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ARE SMALLER CORES SAFER? ENERGY BALANCE CALCULATION FOR INTEGRAL TYPE PWR

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ABSTRACT

In order to take advantage of economies of scale, the general trend in commercial nuclear power plant design has been to increase core size and power. Decay heat removal is a primary safety function of many safety systems at pressurized water reactors (PWRs) and the most limiting performance requirements and technical specifications of safety-related components are often derived from decay heat requirements. For example, the low pressure safety injection system (LPSI) of the OPR1000 is an important safety system to makeup reactor coolant system (RCS) inventory during a large break loss of coolant accident (LBLOCA) but also doubles duties as the shutdown cooling system (SCS). Although LBLOCA is a very challenging design basis accident to mitigate, the rated flow of the low-head, high capacity pump of the LPSI is determined by the greater flow rate demand during SCS mode required for decay heat removal. Decay heat levels generated by large PWR cores require very large safety system components (pumps, valves, piping, etc.) which in turn may need supporting subsystems to function properly adding complexity, cost, maintenance requirements, and reduced system reliability and availability.

New PWR designs have been proposed with small cores falling into the categories of “small, modular reactors” and “integral-type reactors”. These reactor concepts with small cores are often advertised as economical and safer than their much larger cousins currently in operation. The small core reactors may have economies of scale at the other end of the spectrum because the proportionately smaller decay power levels allow for much smaller safety system components and decay heat removal performance requirements and can allow for more readily adoption of passive safety systems.

This paper presents an energy balance calculation for and integral-type PWR with a small 365 MWt core based off the SMART design (System-integrated Modular Advanced ReacTor). SMART RCS and nuclear steam supply system including the core, steam generator modules, and pressurizer are completely contained inside a large steel pressure vessel. The purpose of the energy balance calculation is to derive heat removal capacity performance targets for the passive residual heat removal system (PRHRS) of SMART. The PRHRS design basis is to cooldown and depressurize the RCS after normal shutdown. The very large primary side water inventory and very large steel mass of the pressure vessel, approximately 180 tonnes and 872 tonnes, respectively, represent huge sources of stored energy that are much larger on a relative basis to decay heat when compared to conventional PWR designs. Stored energy in the RCS fluid is approximately 107 GJ which is equal to the decay energy generated during the *first ten hours* after reactor trip. Stored energy in the pressure vessel and other structural material is estimated to be approximately 50 GJ which is equal to the decay energy generated during the *first three hours* after reactor trip. Stored energy in the fuel is insignificant to the other energy sources at only 4 GJ. For mission times between 12 and 36 hours, the average heat removal rate performance target of a PRHRS train is between 3.3 MW and 1.7 MW. 60% of the 3.3 MW heat removal rate and 35% of the 1.7 MW heat removal rate is dedicated for removing stored energy from the RCS fluid inventory and stored energy from structural material. The remainder heat removal capacity is attributed to removing decay heat generated from 12 to 36 hours. While decay heat removal is still a primary design objective of safety systems for small core reactors, safety systems must also be specifically designed and sized for removal of stored energy.