Systems for High-Power Density Applications

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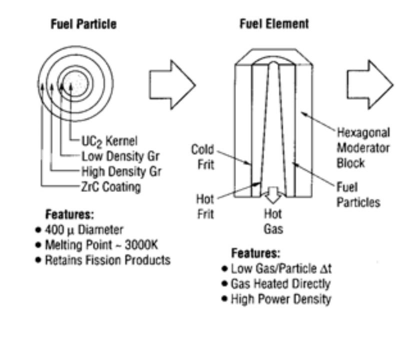
The next generation neutron source reactors, nuclear thermal propulsion reactors, spallation neutron sources, and accelerator targets will all have one common thread - they will all operate at power densities significantly higher than the current generation. Thus, heat removal from the solid component to an appropriate coolant becomes a significant issue affecting performance, safety etc. of the element/target. Heat transfer between a solid and the surrounding coolant can be simply expressed as a product of the heat transfer coefficient, the heat transfer area, and a thermal gradient. The first and third terms are a function of the coolant properties, and the solid properties respectively. However, the second term is determined entirely by the geometrical design of the element/target. Randomly packed spheres result in the largest area per unit volume for contact between the solid surface and the coolant, when compared to other common geometric shapes for the same characteristic dimension. This property has been exploited in the following applications at BNL.



Nuclear Thermal Propulsion. - During the Space Nuclear Thermal Propulsion (SNTP) program a series of reactor designs was investigated, which were based on the direct cooling of fuel micro-spheres randomly packed in cylindrical shaped beds. The coolant in these reactor designs was hydrogen, the particle diameter was ~ 500 μm, and the beds were ~ 1.5 cm thick. Experiments were carried out during this project in which power densities of 21.8 MW/L was measured for flowing hydrogen coolant with a bed outlet temperature of 1770 K and a pressure of 5.2 Mpa.

Very high flux reactors - Two applications of very high flux reactors were investigated. First, it can be shown that to first order the "brightness" of a neutron source reactor is proportional to the product of the cube root of the thermal power and the two thirds root of the power density. The ANS, which was designed with an average power density of 5 MW/L, required a power of well over 300 MW to achieve a flux of 5.0E+15 n/cm2-s. Doubling the ANS power density, requires only 80 MW to equal the ANS flux performance, and quadrupling the ANS power density requires 160 MW to double the ANS performance.The advantage of generating high neutron fluxes at low power is that the gamma-ray background is lower, which has several beneficial engineering and neutron physics implications.

An actinide burner based on a high power density reactor was also investigated.The advantage of this arrangement is that the transmutation proceeds very rapidly, and that both iodine and technetium can also be transmuted.

Pulsed spallation neutron source - The arguments made regarding the efficient removal of heat from an appropriate bed of particles, which act as the target material in a spallation source, also apply to this application with the following additional advantage. In the case of a pulsed spallation source the proton beam power is deposited in ~ 1 ms. This short time results in a thermo-mechanically enhanced thermal stress which is a function of the sonic velocity in the material, and the characteristic size. Since the particles can be made as small as desired, the stresses in the particles can be controlled. Possible target designs have been developed for a 5 MW pulsed source and for theBNL-AGS.

Steady state accelerator targets - Steady state spallation targets have also been designed as neutron sources to replace the BNL-HFBR, and as a source for a sub-critical multiplier blanket. These have used the efficient heat removal properties of randomly packed particle beds to result in bright sources, limited only by the material damage of the front window. Liquid metal, heavy water, and helium coolants were explored in these studies.

Other accelerator applications - Concentrating beam loss in one section of an accelerator is desirable and can be achieved by designing appropriate collimators. Collimator designs to control the loss in the HEBT, Ring, and RTBT of the SNS accelerator facility are based on particle beds of stainless steel cooled by water. These designs require a structure to remove the deposited heat, and survive the transient thermal stresses.

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