SECTION 4

REACTOR

4.1 SUMMARY DESCRIPTION

This chapter describes the following: 1) the mechanical components of the reactor and reactor core including the fuel rods and fuel assemblies, reactor internals, and the control rod drive mechanisms, 2) the nuclear design, and 3) the thermal-hydraulic design.

The reactor core is comprised of an array of fuel assemblies which are similar in mechanical design and fuel enrichment. The Salem Unit 1 and 2 cores may consist of any combination of fuel designs including Vantage 5H, Vantage+, and standard Robust Fuel Assembly (RFA and RFA-2, which further enhances the anti-fretting characteristics with improved mid grids) as described in Section 4.2.1.2. The most significant difference between the Vantage+ and RFA fuel and the others is the application of Zirlo™ cladding, guide thimble and instrument tubes. The Vantage+ and RFA are modifications of the NRC-approved Vantage 5H fuel assembly design (Reference 1). A detailed description and evaluation of the Vantage+ and RFA features is provided in References 2, 4, 5 and 6.

The core is cooled and moderated by light water at a pressure of 2250 psia in the Reactor Coolant System. The moderator coolant contains boron as a neutron absorber. The concentration of boron in the coolant is varied as required to control relatively slow reactivity changes including the effects of fuel burnup. Additional boron, in the form of burnable absorber rods and/or IFBAs, may be employed in the core to establish the desired initial reactivity.

Two hundred and sixty-four fuel rods are mechanically joined in a square array to form a fuel assembly. The fuel rods are supported in intervals along their length by grid assemblies which maintain the lateral spacing between the rods throughout the design life of the assembly. The grid assembly consists of an "egg-crate" arrangement of interlocked straps. The straps contain spring fingers and dimples for fuel rod support as well as coolant mixing vanes. The fuel rods consist of slightly enriched uranium dioxide ceramic cylindrical pellets contained in slightly cold worked Zircaloy-4 or Zirlo ™ tubing which is plugged and seal welded at the ends to encapsulate the fuel. All fuel rods are pressurized with helium during fabrication to reduce stresses and strains and to increase fatigue life. In addition, the Zirlo™ fuel rods may be oxide coated at the lower end for additional protection against fretting. RFA fuel rods will utilize annular pellets at the top and bottom 6" to provide lower rod internal pressures.

The center position in the assembly is reserved for the in-core instrumentation, while the remaining 24 positions in the array are equipped with guide thimbles joined to the grids and the top and bottom nozzles. Depending upon the position of the assembly in the core, the guide thimbles are used as core locations for rod cluster control assemblies, neutron source assemblies, and burnable absorber rods. The remaining guide thimbles may be fitted with plugging devices to limit bypass flow. The use of plugging devices is optional.

The bottom nozzle is a box-like structure which serves as a bottom structural element of the fuel assembly and directs the coolant flow distribution to the assembly.

The top nozzle assembly functions as the upper structural element of the fuel assembly in addition to providing a partial protective housing for the rod cluster control assembly or other core components.

The rod cluster control assemblies each consist of a group of individual absorber rods fastened at the top end to a common hub or spider assembly. These assemblies have rods containing absorber material to control the reactivity of the core under operating conditions.

The control rod drive mechanisms are of the magnetic latch type. The latches are controlled by three magnetic coils. They are so designed that upon a loss of power to the coils, the rod cluster control assembly is released and falls by gravity to shut down the reactor.

The components of the reactor internals are divided into three parts consisting of the lower core support structure (including the entire core barrel and thermal shield), the upper core support structure and the in-core instrumentation support structure. The reactor internals support the core, maintain fuel alignment, limit fuel assembly movement, maintain alignment between the fuel assemblies and control rod drive mechanisms, direct coolant flow past the fuel elements and to the pressure vessel head, provide gamma and neutron shielding, and provide guides for the in-core instrumentation.

The nuclear design analyses and evaluation establish physical locations for control rods and burnable absorbers, and physical parameters such as fuel enrichments and boron concentration in the coolant such that the reactor core has inherent characteristics which, together with corrective actions of the Reactor Control, Protection and Emergency Cooling Systems provide adequate reactivity control even if the highest reactivity worth rod cluster control assembly is stuck in the fully withdrawn position. The design also provides for inherent stability against diametral and azimuthal power oscillations.

The thermal-hydraulic design analyses and evaluation establish coolant flow parameters which assure that adequate heat transfer is assured between the fuel cladding and the reactor coolant. The thermal design takes into account local variations in fuel rod dimensions, power generation, flow distribution, and mixing. The mixing vanes incorporated in the fuel assembly spacer grid design induces additional flow mixing between the various flow channels within a fuel assembly as well as between adjacent assemblies.

Instrumentation is provided in and out of the core to monitor the nuclear, thermal-hydraulic, and mechanical performance of the reactor and to provide inputs to automatic control functions.

The reactor core design together with corrective actions of the Reactor Control, Protection and Emergency Cooling Systems can meet the reactor performance and safety criteria specified in Section 4.2.

To illustrate the effects of the change in fuel design, Table 4.1-1 presents principal nuclear, thermal-hydraulic, and mechanical design parameters for the Salem 17 x 17 Vantage 5H, Vantage+, and RFA fuel assemblies.

The effects of fuel densification were evaluated (Reference 3).

The analytical techniques employed in the core design are tabulated in Table 4.1-2. The loading conditions considered in general for the core internals and components are tabulated in Table 4.1-3. Specific or limiting loads considered for design purposes of the various components are listed as follows: fuel assemblies in Section 4.2.1.1.2; reactor internals in Section 4.2.2.3 and Table 5.1-10; neutron absorber rods, burnable absorber rods, neutron source rods, and thimble plug assemblies (if used) in Section 4.2.3.1.3; control rod drive mechanisms in Section 4.2.3.1.4.

4.1.1 Reference for Section 4.1

1. Davidson, S.L. (Ed.), et al., "Vantage 5H Fuel Assembly Reference Core Report," WCAP-10444-P-A and Appendix A, September 1985; Addendum 2-A, March 1986; Addendum 2-A, April 1988.

2. Davidson, S.L., Nuhfer, D.L. (Eds.), "Vantage+ Fuel Assembly Reference Core Report," WCAP-12610-P-A, April 1995.

3. Hellman, J. M. (Ed.), "Fuel Densification Experimental Results and Model for Reactor Application," WCAP-8218-P-A (Proprietary) and WCAP-8219-A (Nonproprietary), March 1975.

4. Letter from W.J. Rinkacs (Westinghouse) to M.M. Mannion (PSE&G), "Westinghouse Fuel Features Recommendation for Cycle 11", July 22, 1998.

5. Letter from W.J. Rinkacs (Westinghouse) to M.M. Mannion (PSE&G), "Westinghouse Generic Safety Evaluation for the 17x17 Standard Robust Fuel Assembly", October 1, 1998.

6. Garde, A., et al., "Westinghouse Clad Corrosion Model for ZIRLO and Optimized ZIRLO," WCAP-12610-P-A & CENPD-404-P-A, Addendum 2-A, October 2013.