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PRTR TOTAL ENERGY DISTRIBUTION CALCULATIONS.

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PRTR TOTAL ENERGY DISTRIBUTION CALCULATIONS

INTRODUCTION

Since the calculation of the PRTR energy distribution was first carried out by J. R. Triplett(1), the design has become sufficiently fixed to allow a refinement of his values.

The present analysis, also, includes a calculation of the fraction of energy which is released in the shroud and process tubes that flows to the primary coolant and moderator. In addition, the heat transferred from the primary coolant to the top and bottom shield coolant is taken into consideration. Nuclear data used in the original calculations still appears satisfactory and is, therefore, utilized in the present analysis.

SUMMARY

The results of the heat transfer and physics analysis indicate the primary coolant removes 94.8 percent or 66.4 MW of the 70 MW nominal total power. The reflector energy is .92 percent or .606 MW. The total heat load on the top and bottom shield coolant is .78 percent or .545 MW. In addition .36 percent or .251 MW are removed in the radial cast iron shield; therefore, the total energy removed by all the shields is 1.14 percent or .796 MW. Then by the difference of the heat removed by the primary coolant, shields, and reflector and the total heat, the moderator heat load is 3.14 percent or 2.2 MW. Previously, Triplett had estimated the moderator heat load as 2.019 MW.

Calculations based on the "hottest channel" indicate that moderator boiling on the surface of the shroud tube will not occur when the process tube is centered. However, if the process tube is off-center by .219" mild surface boiling may occur.

Temperature calculations in the exposed shroud tube above the moderator level of the "hottest channel" indicate that the maximum is 560 F. Finally, temperature calculations at the upper surface of the moderator indicate that mild boiling will occur on the shroud tube surface.

DISCUSSION

1. Total Energy Distribution Calculations

Previously, J. R. Triplett had determined the heating load in the PRTR moderator. In his calculations the portions of gamma and neutron energies released in the shroud and process tubes that entered the primary coolant and moderator were assumed values. Therefore, a heat transfer analysis was made in an effort to evaluate the actual shroud-process tube energy split. Then, based on these heat transfer results, a refined calculation was made on the physics aspects to determine the total heat load on the D_2O moderator system.

In addition, in Triplett's original work heat transfer by conduction from the process channel to the top and bottom primary shield coolant was neglected. An estimate of this energy transfer was determined in an effort to evaluate the total heat load on the shield coolant circuit.

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(1) Triplett, J. R., PRTR Gamma Ray and Neutron Heat Generation Calculations, HW-52347, October 21, 1957.

1.1 Heat Transfer Analysis

1.1.1 Moderator heat load calculation

The energy transferred into the moderator is derived from gamma and neutron energy releases in the shroud tubes and from heat transfer across the helium gas annulus from the process tubes. The total energy transferred into the moderator is thus determined from a heat balance on the aluminum shroud tube. Assuming the average process tube temperature is 504 F and the average moderator temperature is 140 F, the thermal conductance across the helium annulus is 5.35 B/hr ft F. Specific gamma heat rates in the shroud and process tube are derived from Triplett's original values using more recent core power distributions.(2) The values used in these calculations are .476 w/gm and .51 w/gm for the aluminum shroud and the Zr-2 process tubes, respectively. The water film coefficient on the shroud tube - moderator interface is 100 B/hr ft^2 F. The dimensions of the shroud and process tubes are 4.25" OD x .060" wall and 3.55" OD x .015" wall, respectively. The D_2O moderator flow rate is 1100 gpm at an inlet temperature of 137 F.

Based upon these values, the total heat transferred into the moderator circuit from the 85 shroud and process tubes is calculated to be 0.561 MW. These calculations, also, show that a net transfer of energy from the primary coolant to the moderator does not occur. Instead, the total energy transferred to the moderator is derived from the gamma heating in the shroud and process tubes. All the gamma heat released from the shroud tube and 44 percent of the gamma heating in the process tube the moderator. Similarly, if the shroud and process tube are considered as one unit, the heat transferred to the primary coolant is 40 percent of the combined gamma heating. However, if the tubes are considered individually the heat transferred to the primary coolant is made up of zero percent shroud tube gamma heat and 56.0 percent process tube gamma heat.

1.1.2 Total shield heat load calculations

In the calculations performed by Triplett,(1) heat transfer by conduction from the primary coolant to the top and bottom primary shield coolant was neglected. An estimate of this heat transfer rate has been made in order to ascertain the total heat load on the top and bottom primary shield heat exchanger.

In these calculations, it is assumed that gamma heating in the piping (including shield plugs) within the shield boundaries is negligible. Therefore, any transfer of heat to the shields must originate from the primary coolant. The shield coolant temperature is assumed to be constant at 110 F. The primary coolant temperature in the top and

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(1) Op. cit., Page 4
(2) Heginbal, J. J., Effect of Moderator Height on Reactivity and Vertical Flux Distribution in PRTR, HW-59373, March 3, 1959.

bottom shields is taken to be 530 F and 478 F, respectively. The calculated total heat conductance per process tube between the primary coolant and the top shield coolant is 13.24 B/hr F and is 12.56 B/hr F between the primary coolant and the bottom shield coolant.

Based upon these values, the heat transferred from the 85 process channels to the top shield coolant is 0.139 MW, and 0.115 MW to the bottom shield coolant. Triplett(1) has estimated that the heating in each primary shield due to gamma and neutron absorption is 0.1457 MW. The total heat loads are then, 0.2847 MW and 0.2607 MW for the top and bottom shields, respectively. Therefore, the total load on the shield heat exchanger is 0.545 MW.

Triplett(1) has also determined that 0.2506 MW of gamma and neutron energies are absorbed in the radial shield. Thus, the total heating load for all the shields is 0.796 MW or 1.14 percent of the 70 MW nominal total reactor power.

1.2 Physics Analysis

Calculation of that fraction of the total energy per fission which is transferred to the coolant is carried out by the same method as originally employed by Triplett.(1) Evaluation of the various energy generation processes is as follows:

1.2.1 Fission product kinetic energy - 168 Mev/fission

1.2.2 Fission product beta decay - 7 Mev/fission

Because of the extremely short range of these particles, the energy of these two processes is entirely converted to heat within the fuel and transferred to the coolant.

1.2.3 Neutron kinetic energy - 5 Mev/fission

The ratio of slowing down in coolant and fuel to the total is given by

$$\frac{[\xi\Sigma_s V]_{\text{fuel}} + [\xi\Sigma_s V]_{\text{cool}}}{[\xi\Sigma_s V]_{\text{fuel}} + [\xi\Sigma_s V]_{\text{cool + mod.}}},$$

where ξ is the logarithmic energy loss per collision, Σ_s is the macroscopic scattering cross section and V is the volume of the material.

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(1) Op. cit., Page 1

For the 19-rod cluster fuel assembly this amounts to approximately 10 percent. Therefore, of the 5 Mev, 0.5 Mev is transferred to the coolant.

1.2.4 0.7 Mev fission product gammas - 4 Mev/fission

Since the escape probability for these gamma rays from the fuel-coolant is 0.22, 78 percent of this energy goes to the coolant directly. Seventeen percent of the 0.22 fraction escaped is absorbed in the process tube of which 56 percent or 0.020 goes to the coolant. It can be shown that roughly 0.027 is absorbed in neighboring fuel rods and process tubes. Thus, (0.78 + 0.020 + 0.027) or 82.7 percent (3.31 Mev) is transferred to the coolant.

1.2.5 2 Mev fission and fission product gammas - 9 Mev/fission

As above, the fuel-coolant escape probability is 0.408 and of these 0.11 are absorbed in the process tube. Fifty-six percent of this energy is returned to the coolant, resulting in 0.024 plus 0.592 or 61.6 percent of the energy which appears as heat in the original channel. The UO_2 and 40 percent of the Al-Zr contribute 44 percent of the heat from these gammas in the core, and it can be shown that 25.6 percent of this energy escapes the cell. Thus, (0.616 + 0.44 x 0.256) or 72.9 percent (6.56 Mev) flows to the coolant.

1.2.6 5 Mev fuel capture gammas - 5 Mev/fission

Again, the escape probability of the fuel-coolant is 0.430 and of this 0.09 are absorbed in the process tube of which 56 percent is returned to the coolant. Thus, 59 percent of the heat flows to the original channel.

The fraction reaching the cell boundary can be shown to be 0.316, and the UO_2 and 40 percent of the Al-Zr contribute 54 percent of the absorption of these gammas in the core. Thus, the heat to the coolant is (0.59 + 0.54 x 0.316) or 76 percent (3.80 Mev).

1.2.7 9 Mev non-fuel capture gammas - 2 Mev/fission

In the homogenized core, the D_2O, UO_2 and Al-Zr contribute 0.35, 0.58 and 0.07 of the absorption of these gammas, respectively. Therefore, since 9 percent of the D_2O heat is in the coolant and 40 percent of the Al-Zr heat goes to the coolant, (0.58 + 0.35 x 0.09 + 0.07 x 0.40) or 64 percent (1.28 Mev) appears in the coolant.

Summing processes 1 through 7 results in a total of 190.39 Mev/fission or 95.19 percent of the 200 Mev/fission is available to the primary coolant. However, heat transfer calculations (Section 1.1.2) indicate that 0.254 MW is transferred by thermal radiation and conduction to the top and bottom biological shields. Therefore, 94.80 percent or 66.4 MW of the 70 MW nominal total reactor power is removed by the primary coolant.

The total heating, generated and/or transferred, in the combined shields is 1.14 percent. For the reflector, the total is 0.92 percent. Thus, by difference between the total heat and the heat added to the primary coolant, shields, and reflector, the heat load on the moderator circuit is 3.14 percent or 2.20 MW of the 70 MW total reactor power.

2. Effects of Eccentrically Placed Process Tubes

Based on the normal operating conditions of the "hottest channel", calculations were made to determine the effects of eccentrically placed process tubes in promoting subcooled surface boiling on the shroud tube. The results indicate that when the process tube is concentric with the shroud tube, the maximum shroud tube temperature is 172 F. Therefore, surface boiling will not occur. However, if the process tube is placed off-center by .219" (helium annulus is a nominal .290") the calculated shroud tube temperature is 212 F. Therefore if the process tube is off-center by more than .219" local surface boiling is indicated. However, calculations at the .219" offset indicate the surface heat flux on the shroud tube is only 6,700 B/hr ft^2. At these low heat fluxes, any boiling which may result is not apt to become vigorous, and the heat transfer mechanism may even remain free convection.

3. Shroud Tube Temperature Above the Moderator

The maximum temperatures of the shroud tube exposed above the moderator and at the moderator surface were calculated.

The maximum shroud tube temperature exposed above the moderator was calculated assuming only radial heat transfer from shroud tube to the process tube and subsequently to the primary coolant. Based on .067 w/gm gamma heat in the exposed shroud tube and 542 F primary coolant temperature, the calculated maximum shroud tube temperature is 560 F.

The shroud tube temperature at the moderator surface was determined by deriving separate heat balance equations for the shroud tube above and below the moderator level. The solution of these equations assumed a constant temperature and temperature gradient in the shroud tube at the moderator surface and that the shroud tubes extended to infinity in both directions away from the moderator surface.

Assuming a constant gamma heat of .067 w/gm in both sections of the shroud tube, and a non-boiling film coefficient in the submerged section of the shroud tube, the calculated temperature and heat flux are 238.4 F and 9,460 B/hr ft^2, respectively. Therefore, mild boiling will occur on the shroud tube at the surface of the moderator.

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