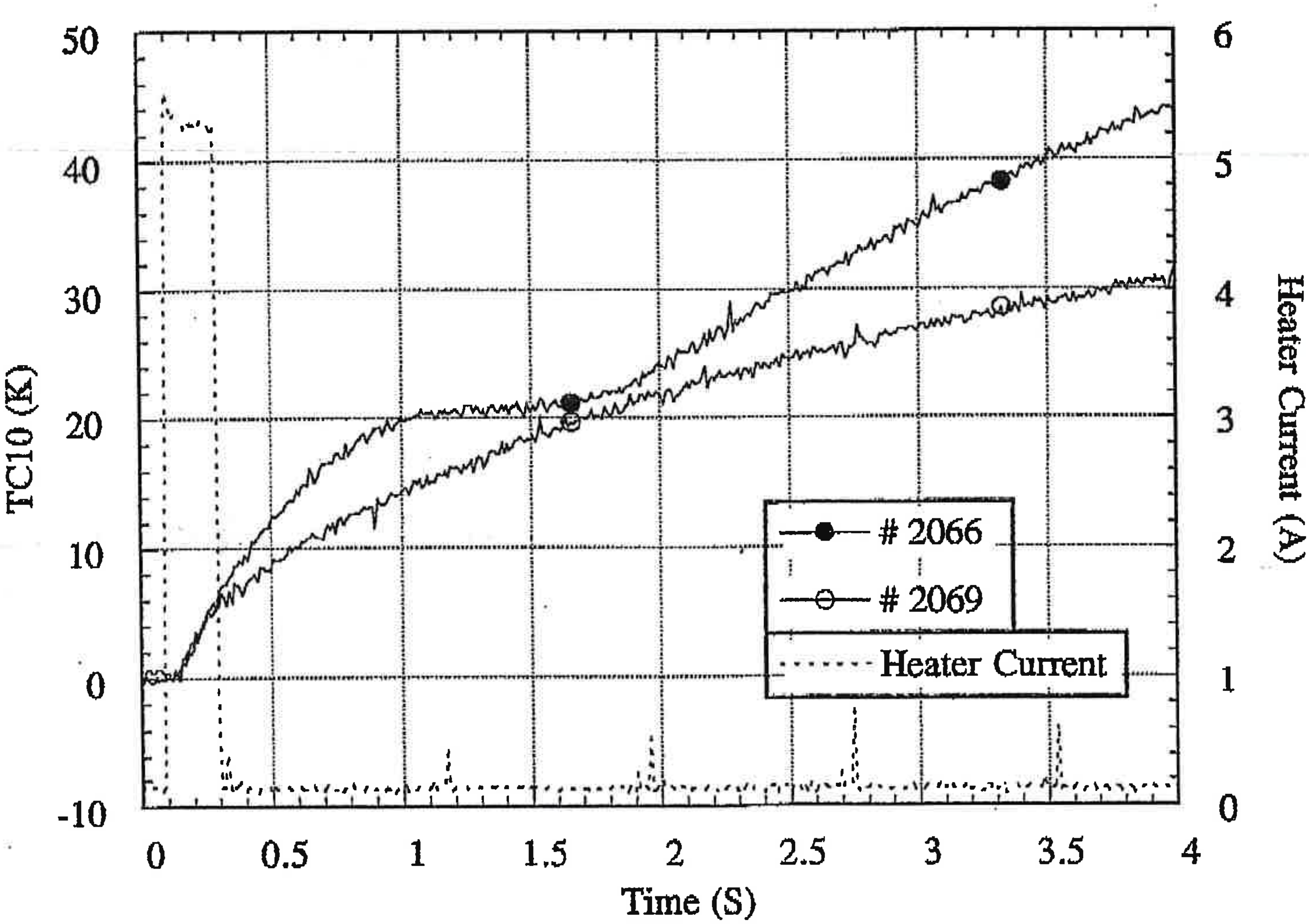
The time when ΔT reaches $(T_\alpha - T_b)$ marks the onset of THQ. It was further shown that the frictional term is much less than the compressional term for the onset of THQ. Thus a formula for the onset of THQ was derived:

$$\left(\frac{4fZ}{D}\right)^{3/2} \frac{D}{4fct} = \left[\left(\frac{\partial p}{\partial T}\right)_V \Delta T\right] / A\rho c^2 \,. \qquad (3)$$

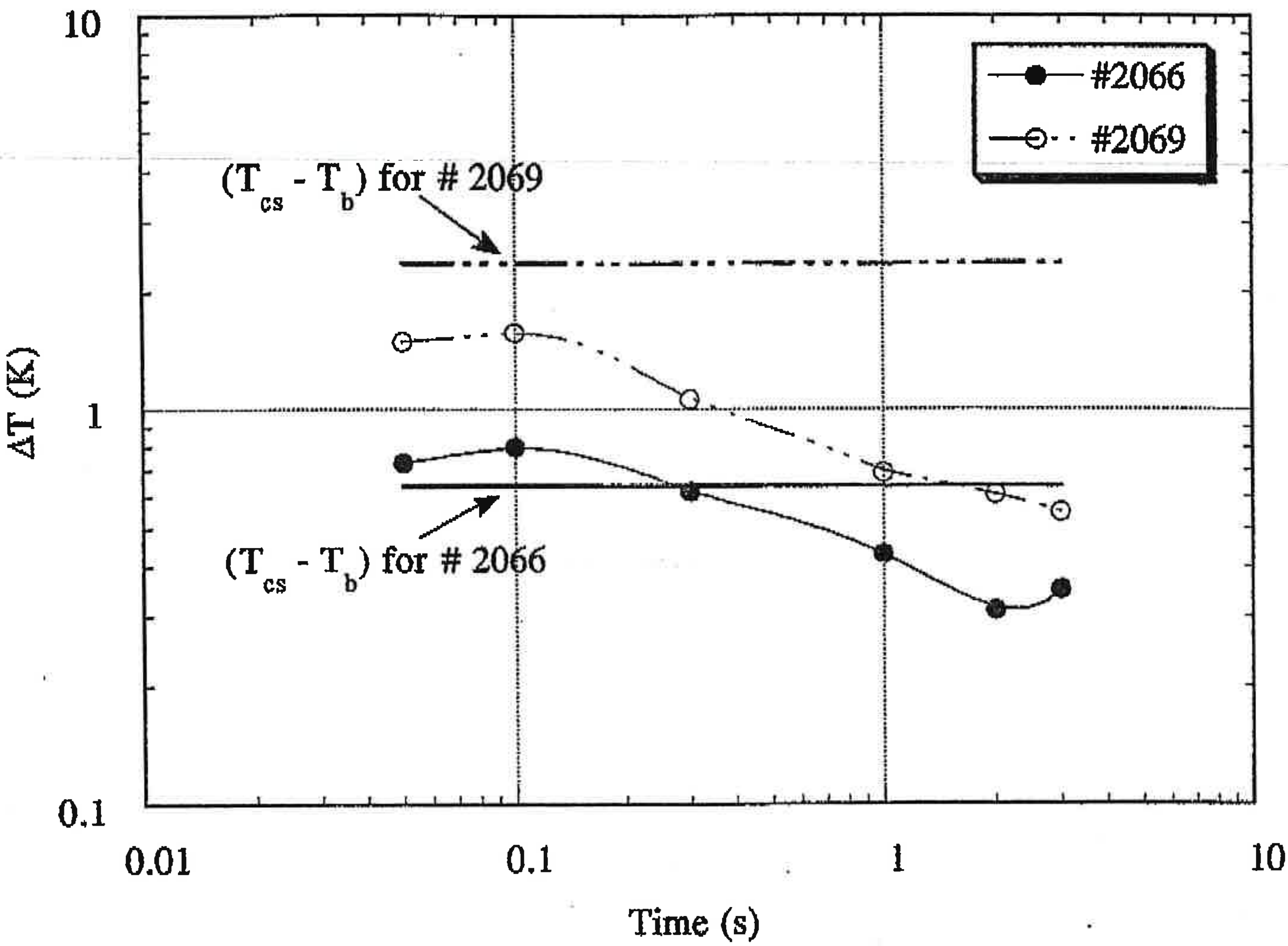
In order to calculate the onset time, the rate of growth of the normal zone before THQ, i.e. the piston displacement Z(t), must be known. It was assumed that the piston displacement was proportional to a power of the elapsed time

$$Z = X\, t^n \,. \qquad (4)$$

Now, the left-hand side of Eq. 3 varies as the $(3n/2 - 1)$ power of the time. So if $n > 1$, as we first imagined, then $(3n/2 - 1) > 0.5$. A small change of the right-hand side (for example in ΔT) would require a comparatively small change in t to satisfy the left-hand side. On the other hand, if $n < 1$, say 0.7 for example, then $(3n/2 - 1) = 0.05$. A small change in the right-hand side, say by a factor of 1.2, would require a change in t by a factor of 38. Such a vast delay in onset would appear experimentally as a threshold.



Examples of Measured Temperature Excursion at the Heated Zone.



Calculated Temperature Rise in Cold Helium in Comparison with the Current Sharing Margin for a Shot with THQ and one without THQ. This was done with the technique of Dresner's IEEE '89 paper.

10

Table 1. Shot Conditions and the Existence of THQ

Shot	heater	I_a (A)	B (T)	T_b (K)	p_o (atm)	v_{He} (m/s)	THQ	$(T_{cs}-T_b)$	ΔT_{Max}
2057	4	980	0	6.3	1.8	2.0	No	1.72	0.83
2066	4	870	0	7.5	3.1	3.5	Yes	0.64	0.80
2069	4	660	0	6.0	3.9	1.2	No	2.37	1.57
2070	4	660	2.4	6.5	3.6	1.5	Yes	0.73	1.09
2073	4	560	2.4	6.4	2.9	1.9	No	0.95	0.91
2074	4	595	2.4	6.6	2.8	2.9	Yes	0.71	0.92
2075	4	600	1.2	6.6	3.1	2.9	No	1.27	1.07
2076	3	600	2.4	6.6	3.0	3.2	Late	0.70	0.83
2077	3	700	2.4	6.7	3.3	3.1	Yes	0.48	0.81
2081	3	695	1.2	7.1	4.8	3.0	Late	0.66	0.80
2078	3 & 4	500	2.4	6.8	3.5	3.2	Late	0.63	1.46
2079	3 & 4	550	2.4	6.8	4.0	3.2	Yes	0.56	1.42
2080	3 & 4	590	2.4	7.0	4.5	3.2	Yes	0.32	1.93

CONCLUSION

- The existence of THQ was verified experimentally.
- When THQ occurred, normal zone propagation approaching the velocity of sound was observed.
- Thresholds for THQ as functions of current, temperature, heated length, and field were observed. This threshold can also be accounted for the Dresner's theory.
- Further experiments are needed to pinpoint the expansion power of the initial normal zone at early time of the propagation.