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ATOMICS INTERNATIONAL <small>A Division of North American Aviation, Inc.</small>		NAA-SR-TDR TDR NO 9244		APPROVALS <i>H. L. Sletten</i>	
TECHNICAL DATA RECORD		PAGE 1 OF 32			
AUTHOR J. K. Imig		DEPT & GROUP NO. 717 724		DATE 11-19-63	
				GO NO 7519	
TITLE 1000 Mwe SGR Parameter Study - Core Thermal and Hydraulic Analysis		S/A NO 4410		TWR 51833	
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DISTRIBUTION W. O. Allen, Jr. R. F. Audette M. P. Aronchick D. R. Anderson R. J. Beeley F. Bergonzoli D. F. Casey J. C. Cochran R. S. Duncan J. J. Droher D. T. Eggen R. C. Gerber S. Galan C. W. Griffin R. A. Hewson H. B. Holz B. R. Hayward C. G. Johnson J. Leppard J. E. Mahlmeister J. A. McEdwards R. C. Noyes H. Rood R. H. Sevy H. L. Sletten D. J. Stoker A. C. Williams L. J. Zimmer	STATEMENT OF PROBLEM Perform parametric heat transfer and hydraulic studies on a 1000 Mwe UC-fueled SGR, which will provide information that can be combined with nuclear, design, and economics information, and which will lead to the selection of an economically optimum power plant.				
	ABSTRACT Parametric heat transfer studies have been performed for a 1000 Mwe SGR core to assist in determining an optimum power plant design. This design is then to be used as the basis for the design of a 200 Mwe prototype SGR. The actual selection of the optimum design which involves the fuel cycle and capital cost economics is outside the scope of this report and is discussed in Reference 1.				
	The parameters which affect heat transfer and which were studied for this report are maximum fuel centerline temperature, diameter of fuel rods, number of fuel rods per element, and coolant velocity. A total of 30 cases were studied.				
	Nine fuel element geometries were studied consisting of 3 types of fuel rod clusters (n = 12, 18, and 30 rods per cluster) with 3 rod diameters for each type of cluster.				
	In 27 of the 30 cases the velocity was adjusted to give a constant core pressure drop ($\Delta p = 17.8$ psi) and each of the 9 geometries was studied with 3 maximum fuel centerline temperatures. Results are shown in Figure 1.				
	In 3 of the cases the effect of variable pressure drop was studied for one geometry with the same maximum fuel centerline temperature. Results are shown in Figures 2a and 2b.				
	In addition to the heat transfer studies a new heat transfer code, SORTD II, is described. This code will adjust the input process tube diameter to obtain a specified maximum fuel centerline temperature.				

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Abstract: (cont'd)

Uniform bulk sodium coolant temperature at all elevations in the core was assumed for all cases. While this assumption follows from the assumption of complete coolant mixing, it also follows from the assumption of no coolant mixing and ideal fuel rod spacing (Ref. 5). This uniform bulk coolant temperature assumption reduces the required number of fuel elements by about 3% from the required number for the assumption of no mixing and uniform fuel rod spacing.

Complete computer data except temperature profiles are included in the report in a readily useable form. Most of the portrayal of the data has been done by means of empirical equations (Sec. V), which are believed to be more useful and descriptive than a large number of curves.

General conclusions from this study are as follows:

1. The total required length of fuel rod in the core, nNL , is largely an inverse function of maximum fuel centerline temperature, i.e., of $\frac{1}{T_{f_{\max}} - 950}$, and a lesser function of the elemental peak-to-average

fuel rod power ratio, the rod diameter, and the sodium velocity.

2. For velocity variation of $V = 10 - 30$ ft/sec in cases 11A, 11, 11B, and 11C, with the other parameters held constant, the required number of fuel elements varies as

$$N = 513 \left(1 + \frac{1}{V^{.714}} \right) \text{ to } \pm 1\%$$

where V is in fps.

3. In general, a small core and corresponding low capital cost, and a small fuel inventory can be realized by using clusters consisting of large numbers of small diameter fuel rods. This must be balanced against the increasing fuel cycle cost with decreasing rod diameter as is discussed in Reference 1.

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I. Derivation of Equations

A brief derivation of the heat transfer equations for a chopped cosine axial power distribution in the coolant channels of a reactor core follows. A similar derivation is given in Reference 2, except that uniform bulk coolant temperature is assumed in the following, whereas the derivation in Reference 2 assumes no coolant mixing and uniform fuel rod spacing. Uniform bulk coolant temperature should be a good assumption since (a) the coolant Reynolds number is the order of 200,000, (b) the thermal conductivity of the sodium coolant is relatively high compared to that of many other common coolants, (c) non-uniform fuel rod spacing may be used to distribute the coolant flow according to the fuel rod power distribution, and, (d) the spacing of the fuel rods is large enough to allow mixing due to lateral flow.

The hot channel coolant temperature rise above the inlet temperature is

$$T_b - T_{in} = \frac{\Delta T}{2} \left(1 + \frac{\sin \frac{\pi Z}{L_o}}{\sin \frac{\pi L}{2L_o}} \right) F \Delta T \quad (1)$$

where T_b = (uniform) bulk hot channel coolant temperature

T_{in} = inlet coolant temperature

ΔT = nominal coolant temperature rise

Z = distance above or below core midlength

L, L_o = actual, extrapolated core length

$F \Delta T$ = coolant hot channel factor

The hot channel fuel centerline temperature rise above the inlet temperature is

$$T_f - T_{in} = \frac{\Delta T}{2} \left(1 + \frac{\sin \frac{\pi Z}{L_o}}{\sin \frac{\pi L}{2L_o}} \right) F \Delta T + \frac{M q'_{max} \cos \frac{\pi Z}{L_o}}{2\pi} \quad (2)$$

where T_f = hot channel fuel centerline temperature

M = overall resistance parameter

q'_{max} = maximum linear heat rate per rod

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The overall resistance parameter, M, is defined as

$$M = F_0 \left(\frac{2}{D_3 h} + \frac{\ln \frac{D_3}{D_5}}{K_{clad}} + \frac{\ln \frac{D_5}{D_4}}{K_{bond}} + \frac{1}{2 K_{fuel}} \right) \quad (3)$$

where F_0 = composite fuel, bond, clad, and film hot channel factor

D_3, D_4, D_5 = clad o.d., fuel slug o.d., clad i.d.

h = coolant film coefficient

$K_{clad}, K_{bond}, K_{fuel}$ = clad, bond, and fuel thermal conductivities

The convection coefficient, h , is given by the Lubarsky - Kaufman equation,

$$Nu = .625 Pe^{.4}$$

$$h = .625 \left(\frac{K}{De} \right)^{.6} (c \rho v)^{.4} \quad (4)$$

where the properties are those of the coolant, V is the coolant velocity in the maximum power fuel element, and De is the hydraulic diameter.

To obtain the maximum hot channel fuel temperature, T_f is differentiated with respect to Z in Equation 2 and $\frac{dT_f}{dZ}$ is set equal to 0. The result is

$$\beta \equiv \tan \frac{\pi Z_{max}}{L_0} = \frac{\pi F_{\Delta T} \Delta T}{M q'_{max} \sin \frac{\pi L}{2 L_0}} \quad (5)$$

By substituting the following two trigonometric identities in Equation 2.

$$\sin \frac{\pi Z_{max}}{L_0} = \frac{\beta}{\sqrt{1+\beta^2}} \quad \text{and} \quad \cos \frac{\pi Z_{max}}{L_0} = \frac{1}{\sqrt{1+\beta^2}}$$

the result is

$$\frac{2\pi (T_{fmax} - T_{in})}{q'_{max} M} = \beta \sin \frac{\pi L}{2 L_0} + \sqrt{1+\beta^2} \quad (6)$$

Rearranging Eq. 5 gives

$$\frac{\pi}{M q'_{max}} = \frac{\beta \sin \frac{\pi L}{2 L_0}}{F_{\Delta T} \Delta T} \quad (7)$$

Substituting Equation 7 in the left side of Equation 6 and solving for β

$$\beta = \left\{ \right\}^{-1/2}$$

where

$$\left\{ \right\} = \left\{ \left[\sin \frac{\pi L}{2L_0} \left(\frac{2(T_{fmax} - T_{IN})}{F_{\Delta T} \Delta T} - 1 \right) \right]^2 - 1 \right\} \quad (8)$$

Eliminating β from Equation 8 using Equation 5 and solving for q'_{max}

$$q'_{max} = \frac{\pi F_{\Delta T} \Delta T}{M \sin \frac{\pi L}{2L_0}} \left\{ \right\}^{1/2} \quad (9)$$

The relation between q'_{max} and the thermal power is

$$\frac{P}{n N L} = \frac{q'_{max}}{(1-b) \phi_e \phi_r \phi_a} \quad (10)$$

where

P = thermal power

n = number of rods per fuel element cluster

N = number of fuel elements

b = fraction of power generated that is absorbed outside the fuel rods

ϕ_e, ϕ_r, ϕ_a = elemental, radial, axial peak-to-average power ratio

Substituting for q'_{max} from Equation 9 in Equation 10 and using $\phi_a = \frac{\pi L}{2L_0 \sin \frac{\pi L}{2L_0}}$

$$\frac{n N L}{\phi_e M} = \frac{P \left(\frac{L}{L_0} \right) \phi_r (1-b)}{2 F_{\Delta T} \Delta T \left\{ \left[\sin \frac{\pi L}{2L_0} \left(\frac{2(T_{fmax} - T_{IN})}{F_{\Delta T} \Delta T} - 1 \right) \right]^2 - 1 \right\}^{1/2}} \quad (11)$$

The quantity $\frac{n N L}{\phi_e M}$ is plotted vs. T_{fmax} in Figure 3 using Equation 11 and the input data given in Appendix II.

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II. SORTD Code Modification for Perfect Mixing

The heat transfer equation which is solved by both the SORTD I and II codes assumes no coolant mixing and uniform fuel rod spacing:

$$\frac{nNL}{\phi_e M} = \frac{\rho \left(\frac{L}{L_o}\right) \phi_r (1-b)}{2 F_{\Delta T} \phi_e \Delta T \left\{ \left[\sin \frac{\pi L}{2L_o} \left(\frac{2(T_{fmax} - T_{IN})}{F_{\Delta T} \phi_e \Delta T} - 1 \right) \right]^2 - 1 \right\}^{1/2}} \quad (12)$$

Comparison of this equation with the uniform bulk coolant temperature Equation 11 shows that a fictitious hot channel factor must be used in the code input:

$$F_{\Delta T} \text{ code input} = \frac{F_{\Delta T} \text{ actual}}{\phi_e} \quad (13)$$

if the code is to solve Equation 11.

III. SORTD II Heat Transfer and Fluid Flow Code - Process Tube Iteration Program

The SORTD I code (Ref. 3) computes core parameters including maximum fuel centerline temperature, T_{fmax} , and either coolant velocity, V , or number of fuel elements, N , as a function of input data. If the code calculates V as output, then N must be specified as input, and vice versa, i.e., there is an option between computing either V or N as output but not both.

The SORTD II code which was devised by G. C. Burry, Dept. 717-72, differs from SORTD I in that it will iterate to obtain a specified T_{fmax} by adjusting the input process tube diameter, D_1 . That is, the code computes a value for T_{fmax} using the input process tube diameter, and then computes a new input value for the process tube diameter using the original input diameter, the computed T_{fmax} , and the specified T_{fmax} .

The equation used to compute new input values of the process tube diameter, D_1 , is derived as follows.

Equation 11 can be rearranged to give

$$\frac{N \{ \}^{1/2}}{M} = \frac{\phi_e \rho \left(\frac{L}{L_o}\right) \phi_r (1-b)}{2 n L F_{\Delta T} \Delta T} \quad (14)$$

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The right side of this equation remains constant even though D_1 and T_{fmax} change. Also, the overall resistance parameter M remains approximately constant. Therefore,

$$N_{orig. output} \left\{ \right\}_{orig. output}^{1/2} \approx N_{new output} \left\{ \right\}_{specified}^{1/2} \quad (15)$$

As an additional approximation which is only fair, both of the "-1" terms in the brackets are neglected, so that,

$$\frac{N_{orig. output}}{N_{new output}} = \frac{T_{fmax} specified - C}{T_{fmax} orig. output - C}$$

where $C = T_{in} + \frac{F_{or} \Delta T}{2}$ (16)

The volumetric flow is constant since the power output and core ΔT remain the same, i.e.,

$$N V A_f = \text{constant}$$

where

$$A_f = \text{coolant flow area per element}$$

Since the velocity also stays constant in the input

$$\frac{N_{orig. output}}{N_{new output}} = \frac{A_{f new input}}{A_{f orig. input}}$$

and substituting in Equation 16 using $A_f = \frac{\pi}{4} (D_1^2 - D_2^2 - n D_3^2)$,

the result is

$$\frac{D_{1 new input}^2 - D_2^2 - n D_3^2}{D_{1 orig. input}^2 - D_2^2 - n D_3^2} = \frac{T_{fmax specified} - C}{T_{fmax orig. output} - C} \quad (17)$$

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Equation 17 is the one used by the code to determine the new process tube diameter input for each subsequent iteration. Due to the approximations used in obtaining Equation 17, the machine may have to iterate several times depending on how closely $T_{f \max}$ output is required to approach the specified $T_{f \max}$ specified.

The input format for SORTD II is identical to that for SORTD I (Ref. 3) except that one additional card is required as shown:

FORTRAN FIXED 10 DIGIT DEC

DECK NO. PROGRAMMER DATE

	NUMBER	IDENTIFICATION	DESCRIPTION	DO M
1	—			
13	1.750.0		$T_{f \max}$ specified	
25	958.0			
37	1.0		$\epsilon_{\max}$	
49		73		80
61			X X X	

where

$$\epsilon = \left| T_{f \max \text{ output}} - T_{f \max \text{ specified}} \right|$$

The code will continue to iterate until $\epsilon \leq \epsilon_{\max}$.

IV. Effect of Assuming Uniform Bulk Coolant Temperature

The effect of assuming uniform bulk coolant temperature compared to no mixing and uniform fuel rod spacing with all other conditions unchanged can be seen by dividing both sides of Equation 12 by both sides of Equation 11:

$$\frac{N_{eq. 12}}{N_{eq. 11}} = \frac{\left\{ \left[\sin \frac{\pi L}{2L_0} \left(\frac{2(T_{f \max} - T_{IN})}{F_{AT} \Delta T} - 1 \right) \right]^2 - 1 \right\}^{V/2}}{\phi_e \left\{ \left[\sin \frac{\pi L}{2L_0} \left(\frac{2(T_{f \max} - T_{IN})}{F_{AT} \phi_e \Delta T} - 1 \right) \right]^2 - 1 \right\}^{V/2}} \quad (18)$$

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Taking case 11 as an example ($\sin \frac{\pi L}{2L} = .96388$, $T_{f \max} = 2000^\circ\text{F}$,
 $T_{in} = 750^\circ\text{F}$, $F_{\Delta T} = 1.04$, $\phi_e = 1.11$, $\Delta T = 400^\circ\text{F}$), the result is

$$\frac{N_{e, 12}}{N_{e, 11}} = 1.03$$

V. Empirical Equations

The analytical heat transfer and fluid flow equations are somewhat complex, and it is difficult to see which are the sensitive parameters. Therefore, the following simple empirical equations have been devised to fit the analytically computed data.

Cases 1 - 27 (except cases 11A, 11B, 11C)

$$q'_{\max} = .03615 (T_{f \max} - 950) D_4^{0.2} \quad \text{to } \pm 1\frac{1}{4}\% \quad (19)$$

where $q'_{\max}$ is in Kw/ft, $T_{f \max}$ in $^\circ\text{F}$, and D_4 is the fuel slug diameter in inches. Alternatively, $q'_{\max}$ from Equation 19 can be substituted in Equation 10 to give the total required length of fuel rod

$$n N L = \frac{1.237 \times 10^8 \phi_e}{(T_{f \max} - 950) D_4^{0.2}} \quad \text{to } \pm 1\frac{1}{4}\% \quad (20)$$

Simpler but less precise expressions for the required length of fuel rod are:

Cases 1 - 9 (12 rod elements)

$$n N L = \frac{1.53 \times 10^8}{(T_{f \max} - 950)} \quad \text{to } \pm 2.0\% \quad (21)$$

Cases 10 - 18 (18 rod elements)

$$n N L = \frac{1.585 \times 10^8}{(T_{f \max} - 950)} \quad \text{to } \pm 1.6\% \quad (22)$$

Cases 19 - 27 (30 rod elements)

$$n N L = \frac{1.77 \times 10^8}{(T_{f \max} - 950)} \quad \text{to } \pm 1.2\% \quad (23)$$

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Cases 11A, 11, 11B, and 11C

All of the input parameters were held constant in these four cases except the velocity and the process tube diameter which were varied such that the maximum fuel temperature remained constant (at $T_f \text{ max} = 2000^\circ\text{F}$). The velocity was varied from 10 to 30 fps, and the required number of fuel elements can be expressed as

$$N = 513.0 \left(1 + \frac{1}{V^{.775}} \right) \text{ to } \pm 1\% \quad (24)$$

where V is in fps. Besides the variation of the number of fuel elements with velocity, it is important from nuclear physics considerations of the amount of sodium poison in the core to note that the total required flow area is inversely proportional to the first power of the velocity.

The core pressure drop can be expressed as

$$P = .076 V^{2.1} \text{ to } \pm 6.6\% \quad (25)$$

where V is in fps. An exact expression for the pressure drop requires the addition only of the hydraulic diameter, D_e , as a parameter (Eq. 26); the inaccuracy of Eq. 25 is due to reduction in D_e by a factor of 2.5 as the velocity increases from 10 to 30 fps.

VI. Core Pressure Drop

The core pressure drop can be obtained from

$$\Delta P = \frac{\rho v^2}{2g} \left[K_e + K_x + f \frac{L_{ef}}{D_e} \right] + \Delta P_o$$

where ΔP = core pressure drop

$$\frac{\rho v^2}{2g} = \text{velocity head}$$

K_e, K_x = entrance, exit loss coefficients

f = friction factor

L_{ef} = length of effective run ,

D_e = hydraulic diameter

ΔP_o = losses for wide open throttling orifices and discharge tube

The smooth tube friction factor can be obtained from the well known relation

$$f_{\text{smooth}} = .316 R_e^{-1/4}$$

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Values which were used in determining the pressure drop for the 360 Mwe SGR (Ref. 4) were assumed to apply

$$\frac{\rho}{2g} = \left(\frac{51.65}{64.4} \right) \left(\frac{1}{144} \right) = .005565 \frac{\text{lb sec}^2}{\text{ft}^2 \text{ in}^2}$$

$$K_e + K_x = 2.1 + 3.8 = 5.9$$

$$f = 2.19 f_{\text{smooth}}$$

$$L_{\text{ef.}} = 17 \text{ ft}$$

$$\Delta P_o = 3.5 \text{ psi}$$

Then

$$f = 2.19 (.316) \left[\frac{1}{\rho V D_e} \right]^{1/4} = .692 \left[\frac{.54}{(51.65)(3600)(V)(D_e)} \right]^{1/4}$$

$$V^{1/4} \frac{.0286}{D_e^{1/4}}$$

and

$$\Delta P = 5.565 \times 10^{-3} V^2 \left[5.9 + \frac{.487}{V^{1/4} D_e^{5/4}} \right] + 3.5 \quad (26)$$

where ΔP is in psi, V is in ft/sec, and D_e is in ft.

VII. Method of Velocity Recalculation for Adjustment of Core Pressure Drop

In this study it was desired that the core pressure drop be equal for cases 1-27, i.e. $\Delta P = 17.8$ psi. As is explained in Sec. III, the SORTD II code will, for a given velocity or number of fuel elements and maximum fuel centerline temperature input, calculate the required process tube diameter, hydraulic diameter, and other core parameters. However, the input velocity and output hydraulic diameter usually will not produce the desired pressure drop due to the input velocity being too high or too low.

After a case was run once with an estimated input velocity, the following method was used to determine a new input velocity which gave the desired pressure drop to a sufficient degree of accuracy in the next run.

Since the mass and volumetric flow per element are approximately constant between runs (the number of fuel elements changes only slightly as the velocity is varied):

$$V A_f \approx \text{constant}$$

The hydraulic diameter is given by

$$D_e = \frac{4 A_f}{P}$$

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and since the perimeter does not vary nearly as much as the flow area as the velocity and process tube diameter vary from run to run

$$De \approx \text{constant } A_f$$

Therefore

$$V De \approx \text{constant}$$

as the pressure drop varies.

The procedure was as follows:

1. The pressure drop Eq. 26 for $\Delta P = 17.8$ psi can be reduced to

$$\frac{1}{De^{5/4}} = \frac{6450}{V^{1.75}} - 12.1 V^{1/4}$$

Using this equation, a plot was made of V vs. $V De$.

2. After the first run was made with the estimated value of V , $V De$ was computed and a corrected value of V was read from the plot.
3. A second run was made with the corrected value of V , which would usually produce very close to the desired pressure drop, so that third runs were unnecessary.

VIII. Minimum Process Tube Diameter

The minimum process tube inside diameter, D_1 min., is limited by geometry considerations, i.e. number of rods per element, n , central support tube and rod diameters, D_2 and D_3 , and the minimum allowable spacing between rods, support tube, and process tube, S , which was assumed to be $S = .09$ in. D_1 min. was determined for each of the 9 geometries considered in this study - $n = 12, 18$, and 30 rod clusters with 3 rod diameters, D_3 , per cluster. None of the 30 cases are limited by D_1 min., including case 11C with a sodium velocity of $V = 30$ fps.

To determine D_1 min. a layout was assumed for each cluster and analyzed as follows:

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A. 12 Rod Element - 4 - 8 Configuration

In the figure let

$$D_{1 \min} = D_1' + S$$

$$D_2' = D_2 + S$$

$$D_3' = D_3 + S$$

$$S = .09 \text{ in.}$$

$$\cos \theta = \frac{a^2 + C^2 - D_3'^2}{2aC}$$

$$\sin \gamma = D_3' / 2C$$

$$\theta + \gamma = 45^\circ$$

$D_2 = .50 \text{ in.}$ is assumed for all three rod diameters, D_3 .

For the small rods - $D_3 = .68 \text{ in.}$ - the following equations apply:

$$a = \frac{.59}{2} + \frac{.77}{2} = .68 \quad a^2 = .4624 \quad D_3'^2 = .5929$$

$$\cos \theta = \frac{C^2 - .1305}{1.36 C} \quad \sin \gamma = \frac{.385}{C}$$

Solving iteratively such that $\theta + \gamma = 45^\circ$ gives

$$C = 1.3031, \quad \frac{D_1'}{2} = 1.3031 + .3850 = 1.6881, \quad D_1' = 3.3762, \quad D_{1 \min} = 3.4662$$

say 3.47 in.

The medium and large rod elements - $D_3 = .79 \text{ in.}$ and $.90 \text{ in.}$ are solved similarly. The results are

12 Rod Element Diameters, in.

D_2	D_3	$D_{1 \min.}$
.5	.68	3.47
.5	.79	3.90
.5	.90	4.33

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B. 18 Rod Element - 6 - 12 Configuration

The support tube diameter is assumed equal to the fuel rod diameter ($D_2 = D_3$); note that the process tube diameter $D_{1 \text{ min.}}$ cannot be reduced by making $D_2 < D_3$. Also note that it makes no difference whether a triangular pitch is used, or whether constant inner and outer radii are used for the inner and outer rows of rods.

From the figure with $D_2 = D_3$

$$D_{1 \text{ min.}} = 5 D_3 + 6S$$

and for $D_3 = .57 \text{ in.}, .6525 \text{ in.}, \text{ and } .735 \text{ in.}$ and $S = .09 \text{ in.}$ the results are

18 Rod Element Diameters, in.

$D_2 = D_3$	$D_{1 \text{ min.}}$
.57	3.39
.6525	3.8025
.735	4.215

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C. 30 Rod Element - 5 - 10 - 15 Configuration

For simplicity of analysis, it is assumed that $D_2 = D_3$, although a somewhat smaller value for D_1 min. can be obtained by assuming that $D_2 < D_3$. From the figure

$$\begin{aligned}
 D_1 \text{ min.} &\approx 2 \left\{ \sqrt{[(D_3 + S)(2 \cos 36^\circ) + (D_3 + S)]^2 + [D_3 + S]^2} + \frac{D_3}{2} + S \right\} \\
 &= 2 \left\{ (D_3 + S) \sqrt{[2 \cos 36^\circ + 1]^2 + 1} + \frac{D_3}{2} + S \right\} \\
 &= 6.6 D_3 + 7.6 S
 \end{aligned}$$

and for $D_3 = .46$ in., $.515$ in., and $.57$ in. and $S = .09$ in.

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30 Rod Element Diameters, in.

<u>$D_2 = D_3$</u>	<u>D_1 min.</u>
.46	3.72
.515	4.08
.57	4.44

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Appendix I References

1. Hewson, R. A., and Rood, H., Information to be published on 1000 Mwe SGR Optimization Study.
2. Adler, K. L., Gylfe, J. D. and others, "Organic Heat Transfer Manual," NAA-SR-Memo - 7343, December 1, 1962.
3. Burry, G. C. and Johnson, C. G., "The Sodium Reactor Thermal Design (SORTD) Program," TDR-8949, September 5, 1963.
4. Sletten, H. L., Unpublished Calculations for the 360 Mwe SGR Core Pressure Drop
5. Sletten, H. L., Personal Communication

Appendix II

Computer Data and Curves

Common Input Data for All Cases

Reactor Thermal Power, P	2350 Mw
Length of Core, L	14 ft
Length/Extrapolated Length, L/L _o	.8284
Thermal Conductivities	
Uranium Carbide Fuel, K _{fuel}	13.3 Btu/hr-ft-°F
Na Coolant and Bond, K _{bond}	38.4 " "
Stainless Steel Clad, K _{clad}	12.7 " "

Na Properties

Density, ρ	51.65 lb/ft ³
Viscosity, μ	.54 lb/ft-hr
Specific Heat, C	.3015 Btu/lb-°F

Temperatures

Core Rise, ΔT	400°F
Inlet, T _{in} .	750°F

Peak to Average Power Ratios

Radial, ϕ_r	1.5
Axial, ϕ_a	1.35

Hot Channel Factors

Fuel, F _Q	1.14
Coolant, F ΔT^*	1.04

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Fraction of Heat in Moderator, b	.06
Number of Sources	1
Average Core Burnup	25,000 Mwd/MTU
Plant Factor	.8
Element Pitch	10.25 in.
Pitch Weighting Factor	1.0
Frontal Area	0
Added Wetted Perimeter	0
Temperature Constant, C **	900°F
Convergence Criterion on Maximum Fuel Temperature, $\epsilon_{\max}$	1°F

* Not a code input. See Sec. II.

** Should be 958 per definition in Section III, but was rounded off to 900 as the exact value is not critical.

COMPUTED RESULTS-CASE

12 ROD ELEMENT - SMALL RODS

	1	2	3
CORE POWER, BTU/HR	.80205499E 10	.80205499E 10	.80205499E 10
CORE FLOW RATE, LB/HR.	.66505390E 08	.66505390E 08	.66505390E 08
MAXIMUM ELEMENT COOLANT FLOW RATE, LB/SEC	.24451651E 02	.32451986E 02	.40247085E 02
NUMBER OF ELEMENTS	.11332805E 04	.85389471E 03	.68851145E 03
VELOCITY OF COOLANT, FT/SEC.	.12170000E 02	.13180000F 02	.13970000E 02
HEAT TRANSFER COEFFICIENT, BTU/HR-SQ.FT-F.	.73899952E 04	.68247021E 04	.64152249E 04
OVERALL RESISTANCE PARAMETER, HR-FT-F/BTU.	.53810938E-01	.54261914E-01	.54638220E-01
BETA - TAN FCN LOC OF FUEL HOT SPOT.	.28308047E-00	.21152040E-00	.16937827E-00
MAXIMUM LINEAR HEAT RATE, KW/FT.	.26079365E 02	.34612271E 02	.42926280E 02
MAXIMUM LINEAR HEAT RATE, BTU/HR-FT.	.89008874E 05	.11813167E 06	.14650739E 06
FLOW AREA, SQ. FT.	.38899793E-01	.47671141E-01	.55778613E-01
ACTIVE EFFECTIVE CORE DIAMETER, FT	.34428082E 02	.29888351E 02	.26841676E 02
HYDRAULIC DIAMETER, FT	.48494360E-01	.58394937E-01	.67300078E-01
SURFACE AREA OF OUTSIDE CLAD, SQ.FT./FT.	.17802360E-00	.17802360E-00	.17802360E-00
TOTAL WETTED PERIMETER, FT	.32086035E 01	.32654297E 01	.33152183E 01
VOLUME OF FUEL, CUBIC INCHES	.64598189E 06	.48672904E 06	.39245883E 06
CORE LOADING, KG. U.	.13502537E 06	.10173779E 06	.82033108E 05
AVERAGE CORE SPECIFIC POWER, KW/KG.U	.17404135E 02	.23098593E 02	.28646970E 02
AVERAGE CORE POWER DENSITY, KW/CUBIC FT.	.18031180E 03	.23924666E 03	.29664059E 03
AVERAGE FUEL POWER DENSITY, KW/CUBIC IN.	.36378729E 01	.48281482E 01	.59878892E 01
FUEL IN-CORE RESIDENCE TIME, YEARS	.49193157E 01	.37065650E 01	.29886734E 01
MAX. NOMINAL ELEMENT CHANNEL POWER, KW	.31104392E 04	.41281435E 04	.51197404E 04
MAX. NOMINAL HEAT FLUX, BTU/HR-SQ.FT	.49998356E 06	.66357315E 06	.82296613E 06
AVERAGE FUEL ROD HEAT FLUX, BTU/HR-SQ.FT	.22243735E 06	.29521662E 06	.36612885E 06
NUMBER OF CONTROL RODS IS 1/8 N.	.14166006E 03	.10673684E 03	.86063931E 02

H.C. Fuel Temp, F	1750.25	2000.76	2250.17
Velocity, ft/sec (input data)	12.17	13.18	13.97
Process Tube ID, in.	3.59596166	3.81302190	4.00320029
Core Pressure Drop, psi	20.4 17.8	20.4 17.8	20.4 17.9

Input Data, Cases 1,2,3 only

MASS OF FUEL SLUG/FT, KG U/FT.	0.70919999
ELEMENT PEAKING FACTOR	1.11000000
*COOLANT HOT CHANNEL FACTOR (fictitious)	0.93692999
CENTRAL TUBE OD, INCHES.	0.50000000
CLAD OD, INCHES.	0.68000000
FUEL DIAMETER, INCHES.	0.59999999
CLAD ID, INCHES.	0.66000000

* see sec. II

COMPUTED RESULTS - CASE

12 ROD ELEMENT - MEDIUM RODS

4

5

6

CORE POWER, BTU/HR	.80205499E 10	.80205499E 10	.80205499E 10
CORE FLOW RATE, LB/HR.	.66505390E 08	.66505390E 08	.66505390E 08
MAXIMUM ELEMENT COOLANT FLOW RATE, LB/SEC .	.24193155E 02	.32132185E 02	.39920933E 02
NUMBER OF ELEMENTS	.11453892E 04	.86239321E 03	.69413656E 03
VELOCITY OF COOLANT, FT/SEC.	.11669999E 02	.12700000E 02	.13479999E 02
HEAT TRANSFER COEFFICIENT, BTU/HR-SQ.FT-F.	.76797938E 04	.71109701E 04	.66777337E 04
OVERALL RESISTANCE PARAMETER, HR-FT-F/BTU.	.52498037E-01	.52858772E-01	.53174750E-01
BETA - TAN FCN LOC OF FUEL HOT SPOT. . . .	.28305946E-00	.21166835E-00	.16935854E-00
MAXIMUM LINEAR HEAT RATE, KW/FT.	.26733523E 02	.35506181E 02	.44112774E 02
MAXIMUM LINEAR HEAT RATE, BTU/HR-FT. . . .	.91241512E 05	.12118259E 06	.15055689E 06
FLOW AREA, SQ. FT.	.40137593E-01	.48985352E-01	.57337727E-01
ACTIVE EFFECTIVE CORE DIAMETER, FT	.34611377E 02	.30036564E 02	.26950959E 02
HYDRAULIC DIAMETER, FT	.44228517E-01	.53197616E-01	.61468025E-01
SURFACE AREA OF OUTSIDE CLAD, SQ.FT./FT. .	.20682153E-00	.20682153E-00	.20682153E-00
TOTAL WETTED PERIMETER, FT	.36300193E 01	.36832742E 01	.37312230E 01
VOLUME OF FUEL, CUBIC INCHES	.88864767E 06	.66908585E 06	.53854429E 06
CORE LOADING, KG. U.	.18574822E 06	.13985465E 06	.11256840E 06
AVERAGE CORE SPECIFIC POWER, KW/KG.U . . .	.12651534E 02	.16803159E 02	.20876195E 02
AVERAGE CORE POWER DENSITY, KW/CUBIC FT. .	.17840707E 03	.23689142E 03	.29423976E 03
AVERAGE FUEL POWER DENSITY, KW/CUBIC IN. .	.26444676E 01	.35122547E 01	.43636150E 01
FUEL IN-CORE RESIDENCE TIME, YEARS	.67672773E 01	.50952582E 01	.41011513E 01
MAX. NOMINAL ELEMENT CHANNEL POWER, KW . .	.30775564E 04	.40874626E 04	.50782514E 04
MAX. NOMINAL HEAT FLUX, BTU/HR-SQ.FT . . .	.44116059E 06	.58592831E 06	.72795561E 06
AVERAGE FUEL ROD HEAT FLUX, BTU/HR-SQ.FT .	.18944094E 06	.25160636E 06	.31259500E 06
NUMBER OF CONTROL RODS IS 1/8 N.	.14317365E 03	.10779915E 03	.86767069E 02

H.C. Fuel Temp, F	1750.30	2000.06	2250.31
Velocity, ft/sec (Input data)	11.67	12.70	13.48
Process Tube ID, in.	3.88565135	4.08906978	4.27222079
Core Pressure Drop, psi	207 17.8	208 17.8	207 17.8

Input Data, Cases 4,5,6 only

MASS OF FUEL SLUG/FT, KG U/FT.	0.96530000
ELEMENT PEAKING FACTOR	1.14999999
*COOLANT HOT CHANNEL FACTOR (fictitious).	0.90434000
CENTRAL TUBE OD, INCHES.	0.50000000
CLAD OD, INCHES.	0.79000000
FUEL DIAMETER, INCHES.	0.70000000
CLAD ID, INCHES.	0.77000000

* see sec. II

COMPUTED RESULTS - CASE

12 Rod Element - Large Rods

	7	8	9
CORE POWER, BTU/HR	.80205499E 10	.80205499E 10	.80205499E 10
CORE FLOW RATE, LB/HR.	.66505390E 08	.66505390E 08	.66505390E 08
MAXIMUM ELEMENT COOLANT FLOW RATE, LB/SEC	.23823479E 02	.31673077E 02	.39398115E 02
NUMBER OF ELEMENTS	.11631625E 04	.87489381E 03	.70334785E 03
VELOCITY OF COOLANT, FT/SEC.	.11219999E 02	.12239999E 02	.13029999E 02
HEAT TRANSFER COEFFICIENT, BTU/HR-SQ.FT-F.	.79625572E 04	.73765017E 04	.69343895E 04
OVERALL RESISTANCE PARAMETER, HR-FT-F/BTU.	.51521779E-01	.51825105E-01	.52087858E-01
ETA - TAN FCN LOC OF FUEL HOT SPOT.	.28305257E-00	.21165702E-00	.16929775E-00
MAXIMUM LINEAR HEAT RATE, KW/FT.	.27240682E 02	.36216215E 02	.45049321E 02
MAXIMUM LINEAR HEAT RATE, BTU/HR-FT.	.92972450E 05	.12360594E 06	.15375333E 06
LOW AREA, SQ. FT.	.41109483E-01	.50100093E-01	.58541077E-01
CTIVE EFFECTIVE CORE DIAMETER, FT	.34878674E 02	.30253252E 02	.27128965E 02
HYDRAULIC DIAMETER, FT	.40564433E-01	.48828643E-01	.56431339E-01
URFACE AREA OF OUTSIDE CLAD, SQ.FT./FT.	.23561947E-00	.23561947E-00	.23561947E-00
TOTAL WETTED PERIMETER, FT	.40537465E 01	.41041560E 01	.41495436E 01
OLUME OF FUEL, CUBIC INCHES	.11786933E 07	.88657556E 06	.71273908E 06
ORE LOADING, KG. U.	.24637458E 06	.18531510E 06	.14897919E 06
VERAGE CORE SPECIFIC POWER, KW/KG.U	.95383216E 01	.12681103E 02	.15774014E 02
VERAGE CORE POWER DENSITY, KW/CUBIC FT.	.17508306E 03	.23351012E 03	.29039115E 03
VERAGE FUEL POWER DENSITY, KW/CUBIC IN.	.19937331E 01	.26506482E 01	.32971392E 01
UEL IN-CORE RESIDENCE TIME, YEARS	.89760484E 01	.67514975E 01	.54276885E 01
AX. NOMINAL ELEMENT CHANNEL POWER, KW	.30305307E 04	.40290603E 04	.50117449E 04
AX. NOMINAL HEAT FLUX, BTU/HR-SQ.FT	.39458729E 06	.52459987E 06	.65254934E 06
VERAGE FUEL ROD HEAT FLUX, BTU/HR-SQ.FT	.16374616E 06	.21769887E 06	.27079545E 06
UMBER OF CONTROL RODS IS 1/8 N.	.14539532E 03	.10936172E 03	.87918480E 02

I.C. Fuel Temp, F
 Velocity, ft/sec (input data)
 Access Tube ID, in
 Core Pressure Drop, psi

1750.32	2000.11	2250.76
11.22	12.24	13.03
4.18417007	4.37671971	4.55008799
240 17.9	240 17.9	240 17.9

Input Data, Cases 7,8,9 only

MASS OF FUEL SLUG/FT, KG U/FT.	1.26079999
ELEMENT PEAKING FACTOR	1.19000000
*COOLANT HOT CHANNEL FACTOR (K ₁ K ₂ K ₃ K ₄)	0.87394001
CENTRAL TUBE OD, INCHES.	0.50000000
CLAD OD, INCHES.	0.90000000
FUEL DIAMETER, INCHES.	0.80000000
CLAD ID, INCHES.	0.88000000

* see sec. II

COMPUTED RESULTS - CASE

1/8 ROD ELEMENT - SMALL RODS

	10	11	12
CORE POWER, BTU/HR	.80205499E 10	.80205499E 10	.80205499E 10
CORE FLOW RATE, LB/HR.	.66505390E 08	.66505390E 08	.66505390E 08
MAXIMUM ELEMENT COOLANT FLOW RATE, LB/SEC	.35404640E 02	.46878072E 02	.58046326E 02
NUMBER OF ELEMENTS	.78268211E 03	.59112027E 03	.47738730E 03
VELOCITY OF COOLANT, FT/SEC.	.12870000E 02	.13880000E 02	.14649999E 02
HEAT TRANSFER COEFFICIENT, BTU/HR-SQ.FT-F.	.70149029E 04	.64622031E 04	.60562757E 04
OVERALL RESISTANCE PARAMETER, HR-FT-F/BTU.	.55735426E-01	.56320658E-01	.56818514E-01
BETA - TAN FCN LOC OF FUEL HOT SPOT.	.28313164E-00	.21161306E-00	.16940074E-00
MAXIMUM LINEAR HEAT RATE, KW/FT.	.25174320E 02	.33332455E 02	.41273595E 02
MAXIMUM LINEAR HEAT RATE, BTU/HR-FT.	.85919955E 05	.11376367E 06	.14086678E 06
FLOW AREA, SQ. FT.	.53261247E-01	.65389792E-01	.76712616E-01
ACTIVE EFFECTIVE CORE DIAMETER, FT	.28616273E 02	.24873568E 02	.22356986E 02
HYDRAULIC DIAMETER, FT	.54901905E-01	.66200782E-01	.76463375E-01
SURFACE AREA OF OUTSIDE CLAD, SQ.FT./FT.	.14922566E-00	.14922566E-00	.14922566E-00
TOTAL WETTED PERIMETER, FT	.38804661E 01	.39509981E 01	.40130384E 01
VOLUME OF FUEL, CUBIC INCHES	.46472616E 06	.35098420E 06	.28345399E 06
CORE LOADING, KG. U.	.97138675E 05	.73363936E 05	.59248537E 05
AVERAGE CORE SPECIFIC POWER, KW/KG.U	.24192217E 02	.32032087E 02	.39663426E 02
AVERAGE CORE POWER DENSITY, KW/CUBIC FT.	.26098990E 03	.34544081E 03	.42758583E 03
AVERAGE FUEL POWER DENSITY, KW/CUBIC IN.	.50567412E 01	.66954579E 01	.82905868E 01
FUEL IN-CORE RESIDENCE TIME, YEARS	.35390074E 01	.26728336E 01	.21585739E 01
MAX. NOMINAL ELEMENT CHANNEL POWER, KW	.45037441E 04	.59632533E 04	.73839416E 04
MAX. NOMINAL HEAT FLUX, BTU/HR-SQ.FT	.57577197E 06	.76235995E 06	.94398495E 06
AVERAGE FUEL ROD HEAT FLUX, BTU/HR-SQ.FT	.25615481E 06	.33916581E 06	.41996884E 06
NUMBER OF CONTROL RODS IS 1/8 N.	.97835264E 02	.73890034E 02	.59673412E 02

H. C. Fuel Temp, F

Velocity, ft/sec (input data)

Process Tube ID, in

Core Pressure Drop, psi

1750.12

12.87
3.99228781

17.8

2000.33

13.88
4.26170015

17.8

2250.00

14.65
4.44867624

17.9

Input Data, Cases 10, 11, 12 only

MASS OF FUEL SLUG/FT, KG U/FT.	0.49250000
ELEMENT PEAKING FACTOR	1.11000000
*COOLANT HOT CHANNEL FACTOR (fictitious)	0.93692999
CENTRAL TUBE OD, INCHES.	0.56999999
CLAD OD, INCHES.	0.56999999
FUEL DIAMETER, INCHES.	0.50000000
CLAD ID, INCHES.	0.55000000

*see sec. II

COMPUTED RESULTS-CASE

1/8 ROD ELEMENT - MEDIUM RODS

	13	14	15
CORE POWER, BTU/HR	.80205499E 10	.80205499E 10	.80205499E 10
CORE FLOW RATE, LB/HR.	.66505390E 08	.66505390E 08	.66505390E 08
MAXIMUM ELEMENT COOLANT FLOW RATE, LB/SEC	.46587899E 02	.57743634E 02	.57743634E 02
NUMBER OF ELEMENTS	.59480207E 03	.47988977E 03	.47988977E 03
VELOCITY OF COOLANT, FT/SEC.	.12379999E 02	.13419999E 02	.14219999E 02
HEAT TRANSFER COEFFICIENT, BTU/HR-SQ.FT-F.	.72734390E 04	.67156802E 04	.63060036E 04
OVERALL RESISTANCE PARAMETER, HR-FT-F/BTU.	.54246043E-01	.54724841E-01	.55130474E-01
BETA - TAN FCN LOC OF FUEL HOT SPOT.	.28310203E-00	.21151778E-00	.16939816E-00
MAXIMUM LINEAR HEAT RATE, KW/FT.	.25868180E 02	.34319864E 02	.42537947E 02
MAXIMUM LINEAR HEAT RATE, BTU/HR-FT.	.88288100E 05	.11713369E 06	.14518201E 06
FLOW AREA, SQ. FT.	.54916456E-01	.67212538E-01	.78620209E-01
ACTIVE EFFECTIVE CORE DIAMETER, FT	.28733889E 02	.24950795E 02	.22415400E 02
HYDRAULIC DIAMETER, FT	.50367670E-01	.60709428E-01	.70077809E-01
SURFACE AREA OF OUTSIDE CLAD, SQ.FT./FT.	.17082411E-00	.17082411E-00	.17082411E-00
TOTAL WETTED PERIMETER, FT	.43612464E 01	.44284745E 01	.44875951E 01
VOLUME OF FUEL, CUBIC INCHES	.61966864E 06	.46706772E 06	.37683295E 06
CORE LOADING, KG. U.	.12979748E 06	.97833280E 05	.78932460E 05
AVERAGE CORE SPECIFIC POWER, KW/KG.U	.18105126E 02	.24020455E 02	.29772288E 02
AVERAGE CORE POWER DENSITY, KW/CUBIC FT.	.25885765E 03	.34330574E 03	.42536023E 03
AVERAGE FUEL POWER DENSITY, KW/CUBIC IN.	.37923493E 01	.50313901E 01	.62361849E 01
FUEL IN-CORE RESIDENCE TIME, YEARS	.47288503E 01	.35643136E 01	.28757090E 01
MAX. NOMINAL ELEMENT CHANNEL POWER, KW	.44669077E 04	.59263411E 04	.73454368E 04
MAX. NOMINAL HEAT FLUX, BTU/HR-SQ.FT	.51683627E 06	.68569765E 06	.84989178E 06
AVERAGE FUEL ROD HEAT FLUX, BTU/HR-SQ.FT	.22193721E 06	.29444881E 06	.36495622E 06
NUMBER OF CONTROL RODS IS 1/8 N.	.98642064E 02	.74350259E 02	.59986221E 02

H. C Fuel Temp F

Velocity, ft/sec (input data)

Pressure Drop, psi

Core Pressure Drop, psi

Input Data, Cases 13, 14, 15 only

MASS OF FUEL SLUG/FT, KG U/FT.	0.65270000
ELEMENT PEAKING FACTOR	1.14999999
*COOLANT HOT CHANNEL FACTOR (fictitious)	0.90434000
CENTRAL TUBE OD, INCHES.	0.65250000
CLAD OD, INCHES.	0.65250000
FUEL DIAMETER, INCHES.	0.57500000
CLAD ID, INCHES.	0.63249999

* see sec. II

COMPUTED RESULTS - CASE
18 Rod ELEMENT - LARGE RODS

	16	17	18
CORE POWER, BTU/HR	.80205499E 10	.80205499E 10	.80205499E 10
CORE FLOW RATE, LB/HR.	.66505390E 08	.66505390E 08	.66505390E 08
MAXIMUM ELEMENT COOLANT FLOW RATE, LB/SEC	.34673306E 02	.46040437E 02	.57124297E 02
NUMBER OF ELEMENTS	.79919057E 03	.60187481E 03	.48509269E 03
VELOCITY OF COOLANT, FT/SEC.	.11969999E 02	.12970000E 02	.13769999E 02
HEAT TRANSFER COEFFICIENT, BTU/HR-SQ.FT-F.	.75457090E 04	.69525165E 04	.65302540E 04
OVERALL RESISTANCE PARAMETER, HR-FT-F/BTU.	.53096261F-01	.53517164E-01	.53863373E-01
BETA - TAN FCN LOC OF FUEL HOT SPOT.	.28307088E-00	.21150560E-00	.16937136E-00
MAXIMUM LINEAR HEAT RATE, KW/FT.	.26431195E 02	.35096271E 02	.43545413E 02
MAXIMUM LINEAR HEAT RATE, BTU/HR-FT.	.90209668E 05	.11978357E 06	.14862049E 06
FLOW AREA, SQ. FT.	.56082942E-01	.68727278E-01	.80318688E-01
ACTIVE EFFECTIVE CORE DIAMETER, FT	.28916148F 02	.25098480E 02	.22536360E 02
HYDRAULIC DIAMETER, FT	.46323403E-01	.56013714E-01	.64710837E-01
SURFACE AREA OF OUTSIDE CLAD, SQ.FT./FT.	.19242257E-00	.19242257E-00	.19242257E-00
TOTAL WETTED PERIMETER, FT	.48427306E 01	.49078893E 01	.49647750E 01
VOLUME OF FUEL, CUBIC INCHES	.80195271E 06	.60395499E 06	.48676926E 06
CORE LOADING, KG. U.	.16762190E 06	.12623698E 06	.10174314E 06
AVERAGE CORE SPECIFIC POWER, KW/KG.U	.14019646E 02	.18615781E 02	.23097378E 02
AVERAGE CORE POWER DENSITY, KW/CUBIC FT.	.25560477E 03	.33927744F 03	.42080632E 03
AVERAGE FUEL POWER DENSITY, KW/CUBIC IN.	.29303472E 01	.38910183E 01	.48277493E 01
FUEL IN-CORE RESIDENCE TIME, YEARS	.61068896E 01	.45991321E 01	.37067599F 01
MAX. NOMINAL ELEMENT CHANNEL POWER, KW	.44107126E 04	.58566996E 04	.72666523E 04
MAX. NOMINAL HEAT FLUX, BTU/HR-SQ.FT	.46881022E 06	.62250272E 06	.77236518E 06
AVERAGE FUEL ROD HEAT FLUX, BTU/HR-SQ.FT	.19454724E 06	.25832668E 06	.32051673E 06
NUMBER OF CONTROL RODS IS 1/8 N.	.99898820E 02	.75234351E 02	.60636587E 02

H. C. Fuel Temp F
Velocity, ft/sec (input data)
Process Tube ID, in
Core Pressure Drop, psi

Input Data, Cases 16,17,18 only

MASS OF FUEL SLUG/FT, KG U/FT.	0.83230000
ELEMENT PEAKING FACTOR	1.19000000
*COOLANT HOT CHANNEL FACTOR (F ₁ F ₂ F ₃)	0.87394001
CENTRAL TUBE OD, INCHES.	0.73500000
CLAD OD, INCHES.	0.73500000
FUEL DIAMETER, INCHES.	0.65000000
CLAD ID, INCHES.	0.71500000

*see sec. II

COMPUTED RESULTS-CASE
30 ROD ELEMENT - SMALL RODS

19

20

21

CORE POWER, BTU/HR	.80205499E 10	.80205499E 10	.80205499E 10
CORE FLOW RATE, LB/HR	.66505390E 08	.66505390E 08	.66505390E 08
MAXIMUM ELEMENT COOLANT FLOW RATE, LB/SEC	.52783707E 02	.69701578E 02	.86029166E 02
NUMBER OF ELEMENTS	.52498356E 03	.39756028E 03	.32210679E 03
VELOCITY OF COOLANT, FT/SEC	.13459999E 02	.14479999E 02	.15200000E 02
HEAT TRANSFER COEFFICIENT, BTU/HR-SQ.FT-F	.66553193E 04	.61246917E 04	.57196366E 04
OVERALL RESISTANCE PARAMETER, HR-FT-F/BTU	.58613768E-01	.59388043E-01	.60075776E-01
BETA - TAN FCN LOC OF FUEL HOT SPOT	.28311990E-00	.21160616E-00	.16948249E-00
MAXIMUM LINEAR HEAT RATE, KW/FT	.23939095E 02	.31611890E 02	.39016971E 02
MAXIMUM LINEAR HEAT RATE, BTU/HR-FT	.81704132E 05	.10789137E 06	.13316492E 06
FLOW AREA, SQ. FT.	.75924949E-01	.93197387E-01	.10958013E-00
ACTIVE EFFECTIVE CORE DIAMETER, FT	.23443049E 02	.20406117E 02	.18372668E 02
HYDRAULIC DIAMETER, FT	.61752283E-01	.74463447E-01	.86202422E-01
SURFACE AREA OF OUTSIDE CLAD, SQ.FT./FT	.12042773E-00	.12042773E-00	.12042773E-00
TOTAL WETTED PERIMETER, FT	.49180334E 01	.50063428E 01	.50847818E 01
VOLUME OF FUEL, CUBIC INCHES	.33249578E 06	.25179286E 06	.20400476E 06
CORE LOADING, KG. U.	.69499423E 05	.52630619E 05	.42641785E 05
AVERAGE CORE SPECIFIC POWER, KW/KG.U	.33813230E 02	.44650813E 02	.55110262E 02
AVERAGE CORE POWER DENSITY, KW/CUBIC FT.	.38888541E 03	.51325022E 03	.63314817E 03
AVERAGE FUEL POWER DENSITY, KW/CUBIC IN.	.70677587E 01	.93330681E 01	.11519338E 02
FUEL IN-CORE RESIDENCE TIME, YEARS	.25320396E 01	.19174664E 01	.15535480E 01
MAX. NOMINAL ELEMENT CHANNEL POWER, KW	.67144958E 04	.88665798E 04	.10943574E 05
MAX. NOMINAL HEAT FLUX, BTU/HR-SQ.FT	.67844949E 06	.89590146E 06	.11057662E 07
AVERAGE FUEL ROD HEAT FLUX, BTU/HR-SQ.FT	.28392947E 06	.37493261E 06	.46276052E 06
NUMBER OF CONTROL RODS IS 1/8 N.	.65622945E 02	.49695035E 02	.40263350E 02

H.C. Fuel Temp F

Velocity, ft/sec (input data)

Process Tube ID, in

Core Pressure Drop, psi

1750.15

13.46

4.52550244

2000.36

14.48

4.86281943

2249.39

15.20

5.162434

20.4 17.8

21.0 17.8

20.4 17.8

Input Data, Cases 19,20,21 only

MASS OF FUEL SLUG/FT, KG U/FT.	0.31519999
ELEMENT PEAKING FACTOR	1.17999999
*COOLANT HOT CHANNEL FACTOR (Fictitious)	0.88135000
CENTRAL TUBE OD, INCHES	0.45999999
CLAD OD, INCHES	0.45999999
FUEL DIAMETER, INCHES	0.40000000
CLAD ID, INCHES	0.44000000

* see sec. II

COMPUTED RESULTS - CASE
30 Rod ELEMENT - MEDIUM RODS

22

23

24

CORE POWER, BTU/HR	.80205499E 10	.80205499E 10	.80205499E 10
CORE FLOW RATE, LB/HR.	.66505390E 08	.66505390E 08	.66505390E 08
MAXIMUM ELEMENT COOLANT FLOW RATE, LB/SEC	.52526511E 02	.69494030E 02	.85874858E 02
NUMBER OF ELEMENTS	.52755415E 03	.39874762E 03	.32268558E 03
VELOCITY OF COOLANT, FT/SEC.	.13069999E 02	.14119999E 02	.14850000E 02
HEAT TRANSFER COEFFICIENT, BTU/HR-SQ.FT-F.	.68714885E 04	.63350064E 04	.59168866E 04
OVERALL RESISTANCE PARAMETER, HR-FT-F/BTU.	.56973523E-01	.57628259E-01	.58220869E-01
BETA - TAN FCN LOC OF FUEL HOT SPOT.	.28309931E-00	.21154728E-00	.16945162E-00
MAXIMUM LINEAR HEAT RATE, KW/FT.	.24629989E 02	.32586158E 02	.40267225E 02
MAXIMUM LINEAR HEAT RATE, BTU/HR-FT.	.84062155E 05	.11121655E 06	.13743203E 06
FLOW AREA, SQ. FT.	.77809505E-01	.95288938E-01	.11196164E-00
ACTIVE EFFECTIVE CORE DIAMETER, FT	.23500276E 02	.20436497E 02	.18389123E 02
HYDRAULIC DIAMETER, FT	.57412104E-01	.69217484E-01	.80210880E-01
SURFACE AREA OF OUTSIDE CLAD, SQ.FT./FT.	.13482669E-00	.13482669E-00	.13482669E-00
TOTAL WETTED PERIMETER, FT	.54211219E 01	.55066397E 01	.55833642E 01
VOLUME OF FUEL, CUBIC INCHES	.42287549E 06	.31962708E 06	.25865748E 06
CORE LOADING, KG. U.	.88385364E 05	.66805378E 05	.54062097E 05
AVERAGE CORE SPECIFIC POWER, KW/KG.U	.26588112E 02	.35176808E 02	.43468531E 02
AVERAGE CORE POWER DENSITY, KW/CUBIC FT.	.38699369E 03	.51172533E 03	.63201562E 03
AVERAGE FUEL POWER DENSITY, KW/CUBIC IN.	.55571912E 01	.73523179E 01	.90853740E 01
FUEL IN-CORE RESIDENCE TIME, YEARS	.32201021E 01	.24338887E 01	.19696188E 01
MAX. NOMINAL ELEMENT CHANNEL POWER, KW	.66817785E 04	.88401781E 04	.10923946E 05
MAX. NOMINAL HEAT FLUX, BTU/HR-SQ.FT	.62348301E 06	.82488528E 06	.10193236E 07
AVERAGE FUEL ROD HEAT FLUX, BTU/HR-SQ.FT	.25237118E 06	.33389406E 06	.41259811E 06
NUMBER OF CONTROL RODS IS 1/8 N.	.65944268E 02	.49843452E 02	.40335698E 02

H.C. Fuel Temp, F
Velocity, ft/sec (input data)
Process Tube ID, in
Core Pressure Drop, psi

1750.20	2000.63	2249.62
13.07	14.12	14.85
4.74215918	5.06881309	5.36187918
20.8 17.8	21.0 17.9	21.0 17.9

Input Data, Cases 22, 23, 24 only

MASS OF FUEL SLUG/FT, KG U/FT.	0.39889999
ELEMENT PEAKING FACTOR	1.22000000
*COOLANT HOT CHANNEL FACTOR (friction loss)	0.85245000
CENTRAL TUBE OD, INCHES.	0.51499999
CLAD OD, INCHES.	0.51499999
FUEL DIAMETER, INCHES.	0.45000000
CLAD ID, INCHES.	0.49500000

* See sec. II

COMPUTED RESULTS - CASE
30 Rod ELEMENT - LARGE RODS

25

26

27

CORE POWER, BTU/HR	.80205499E 10	.80205499E 10	.80205499E 10
CORE FLOW RATE, LB/HR.	.66505390E 08	.66505390E 08	.66505390E 08
MAXIMUM ELEMENT COOLANT FLOW RATE, LB/SEC	.52049602E 02	.68895497E 02	.85314430E 02
NUMBER OF ELEMENTS	.53238791E 03	.40221176E 03	.32480530E 03
VELOCITY OF COOLANT, FT/SEC.	.12689999E 02	.13729999E 02	.14500000E 02
HEAT TRANSFER COEFFICIENT, BTU/HR-SQ.FT-F.	.70759865E 04	.65247228E 04	.61060290E 04
OVERALL RESISTANCE PARAMETER, HR-FT-F/BTU.	.55676357E-01	.56249484E-01	.56753933E-01
BETA - TAN FCN LOC OF FUEL HOT SPOT.	.28306913E-00	.21167586E-00	.16941906E-00
MAXIMUM LINEAR HEAT RATE, KW/FT.	.25206572E 02	.33364700E 02	.41316058E 02
MAXIMUM LINEAR HEAT RATE, BTU/HR-FT.	.86030031E 05	.11387371E 06	.14101170E 06
FLOW AREA, SQ. FT.	.79411879E-01	.97151606E-01	.11391585E-00
ACTIVE EFFECTIVE CORE DIAMETER, FT	.23607513E 02	.20524880E 02	.18449257E 02
HYDRAULIC DIAMETER, FT	.53608526E-01	.64676729E-01	.74912057E-01
SURFACE AREA OF OUTSIDE CLAD, SQ.FT./FT.	.14922566E-00	.14922566E-00	.14922566E-00
TOTAL WETTED PERIMETER, FT	.59253170E 01	.60084427E 01	.60826445E 01
VOLUME OF FUEL, CUBIC INCHES	.52685202E 06	.39802946E 06	.32142790E 06
CORE LOADING, KG. U.	.11012443E 06	.83197499E 05	.67185975E 05
AVERAGE CORE SPECIFIC POWER, KW/KG.U	.21339495E 02	.28246041E 02	.34977537E 02
AVERAGE CORE POWER DENSITY, KW/CUBIC FT.	.38348588E 03	.50732771E 03	.62790228E 03
AVERAGE FUEL POWER DENSITY, KW/CUBIC IN.	.44604554E 01	.59040854E 01	.73111261E 01
FUEL IN-CORE RESIDENCE TIME, YEARS	.40121115E 01	.30310951E 01	.24477548E 01
MAX. NOMINAL ELEMENT CHANNEL POWER, KW	.66211119E 04	.87640400E 04	.10852655E 05
MAX. NOMINAL HEAT FLUX, BTU/HR-SQ.FT	.57650962E 06	.76309741E 06	.94495612E 06
AVERAGE FUEL ROD HEAT FLUX, BTU/HR-SQ.FT	.22594929E 06	.29907796E 06	.37035318E 06
NUMBER OF CONTROL RODS IS 1/8 N.	.66548489E 02	.50276469E 02	.40600663E 02

H.C. Fuel Temp F
Velocity ft/sec (input data)
Mass Flow lb, in
Core Power - Dry, psi

1750.28	2000.03	2249.86
12.69	13.73	14.50
4.96304226	5.28055912	5.56395895
24.8 17.8	24.9 17.8	24.0 17.9

Input Data, Cases 25, 26, 27 only

MASS OF FUEL SLUG/FT, KG U/FT.	0.49250000
ELEMENT PEAKING FACTOR	1.25999999
*COOLANT HOT CHANNEL FACTOR (Circulations)	0.82539000
CENTRAL TUBE OD, INCHES.	0.56999999
CLAD OD, INCHES.	0.56999999
FUEL DIAMETER, INCHES.	0.50000000
CLAD ID, INCHES.	0.55000000

*see sec. II

COMPUTED RESULTS - CASE
 1/8 ROD ELEMENT - SMALL RODS -
 variable pressure drop

	II A	II	II B	II C
CORE POWER, BTU/HR	.80205499E 10	.80205499E 10	.80205499E 10	.80205499E 10
CORE FLOW RATE, LB/HR.	.66505390E 08	.66505390E 08	.66505390E 08	.66505390E 08
MAXIMUM ELEMENT COOLANT FLOW RATE, LB/SEC	.44904035E 02	.46878072E 02	.48654769E 02	.50222832E 02
NUMBER OF ELEMENTS	.61710667E 03	.59112027E 03	.56953470E 03	.55175261E 03
VELOCITY OF COOLANT, FT/SEC.	.99999998E 01	.13880000E 02	.20000000E 02	.30000000E 02
HEAT TRANSFER COEFFICIENT, BTU/HR-SQ.FT-F.	.48607459E 04	.64622031E 04	.89554799E 04	.12981009E 05
OVERALL RESISTANCE PARAMETER, HR-FT-F/BTU.	.58767878E-01	.56320658E-01	.54252698E-01	.52590560E-01
ETA - TAN FCN LOC OF FUEL HOT SPOT.	.21171642E-00	.21161306E-00	.21165726E-00	.21152949E-00
MAXIMUM LINEAR HEAT RATE, KW/FT.	.31928824E 02	.33332455E 02	.34595708E 02	.35710733E 02
MAXIMUM LINEAR HEAT RATE, BTU/HR-FT.	.10897307E 06	.11376367E 06	.11807536E 06	.12188073E 06
LOW AREA, SQ. FT.	.86939082E-01	.65389792E-01	.47100455E-01	.32412283E-01
CRITICAL EFFECTIVE CORE DIAMETER, FT	.25413621E 02	.24873568E 02	.24415894E 02	.24032316E 02
HYDRAULIC DIAMETER, FT	.85519725E-01	.66200782E-01	.49027869E-01	.34604922E-01
SURFACE AREA OF OUTSIDE CLAD, SQ.FT./FT.	.14922566E-00	.14922566E-00	.14922566E-00	.14922566E-00
TOTAL WETTED PERIMETER, FT	.40663873E 01	.39509981E 01	.39427494E 01	.37465517E 01
VOLUME OF FUEL, CUBIC INCHES	.36641391E 06	.35098420E 06	.33816753E 06	.32760922E 06
CORE LOADING, KG. U.	.76589106E 05	.73363936E 05	.70684949E 05	.68478016E 05
AVERAGE CORE SPECIFIC POWER, KW/KG.U	.30683214E 02	.32032087E 02	.33246115E 02	.34317582E 02
AVERAGE CORE POWER DENSITY, KW/CUBIC FT.	.33091520E 03	.34544081E 03	.35851274E 03	.37004843E 03
AVERAGE FUEL POWER DENSITY, KW/CUBIC IN.	.64135118E 01	.66954579E 01	.69492182E 01	.71731801E 01
FUEL IN-CORE RESIDENCE TIME, YEARS	.27903346E 01	.26728336E 01	.25752313E 01	.24948271E 01
AX. NOMINAL ELEMENT CHANNEL POWER, KW	.57121404E 04	.59632033E 04	.61802628E 04	.63887326E 04
AX. NOMINAL HEAT FLUX, BTU/HR-SQ.FT	.73025694E 06	.76235995E 06	.79125368E 06	.81675448E 06
AVERAGE FUEL ROD HEAT FLUX, BTU/HR-SQ.FT	.32488353E 06	.33916581E 06	.35202033E 06	.36336536E 06
NUMBER OF CONTROL RODS IS 1/8 N.	.77138333E 02	.73890034E 02	.71191837E 02	.68969077E 02

1. C. Fuel Temp, F
 velocity, ft/sec (input data)
 Process Tube ID, in.
 Core Pressure Drop, psi

2000.72	2000.33	2000.12	1999.84
10.00	13.88	20.00	30.00
4.70245409	4.26170015	3.84822071	3.48077258
9.62 10.1	20.9 17.8	54.7 39.0	145.8 103.5

Input Data, Cases IIA, II, IIB, IIC only

MASS OF FUEL SLUG/FT, KG U/FT.	0.49250000
ELEMENT PEAKING FACTOR	1.11000000
*COOLANT HOT CHANNEL FACTOR (fictitious)	0.93692999
CENTRAL TUBE OD, INCHES.	0.56999999
CLAD OD, INCHES.	0.56999999
FUEL DIAMETER, INCHES.	0.50000000
CLAD ID, INCHES.	0.55000000
* see sec. II	

Maximum Linear Heat Rate, kw/ft

Figure 1
1000 MWE SGR
Maximum Linear Heat Rate
vs
Maximum Fuel Centerline Temperature
Cases 1-27