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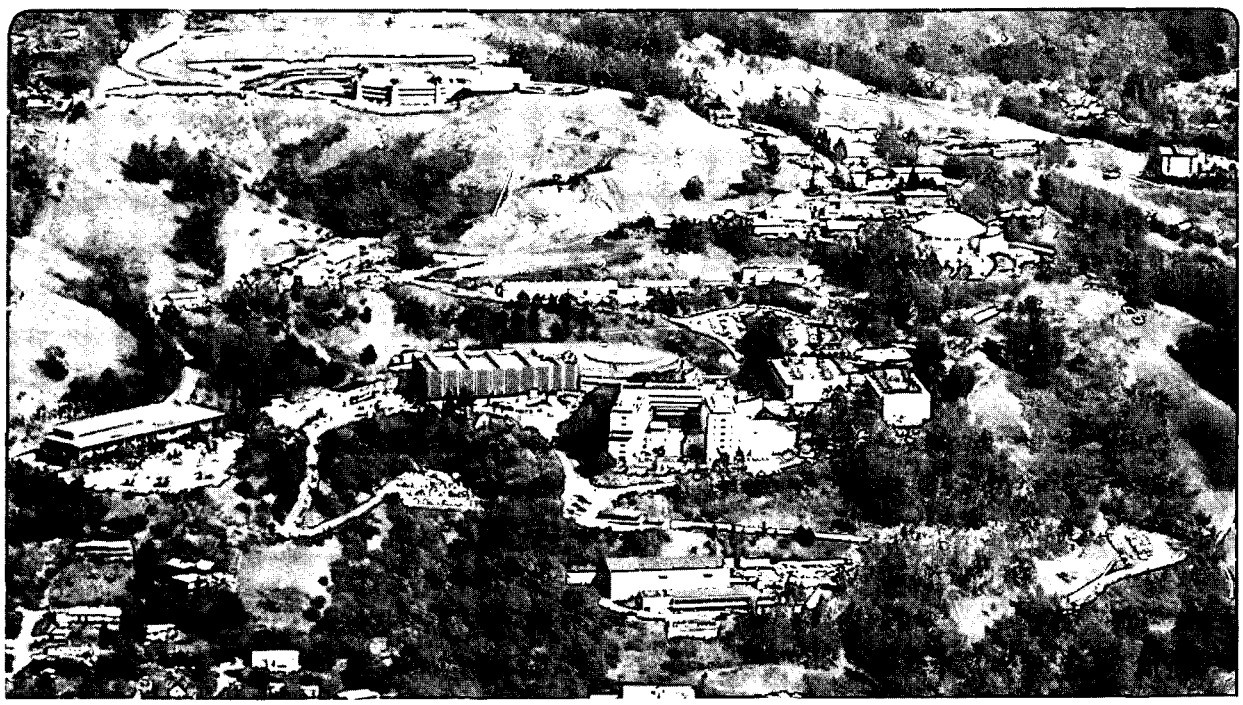

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LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA
ENGINEERING NOTE

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PE1161	M5330	1 of 8

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PROGRAM — PROJECT — JOB
PEP II RING MAGNET DEVELOPMENT

CRYOGENIC SYSTEMS

TITLE
HELIUM II CRYOGENIC SYSTEM, FIRST CUT

ABSTRACT

This note presents a conceptual design of the cryogenic system for a 1.8K accelerator and includes some very preliminary sizing relating to the spacing between cooling stations which is based on a recently reported He II heat flow model

SUMMARY

The system proposed includes a stationary (zero net mass flow) He II reservoir at 1.8K which is cooled at intervals by expanded helium which is drawn from a parallel circuit in which two phase He I is circulated. The two phase circuit also provides thermal shielding and pressurization for the He II reservoir. The distance between cooling stations for the 1.8K reservoir is computed as a function of heat load, temperature rise midway between cooling stations, and cross sectional area available for heat flow in the He II. For example for a heat load of 0.1 W/m and a He II cross section of 70 cm², a 10 mK temperature rise will result midway between cooling stations located 280 m apart. If the allowable temperature rise is increased to 50 mK the spacing may be increased to 400 m. Note the extreme non linearity between ΔT and L. If the heat rate is 1. W/m then these lengths are reduced to 48 m and 68 m.

SYSTEM DESCRIPTION

The system is shown schematically in Fig 1. The beam space and magnets are contained within an elongated reservoir which is filled with single phase, subcooled, He II at 1.8K. The only flow in the He II space is that associated with the counterflow convection mechanism (zero net mass flow) which is peculiar to the transport of heat in He II. This reservoir is thermally shielded by a flowing, 2-phase He II system which also pressurizes the He II space in a manner analogous to that reported by Bon Mardion.[1] Heat is extracted from the He II by expanded helium which is withdrawn as a liquid from the 2 phase circuit and subcooled in HE2 prior to expansion as shown on the schematic. The low pressure helium at a temperature of <1.8K extracts heat from the He II in HE1 where it is completely vaporized. This low pressure gas is then warmed to a temperature $>T_\lambda$ in HE2 and to ambient temperature in HE3. This gas is compressed to approximately 1atm in vacuum pump C1, then cooled to ≈4K in HE3 and returned to the refrigerator as shown on Fig 1. Heat exchangers, HE1, are distributed along the length of the accelerator as necessary to limit the temperature rise in the He II. Refrigerators, heat exchangers HE3 and vacuum pumps C1, may be located at each cooling station or may serve several cooling stations as suggested on Fig 1.

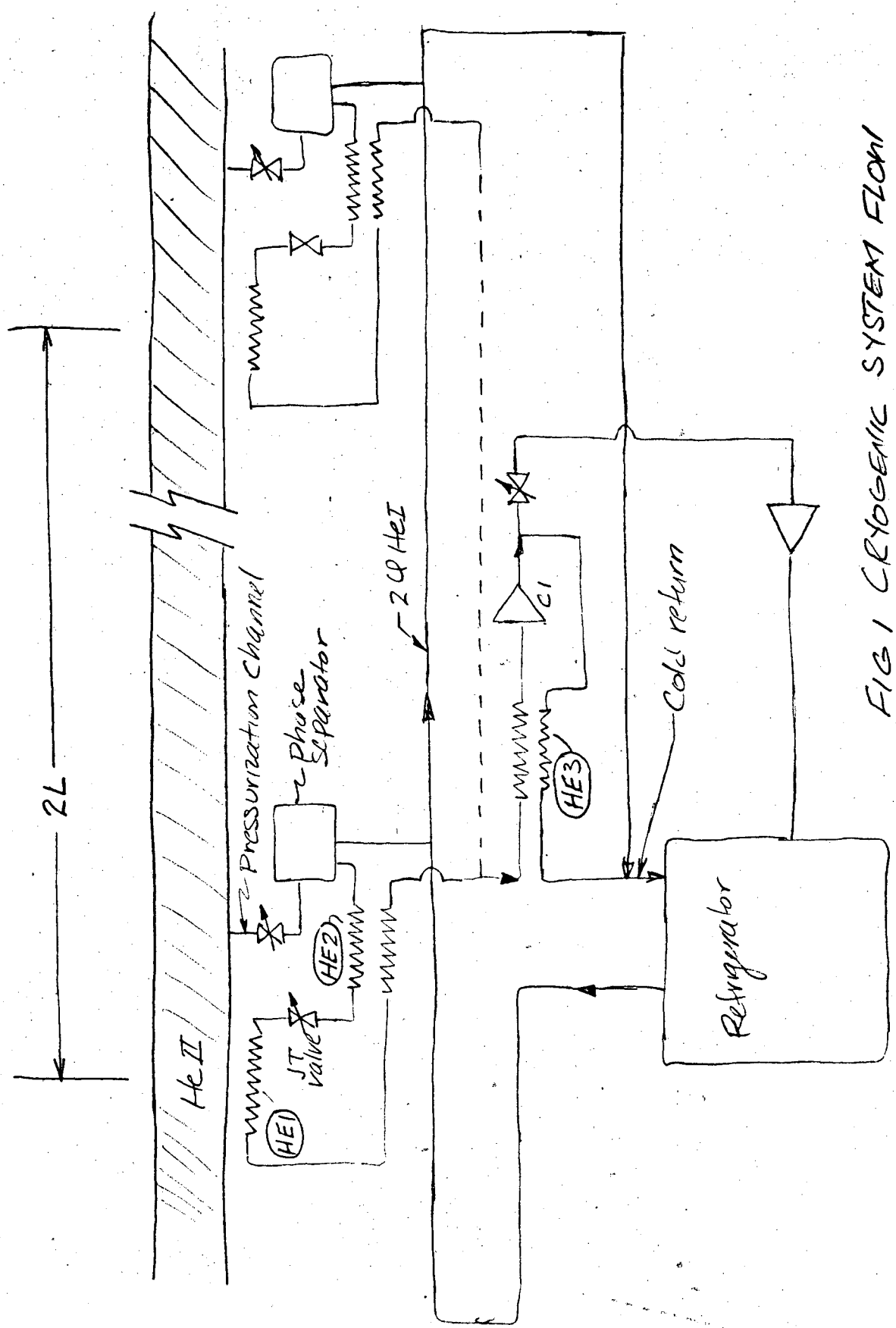


FIG 1 CRYOGENIC SYSTEM FLOW SCHEMATIC

ANALYSIS

We proceed to compute the temperature profiles (or conversley the length between cooling stations for a given temperature rise) on the basis of a semi-emperical He II heat flow model based on the Gorter-Mellink relation

$$(q/A)^m \propto \nabla T \qquad m \approx 3$$

as developed by Ben Mardion[2].
For vanishing small temperature differences, Ben Mardion writes

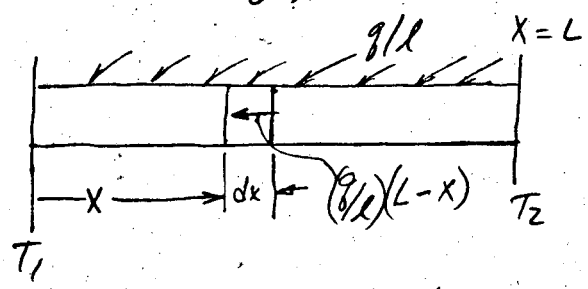
$$(q/A)^m = f(T)\cdot\nabla T$$

or for finite temperature differences

$$(q/A)^m = F(T_1, T_2)/L$$

where $F(T_1, T_2) = \int_{T_1}^{T_2} f(T)\,dT$

Now consider a channel (He II reservoir) which is uniformily heated at rate q/l



from the first relation above the temperature rise in the element dx is

$$dT = \frac{(q/A)^m\,dx}{f(T)} = \left[\frac{(q/L)(L-x)}{A}\right]^m \frac{dx}{f(T)}.$$

integrating over the length

$$\int_{T_1}^{T_2} dT = \left(\frac{q/\ell}{A}\right)^m \frac{1}{f(T)} \int_0^L (L-x)^m dx$$

leads to

$$T_2 - T_1 = \left(\frac{q/\ell}{A}\right)^m \frac{L^{m+1}}{(m+1)\, f(T)}$$

or $$L = \left[(m+1)\, f(T)\, \Delta T\right]^{\frac{1}{m+1}} \left(\frac{A}{q/\ell}\right)^{\frac{m}{m+1}}$$

Bon Mardion has found the experimental data at P=1 Bar is best fit with m=3.4. He also provides a plot of $F(T, T_\lambda)$ vs T from which we can extract $f(T)$. We can write

$$F(T_1, T_\lambda) - F(T_2, T_\lambda) = \int_{T_1}^{T_2} f(T)\, dT$$

from which

$$\bar{f}(T) = \frac{F(T_1, T_\lambda) - F(T_2, T_\lambda)}{T_2 - T_1}$$

Choosing $T_1 = 1.80K$ and $T_2 = 1.85K$ we find from Ref 2

$$F(T_1, T_\lambda) = 360\ (W/cm^2)^{3.4}\ cm$$
$$F(T_2, T_\lambda) = 293$$

So that $$\bar{f}(T) = \frac{360 - 293}{.05} = 1340\ (W/cm^2)^{3.4} \frac{cm}{K}$$

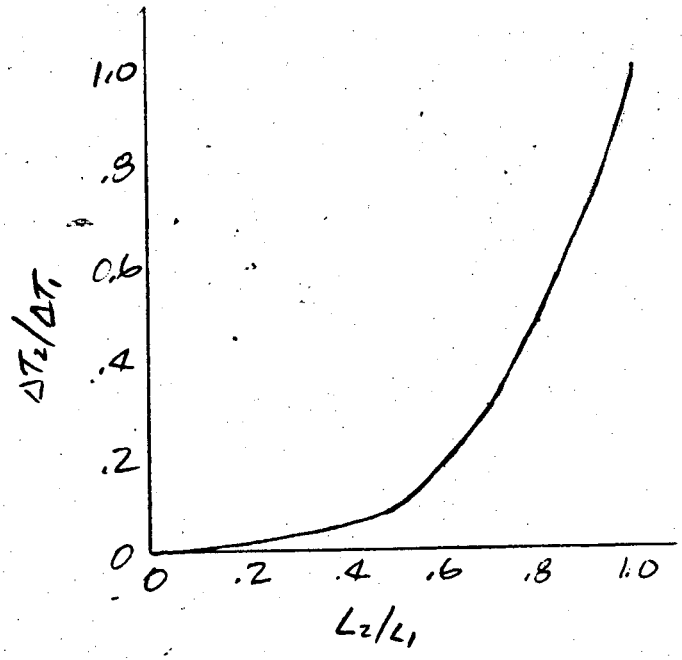
This value is used in the equation above for L. The results are plotted on Fig 2 for $\Delta T = 0.01$ & 0.05, A from 10 to 1000 cm^2 and q/ℓ from 0.01 to 1 W/m. For some points of reference, for a one cm layer surrounding the structural rings of the base case of magnet parameter study in (3) $A = 70\ cm^2$

The circumference of the PEP ring is approx. 2200 m. So that for the proposed cooling concept to be of interest there L should be of the order of 10^2 m or more. From Fig 2 for $A = 70\ cm^2$, $\Delta T = 0.05K$ & $q/l = 0.1\ W/m$ $L = 200$ m so that approximately 5 cooling stations would be required. If the heat load were to go up to 1 W/m, $L = 34$ m and approx. 32 cooling stations are required. Which is still a managable number, but the importance of keeping the heat load on the He II system down is clearly demonstated.

The dependance of ΔT on L is worth porsuing further. From the above

$$\frac{\Delta T_2}{\Delta T_1} = \left(\frac{L_2}{L_1}\right)^{3.4}$$

These ratios are plotted to the right. Note that 90% of the temperature rise occurs in 50% of the length. Little is to be gained, therefore, in making small increases in the allowable temperature rise.



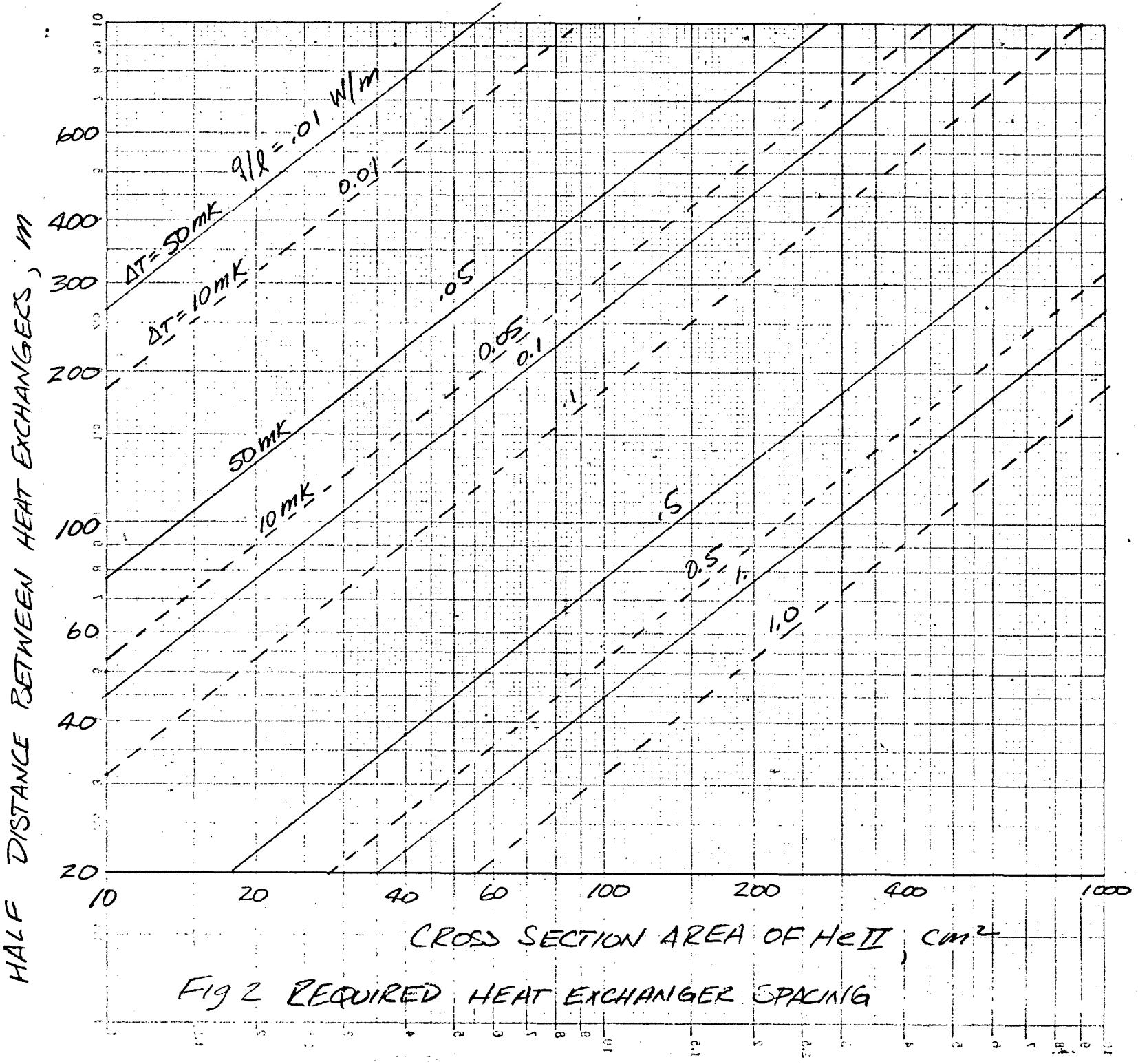


Fig 2 REQUIRED HEAT EXCHANGER SPACING

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3. Gilbert, WS, Lambertson, GR, and Meuser RB, "Eight-Tesla Synchrotron Dipoles - Design Alternatives" 1979 Particle Accelerator Conference

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