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**STATEMENT OF PROBLEM**

Perform a thermal analysis on the SNAP 2 and SNAP 8 reactors modified for use in an under water environment SNAP 6 system. The primary purpose of this effort is to determine the limitations that exist in the SNAP 2 and 8 reactors when operated at SNAP 6 conditions.


**ABSTRACT**

The following specific items are contained in this report:

1. Maximum fuel element thermal stress as a function of core power.

2. Maximum fuel and cladding temperature as a function of core power and exit NaK temperature for NaK $\Delta T$'s from 100°F to 400°F.

3. Pressure drop through core as a function of flow rate.

4. Fuel element swelling as a function of core power and fuel temperature.

5. Maximum reflector temperature as a function of core power.

Thermal stress considerations limit the power in the SNAP 2 core to 150 kw and that in the SNAP 8 core to 1000 kw. The problem of fuel element expansion may lower these limits, e.g., for a 2% allowable expansion and a fuel temperature of 1100°F, the maximum power for a five year lif[redacted] becomes 500 kw.


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1. THERMAL STRESS

1.1 Results The maximum thermal stress has been calculated for both the SNAP 2 and SNAP 8 cores as a function of the power level. In Figure 1, the curve for the SNAP 2 core was based on a peak-to-average flux of 1.91, while that for the SNAP 8 was 1.82. The maximum thermal stress is directly proportional to the peak-to-average flux, the reported values can be corrected for any change in the flux distribution.

At the present time, the maximum stress in the fuel elements is limited to 20,000 psi, and is essentially independent of temperature between 1000-1400°F. Since little data are available to support this value, a safe design limit should be somewhat less than this, perhaps 15,000 psi.

The maximum power for the SNAP 8 core is therefore approximately 1,000 kw, and that for the SNAP 2 core is 150 kw, from a stress standpoint.

1.2 Method[1] The maximum thermal stress, $\sigma_{max}$, for a cylindrical fuel element may be calculated from the relationship:

$$\sigma_{max} = \frac{-E\alpha \; Q_{max} \; r^2}{8k} \left( \frac{1}{1-\nu} \right) \qquad (1)$$

When the fuel elements are in a triangular arrangement, an additional term must be included to account for the asymmetrical flow of heat. The above equation then becomes

$$\sigma_{max} = \frac{-E\alpha \; Q_{max} \; r^2}{4k} \left( \omega + \frac{1}{2(1-\nu)} \right) \qquad (2)$$

Where $\omega$ is a function of the pitch-to-diameter ratio $\alpha$.

1.3 Sample Calculation Values of the constants used in equation (2) were the following:

$E = 10^7$ psi

$\alpha = 6.7 \times 10^{-6}$ degree$^{-1}$

$k = 12$ Btu/hr-ft-°F

$\nu = 0.3$

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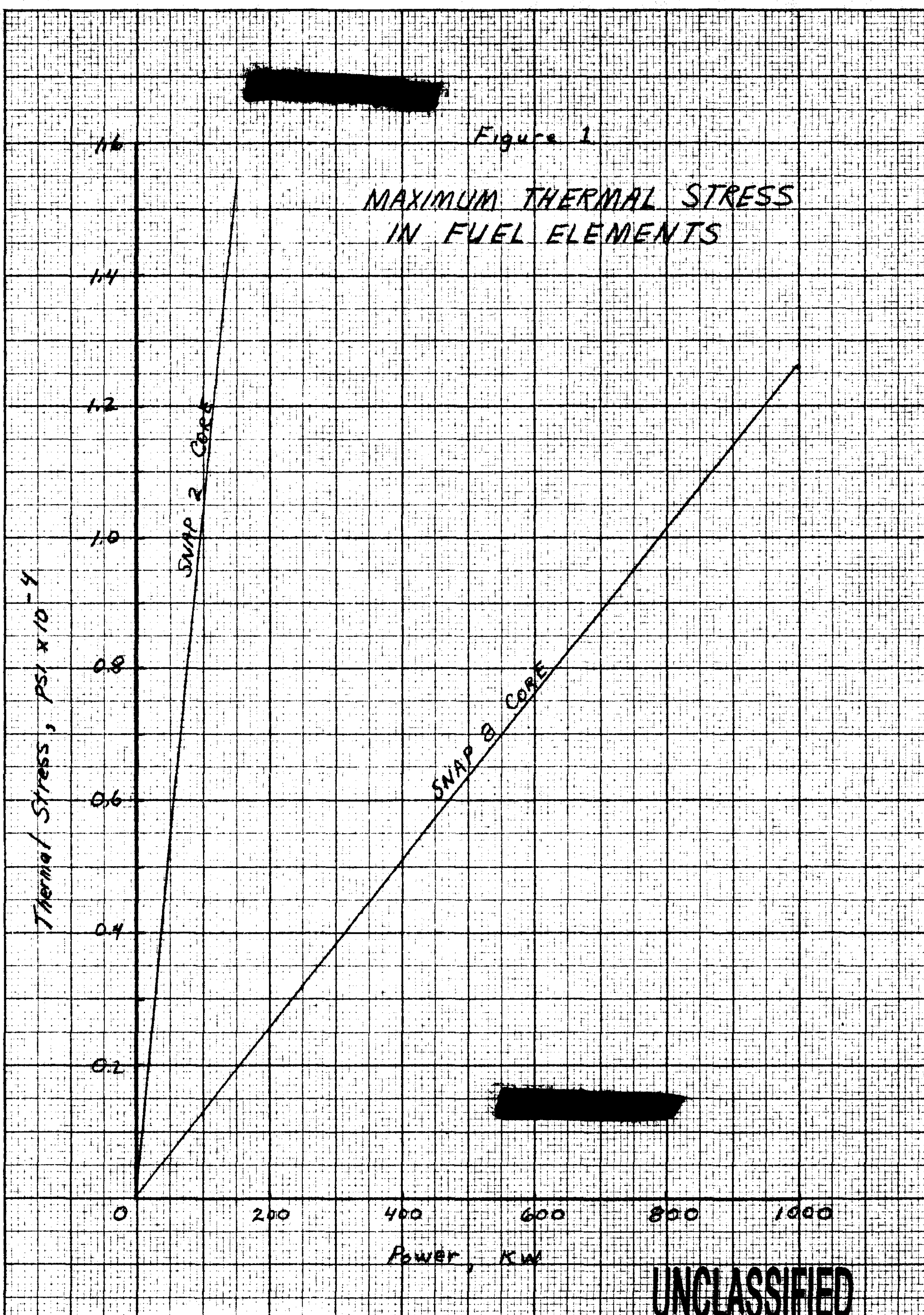


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1.3 Sample Calculation (Continued)

For the SNAP 8 configuration, the value for $\omega$ was 0.62, and for SNAP 2 it was 0.68. The diameter of SNAP 8 fuel elements is 0.534 inches; that for SNAP 2 is 1.21 inches.

When the SNAP 8 core is operated at 500 kw, the maximum heat generation rate is $6.92 \times 10^6$ Btu/hr-ft$^3$. The maximum thermal stress from equation (2) is therefore:

$$\sigma_{max} = \frac{10^7(6.7 \times 10^{-6})(6.92 \times 10^6)}{4(12)} \left(\frac{0.534}{2(12)}\right)^2 \left(.62 + \frac{1}{2(1 - 0.3)}\right)$$

$$= 6.32 \times 10^3 \text{ psi}$$

## 2. TEMPERATURES OF FUEL AND CLADDING

2.1 Results The maximum temperature in both the fuel element and in the cladding has been calculated as a function of both the reactor power and the NaK $\Delta T$ rise through the core. The difference between the maximum temperature and the exit temperature of the NaK is reported here. Figures 2 and 3 show the maximum fuel and cladding temperatures, respectively, for the SNAP 2 core. Figures 4 and 5 show the same for the SNAP 8 core.

Since a satisfactory method for determining the temperature distribution in a fuel element in a SNAP core configuration has not yet been developed, these reported values are only approximately. No allowance has been made for the hot-channel factor, about 1.22[(2)], which includes deviations in uranium content, hydrogen distribution, neutron flux, and coolant flow. Nevertheless, these temperatures should be satisfactory for preliminary design purposes.

Temperature limitations do not appear to present a serious problem. A temperature of 1400°F in the coating is the limiting condition. The maximum coating temperature reported here, that for the SNAP 2 core at 150 kw power with a NaK $\Delta T$ of 100°F and exit temperature of 1100°F, is 1300°F.

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Figure 2

MAXIMUM FUEL TEMPERATURE
SNAP 2 CORE

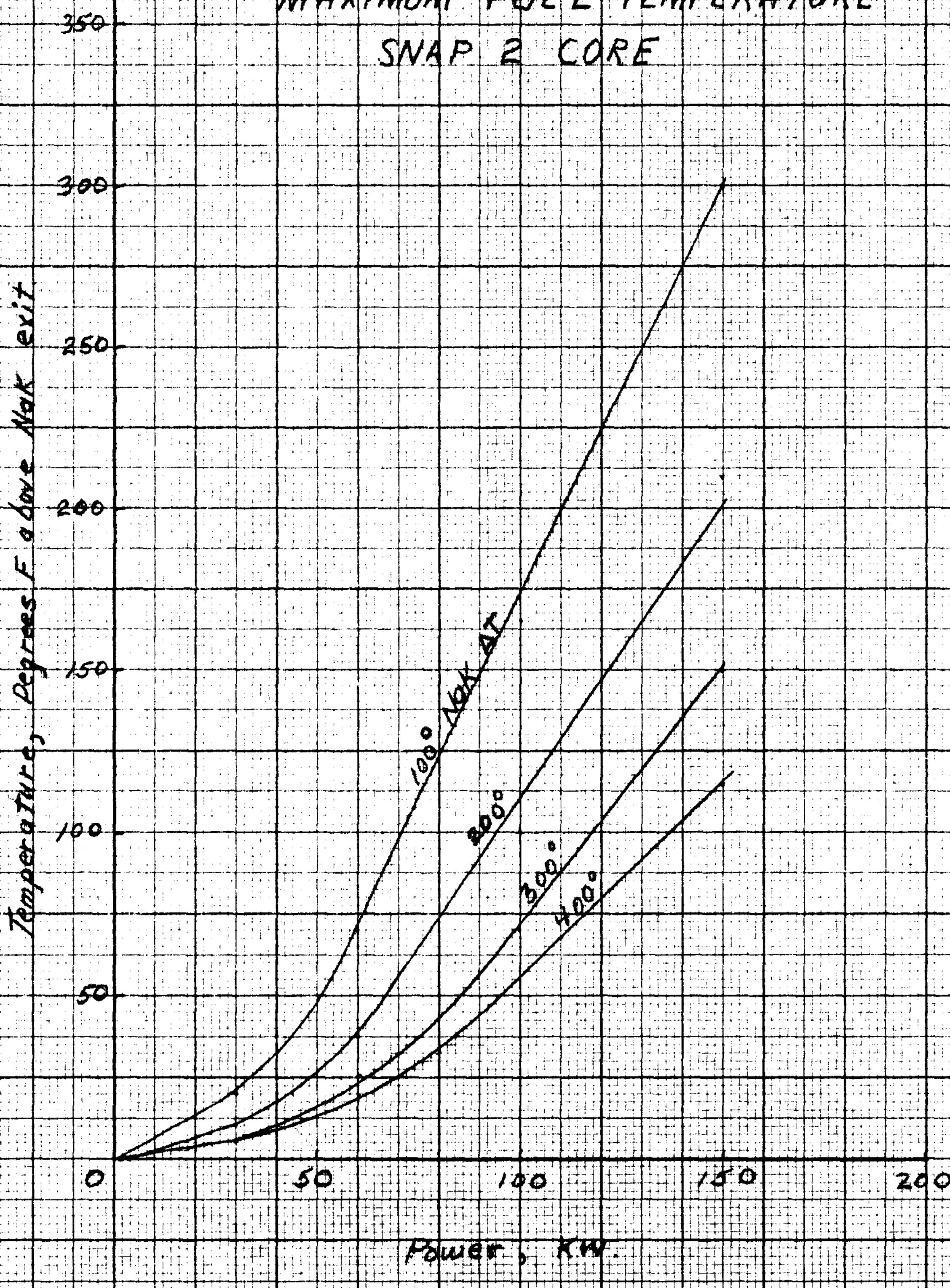




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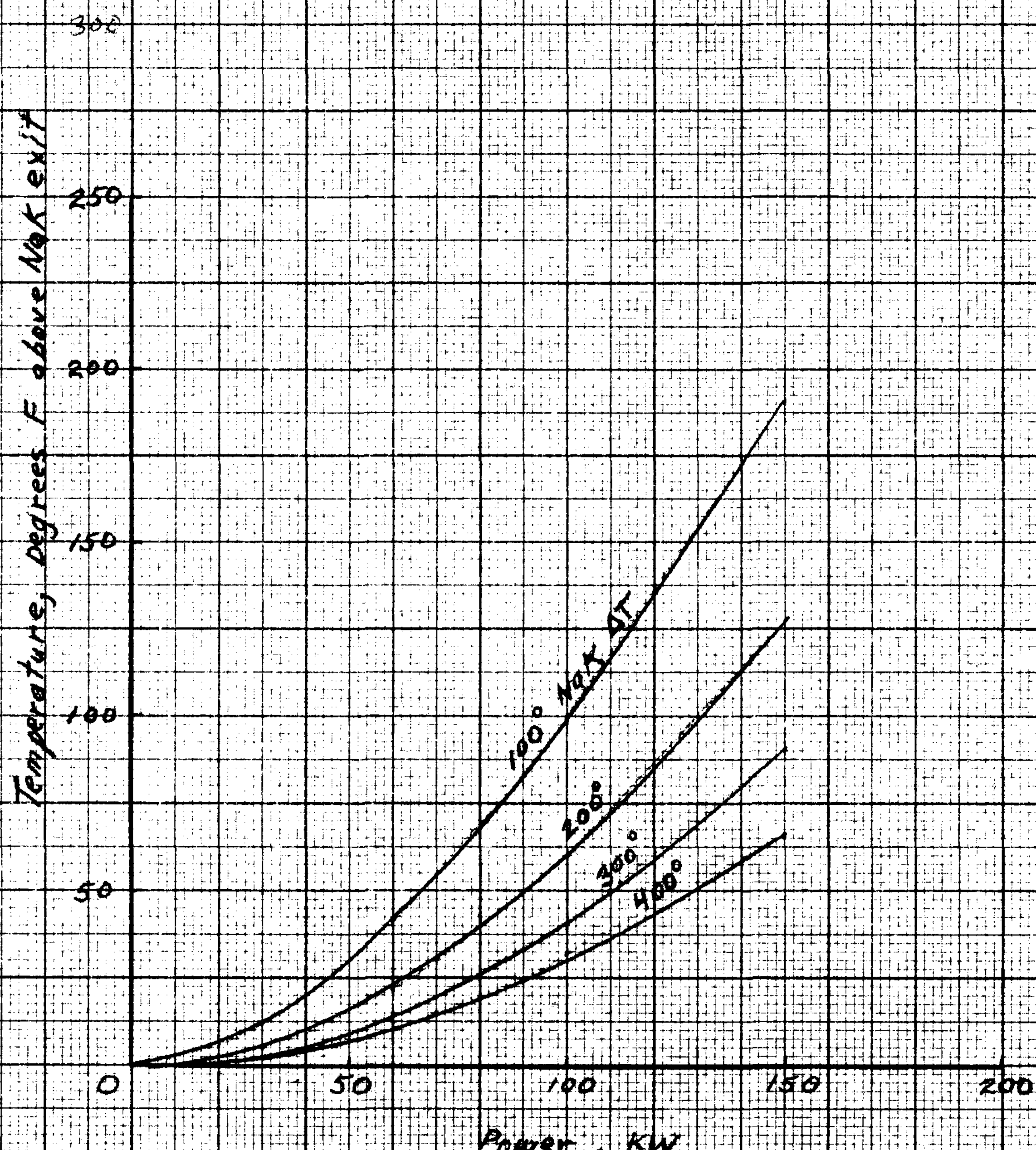
Figure 3

MAXIMUM CLADDING TEMPERATURE

SNAP 2 CORE

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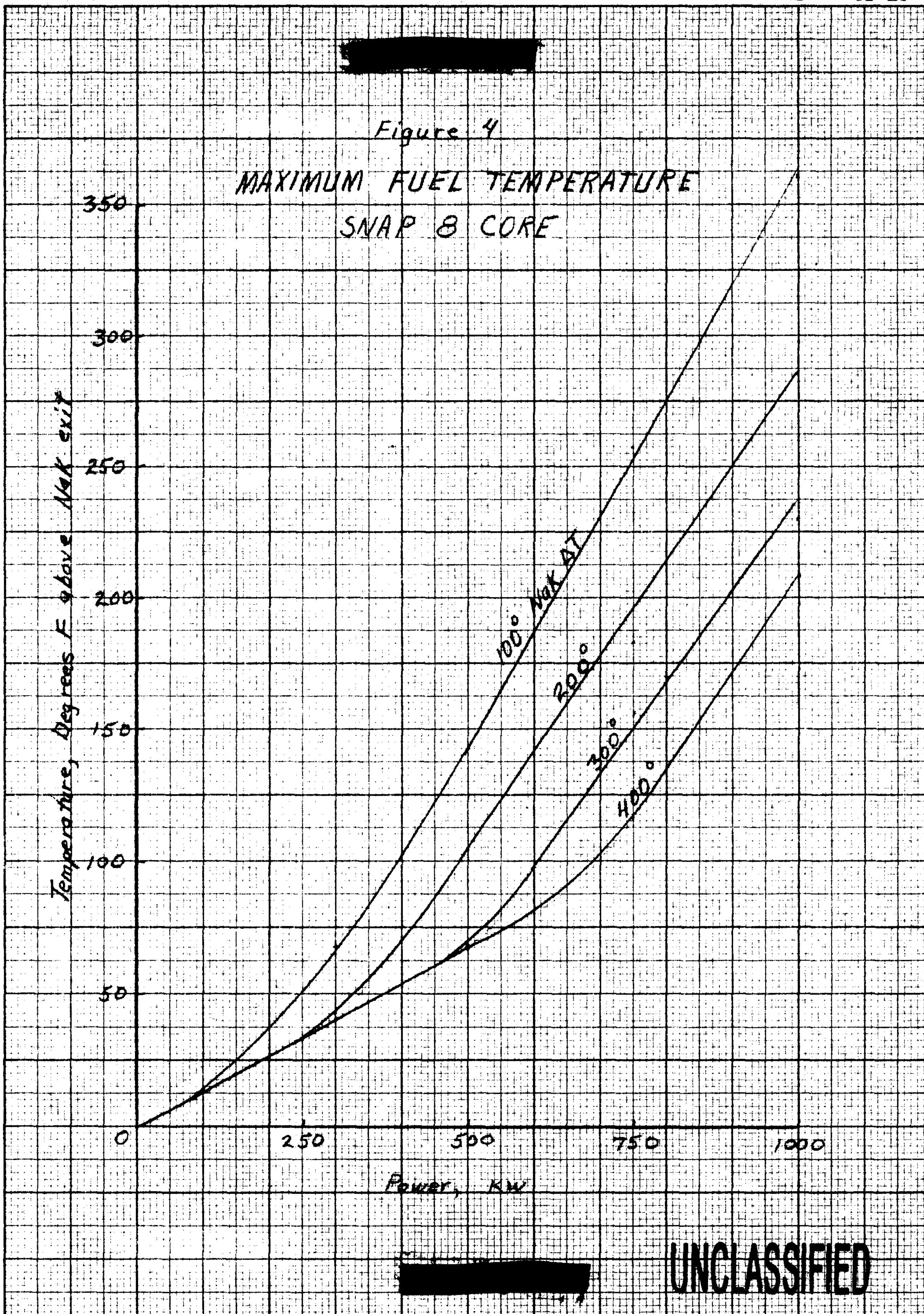


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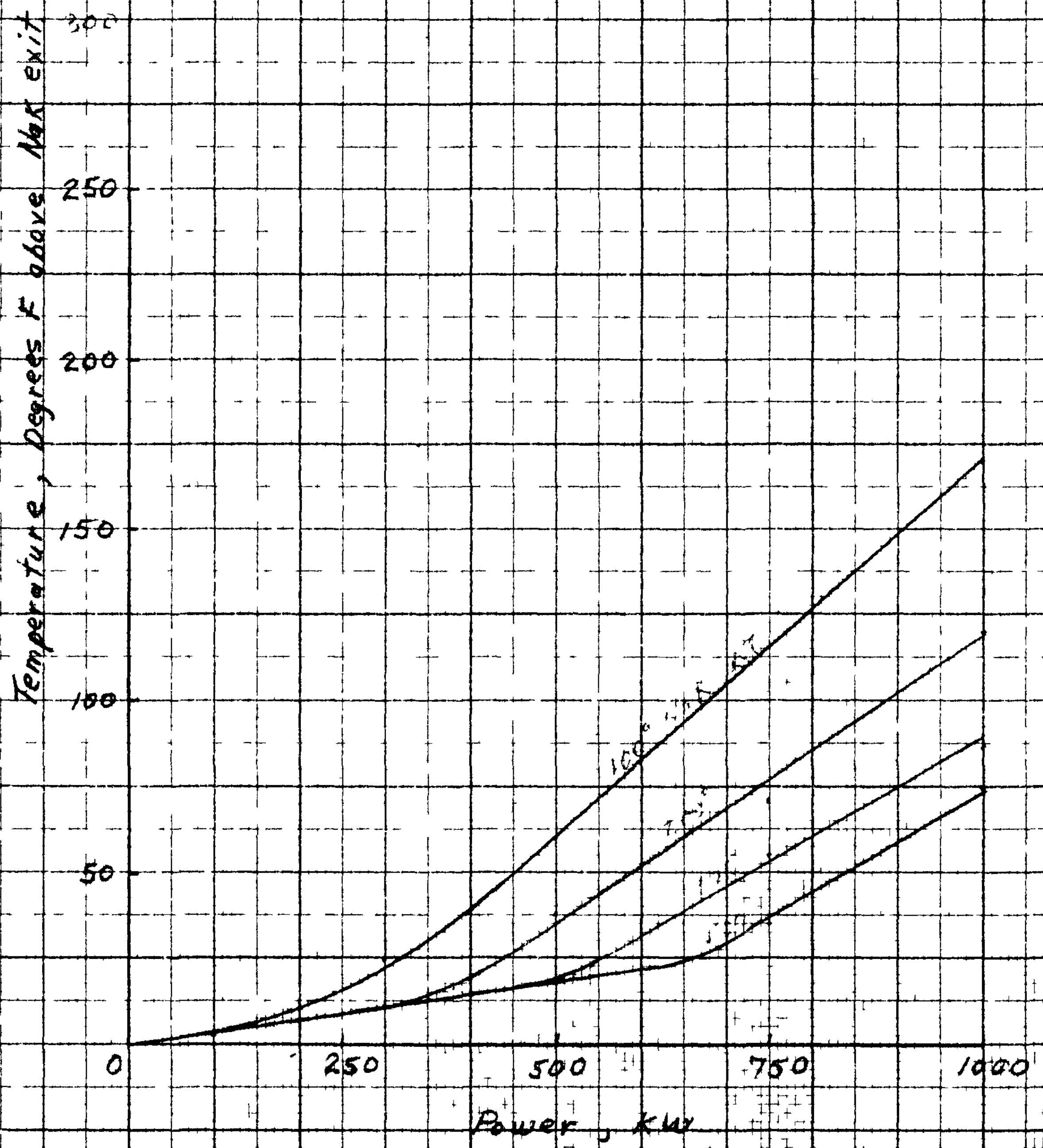
Figure 5

MAXIMUM CLADDING TEMPERATURE
SNAP 8 CORE

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2.2 Method By considering the fuel element as a thin rod with heat generation proportional to the flux distribution and bounded by a coolant whose temperature also depends on the flux distribution, the point at which the wall temperature is a maximum can be found. In this calculation the resistances of the cladding, ceramic, and hydrogen layers were included in the heat transfer coefficient of the coolant. The maximum fuel temperature, assumed to be a maximum at the same height as that of the wall maximum, was then calculated for a single fuel element. The maximum cladding temperature was taken as the difference between the maximum wall temperature and temperature drop across the hydrogen layer. The temperature of the ceramic was set equal to that of the cladding.

When these results were applied to the triangular arrangement of fuel rods in the SNAP cores[1] the estimated effect of the asymmetrical cooling had to be included. For the SNAP cores, the maximum fuel temperature was estimated to be $\Delta T_o$ higher than the normal maximum, where $\Delta T_o$ was the normal center to wall temperature difference for a single fuel element. The maximum cladding temperature was estimated to be $\Delta T_o$ higher than normal for SNAP 8 and 1.25 $\Delta T_o$ higher for SNAP 2.

Values of constants in these calculation were as follows:

$k_{fuel}$ = 12 Btu/hr-ft-°F

$k_{cer}$ = 1

$k_{clad}$ = 18

$k_{H2}$ = .25

$X_{cer}$ = 0.001 in.

$X_{clad}$ = 0.010 in. for SNAP 8, = 0.015 in. for SNAP 2

$X_{H2}$ = 0.001 in.

$h_{NaK}$ = 10,000 Btu/hr-ft$^2$-°F for SNAP 8, = 5,000 for SNAP 2

Peak/Average radial flux = 1.3

Point/Average axial flux $= 1.4 \cos \frac{\pi}{1.24} (\frac{Z}{L} - 0.5)$ for SNAP 8

$= 1.47 \cos \frac{\pi}{1.07} (\frac{Z}{L} - 0.5)$ for SNAP 2

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3. PRESSURE DROP The variation of pressure drop through the core assembly with flow rate is shown in Figure 6. These values do not include the static head, which is about 0.5 psi.

These results were based on a calculated pressure drop for the SNAP 2 and a measured pressure drop for SNAP at their respective design flow rates. Pressure drops at other flow rates were assumed to be directly proportional to the velocity squared.

4. FUEL ELEMENT BURNUP

4.1 Results Present data[3] indicate that the rate of swelling of the fuel elements is about five times the burnup rate at a fuel temperature of 1200°F, two times at a temperature of 100°F and equal to the burnup rate at lower temperatures. Figure 7 shows the increase in volume of the elements as a function of power and temperature for a five-year life.

Not enough data are available at this time to establish the burnup limitations of the fuel elements. Experimental work is now being done to define these limits. A conservative limit is set by the geometry of the element - the fuel may swell until it contacts the cladding. For a .001 inch hydrogen gap in the SNAP 8 element, the maximum swelling is less than 1.5%.

4.2 Sample Calculation To operate at 100 kw for five years requires $4.95 \times 10^{23}$ fissions. Since the fuel volume of the SNAP 8 core is $1.28 \times 10^{4}$ cc, this requires an average fission density of $3.87 \times 10^{19}$ fissions/cc. At the center, the fission density will be 1.82 times this, or $7.02 \times 10^{19}$. Without the hydrogen, the fuel contains about $4.4 \times 10^{22}$ atoms/cc. Burnup is, therefore, 0.16%. For a fuel temperature of 1200°F, the element will swell by a factor of five times the burnup, or 0.8%. If the maximum permissible swelling is 2%, the maximum power level is 250 kw.

5. REFLECTOR TEMPERATURE

5.1 Results The maximum temperatures in the reflector, control drum, and pressure vessel were calculated as a function of core power. These results are shown in Figure 8 for a NaK entrance temperature of 800°F and exit temperature of 1000°F.

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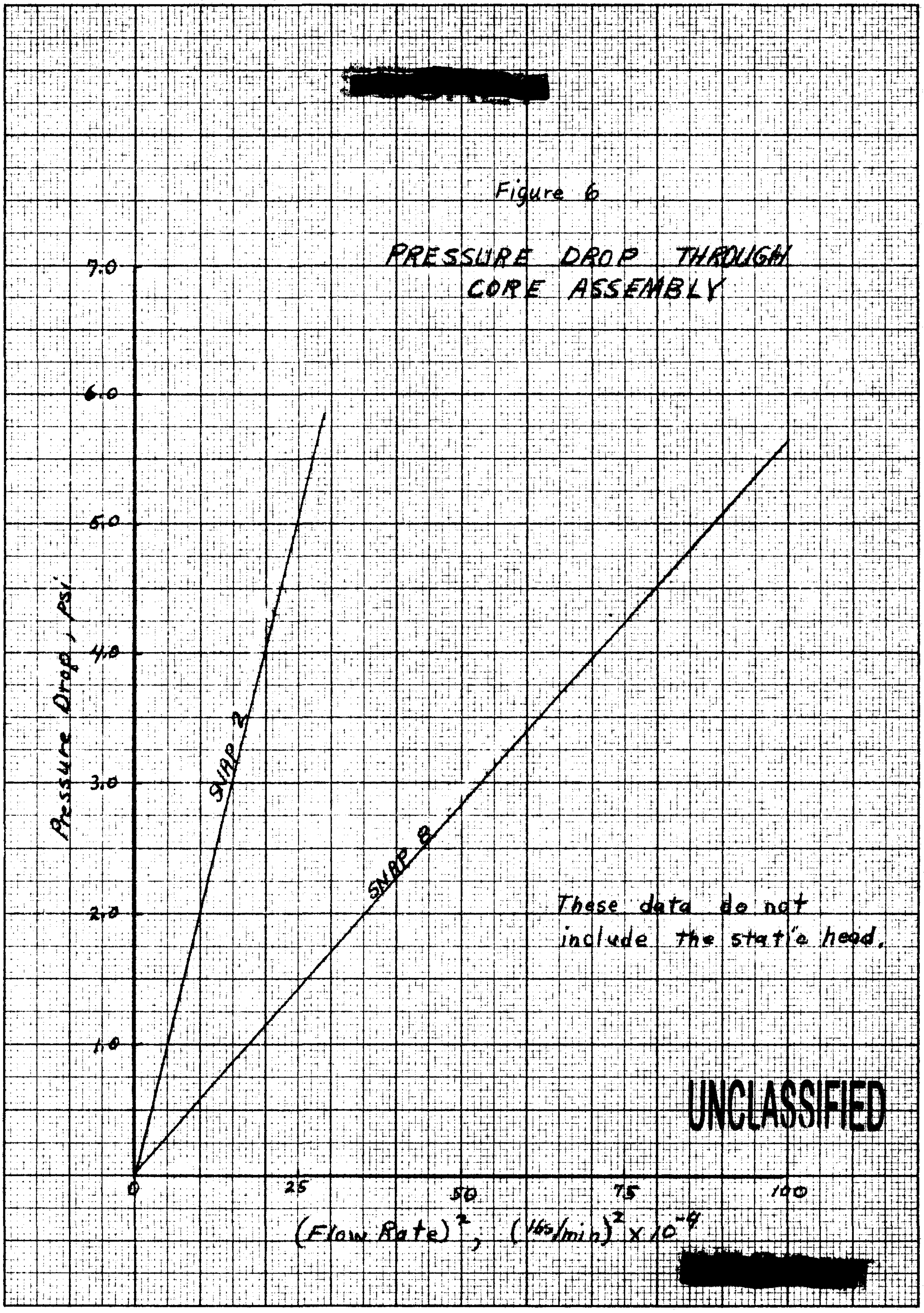


Figure 6

PRESSURE DROP THROUGH CORE ASSEMBLY

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Figure 7

# FUEL ELEMENT SWELLING

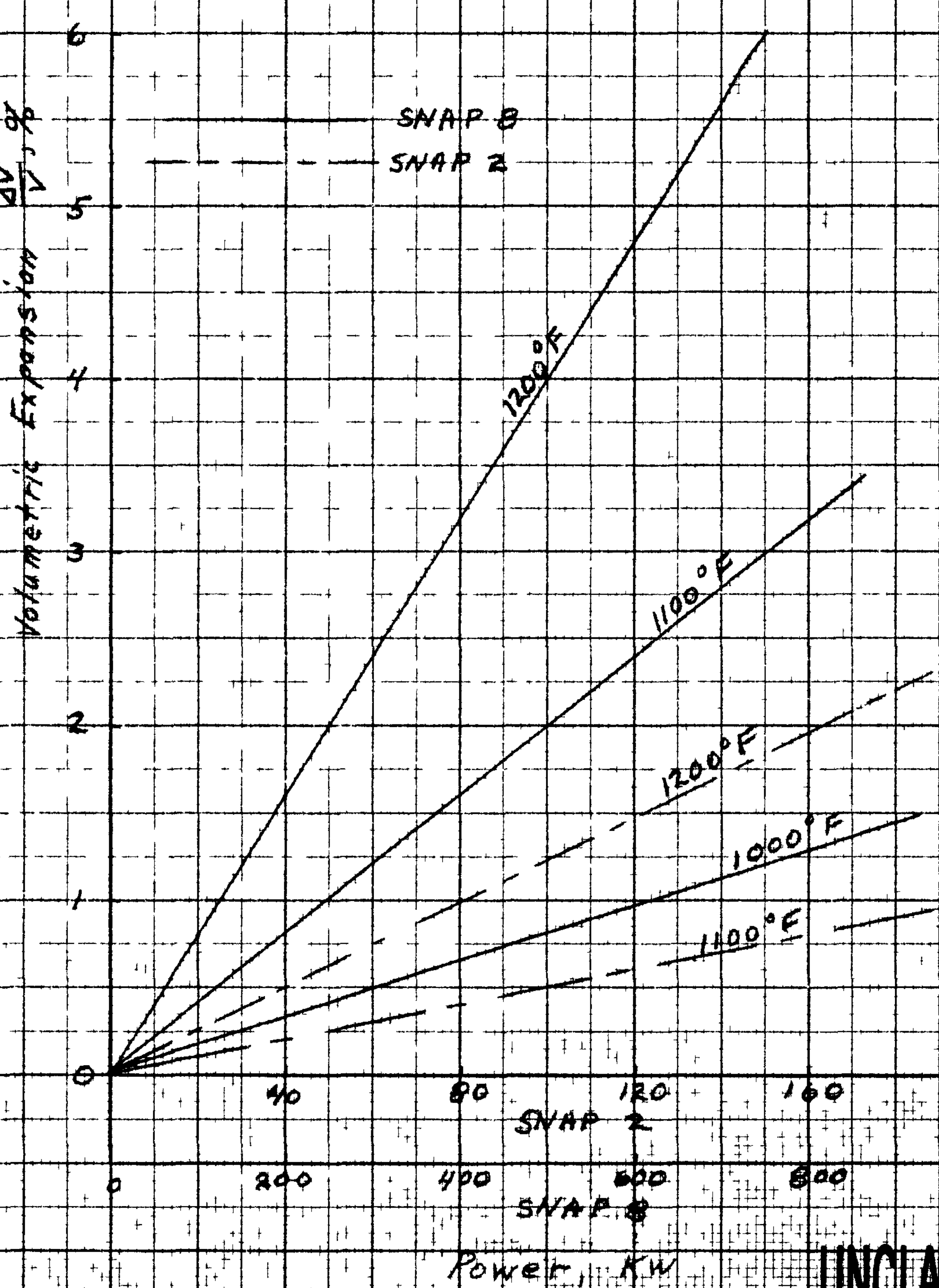


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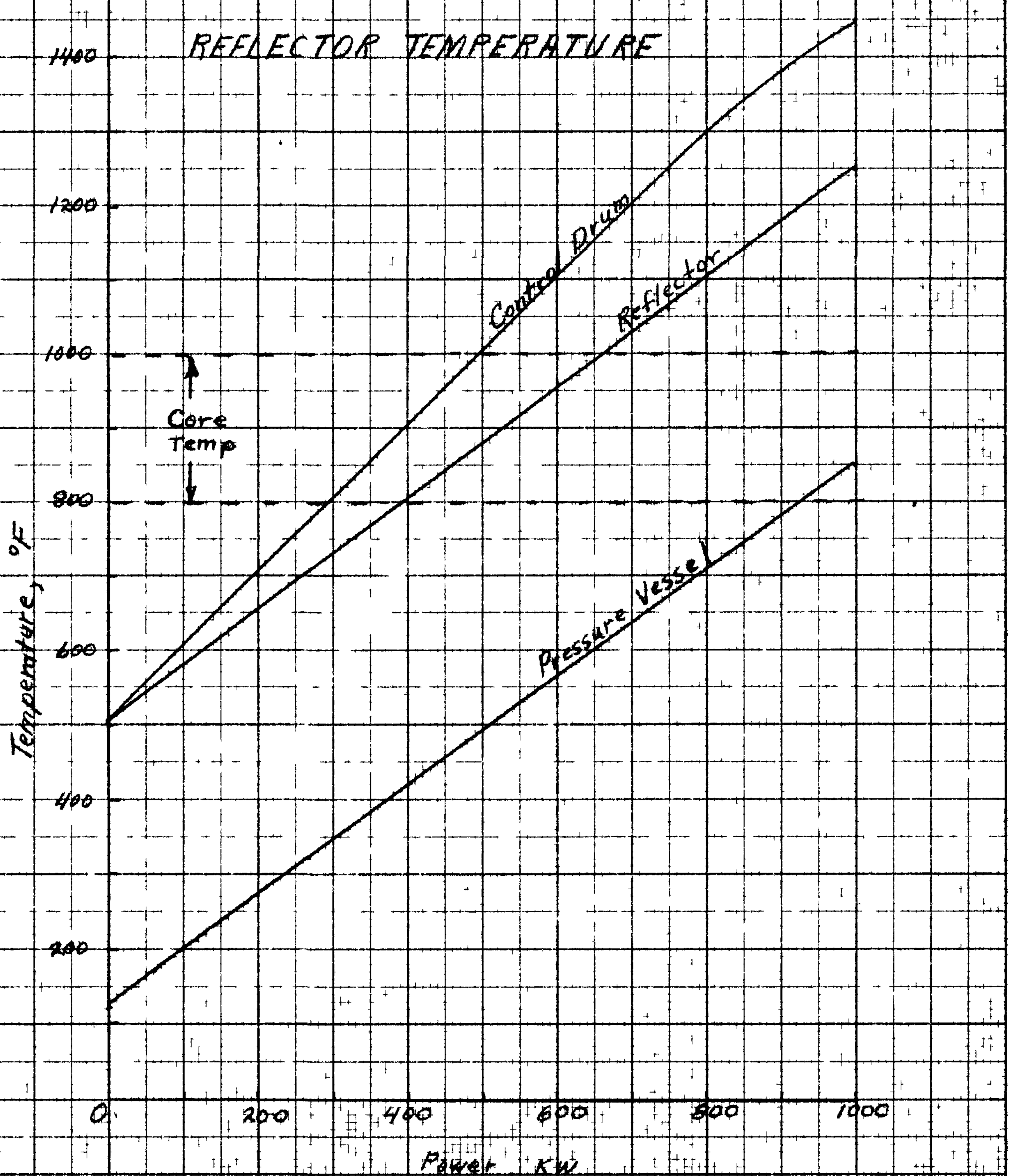
Figure 8

REFLECTOR TEMPERATURE

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Although the values of quantities used in this calculation were approximations, these temperatures should be sufficiently accurate for this preliminary design study, the purpose of which is to determine the limitations of the SNAP 6 system. The results of this calculation indicate that the maximum temperature, that in the control drum, does not limit the power level in SNAP 6 to less than 1 Mw. However, the factors which control the temperature in the reflector should be considered in the design of the SNAP 6.

The significant resistances to heat transfer are across the gaps between the core and reflector, the control drum and reflector, and the pressure vessel and reflector, and through the pressure vessel and lead shield. Not much can be done to change the resistance through the vessel wall, but that across the gaps may be changed considerably. By using helium for the gas in the void space, one takes advantage of its high thermal conductivity to increase the heat transfer across the gaps. In addition, the surfaces of adjacent pieces should be coated to increase their emissivity, and thereby increase the rate of heat transfer via radiation.

5.2 Method The geometry of the reflector was simplified to that of a solid cylindrical shell with an 1/8 inch gap between it and the core and an 1/4 inch gap between it and the vessel wall. Under these conditions, about 75% of the heat generation was due to the core gammas. The energy absorbed in the reflector was approximated to be 2.3% of the core power and that absorbed in the vessel wall adjacent to the reflector was approximated to be 3.5% of the core power. The reflector temperature and maximum wall temperature were then determined, using the Reflector Heating Code[4].

The temperature of the control drum was set equal to that necessary to transfer the heat generated in it to the reflector. It was estimated that if the boron were added to the reflector, the heat generation rate would be increased from 2.3 to 3% of the core power. The heat generated in a single control drum, 0.25% of core power, was obtained by assuming that the volume of a control drum was 1/12 that of the reflector shell. The gap between the control drum and the reflector, across which this generated heat must be transferred, was 1/4 inch.

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5.2 <u>Method</u> (Continued)

At a thermal power of 1 Mw, 33% of the heat generated in a control drum was transferred to the reflector via conduction through the helium, the rest via radiation. Since the rate of transfer by radiation decreases rapidly with decreasing temperature, at lower powers, most of the heat is transferred by conduction.

The following coefficients were used in this calculation:

$$k_{He} = 0.15 \text{ Btu/hr-ft-°F}$$

$$k_{Be} = 72$$

$$k_{Fe} = 12$$

$$k_{Pb} = 18$$

$$h_{film} = 100 \text{ Btu/hr-ft}^2\text{-°F}$$

Core $\epsilon = 0.3$

Inner Reflector $\epsilon = 0.15$

All Other Surfaces $\epsilon = 0.5$

Note: Hydrogen loss has been estimated to be about 1.8% for the reactor operating for 5 years with a cladding temperature of 1150°F. (5)

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REFERENCES [redacted]

1. NAA-SR-6561 "Thermal Design of SNAP Reactors," P. D. Cohn, 1962
2. IOL From R. H. Anderson to H. Pearlman, "Statistical Evaluation of all Inspection Data Relative to the SNAP 8ER Core", October 8, 1962
3. 62-IOL-68, "S8ER Fuel Swelling", J. C. Spraul, 1962
4. AI TDR 6906, "Reflector Heating Code", P. D. Cohn, G. Long, R. W. Winson, 1961.
5. AI-MEMO 7838, "Preliminary Nuclear Analysis of SNAP 6", B. W. Colston, 1962

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[redacted]