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REPORT HDC 1688

TITLE: GAS COOLING OF CYLINDRICAL CONTROL RODS FOR FILE AREA "G":
PRELIMINARY REPORT

Information Prepared for Reactor Division

Information Prepared by C. H. Robbins

Date: March 23, 1950

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GAS COOLING OF CYLINDRICAL CONTROL RODS: PRELIMINARY REPORT

INTRODUCTION

A first approximation of the gas required to cool control rods for Pile Area "G" is presented in the following report. Since the results are based on a number of assumptions and approximations, they should be considered only as a first approximation and subject to revision.

CONCLUSIONS

1. A gadolinium-stainless steel control rod can probably be readily cooled by gas. Either 300 lbs./hr. of helium or 1000 lbs./hr. of carbon dioxide for each rod is recommended as a basis for preliminary design.
2. A boron-stainless steel control rod would be difficult to cool with gas and would probably require about 1000 lbs./hr. of helium per rod. This would probably cause an excessive pressure drop over the length of the rod.
3. Carbon dioxide has a slight advantage over helium as a cooling agent for control rods. This advantage is so small that the problems of gas cooling control rods should not influence the decision whether to use helium or carbon dioxide in the pile.

BASIS OF CALCULATIONS

The results in this report are based on the following conditions and assumptions. The method of calculations is described in HDC-FT-104.

800 MW power level

Hollow cylindrical rod, 3" OD, 3/16" wall thickness, 33' long in pile

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BASIS OF CALCULATIONS - continued

Rod composition: Gadolinium and stainless steel or boron and stainless steel

Thermal conductivity of graphite: 6.3 BTU/hr F ft (K_0/K equals 10)

Reciprocal of mean free path of gamma rays from gadolinium in graphite: 0.075/cm

Average energy per gamma ray from gadolinium: 6.3 MEV

Neutron capture in rod based on a single central rod fully inserted

Flow of heat in graphite based on rod spacing of 8 blocks from front to rear and 12 blocks from side to side

Cooling effect of postum tubes ignored

Mean graphite temperature around process tubes assumed to be 500 degrees F

Emissivity coefficient between rod and graphite: 0.7

RESULTS OF CALCULATIONS

TABLE I
Gadolinium-Stainless Steel
(Calculations are based on Curve I, Figure I)

Cooling Gas	Helium	Helium	Carbon Dioxide
Gas Rate, lbs./hr.	300	100	1000
Maximum graphite temperature around the rod, deg. F.	660	700	610
Maximum rod temperature, deg. F	485	505	420
Pressure drop across rod length, psi	0.11		0.09
Approximate horsepower per rod required for pressure drop across rod length	0.2		0.06

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RESULTS OF CALCULATIONS - continued

TABLE II
Gadolinium-Stainless Steel
(Calculations are based on Curve II, Figure I)

Cooling Gas	Helium	Helium	Helium
Gas Rate, lbs./hr.	400	300	100
Maximum graphite temperature around the rod, deg. F	500	530	610
Maximum rod temperature, deg. F	395	425	530

TABLE III
Boron-Stainless Steel

Cooling Gas	Helium	Helium
Gas Rate, lbs/hr. .	600	1000
Maximum graphite temperature around the rod, deg. F	805	
Maximum rod temperature, deg. F	930	600 (estimated)
Pressure drop across rod length, psi .		0.8 (estimated)
Approximate horsepower required for pressure drop across rod length		2.5

DISCUSSION

Gadolinium

A gadolinium-stainless steel control rod emits gamma rays, primarily, which are dissipated in the surrounding graphite. Consequently, most of the heat caused by this type of rod is generated in the graphite rather than in the rod itself. A major problem in calculating gas requirements is to determine how much of the heat generated in the graphite flows to the process

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DISCUSSION - continued.

tubes and how much is carried off by the cooling gas. The proportion of heat flow to the gas is a function of the temperature difference between the graphite around the process tubes and the graphite around the rod. The methods used to determine this relationship (Figure I) are comparatively crude but probably give an answer that is off by not more than a factor of two. Fortunately, this may be accurate enough, as is indicated by the results of Tables I and II. There is little difference in the maximum rod temperatures for comparable gas rates in the two tables although the heating curves (Figure I) differ by a factor of about two and a half. The flow of heat from the graphite to the gas is apparently somewhat self-regulating. If the gas flow is reduced, the graphite around the rod heats up relative to the graphite around the process tubes. Consequently more of the heat in the graphite is carried off by the process tubes and less by the gas around the rod.

It is conceivable that no cooling system is necessary for a gadolinium-stainless steel control rod, since Table I shows an increase in maximum rod temperature from 485 to 505 degrees F when the gas flow rate is reduced from 300 lbs./hr. to 100 lbs./hr. No effort was made to investigate lower flow rates than 100 lbs./hr., because this involved using a range on the heating curve which could not be readily determined with the methods of calculation used.

Boron

Gas cooling a boron-stainless steel rod is considerably more difficult than gas cooling a gadolinium-stainless steel rod. This is because of the amount of heat generated in the boron rod.

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DISCUSSION - continued

Helium vs. Carbon Dioxide

From a theoretical standpoint, carbon dioxide should be slightly better than helium as a gas cooling agent. This is borne out by the results shown in Table I.

FUTURE WORK

The heating curve may be determined more accurately by using computing devices. It is hoped that a three dimensional electrical analogue can be set up within the next few months so that the heating curve can be determined with good accuracy.

Since the flow cross section for gas is unusual, tests will be necessary to determine the convection heat transfer coefficient and the pressure drop.

Tests of heating due to neutron capture will be made on the possible control rod materials.

Further calculations will be made following completion of these tests. At that time a better value for the gas requirements will be obtained. These calculations will include the problems of rod tip heating, partially inserted rods, and control rods of solid titanium.

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HEAT FLOW FROM GRAPHITE TO GAS AND/OR ROD AS A FUNCTION OF TEMPERATURE DIFFERENCE BETWEEN THE GRAPHITE AT THE ROD AND AT THE PROCESS TUBES

Conditions: Gadolinium-stainless steel control rod, 3" O.D., 33' long, fully inserted in an 800 MW pile. Heat flow for center of pile.

Example: At the middle of the pile, the mean graphite face temperature around the control rod is given to be 200 degrees F warmer than the mean temperature of the graphite face around the adjacent process tubes. The abscissa of the graph is then plus 200. Curve I indicates 12,500 BTU/HR will flow from the graphite to the gas and/or rod per two foot rod length.

FIGURE I

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