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THERMAL STRUCTURE FOR THE REGION BEYOND THE
ART REFLECTOR - - SUPPLEMENT IABSTRACT

The thermal structure of the region beyond the ART reflector has been studied using a third idealized system. This system differs from the two previously studied in that a portion of the boron carbide has been replaced by a stainless steel clad copper-boron carbide matrix.

The altered geometry resulted in an increased temperature rise (36°F) of the sodium coolant stream and a decreased maximum boron carbide temperature (1526°F).

The temperature drop across the inner Inconel shell was increased by $30\text{-}35^{\circ}\text{F}$. The gradient in the outer Inconel shell was essentially unchanged.

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INTRODUCTION

In the previous memorandum ¹ concerning the thermal structure in the region beyond the ART reflector two limiting geometries were considered. In each of these systems, the core neutrons leaking through the reflector are absorbed near the surface of the boron carbide layer. One of the results of these neutron absorptions is the formation of sub-surface helium. Since B_4C is a brittle material, the build-up of helium pressure within the thin absorption layer will result in spalling of the B_4C surface. To prevent the destruction of the boron carbide, the system geometry has been modified by inserting a copper-boron carbide mixture * between the B_4C and the reflector. The neutrons are now stopped in the surface layers of this copper- B_4C matrix and the helium pressure is relieved without structural damage to the material. A schematic of the system is given in Figure 1.

Method of Analysis

The following idealizations are again made:

- (1) The system is closely approximated by a slab (parallel plate) geometry.
- (2) No thermal resistances exist at the interfaces between solid components.
- (3) Uniform heat generation is assumed within each of the system elements.

¹ Hoffman, H. W., Copenhaver, C. M., Wantland, J. L. - "Thermal Structure for the Region Beyond the ART Reflector", ORNL CF 56-3-23, (1956), Secret.

* The copper-boron carbide mixture contains 6.57 weight percent B_4C . This core mixture is clad on both sides by 1 to 2 mils of copper and 10 mils of type 430 stainless steel.

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Fig. 1. Idealization of Physical System

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- (4) The effect of radiative and convective heat transfer within the helium gaps is negligible in comparison with the conduction heat transfer. *
- (5) The total quantity of heat generated in the 2 inches of beryllium immediately adjacent to the sodium is transferred to the sodium. ‡
- (6) The temperatures along a fictitious boundary 4 inches from the beryllium-sodium interface are assumed to be the core-side sodium temperatures at the corresponding axial positions. ‡

Based on these idealizations, system C can be analyzed by the iterative method described in the previous memorandum. The heat deposition rates needed in this analysis were given by H. W. Bertini as tentative upper limits and are presented in Table II of the Appendix.

RESULTS

The sodium temperature rise and the temperatures in the region between the sodium and fuel streams were determined for three sodium inlet temperatures. Detailed tables of results are given in the Appendix. From Table III it is seen that, as the sodium inlet temperature was varied from 1150°F to 1200°F, the sodium temperature rise in the return circuit for system C changed from 33.4°F to 36.3°F.

Typical temperature profiles at the inlet and outlet ends of system C are presented in Figure 2. In comparison, the temperature profiles for the corresponding positions in system B are shown also.

* A calculation shows the radiative and convective heat transfer to be less than 6% of the total heat transfer.

‡ Assumptions 5 and 6 are necessary in establishing the thermal flux through the beryllium-sodium interface.

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Fig. 2. Comparison of Temperature Profiles at the Inlet and Outlet Ends of Systems B and C for a Sodium Inlet Temperature of 1175°F

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CONCLUSIONS

The thermal structure of the region of the ART between the reflector and the fuel return circuit has been studied using a third idealized system. System C differs from the previously examined system B in that a portion of the boron carbide has been replaced by a copper-boron carbide matrix. The following results were obtained:

- (1) The temperature rise of the sodium coolant stream between the core outlet and the sodium pumps ranged from 33°F to 36°F , a change of 3°F while the sodium inlet temperature varied 50°F .
- (2) The sodium temperature rise for system C was greater than that for systems A or B. This resulted from the greater total heat deposition and from the altered thermal resistance of the system causing more of the heat generated at the surface, x_e , to flow into the sodium.
- (3) As a further result of the altered geometry, the boron carbide temperature was reduced. The maximum B_4C temperature in system C was 1526°F as compared to 1586°F in system B. However, at the inlet end, the temperature drop across the B_4C of system C was from 1.5 to 2 times that for system B. At the outlet end, the B_4C temperature drop was only 15 to 25% that of system B.
- (4) The maximum temperature in the system (1595°F) occurred at the inlet end of the Inconel-fuel interface. The temperatures along the fuel-side Inconel surface were relatively insensitive to the system geometry, since the temperature variation of the fuel is established by the fuel to NaK heat exchanger.

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- (5) The changed geometry increased the temperature drop across the inner Inconel shell by 30 - 35°F. The temperature gradient in the outer Inconel shell was essentially unchanged.

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APPENDIXTABLE IINTERFACE LOCATIONS AND THERMAL RESISTANCES
SYSTEM C

Locations (ft x 10 ³)		Resistances * (hr-ft ² -°F/Btu x 10 ³)	
x_m	0.0	R_M	0.500
x_l	5.167	R_L	0.420
x_k	6.000	R_K	4.760
x_j	6.417	R_J	0.032
x_i	28.499	R_I	6.134
x_h	28.916	R_H	0.032
x_g	29.749	R_G	4.760
x_f	30.582	R_F	0.063
x_e	37.249	R_E	0.032
x_d	38.082	R_D	0.063
x_c	58.915	R_C	1.693
x_b	66.749	R_B	0.056
		R_T	18.545

* Nomenclature and resistances as given in ORNL CF-56-3-23.

Note: Correct thermal conductivity of helium to read 0.175 Btu/hr-ft-°F.

R_E : Assumed to be pure copper, $k_e = 207$ Btu/hr-ft-°F.

R_D, R_F, R_H, R_J : Thermal conductivity of stainless steel,

$k_D = k_F = k_H = k_J = 13.2$ Btu/hr-ft-°F

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TABLE II

HEAT DEPOSITION RATES FOR REGION BEYOND ART REFLECTOR
SYSTEM C

Beryllium,

2" from Be-Na interface	: $W_{A,2} = 4.639 \times 10^4$ Btu/hr-ft ³
1" from Be-Na interface	: $W_{A,1} = 6.282 \times 10^4$ Btu/hr-ft ³
at Be-Na interface	: $W_{A,0} = 9.568 \times 10^4$ Btu/hr-ft ³

Sodium

: $W_B = 3.479 \times 10^4$ Btu/hr-ft³

Inner Inconel Shell

: $W_C = 7.732 \times 10^5$ Btu/hr-ft³

Stainless steel jacket for Cu-B₄C

inner side

: $W_D = 8.698 \times 10^5$ Btu/hr-ft³

outer side

: $W_F = 6.765 \times 10^5$ Btu/hr-ft³

Copper-boron carbide,

volume

: $W_E = 10.631 \times 10^5$ Btu/hr-ft³

flux at reflector-side surface

: $W' = 4.154 \times 10^4$ Btu/hr-ft²

Stainless steel jacket for B₄C,

inner side

: $W_H = 6.765 \times 10^5$ Btu/hr-ft³

outer side

: $W_J = 6.765 \times 10^5$ Btu/hr-ft³

Boron carbide

: $W_I = 1.933 \times 10^5$ Btu/hr-ft³

Outer Inconel Shell

: $W_L = 9.665 \times 10^5$ Btu/hr-ft³

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TABLE III
SUMMARY OF RADIAL TEMPERATURE PROFILES IN REGION BEYOND THE ART REFLECTOR
SYSTEM C
(Body of Table - °F)

Axial Position	Radial Position												
	Sodium	x_c	x_d	x_e	x_f	x_g	x_h	x_i	x_j	x_k	x_l	x_m	Fuel
30 °	1150.0	1154.9	1288.7	1293.2	1293.9	1295.3	1395.6	1396.3	1510.7	1511.3	1588.6	1594.3	1600
55.75	1159.4	1164.0	1290.2	1294.3	1295.0	1296.0	1374.7	1375.2	1461.7	1462.1	1517.8	1521.6	1525
73.75	1166.6	1171.1	1291.7	1295.6	1296.2	1297.0	1360.2	1360.7	1427.3	1427.6	1467.8	1470.3	1472
90	1172.9	1175.2	1293.0	1296.7	1297.2	1297.9	1347.4	1347.7	1396.7	1396.9	1423.4	1424.7	1425
106.25	1178.4	1182.5	1293.5	1297.1	1297.5	1298.0	1334.0	1334.2	1365.9	1366.0	1379.0	1379.1	1378
124.25	1183.0	1187.0	1292.7	1296.1	1296.3	1296.6	1317.9	1318.0	1330.6	1330.6	1328.9	1327.7	1325
150	1186.3	1190.0	1288.6	1291.7	1291.8	1291.9	1293.0	1293.0	1279.7	1279.6	1257.8	1254.8	1250
30	1175.0	1179.8	1311.4	1315.7	1316.5	1317.7	1411.6	1412.3	1518.4	1518.9	1589.8	1595.0	1600
55.75	1184.4	1189.0	1312.8	1316.9	1317.5	1318.5	1390.7	1391.2	1469.4	1469.8	1519.0	1522.3	1525
73.75	1191.5	1195.9	1314.2	1318.1	1318.6	1319.4	1376.2	1376.6	1434.9	1435.2	1469.0	1470.9	1472
90	1197.6	1201.8	1315.3	1319.0	1319.4	1320.0	1363.2	1363.5	1404.3	1404.4	1424.6	1425.4	1425
106.25	1202.8	1206.9	1315.6	1319.1	1319.4	1319.9	1292.9	1349.8	1373.4	1373.4	1380.2	1379.8	1378
124.25	1207.0	1210.9	1314.4	1317.7	1317.9	1318.2	1333.3	1333.4	1338.0	1337.9	1330.1	1328.3	1325
150	1209.9	1213.6	1310.0	1313.0	1313.1	1313.1	1308.2	1308.1	1287.0	1286.8	1258.9	1255.4	1250
30	1200.0	1204.7	1334.0	1338.3	1339.0	1340.2	1427.6	1428.2	1526.1	1526.6	1591.1	1595.7	1600
55.75	1209.4	1213.9	1335.4	1339.4	1340.0	1340.9	1406.7	1407.1	1477.1	1477.4	1520.3	1523.0	1525
73.75	1216.4	1220.7	1336.8	1340.6	1341.0	1341.7	1392.1	1392.5	1442.6	1442.8	1470.2	1471.6	1472
90	1222.3	1226.4	1337.7	1341.3	1341.7	1342.2	1379.0	1379.3	1411.9	1412.0	1425.9	1426.0	1425
106.25	1227.2	1231.2	1337.7	1341.1	1341.4	1341.7	1365.3	1365.4	1380.9	1380.9	1381.4	1380.4	1378
124.25	1231.1	1234.9	1336.2	1339.5	1339.6	1339.8	1348.7	1348.8	1345.4	1345.3	1331.3	1328.9	1325
150	1233.4	1237.0	1331.2	1334.2	1334.3	1334.1	1323.2	1323.1	1294.2	1294.0	1260.1	1256.0	1250

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TABLE IV
NET THERMAL FLUX AT SYSTEM BOUNDARIES
SYSTEM C

Axial Position	Radial Position								
	x_b			x_c			x_m		
	Btu/hr-ft ² x 10 ⁻³								
Sodium Inlet Temperature →	1150°F	1175	1200	1150	1175	1200	1150	1175	1200
30 °	-10.93*	-10.93	-10.93	87.10	85.75	84.40	11.25	9.90	8.55
55.75	- 6.55	- 5.78	- 5.03	82.65	81.30	79.97	6.69	5.35	4.00
73.75	- 3.49	- 2.18	- 0.91	79.53	78.18	76.88	3.45	2.11	0.76
90	- 0.73	+ 1.07	+ 2.81	76.72	75.37	74.08	0.57	- 0.76	- 2.09
106.25	+ 2.03	4.32	6.53	73.91	72.56	71.29	-2.26	- 3.57	- 4.89
124.25	5.09	7.92	10.65	70.79	69.44	68.19	-5.36	- 6.66	- 7.96
150	9.47	13.07	16.55	66.34	64.99	63.76	-9.58	-10.86	-12.12

* Sign indicates direction of heat flow - positive for increasing x .

Note: The signs of all the heat fluxes listed in column x_h of Table VII of the previous memorandum (ORNL CF 56-3-23) should be reversed.

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