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INTRODUCTION AND GENERAL DESCRIPTION

The Heavy Water Components Test Reactor (HWCTR)(1) was built for the Atomic Energy Commission by the Du Pont Company to satisfy a need for fuel testing in the AEC's Heavy Water Power Reactor Program. The reactor was designed to provide a realistic test environment for full size fuel candidates.

Containment Building

The HWCTR is housed in a containment building 70 ft in diameter and 125 ft high, shown in figure 1. About half of the building is below grade and constructed of post-tensioned concrete. The upper half is constructed of carbon steel. The building is designed to contain an internal pressure of 24 psig. The containment building houses the reactor and coolant system, the charge-discharge machine and the reactor instrumentation. The control room and auxiliary services and equipment are housed in other buildings. The containment building is ventilated and air conditioned, and the normal 5000 cfm air throughput exhausts from an 30 ft stack. Upon receipt of certain signals (high internal temperature or pressure, high activity) the building is automatically isolated by two pairs of butterfly valves in the inlet and outlet air ducts. Four banks of carbon absorber units with their own circulating systems are also activated by the isolation signal. They trap fission products that may be released to the containment building following an accident and reduce the consequences of the maximum credible accident.

Vertical Cross Section of the Reactor Vessel

The reactor vessel shown in figure 2, is about 30 ft high and has a maximum inside diameter of 7 ft. The bottom head has 43 nozzles through which pass monitor pins for each fuel assembly and various instrument leads. The top head is bolted to the reactor and must be removed for charging fuel. The control and safety rod drive mechanisms are bolted to the head and lift with it when the head is removed; the delatched rods remain in the core.

The design pressure is 1500 psig at 315°C and the maximum power is 70 MW. Currently the reactor power is 45 MW with an outlet temperature of 250°C at 1200 psig. The system is pressurized with helium and the reactor outlet temperature at every operating pressure is at least 10°C subcooled. Film boiling is permitted at the hot spots. Heat is removed from the reactor by circulating D_2O at 10,000 gpm first through the fuel then through the bulk moderator and then through two vertical U-tube steam generators. H_2O steam from the boilers carries off the energy to the atmosphere.

Core Layout

The core contains a driver ring of 24 fuel tubes, each loaded with 1 kg of U-235 and a burnable boron-stainless steel target. A layout of the core is shown in figure 3. The central test region can accommodate 12 elements up to 10 ft long. The heat removal capacity is 2 MW per position.

A ring of 12 boron-stainless steel rods containing 1 wt % natural boron provides reactivity control. The six fast shutdown rods, called safety rods, decrease reactivity by 6% Δk/k in 1.5 seconds and 9% Δk/k in 3 seconds. A backup system can inject a potassium tetraborate solution in the moderator to reduce the reactivity by 24% Δk/k within 15 seconds after activation. The normal excess k is about 0.20 k at 20°C. A driver cycle is equivalent to about 9000 MWD in the reactor.

The HWCTR is probably the most heterogeneous power reactor now operating. Notice that the 24 driver fuel positions are not uniformly spaced, but are interrupted at intervals. The gap permits internal piping connections to be made to as many as six isolated test positions with their own coolant systems. So the driver ring cannot be well characterized by a typical lattice cell as is generally done in calculating large reactors. Interposed between the driver fuel and the test fuel are the control rods spaced at regular intervals. Twelve test positions are on a seven-inch triangular pitch, and each can be loaded with different fuel. Loadings tested to date have varied from 15 lb/foot of natural uranium to 10 lb/ft of uranium enriched up to 4% in U-235. Both uranium metal and oxide in the form of rods and tubes have been tested. A central cluster of six control rods, generally removed from the reactor while operating, produces a large moderator flux peak or a strong central flux depression.

LOW POWER PHYSICS TESTS AND COMPARISON WITH CALCULATIONS

The reactor was first made critical on March 3, 1962, and has been operating at power since August 1962. In the interval between March and August, 1962, an extensive set of low power physics tests was performed particularly to verify data obtained in a full scale mockup at temperatures up to 50°C$^{(2)}$, and to obtain additional data up to the operating temperature of 250°C. The 250°C data is the first such critical data for a very heterogeneous D_2O reactor at high temperature.

Rod Worths

Rod worths were measured with the conventional period technique. The differential worth in k/cm was measured at several intervals in typical axial flux shapes and integrated over the full rod length. The period reactivity relationship was calculated by the methods of Finn in reference 3. Appropriate corrections were made for fast fissions in U-238 and for gamma self shielding which influences the effective photoneutron contribution. For a typical case the effective delayed neutron fraction, beta, was increased by the photoneutrons from D_2O to about 0.75%.

Figure 4 is a table of the measured worths of the rods at 20°C and 240°C. Rod worths were also calculated using a two-dimensional multigroup technique to be described shortly. In the calculation, the rods were treated as boundary regions and the logarithmic derivative was set equal to the reciprocal linear extrapolation distance, , computed for a long black cylin in D_2O.(4)

Temperature Coefficients

The reactivity was measured as a function of temperature using the measured rod worths just mentioned. The coefficients shown in figure 5 are the measured values for two-core configurations and the calculated values using the two-dimensional multigroup model. Although these values were measured at effectively zero thermal power and represent data for the isothermal case, the only other important temperature dependent reactivity effect is the Doppler coefficient in the uranium fuel. Changes in the temperature of the coolant and of the driver fuel produce an insignificant reactivity effect. Therefore, at power the large moderator temperature coefficient with a time constant of about 21 seconds determines the kinetic response of the reactor.

Flux Shapes

The HWCTR contains no direct flux measuring devices. The integral power distribution can be inferred from flow and temperature measurements appropriately corrected for gamma heating. But there is no direct method for obtaining the axial flux or power distribution. So one of the most important objectives of the low power tests was to provide data so that a reliable computational model could be developed.

Flux shapes were measured by inserting a small copper tube in the center of each fuel element. The activation distribution in the tube was measured with a scintillation scanning system and the axial flux distribution was obtained directly from the scan. The radial and azimuthal distribution were obtained by integrating the axial distribution and correcting for disadvantage factor differences between the various elements.

The next several figures (6, 7, 8, and 9) show radial and axial measurements for several rod configurations.

Prior to the low power tests, a two-dimensional multigroup code, PDQ-3(5) was used to obtain a preliminary estimate of reactor parameters. The early results were compared to the mockup data of reference 2. The geometrical model finally developed represents each fuel and control position discretely and with the volume characteristic of the fuel assembly. The results obtained with the model are quite sensitive to the assigned fuel volume. Figure 10 depicts the radial model in X, Y geometry. Thermal macroscopic constants are obtained by flux weighting material constants over a partial cell using the full cell flux shape calculated with a one-velocity P_3 approximation. Although the driver fuel cannot be realistically characterized by a typical cell, results obtained using an equivalent 5-inch square pitch are satisfactory for obtaining the heterogeneous constants. Fast macroscopic constants are obtained for the homogenized partial cell with the MUFT code.(6) We have developed a D_2O library for MUFT which yields ages in D_2O as a function of H_2O contamination in good agreement with the data developed by J. W. Wade of Savannah River Laboratory.(7)

The axial model in two dimensions is shown in figure 11. The annular rings are characteristic of the fuel volumes, rather than the cell volumes. Constants are obtained by the same techniques as for the radial problem.

Figure 11 presents two tables that compare measured and calculated values of the important flux dependent parameter Q-max/Q-avg for two temperature extremes. With the two computational models described we calculate the radial and azimuthal shapes to within ±3% and the axial shape to within ±5%.

The effects of fuel depletion are calculated by similar two-dimensional methods using the TURBO code.(8) Comparisons with gamma scans of irradiated fuel are within the ±5% range for fuel exposed up to 5000 MWD/ton.

OPERATING PHILOSOPHY

Since all tests in HWCTR are in-core, the interaction between experiments and the reactor is much stronger than for most "test" reactors. We rely heavily on our ability to predict operating conditions. The reactor power is generally limited by heat transfer on some fuel element. This power determination is directly dependent on the power distribution which is obtained from the calculated power distribution.

In conclusion, let me point out one major difference in approach between operating HWCTR as a test reactor and most test/or power reactors. In general, for a power reactor it is desirable to operate at maximum power for some set of conditions, usually limited by heat transfer. This implies that most efficient operation is obtained when the maximum to average power ratio is minimized. In the HWCTR, the objective is to operate so that all tests or as many as possible are operating at their design (usually heat transfer limited) condition.

This frequently means sacrificing total power in order to obtain proper radial and azimuthal distributions. Hence, "best" operation frequently occurs when the maximum to average power ratio is not minimized.

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