6.2. Neutron sources

BY B. P. SCHOENBORN AND R. KNOTT

6.2.1. Reactors

The generation of neutrons by steady-state nuclear reactors is a well established technique (Bacon, 1962; Kostorz, 1979; Pynn, 1984; Carpenter & Yelon, 1986; Windsor, 1986; West, 1989). Reactor sources that play a major role in neutron-beam applications have a maximum unperturbed thermal neutron flux, $\varphi_{\rm th}$, within the range $1 < \varphi_{\rm th} < 20 \times 10^{14}$ cm^{-2} s^{-1}. A research reactor is essentially a matrix of fuel, coolant, moderator and reflector in a well defined geometry (Fig. 6.2.1.1). The fuel is uranium, and neutron-induced fission in the isotope ^{235}U produces a number of prompt and delayed neutrons (slightly more than a total of two) and, on average, one of these is required to maintain the steady-state chain reaction (*i.e.* criticality). The heat generated ($\sim$200 MeV per fission event) must be removed, hence the need for an efficient coolant. In practice, the simultaneous requirements of complex thermal hydraulics and nuclear reaction kinetics must be addressed. The neutrons produced in the fission event have a mean energy of $\sim$1 MeV, and a material is required to reduce this energy to $\sim$25 meV to take advantage of the larger fission cross section of ^{235}U in the 'thermal' energy range. Such a moderator is composed of a material rich in light nuclei, so that a large fraction of the neutron energy is transferred per collision.

There is an inherent maximum in neutron flux density imposed by the fission process (the number of excess neutrons produced per fission event), by the reduced density of neutron-generation material required for cooling purposes and by the heat-removal capacity of suitable coolants. Detailed design of reactor systems is essential to obtain the correct balance.

6.2.1.1. *Basic reactor physics*

Reactor physics is the theoretical and experimental study of the neutron distributions in the energy, spatial and time domains (Soodak, 1962; Jakeman, 1966; Akcasu *et al.*, 1971; Glasstone & Sesonske, 1994). The fundamental relation describing neutron kinetics is the Boltzmann transport equation (*e.g.* Spanier & Gelbard, 1969; Stamm'ler & Abbate, 1983; Weisman, 1983; Lewis & Miller, 1993). In theory, the transport equation describes the life of the neutron from its birth as a high-energy component of the fission process, through the various diffusion and moderation processes, until its ultimate end in (i) the chain reaction, (ii) leakage into beam tubes, or (iii) parasitic absorption (Williams, 1966). In practice, the complex nuclear reactions and the geometrical configurations of the component materials are such that a rigorous theoretical analysis is not always possible, and simplifying approximations are necessary. Nevertheless, well proven algorithms have been developed, and many have been included in computer codes (*e.g.* Hallsall, 1995).

On examination of the factors that influence the neutron flux distribution, there are three distinct but interdependent functions performed by the coolant, moderator and reflector. The coolant/moderator is of major importance in the fuelled region to sustain optimum conditions for the chain reaction, and the moderator/reflector is important in the regions surrounding the central core (Section 6.2.1.2). It should be noted that reactors for neutron-beam applications must be substantially undermoderated in order to provide a fast neutron flux at the edge of the core, which can be thermalized at the entry to the beam tubes. Most research reactors use H_2O or D_2O as the coolant/moderator.

6.2.1.2. *Moderators for neutron scattering*

The moderator/reflector serves to modify the energy distribution of fast neutrons leaking from the central core, returning a significant number of thermalized neutrons to the core region to provide for criticality with a smaller inventory of fuel and providing excess neutrons for a range of applications, including neutron-beam applications. The moderator/reflector may be H_2O, D_2O, Be, graphite or a combination of these. Almost all choices have been used; however, the optimum is not achieved with any choice, and priorities must be set in terms of neutron-beam performance, other source activities and the reactor fuel cycle.

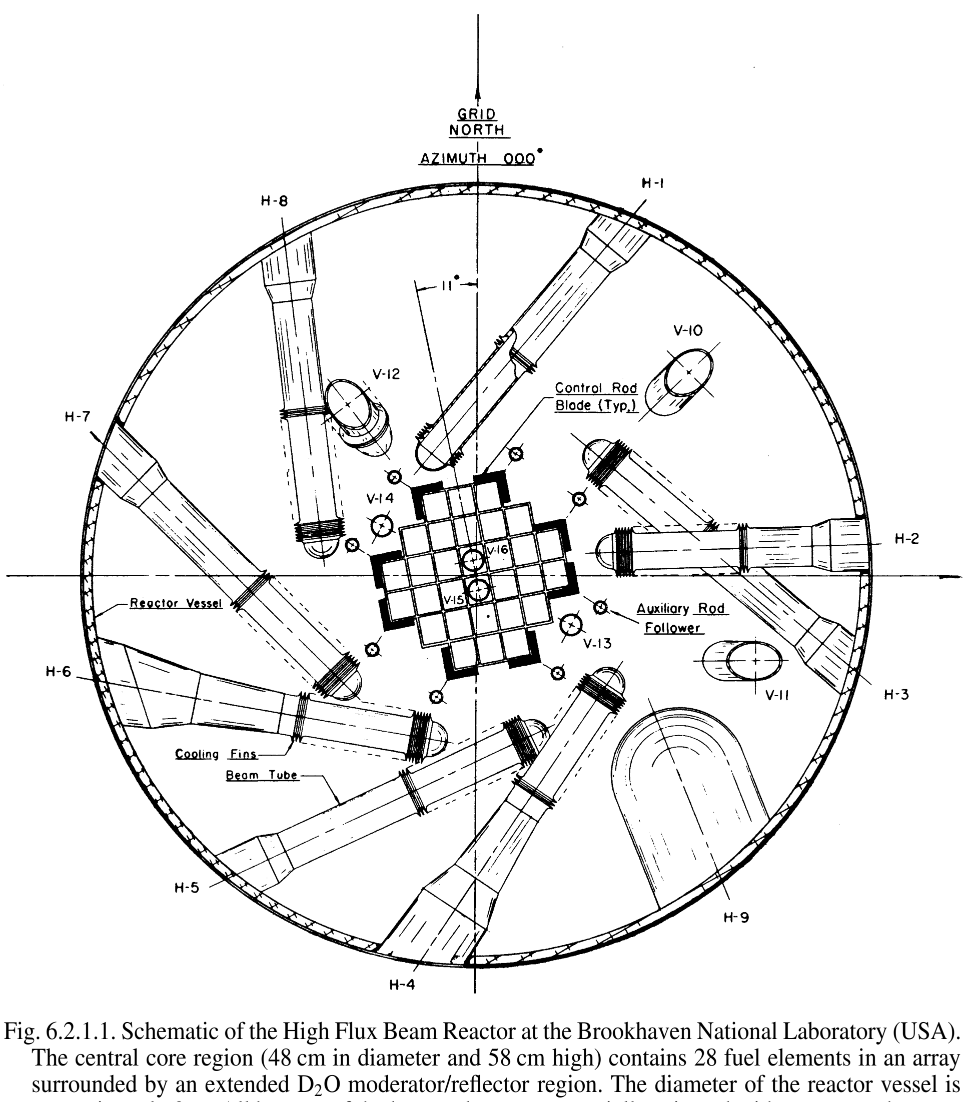

Fig. 6.2.1.1. Schematic of the High Flux Beam Reactor at the Brookhaven National Laboratory (USA). The central core region (48 cm in diameter and 58 cm high) contains 28 fuel elements in an array surrounded by an extended D_2O moderator/reflector region. The diameter of the reactor vessel is approximately 2 m. All but one of the beam tubes are tangentially oriented with respect to the core. The cold neutron source is located in the H9 beam tube.

references