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SAFETY ASPECTS OF THE BROOKHAVEN HIGH FLUX BEAM REACTOR

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Safety Design Basis for the HFBR and Current Status

Description

The High Flux Beam Reactor (HFBR) is a 60 MW_{th} research reactor designed to produce intense thermal neutron beams (10^{15}n/cm^2-s). Originally designed for 40 MW and upgraded to 60 MW in 1983, the reactor is presently rated at 35.4 MW. The HFBR is D_2O cooled and moderated with a core inlet temperature of 328 K (131°F) and outlet temperature of 331 K (136.5°F). The reactor has a nominal operating pressure of 1.38-MPa (200 psi). Maximum thermal flux is presently 5.25 x 10^{14} n/cm^2-s, and unlike most reactors, the vast majority of the neutron thermalization takes place in the D_2O reflector which surrounds the undermoderated core. The peaking of the thermal flux outside the core was a unique HFBR design characteristic, which produced enhanced thermal neutron accessibility to the nine experimental beam tubes. A portion of thermal neutrons must diffuse back into the core in order to sustain the nuclear chain reaction. The active core has a height of 57.8 cm (22.75 in.) and a volume of 97 liters. The core contains 9.8 kg of highly enriched (93%) ^{235}U loaded into 28 MTR type curved plate elements. Each fuel plate consists of a U_3O_8 aluminum cermet with aluminum cladding.

Reactor control is achieved by the use of eight main blades and eight auxiliary blades which surround the outside of the core. The control blades perform their function by absorbing thermal

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neutrons which are diffusing back into the core from the reflector. The main blades have Eu_2O_3 and Dy_2O_3 as their poison material, the auxiliary blades just contain Eu_2O_3.

The aluminum reactor vessel is approximately 7.2 m(23.5 ft) high and consists of an upper cylindrical section which is welded to a bottom 2.1 m (6.8 ft) diameter spherical section which contains the core, control rods, and beam tubes. The bottom half of the vessel is surrounded by a lead and steel thermal shield, the primary purpose of which is to protect the concrete biological shield from excessive radiation heating. An important safety function of the thermal shield is to serve as a secondary vessel to contain primary coolant during a beam tube rupture LOCA and thereby keep the core covered.

Pressure in the vessel is maintained by a helium cover gas system which uses inlet and outlet pressure control valves to maintain 1.38 -MPa (200 psi) pressure. Downward flow of primary coolant through the core at 1.13 m^3/sec (17,900 gal/min) is provided by two AC motor driven primary pumps. Decay heat is removed by either the primary pumps (via normal AC power), a DC powered shut down cooling system or a DC powered pony motor which automatically couples to each primary pump following flow coastdown. Four flow reversal valves are installed in the reactor vessel to facilitate flow reversal and natural circulation cooling if forced flow is not maintained. A schematic showing some of the HFBR flow process systems is attached.

The reactor, auxiliary equipment, and experimental facilities are contained in a welded steel confinement hemisphere 53.6 m (176 ft) in diameter. The confinement is kept at a slight negative pressure by exhaust fans which discharge to the environment via a 100 m (328 ft) stack after passing through a series of high efficiency particulate air (HEPA) and charcoal filters.

Reactor Safety Design Basis

The safety design of the HFBR is based upon the automatic shutdown systems, defense-in-depth decay heat removal systems, light water flooding protection, and the reactor confinement system.

The safe shutdown of the HFBR is performed by the rapid insertion of the main control blades. An automatic scram system employs a 2 out of 3 logic from 7 different scram signals. There are manual scram capabilities in the control room as well as six locations throughout the plant. The scram system is de-energized to operate, therefore loss of electrical power will result in scram action.

Decay heat is removed by either the primary pumps, DC powered shut down cooling pumps, DC powered pony motor system or natural circulation. Both of the shutdown cooling pump motors and each of the two pony motors have their own dedicated back up battery supplies. Flow reversal and subsequent natural circulation cooling provide the defense in depth approach for decay heat removal. Operations are presently limited by a conservative analytical model which supports safe flow reversal with no fuel damage for operating power levels up to 35.4 MW.

All loss-of-coolant accidents (LOCAs) up to the design basis, defined as leaks up to 9 cm^2 (1.39 in^2), have been shown not to cause fuel damage at the operating power limit of 35.4 MW. However, since there is no automatic emergency core cooling (ECC) make up function, operator action is required for long term cooling. A LOCA greater than 9 cm^2 (1.39 in^2), which is not part of the design basis, could cause fuel damage should it occur. The probabilistic risk assessment[1] estimated the frequency of these LOCAs to be about 1.4×10^{-4} per reactor year.

H_20 flooding of the primary cooling water system could result in positive reactivity effects beyond the capability of the control rods to maintain the reactor in a safe shutdown condition. A 1.3 m^3 (350 gallons) cadmium nitrate poison water system is provided to maintain the reactor sub-critical (k_{eff} .54) with 100% H_2O flooding.

The reactor confinement system limits the design basis siting LOCA to values approximately 30% of 10 CFR 100.

Status and Future Plans

The HFBR has been operating at 30 MW since June of 1991. Future plans for Brookhaven National Laboratory (BNL) are to escalate the HFBR power level back to 40 and then 60 MW. The main thrust of the power escalation plans is the performance of thermal hydraulic tests on simulated HFBR fuel channels. The results of these tests should allow BNL to increase reactor power while still maintaining the present flow reversal criteria of no fuel damage during the design base loss-of-coolant accident.

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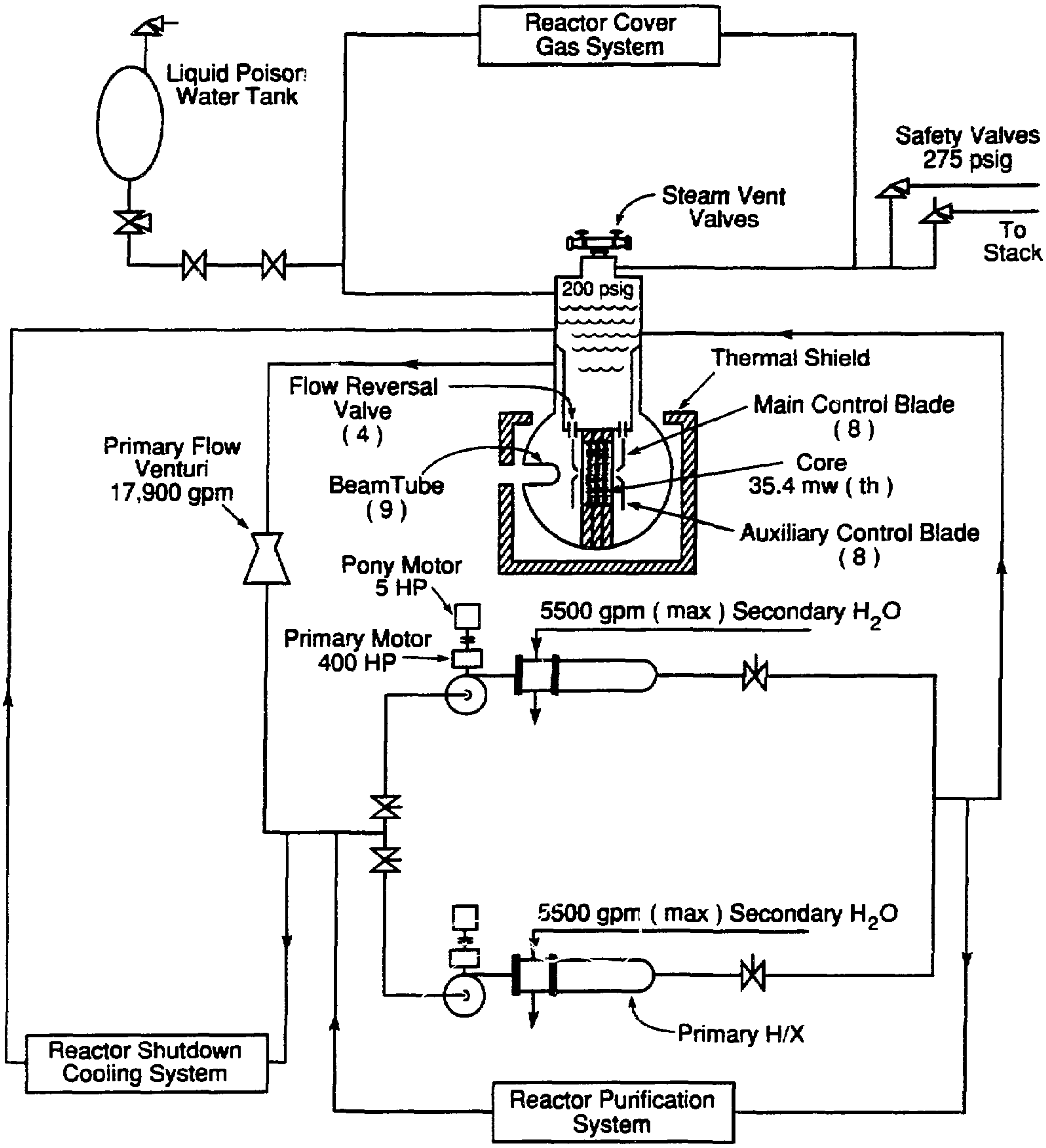
[1] "Level One Internal Event PRA for the HFBR," July 1990, M. A. Azarm, et.al. Rev. 1.



HFBR Process Systems