INNOVATIVE BWR CORE DESIGN WITH TOP-ENTRY CONTROL RODS

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ABSTRACT

The design of a natural circulation system in a BWR requires having a chimney above the core. The top-entry control-rod core design takes advantage of additional space in the chimney area and reduces the plant size and cost for a natural circulation BWR. A BWR conceptual core design with top-entry control rods is shown feasible to meet the cycle energy, hot and cold reactivity margin, and other thermal limits by optimizing axial fuel Gd loading.

1. INTRODUCTION

The utilization of natural circulation and passive safety systems in a BWR simplifies reactor system designs, enhances safety and reduces cost[1] and this type of BWR is classified as Simplified Boiling Water Reactor (SBWR). The design of a natural circulation system in a BWR requires having a chimney above the core. To take advantage of additional space in the chimney area, an innovative design has been developed for a BWR core with top-entry control rods rather than conventional bottom-entry control rods. In this paper, an Advanced Boiling Water Reactor (ABWR) core configuration was chosen as a reference for study and a BWR conceptual core design with top-entry control rods is demonstrated to be feasible.

The ABWR has evolved as one of the most advanced, commercially available nuclear power reactors. The first ABWR was completed in 1996 and is successfully being operated at full power in Japan. Two ABWRs are being installed in Taiwan.

A BWR conceptual core with top-entry control rods was designed to operate on 15-month fuel cycle and utilized GE11 fuel assembly design, consisting of a 9x9 fuel rod array with 74 fuel rods and two central water rods. The major difficulty in a BWR core design with top-entry control rods is the severe bottom peak due to partially inserted deep control rods and un- or low-voided bottom in-channel water. This difficulty has been overcome by optimizing axial Gd loading in fuel assemblies during the core design.

The methods used for the fuel and core designs are discussed prior to the description of fuel and core designs in the following.

2. FUEL AND CORE DESIGNS METHODS

The fuel designs employed TGBLA[2], which is a neutron transport and diffusion coupled lattice design computer program. TGBLA uses mainly ENDF/B-V cross-section library, uses integral transport theory methods to solve for cell neutron spectra in thermal, resonance and fast energy range, and uses leakage-dependent diffusion theory methods to solve for lattice k_∞ and power distribution. TGBLA is benchmarked against MCNP[3], a well-known continuous energy Monte Carlo computer program.

The core designs employed PANACEA[4], which is a 3-dimensional, neutron diffusion BWR simulator. PANACEA receives lattice-averaged cross sections from TGBLA and solves a modified one-group diffusion equation for k_{eff} and power distribution of a BWR core. The PANACEA k_{eff} preserves the fundamental mode k_{eff} of the three-group core neutron diffusion equations. PANACEA was qualified against the operating plant simulation, eigenvalue tracking, and gamma scan measurements.

3. FUEL DESIGNS

The fuel assemblies contain four distinct GE11 lattices (the upper, middle, lower, and blanket lattices) at five elevations to optimize Gd loading. Each assembly is composed of a thin bottom natural uranium blanket, a lower and a middle lattice spanning up to 2/3 of the active core, an upper lattice containing eight rod-vanished regions, and a thin top natural uranium blanket. The eight rod-vanished regions provide increased flow area in the high steam voids region for reducing pressure drop and thus improve the core stability performance.

The Gd rod numbers and/or Gd weight percent in the Gd rods are varied axially in assemblies to optimize the axial power shape. To reduce the bottom power peaking, more Gd rods and/or higher Gd weight percent (w/o) are placed in the lower portions of the assemblies. Consequently, the lower lattice (9x9 array) contains eight Gd rods with 4.5 Gd w/o, five Gd rods with 4 Gd w/o and 61 UO2 rods. The middle lattice contains 12 Gd rods with 4 Gd w/o and 62 UO2 rods. The upper lattice contains eight Gd rods with 4 Gd w/o, four Gd rods with 3 Gd w/o, 54 UO2 rods and eight rod-vanished regions. The fuel rod U-235 enrichment in the lower, middle and upper lattice designs varies from 1.6 to 4.9 w/o in order to minimize the lattice relative power peaking.

4. CORE DESIGNS

The core excess reactivity is mainly stored by insertion of control rods and use of burnable poison, gadolinia (Gd), throughout a cycle. The Gd is distributed with fresh fuel and provides globally and slowly varying, mild reactivity control, whereas the control rods provide local strong reactivity control. It has more advantage to maximize and optimize the use of Gd and to confine and simplify the use of control rods for BWR normal operations during a cycle. For example, the utilization of a control-cell core design is a very good case to illustrate this principle. For designing a BWR conceptual core with top-entry control rods, this principle can also be employed to optimize axial Gd loading and Gd utilization in order to overcome the difficulties associated with the severe bottom peak due to partially inserted deep control rods and un- or low-voided bottom in-channel water.

The axial Gd loading is mostly needed at the beginning and during the middle of cycle to balance out the local reactivity effect of partially top-inserted control rods. At the end of cycle, the control rods are withdrawn for providing additional reactivity to compensate fuel depletion and there is no need to use Gd to balance out partially top-inserted control rods. Consequently, the residual Gd should be minimized in the core design at the end of cycle.

A 15-month-cycle, equilibrium BWR conceptual core with top-entry control-rods and GE11 fuel is designed satisfactorily and the results are summarized in Table I. The core hot excess reactivity throughout the cycle is shown in Fig. 1. All safety-related design parameters such as CSDM (cold shutdown margin), MLHGR (maximum linear heat generation rate), and MCPR (minimum critical power ratio) satisfy the design criteria for an ABWR core.

Table I. Design Summary for 15-Month Equilibrium-Cycle BWR Conceptual Core with Top-Entry Control Rods

Plant Electric Power Rating, MWth	**3926**
Effective Full-Power Days, EFPD	**416**
Overall Capacity Factor	**91%**
Reload Batch, bundles	**200**
Reload Batch Fraction	**0.229**
Initial Uranium mass (MT)	**148.8**
Cycle Exposure, GWd/MT	**10.17**
EOC Av. Exposure, GWd/MT	**29.7**
Max. Discharge Exposure, GWd/MT	**46.9**
Av. Discharge Exposure, GWd/MT	**44.5**

5. CONCLUSION

A BWR conceptual core design with top-entry control rods has been shown feasible to meet the cycle energy, hot and cold reactivity margin, and other thermal limits by optimizing axial fuel Gd loading. The top-entry control-rod core design takes advantage of additional space in the chimney area and, therefore, reduces the plant size and cost for a natural circulation BWR.

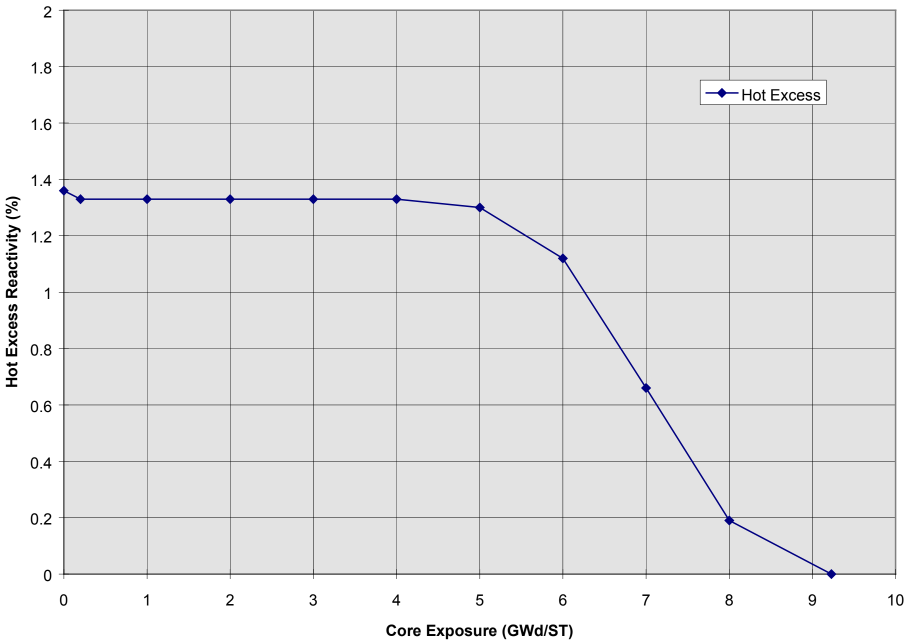

Figure 1. Core Hot Excess Reactivity

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