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*E.R. Costley*DESIGN REQUIREMENTS TO REDUCE NFR GRAPHITE TEMPERATURES

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DESIGN REQUIREMENTS TO REDUCE NPR GRAPHITE TEMPERATURES

INTRODUCTION

The present NPR design criteria limits maximum graphite temperature to 1200°C and maximum bulk structural (supporting) graphite temperature to 800°C. The 800°C limit is required to maintain design graphite contraction rate at or below the design rate of 0.02 percent per 1000 MBT/AT. Recent re-evaluation of the NPR graphite contraction problem indicates that contraction may be greater than the design rate. This document presents a discussion of the various means which can be used to reduce graphite temperatures below present design limits. Reduction in graphite temperature will reduce the contraction rate if graphite contraction is temperature sensitive and in addition will reduce process tube surface temperatures.

SUMMARY

The only practical method of reducing graphite temperatures is to reduce the process tube channel clearance, presently 150 mils. If enough clearance reduction is allowed, the load bearing graphite temperature can be reduced to 500°C. The decision to reduce the process tube channel clearance cannot be made until an inpile test to determine the effect of channel contraction on the tube block and process tube stresses is completed. In order not to delay the purchase of NPR graphite, it is recommended that the tube blocks be ordered with a channel having tube installation clearance, only. Depending on the results and availability of test data, the final process tube channel clearance can be established at a later date which will have to be compatible with vendor production and NPR construction schedules.

DISCUSSION

Graphite temperatures and consequently process tube temperatures can be reduced by one or a combination of several of the following techniques:

1. Using larger moderator cooling tubes.
2. Reducing moderator cooling tube insertion allowances and thereby increasing cooling effectiveness.
3. Reducing the process tube-graphite channel clearance to increase cooling effectiveness of the process tube.

In order to determine the results of the above techniques, several heat transfer problems have been run on the NPR lattice heat transfer program written for the IBM-709 computer. Comparison must be judged against a standard. In this case, the standard is the design presently considered as suitable for NPR. It consists of a 3/4-inch moderator cooling tube with a 15 mil tube-graphite clearance and a process tube centered in its channel by means of trunnions on 32-inch centers. Total process tube-channel clearance at the trunnion is 15 mils, that

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between trunnions is 150 mils, or a 75 mil radial clearance between the centered tube and channel. Total moderator cooling system design heat load is 60 MW. A summary of heat transfer data based on this design is contained in Table I, Appendix A.

Using Larger Moderator Cooling Tubes

Figure 1-a shows the effect of reducing graphite temperatures by increasing the size of the moderator cooling tube size. The process tube configuration was held to the values for the standard case, (150 mils of process tube clearance, etc.) and the cooling tube clearance was held at 15 mils.

The temperatures shown are an average of what will exist in a load bearing tier with and without a trunnion. The trunnion, providing a good path for heat transfer to the process water, contributes substantially to the cooling of the load bearing graphite.

Enlarging the cooling tube is not an effective means of reducing graphite temperature. The tube size must be almost doubled to achieve a 100°C reduction in graphite temperature. Also, the moderator cooling system capacity will have to be increased by 52 percent.

Reducing Moderator Cooling Tube Clearance

The minimum cooling tube clearance required to insert a tube into the stack is estimated to be 15 mils. The original design called for a 50 mil clearance for the cooling tubes. It has been estimated that a 70°C reduction in load bearing graphite temperature was obtained by reducing the cooling tube design clearance to 15 mils. Refined calculations show that this value will not increase the required capacity of the moderator cooling system above the design 60 MW. There is, therefore, definite incentive to reduce the moderator cooling tube to 15 mils.

* Some reduction of the cooling tube gap due to contraction of the filler bar, may take place so that the cooling tube may eventually seize in its channel. This will not be serious. If the cooling tube must be removed, the thin tube wall can be split and the channel can be breached before installing a new tube.

* There has been some thought given to reducing the clearance further by expanding the tube after it has been installed. No method has been perfected yet so that this technique may likely not be feasible. A calculation was made to determine the extra cooling benefit of expanding the tube so that an equivalent 4 mil total tube channel clearance existed. In this case, the temperature of the load bearing graphite was reduced an additional 100°C from that shown in Table I. But as a consequence, the fraction of total heat increased to 39 percent. This would require a 30 percent increase in the capacity of the moderator cooling heat removal system. Therefore, this technique cannot be used without a capital cost increase unless some compensating change in lattice design is made to offset the flow of heat to the moderator cooling tubes.

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Reducing Process Tube-Graphite Channel Clearance

The greatest gains in graphite temperature reduction can be made by reducing the process tube channel clearance. This becomes evident when it is realized that about 70 percent of the heat generated in the graphite is removed through the process tube.

It has been calculated that the load bearing graphite temperature can be reduced 104°C from the temperatures in Table I, Appendix A, (to $575-606^{\circ}\text{C}$) by reducing the process tube channel clearance from 150 mils to 75 mils. There is simultaneously a 15 percent reduction in the fraction of heat flowing to the moderator cooling system.

Before the decision can be made to reduce process tube channel clearance, the effects of contraction on clearance requirements must be examined. The design contraction rate is presently 0.02 percent/1000 MWD/AT. Contraction will ideally cause a tube block to contract by the amount ϵ shown in dash line in the sketch. Therefore, it follows that the channel bore diameter will contract by an amount ϵ . The value of ϵ can be estimated as follows:

The total accumulated exposure to the graphite will be 165,000 MWD/AT for 25 years. This value is based on 226 kw/ft specific tube power and a 20 lb/ft fuel element. This number is therefore on the high side, since worst conditions are assumed. Now using the design contraction rate, the graphite will contract $0.02 \times 10^{-3} \times 165,000$ equals 3.3 percent. Therefore, it is probable that a 3.4 inch diameter channel will contract 0.112 inches.

The question that must be answered before clearances are reduced is: Must the process tube be fully protected against this much contraction? This can be answered with certainty only if the following additional questions can be answered:

1. Does a graphite channel contract at the same rate as the external dimensions of the block?
2. As the graphite contracts around a process tube, will the contraction be retarded or stopped due to reduction in graphite temperature and/or the restraining force exerted by the process tube? Will the restraining forces damage the tube and/or tube block?

The 150 mil process tube channel clearance assumes worst conditions, by allowing 112 mils for contraction and 38 mils for installation clearance and a factor of safety. If contraction around a process tube is restrained this design clearance can be reduced to obtain lower graphite temperatures.

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Maximum process tube surface temperature must be considered along with process tube channel clearances. Maximum process tube surface temperatures will exist at points where the tube contacts graphite. The bases of centering the process tubes on trunnions has been to restrict these points of contact to locations near cooled filler bars. Trunnion clearance has been established at 15 mils to reduce the heat transfer load across the actual point of contact. By proper arrangement of the trunnion, the maximum process tube temperature can be restricted to $\sim 665^{\circ}\text{F}$. (see HW-63953). The process tube can still touch graphite away from the trunnion because of stack distortion. Even for 32-inch trunnion spacing, when the tube will most likely touch over a cooled filler bar, the process tube surface temperature will go to 730°F , due to the 150 mil channel clearance.

If the process tube channel clearance can be reduced to 75 mils, the temperature for a tube touching away from trunnion can be reduced to $\sim 705^{\circ}\text{F}$.

Therefore, we can either protect the process tube against a high surface temperature by reducing channel clearance, or we can protect the process tube and tube block against the consequences of channel contraction by enlarging the clearance. These two possibilities are mutually incompatible.

To increase the channel clearance to 250 mils to protect against a possible 0.04 percent contraction rate appears to be unwarranted in any case. Load bearing graphite temperatures will increase to near the 800°C limit, process tube temperatures will increase to 600°C at the trunnion and 750°F if it touches graphite between trunnions. In addition, the increased heat flow to the moderator cooling tube will require a 15 percent increase in heat removal capacity.

As a final study, the author has hypothesized a case where the process tube channel contraction allowances have been completely minimized. The case assumed a 50 mil process tube clearance for tube installation allowances. Secondly, the trunnions were eliminated. Eliminating trunnions would make post startup tube installation easier, since channel branching will be simplified. Therefore, the process tube was assumed to lay along the entire channel. The results are: The volume average temperature of the load bearing graphite was reduced to 504°C , while the maximum process tube temperature was 373°C (704°F). The heat load on the moderator cooling system dropped to about 41 MW, so that either a larger cooling tube or a tube expansion technique could be used without exceeding the 60 MW capacity of the system. For instance, a 1-inch moderator cooling system will reduce load bearing graphite temperature to 470°C , maximum process tube temperature to 369°C (697°F) while the system heat load becomes 50 MW.

CONCLUSIONS AND RECOMMENDATIONS

There appears to be only one method available to reduce graphite temperatures that will not require an increase in capital costs. This is to reduce process tube channel clearance for the present design of 150 mils. In addition, process tube channel clearance cannot be increased much above 150 mils without seriously raising graphite and process tube temperatures and requiring an increase in moderator cooling system heat removal capacity. Also, the moderator cooling tube size cannot be increased without a corresponding increase in the heat removal system

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capacity, unless the process tube channel clearances are reduced to keep the heat flow split as now designed.

The effects of graphite contraction around a process tube must be determined before a reduced process tube channel clearance can be used. Hanford Laboratories is presently conducting an inpile test to determine the effect of graphite contraction on a channel.* It will be some time before conclusive results will be available. Since the design of NPR cannot wait, the author proposes the following course of action to be taken.

Order the graphite with enough clearance for tube installation only. The final decision on additional tube clearance requirement can be delayed in expectation that test data will be available from HLG before graphite machining starts. If the test results are favorable, the process tube clearance can be left with installation clearances only. If less than 50 mils clearance is required, the trunnions can be eliminated. If test results are unfavorable or unavailable, the 50 mil clearance can be breached to a maximum of 150 mils. Trunnions must then be used. The incentive of a possible 200°C reduction in graphite temperatures appears to warrant the above procedure.

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Attachment

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APPENDIX A
METHOD OF HEAT TRANSFER ANALYSIS

The results contained in this report were obtained from an IBM 709 program especially designed to simulate the NPR lattice. Briefly, the lattice has been divided into 656 nodes. The nodes are interconnected through heat flow paths, forming a heat transfer network. Heat input depending on the volume and material of each node is input to each node. The solution consists of specifying a heat balance on each node (heat into a node must equal the heat flow out). The temperature distribution required to satisfy the heat balance of all the nodes is calculated by the Jacobi-Seidel iteration process. A full detailed report of this program is forthcoming.

Table I, this appendix lists important heat transfer properties of the lattice arrangement presently considered most suitable for NPR at this time. Table II lists the thermal properties, specific tube, etc., used in all the calculations used to prepare this report.

TABLE I

Basis	Present NPR stack design
	Total process tube clearance - 150 mils
	Process tube centered
	Cooling tube diameter - 3/4 inch
	Cooling tube clearance - 15 mils
	Trunnion length - 3.2 inches
	Total trunnion clearance - 15 mils
a. Volume average temperature of load bearing graphite	622°C, 706°C ⁽¹⁾
b. Maximum graphite temperature	917°C, 959°C ⁽¹⁾
c. Maximum process tube temperature	351°C, 371°C, 387.5°C ⁽²⁾
d. Percent heat flowing to the cooling tube	26%, 29.3% ⁽³⁾

- (1) The first value represents that in a support tier where a trunnion is located. The second value represents the temperature in a support tier without a trunnion. Since trunnions are on 32-inch centers and cooling tubes are on 16-inch centers, every other support tier will be cooled to the first value, etc.
- (2) The first temperature is for a tube at a trunnion which has been partially insulated with a ceramic to reduce heat transfer through the trunnion. The second temperature is for a tube at a trunnion which has not been insulated and the third temperature is for a tube touching midway between trunnion. (see HW-63953, for a further discussion.)
- (3) This value is the fraction of the total heat generated in the graphite and process tube which is removed by the moderator cooling tube. The first value is for the case where an insulated trunnion is present, the second for no trunnion over the cooled filler bar.

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TABLE II
PHYSICAL CONSTANTS USED IN HEAT TRANSFER ANALYSIS

1. Thermal conductivity of graphite	See note 1 & Fig. 2-b
2. Thermal conductivity of reactor atmosphere	See Fig. 2-a
3. Emissivity of zirconium oxide (process tube)	0.6(2)
4. Emissivity of zirconium (moderator cooling tube)	0.3
5. Thermal conductivity of zirconium	8 Btu/hr-ft ² -°F
6. Specific tube power	226 kw/ft
7. Percent heat generation in the graphite	4.55(3)
8. Percent heat generation in the process tube	0.4(3)
9. Process water temperature (at stack center)	460°F
10. Moderator coolant temperature	150°F
11. Process tube film coefficient	5000 Btu/hr-ft ² -°F
12. Cooling tube film coefficient	3000 Btu/hr-ft ² -°F

- (1) Based on an average of the values shown in Figure 1.1.3, HW-53612 REV, for irradiated graphite.
- (2) NASA-MEMO-1-20-591, "Measurement of Total Hemispherical Emissivity of Several Stable Oxidized Metals and Some Refractory Oxide Coating," W. R. Wade, 1959.
- (3) HW-59075, "NPR Heat Generation Rates During Operation," R. Nilson, 2/13/59.

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FIGURE 1

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FIGURE 2

a.

THERMAL CONDUCTIVITY OF HELIUM

b.

THERMAL CONDUCTIVITY OF GRAPHITE

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