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Thermal Reactor Design for a Neutron Scattering Source Facility*

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Material scientists have expressed interest in a neutron scattering facility with a thermal neutron source strength corresponding to a flux of 5.0×10^{15} n/cm^2-sec. The source would need to be steady over extended time periods and be accessible to experimental stations. For this purpose, we are investigating reactor designs with high thermal flux levels outside the core. The desired core full-power operating period between refuelings is two weeks or longer.

The purpose of this paper is to present conclusions drawn from preliminary neutronic calculations and to present a possible reactor design configuration capable of meeting the above thermal flux level, flux location, and lifetime requirements.

Currently, the High-Flux-Isotope-Reactor (HFIR) at Oak Ridge National Laboratory provides a maximum thermal flux level of $\sim 5.5 \times 10^{15}$ n/cm^2-sec in the central target region; however, the peak thermal flux in the reflector is only $\sim 1.0 \times 10^{15}$ n/cm^2-sec. HFIR is a 100-MW$_{th}$ light-water cooled and moderated reactor with a beryllium reflector. The fuel is U_3O_8 (in aluminum filler) contained in aluminum plates. Neutronic calculations performed using a two-dimensional model of the existing HFIR showed that doubling the power level and using various core configurations would not achieve the desired flux level of 5×10^{15} n/cm^2-sec in the reflector.

In an attempt to obtain a reactor design with a higher flux in the reflector, scoping calculations were performed for various core configurations, coolants, and reflector materials. The VENTURE[1] modular code system was used and the reactor was modelled in two-dimensional R-Z geometry; six energy groups were used to account for spectrum effects; 16-day burnup histories were followed; and burnable poison distributions, control rod movements, and radial fuel grading were modelled to assess their effects upon fuel requirements and flux distributions. The conclusions drawn from the scoping analysis are that

1) Substituting D_2O for H_2O as the moderator and coolant results in a higher thermal flux level in the reflector. However, use of D_2O also results in an increase in the fissile loading requirements.

With a D_2O moderator and reflector,

2) A fractional increase in the total core power increases the peak reflector flux, ϕ_r, but not by the same fractional amount. The reason is that changes in fuel burnup effects (fuel depletion, control rod motion, burnable poison distributional changes) are not proportional to the change in total power. Thus the initial fissile loadings and burnable poison distributions are quite different for two given power levels.

3) For the same power, reasonable changes in the core configuration increases ϕ_r by 10-25%.

4) Decreasing the fuel-to-moderator volumetric ratio from that used in HFIR reduces the fissile loading but also decreases ϕ_r.

These conclusions lead to the identification of a D_2O moderated, cooled and reflected design that, at a power level of 200 MW_{th}, has a peak thermal flux in the reflector of at least 5×10^{15} n/cm^2-sec for a 16-day full-power fueling period. Table I lists the design data and the calculated performance data.

The use of D_2O in the reactor core enables a larger fraction of fast neutrons to escape the core and become thermalized in the reflector compared to the more effective H_2O moderator. Moreover, the D_2O reflector diffusion length is much greater than that of an H_2O or Be reflector and thus the reflector peak thermal flux is further removed from the core. As the peak flux is moved away from the core, experimental access is facilitated.

The control system is a cylindrical sheath of boron and aluminum between the core and the reflector. Because the peak thermal flux in the reflector is primarily determined by slowing down of fast neutrons from the core, movement of the control cylinder has a negligible effect upon the location and magnitude of the peak flux. Thus the effect of reactor control over the fuel cycle lifetime upon the neutron source requirement does not introduce serious additional design constraints for the D_2O cooled and reflected reactor.

From a fuel utilization standpoint, using D_2O rather than H_2O as the coolant results in an undermoderated core and requires a greater inventory of fuel. Table I shows that the initial ^{235}U loading for a 16-day full-power cycle is 13.1 kg, and the end-of-cycle fissile inventory is 8.6 kg. These figures compare with values of 9.7 kg and 6.1 kg for the HFIR operating at the same power and for the same cycle length.

The conceptual design study conclusion is that use of D_2O as a coolant, moderator, and reflector is capable of producing the required reflector thermal flux of 5.0×10^{15} n/cm^2-sec. However, a fuel-cycle cost penalty and the complications of handling D_2O are negative factors that will be considered in future assessments.

Table 1. Design and Performance Data for a 200-MW_{th} D_2O Moderated Reactor

Core Power, $MW_{(th)}$	200
Core Height, m	0.64
Core Diameter, m	0.36

Full-Power Days	Control Position (cm)[a]	^{235}U (kg)	^{10}B (g)[b]	Peak Reflector Thermal Flux (10^{15}n/cm^2-sec)	Peak Power Density (kW/cm^3)
0	0	13.1	5.96	5.3	11.7
4	8	11.9	3.57	5.6	10.4
8	16	10.8	2.46	5.8	9.4
12	32	9.7	1.48	6.0	8.5
16	∞	8.6	0.91	6.2	8.1

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[a] Axial distance from core centerline.

[b] Burnable poison.

References

1. Vondy, D. R., T. B. Fowler, and G. W. Cunningham, "The Bold Venture Computation System for Nuclear Reactor Core Analysis, Versian III", ORNL-5711, June 1981.