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TECHNICAL DIVISION
SAVANNAH RIVER LABORATORY

DPST-65-165

HTR-84
REA(HWCTR)-P9

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March 8, 1965

MEMORANDUM

TO: L. M. ARNETT

FROM: P. L. GRAY - V. D. VANDERVELDE

P.L.G.

HTR-84

ROTAH IBM PROGRAMS FOR FUEL CALCULATIONS

INTRODUCTION

A series of codes was prepared for computing the complete exposure history for the fuel in the HWCTR (reference 1). The last code, ROTAH (Records of Temperature and Heat), was the ultimate goal of the series and was used to calculate the operating conditions within a fuel assembly. ROTAH, and the other codes, were used in preparing the detailed Test Operating Histories to be issued for all test fuel assemblies and for the four driver elements that were inspected. This memorandum describes the ROTAH programs (one each for single and two-piece fuel elements) and the equations used in them.

SUMMARY

The input information for ROTAH is listed. The equations used to calculate power, channel coolant temperature, sheath (surface) temperature, core temperature, $\int k d\theta$, heat flux, volumetric heat generation, specific power, and also to obtain time-averaged values for some of these parameters are listed. The IBM-704 Fortran source deck listings are appended as well as examples of output data sheets. Dimensional units for quantities are listed. The Fortran souce decks and their compiled object decks are available in the permanent HWCTR files.

DISCUSSION

Input Information

The following input information about a fuel element is needed for ROTAH calculations:

The name of the element and its type. Types are:

- -1 = uranium oxide rods
- 0 = uranium oxide tubes
- 1 = uranium metal tubes
- 2 = Zircaloy-uranium alloy metal tubes
- 3 = thorium metal tubes

This information is listed on input card 1 according to FORMAT 2 (appendices D and E).

The heat split (b'), flow split (f), velocity constant (C_2) and hydraulic diameter (D_e) for all coolant channels successively from the innermost outwards. The heat split (b') is not listed for two-tube elements. This information is listed on input card 2 according to FORMAT 3 and is also printed on the first line of the first sheet of the ROTAH printout (see first page Appendices B and C).

The heat split (b), area (A_h), and cladding thickness (c) for all fuel surfaces successively from the innermost outwards. This information is listed on input card 3 according to FORMAT 3 and is also printed on the second line of the first sheet of the ROTAH printout (see first page of Appendices B and C).

The flow and sampling constant (C_1), core volume (V), core thickness (d) and core weight (W) for all fuel pieces successively from the innermost outwards. In two tube elements the constant C_1 is not listed; heat split between the two fuel pieces is handled by Ø, the axial power shapes, for these assemblies. The value for C_1 is listed in Test Operating Histories as heat split under Fuel Piece for single tube elements. This information is listed on input card 4 according to FORMAT 3 and is also printed on the third line of the first sheet of the ROTAH printout (see first page of Appendices B and C).

The key, date, delta T (Δt_{cool}), flow (F), inlet temperature (t_i), saturation temperature (t_s), and length of exposure interval (T) for the first exposure interval. Key is +1. This information is listed on input card 5 according to FORMAT 4.

The power shape (Ø) for 21 layers for all fuel pieces successively from the innermost outwards. These cards are the output of the AUX 1 (ref.2) program. If the fuel assembly has one piece, there are 3 cards; if two, 6 cards. These data are contained on these cards according to FORMAT 5.

The specific exposure (x) for 21 layers for all fuel pieces successively from the innermost outwards. These cards are the output of the AUX 1 program. If the fuel assembly has one piece, there are 3 cards; if two 6 cards. These data are contained on these cards according to FORMAT 5.

For each succeeding exposure interval another set of cards (7 cards in single tube elements; 13 cards in two-tube elements) starting with card 5 is required.

If, at the end of any given exposure interval, some change in the data processing is required, a card with Key having some value other than +1 is inserted. The following can be accommodated.

Key = 0 ROTAH calculates time-weighted average values, prints these (previously calculated data has already been printed), and prints the data reduction by layers. If this is followed by a second card with Key = 0, ROTAH prints END OF PROGRAM. If the first Key = 0 card is followed by a Key = +1 card, ROTAH clears all stored data and accepts a new fuel assembly for calculation starting with the new element's input card 1.

Key = +3 The ROTAH program accepts new input constants on cards 2, 3, and 4 (all constants must be listed on these cards even though only some constants change) and then continues calculations for the next exposure interval(s). Such a case occurs, for example, when a housing is changed, resulting in a new flow split or a new cross-sectional flow area (velocity changes). Changes in the fuel column itself are not handled this way.

Key = -1 This is used when the fuel column length is changed (e.g., by removal of a fuel slug in a segmented column). ROTAH completes all calculations and prints all data for the before-modification case; it then accepts new input constant cards 1, 2, 3, and 4 for the after-modification case. A second Key = -1 card is then required to obtain time-weighted average data for fuel pieces remaining in the column. These data are printed. Then the data calculations resume with the next set of exposure interval cards starting with a card identical to card 5.

Equations

The equations used by ROTAH are presented in this section. The symbols, corresponding ROTAH symbols, definitions, and units are presented in Appendix A.

The power removed from an element by the coolant is:

$$P = 0.000265\,(F)(\Delta t_{cool})(C_1) \tag{1}$$

where 0.000265 includes ρ and Cp for D_2O at 180°C and also includes conversion factors. The use of constant values for ρ and Cp introduces less than ±0.5% error between 165°C and 245°C. The constant, C_1, reduces the total flow to that fraction which removes heat and also corrects for sampling errors where the thermocouple does not see the correct mixed effluent temperature; the constant is equal to 1.0 for most elements. It is called "Heat split" in the listing of ROTAH input data for fuel pieces in the Test Operating Histories. It was not used in the "Two-tube ROTAH".

The temperature of the coolant in any channel at any elevation is (see also equation (26)):

$$t_c = t_i + (\Delta t_{cool})(Mx)(b)/(f) \tag{2}$$

The velocity of the coolant in any channel is:

$$v = (F)(f)(C_2) \tag{3}$$

where the constant, C_2, is equal to conversion factors divided by the cross-sectional flow area of the coolant channel, A_f.

The heat transfer coefficient for a fuel surface in any channel is:

$$h = 570 \, (v)^{0.8}/(De)^{0.2} \tag{4}$$

where v is obtained from equation (3), and where 570 accounts for physical properties of D_2O and conversion factors. The equation was developed by SRL.

The film temperature difference at any elevation on any fuel surface is:

$$\Delta t_f = (q/A) \, / \, (h) \tag{5}$$

This is not strictly correct for all cases because Δt_f is reduced in those cases where t_{surf}, the fuel surface temperature, is limited by local boiling as discussed subsequently.

The heat flux at any elevation on any fuel surface is:

$$q/A = 502 \, (F) \, (\Delta t_{cool})(\phi)(b) \, / \, (A_h) \tag{6}$$

where 502 accounts for conversion factors.

The temperature of any fuel surface at any elevation is calculated by:

$$t_{surf} = t_c + \Delta t_f \tag{7}$$

where t_c is from equation (2) and Δt_f is from equation (5). Because the surface temperature can be limited to a value about 10°C above the saturation temperature when local boiling occurs, the ROTAH program tests every calculation made by equation (7) with equation (8) below and accepts the lower of the two values obtained:

$$t_{surf}' = t_s + 10°C \tag{8}$$

Note that the reduction in Δt_f, discussed previously, is not calculated by ROTAH in cases of local boiling but is implied by t_{surf}'.

The thermal conductivities of the cladding and core materials are:

$$k_{Zirc} = 7.8 + 0.001 \, t \quad \text{(use for cladding)} \tag{9}$$

$$k_{Zirc-U} = 6.2 + 0.005 \, t \quad \text{(use for drivers)} \tag{10}$$

$$k_U = 13.9 + 0.01 \, t \quad \text{(use for U metal)} \tag{11}$$

$$k_{Th} = 21.27 + 0.0073 \, t \quad \text{(use for Th metal)} \tag{12}$$

where the temperature, t, is selected as follows for the evaluation of k:

(1) t in equation (9) for cladding is:

$$t = (t_{surf} + t_{int}) \, / \, 2 \tag{9a}$$

i.e., the average cladding temperature;

(2) t in equations (10, 11, 12) for various cores is:

$$t = (t_{av} + 2\ t_{cm}) / 3 \qquad (10a, 11a, 12a)$$

No thermal conductivity is listed for oxide elements because oxide temperatures are evaluated by $\int k d\theta$ (see below).

Because k (using, for example, (9a) in (9))is a function of a desired temperature within a fuel piece, and because the desired temperature is a function of k, ROTAH does not calculate k directly but uses equations (16), (21), (22), and (23) below to calculate the desired temperature.

The temperature difference across the cladding for any fuel surface at any elevation is:

$$\Delta t_{clad} = (q/A)\ (c) / (k) \qquad (13)$$

The temperature at the interface between the cladding and the fuel core for any surface at any elevation is:

$$t_{int} = t_{surf} + \Delta t_{clad} \qquad (14)$$

In ROTAH, equations (14), (13), (9a), and (9) are combined to yield a direct solution for t_{int}. Thus:

$$t_{int} = t_{surf} + (q/A)(c) / (7.8 + 0.0005\ t_{surf} + 0.0005\ t_{int}) \qquad (15)$$

Equation (15) is solved for t_{int}:

$$t_{int} = 1000 \left(\left[60.84 + .000001(t_{surf})^2 + .0156(t_{surf}) + .002\ (q/A)(c) \right]^{\frac{1}{2}} - 7.8 \right) \qquad (16)$$

For elements cooled on two surfaces an average interface temperature is calculated prior to obtaining the central core temperature:

$$t_{av} = \left[(t_{int})_{one\ surface} + (t_{int})_{other\ surface} \right] \Big/ 2 \qquad (17)$$

The volumetric heat generation rate at any elevation within a fuel piece is:

$$Q = 502\ (F)\ (\Delta t_{cool})\ (\phi)\ (C_1) / (V) \qquad (18)$$

where 502 includes conversion factors and C_1 was previously discussed under equation (1).

The temperature difference between the center of the core and the surface (or surfaces) of the core at any elevation is:

$$\Delta t_{core} = (Q)\ (d) / 8\ (k) \qquad (19)$$

The temperature at the hottest part of the core at a given elevation is:

$$t_{core} = t_{av} + \Delta t_{core} \qquad (20)$$

In ROTAH, equations (20), (19), (10a, 11a, or 12a), and (10, 11, or 12) are combined to yield a direct solution for t_{core}. These ROTAH equations are:

t_{core} (for uranium-Zircaloy alloy drivers) =

$$\left[(.0133t_{av}-49.6)+\left[(.0133t_{av}-49.6)^2+.1067(49.6t_{av}+.0133t_{av}{}^2+Qd^2)\right]^{\frac{1}{2}}\right]\Big/.0533 \qquad (21)$$

t_{core} (for uranium metal elements) =

$$\left[(.0267t_{av}-111.2)+\left[(.0267t_{av}-111.2)^2+.2133(111.2t_{av}+.0267t_{av}{}^2+Qd^2)\right]^{\frac{1}{2}}\right]\Big/.1067 \qquad (22)$$

t_{core} (for thorium metal elements) =

$$\left[(.0194t_{av}-170.2)+\left[(.0194t_{av}-170.2)^2+.1552(170.2t_{av}+.0194t_{av}{}^2+Qd^2)\right]^{\frac{1}{2}}\right]\Big/.0776 \qquad (23)$$

The "temperature" of an oxide element at any elevation is:

$$\int k d\Theta = (Q)(d)^2 / (8)(57.8) \qquad \text{(for tubular elements)} \qquad (24)$$

where 57.8 accounts for conversion factors, and:

$$\int k d\Theta = (Q)(d)^2 / (16)(57.8) = (Q)(r)^2 / (4)(57.8) \qquad \text{(for rods)} \qquad (25)$$

The temperature within the core of an element, or the $\int k d\Theta$, is calculated by equation (19) or (24). These equations use the slab geometry for the fuel piece rather than a cylindrical wall geometry. The more simple slab form of the equation was used because all the HWCTR fuel tested had a high enough ratio of diameter to wall thickness so that the temperature error was at worst about 1% and in most cases considerably below 1%.

In the special case of a coolant annulus that has two heated surfaces – the intermediate channel of a two-tube element – the temperature of the coolant at any given elevation is:

$$t_c = t_i + \Delta t_{cool} \, (Mx\ b + Mx\ b) / (f) \qquad (26)$$

where the first Mx is for the inner fuel piece and the first b for the outer surface thereof, and where the second Mx is for the outer fuel piece and the second b for the inner surface thereof, and where f is the flow split for the intermediate channel.

The specific power of a given fuel piece at any given elevation is:

$$p = (P)(\phi) / (W) \qquad (27)$$

where W, the weight, is normally in tonnes, but for driver elements it is the equivalent core length times 10^{-3} so that p will have the units KW/ft.

Time—Weighted Average Values

Time-weighted average values are obtained using an equation similar to the example shown here for specific power:

$$p_{\text{time-weighted average}} = \frac{\sum(p_1T_1 + p_2T_2 + \ldots\ldots. p_NT_N)}{\sum(T_1 + T_2 + \ldots.. T_N)} \qquad (28)$$

Axial Power Shape

The distribution of the total fuel assembly power within the length of the fuel column at any given time is described by the axial power shape for the element for that time.

This quantity is Ø in the equations preceding and is ENX in the ROTAH program.

It is calculated in the TURBO and RITE programs (ref. 1) and punched on cards by the AUX-1 program (ref. 2). These cards are a part of the input data for ROTAH.

The power shape is the product of the flux shape and the fissionable material abundance shape. Power shape rather than flux shape is used because there are significant differences between the two at fuel exposures achieved in the HWCTR.

In a single tube element, the power shape values are relative to an average value of 1.0 for the column. This can be demonstrated by summing up half of the 1st and 21st values with the other 19 values and dividing by 20.

In a two-tube element, two sets of power shape values are listed. These describe not only the axial power shape in each fuel piece but also the power split between the two fuel pieces. Thus,half of the 1st and 21st values plus the other 19 values on one fuel piece (either inner or outer) divided by 20 will yield the fraction of total element power developed within that fuel piece.

ROTAH for the SOT-7 Case

This fuel assembly (the SOT-7-2) was unique in the HWCTR test program in that it contained fuel pieces having both natural and enriched uranium. Thus, although the axial flux shape was a smooth curve without discontinuities, there was an abrupt change in the axial power shape at the junctures between the two fuel types. A special subsection of the single-tube ROTAH program was prepared to handle this case.

The ROTAH layers read upwards from layer 1 at the fuel column bottom to layer 17 at the fuel column top (the element had upflow cooling in the liquid loop bayonet). Layers 1 through 5 apply to the bottom two natural UO_2 slugs. Layers 5 and 6 are, unlike other ROTAH layers, at the same elevation between the two fuel types; and layer 5 data (using the natural fuel Ø) are applicable to the natural UO_2 fuel, while layer 6 data (using the enriched Ø) are applicable to the enriched UO_2 fuel. Layers 6 through 10 are applicable to the two enriched UO_2 fuel pieces. Layers 10 and 11 are used in a fashion similar to layers 6 and 5 in handling the return to natural fuel for the remainder of the column. The last three natural UO_2 fuel pieces are covered by layers 11 through 17.

ROTAH Printouts

The data calculated by ROTAH are obtained on printout sheets examples of which are shown in Appendices B and C. The first sheet (see Appendices B1 and C1) lists the element name and input constants as previously described. This is followed by one sheet for each exposure intervals where the date of the interval is given in the heading of the sheet. Examples are shown as Appendices B2 and C2. Data are presented for all layers within the fuel. All units for these data are as given in Appendix A. Where not otherwise identified, all data in ROTAH printouts read from the center of the fuel outwards.

Examples of the time-weighted average values are shown in Appendices B3 and C3. The last examples shown, Appendices B4 and C4, are for the data reduction by layers where data for all the exposure intervals are shown for one layer on each sheet.

REFERENCES

1. Vandervelde, V. D., memorandum to L. M. Arnett, "IBM Codes for Calculating Fuel Exposure in HWCTR," HTR-66, March 11, 1964.

2. Vandervelde, V. D., memorandum to L. M. Arnett, "RITE IBM Program for Power Shapes and Exposure Profiles," HTR to be issued.

PLG/VDV:eda

INDEX TO APPENDICES

APPENDIX A

SYMBOLS, DEFINITIONS, AND UNITS

Symbol	ROTAH Symbol	Definition	Units
A_f	(1)	Coolant flow area (cross-sectional area of a given coolant channel)	in.^{2}
A_h	AREA	Heat transfer area of a given surface	ft^2
b	HSPLIT	Fraction of total heat within a given fuel piece leaving through a given surface	-
b'	H	Fraction of total heat entering a given coolant channel	-
C_1	CON	Constant to correct for thermocouple sampling errors and also for flow that bypasses the heated channels	-
C_2	VEL	Velocity constant	(ft/sec)/gpm
C_p	(1)	Specific heat of D_2O	pcu/lb °C
c	CLAD	Cladding thickness	ft
D_e	DIAM	Equivalent (or hydraulic) diameter	in.
d	CORE	Core thickness (tubular fuel) Core diameter (rods)	ft ft
F	FLOW	Total coolant flow rate	gpm
f	FSPLIT	Fraction of total flow within an assembly going through a given channel	-
h	(1)	Heat transfer coefficient	pcu/hr ft^2 °C
k	(1)	Thermal conductivity	pcu/hr ft °C
M_x	EMX	Heat accumulated in a given fuel piece from coolant inlet end as a fraction of total heat in that fuel piece.	-
P	POW	Total element power	MW
p	SPEPOW	Specific power	W/g (test) kW/ft (driver)
Q	GEN	Volumetric heat generation rate	pcu/hr ft^3
q/A	HFLUX	Heat flux	pcu/hr ft^2
T	Time	Length of a given exposure interval	days

APPENDIX A (Contd)

Symbol	ROTAH Symbol	Definition		Units
t_i	TIN	Coolant inlet temperature		°C
t_s	TSAT	Saturation temperature		°C
t_c	TCHAN	Coolant temperature within a given channel		°C
t_{surf}	SURFT	Fuel surface temperature		°C
$t_{surf'}$	TDUM	Fuel surface temperature in local boiling		°C
t_{int}	FTINT	Temperature at interface of core and cladding		°C
t_{av}	AVTINT	Average of t_{int} for two cooled surfaces		°C
t_{cm}	TCORE(2)	Central core temperature		°C
Δt_{cool}	DELTAT	Coolant temperature rise		C°
Δt_f	(1)	Film temperature difference		C°
Δt_{clad}	(1)	Cladding temperature difference		C°
Δt_{core}	(1)	Core temperature difference		C°
V	VOL	Fuel element core volume		ft^3
v	(1)	Coolant velocity		ft/sec
W	TON	Weight (Length in the case of drivers x 10^{-3})		tonnes ft x 10^{-3}
X	SPEX	Specific exposure	(test) (drivers)	WD/g atom % fission burnup
$\int kd\phi$	TCORE(3) KDTHETA	Oxide "temperature"		W/cm
ρ	(1)	Density of D_2O		lb/ft^3
ϕ	ENX	Axial power shape (see text)		-

NOTES

(1) Does not appear in ROTAH as such.
(2) See also $\int kd\theta$
(3) TCORE is used internally in ROTAH for $\int kd\theta$ calculations but the results are listed in the printout under KDTHETA.

ROTAH FOR A SINGLE ELEMENT SOT 6-2

0.43000	0.40700	0.32100	0.34100	0.57000	0.56000	0.21900	0.31800
0.43000	3.01000	0.00183	0.57000	4.16000	0.00192		
1.00000	0.09180	0.02560	0.02275				

ELEMENT SOT 6-2 DATE 1/09/64 DEL T 9.3 FLOW 150. INLET 200.0 POWER 0.370

	POWER SHAPE	SPECIFIC EXPOSURE	K D THETA	CHANNEL TEMPERATURE		SURFACE TEMPERATURE		SURFACE .....HEAT FLUX.......		VOL HEAT GENERATION	SPEC POWER
1	0.397	15.9	4.3	200.0	200.0	205.2	205.2	0.397E 05	0.381E 05	0.303E 07	6.5
2	0.668	26.7	7.2	200.3	200.3	209.0	209.0	0.668E 05	0.641E 05	0.510E 07	10.9
3	0.969	38.7	10.5	200.7	200.6	213.3	213.3	0.969E 05	0.930E 05	0.739E 07	15.7
4	1.263	50.4	13.7	201.2	201.2	217.8	217.6	0.126E 06	0.121E 06	0.964E 07	20.5
5	1.525	60.9	16.5	201.9	201.8	221.9	221.7	0.153E 06	0.146E 06	0.116E 08	24.8
6	1.730	69.0	18.7	202.7	202.6	225.3	225.1	0.173E 06	0.166E 06	0.132E 08	28.1
7	1.858	74.2	20.1	203.6	203.4	227.9	227.7	0.186E 06	0.178E 06	0.142E 08	30.2
8	1.897	75.7	20.5	204.5	204.3	229.3	229.1	0.190E 06	0.182E 06	0.145E 08	30.8
9	1.838	73.4	19.9	205.4	205.2	229.5	229.2	0.184E 06	0.176E 06	0.140E 08	29.9
10	1.672	66.8	18.1	206.3	206.1	228.2	227.8	0.167E 06	0.160E 06	0.128E 08	27.2
11	1.391	55.5	15.0	207.0	206.8	225.3	224.9	0.139E 06	0.133E 06	0.106E 08	22.6
12	1.100	43.9	11.9	207.7	207.4	222.1	221.7	0.110E 06	0.106E 06	0.839E 07	17.9
13	0.891	35.6	9.6	208.1	207.8	219.8	219.4	0.891E 05	0.855E 05	0.679E 07	14.5
14	0.730	29.1	7.9	208.5	208.2	218.1	217.7	0.730E 05	0.700E 05	0.557E 07	11.9
15	0.598	23.9	6.5	208.9	208.5	216.7	216.3	0.598E 05	0.574E 05	0.456E 07	9.7
16	0.487	19.4	5.3	209.1	208.8	215.5	215.1	0.487E 05	0.467E 05	0.371E 07	7.9
17	0.392	15.6	4.2	209.3	209.0	214.5	214.1	0.392E 05	0.376E 05	0.299E 07	6.4
18	0.310	12.4	3.4	209.5	209.2	213.6	213.2	0.310E 05	0.298E 05	0.237E 07	5.0
19	0.240	9.6	2.6	209.6	209.3	212.8	212.4	0.240E 05	0.230E 05	0.183E 07	3.9
20	0.179	7.1	1.9	209.8	209.4	212.1	211.7	0.179E 05	0.172E 05	0.137E 07	2.9
21	0.127	5.1	1.4	209.8	209.5	211.5	211.1	0.127E 05	0.122E 05	0.970E 06	2.1

CHAN EFF 209.8 SURF TEMP 229.5 K D THETA 20.51 HEAT FLUX 189802.

TIME WEIGHTED AVERAGE VALUES FOR ELEMENT SOT 6-2

	K D THETA	SURFACE TEMPERATURE		SURFACE .....HEAT FLUX......		SPEC POWER
1	4.3	226.9	226.9	0.397E 05	0.381E 05	6.4
2	7.2	230.7	230.6	0.668E 05	0.640E 05	10.8
3	10.5	235.0	234.9	0.970E 05	0.930E 05	15.8
4	13.7	239.3	239.2	0.127E 06	0.122E 06	20.6
5	16.7	243.6	243.4	0.154E 06	0.148E 06	25.1
6	19.2	247.4	247.2	0.178E 06	0.171E 06	28.9
7	21.2	250.7	250.4	0.196E 06	0.188E 06	31.9
8	22.6	253.3	253.0	0.210E 06	0.201E 06	34.0
9	23.4	255.3	254.9	0.217E 06	0.208E 06	35.2
10	23.6	256.5	256.1	0.218E 06	0.209E 06	35.4
11	23.0	256.8	256.4	0.213E 06	0.204E 06	34.6
12	21.8	256.3	255.8	0.201E 06	0.193E 06	32.7
13	19.9	255.0	254.5	0.185E 06	0.177E 06	30.0
14	17.7	253.1	252.6	0.164E 06	0.157E 06	26.6
15	15.4	251.0	250.5	0.142E 06	0.136E 06	23.1
16	13.0	248.9	248.4	0.121E 06	0.116E 06	19.6
17	10.8	246.8	246.3	0.100E 06	0.959E 05	16.2
18	8.7	244.8	244.2	0.807E 05	0.774E 05	13.1
19	6.8	242.9	242.3	0.632E 05	0.606E 05	10.3
20	5.1	241.1	240.6	0.476E 05	0.456E 05	7.7
21	3.7	239.6	239.1	0.339E 05	0.325E 05	5.5

VARIABLES VS SPECIFIC EXPOSURE   SOT 6-2   LAYER 8

SPECIFIC EXPOSURE	K D THETA	CHANNEL TEMPERATURE		SURFACE TEMPERATURE		SURFACE .....HEAT FLUX......		VOL HEAT GENERATION	SPEC POWER
75.7	20.5	204.5	204.3	229.3	229.1	0.190E 06	0.182E 06	0.145E 08	30.8
321.0	20.7	204.4	204.2	229.4	229.2	0.191E 06	0.183E 06	0.146E 08	31.1
570.9	21.1	204.5	204.3	230.0	229.7	0.195E 06	0.187E 06	0.149E 08	31.7
818.3	21.4	204.5	204.4	230.5	230.2	0.198E 06	0.190E 06	0.151E 08	32.2
954.9	21.9	204.6	204.5	231.1	230.8	0.202E 06	0.194E 06	0.154E 08	32.9
979.6	9.8	202.0	201.9	213.9	213.7	0.907E 05	0.870E 05	0.692E 07	14.7
1235.3	23.9	204.8	204.6	233.8	233.5	0.221E 06	0.212E 06	0.169E 08	36.0
1482.9	23.4	234.7	234.6	263.1	262.8	0.217E 06	0.208E 06	0.165E 08	35.2
1703.1	23.3	234.7	234.6	263.0	262.7	0.216E 06	0.207E 06	0.165E 08	35.1
1919.3	22.7	234.6	234.4	262.1	261.8	0.210E 06	0.202E 06	0.160E 08	34.1
2133.1	26.2	235.3	235.1	267.0	266.6	0.242E 06	0.232E 06	0.185E 08	39.3
2336.8	25.3	235.1	234.9	265.7	265.4	0.234E 06	0.225E 06	0.179E 08	38.1
2531.5	25.1	235.1	234.9	265.6	265.2	0.233E 06	0.223E 06	0.177E 08	37.8
2694.9	24.4	234.9	234.7	264.5	264.1	0.226E 06	0.217E 06	0.172E 08	36.7
2857.7	24.5	234.9	234.8	264.6	264.2	0.226E 06	0.217E 06	0.173E 08	36.8
3012.3	23.4	234.7	234.5	263.1	262.8	0.217E 06	0.208E 06	0.165E 08	35.2
3166.8	23.5	234.7	234.5	263.1	262.8	0.217E 06	0.208E 06	0.166E 08	35.3
3322.5	24.3	234.4	234.2	261.5	261.2	0.225E 06	0.216E 06	0.171E 08	36.5
3415.4	23.4	234.2	234.0	260.3	260.0	0.216E 06	0.208E 06	0.165E 08	35.2
3463.4	23.6	234.2	234.1	260.6	260.3	0.218E 06	0.209E 06	0.166E 08	35.4
3608.6	23.5	234.2	234.1	260.5	260.2	0.218E 06	0.209E 06	0.166E 08	35.4
3720.3	23.2	234.2	234.0	260.1	259.8	0.215E 06	0.206E 06	0.164E 08	34.9
3786.3	22.7	234.1	233.9	259.4	259.1	0.210E 06	0.201E 06	0.160E 08	34.1
3897.4	21.5	233.8	233.7	257.8	257.6	0.199E 06	0.191E 06	0.152E 08	32.3
4008.0	21.5	233.8	233.7	257.8	257.6	0.199E 06	0.191E 06	0.152E 08	32.3
4120.4	20.4	233.6	233.5	256.4	256.2	0.189E 06	0.181E 06	0.144E 08	30.7
4232.1	21.4	233.8	233.7	257.8	257.5	0.198E 06	0.190E 06	0.151E 08	32.2
4284.1	20.8	233.7	233.6	257.0	256.7	0.193E 06	0.185E 06	0.147E 08	31.3
4491.5	20.2	234.4	234.3	258.9	258.6	0.187E 06	0.180E 06	0.143E 08	30.4
4674.0	23.5	235.1	234.9	263.5	263.2	0.217E 06	0.208E 06	0.166E 08	35.3
4715.9	21.9	234.6	234.5	261.2	260.9	0.203E 06	0.195E 06	0.155E 08	33.0
4865.4	22.3	234.7	234.5	261.7	261.4	0.206E 06	0.198E 06	0.157E 08	33.5
AVERAGE	22.6			253.3	253.0	0.210E 06	0.201E 06		34.0

ROTAH FOR A 2 TUBE ELEMENT TWNT-5

```
0.11400 0.95000 0.65600 0.43100 0.22400 0.62500 0.45500 0.20600 0.42400
0.42860 1.43000 0.00208 0.57140 2.23000 0.00208 0.47060 3.70000 0.00208 0.52940 4.48000 0.00208
0.02020 0.01110 0.01064 0.04420 0.01080 0.02393
```

ELEMENT TWNT-5 DATE 10/25/62 DEL T 16.7 FLOW 106. INLET 238.2 POWER 0.469

	CHANNEL TEMPERATURE			******************SURFACE CONDITIONS INSIDE TO OUTSIDE******************							
	INNER	INTER	OUTER	TEMP	HEAT FLUX	TEMP	HEAT FLUX	TEMP	HEAT FLUX	TEMP	HEAT FLUX
1	238.2	238.2	238.2	238.5	0.134E 04	238.5	0.115E 04	238.5	0.140E 04	238.5	0.130E 04
2	238.2	238.2	238.2	239.5	0.532E 04	239.4	0.455E 04	239.6	0.557E 04	239.4	0.517E 04
3	238.3	238.3	238.3	240.6	0.987E 04	240.4	0.844E 04	240.9	0.103E 05	240.6	0.959E 04
4	238.5	238.5	238.4	242.0	0.152E 05	241.7	0.130E 05	242.5	0.159E 05	241.9	0.148E 05
5	238.7	238.7	238.6	243.6	0.217E 05	243.3	0.185E 05	244.4	0.227E 05	243.5	0.211E 05
6	239.0	239.0	238.8	245.7	0.293E 05	245.3	0.250E 05	246.7	0.306E 05	245.5	0.285E 05
7	239.4	239.5	239.1	248.1	0.383E 05	247.6	0.327E 05	249.4	0.401E 05	247.9	0.372E 05
8	239.9	240.0	239.5	251.1	0.489E 05	250.4	0.418E 05	252.7	0.512E 05	250.7	0.476E 05
9	240.5	240.7	240.0	254.7	0.617E 05	253.8	0.527E 05	256.7	0.645E 05	254.1	0.600E 05
10	241.4	241.6	240.6	259.1	0.776E 05	258.1	0.663E 05	261.7	0.811E 05	258.4	0.754E 05
11	242.4	242.7	241.4	265.1	0.993E 05	263.8	0.849E 05	268.5	0.104E 06	264.1	0.965E 05
12	243.7	244.1	242.4	272.8	0.127E 06	271.1	0.109E 06	277.1	0.133E 06	271.5	0.123E 06
13	245.4	245.8	243.7	279.1	0.147E 06	277.1	0.126E 06	284.1	0.154E 06	277.4	0.143E 06
14	247.2	247.8	245.0	283.1	0.157E 06	281.1	0.134E 06	288.6	0.164E 06	281.0	0.153E 06
15	249.0	249.8	246.4	285.0	0.157E 06	283.1	0.134E 06	290.6	0.164E 06	282.4	0.153E 06
16	250.8	251.7	247.8	284.7	0.148E 06	283.2	0.127E 06	290.2	0.155E 06	281.7	0.144E 06
17	252.5	253.4	249.1	282.5	0.131E 06	281.4	0.112E 06	287.6	0.137E 06	279.2	0.128E 06
18	253.9	255.0	250.2	278.7	0.109E 06	278.0	0.929E 05	283.2	0.114E 06	275.0	0.106E 06
19	255.0	256.2	251.0	273.8	0.822E 05	273.6	0.703E 05	277.5	0.860E 05	269.8	0.799E 05
20	255.8	257.0	251.6	268.4	0.551E 05	268.7	0.471E 05	271.3	0.577E 05	264.2	0.536E 05
21	256.3	257.6	252.0	263.4	0.309E 05	264.1	0.264E 05	265.6	0.323E 05	259.1	0.300E 05

	*************INNER FUEL PIECE************					**************OUTER FUEL PIECE************				
	SHAPE	EXPOSURE	POWER	CORETEMP	HEAT GEN	SHAPE	EXPOSURE	POWER	CORETEMP	HEAT GEN
1	0.005	0.3	0.2	239.0	0.221E 06	0.012	0.4	0.2	239.1	0.249E 06
2	0.020	1.3	0.9	241.5	0.879E 06	0.049	1.5	1.0	241.8	0.991E 06
3	0.037	2.5	1.6	244.4	0.163E 07	0.091	2.7	1.8	244.9	0.184E 07
4	0.057	3.8	2.5	247.9	0.252E 07	0.141	4.2	2.8	248.7	0.284E 07
5	0.081	5.4	3.6	252.0	0.358E 07	0.201	6.0	3.9	253.2	0.403E 07
6	0.110	7.4	4.8	257.0	0.484E 07	0.271	8.1	5.3	258.5	0.545E 07
7	0.144	9.6	6.3	262.9	0.632E 07	0.354	10.5	6.9	264.9	0.713E 07
8	0.184	12.3	8.1	270.0	0.808E 07	0.453	13.5	8.9	272.5	0.911E 07
9	0.232	15.5	10.2	278.4	0.102E 08	0.571	17.0	11.2	281.5	0.115E 08
10	0.291	19.5	12.8	288.9	0.128E 08	0.718	21.4	14.1	292.8	0.144E 08
11	0.373	24.9	16.4	303.1	0.164E 08	0.919	27.3	18.0	308.0	0.185E 08
12	0.477	31.9	21.0	321.2	0.210E 08	1.176	35.0	23.0	327.4	0.236E 08
13	0.553	37.0	24.4	335.0	0.243E 08	1.364	40.6	26.7	342.1	0.274E 08
14	0.590	39.4	26.0	342.6	0.259E 08	1.453	43.2	28.5	350.0	0.292E 08
15	0.590	39.4	26.0	344.6	0.259E 08	1.454	43.3	28.5	351.7	0.292E 08
16	0.556	37.2	24.5	341.1	0.245E 08	1.372	40.8	26.9	347.6	0.276E 08
17	0.493	33.0	21.8	332.7	0.217E 08	1.216	36.2	23.8	338.1	0.245E 08
18	0.408	27.3	18.0	320.5	0.179E 08	1.005	29.9	19.7	324.5	0.202E 08
19	0.309	20.7	13.6	305.7	0.136E 08	0.761	22.6	14.9	308.2	0.153E 08
20	0.207	13.8	9.1	290.1	0.910E 07	0.510	15.2	10.0	291.0	0.103E 08
21	0.116	7.8	5.1	275.9	0.510E 07	0.286	8.5	5.6	275.4	0.575E 07

CHAN EFF 257.6 SURF TEMP 290.6 CORE TEMP 351.7 HEAT FLUX 164320.

APPENDIX C

APPENDIX C

TIME WEIGHTED AVERAGE VALUES FOR ELEMENT TWNT-5

	****************SURFACE CONDITIONS INSIDE TO OUTSIDE							****************	INNER FUEL TUBE		OUTER FUEL TUBE	
	TEMP	HEAT FLUX	TEMP	HEAT FLUX	TEMP	HEAT FLUX	TEMP	HEAT FLUX	POWER	COR TEMP	POWER	COR TEMP
1	237.6	0.204E 04	237.5	0.175E 04	237.6	0.214E 04	237.6	0.199E 04	0.3	238.3	0.4	238.5
2	239.0	0.816E 04	238.9	0.698E 04	239.3	0.854E 04	239.0	0.793E 04	1.4	242.2	1.5	242.6
3	240.8	0.153E 05	240.5	0.131E 05	241.3	0.160E 05	240.7	0.149E 05	2.5	246.7	2.8	247.5
4	243.0	0.241E 05	242.7	0.206E 05	243.8	0.252E 05	242.9	0.234E 05	4.0	252.4	4.4	253.6
5	245.9	0.352E 05	245.4	0.301E 05	247.1	0.368E 05	245.7	0.342E 05	5.8	259.5	6.4	261.3
6	249.6	0.493E 05	248.9	0.421E 05	251.3	0.516E 05	249.3	0.479E 05	8.2	268.7	8.9	271.2
7	254.7	0.682E 05	253.7	0.583E 05	256.9	0.714E 05	254.2	0.663E 05	11.3	280.9	12.4	284.4
8	261.6	0.943E 05	260.3	0.806E 05	264.8	0.987E 05	260.9	0.917E 05	15.6	297.7	17.1	302.5
9	269.1	0.122E 06	267.4	0.104E 06	273.2	0.127E 06	268.2	0.118E 06	20.1	315.5	22.1	321.7
10	275.6	0.143E 06	273.6	0.122E 06	280.4	0.150E 06	274.2	0.139E 06	23.6	329.8	25.9	336.9
11	280.8	0.158E 06	278.8	0.135E 06	286.3	0.166E 06	279.1	0.154E 06	26.2	340.8	28.7	348.5
12	284.9	0.168E 06	282.8	0.143E 06	290.8	0.175E 06	282.7	0.163E 06	27.7	348.4	30.4	356.4
13	287.6	0.171E 06	285.6	0.146E 06	293.7	0.179E 06	284.9	0.166E 06	28.2	352.2	31.0	360.1
14	288.7	0.167E 06	286.9	0.143E 06	294.9	0.175E 06	285.6	0.162E 06	27.6	352.0	30.3	359.4
15	288.3	0.157E 06	286.8	0.134E 06	294.3	0.164E 06	284.7	0.152E 06	25.9	347.9	28.4	354.6
16	286.5	0.141E 06	285.3	0.120E 06	292.1	0.147E 06	282.4	0.137E 06	23.3	340.2	25.6	345.9
17	283.3	0.120E 06	282.6	0.103E 06	288.4	0.126E 06	278.9	0.117E 06	19.9	329.5	21.8	333.8
18	279.1	0.965E 05	278.9	0.825E 05	283.5	0.101E 06	274.4	0.939E 05	16.0	316.5	17.5	319.4
19	274.4	0.715E 05	274.7	0.611E 05	278.1	0.748E 05	269.4	0.695E 05	11.8	302.4	13.0	303.8
20	269.5	0.471E 05	270.2	0.403E 05	272.5	0.493E 05	264.4	0.458E 05	7.8	288.3	8.6	288.3
21	265.2	0.262E 05	266.2	0.224E 05	267.5	0.275E 05	259.9	0.255E 05	4.3	276.0	4.8	274.8

VARIABLES VS SPECIFIC EXPOSURE   TWNT-5   LAYER 15

INNER FUEL							OUTER FUEL						
EXPOSURE	CORE TEMP	POWER	SURF TEMP		SURFACE HEAT FLUX		EXPOSURE	CORE TEMP	POWER	SURF TEMP		SURFACE HEAT FLUX	
39.4	344.6	26.0	285.0	283.1	0.157E 06	0.134E 06	43.3	351.7	28.5	290.6	282.4	0.164E 06	0.153E 06
200.4	352.3	26.7	291.0	289.5	0.161E 06	0.138E 06	219.7	359.1	29.3	297.1	287.2	0.169E 06	0.157E 06
336.0	349.3	26.0	289.6	288.2	0.157E 06	0.134E 06	368.4	355.8	28.5	295.6	285.7	0.164E 06	0.153E 06
532.5	346.5	25.4	288.1	286.7	0.153E 06	0.131E 06	584.2	353.1	27.9	294.0	284.6	0.161E 06	0.149E 06
687.7	345.9	25.9	286.3	284.8	0.156E 06	0.134E 06	754.7	352.6	28.4	292.3	282.8	0.164E 06	0.152E 06
800.8	346.5	25.8	287.3	285.8	0.156E 06	0.133E 06	879.0	353.3	28.3	293.4	283.8	0.163E 06	0.152E 06
AVERAGE	347.9	25.9	288.3	286.8	0.157E 06	0.134E 06		354.6	28.4	294.3	284.7	0.164E 06	0.152E 06

```
C  VANDERVELDE COST CODE 8370    S-11 ROTAH-1
C
   1 FORMAT(28H1 ROTAH FOR A SINGLE ELEMENT   ,2A6///)
C
   2 FORMAT(2A6,4I2)
   3 FORMAT(8F9.5)
 103 FORMAT(12F9.5)
   4 FORMAT(I3,3A6,5F6.2)
   5 FORMAT(7F10.4)
   6 FORMAT(9H1ELEMENT ,2A6,7H  DATE ,3A6,7H  DEL T,F5.1,6H  FLOW,F5.0,
    17H  INLET,F6.1,7H  POWER,F6.3  ///)
   7 FORMAT(I3,F7.3,F10.3,F7.1,F8.1,F7.1,F8.1,F7.1,E12.3,E11.3,E12.3,
    1 F7.1)
   8 FORMAT(I3,F7.3,F10.1,F7.1,F8.1,F7.1,F8.1,F7.1,E12.3,E11.3,E12.3,
    1 F7.1)
 108 FORMAT(10X     ,F10.1,F7.1,F8.1,F7.1,F8.1,F7.1,E12.3,E11.3,E12.3,
    1 F7.1)
 118 FORMAT(10X     ,F10.3,F7.1,F8.1,F7.1,F8.1,F7.1,E12.3,E11.3,E12.3,
    1 F7.1)
  10 FORMAT(99H      POWER  SPECIFIC   CORE      CHANNEL       SURFACE
    1          SURFACE          VOL HEAT    SPEC  /
    2        99H      SHAPE  EXPOSURE   TEMP    TEMPERATURE    TEMPERATUR
    3E    .....HEAT FLUX......  GENERATION  POWER //)
 110 FORMAT(99H             SPECIFIC   CORE      CHANNEL       SURFACE
    1          SURFACE          VOL HEAT    SPEC  /
    2        99H             EXPOSURE   TEMP    TEMPERATURE    TEMPERATUR
    3E    .....HEAT FLUX......  GENERATION  POWER //)
   9 FORMAT(99H      POWER  SPECIFIC   K D       CHANNEL       SURFACE
    1          SURFACE          VOL HEAT    SPEC  /
    2        99H      SHAPE  EXPOSURE  THETA    TEMPERATURE    TEMPERATUR
    3E    .....HEAT FLUX......  GENERATION  POWER //)
 109 FORMAT(99H             SPECIFIC   K D       CHANNEL       SURFACE
    1          SURFACE          VOL HEAT    SPEC  /
    2        99H             EXPOSURE  THETA    TEMPERATURE    TEMPERATUR
    3E    .....HEAT FLUX......  GENERATION  POWER //)
  11 FORMAT(I3,F7.1,F8.1,F7.1,E12.3,E11.3,F7.1)
 111 FORMAT(8H0AVERAGE,12X,F7.1,15X,F8.1,F7.1,E12.3,E11.3,12X,F7.1)
  12 FORMAT(1H0/// 9H CHAN EFF,F6.1,11H  SURF TEMP,F6.1,11H  K D THETA,
    1F6.2,11H  HEAT FLUX,F9.0)
  13 FORMAT(1H0/// 9H CHAN EFF,F6.1,11H  SURF TEMP,F6.1,11H  CORE TEMP,
    1F6.1,11H  HEAT FLUX,F9.0)
  14 FORMAT(42H1 TIME WEIGHTED AVERAGE VALUES FOR ELEMENT ,2A6///)
  16 FORMAT(55H      CORE     SURFACE          SURFACE          SPEC
    1   /  55H      TEMP    TEMPERATURE    .....HEAT FLUX......  POWER
    2 //)
  15 FORMAT(55H      K D      SURFACE          SURFACE          SPEC
    1   /  55H     THETA    TEMPERATURE    .....HEAT FLUX......  POWER
    2 //)
  17 FORMAT(32H1 VARIABLES VS SPECIFIC EXPOSURE,2A6,6H LAYER,I3 ///)
  18 FORMAT(15H1END OF PROBLEM  ////// )
     DIMENSION H(2),FSPLIT(2),VEL(2),HSPLIT(2),AREA(2),DIAM(2),CLAD(2),
    1Z(21),DUM(8,21),       ENX(21),SPEX(21),EMX(21),TCHAN(21,2),HFLUX(
    221,2),SURFT(21,2),FTINT(21,2),AVTINT(21   ),GEN(21   ),TCORE(21   ),
    3SPEPOW(21),X( 8,21),A1(21),A2(21),Y(10,21,75),Q(10,21,33)
  69 DUM3=0.
     DO 75 J=1,21
```

```
      DO 71 L=1,8
   71 X(L,J)=0.
      DO 72 L=1,2
   72 TCHAN(J,L)=0.
      DO 73 L=1,2
      HFLUX(J,L)=0.
      SURFT(J,L)=0.
   73 FTINT(J,L)=0.
      AVTINT(J  )=0.
      GEN(J   )=0.
      TCORE(J   )=0.
      DO 74 L=1,10
      DO 74 K=1,99
   74 Y(L,J,K)=0
   75 CONTINUE
      K1=0
C  ITYPE=0 FOR OXIDE
C  ITYPE=1 FOR URANIUM
C  ITYPE=2 FOR ZIRCALOY
C  ITYPE=3 FOR THORIUM
   20 READ 2,W1,W2,ITYPE
      READ 3,(H(L),FSPLIT(L),VEL(L),DIAM(L),L=1,2)
      READ 3,(HSPLIT(L),AREA(L),          CLAD(L),L=1,2)
      READ 3,CON,VOL,CORE,TON
      WRITEOUTPUTTAPE10,1,W1,W2
      WRITEOUTPUTTAPE10,103,(H(L),FSPLIT(L),VEL(L),DIAM(L),L=1,2)
      WRITEOUTPUTTAPE10,103,(HSPLIT(L),AREA(L),CLAD(L),L=1,2)
      WRITEOUTPUTTAPE10,103,CON,VOL,CORE,TON
   21 READ 4,KEY,D1,D2,D3,DELTAT,FLOW,TIN,TSAT,TIME
      IF(KEY)220,70,22
   22 IF(KEY-2)218,70,20
  218 READ 5,(ENX(J),J=1,21)
      READ 5,(SPEX(J),J=1,21)
      SUM=0.
      DUM2=0.
      K1=K1+1
      IF(ENX(21))230,230,245
  230 CONTINUE
C     SOT 7-2 ROUTUNE
      DO 231 J=1,3,2
      F1=ENX(J+1)-ENX(J)
      F2=ENX(J+2)-ENX(J)
      A1(J)=2.*F1-.5*F2
      A2(J)=.5*F2-F1
  231 SUM=SUM+2.*ENX(J)+2.*A1(J)+8.*A2(J)/3.
      DO 232 J=6,8,2
      F1=ENX(J+1)-ENX(J)
      F2=ENX(J+2)-ENX(J)
      A1(J)=2.*F1-.5*F2
      A2(J)=.5*F2-F1
  232 SUM=SUM+2.*ENX(J)+2.*A1(J)+8.*A2(J)/3.
      DO 233 J=11,15,2
      F1=ENX(J+1)-ENX(J)
      F2=ENX(J+2)-ENX(J)
      A1(J)=2.*F1-.5*F2
      A2(J)=.5*F2-F1
```

```
233 SUM=SUM+2.*ENX(J)+2.*A1(J)+8.*A2(J)/3.
    DO 241 J=1,3,2
    DUM1=DUM2+ENX(J)+A1(J)/2.+A2(J)/3.
    DUM2=DUM2+2.*ENX(J)+2.*A1(J)+8.*A2(J)/3.
    EMX(J+1)=DUM1/SUM
241 EMX(J+2)=DUM2/SUM
    EMX(6)=EMX(5)
    DO 242 J=6,8,2
    DUM1=DUM2+ENX(J)+A1(J)/2.+A2(J)/3.
    DUM2=DUM2+2.*ENX(J)+2.*A1(J)+8.*A2(J)/3.
    EMX(J+1)=DUM1/SUM
242 EMX(J+2)=DUM2/SUM
    EMX(11)=EMX(10)
    DO 243 J=11,15,2
    DUM1=DUM2+ENX(J)+A1(J)/2.+A2(J)/3.
    DUM2=DUM2+2.*ENX(J)+2.*A1(J)+8.*A2(J)/3.
    EMX(J+1)=DUM1/SUM
243 EMX(J+2)=DUM2/SUM
    DO 244 J=18,21
244 EMX(J)=1.0
C   END SOT 7-2
    GO TO 246
245 CONTINUE
    DO 23 J=1,19,2
    F1=ENX(J+1)-ENX(J)
    F2=ENX(J+2)-ENX(J)
    A1(J)=2.*F1-.5*F2
    A2(J)=.5*F2-F1
 23 SUM=SUM+2.*ENX(J)+2.*A1(J)+8.*A2(J)/3.
    DO 24 J=1,19,2
    DUM1=DUM2+ENX(J)+A1(J)/2.+A2(J)/3.
    DUM2=DUM2+2.*ENX(J)+2.*A1(J)+8.*A2(J)/3.
    EMX(J+1)=DUM1/SUM
 24 EMX(J+2)=DUM2/SUM
246 CONTINUE
    EFFMAX=0.
    SURMAX=0.
    CORMAX=0.
    HFLXMX=0.
    DO 27 L=1,2
    DO 25 J=1,21
 25 TCHAN(J,L)=TIN+DELTAT*EMX(J)*(H(L)/FSPLIT(L))
    IF(EFFMAX-TCHAN(21,L))26,26,27
 26 EFFMAX=TCHAN(21,L)
 27 CONTINUE
    DO 37 L=1,2
    DO 37 J=1,21
    HFLUX(J,L)=(DELTAT*FLOW*502.)*(HSPLIT(L)/AREA(L))*ENX(J)
    IF(HFLXMX-HFLUX(J,L))31,32,32
 31 HFLXMX=HFLUX(J,L)
 32 CONTINUE
    SURFT(J,L)=TCHAN(J,L )+HFLUX(J,L)*DIAM(L )**.2/(570.*(FLOW*VEL(L )
   1*FSPLIT(L ))**.8)
    TDUM=TSAT+10.-SURFT(J,L)
    IF(TDUM)33,34,34
 33 SURFT(J,L)=TSAT+10.
```

```
34 CONTINUE
   IF(SURMAX-SURFT(J,L))35,36,36
35 SURMAX=SURFT(J,L)
36 CONTINUE
   FTINT(J,L)=1000.*(SQRTF(60.84+.000001*SURFT(J,L)**2+.0156*SURFT
  1(J,L)+.002*HFLUX(J,L)*CLAD(L))-7.8)
37 CONTINUE
   DO 51 J=1,21
40 AVTINT(J  )=(FTINT(J,1)+FTINT(J,2))/2.
41 CONTINUE
   GEN(J  )=(DELTAT*FLOW*502.)*(CON   /VOL   )*ENX(J)
   IF(ITYPE-1)42,46,47
42 D=8.
45 TCORE(J  )=GEN(J  )*CORE   **2/(57.8*D)
   GO TO 49
46 E=111.2
   F=.08/3.
   GO TO 48
47 IF(ITYPE-3)44,43,43
44 E=49.6
   F=.04/3.
   GO TO 48
43 E=170.2
   F=.0582/3.
48 CONTINUE
   TCORE(J  )=((F*AVTINT(J  )-E)+SQRTF((F*AVTINT(J  )-E)**2+8.*F*(
  1E*AVTINT(J  )+F*AVTINT(J  )**2.+GEN(J  )*CORE   **2)))/(4.*F)
49 CONTINUE
   IF(CORMAX-TCORE(J  ))50,51,51
50 CORMAX=TCORE(J)
51 CONTINUE
   POW=DELTAT*FLOW*.000265*CON
   DO 52 J=1,21
   SPEPOW(J)=ENX(J)*(POW/TON)
52 CONTINUE
   WRITEOUTPUTTAPE10,6,W1,W2,D1,D2,D3,DELTAT,FLOW,TIN,POW
   IF(ITYPE)53,53,54
53 WRITEOUTPUTTAPE10,9
   GO TO 55
54 WRITEOUTPUTTAPE10,10
   IF(ITYPE-2)55,80,55
80 WRITEOUTPUTTAPE10,7,(J,ENX(J),SPEX(J),TCORE(J),(TCHAN(J,L),L=1,2),
  1(SURFT(J,L),L=1,2),(HFLUX(J,L),L=1,2),GEN(J),SPEPOW(J),J=1,21)
   GO TO 81
55 WRITEOUTPUTTAPE10,8,(J,ENX(J),SPEX(J),TCORE(J),(TCHAN(J,L),L=1,2),
  1(SURFT(J,L),L=1,2),(HFLUX(J,L),L=1,2),GEN(J),SPEPOW(J),J=1,21)
81 CONTINUE
   IF(ITYPE)56,56,57
56 WRITEOUTPUTTAPE10,12,EFFMAX,SURMAX,CORMAX,HFLXMX
   GO TO 58
57 WRITEOUTPUTTAPE10,13,EFFMAX,SURMAX,CORMAX,HFLXMX
58 CONTINUE
   DO 61 J=1,21
   X(1,J)=X(1,J)+TIME*SPEPOW(J)
   X(8   ,J)=X(8   ,J)+TIME*TCORE(J)
   Y(1 ,J,K1)=SPEX(J)
```

```
      Y(2 ,J,K1)=TCORE(J)
      Y(9 ,J,K1)=GEN(J)
      Y(10,J,K1)=SPEPOW(J)
      DO 59 L=1,2
      Y(L+2,J,K1)=TCHAN(J,L)
      Y(L+4,J,K1)=SURFT(J,L)
      Y(L+6,J,K1)=HFLUX(J,L)
      X(L+1,J)=X(L+1,J)+TIME*SURFT(J,L)
      X(L+5,J)=X(L+5,J)+TIME*FTINT(J,L)
   59 X(L+3,J)=X(L+3,J)+TIME*HFLUX(J,L)
   61 CONTINUE
      DUM3=DUM3+TIME
      GO TO 21
  220 D=.868275
      Z(1)=3.6345
      DO 221 J=2,20
  221 Z(J)=Z(J-1)+D
      Z(21)=21.
      DO 229 J=1,21
      B=3.
  223 B=B+1.
      IF(Z(J)-B)224,225,223
  224 D=Z(J)-B+2.
      K=B-1.
      GO TO 227
  225 K=B
      DO 226 L=1,8
  226 DUM(L,J)=X(L,J)
      DO 236 N=1,K1
      DO 236 L=1,10
  236 Q(L,J,N)=Y(L,J,N)
      GO TO 229
  227 CONTINUE
      DO 228 L=1,8
      B1=-.5*X(L,K+1)+2.*X(L,K)-1.5*X(L,K-1)
      B2= .5*X(L,K+1)-   X(L,K)+ .5*X(L,K-1)
  228 DUM(L,J)=X(L,K-1)+B1*D+B2*D*D
      DO 238 N=1,K1
      DO 238 L=1,10
      B1=-.5*Y(L,K+1,N)+2.*Y(L,K,N)-1.5*Y(L,K-1,N)
      B2= .5*Y(L,K+1,N)-   Y(L,K,N)+ .5*Y(L,K-1,N)
  238 Q(L,J,N)=Y(L,K-1,N)+B1*D+B2*D*D
  229 CONTINUE
      DO 222 J=1,21
      DO 237 N=1,K1
      DO 237 L=1,10
  237 Y(L,J,N)=Q(L,J,N)
      DO 222 L=1,8
  222 X(L,J)=DUM(L,J)
   70 CONTINUE
      DO 64 J=1,21
      SPEPOW(J)=X(1,J)/DUM3
      DO 62 L=1,2
      SURFT(J,L)=X(L+1,J)/DUM3
      FTINT(J,L)=X(L+5,J)/DUM3
      HFLUX(J,L)=X(L+5,J)/DUM3
```

```
 62 CONTINUE
    TCORE(J   )=X(8    ,J)/DUM3
 64 CONTINUE
    WRITEOUTPUTTAPE10,14,W1,W2
    IF(ITYPE)65,65,66
 65 WRITEOUTPUTTAPE10,15
    GO TO 67
 66 WRITEOUTPUTTAPE10,16
 67 WRITEOUTPUTTAPE10,11,(J,TCORE(J),(SURFT(J,L),L=1,2),(HFLUX(J,L),
   1 L=1,2),SPEPOW(J),J=1,21)
    IF(KEY)21,219,21
219 CONTINUE
    DO 76 J=1,21
    WRITEOUTPUTTAPE10,17,W1,W2,J
    IF(ITYPE)77,77,78
 77 WRITEOUTPUTTAPE10,109
    GO TO 179
 78 WRITEOUTPUTTAPE10,110
179 IF(ITYPE-2)79,180,79
180 WRITEOUTPUTTAPE10,118,((Y(L,J,N),L=1,10),N=1,K1)
    GO TO 181
 79 WRITEOUTPUTTAPE10,108,((Y(L,J,N),L=1,10),N=1,K1)
181 WRITEOUTPUTTAPE10,111,   TCORE(J),(SURFT(J,L),L=1,2),(HFLUX(J,L),
   1 L=1,2),SPEPOW(J)
 76 CONTINUE
    READ 4,KEY
    IF(KEY)20,68,69
 68 CONTINUE
    WRITEOUTPUTTAPE10,18
    END(2,0,0,0,1)
```

```
C       VANDERVELDE  COST CODE 8370                                    ROTAH-2
C
C         2T-7
C
    1 FORMAT(28H1 ROTAH FOR A 2 TUBE ELEMENT  ,2A6///)
C
C
    2 FORMAT(2A6,4I2)
    3 FORMAT(12F6.4)
    4 FORMAT(I3,3A6,5F6.2)
    5 FORMAT(7F10.4)
    6 FORMAT(9H1ELEMENT ,2A6,7H  DATE ,3A6,7H  DEL T,F5.1,6H  FLOW,F5.0,
     17H  INLET,F6.1,7H  POWER,F6.3  //)
    7 FORMAT(99H     CHANNEL TEMPERATURE  *****************SURFACE COND
     1ITIONS INSIDE TO OUTSIDE******************  /
     2       99H      INNER INTER OUTER    TEMP  HEAT FLUX    TEMP  HEAT
     3 FLUX    TEMP  HEAT FLUX    TEMP  HEAT FLUX     //  )
    8 FORMAT(I3,F8.1,2F6.1,F8.1,E11.3,F8.1,E11.3,F8.1,E11.3,F8.1,E11.3)
    9 FORMAT(1H0/ 96H      *************INNER FUEL PIECE*************
     1 **************OUTER FUEL PIECE*************    /
     2            96H      SHAPE  EXPOSURE  POWER  KD THETA  HEAT GEN
     3 SHAPE  EXPOSURE  POWER  KD THETA  HEAT GEN   //)
   10 FORMAT(1H0/ 96H      *************INNER FUEL PIECE*************
     1 **************OUTER FUEL PIECE*************    /
     2            96H      SHAPE  EXPOSURE  POWER  CORETEMP  HEAT GEN
     3 SHAPE  EXPOSURE  POWER  CORETEMP  HEAT GEN   //)
   11 FORMAT(I3,F7.3,F10.1,F7.1,F10.1,E11.3,F10.3,F10.1,F7.1,F10.1,E11.3
     1)
   12 FORMAT(1H0/   9H CHAN EFF,F6.1,11H  SURF TEMP,F6.1,11H  K D THETA,
     1F6.2,11H  HEAT FLUX,F9.0)
   13 FORMAT(1H0/   9H CHAN EFF,F6.1,11H  SURF TEMP,F6.1,11H  CORE TEMP,
     1F6.1,11H  HEAT FLUX,F9.0)
   14 FORMAT(42H1 TIME WEIGHTED AVERAGE VALUES FOR ELEMENT ,2A6///)
   15 FORMAT(114H      *****************SURFACE CONDITIONS INSIDE TO OUT
     1SIDE******************  INNER FUEL TUBE   OUTER FUEL TUBE  /
     2       114H      TEMP  HEAT FLUX    TEMP  HEAT FLUX    TEMP  HEAT
     3FLUX    TEMP  HEAT FLUX  POWER  KD THETA   POWER  KD THETA  //)
   16 FORMAT(114H      *****************SURFACE CONDITIONS INSIDE TO OUT
     1SIDE******************  INNER FUEL TUBE   OUTER FUEL TUBE  /
     2       114H      TEMP  HEAT FLUX    TEMP  HEAT FLUX    TEMP  HEAT
     3FLUX    TEMP  HEAT FLUX  POWER  COR TEMP   POWER  COR TEMP  //)
   17 FORMAT(I3,F7.1,E11.3,F8.1,E11.3,F8.1,E11.3,F8.1,E11.3,F8.1,F10.1,
     1F8.1,F10.1)
   18 FORMAT(15H1END OF PROBLEM  ////// )
   19 FORMAT(12F9.5)
  108 FORMAT(32H1 VARIABLES VS SPECIFIC EXPOSURE,2A6,6H LAYER,I3)
  109 FORMAT(117H ***********************INNER FUEL*******************
     1***  ***********************OUTER FUEL********************** /
     2       117H EXPOSURE  KD THETA  POWER   SURF TEMP   SURFACE HEAT F
     3LUX  EXPOSURE  KD THETA  POWER   SURF TEMP   SURFACE HEAT FLUX )
  110 FORMAT(2F9.1,F8.1,F7.1,F6.1,2E10.3,2F9.1,F8.1,F7.1,F6.1,2E10.3)
  111 FORMAT(      9H AVERAGE  ,F9.1,F8.1,F7.1,F6.1,2E10.3,9X,F9.1,F8.1,
     1F7.1,F6.1,2E10.3 )
  119 FORMAT(117H ***********************INNER FUEL*******************
     1***  ***********************OUTER FUEL********************** /
     2       117H EXPOSURE CORE TEMP  POWER   SURF TEMP   SURFACE HEAT F
```

```
      3LUX  EXPOSURE CORE TEMP  POWER   SURF TEMP   SURFACE HEAT FLUX //)
       DIMENSION FSPLIT(3),VEL(3),DIAM(3),HSPLIT(4),AREA(4),CLAD(4),VOL
      1(2),CORE(2),ENX(21,2),SPEX(21,2),A1(21,2),A2(21,2),DUM2(2),EMX(21,
      22),DUM1(2),TCHAN(21,3),HFLUX(21,4),SURFT(21,4),FTINT(21,4),AVTINT
      3(2),GEN(21,2),TCORE(21,2),SPEPOW(21,2),X(12,21),TON(2),Y(21,14,53)
       COMMON FSPLIT,VEL,DIAM,HSPLIT,AREA,CLAD,VOL,CORE,ENX,SPEX,A1,A2,
      1DUM2,EMX,DUM1,TCHAN,HFLUX,SURFT,FTINT,AVTINT,GEN,TCORE,SPEPOW,X,
      2TON,Y
   69 DUM3=0.
      K1=0
      DO 52 J=1,21
      DO 51 L=1,4
      X(L,J)=0.
   51 X(L+4,J)=0.
      DO 52 L=1,2
      X(L+8,J)=0.
   52 X(L+10,J)=0.
C       ITYPE=2   LIGHT METAL (METAL DRIVERS)
C       ITYPE=1   HEAVY METAL  (METAL TEST)
C       ITYPE=0   OXIDE TUBES
C       ITYPE=-1  OXIDE RODS
   20 READ 2,W1,W2,ITYPE
      READ 3,(      FSPLIT(L),VEL(L),DIAM(L),L=1,3)
      READ 3,(HSPLIT(L),AREA(L),          CLAD(L),L=1,4)
      READ   3,(VOL(L),CORE(L),TON(L),L=1,2)
      WRITEOUTPUTTAPE10,1,W1,W2
      WRITEOUTPUTTAPE10,19,(FSPLIT(L),VEL(L),DIAM(L),L=1,3)
      WRITEOUTPUTTAPE10,19,(HSPLIT(L),AREA(L),CLAD(L),L=1,4)
      WRITEOUTPUTTAPE10,19,(VOL(L),CORE(L),TON(L),L=1,2)
   21 READ 4,KEY,D1,D2,D3,DELTAT,FLOW,TIN,TSAT,TIME
      IF(KEY)20,70,22
   22 READ 5,((ENX(J,L),J=1,21),L=1,2)
      READ 5,((SPEX(J,L),J=1,21),L=1,2)
      K1=K1+1
      SUM=0.
      DUM2(1)=0
      DUM2(2)=0
      DO 23 J=1,19,2
      F1=ENX(J+1,1)-ENX(J,1)
      F2=ENX(J+2,1)-ENX(J,1)
      F3=ENX(J+1,2)-ENX(J,2)
      F4=ENX(J+2,2)-ENX(J,2)
      A1(J,1)=2.*F1-.5*F2
      A1(J,2)=2.*F3-.5*F4
      A2(J,1)=.5*F2-F1
      A2(J,2)=.5*F4-F3
   23 SUM=SUM+2.*(ENX(J,1)+ENX(J,2))+2.*(A1(J,1)+A1(J,2))+8.*(A2(J,1)+A2
     1(J,2))/3.
      DO 24 J=1,19,2
      DO 24 L=1,2
      DUM1(L)=DUM2(L)+ENX(J,L)+A1(J,L)/2.+A2(J,L)/3.
      DUM2(L)=DUM2(L)+2.*ENX(J,L)+2.*A1(J,L)+8.*A2(J,L)/3.
      EMX(J+1,L)=DUM1(L)/SUM
   24 EMX(J+2,L)=DUM2(L)/SUM
      EFFMAX=0.
      SURMAX=0.
```

```
      CORMAX=0.
      HFLXMX=0.
      POW=DELTAT*FLOW*.000265
      DO 25 J=1,21
      TCHAN(J,1)=TIN+DELTAT*EMX(J,1)*HSPLIT(1)/FSPLIT(1)
      TCHAN(J,3)=TIN+DELTAT*EMX(J,2)*HSPLIT(4)/FSPLIT(3)
   25 TCHAN(J,2)=TIN+DELTAT*(EMX(J,1)*HSPLIT(2)+EMX(J,2)*HSPLIT(3))/
     1FSPLIT(2)
      DO 27 L=1,3
      IF(EFFMAX-TCHAN(21,L))26,27,27
   26 EFFMAX=TCHAN(21,L)
   27 CONTINUE
      DO 37 L=1,4
   74 IF(L-3)28,29,29
   28 L1=L
      L2=1
      GO TO 30
   29 L1=L-1
      L2=2
   30 CONTINUE
      DO 37 J=1,21
      HFLUX(J,L)=(DELTAT*FLOW*502.)*(HSPLIT(L)/AREA(L))*ENX(J,L2)
      IF(HFLXMX-HFLUX(J,L))31,32,32
   31 HFLXMX=HFLUX(J,L)
   32 CONTINUE
      SURFT(J,L)=TCHAN(J,L1)+HFLUX(J,L)*DIAM(L1)**.2/(570.*(FLOW*VEL(L1)
     1*FSPLIT(L1))**.8)
      TDUM=TSAT+10.-SURFT(J,L)
      IF(TDUM)33,34,34
   33 SURFT(J,L)=TSAT+10.
   34 CONTINUE
      IF(SURMAX-SURFT(J,L))35,36,36
   35 SURMAX=SURFT(J,L)
   36 CONTINUE
      FTINT(J,L)=1000.*(SQRTF(60.84+.000001*SURFT(J,L)**2+.0156*SURFT
     1(J,L)+.002*HFLUX(J,L)*CLAD(L))-7.8)
   37 CONTINUE
      DO 50 J=1,21
      IF(ITYPE)39,39,38
   38 AVTINT(1)=(FTINT(J,1)+FTINT(J,2))/2.
      AVTINT(2)=(FTINT(J,3)+FTINT(J,4))/2.
   39 CONTINUE
      DO 50 L=1,2
      GEN(J,L)=(DELTAT*FLOW*502.)*ENX(J,L)/VOL(L)
      IF(ITYPE-1)40,44,45
   40 IF(ITYPE)41,42,42
   41 D=16.
      GO TO 43
   42 D=8.
   43 TCORE(J,L)=GEN(J,L)*CORE(L)**2/(57.8*D)
      GO TO 47
   44 E=111.2
      F=.026666667
      GO TO 46
   45 E=49.6
      F=.013333333
      [illegible]
```

```
46 TCORE(J,L)=((F*AVTINT(   L)-E)+SQRTF((F*AVTINT(   L)-E)**2+8.*F*(
  1E*AVTINT(   L)+F*AVTINT(   L)**2.+GEN(J,L)*CORE(L)**2)))/(4.*F)
47 CONTINUE
   IF(CORMAX-TCORE(J,L))48,49,49
48 CORMAX=TCORE(J,L)
49 CONTINUE
50 SPEPOW(J,L)=ENX(J,L)*POW/TON(L)
   WRITEOUTPUTTAPE10,6,W1,W2,D1,D2,D3,DELTAT,FLOW,TIN,POW
   WRITEOUTPUTTAPE10,7
   WRITEOUTPUTTAPE10,8,(J,(TCHAN(J,L),L=1,3),(SURFT(J,L),HFLUX(J,L),
  1L=1,4),J=1,21)
   IF(ITYPE)53,53,54
53 WRITEOUTPUTTAPE10,9
   GO TO 55
54 WRITEOUTPUTTAPE10,10
55 WRITEOUTPUTTAPE10,11,(J,(ENX(J,L),SPEX(J,L),SPEPOW(J,L),TCORE(J,L)
  1,GEN(J,L),L=1,2),J=1,21)
   IF(ITYPE)56,56,57
56 WRITEOUTPUTTAPE10,12,EFFMAX,SURMAX,CORMAX,HFLXMX
   GO TO 58
57 WRITEOUTPUTTAPE10,13,EFFMAX,SURMAX,CORMAX,HFLXMX
58 CONTINUE
   DO 61 J=1,21
   DO 59 L=1,4
   Y(J,L+10,K1)=HFLUX(J,L)
   Y(J,L+ 6,K1)=SURFT(J,L)
   X(L   ,J)=X(L   ,J)+TIME*SURFT(J,L)
59 X(L+4 ,J)=X(L+4 ,J)+TIME*HFLUX(J,L)
   DO 60 L=1,2
   Y(J,L  ,K1)=SPEX  (J,L)
   Y(J,L+2,K1)=TCORE (J,L)
   Y(J,L+4,K1)=SPEPOW(J,L)
   X(L+8 ,J)=X(L+8 ,J)+TIME*SPEPOW(J,L)
60 X(L+10,J)=X(L+10,J)+TIME*TCORE(J,L)
61 CONTINUE
   DUM3=DUM3+TIME
   GO TO 21
70 CONTINUE
   DO 64 J=1,21
   DO 62 L=1,4
   SURFT (J,L)=X(L   ,J)/DUM3
62 HFLUX (J,L)=X(L+4 ,J)/DUM3
   DO 63 L=1,2
   SPEPOW(J,L)=X(L+8 ,J)/DUM3
63 TCORE (J,L)=X(L+10,J)/DUM3
64 CONTINUE
   WRITEOUTPUTTAPE10,14,W1,W2
   IF(ITYPE)65,65,66
65 WRITEOUTPUTTAPE10,15
   GO TO 67
66 WRITEOUTPUTTAPE10,16
67 WRITEOUTPUTTAPE10,17,(J,(SURFT(J,L),HFLUX(J,L),L=1,4),(SPEPOW(J,L)
  1,TCORE(J,L),L=1,2),J=1,21)
   DO 75 J=1,21
   WRITEOUTPUTTAPE10,108,W1,W2,J
   IF(ITYPE)71,71,72
```

```
 71 WRITEOUTPUTTAPE10,109
    GO TO 73
 72 WRITEOUTPUTTAPE10,119
 73 WRITEOUTPUTTAPE10,110,(Y(J,1,K),Y(J,3,K),Y(J,5,K),(Y(J,L,K),L=7,8)
   1,(Y(J,L,K),L=11,12),    Y(J,2,K),Y(J,4,K),Y(J,6,K),(Y(J,L,K),L=9,10
   2),(Y(J,L,K),L=13,14),K=1,K1)
    WRITEOUTPUTTAPE10,111,TCORE(J,1),SPEPOW(J,1),(SURFT(J,L),L=1,2),
   1(HFLUX(J,L),L=1,2),    TCORE(J,2),SPEPOW(J,2),(SURFT(J,L),L=3,4),
   2(HFLUX(J,L),L=3,4)
 75 CONTINUE
    READ 4,KEY
    IF(KEY)20,68,69
 68 CONTINUE
    WRITEOUTPUTTAPE10,18
    PRINT 18
    END(2,0,0,0,1)
```