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Conf. 931160--11

ESTIMATION OF MAXIMUM TEMPERATURES IN SPALLATION TARGETS

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An important feature of neutron spallation targets is that the decay heat after beam shut-down is low compared to that found in nuclear reactors operating at the same neutron flux level. A complete loss of cooling in a water-cooled reactor can cause core damage due to high decay heat. Conversely, spallation targets can be designed to incur no damage in the case of loss of liquid cooling because of their relatively low decay heat. To effect such a design, it is important to know the maximum temperatures that can occur under severe accident conditions, and how those temperatures are affected by certain design parameters.

Heat transfer analyses have been performed to calculate the temperatures that would result in a neutron spallation target given absence of water cooling, complete dryout, and power at decay heat levels. A preliminary evaluation suggests that radiation is by far the dominant heat transfer mode. Thus, a steady-state radiation heat transfer model was developed to estimate temperatures for a typical spallation target configuration. Conduction and convection contributions to heat transfer are neglected in this analysis, but would be expected to reduce temperatures below those given here.

The geometry considered in the model is a group of rod bundles enclosed in a chamber which acts as a heat sink. This is typical of designs being considered for spallation targets. Each bundle contains 91 rods within a hexagonal shell with appropriate spacing between rods. If rod temperatures are assumed to be invariant to 60-degree rotations and are mirror-symmetric, the rod array is 12-fold symmetric within the hexagonal shell. Only 12 representative rods need to be modeled. In the model it is assumed that all surfaces are

*This work was supported by the U.S. Department of Energy under Contract DE-AC04-76DP00789.

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approximated as isothermal diffuse-gray emitters and reflectors.

The radiative transfer equation was written for the surfaces of each of the 12 representative rods, the inner shell surface, the outer shell surface, and the heat sink surface. One additional equation equates the radiant flux entering the inner shell surface with the radiant flux leaving the outer shell surface. The resulting matrix was inverted to solve for the rod and shell temperatures, and for the shell and heat sink surface fluxes. The number of rod bundles within the heat sink is incorporated in the heat sink equation. For a geometry with more than one rod bundle, this requires that all shells be assumed to have the same temperature and view factor to the heat sink.

The parameters varied in the study were surface emissivity, ϵ , the view factor from the shell(s) to the ultimate heat sink, F , number of rod bundles, N , and spacing between rods within bundles, s/D . Depending on the particular application, the decay power can range from a few MW/m^3 to 10's of MW/m^3 . At 10 MW/m^3 , Figure 1 shows that for ϵ and F of 0.5, the average rod temperature is near 1600 K. Changes in emissivities produce significant changes in temperature, indicating that rod temperatures can be significantly reduced by using target materials of high emissivity. A reduction in the spacing between rods within the bundle increases temperature only slightly. Of course, another way to reduce temperature is to reduce the decay power density by using a larger target and beam size. Figure 2 shows that the view factor from the shell to the heat sink, and the number of rod bundles within the chamber, have a small effect on temperature.

Assurance of target integrity under dryout conditions can be increased by sizing the target for operation at low power densities, and by using target materials of high emissivity that can withstand temperatures on the order of 1500-2000 K.

Figure 1. Average rod temperatures using $N = 104$, $F = 0.5$.

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Figure 2. Average rod temperature using $\epsilon = 0.5$, $s/D = 0.32$.

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