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COVER SHEET

DOCUMENT TITLE

Core Test Reactor Shield Cooling System Analysis

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ABSTRACT

System requirements for cooling the shield within the vacuum vessel for the core test reactor are analyzed. The total heat to be removed by the coolant system is $< 22,700$ Btu/hr, with an additional 4600 Btu/hr to be removed by the 2-inch thick steel plate below the shield. This latter heat is radiated to the walls of the vacuum chamber where the heat is removed by the cooling coils wrapped around the outside of the chamber. The maximum temperature of the concrete in the shield can be kept below 200°F if the shield plug walls are kept below 160°F . The walls of the two "donut" shaped shield segments, which are cooled by the water from the shield and vessel cooling system, should operate below 95°F . The walls of the center plug, which are cooled with nitrogen, should operate below 100°F .

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I. INTRODUCTION

The Core Test Reactor is to be suspended from a steel lined concrete shield installed within the Bldg. 059 Vacuum Chamber, see Figure 1. During operation, cooling must be provided to prevent dehydrating the concrete due to nuclear and thermal heating. This document describes the thermal analysis performed on the shield to verify that the concrete temperatures would not exceed 200°F. This analysis assumes adequate coolant will be supplied from the cooling system described in Ref. 1. The cooling system uses water to cool the two donut shaped segments and high pressure nitrogen to cool the center plug.

II. THERMAL MODEL

A thermal model was devised to represent a vertical section through the shield and through the 2-inch thick steel plate suspended below the shield. This model, which is shown schematically in Figure 2, was somewhat idealized from the actual shield in that the steps, or off-sets in the vertical members were ignored. This simplification would have a negligible effect on temperature distributions in the lower 2 ft of the shield, where most of the heat is deposited.

Another simplification used in the model was that the gaps between adjacent steel jackets were ignored. It was planned that the effects of these gaps would be studied separately, but this turned out to be unnecessary except in the NaK annulus between the

FIGURE 2. SCHEMATIC DIAGRAM OF THERMAL MODEL FOR ANALYSIS OF SHIELD TEMPERATURES

reactor vessel and the shield center plug. A discussion of heat transfer in the NaK annulus is presented in Section 4. The vertical steel members were thus three in number, the first bounded by radii 5.75 and 6.50 in., the second bounded at 24.0 and 25.0 in., and the third on the outside of the shield between 35.5 and 36.0 in. (After the model had been prepared, the shield design was changed, with the second boundary moved out to about 28.0 in. This change affects the temperatures and relative heat loads somewhat, but considering the change will decrease not increase local temperatures, it will be ignored.)

The steel plate below the shield was assumed to be thermally insulated from the shield, and thus was forced to dissipate all of the heat generated within it by thermal radiation to the walls of the test chamber. The chamber walls are cooled to $<100^{\circ}\text{F}$ by the existing shield and vessel cooling system. Radiation from the reactor vessel to the innermost part of the steel plate was included, but other radiant heat exchanges between reactor components and the plate were deemed to be of negligible magnitude.

The top of the reactor vessel was assumed to be at 1200°F , and all of the steel jackets around the concrete shield were assumed to be at 150°F , except the top cover, which was assumed to be at 100°F . This assumption about jacket temperatures was arbitrary, based on the premise that the jackets could be cooled to these temperatures or less if

sufficient coolant were supplied, see Section 3 "Expected Cooling Coil Temperatures." Since the system is nearly linear, corrections for other jacket temperatures can be made by simple addition or subtraction of temperature differences.

Thermophysical properties used in this analysis were as follows:

Material	Type 304 SST	Concrete
Density (lb/ft ³)	485	144
Specific Heat (Btu/lb-°F)	0.12	0.16
Conductivity (Btu/hr-ft-°F)	15.0	1.0
Thermal Emittance	0.2	—

The thermal computations were performed by use of the TAP-4 Thermal Analyzer Program (Ref. 2), with the addition of a special drop-in subroutine called SUB98. This subroutine computed the thermal conductance of each heat-flow path in the 427-node network. It also computed the volume of each node, and then called another subroutine, named HEAT, to compute the heat generation in each node. Subroutine HEAT was supplied with coefficients which enabled it to duplicate the heat generation values given by G. Schwab in Ref. 2. Listings of the special subroutines and the TAP IV listing for the main program are given in Appendix 1.

A contour map and node map shield temperature for a normal concrete shield are shown in Figures 3 and 4. Heat generation rates for both normal and borated concrete shield nodes are given in Figures 5 and 6. The temperature profile is for ordinary concrete. (Heat rates for borated concrete are lower, as shown in Figures 5 and 6, but temperature distributions in borated concrete have not been run.) The hottest region in the concrete was found to occur at a radius of about 14 in. and at a distance of 8 in. above the bottom of the shield. This maximum temperature is 36°F above the steel jacket temperature, or 186°F with a jacket temperature of 150°F .

The temperature of the steel plate below the shield was found to range from 560°F to 460°F , dissipating its heat load of 6000 Btu/hr by thermal radiation to the 100°F walls of the lower chamber.

The temperatures shown in Figures 3 and 4 are based on normal concrete heat generation rates, which as shown in Figures 5 and 6 are generally significantly higher than borated concrete heat generation rates. Rerunning the shield temperature distribution for the borated concrete case is not considered necessary because: (1) the calculated temperatures are all well under 200°F ; (2) the borated concrete heat generation rates are lower than those used in calculating these temperatures; and (3) as will be shown in Section 3, the effective wall temperature will be lower than the 150°F value used in this analysis.

9-29-70

NODAL TEMPERATURE DISTRIBUTION

FIGURE 4

260

151

240

157

156

155

152

220

159

158

156

153

200

162

160

157

153

180

164

162

159

154

160

167

165

161

155

140

169

167

163

152

120

170

168

164

157

100

171

169

164

158

80

170

168

165

159

60

167

166

165

162

40

161

161

162

171

20

155

153

159

162

0

1

2

3

4

INSUL

NODE 779
1200°F

Y506

Y507

INSUL

557

543

530

517

506

496

487

476

468

467

Y986

Y987

NODE 500, 100°F

11-759-230-003
10

GENERATION RATES
ARE IN BTU/HR
(ROUNDED TO NEAR-
EST WHOLE NUMBER)
A DASH (-) = < 0.5

III. EXPECTED COOLING COIL TEMPERATURES

When the thermal model described in the previous section was devised, the tentative shield coolant was gaseous nitrogen. Since that time, the coolant for the two large donut shaped shield segments has been changed to water, see Ref. 1, and only the center plug is cooled with nitrogen. The wall temperatures (150°F) used in the thermal model were those which were easily achievable with nitrogen. The vastly superior thermal capacity (density x specific heat) of water will result in a much lower ΔT and will result in a much lower effective wall temperature. With nitrogen, the expected outlet temperature was $\sim 100^\circ\text{F}$ for an inlet temperature of 60°F but an outlet temperature of 160°F was used to cover the possibility that the gas would not be pre-cooled and would enter at $100\text{--}120^\circ\text{F}$. Water will enter at a maximum temperature of 80°F and assuming all coils are operating, the water will exit at an average temperature of $< 84^\circ\text{F}$. Even if only one-half the coils are operating, the water will exit at only 87°F . The expected inlet and outlet temperatures for the center plug nitrogen coolant are 60 and 90°F , respectively. The foregoing will result in cooling coil temperatures of $80\text{--}90^\circ\text{F}$ not the 150°F used in the thermal model. The use of high wall temperatures in the thermal model results in conservative (higher than expected) concrete temperatures. The temperature rise in going from the cooling coil to the shield shell (wall) will be about 10°F . This value represents the ΔT in the wall surrounding the

NaK pipes which penetrate the shield. This should be about the most severe shield region where only one coil set is available to remove the heat input. The shield region where the core vessel passes through the shield has a higher thermal input but three coil sets are available.

The shield is penetrated by three 3-inch diameter (one inlet and two outlet) pipes which conduct the NaK coolant to and from the reactor. Each pipe passes through a conduit which is made by imbedding a 5-in. O.D. by 0.188-in. wall stainless steel tube in the concrete. Figure 7 shows a cross-section through a portion of a NaK pipe and conduit. The annular space between the pipe and the conduit is filled with insulation which for this analysis was assumed to be a multiple wrapping of 5-mil thick stainless steel foil, dimpled to minimize the area of metallic contact between layers of the wrapping. (Commercial insulations, such as Linde Superinsulation - see Ref. 4, are available which have significantly lower conductivities than those assumed in this study.)

The outside of the conduit is wrapped with a double helix of stainless steel tubing, 0.50-in. O.D. by 0.049-in. wall. The tubing is silver brazed to the conduit for good thermal contact. A helical pitch of 4 inches was selected with 2 inches separation between adjacent coils. The double helix allows the coolant to be separately valved in two paths, giving a back-up capability in case one path plugs or leaks.

FIGURE 7
SECTION THROUGH NaK PIPE, CONDUIT,
AND COOLING COILS

A thermal model was made to represent half of a coolant tube and the portion of conduit wall from which the half-tube draws heat. Figure 8 shows the model used, with temperatures at nodal points indicated. The program listing for the thermal model is presented in Appendix 2. The surface of the NaK pipe was assigned a temperature of 1220°F, corresponding to the design coolant outlet temperature for the core-test reactor. The dimpled foil wrapping between the NaK pipe and the conduit was assumed to be representable by five concentric tubes of negligible wall thickness, and having a thermal emittance of 0.2. (The actual wrapping may have more than five layers, or as mentioned previously, may be a commercial product.) There is a near-vacuum in the space between the NaK pipe and the conduit, the gas pressure being less than 0.01 torr (0.01 mm Hg) of nitrogen. At this pressure, conduction through the gas is negligible.

The heat transfer coefficient (h) on the nitrogen side of the coolant tube was calculated by use of the Colburn equation, assuming 138 lb/hr (per tube) flow of nitrogen at 125 psia and 60°F with a result: $h = 105 \text{ Btu/ft}^2\text{-hr-}^\circ\text{F}$. (Note the h for water will be $\sim 250 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$.) The conductivity of the stainless steel was taken to be $15 \text{ Btu/ft-hr-}^\circ\text{F}$, and the brazing material was assumed to have a conductivity of $60 \text{ Btu/ft-hr-}^\circ\text{F}$.

Run -13 9-01-70

HEAT FLUX, (FOR THIS CONFIGURATION,
ASSUMING 1-FT THICKNESS) =
20.43 BTU/HR

MEAN WALL TEMP. 157.15°
MEAN TUBE TEMP. 153.65°

$$\Delta T = 3.50^\circ$$

CONDUCTANCE PER
RUNNING FOOT OF THIS
CONFIGURATION (2 IN. WIDE):

$$Y = 2 \times 20.43 / 3.50 = 11.8 \text{ BTU/HR-}^\circ\text{F}$$

156	156	156	157	157	157	158	158	158	158
156	156	156	157	157	157	158	158	158	158
156	156	156	157	157	157	158	158	158	158
156	156	156	157	157	157	158	158	158	158

NaK PIPE 1220°F

1.00

FIGURE 8
THERMAL MODEL FOR ANALYSIS
OF TUBE TO WALL TEMPERATURES

5X SIZE

P. Elliott 9/70

The significance of the results of the thermal calculations made with this model, as shown in Figure 8, is that there is only an 8°F temperature difference between the hottest region of the conduit and the bulk temperature of the coolant for the expected heat flux. The heat flux from the 1220°F NaK pipe with the assumed insulation is 1.72 Btu/hr-in.². The switch from nitrogen to water will drop the ΔT slightly but as conductivity through the metal is controlling, the effect will be very small.

IV. HEAT GENERATION AND CONDUCTION RATES

As mentioned previously, the heat generation rates used in the temperature distribution study were the normal concrete values taken from Ref. 3. These values are conservative in that the shield will be borated and the heat generation in borated concrete is significantly less. The total heating for normal concrete is 14928 Btu/hr (6000 Btu/hr of which is absorbed in 2-in. baffle below the shield) but is only 11427 Btu/hr (4600 Btu/hr to the baffle) for borated concrete. The only other thermal inputs to the concrete in the shield are: (1) conduction and radiation from the NaK pipes; (2) conduction and radiation from the 2-in. thick metal baffle below the shield; and (3) conduction and convection up the core vessel and NaK annulus.

In the previous development and in the coolant selection study of Ref. 1, it was assumed that the NaK pipe and 2-in. plate were insulated

from the shield by multi-layer reflective insulation. This insulation could be fabricated by AI from dimpled foil. Commercial insulations are available, see Ref. 4 as an example, which have conductivities 10-to-100 times less than those used in this study. These insulations would be more expensive but if desired, the heat input from the NaK pipes can be reduced from an assumed value of 6800 Btu/hr to ~ 450 Btu/hr and the heat input from the 2-in. baffle can be reduced from 450 Btu/hr to < 35 Btu/hr. The borated concrete shield will also result in less conductivity from the 2-in. baffle to the shield due to lower heating in the 2-in. baffle. As noted above, 6000 Btu/hr is produced in the baffle for the normal concrete shield but only 4600 Btu/hr is produced in the borated case.

The sum of the conduction up the core vessel, conduction up the center plug shell, and the conduction and convection up the NaK annulus between the core vessel and center plug have been assumed to be ~ 6800 Btu/hr. The total heat transfer from conduction (3200 Btu/hr) is simply evaluated but the convection term is uncertain. The S8ER and SER experience indicate very little convective heat transfer occurs. This was attributed to the presence of trapped cover gas in the annulus which blocked NaK from freely entering the annulus. The core test reactor and primary system will not contain large quantities of gas in the coolant which may allow NaK into this annulus. Considering the large L/X (~ 200) of the annulus and the symmetry of the annulus, conduction not convection should be controlling and the actual total heat

transferred up the annulus should be closer to 3200 Btu/hr than the assumed 6800 Btu/hr. If it is desired to present all convection, the center plug could be built with "piston" rings to impede movement in the NaK annulus. Table 1 presents a summary of the thermal input used in the study. Expected and achievable values are also presented for comparison.

V. CONCLUSIONS

Considering the results of the temperature distribution study where all concrete temperatures are well under 200°F and the highly conservative assumptions used in performing the study, it is concluded that the present cooling system design is capable of maintaining the concrete well below 200°F.

Table 1

Thermal Inputs to the Shield

Heat Load, Btu/hr	Used in Thermal Analysis	Expected Value	
		Model Insulation	Super Insulation
γ -n heating in the shield	8928		6827
γ -n heating in the 2-in. baffle	6000		4600
Conduction from the NaK pipes	6800	6800	450
Conduction from the 2-in. baffle	450	340	35
Conduction up the core vessel	6800	6400*	3200**
Thermal Input to Shield Used in Study	22978		
Conservatively Expected Value		20367	
Achievable Value			10512

* Convection assumed to be equal to conduction

** Convection prevented

REFERENCES

1. TI-759-230-004, "Core Test Reactor Shield Coolant Selection," by E. M. Larson, February 1971
2. NAA-SR-11812, "Thermo-Physics Note No. 57 Thermal Analyzer Program (TAP) User's Manual - Fortran II Version," by B. J. Dray, January 11, 1966
3. TI-759-240-013, "ZrH Core Test Shield Plug Nuclear Analysis," by G. Schwab, October 14, 1970
4. "Linde Super Insulation Systems," Brochure F-2757A, Union Carbide Corporation

APPENDIX 1

APPENDIX 1

TAP 4E LISTING FOR CORE TEST REACTOR SHIELD TEMPERATURE DISTRIBUTION

TITLES AND STORED COMMENTS
 CORE-TEST REACTOR SHIELD TEMPERATURE DISTRIBUTION

00000010

00000020

00100000

NETWORK DESCRIPTION											
1	401	C	0.0	0.0	1	2	20	20	20	RADIAL CONDUCT.	00100010
2	402	C	0.0	0.0	2	3	20	20	20		00100020
3	403	C	0.0	0.0	3	4	20	20	20		00100030
4	404	C	0.0	0.0	4	5	20	20	20		00100040
5	405	C	0.0	0.0	5	6	20	20	20		00100050
6	406	C	0.0	0.0	6	7	20	20	20		00100060
7	407	C	0.0	0.0	7	8	20	20	20		00100070
8	408	C	0.0	0.0	8	9	20	20	20		00100080
9	409	C	0.0	0.0	9	10	20	20	20		00100090
10	410	C	0.0	0.0	10	11	20	20	20		00100100
11	411	C	0.0	0.0	11	12	20	20	20		00100110
12	412	C	0.0	0.0	12	13	20	20	20		00100120
13	413	C	0.0	0.0	13	14	20	20	20		00100130
14	414	C	0.0	0.0	14	15	20	20	20		00100140
15	415	C	0.0	0.0	15	16	20	20	20		00100150
16	416	C	0.0	0.0	16	17	20	20	20		00100160
501	501	C	0.0	0.0	1	21	20	20	20	AXIAL CONDUCT.	00101010
502	502	C	0.0	0.0	2	22	20	20	20		00101020
503	503	C	0.0	0.0	3	23	20	20	20		00101030
504	504	C	0.0	0.0	4	24	20	20	20		00101040
505	505	C	0.0	0.0	5	25	20	20	20		00101050
506	506	C	0.0	0.0	6	26	20	20	20		00101060
507	507	C	0.0	0.0	7	27	20	20	20		00101070
508	508	C	0.0	0.0	8	28	20	20	20		00101080
509	509	C	0.0	0.0	9	29	20	20	20		00101090
510	510	C	0.0	0.0	10	30	20	20	20		00101100
511	511	C	0.0	0.0	11	31	20	20	20		00101110
512	512	C	0.0	0.0	12	32	20	20	20		00101120
513	513	C	0.0	0.0	13	33	20	20	20		00101130
514	514	C	0.0	0.0	14	34	20	20	20		00101140
515	515	C	0.0	0.0	15	35	20	20	20		00101150
516	516	C	0.0	0.0	15	36	20	20	20		00101160
517	517	C	0.0	0.0	17	37	20	20	20		00101170
518	518	C	4.00000E 00	0.0	5	499	0	0	1		
519	519	C	0.0	0.0	6	499	0	0	1		
520	520	C	0.0	0.0	6	500	1	0	1	RADIATION	

*02C

00200000

[illegible]

1

35	0	0	2.10000E 01	0.0	0	0	0	0	1	
36	0	0	2.50000E 01	0.0	0	0	0	0	1	00201360
37	0	0	2.90000E 01	0.0	0	0	0	0	1	00201370
38	0	0	3.30000E 01	0.0	0	0	0	0	1	00201380
39	0	0	3.70000E 01	0.0	0	0	0	0	1	00201390
40	0	0	4.10000E 01	0.0	0	0	0	0	1	00201400
41	0	0	4.50000E 01	0.0	0	0	0	0	1	00201410
42	0	0	4.90000E 01	0.0	0	0	0	0	1	00201420
43	0	0	5.30000E 01	0.0	0	0	0	0	1	00201430
44	0	0	5.70000E 01	0.0	0	0	0	0	1	00201440
45	0	0	5.95000E 01	0.0	0	0	0	0	1	00201450
51	5	0	1.50000E 00	0.0	0	0	0	0	1	DELTA-R 00201510
55	0	0	5.00000E-01	0.0	0	0	0	0	1	00201550
54	0	0	1.25000E 00	0.0	0	0	0	0	1	
55	0	0	7.50000E-01	0.0	0	0	0	0	1	
56	62	0	2.50000E 00	0.0	0	0	0	0	1	00201560
63	0	0	1.00000E 00	0.0	0	0	0	0	1	00201630
64	66	0	3.50000E 00	0.0	0	0	0	0	1	00201640
67	0	0	5.00000E-01	0.0	0	0	0	0	1	00201670
71	72	0	5.00000E-01	0.0	0	0	0	0	1	
73	78	0	1.00000E 00	0.0	0	0	0	0	1	
79	84	0	2.00000E 00	0.0	0	0	0	0	1	
85	94	0	4.00000E 00	0.0	0	0	0	0	1	
95	0	0	1.00000E 00	0.0	0	0	0	0	1	
121	0	0	-3.50000E 00	0.0	0	0	0	0	1	
122	0	0	3.75000E-01	0.0	0	0	0	0	1	
123	0	0	1.37500E 00	0.0	0	0	0	0	1	
171	0	0	2.00000E 00	0.0	0	0	0	0	1	
172	0	0	7.50000E-01	0.0	0	0	0	0	1	
173	0	0	1.25000E 00	0.0	0	0	0	0	1	
18	0	0	2.24000E 02	0.0	0	0	0	0	1	WD(370/HR-IN3) 00202180
19	0	0	1.80000E-01	0.0	0	0	0	0	1	
46	0	0	1.00000E 00	0.0	0	0	0	0	1	COND OF CONCRETE 00202480
49	0	0	1.50000E 01	0.0	0	0	0	0	1	COND OF STEEL 00202490
*030										00300000

FUNCTION STATEMENTS

1	0	100	0.0	1.00000E 00	2	1	0	0	1	00300010
Y 5	0	101	0.0	0.0	Y 5	0	0	0	1	SET TO ZERO
63	0	161	0.0	1.00000E 00	C 1	0.497	0	0	1	TOTAL VOLUME 00300020
69	0	161	0.0	1.00000E 00	Q 1	0.497	0	0	1	TOTAL HEAT GEN 00300030
70	0	161	0.0	1.00000E 00	Q 6	0.17	0	0	1	HEAT IN STEEL
Y985	0	49	0.0	6.30000E-02	0	0	0	0	1	RADIATION
Y986	997	49	0.0	1.33833E-03	0	0.106	0	1	1	RADIATION

T 21	461	46	0.0	1.00000E 00	Y521	0	20	0	20	MATRIX SOLUTIONS	00300040
T 23	463	47	0.0	1.00000E 00	Y523	0	20	0	20		00300050
T 46	465	47	0.0	1.00000E 00	Y546	0	20	0	20	MATRIX SOLUTIONS	
T 48	466	47	0.0	1.00000E 00	Y549	0	20	0	20	MATRIX SOLUTIONS	
T 50	470	47	0.0	1.00000E 00	Y550	0	20	0	20	MATRIX SOLUTIONS	
T 52	472	47	0.0	1.00000E 00	Y552	0	20	0	20	MATRIX SOLUTIONS	
T 54	474	47	0.0	1.00000E 00	Y554	0	20	0	20	MATRIX SOLUTIONS	
T 56	476	47	0.0	1.00000E 00	Y556	0	20	0	20	MATRIX SOLUTIONS	
T 22	462	46	0.0	1.00000E 00	Y522	0	20	0	20		00300120
T 24	464	47	0.0	1.00000E 00	Y524	0	20	0	20		00300130
T 47	467	47	0.0	1.00000E 00	Y547	0	20	0	20	MATRIX SOLUTIONS	
T 49	469	47	0.0	1.00000E 00	Y549	0	20	0	20	MATRIX SOLUTIONS	
T 51	471	47	0.0	1.00000E 00	Y551	0	20	0	20	MATRIX SOLUTIONS	
T 55	475	47	0.0	1.00000E 00	Y555	0	20	0	20	MATRIX SOLUTIONS	
T 6	17	47	0.0	1.00000E 00	Y 6	0	1	0	1		
Y985	0	49	0.0	6.30000E-02	0	0	0	0	1	RADIATION	
Y986	997	49	0.0	1.30000E-03	0	0106	0	1	1	RADIATION	
1	0	96	0.0	1.00000E 00	0	78	0	0	1	DUMP AT 2ND ITER	00300170
* 70											00700000

CONTROL CONSTANTS

3	5.00000E-01	DELTA TIME MULTIPLIER	00700030
4	2.00000E-03	CONVERGENCE TEST ON RATE OF TEMPERATURE CHANGE	00700040
5	1.00000E 00	0. = TRANSIENT; +1. = STEADY STATE; >1. = AITKEN	00700050
9	1.71400E-09	STEFAN-BOLTZMANN CONSTANT	

* 80

PRINT-OUT SPECIFICATIONS

T 6	17	0	0.0	0.0	0	0	0	0	1	00800002
Y986	997	0	0.0	0.0	0	0	0	0	1	00800004
T 21	100	C	0.0	0.0	0	0	0	0	1	00800010
T 1	461	C	0.0	0.0	0	0	0	0	20	00800020
* 90										00900000

PRINT-OUT AND STOP TIMES

0	C	0	0.0	2.50000E 01	0	0	0	0	1	00900010
0	C	0	2.00000E 02	0.0	0	0	0	0	1	00900020
* 99										00990000

COMPILED OPTIONS - NAME= MAIN,OPT=C2,LINECNT=40,SOURCE,FBCDIC,NOLIST,DECK,LOAD,MAP,NOEDIT,10,)

ISN 0002

SUBROUTINE SUB98

COMPUTES THERMAL PARAMETERS FOR CORE-TEST REACTOR SHIELD

COMPOSED BY R D ELLIOTT ON 07-16-70

Subroutine SUB98, Sheet 1

C REVISED ON 09-22-70

ISN 0003

COMMON//TIME,D(1000),Y(1000),T(1000),C(1000),Q(1000),G(3999)

COMPUTE NODE VOLUMES AND HEAT GENERATION RATES

ISN 0004

DO 10 I=1,17

ISN 0005

10 D(100+I)=6.2832*D(I)*D(50+I)

(Cross-Sectional Areas)

ISN 0006

JJ=0

ISN 0007

DO 20 J=1,25

ISN 0008

DZ=D(70+J)

ISN 0009

Z=D(20+J)

ISN 0010

DO 15 I=1,17

ISN 0011

N=JJ+1

ISN 0012

C(N)=D(100+I)*DZ

(Volumes)

ISN 0013

R=D(I)

ISN 0014

D(500+N)=QVOL(R,Z)

ISN 0015

Q(N)=C(N)*D(500+N)

(Heat rate per node)

ISN 0016

15 CONTINUE

ISN 0017

20 JJ=JJ+20

ISN 0018

JJ=0

ISN 0019

DO 120 J=1,3

ISN 0020

DZ=D(170+J)

ISN 0021

Z=D(120+J)

ISN 0022

DO 115 I=6,17

ISN 0023

N=JJ+1

ISN 0024

C(N)=D(100+I)*DZ

ISN 0025

R=D(I)

ISN 0026

D(500+N)=QVOL(R,Z)

ISN 0027

Q(N)=C(N)*D(500+N)

ISN 0028

115 CONTINUE

ISN 0029

120 JJ=JJ+20

ISN 0030

IF (G(1).EQ.1.) CALL HEAT

(S/R HEAT supersedes QVOL, computing heat generation rates to agree with G.Schwab's values.)

COMPUTE RADIAL CONDUCTANCES

ISN 0032

DO 30 I=1,16

ISN 0033

RATIO=ALOG(D(I+1)/D(I))

ISN 0034

N=1

ISN 0035

DO 25 J=1,25

This subroutine is called by the TAP-4 code once at the start of a run.

```

ISN 0036      COND=D(48)                                (Conductivity of Concrete)
ISN 0037      IF (J.EQ.1.OR.J.EQ.25) COND=D(49)        (Conductivity of Steel)
ISN 0039      DZ=D(70+J)/12.
ISN 0040      Y(N)=6.2832*COND*DZ/RATIO
ISN 0041      25 N=N+20
ISN 0042      30 CONTINUE
ISN 0043      DO 130 I=6,17
ISN 0044      RATIO=ALOG(D(I+1)/D(I))
ISN 0045      N=I
ISN 0046      DO 125 J=1,3
ISN 0047      COND=D(49)
ISN 0048      IF (J.EQ.3) COND=D(48)
ISN 0050      DZ=D(170+J)/12.
ISN 0051      Y(N)=6.2832*COND*DZ/RATIO
ISN 0052      125 N=N+20
ISN 0053      130 CONTINUE

      COMPUTE AXIAL CONDUCTANCES
ISN 0054      JJ=500
ISN 0055      DO 40 J=1,24
ISN 0056      DZ1=D(70+J)/24.
ISN 0057      DZ2=D(71+J)/24.
ISN 0058      DO 35 I=1,17
ISN 0059      AREA=A*D(100+I)/144.
ISN 0060      N=JJ+I
ISN 0061      COND1=D(48)
ISN 0062      IF (J.EQ.1) COND1=D(49)
ISN 0064      COND2=D(49)
ISN 0065      IF (J.EQ.24) COND2=D(48)
ISN 0067      IF (I.EQ.5.OR.I.EQ.13.OR.I.EQ.17) GO TO 32
ISN 0069      GO TO 34
ISN 0070      32 COND1=D(49)
ISN 0071      COND2=D(49)
ISN 0072      34 DZOK=(DZ1/COND1+DZ2/COND2)
ISN 0073      35 Y(N)=AREA/DZOK
ISN 0074      40 JJ=JJ+20
ISN 0075      JJ=500
ISN 0076      DO 140 J=1,3
ISN 0077      DZ1=D(170+J)/24.

```


Subroutine SUB98, Sheet 3

```
ISN 0078      072=D(171+J)/24.  
ISN 0079      DO 135 I=6,17  
ISN 0080      AREA=D(100+I)/144.  
ISN 0081      N=JJ+I  
ISN 0082      Y(N)=0.0  
ISN 0083      IF (J.EQ.1) GO TO 135  
ISN 0085      COND1=D(51-J)  
ISN 0086      COND2=D(48)  
ISN 0087      IF(1.EQ.13.OR.1.EQ.17) GO TO 132  
ISN 0089      GO TO 134  
ISN 0090      132 COND1=D(49)  
ISN 0091      COND2=D(49)  
ISN 0092      134 DZOK=(D(1)/COND1+072/COND2)  
ISN 0093      Y(N)=AREA/DZOK  
ISN 0094      135 CONTINUE  
ISN 0095      140 JJ=JJ+20  
ISN 0096      RETURN  
ISN 0097      END
```

COMPILER OPTIONS - NAME= MAIN,OPT=C2,LINECNT=40,SOURCE,EHCDC,NO LIST,DECK,LOAD,MAP,NOEDIT,IO,

ISN 0002	SUBROUTINE HEAT	00001000
ISN 0003	COMMON TIME,D(1000),Y(1000),T(1000),C(1000),Q(1000),G(3999)	00001010
ISN 0004	DIMENSION C1(2),C2(2),E1(2),E2(2)	00001020
ISN 0005	DIMENSION RI(18),RC(17),DR(17)	00001030
ISN 0006	DIMENSION ZI(25,2),ZC(25,2),DZ(25,2),ZO(25,2)	00001040
ISN 0007	DATA DR/3*1.5,1.25,C.75,7*2.5,1.0,3*3.5,0.5/	00001050
ISN 0008	DATA DZ/2*0.5,6*1.0,6*2.0,10*4.0,1.0, *2.0,C.75,1.25,5*1.0,6*2.0,10*4.0,1.0/	00001060 00001070
ISN 0009	DATA ZO/23*.75,24*26.5,21.5,24.0,23*26.75/	00001080
ISN 0010	DATA C1,C2,E1,E2/1.955,0.38,1.545,0.,1.328,0.1214,0.1422,0./	00001090
ISN 0011	RI(1)=0.0	00001100
ISN 0012	DO 100 I=1,17	00001110
ISN 0013	RC(I)=RI(I)+0.5*DR(I)	00001120
ISN 0014	RI(I+1)=RI(I)+DR(I)	00001130
ISN 0015	IP100=I+100	00001140
ISN 0016	D(IP100)=6.2832*DR(I)*RC(I)	00001150
ISN 0017	100 CONTINUE	00001160
ISN 0018	ZI(1,1)=26.0	00001170
ISN 0019	ZI(1,2)=24.0	00001180
ISN 0020	DO 200 K=1,2	00001190
ISN 0021	DO 200 J=1,25	00001200
ISN 0022	ZC(J,K)=ZI(J,K)+0.5*DZ(J,K)	00001210
ISN 0023	ZI(J+1,K)=ZI(J,K)+DZ(J,K)	00001220
ISN 0024	236 FORMAT(2X,4F10.3)	00001230
ISN 0025	200 CONTINUE	00001240
ISN 0026	ZI(1,2)=21.5	00001250
ISN 0027	ZC(1,2)=22.5	00001260
ISN 0028	NR=0	00001280
ISN 0029	DO 300 J=1,25	00001290
ISN 0030	K=1	00001300
ISN 0031	DO 290 I=1,17	00001310
ISN 0032	IF(I.GE.6) K=2	00001320
ISN 0034	N=NR+1	00001330
ISN 0035	ZCSQ=ZC(J,K)*ZC(J,K)	00001340
ISN 0036	HSQ=ZCSQ+RC(I)*RC(I)	00001350
ISN 0037	ZOH SQ=ZCSQ/HSQ	00001360
ISN 0038	DOH=1.-ZC(J,K)/ZC(J,K)	00001370
ISN 0039	DIST=SQRT(HSQ)*DOH	00001380

Subroutine HEAT, Sheet 2

ISN 0040	M=2	00001390
ISN 0041	IF(J.EQ.1) M=1	00001400
ISN 0043	IF(J.EQ.2.AND.I.GE.5) M=1	00001410
ISN 0045	QVOL=(C1(M)*EXP(-E1(M)*DIST)+C2(M)*EXP(-E2(M)*DIST))*ZOH5Q	00001420
ISN 0046	FACTOR=1.	00001421
ISN 0047	IF(J.EQ.25) FACTOR=4.5	00001422
ISN 0049	IF(J.LT.3) GO TO 250	00001423
ISN 0051	IF(I.EQ.5.OR.I.EQ.13.OR.I.EQ.17) FACTOR=4.5	00001426
ISN 0053	250 QVOL=QVOL*FACTOR	00001427
ISN 0054	NP500=N+500	00001430
ISN 0055	D(NP500)=QVOL	00001440
ISN 0056	IP100=I+100	00001450
ISN 0057	C(N)=D(IP100)*DZ(J,K)	00001460
ISN 0058	Q(N)=C(N)*QVOL	00001470
ISN 0059	290 CONTINUE	00001500
ISN 0060	300 NR=NR+20	00001510
ISN 0061	RETURN	00001520
ISN 0062	END	00001530

M=1 signifies steel, M=2 signifies concrete

The heat deposition is assumed to result from capture of particles from two independent streams of different characteristics. The source terms, C1 and C2 were picked to add up to 3.60 Btu/hr-in² at the lower surface of a steel plate located 26 in. from the source, as computed by the ANISN code and reported in Reference _ .

APPENDIX 2 TAP 4E LISTING FOR COIL TO WALL TEMPERATURE DIFFERENCE

COIL-TO-WALL TEMPERATURE DIFFERENCE

-13
9-01-70

00000010

TITLE: COIL-TO-WALL TEMPERATURE DIFFERENCE
COMMENTS: COIL-TO-WALL TEMPERATURE DIFFERENCE

00000030

COIL-TO-WALL TEMPERATURE DIFFERENCE

00000040

COIL-TO-WALL TEMPERATURE DIFFERENCE, COIL PITCH = 2.0 IN.

00000050

00100000

INITIAL TEMPERATURES

11	12	0	1.54000E-04	0.0
21	22	0	1.54000E-04	0.0
31	32	0	1.54000E-04	0.0
41	42	0	1.54000E-04	0.0
51	52	0	1.54000E-04	0.0
60	61	0	1.54000E-04	0.0
101	140	0	1.54000E-04	0.0
141	142	0	1.54000E-04	0.0
142	143	0	1.54000E-04	0.0
143	144	0	1.54000E-04	0.0
144	145	0	1.54000E-04	0.0
145	151	0	1.54000E-04	0.0

11	12	1	1	1
21	22	1	1	1
31	32	1	1	1
41	42	1	1	1
51	52	1	1	1
60	61	0	0	1
1	11	1	1	1
41	51	0	0	1
42	60	0	0	1
43	61	0	0	1
60	52	0	0	1
61	53	0	0	1
51	100	1	0	1

00100010

00100020

00100030

00100040

00100050

00100060

00100070

00100080

00100090

00100100

00100110

00100120

00100130

00200000

INITIAL TEMPERATURES AND INIT. TEMPS

1	12	-1	1.54000E-04	0.0
100	0	-1	1.54000E-04	0.0
11	50	0	1.54000E-04	0.0
51	59	0	1.54000E-04	0.0
60	61	0	1.54000E-04	0.0

0	0	0	0	1
0	0	0	0	1
0	0	0	0	1
0	0	0	0	1
0	0	0	0	1

00200010

00200030

00300000

INITIAL TEMPERATURES

Y101	110	46	1.54000E-04	0	0	0	0	1
11	61	46	1.00000E-00	Y 11	0	1	0	1
11	61	46	1.00000E-00	Y 11	0	1	0	1
11	61	46	1.00000E-00	Y 11	0	1	0	1

0	0	0	0	1
0	1	0	0	1
0	1	0	0	1
0	1	0	0	1

00300010

00700000

INITIAL TEMPERATURES

4	1.54000E-04
5	1.00000E-00
0	1.00000E-00

CONVERGENCE TEST ON RATE OF TEMPERATURE CHANGE
C. = TRANSIENT; +1. = STEADY STATE; -1. = AITKEN
STEIN-RODZMANN CONSTANT

00700040

00700050

00700090

00800000

INITIAL TEMPERATURES

T 1 0 0.0 0.0 0 0 0 0 1

* 00

00400010

00900000

PRINT-OUT AND STOP TIMES

0 0 0 0.0 2.500000 01

0 0 0 0 1

00900010

0 0 0 5.000000 02 0.0

0 0 0 0 1

09000000

* 00