Safety Analysis for a LFR

Kwi-Seok Ha, Won-Pyo Chang, Sang-Ji Kim, Yong-Bum Lee
KAERI, P. O .Box 105, Yuseong, Daejeon, 305-600, Korea
Email:ksha@kaeri.re.kr

1. Introduction

In these days, an interest has been taken world widely in a lead cooled fast reactor (LFR) as an option for generation IV reactors. The stability of lead on chemical as well as nuclear interactions and fuel cycle in which solves the problem of growing spent fuel inventories by reducing the volume of high level waste are a key merit to the adoption. To keep pace with the world wide trend, we developed the conceptual lead cooled fast reactor as shown in Fig.1 and the safety analysis carried out to confirm the meet of some safety criteria applied to the development of KALIMER.

2. Method and Results

For the analysis for the accidents of the LFR, the SSC-K[1, 2] system analysis code has been used. The code has been developed for the purpose of the safety analysis of a sodium cooled fast reactor by Korea Atomic Energy Research Institute (KAERI). The code features a multiple-channel core representation coupled with a point kinetics model with reactivity feedback. It provides a detailed, one-dimensional thermal-hydraulic simulation of the primary and secondary coolant circuits, as well as the balance-of-plant steam/water circuit. Lead thermodynamic properties are implemented into the code to analyze the postulated accidents in the lead cooled fast reactor.

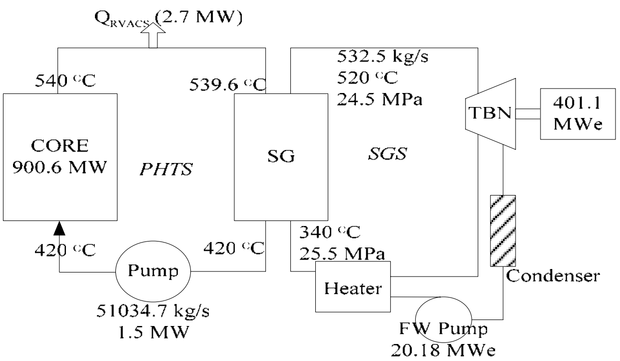

Fig. 1 Energy Balance of the LFR

The ultimate means of protection of public safety from the consequences of postulated ATWS are the inherent negative reactivity feedback resulting from increase of the reactor system temperature, and RVACS(Reactor Vessel Air Cooling System). Analyses of the selected ATWS using SSC-K are conducted to assure that these inherent features are effective in the LFR design. The events considered are: Unprotected control rod withdrawal (UTOP), Unprotected loss of heat sink (ULOHS), Unprotected loss of primary flow (ULOF), and combination of those events. Currently, the safety criteria for the LFR were not prepared, thus the temperature limits for the KALIMER were used. The metallic fuel was loaded in the core of KALIMER and the operational temperatures are similar to those of the LFR.

Table 1. Initial Conditions for the LFR at rated Power

Parameter	Design	SSC-K
Core power, MW	900	900
Mass flow rate, kg/s	51034.7	51077.7
Core inlet temperature, °C	420.0	419.0
Core outlet temperature, °C	540.0	539.0
Pumping power, MW	1.5	1.5
Cover gas pressure, MPa	0.1	0.1
Elevation of hot pool level, m	14.65	14.64
Elevation of cold pool level, m	9.65	9.64
Power removed thru RVACS, MW	2.7	2.71

Unprotected transients are evaluated on the nominal basis. The initial plant conditions are assumed to be full power operation with equilibrium decay heat levels. The reactor protection system and reactor controller subsystem actions are conservatively ignored for the inherent safety analyses of accidents. Table 1 compares the steady-state result of SSC-K and the design values.

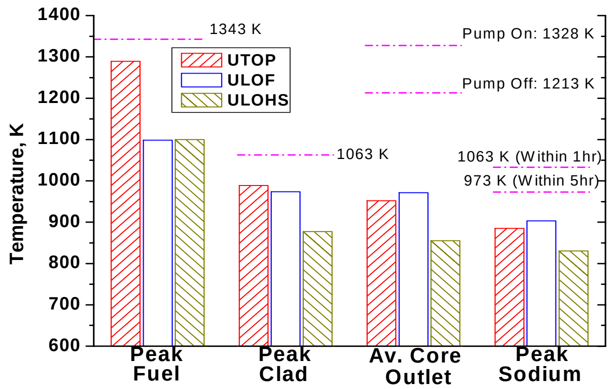

Fig. 2 SSC-K Modeling for the LFR system

2.1 UTOP

It is assumed that the withdrawal of the control rods is at the rate of 2 cents per second. A total of 30 cents has been adopted as the UTOP initiator for the analysis. It is assumed that the primary coolant flow remains constant at the rated conditions, and the feedwater is sufficient to keep a constant lead outlet temperature because of the steam generator.

The power peak jumps to 160 % of the rated power as soon as the external reactivity is inserted short time after the transient and then the power begins to decrease soon after. The reactivity induced by the CRDL and the radial expansion put down the power to converge to stable condition of about 105 % of the rated power. The fuel temperature responds quickly to the peak power, whereas temperatures of coolant, assembly, supporting structures, and control rod drive line increase slowly. The peak fuel centerline temperatures predicted by SSC-K are below the melting temperature of the fuel, 1343 K. There still exists margin of an about 53 K for the event. The peak cladding temperatures are also below the threshold for eutectic formation, 1063 K, and provide safety margin of about 74 K. No cladding damage, therefore, is expected.

2.2 ULOHS

In the analysis, the accident begins with the complete loss of SG flow. All heat generated in the core is, then, would be retained in the primary vessel. The RVACS is designed to avoid such unlimited heat up of the primary system, which could lead to significant core damage. The main concerns in the analysis are to confirm inherent safety characteristic of the LFR core that the core has been shutdown to decay heat level.

On the contrary to the power, the core flow reduction is small and eventually sustains almost 98 % of the initial flow because of the pump operation. As the accident occurs, the core heat generation drops rapidly due to the net negative reactivity. In the present analysis, even though the core protection systems are not assumed to be available, the amount of negative reactivity introduced inherently is found out to be enough to shutdown the reactor. The core power after 1,000 sec tends to keep the decay heat level of about 18 MWt, which corresponds to approximately 2 % of the nominal power. Fig. 3 represents the results of the temperatures in the hot active fuel channel at the sixth axial node, corresponding to that with the highest power generation. The power reduction causes to drop the fuel and clad temperatures. The coolant temperature is increased due to the loss of cooling in the SGs.

2.3 ULOF

The ULOF event is initiated by all primary pump trips followed by coastdown. it is assumed that the RPS fails to detect the mismatch or that the control rods fail to be inserted. For the loss of flow accident, the power to flow ratio is a key parameter that determines the consequences of the accident. Thus, the pump coastdown plays an important role for the plant safety. The power immediately begins to drop and reaches the decay heat level by about 100 seconds, because there is enough negative reactivity to drive the core to sub-critical condition. Finally, all reactivities reach quasi-equilibrium state after 400 seconds.

The cold pool lead temperature goes down and goes up around 100 seconds, however hot pool is heated and cooled. Around 500 seconds, plant maintains quasi-steady state at cold pool temperature of 711 K and hot pool temperature of 753 K.

3. CONCLUSIONS

This paper has focuses primarily on the unprotected event of ATWS analyses of the LFR. There are three events of concern: UTOP, ULOHS, and ULOF. These postulated ATWS events have been analyzed using the SSC-K computer code modified to simulate the transient of a lead cooled fast reactor. At the UTOP event, the fuel rod temperatures are below some criteria. In the ULOHS and ULOF, there are various uncertain factors, however, the analysis results clearly show that the inherent safety characteristics of the LFR resulting from the reactivity feedbacks are ensured. The analysis results indicate that because of the reactivity feedback characteristics, the LFR response against ATWS events become benign.

ACKNOWLEDGMENTS

This work has been performed under the nuclear R&D program supported by the Ministry of Science and Technology of the Korean Government.

REFERENCES

1. Y. M. Kwon et al., “SSC-K Code User’s Manual, Rev.1”, KAERI/TR-2014/2002 (2002).
2. J. G. Guppy, et al., “Super System Code (SSC, Rev. 0) An Advanced Thermal-Hydraulic Simulation Code for Transient in LMFBRs”, NUREG/CR-3169 (1983).
3. D. H. Hahn et al., “Reactivity Feedback Models for SSC-K,” KAERI/TR-1105/98 (1998).
4. D. H. Hahn, et al., “KALIMER Preliminary Conceptual Design Report,” KAERI/TR-1636/2000 (2000).
5. J. G. Van Tuyle et al., “Evaluations of 1990 PRISM Design Revisions,” NUREG/CR-5815 (1992).
6. J. G. Van Tuyle et al., “Analyses of Unscrammed Events Postulated for the PRISM Design”, Nuclear Technology, Vol. 91, pp. 165-184, (1989)