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K REACTOR UNCOOLED HCR EQUILIBRIUM TEMPERATURE STUDY

January 24, 1966

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K REACTOR UNCOOLED HCR
EQUILIBRIUM TEMPERATURE STUDY

ABSTRACT

Temperature calculations were made on a proposed design of an uncooled HCR for the K Reactors. The calculations were performed with the aid of a FORTRAN coded heat transfer program for the UNIVAC 1107. The results of the calculations indicate that such a control rod is feasible for 4400 Mw and 5000 Mw operation provided certain precautions are taken. These precautions include assuring good contact between the rod and the graphite in the high flux regions and providing reasonable contact between the graphite stack and the graphite slider plates that will be placed in the bottom of the rod channels prior to rod insertion and use.

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K REACTOR UNCOOLED HCR
EQUILIBRIUM TEMPERATURE STUDY

INTRODUCTION.

The horizontal control rods in the Hanford production reactors have been, and are at the present time, a source of trouble during operation of the reactors. During the past several years a major design effort has been aimed at the development of an effective control rod that would operate relatively independent of the condition of the graphite stacks of the existing smaller reactors. The natural gravitation of design methods has been towards an uncooled control rod. This type of design has several features that would justify design and prototype costs. The rod can be designed to allow operation in a distorted graphite channel where a rod with coolant flow is limited in the extent of requiring physical continuity of the whole rod. The uncooled rod also has the advantage of not requiring extensive instrumentation that would be associated with a coolant system. However, as one would expect, the temperatures associated with an uncooled control rod could approach the safe operating temperature limit of the rod sheath materials under consideration. This report is concerned with the results of an analytical study performed in an attempt to predict the temperature behavior of the uncooled rod described below

The uncooled rod is made up of many separate modules, each about 40 inches in length. The modules are connected together by hinged joints allowing vertical motion of the separate modules. A typical rod module is shown in Figure I. The poison modules are composed of 32 volume percent dysprosium oxide and 68 volume percent nickel. The sheath material is Inconel 600. Because of the physical separation of the modules a single module was examined analytically with regards to heat transfer characteristics.

The basic mathematical model consisted of a one-inch slice of a single module. Heat transfer was considered in a two-dimensional array of temperature nodes. This arrangement is shown in Figure II.

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FIGURE 1
UNCOOLED CONTROL ROD
(TYPICAL MODULE)

NOTE. THE SHEATH IS METALLURGICALLY
BONDED TO THE CERMENT CORE

FIGURE II
NODAL DISTRIBUTION

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SUMMARY

An analytical model of the proposed uncooled control rod for the K Reactors was examined for excessively high temperatures that might occur during proposed equilibrium operating conditions with the present graphite stack conditions and with varying system parameters. These system parameters, pile gas atmosphere, graphite temperature, heat generation rates and contact coefficients were varied over a sufficient range to include all normal operating conditions. The calculations were performed with the aid of a FORTRAN coded steady state heat transfer program. The analysis was limited to a two-dimensional approach for heat transport with the rationalization that axial heat conduction down the control rod would be held to an insignificant minimum because of the modular design of the rod. The results of the study indicates that the rod sheath can be maintained below 2000 degrees F for the anticipated normal operating conditions, and this temperature range below 2000 degrees F according to recent developmental tests is acceptable from an operational standpoint. Planned in-pile tests with a sample module of the uncooled rod will further amplify the temperature considerations and will help determine the accuracy of the calculated heat generation rates that were, in turn, used in the temperature calculations.

GENERAL APPROACH

The primary basis for the calculations was normal operation of the K Reactors at the present ACRS power limit of 4400 Mw. The uncooled control rod was assumed to be completely inserted in the maximum average flux region of the pile. The pile gas composition was assumed to be that presently in use at the K Reactors. The system parameters were varied during the calculations to simulate normal operating perturbations and different positions in the power region. Also, an additional power level increase to 5000 Mw was included in the parametric study.

Heat transfer in each module of the control rod is, in reality, three dimensional. However, because of the complexity of a three-dimensional heat transfer model and because the 'worst case' with regards to sheath temperature would occur when axial heat transfer is negligible, only a two-dimensional model was considered. This included heat transfer in a radial direction away from the rod and in a peripheral direction caused by rod distortion in the channel. Some allowance can be made for axial heat transfer, which would, in effect, soften or reduce the maximum calculated sheath temperature necessary to permit heat to be removed from the poison.

The calculations were performed with the aid of a FORTRAN coded heat transfer program written for the UNIVAC 1107. The program was styled after the relaxation method of solving complex temperature gradients. This method of solution requires an initial choice of a temperature gradient for the entire model and then a continuous temperature correction node by node until a heat balance on each node results in an error not greater than that specified in the program. This type of solution is only as accurate as the values for the input parameters and/or the assumptions made, including the input values for the physical properties of the materials comprising the system.

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The following tables list the values for the physical properties that were used in the calculations.

TABLE 1
PHYSICAL PROPERTIES

<u>Material</u>	<u>K</u> <u>BTU/hr-ft²-°F/ft</u>	<u>Emissivity</u>	<u>Heat Generation Rate*</u> <u>BTU/hr-in³</u>
Inconel 500	13.0	0.50	238
Poison	17.2	----	366
Graphite	See Table 2	0.85	23.0
Pile Gas	See Table 3	----	----

*Maximum rate in the high power region for 4400 Mw. These values were calculated from physics considerations.

TABLE 2
THERMAL CONDUCTIVITY OF GRAPHITE

<u>Temperature</u> <u>(°F)</u>	<u>K</u> <u>(BTU/hr-ft²-°F/ft)</u>
140	15.0
356	17.0
464	17.5
572	18.0
662	18.0
752	18.0
842	18.0
1112	17.0
2160	15.0

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TABLE 3
THERMAL CONDUCTIVITY OF PILE GAS

Temperature (°F)	K (BTU/hr-ft ² -°F/ft)		
	<u>70% He - 30% CO₂</u>	<u>70% He - 30% N₂</u>	<u>100% H₂</u>
215	.045	.058	.103
392	.054	.069	.119
572	.064	.080	.135
752	.073	.091	.150
932	.083	.103	.166
1112	.093	.114	.181
1290	.103	.126	.197
1470	.112	.137	----

DISCUSSION OF RESULTS

As mentioned earlier in the report, the calculations were performed in a parametric manner. The parameters considered important to the results are pile gas composition, graphite temperature, the contact coefficient between the control rod and the graphite, contact coefficient between the slider graphite plate and the graphite stack, and the heat generation rates or in the case of a rod fully inserted in the maximum power region, the reactor power level. The results of the calculations are shown in Figures III and IV.

The effect of pile gas composition, as is shown in Figure III, is not significant with respect to the resulting sheath temperatures. This representation is not entirely true. Because of the necessity to include the contact coefficient between the control rod and the graphite stack as a system parameter, the variation of the pile gas atmosphere merely shows the effect on the top and sides of the rod. It is obvious that the major portion heat removed via these surfaces is by radiation because of the relatively great distances through the gas medium, and therefore, the effect of thermal conductivity of the gas is negligible. The effect of the gas composition on the heat removal rate through the bottom surface is reflected in the value of the contact coefficient that is used.

The bottom contact coefficient was varied from 1.0 BTU/hr-ft²-°F to 500 BTU/hr-ft²-°F in order to show the effect of this important system parameter. As can be seen in Figure III, the effect is sizable. If the rod, or a single module of the rod, were suspended some 200 mils or more above the graphite, the resulting sheath temperatures would correspond to those for a contact coefficient approaching 1.0 as an extreme for low graphite temperatures and low heat

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GRAPHICAL REFERENCE OF CALCULATIONS

FIGURE III
 C-2 #1: 10
 C-3 #1: 50
 C-4 #1: 500

A-4000 70% HE - 30% CO
 B-7700 70% HE - 30% CO
 C-4000 70% HE
 D-4000 70% HE
 E-4000 70% HE
 F-4000 70% HE
 G-4000 70% HE
 H-4000 70% HE
 I-4000 70% HE
 J-4000 70% HE
 K-4000 70% HE
 L-4000 70% HE
 M-4000 70% HE
 N-4000 70% HE
 O-4000 70% HE
 P-4000 70% HE
 Q-4000 70% HE
 R-4000 70% HE
 S-4000 70% HE
 T-4000 70% HE
 U-4000 70% HE
 V-4000 70% HE
 W-4000 70% HE
 X-4000 70% HE
 Y-4000 70% HE
 Z-4000 70% HE

FIGURE IV CALCULATED TEMPERATURE DISTRIBUTION

POWER LEVEL 4400 MW
MAX POWER REGION
100 % He
GRAPHITE TEMP 700 °F
CONTACT COEFF #1 = 50.0

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generation rates. If the rod surface were in firm contact with the bottom surface of the graphite channel, the sheath temperatures would correspond to those for a contact coefficient of 500 BTU/hr-ft²-°F or greater. The maximum value for the coefficient cannot be adequately determined without more available experimental data. With the module design of the uncooled control rod, the chances for a large portion of the rod to become suspended above the graphite is considerably reduced over that of the solid rod designs. A limiting low value of the coefficient was calculated for the rod channels located near the top of the stack. The center depression of the graphite stack is accentuated at the top resulting in a sharp change in the slope of the rod channels 3 to 5 feet in from the near side reflector face. A value of 50 BTU/hr-ft²-°F was calculated for the bottom contact coefficient of a rod module, one end of which is suspended about 1 inch above the graphite channel with the other end touching the graphite. This 1-inch clearance is estimated to be the present maximum that can be expected in the top rod channels. The bulk graphite temperature in this region will run about 1200 degrees F and the heat generation rate can be expected to be about 70 to 80 percent of the maximum rate. The resulting calculated maximum sheath temperature, obtained from Figure III, is 1950 degrees F. This may be the worst condition that would be seen by the rod under the present operating conditions. In the lower rod channels, the heat generation rates may be higher because of the proximity of the E-ring, but the graphite stack distortion is significantly less resulting in much higher contact coefficients. Recent development tests of the sheath material indicate that temperatures under 2000 degrees F are acceptable from an operational standpoint. Arrangements have been made for an in-reactor test of a representative rod module to experimentally determine sheath temperatures for the case of a module suspended above the graphite in the manner described above.

Variation of graphite temperatures caused considerable change in the calculated sheath temperature as one would expect. Since it is not possible to predict graphite temperatures during future operating periods, the bulk graphite temperature was varied between 1800 degrees F and 700 degrees F which should include all normal operating periods. In determining which graphite temperature to use, it should be noted that the sheath temperature in Figure III is plotted versus the bulk graphite temperature and not the graphite channel surface temperature. This latter surface temperature will, in actuality, vary significantly down the length of the rod channel depending upon the proximity of a water cooled process tube block. The calculations indicate that there will be a temperature gradient through the graphite of about 150 degrees F from the rod channel surface to the point where the bulk graphite temperature will be measured for the maximum heat flux region. In the lower flux regions the temperature gradient will not be as large. At the present time, bulk graphite temperatures in the range of 1400 degrees F to 1650 degrees F should be used for the K Reactors to simulate severe operating conditions at 4400 Mw. These severe temperatures might occur in regions isolated from the process tube blocks and as a consequence would not simulate normal operating temperatures as seen by the control rods. Bulk graphite temperatures in the range of 1100 to 1200 degrees F would not be uncommon for normal operation of the K Reactors at 4400 Mw. As viewed in Figure III, one

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would want to make sure that the uncooled control modules were wholly supported by the graphite slider blocks. Also, one point that has been completely ignored up to now is that care should be taken in placing the graphite slider blocks in the bottom of the control channels to ensure a good contact coefficient. The calculations were based upon a contact coefficient of 500 BTU/hr-ft²-°F at the bottom of the graphite slider blocks, which is not unjustly high as has been proven out by previous K Reactor graphite temperature calculations.

Calculations were performed for power levels of 4400 Mw and 5000 Mw for the K Reactors. The data is published with reference to 4400 Mw; however, for the 5000 Mw cases, the maximum sheath temperatures will be increased 6 to 8 percent over those for the 4400 Mw case, depending somewhat on the resulting graphite temperatures. The calculations indicate that for a 13.6 percent increase in power, with a constant graphite temperature, the resulting sheath temperature is increased about 6 percent. A graphite temperature increase of 80 percent, from 1000 to 1800 degrees F, results in a sheath temperature increase of 11 percent for a constant power level or about 1/8 temperature change of the graphite in the temperature range.

Generally speaking, the calculated temperatures tend to be favorable towards the use of uncooled control rods in the K Reactors. Some attempt should be made to determine the position of the control rod modules in an extreme graphite channel distortion case. The important criteria to successful operation of the uncooled rod during high power operation is to maintain contact of the modules to the graphite. Known excursions to high graphite temperatures should be followed by close examination of the control rod or rods in the high temperature regions. Again, care must be taken in placing the graphite slider blocks in the control rod channels.

The results of a recent in-pile test of a small segment of an uncooled rod in KW Reactor afforded an experimental correlation to the calculations. The small segment, shown in Figure VI, was placed in the 4-B test hole of KW Reactor for a time span of February 26, 1965, through August 22, 1965. The sample was separated from the graphite by small spacer buttons of known height that allowed a reasonable analytical determination of the contact coefficient between the bottom of rod sample and the graphite boat. The contact coefficient was calculated to be 71 BTU/hr-ft²-°F. This, together with the approximated power and flux during the total operating period, allowed a comparison between the experimentally measured data and the calculated data. This comparison is shown in Figure V. Sheath temperature is plotted versus rod channel surface temperature rather than versus bulk graphite temperature. The calculated temperatures are 10 percent higher than the experimentally measured temperatures. This discrepancy can easily be accounted for in the determination of the contact coefficient. A 10 percent error in determining the correct contact coefficient could easily happen because of the possible variations in spacer button high and in the surface conditions of the graphite boat. Variations in heat generation rate calculations could also account for some of the variations. In any event, the calculated temperatures are conservative and should be accepted as such during future evaluation of prototypical designs of uncooled control rods.

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FIGURE V

GRAPHICAL COMPARISON OF CALCULATIONS AND
EXPERIMENTAL DATA

EXPERIMENTAL DATA FROM HOLE 48-KU

(1) 4100 HP CALCULATED DATA
MARCH - JUNE 1967 REDUCTION IN GEN. RATE
CONTACT CORE 21 IN. BOUTHER EFF. 5%

(2) 4100 HP CALCULATED DATA
JULY - SEPT 1967 REDUCTION IN GEN. RATE
CONTACT CORE 21 IN. BOUTHER EFF. 5%

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EXPERIMENTAL
DATA

GRAPHITE CHANNEL SURFACE TEMP. (°F)

FIGURE VI
KW TEST APPARATUS

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CONCLUSIONS

The following conclusions can be made regarding the possible use of uncooled control rods based upon the calculated results of this study.

1. Use of the proposed uncooled control rod is feasible if reasonable contact can be maintained between the rod modules and the graphite in high flux, high graphite temperature regions.
2. Use of the uncooled rod becomes questionable with close but positive clearance maintained between the rod and the graphite of 35 mils or less.
3. Large clearances between the rod modules and the graphite in high flux regions could result in degradation of the rod sheath.
4. Comparisons between the calculated results and experimentally measured data shows the calculated temperatures to be conservative.

J. D. Agar

Reactor Design Analysis

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