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OLD FILE HCR OPERATING TEMPERATURES

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OLD PILE HCR OPERATING TEMPERATURES

October 10, 1963

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INTRODUCTION

Recently several horizontal control rods of the type used in B, D, F, DR and H Reactors have failed structurally while in service. The outer aluminum sheaths of the failed HCR's have been found to be thermally annealed (low Brinell hardness) and three of the damaged rods have shown evidence of bulging or blistering of the outer aluminum sheath. A temperature study of the HCR's under operating conditions has been conducted as an aid to an over-all program for evaluating the causes of rod failure.

The goals of this study were to determine operating temperatures or ranges of temperatures of the outside aluminum sheath and to determine controlling heat transfer parameters of the control rod system.

SUMMARY

A study was made to determine operating temperatures of old pile HCR sheaths. The calculations were performed with the aid of a FORTRAN coded program for the IBM 7090. The difficulty of determining the correct value for the contact coefficient between the HCR and the graphite channel at any point in the channel length resulted in performing the calculations in a parametric style. The independent system parameters were varied during the calculations. These parameters are diametral spacing between the poison rings and the outer aluminum sheath, heat generation rate or reactor power level, the heat transfer contact coefficient between the rod and the graphite channel, and the cooling water temperature or cooling flow rate.

For contact coefficients between 200 and 700 Btu/hr - ft² - °F and for diametral clearances around the poison of 5 mils to 20 mils, the maximum sheath temperature was calculated to vary between 350°F and 650°F.

The dependence of sheath temperature upon the rod coolant temperature or coolant flow rate was found to be small enough to be neglected in the normal flow range of 12 gpm to 15 gpm. For a given increase of the average coolant temperature, the maximum sheath temperature increased about one half as much. Reversing the coolant flow in an HCR would not significantly reduce the maximum sheath temperature.

DISCUSSION

The horizontal control rod heat transfer system of interest is shown in Figure I. The poison section and non-absorbing section of each rod were considered as separate systems during the calculations. The results of the calculations show this approach to be feasible from a temperature distribution standpoint. The temperature of the outer sheath did not vary significantly when traversing the rod from the poison to non-poison section with a constant neutron flux. This was due, in part, to the large air gap resistance between the sheath and the aluminum spacer at the non-poison section.

In reality a vertical adiabatic plane, a non-heat transfer plane, exists on the center line of the center cooling tube in the typical HCR because of the geometric uniformity of the control rod and the uniformity of neutron flux surrounding the rods. Consequently, examination of one half of a rod is adequate to describe the whole rod.

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FIGURE 1
EXHAUSTION CELL FILE HUF
(FDS) SECTION

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FIGURE II

GRAPHITE TEMP 1020°F (MAX. TEMP.)
INLET WATER TEMP 60°F
MAX. FLUX REGION - 2000 MW

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FIGURE III

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The flat, side to side neutron flux distribution in the old piles allowed a two dimensional approach, with respect to energy transport, to be taken. No significant axial heat flow would exist down the length of the rods. For the calculations, heat was allowed to flow in a radial direction, i.e., around the periphery of the rod sheath, and towards the heat sink or cooling tubes in the rod.

The calculations were completed with the aid of a FORTRAN coded heat transfer program written for the IBM 7090. The advantage of using such a program is to allow many system parameters to be varied during the calculations and consequently to allow determination of the important rate controlling parameters. The parameters that were varied are 1) the diametral gap between the poison and the aluminum outer sheath, 2) heat generation rates in the HCR and surrounding graphite, 3) the heat transfer contact coefficient between the HCR and the graphite on the channel bottom, and 4) the cooling water temperature or cooling flow rate. Other parameters such as pile gas composition, graphite temperatures, and the gas atmosphere in the rod proper were determined as corresponding to the past operating experience and inserted in the program as fixed values. The geometry of the non-poison section was fixed during the calculations.

The effects of the diametral clearance between the poison and the outer sheath, and the heat transfer contact coefficient at the bottom of the control rod on the maximum sheath temperature are presented in Figure II. These effects will be discussed later. The heat generation rates for the temperature data presented in Figure II represent the reactor neutron flux at a power level of 1,800 to 2,000 Mw. This latter parameter is quite significant in determining sheath temperatures.

The gas atmosphere in the HCR proper was assumed to be air. The components of the rods are exposed to air during the original assembly and the rods were not flushed with helium or other inert gases after construction. Although helium is produced by the interaction of neutrons and boron during the use of the rods, the ability of the rods to "breathe" during the cooling down and heating up associated with reactor shutdown and startup would tend to maintain an atmosphere of air in the interior of the rod. At any rate, it would be impossible to determine the actual atmosphere so a worst condition, strongly affecting sheath temperatures, was assumed.

The following tables present the values of the physical constants used during the calculations.

TABLE I

PHYSICAL CONSTANTS

<u>Unit</u>	<u>Value</u>
Graphite Emissivity	0.85
Aluminum Thermal Conductivity	119 Btu/hr - ft - °F
Aluminum Emissivity	0.20
Boron-Aluminum Thermal Conductivity	16 Btu/hr - ft - °F
Boron-Aluminum Emissivity (Poison)	0.65

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TABLE II

THERMAL CONDUCTIVITY - AIR

<u>Temperature</u>	<u>K - Btu/hr - ft °F</u>
32°F	0.0140
212	0.0184
392	0.0224
572	0.0260

TABLE III

THERMAL CONDUCTIVITY - 100% HELIUM

<u>Temperature</u>	<u>K - Btu/hr - ft °F</u>
212°F	.103
392	.119
572	.135
752	.150
932	.166
1,111	.182
1,290	.198

TABLE IV

THERMAL CONDUCTIVITY - GRAPHITE

<u>Temperature</u>	<u>K - Btu/hr - ft °F</u>
140°F	15.0
356	17.0
464	17.5
572	18.0
662	18.0
752	18.0
842	18.0
1,111	17.0
2,160	15.0

The maximum sheath temperature was used as the dependent variable in presenting the results of the calculations. In all cases, this maximum temperature existed on the bottom of the HCR sheath. One could have used the average sheath temperature or the minimum sheath temperature. As would be expected, there is not a large difference between any of the three temperatures for the system conditions that were examined. Representative temperatures for the entire cross section of the HCR in a maximum flux position are shown in Figure I. The non-poison section of the HCR, not shown, will not "see" the maximum flux region but such a set of calculations was performed to show that the sheath temperature gradient along the rod length will not change suddenly as the transition from the poison to the non-poison section is made. The temperature gradient along the rod length is a

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a function of the system parameters mentioned earlier; the neutron flux and/or surrounding graphite temperature, the coolant flow rate or temperature, and the diametral clearance between the poison and the sheath.

There is one condition that could distort the temperature gradient mentioned above. An outward bulge of the aluminum sheath, as has been found on several HCR's, would cause a localized hot spot on the sheath. Disregarding the cause for the bulge, once the physical change begins to occur on a rod the local temperature will begin to rise. This increase in sheath temperature will aggravate the situation by rapidly annealing the aluminum in the localized region. The normal variation in the sheath-to-poison gap is from a minimum of 3 to 5 mils on the diameter to a maximum of 18 mils on the diameter. The energy transfer significance of an outward bulge of the sheath is the large increase in the gap distance. Clearances up to 300 mils on the radius have been measured in such a distorted area. Once the gap distance has increased beyond 100 mils the rate of increase of sheath temperature per unit increase in gap distance will be substantially reduced, provided the physical system has not changed. At this point the majority of heat transfer across the gap at the upper portion of the poison is by radiation from the sheath.

Although no calculations were done for that section of the rod where the sheath is bulged or blistered, it is surmised that the outside sheath in contact with the graphite could approach within 200° to 300°F of the graphite temperature. This maximum temperature would be mainly dependent upon the contact coefficient between the sheath and the graphite. The actual shape of the distorted sheath would be very difficult to determine; hence the actual value of the contact coefficient remains unknown.

As in the case of the distorted sheath mentioned earlier, the contact coefficient between the rod sheath in the unaffected or undistorted cross section and the graphite is difficult to evaluate. In this normal geometrical case, however, the range of values that could be expected has been determined. A minimum value of 2 or 3 Btu/hr - ft² - °F would be expected for the case of the rod not in contact with the graphite and where the heat transfer is by conduction through the helium gas gap and by radiation to the graphite. A maximum value of about 500 Btu/hr-ft²-°F has been estimated for full rod contact on the channel bottom. The maximum value is based mostly upon intuition and must be measured or determined experimentally for a completely dependable value. If values above 500 are used, other portions of the system become limiting to heat transfer. The value of this contact coefficient was varied between 50 and 1000 during the calculations and plotted as an independent variable in Figure II. As can be seen in Figure II, the value of the contact coefficient below 500 becomes very important to the determination of the maximum sheath temperature.

The importance of cooling water temperature on the maximum sheath temperature was determined by holding other system parameters constant during a series of calculations. The center or inlet cooling tube water temperature has a small effect. The heat split to the three cooling tubes is 30%, 35%, 35% for the center or inlet tube and the two outside return tubes respectively. This means that 70% of the heat flow to the HCR cooling water is to the two outside return tubes which will be maintained at approximately the same temperature. It was found that increasing the average coolant temperature in the return lines, a total of 150°F resulted in a maximum sheath temperature increase of 70°F. This effect, then, can be neglected for a normal range of coolant flows of from 12 to 15 gpm per HCR. This also indicates that reversing the coolant flow per HCR would have a small effect on the sheath temperature.

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The effect of graphite temperature on the sheath temperature is quite significant. Figure III shows the percentage of heat flowing to the HCR coolant that is generated in the graphite for the tip section and for the non-poison section. Again, the latter section is imagined to "see" the same conditions as the tip section, which in reality does not happen. This was primarily to determine the sheath temperature in the transition between the tip section and non-poison section. The maximum measured graphite temperature of 1,020°F was assumed to exist in the graphite stack at a distance of 1 inch from the HCR channel. The program was then used to calculate the HCR channel surface temperature. This assumption was based upon the heat split in the graphite moderator in the region of the HCR bank, including the intervening process tubes. About 23% of the heat generated in the moderator in this region is transferred to the HCR coolant and the remaining 77% to the process tube coolant. Further refinements to the graphite temperature become increasingly difficult and would be of doubtful value in the face of other necessary assumptions that were made.

CONCLUSIONS

The following conclusions were determined from the results of the calculations:

1. The important system parameters in determining HCR sheath temperatures are the poison to sheath gas gaps, surrounding graphite temperatures or neutron flux levels, and the contact coefficient between the graphite and the outside surface of the HCR sheath.
2. The range of maximum sheath temperatures that normally could be expected to occur in the old piles during reactor operation is from 350°F to 650°F.
3. The effect of HCR coolant temperature on the sheath temperature is small in the range of flows from 12 to 15 gpm. For a given temperature increase in the average coolant temperature, the corresponding increase in the maximum sheath temperature will be about one half as much.
4. The differences in heat transfer characteristics between the active and non-active sections of the HCR can be neglected.

J. D. Agar
Reactor Design Analysis

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