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"Analytical and Numerical Modeling of Quench in CICC"

ANALYTICAL AND NUMERICAL MODELING OF QUENCH IN CICC

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Outline

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3. Fairly general 1-D quench model (Quencher)

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5. Analytic theory of quench

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Introduction and Goals

1. Quantities of interest during quench

    a. Temperature profile

    b. Helium pressure profile

    c. Total normal length

2. Develop fast and reliable methods to model quench

    a. Computer code (Quencher)

    b. Simplified quench model (MacQuench)

    c. Analytic theory of quench

Fairly General 1-D Model

1. 1-D equations (SC/CU and helium)

   a. For SC/CU

$$\rho_c C_c \frac{\partial T_c}{\partial t} = \frac{\partial}{\partial x}\left(\kappa_c \frac{\partial T_c}{\partial x}\right) + \eta_c J_c^2 + \frac{P_c h}{A_c}(T_h - T_c)$$

   b. For the helium

$$\frac{\partial \rho_h}{\partial t} + \frac{\partial}{\partial x}(\rho_h v_h) = 0$$

$$\rho_h \left(\frac{\partial}{\partial t} + v_h \frac{\partial}{\partial x}\right) v_h = -\frac{\partial p_h}{\partial x} - \frac{f \rho_h v_h^2}{2 d_h}$$

$$\rho_h C_V \left(\frac{\partial}{\partial t} + v_h \frac{\partial}{\partial x}\right) T_h + \rho_h C_\beta T_h \frac{\partial v_h}{\partial x} =$$

$$\frac{\partial}{\partial x}\left(\kappa_h \frac{\partial T_h}{\partial x}\right) + \frac{P_c h}{A_h}(T_c - T_h)$$

$$p_h = p_h(\rho_h, T_h)$$

where

$P_c =$ Conductor Perimeter

$A_c =$ Conductor Cross-Sectional Area

$A_h =$ Helium Cross-Sectional Area

$$C_\beta = \frac{1}{\rho}\left(\frac{\partial p}{\partial T}\right)_\rho$$

Fairly General 1-D Quench Model (Quencher)

1. Simplifications of the 1-D Model
   a. Restrict attention only to quench
   b. Exploit high heat transfer
   c. Exploit low helium velocity
   d. No loss in engineering accuracy or reliability

2. Exploit high heat transfer
   a. Add the T equations to annihilate $h\Delta T$ terms
   b. Set $T_h \approx T_c \equiv T$

3. Exploit low helium velocity
   a. Neglect helium inertia

Numerical Procedure

1. Fully implicit time difference (4th order)

2. Spatial solution using collocation scheme
   including automatic remeshing

The Quencher Code

1. Advantages

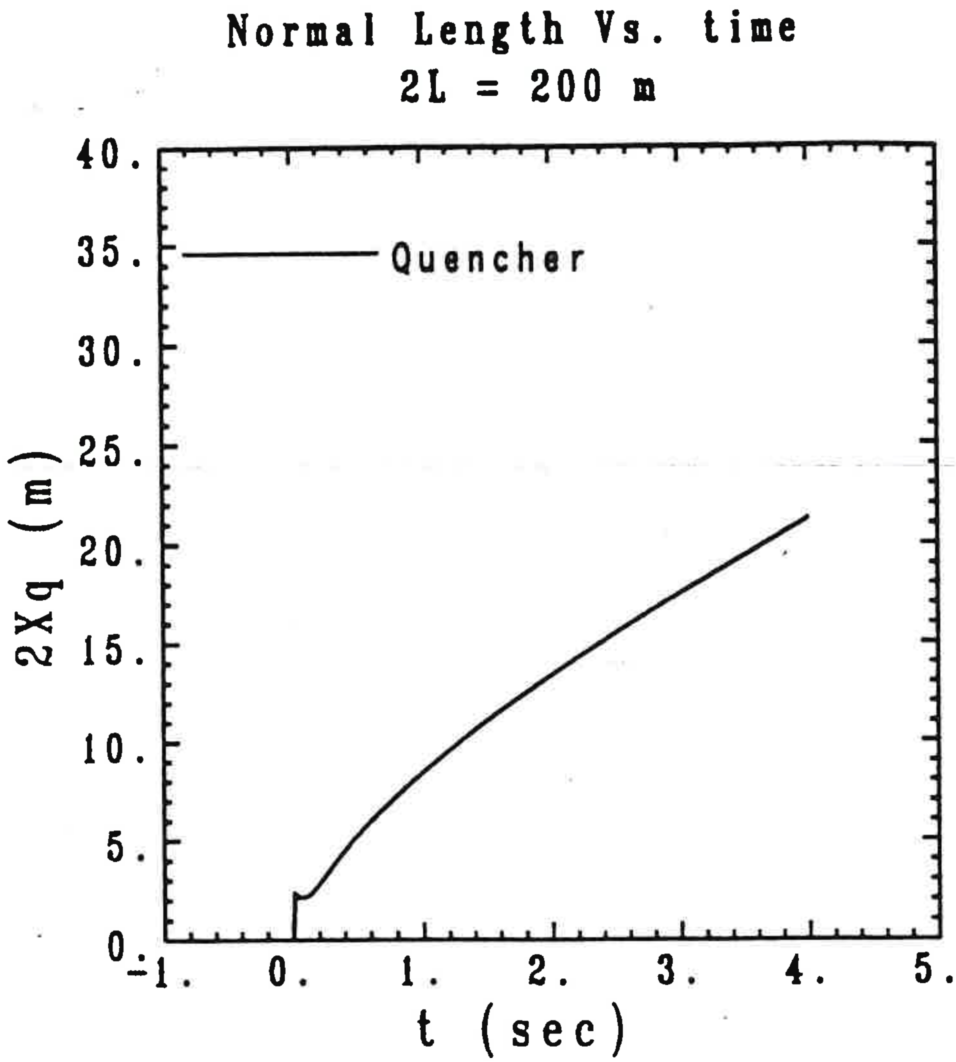
   a. High reliability and accuracy

   b. CPU time: 1-5 minutes CRAY/run

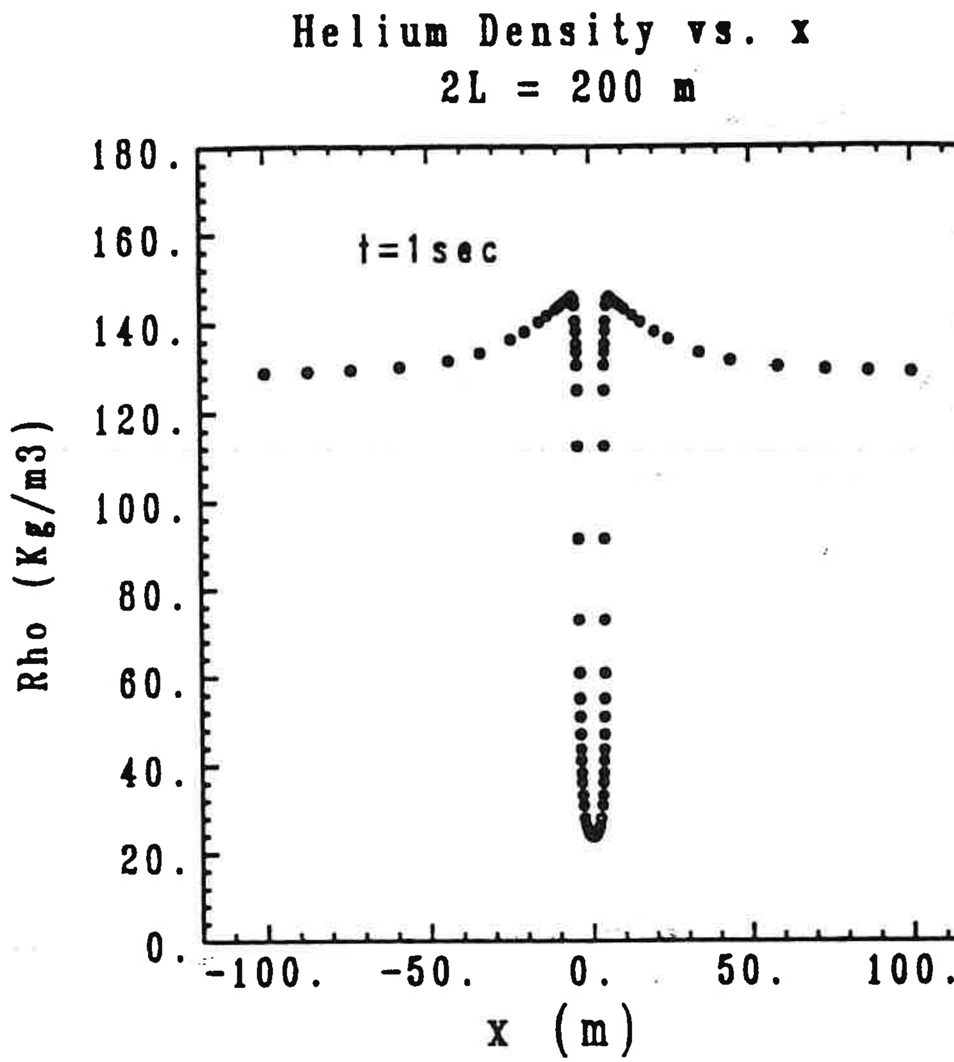
2. Disadvantages

   a. Not adequate for stability

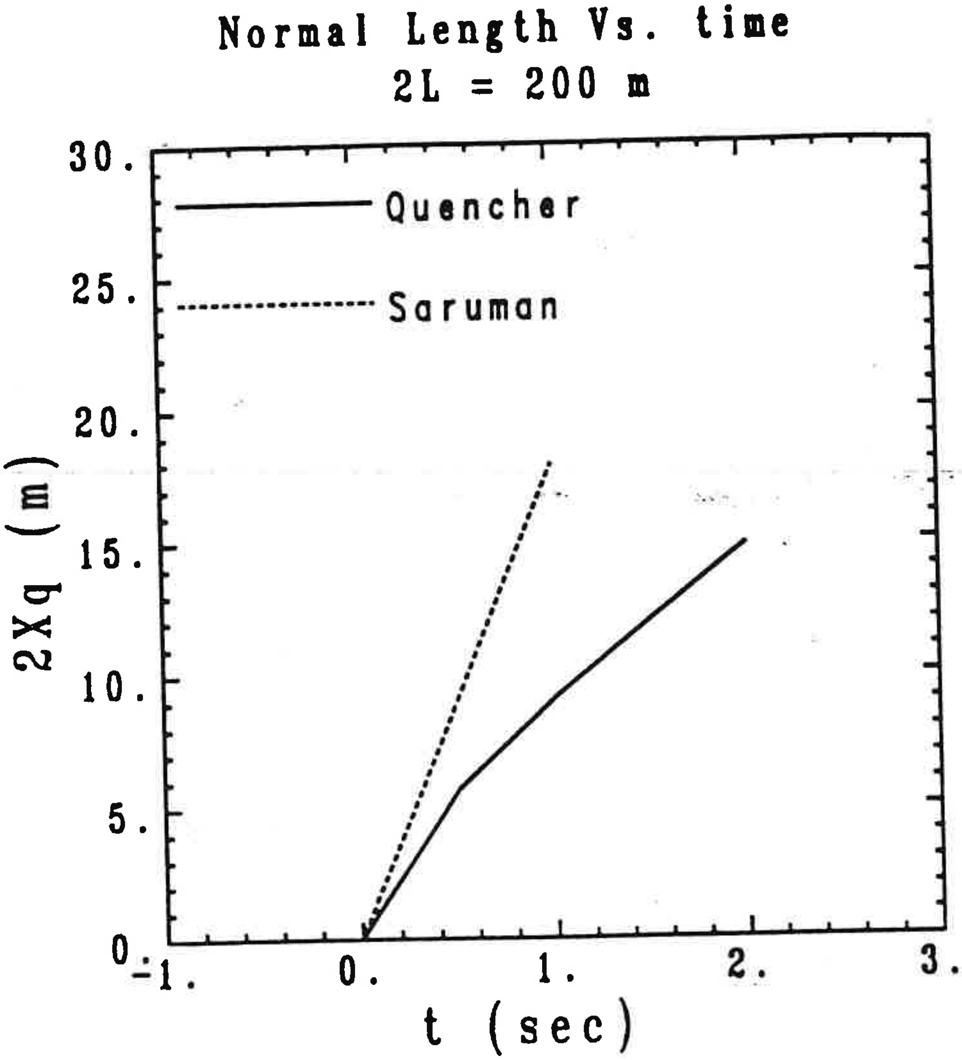
   b. All enhancements not yet installed



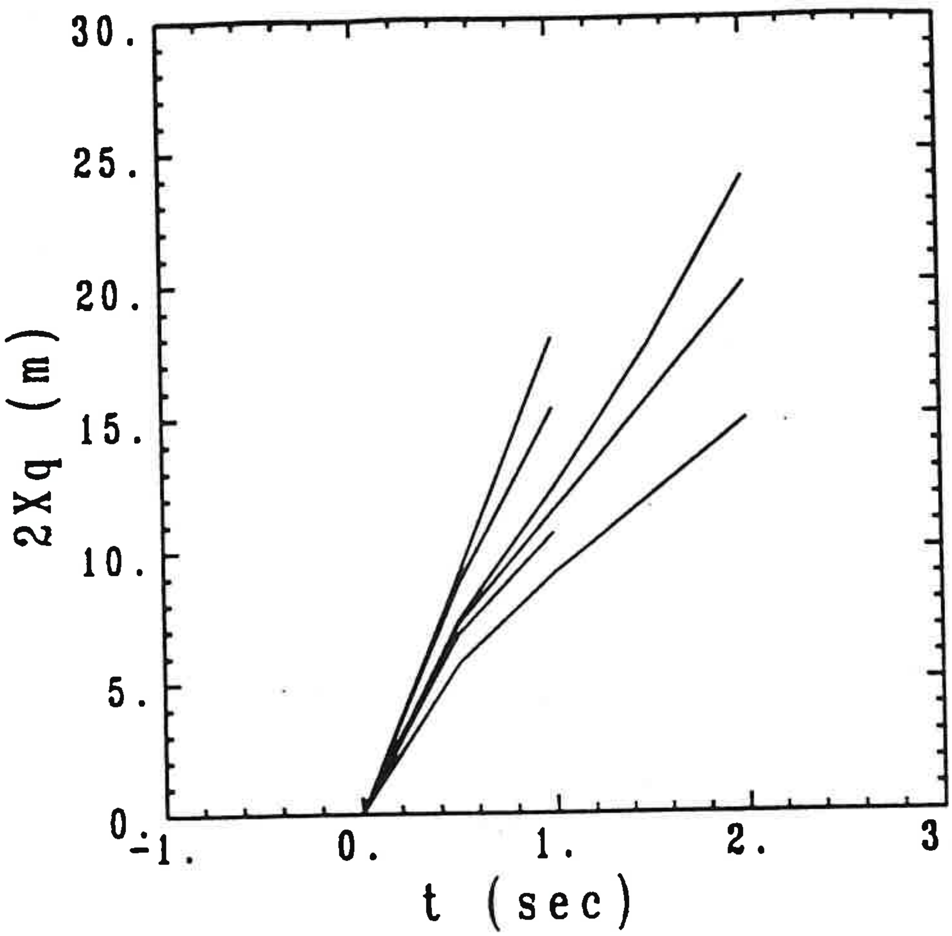
Normal Length Vs. time
2L = 200 m
Quencher
2Xq (m)
t (sec)
40.
35.
30.
25.
20.
15.
10.
5.
0.
-1.
0.
1.
2.
3.
4.
5.



Helium Density vs. x
2L = 200 m
t=1sec
Rho (Kg/m3)
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.
-100.
-50.
0.
50.
100.
x (m)

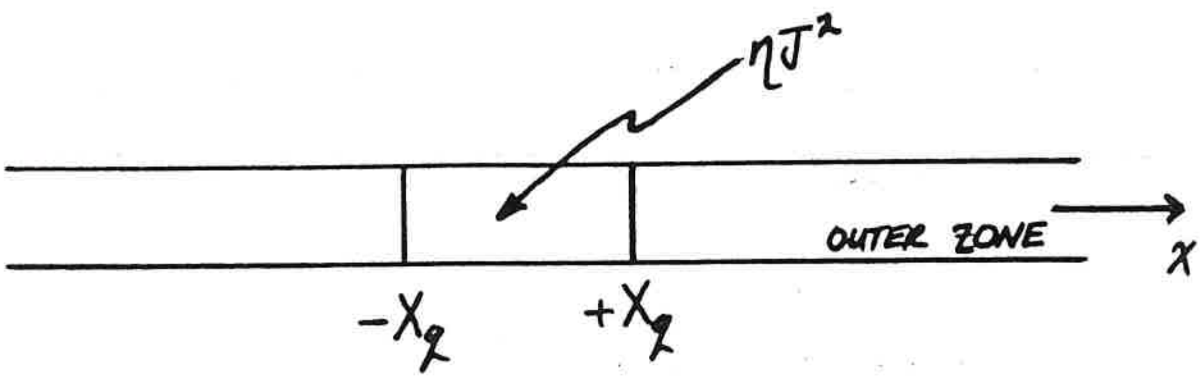

Normal Length Vs. time
2L = 200 m
Quencher
Saruman
2Xq (m)
t (sec)
30.
25.
20.
15.
10.
5.
0.
-1.
0.
1.
2.
3.

Normal Length Vs. time
2L = 200 m



Simplified 1-D Quench Model

1. Quench propagation mechanism



2. Quench is characterized by a narrow moving boundary layer, the quench front

3. Exploit this behavior by
   a. Solving separately behind the quench
   b. Solving separately in front of the quench
   c. Matching across the boundary (quasi-contact discontinuity)

4. Results: MacQuench Code   Analytic Solution

Analytic Solution

1. Maximum temperature

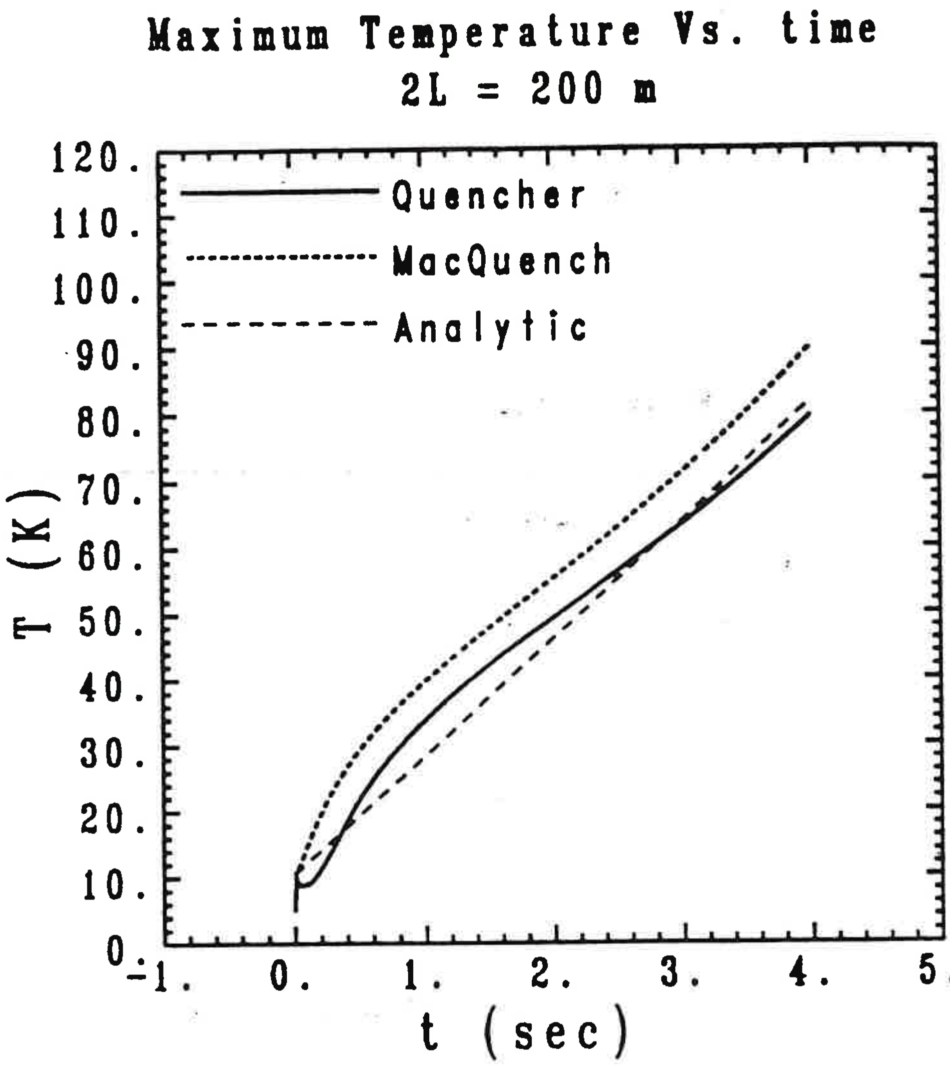
$$T \approx \frac{\eta J^2}{\rho_c C_c}\, t \;+\; T_{cr}$$

2. Maximum helium pressure

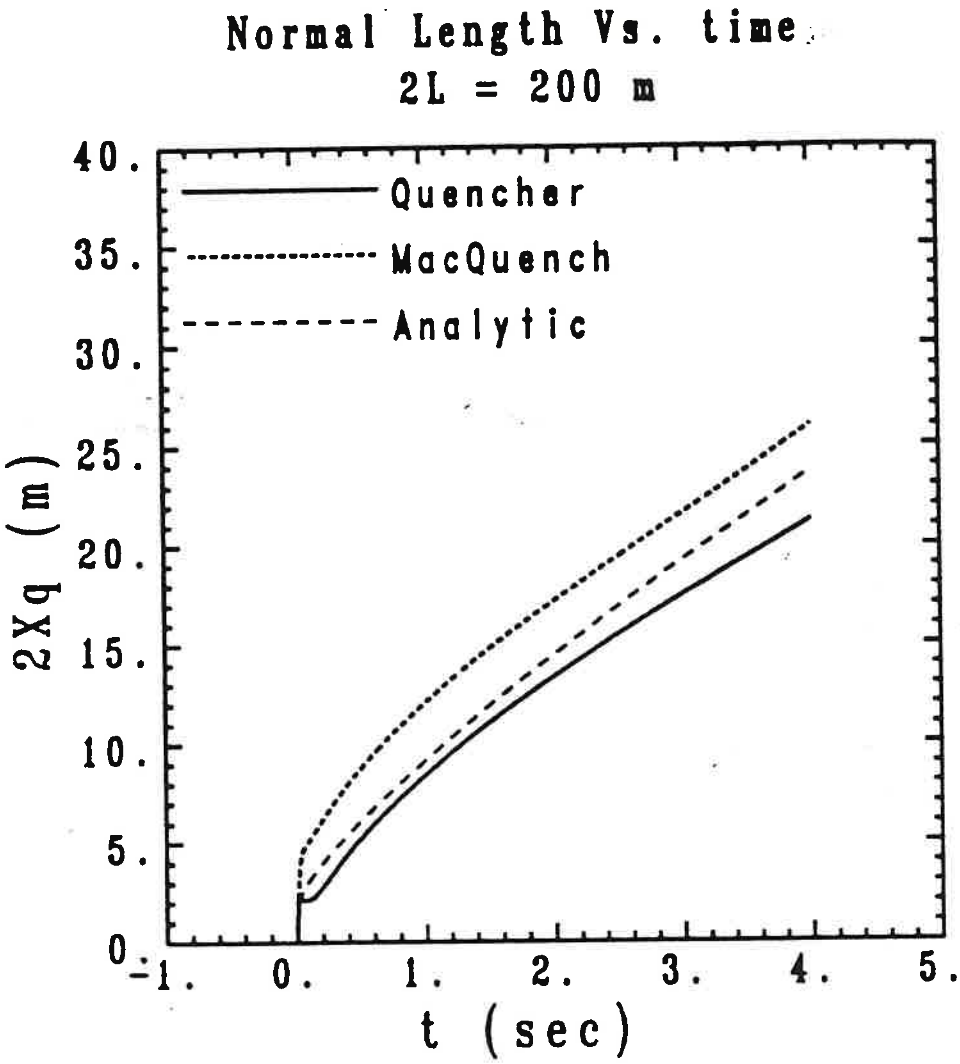
$$p \approx R\rho_0 L_q \,\frac{T}{X_q}$$

3. Quench front

$$X_q \approx 1.2 \left[\left(\frac{R^2}{c_0^2}\right)\left(\frac{d_h}{f}\right)\left(\frac{\eta J^2}{\rho_c C_c}\right)^2 L_q^2 \right]^{1/5} t^{4/5} \;+\; L_q$$



Maximum Temperature Vs. time
2L = 200 m
Quencher
MacQuench
Analytic
T (K)
t (sec)
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
110.
120.
-1.
0.
1.
2.
3.
4.
5.


Normal Length Vs. time
2L = 200 m
Quencher
MacQuench
Analytic
2Xq (m)
t (sec)
0.
5.
10.
15.
20.
25.
30.
35.
40.
-1.
0.
1.
2.
3.
4.
5.

Comparison With Dresner's Results

1. Similarity of models

   a. Both neglect helium inertia

   b. Both assume a piston-like quench propagation

   c. Both include long coils

   d. Both neglect thermal conduction

2. Differences of models

	Dresner	Present Theory
Specific heat ($x < X_q$)	helium	solids
Solid properties	$\eta_c \approx const.$	$\eta_c/C_c \approx const.$
Coil type	long	long and short
Region of validity	$\tau \approx \tau_{init} < \tau_{det}$	$\tau_{init} < \tau \approx \tau_{det}$

3. Dresner's solution

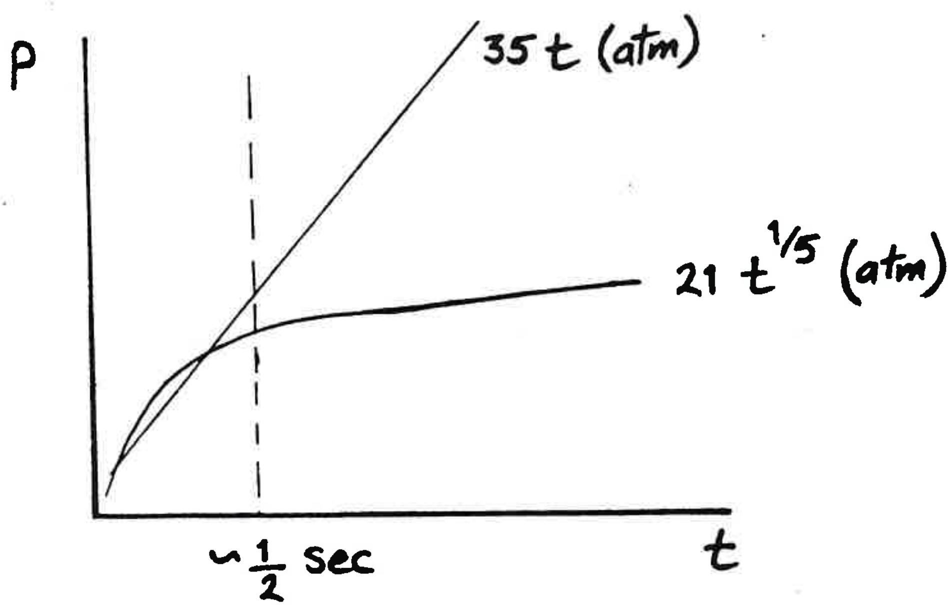
$$p \approx 0.21\,\eta J^2\,t$$

$$X_q \approx 0.25 \left(\frac{d_h^{1/2}\,\eta J^2}{f^{1/2}\rho_0 c_0} \right)^{2/3} t^{4/3}$$

4. Present theory

$$p \approx \left(\frac{R^3 c_0^2 \rho_0^5 L_q^3 f}{d_h} \right)^{1/5} \left(\frac{\eta J^2}{\rho_c C_c} \right)^{3/5} t^{1/5}$$

$$X_q \approx 1.2 \left[\left(\frac{R^2}{c_0^2}\right)\left(\frac{d_h}{f}\right)\left(\frac{\eta J^2}{\rho_c C_c}\right)^2 L_q^2 \right]^{1/5} t^{4/5} \;+\; L_q$$



Summary

1. Fast quench code (Quencher)
2. A systems code (MacQuench)
3. Analytic theory of quench
    a. Long coils
    b. Short coils
    c. Transition between long and short coils
    d. Onset of THQB

Future Plans

1. Calibration of numerical and analytic results versus experiments
2. Enhancement of Quencher (3-D problems, etc.)
3. Extensive numerical study of THQB
4. Analytic theory of THQB after its initiation