Safety Evaluation of Pre-Conceptual Designs of Advanced Burner Reactors

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1. Introduction

KAERI has been performing pre-conceptual design studies of an advanced burner reactor. The proposed concepts are liquid sodium-cooled pool-type metal-fueled reactors with electricity outputs of 600MWe, 1200MWe and 1800MWe, respectively [1]. The safety design philosophy of the proposed burner reactors places maximum reliance on passive responses to abnormal and emergency conditions, and minimizes the need for active and engineered safety systems.

The advanced burner reactors utilize the intrinsic negative reactivity feedback effect under unprotected anticipated transients without scram (ATWS) accident where reactor scram failures are postulated. In order to assess the effectiveness of the inherent and passive safety characteristics of the proposed burner reactors, scoping system analyses during UTOP, ULOF, and ULOHS have been performed using the system-wide transient analysis code SSC-K [2]. These three accident initiators encompass all the ways that operating sodium-cooled fast reactors can be perturbed by a change in reactivity, by a change in coolant flow, and by a change in coolant inlet temperature.

2. Modeling of Burner Reactor Designs

An overall plant component schematic is developed for modeling of the proposed burner reactor designs, as shown in Fig.1, where major components are represented by appropriate SSC-K modules. The components of reactor vessel, IHTS and SG are represented by various volumes and flow elements in the model. The primary circuit contains all of the sodium which flows through the core in the reactor vessel.

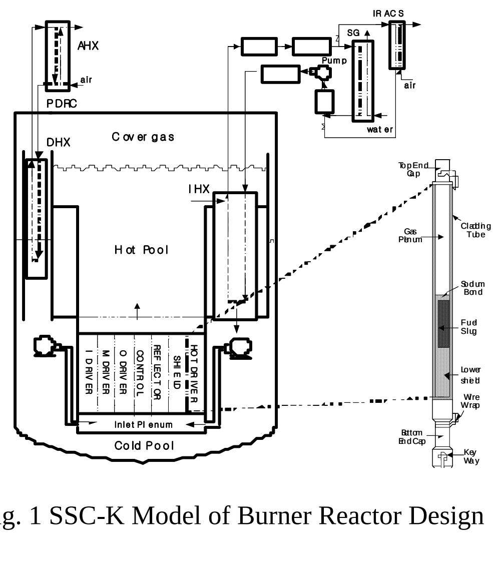

Fig. 1 SSC-K Model of Burner Reactor Design

The whole core region is divided into 7 parallel channels and each channel represents a subassembly or a group of similar subassemblies. The driver fuel of the burner reactor comprises inner, middle, and outer core assemblies. The hot assembly having the highest power-to-flow ratio is expected to have the highest temperature during any particular transient and it is most likely to be the assembly to reach any given failure threshold. The SSC-K channel models for the three burner reactors are shown in Fig.2. The channel model assumes a single pin and the associated coolant and structure geometry for the calculation, which extends from the bottom to the top of the fuel pin.

The 600MWe and 1200MWe reactors have 2 identical IHTS loops, respectively, while the 1800MWe reactor has 3 identical IHTS loops. These are modeled as identical loops, represented by the lumped one loop. The heat removal through the PDRC is actually activated when the sodium level in the hot pool rises above the top of the DHX support barrel. When the sodium heats up, expands, and spills over the top of the barrel, the sodium flows down the cylindrical DHX support barrel and then into the cold pool bypassing the IHX. The 600MWe reactor has 2 PDRC loops with a 15MW heat capacity per loop. The 1200MWe and 1800MWe reactors have 4 and 6 PDRC loops, respectively, with a 10MW heat capacity per loop. The PDRC is designed to always remove about 0.5% of the full power at normal operating condition. In the present ATWS analyses, one PDRC loop is assumed to fail for conservative analyses.

3. ATWS Analysis Results

The present scoping analysis focuses on assessment of inherent and passive safety characteristics that provide self-protection in severe ATWS conditions without producing high temperatures and conditions

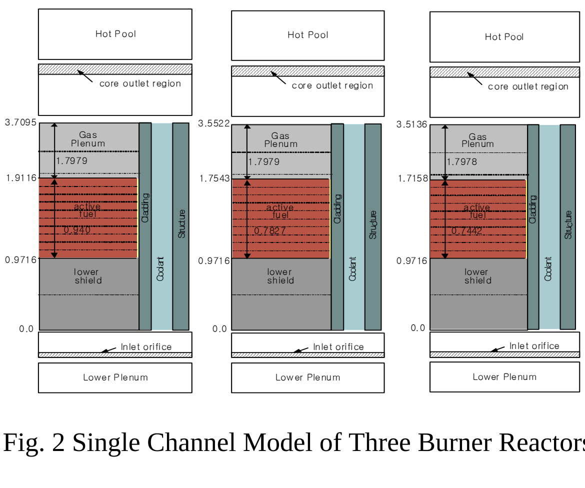

Fig. 2 Single Channel Model of Three Burner Reactors

that might lead to more severe accidents, such as coolant boiling, fuel melting, cladding failure and loss of structural integrity.

In order to account for uncertainties, a total of 40 cents during 15 seconds is adopted as the UTOP initiator, which represents withdrawal of some banks of the primary control rods. The reactor powers for the 600MWe, 1200MWe and 1800MWe reactors reach peaks of about 1.4 times the rated power at approximately 30 seconds and then slowly decreases to seek equilibrium with the available heat sink provided by the coolant system heat capacity and the heat rejection by the SGs. The powers begin to level off at about 1.1 times the rated power by 1000 seconds. The UTOP event results in no fuel failures and no sodium boiling. The self-regulation of power without scram is mainly due to the inherent and passive reactivity feedback.

The ULOF accident is assumed to initiate at the full-power condition. The transient is initiated by all primary pumps trip at 0.0 seconds and following coast down. The power immediately begins to drop and then slowly decreases to seek equilibrium with the available heat sink provided by the coolant system heat capacity and the heat rejection by the SGs. The rapid increase of the fuel temperatures in the early phase of the transient is attributed to the power-to-flow mismatch, and subsequent gradual drops of those temperatures result from the negative feedback effects. The maximum cladding temperatures predicted by SSC-K are below the threshold for eutectic formation; however they potentially threaten the integrity of the cladding.

The ULOHS accident is assumed to start with loss of heat rejection capability at all of the SGs, with PHTS and IHTS pumps continuing to run. The rapid slightly increase of the fuel temperature in the early phase of the transient is attributed to the degraded heat removal through the IHXs. The fuel temperatures ultimately reach a quasi-equilibrium condition as the core heat generation rate is balanced with the heat removal rate by the PDRC. The reactor heat is transported to the heat capacity provided by the PHTS and IHTS coolant inventory, and it is also rejected by the PDRC. The long term cooling calculation begins at a certain time using the plant conditions taken from the SSC-K results. The long-term cooling analysis proves that the PDRC heat removal capacity is sufficient to cool down the plant without jeopardizing the structural integrity of the PHTS within the desired 72 hours.

The summaries of peak temperatures of the safety criteria predicted by SSC-K are presented in Figs 3 through 5. Under both the UTOP and ULOHS accident conditions, the proposed designs provide sufficient safety margins for the criteria of fuel melting (1070°C), cladding failure, loss of structural integrity and sodium boiling. However, in the case of the ULOF accident, the predicted cladding temperatures, for the three proposed reactor designs, are all slightly higher than the lower temperature limitation during relatively short periods. However, no cladding damage is expected during the ULOF accident.

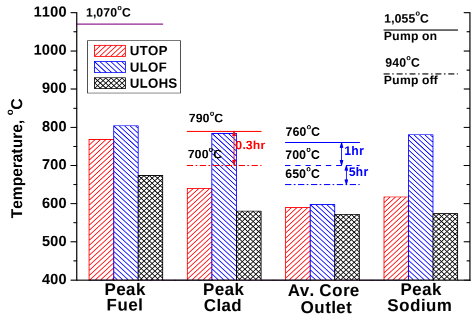

Fig.3 Peak Temperatures for 600MWe Burner Reactor

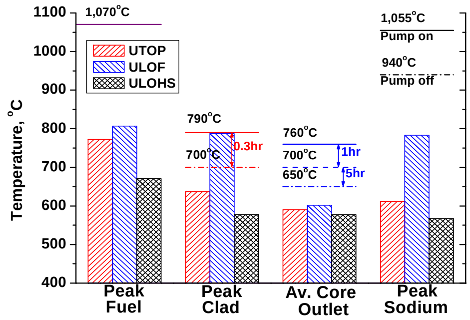

Fig.4 Peak Temperatures for 1200MWe Burner Reactor

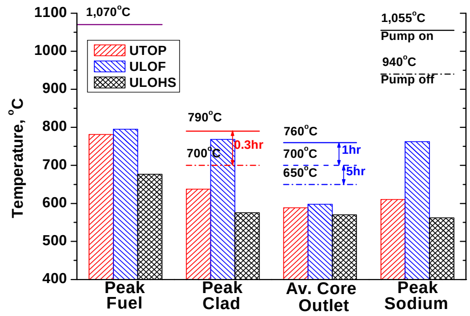

Fig.5 Peak Temperatures for 1800MWe Burner Reactor

4. Conclusion

It is shown that the proposed burner reactor designs have inherent safety characteristics and are capable of accommodating the ATWS events. The inherent safety mechanism in the reactor designs makes the core shutdown with sufficient margin and the passive removal of decay heat with matching the power to heat sink by passive self-regulation. The self-regulation of power without scram is mainly due to the inherent and passive reactivity feedback in conjunction with the large thermal inertia of the PHTS, extended pump coast down characteristics, and reliable PDRC heat capacity.

REFERENCES

[1] Y. I. KIM et al., “Core Design Study of Sodium-Cooled Fast Reactor for TRU Transmutation.” KAERI/RR-3063/2009.

[2] Y. M. Kwon et al., “SSC-K Code Users Manual, Rev.1,” KAERI/TR-2014/2002.