Proceedings of the Korean Nuclear Society Spring Meeting
Cheju, Korea, May 1996

ATWS Performance of KALIMER Uranium Metal Core

Dohee Hahn and Young C. Kim
Korea Atomic Energy Research Institute

Abstract

The KALIMER core, of which nuclear design is largely governed by inherent safety and reactivity control issues, is fueled with metallic fuel, and the initial core will be loaded with 20% enriched Uranium metal fuel. KALIMER safety design objectives include the accommodation of unprotected ATWS events without operator action, and without the support of active shutdown, shutdown heat removal, or any automatic system without damage to the plant and without jeopardizing public safety. The transient analysis of the core designs has been focused on severe events to assess the margins in the design, and ATWS events are the most severe events that must be accommodated by the KALIMER design. The ATWS performance has been evaluated for the preliminary initial core design of KALIMER with a particular emphasis on the inherent negative reactivity feedback effects, including the Doppler, sodium density, fuel axial expansion, core radial expansion, and control rod driveline expansion. Results show that the Uranium metal core design meets the temperature limits with margin.

1. Introduction

The safety design of KALIMER emphasizes accident prevention by using passive and natural processes, which can be accomplished by the safety design objective of the accommodation of unprotected anticipated transients without scram (ATWS) events such as the unprotected transient overpower (UTOP), unprotected loss of flow (ULOF), and unprotected loss of heat sink (ULOHS) events without operator action, and without the support of active shutdown,

shutdown heat removal, or any automatic system without damage to the plant and without jeopardizing public safety. In order to assess the effectiveness of the inherent safety features based upon the negative reactivity feedbacks in achieving the safety design objectives, a preliminary evaluation of ATWS performance for the KALIMER initial core design has been performed.

2. Inherent Negative Reactivity Control

One important design inherency in the liquid metal reactors is the inherent shutdown, which refers to the tendency of the reactor to transition to a much lower power level whenever temperatures rise significantly. This type of behavior was demonstrated in a series of unscrammed tests at EBR-II. The KALIMER is designed to provide a strong inherent negative reactivity feedback with rising temperature. This characteristic, combined with the Reactor Vessel Auxiliary Cooling System (RVACS) heat removal capability, makes the KALIMER capable of safely withstanding severe undercooling and overpower transient events without scram.

Several reactivity feedbacks are important in the inherent shutdown response for the metal cores. Because of the smaller Doppler feedback in the metal core, reactivity feedbacks having little importance in oxide cores are important in the metal core. As the temperature increases during an event, the negative feedback from Doppler, axial fuel expansion, radial core expansion, and control rod driveline expansion are activated, which generate a net negative reactivity for the core loaded with metal fuel. This feedback responds according to the associated time constants, to overcome the positive reactivity from the sodium density / void effect and any external source.

3. Preliminary Uranium Metal Core Design

One of the options being considered for a KALIMER reactor core is the design which utilizes a homogeneous core configuration allowing a compact core and no fuel shuffling. The layout consists of 115 driver fuel assemblies, 6 control rods, and 174 shield assemblies. The inner five rows of the core consist of low enrichment fuel assemblies and six control rods. The outer radial core section contains two rows of high enrichment fuel assemblies. Six control rods are located between two enrichment zones. There are no upper or lower axial blankets surrounding the core.

4. ATWS Performance

ATWS events of UTOP and ULOF are selected for the safety margin assessment of the KALIMER initial core design. The objective of ATWS performance analyses is to evaluate the inherent passive safety features of U metal cores. It should be noted that the KALIMER core option being analyzed has not been optimized yet, and thus there is a room for the improvement in its safety performance. The ARIES code of General Electric has been utilized for the analysis along with ALMR system design data.

Conservative safety criteria are to be established in order to insure that the requirements for ATWS events are met. Safety criteria to be considered include the limited number of cladding failures, maintenance of primary boundary integrity, no sodium boiling, and no positive reactivity addition from fuel movement. Temperature limits are then to be set, based on current knowledge of experimental data, to insure that these safety criteria are met. The temperature limits are dependent on the specific fuel and cladding compositions, and are subject to revision as additional experimental test data become available.

Preliminary temperature limits for accommodated ATWS events of the KALIMER are 1880 ^{0}F (over which for less than two minutes) for peak fuel temperatures of U metal fuels. In order to prevent sodium boiling, the temperature limit for sodium is set at 1750 ^{0}F when no sodium pumps are operating.

4.1 All Primary Rods Withdrawal Without Scram

This event postulates that a malfunction in the reactivity controller causes the shim motor to continue to withdraw all of the primary control rods and that the Reactor Protection System (RPS) either fails to detect the event or the control rods fail to unlatch. The shim motors are assumed to withdraw the control rods at a rate corresponding to $0.02 per second. The secondary control rods are completely withdrawn during normal operation, and it is assumed that these rods do not contribute to the reactivities inserted for this accident. It is assumed that the primary and secondary sodium flows remain at rated conditions for this event and that the feedwater is sufficient to keep the sodium outlet temperature from the steam generator constant. The results of $0.20 UTOP transient for power and flow, the core temperatures, and the reactivity feedbacks are shown in Figures 1 through 3. Due to its rapid progression of the UTOP event, for which case the safety margin is usually determined by the fuel centerline temperature, there is little effect of the reactor configuration on the consequences of this event. Although the design meets the performance limits for ATWS events, the limiting condition appears to be the clad temperature at the elevated equilibrium conditions. This temperature must remain below the 1300 ^{0}F limit to prevent eutectic formation because the reactor could be in that state indefinitely.

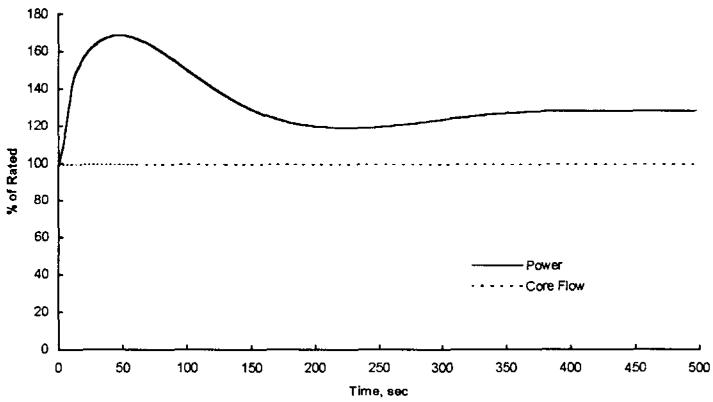

Figure 1. Power and Flow during $0.20 UTOP

4.2 Unprotected Loss of Primary Flow

For the ULOF event, the intermediate heat transport system (IHTS) flow is assumed to be at the rated condition, and the primary pumps are assumed to coastdown. The heat removal

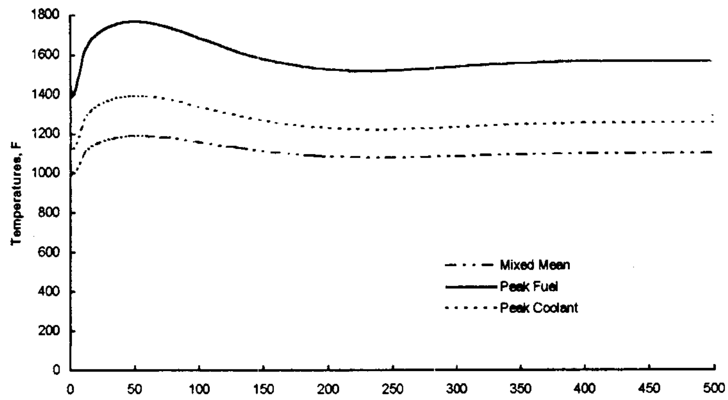

Figure 2. Temperatures during $0.20 UTOP

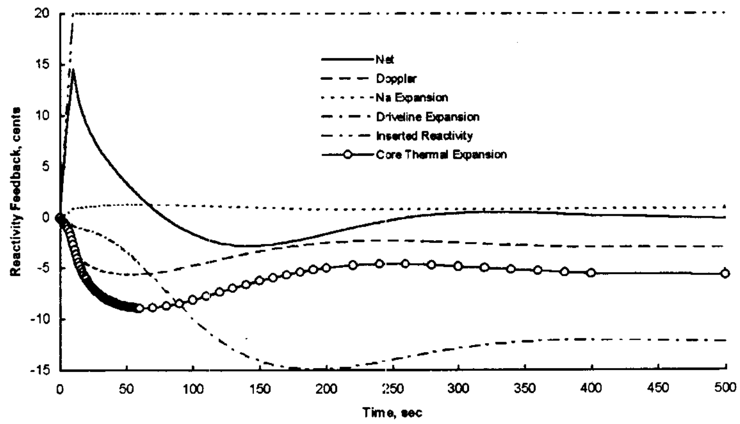

Figure 3. Feedbacks during $0.20 UTOP

from the reactor vessel by RVACS has not been modeled and the reactor heat is removed by the normal path of IHTS. After the coastdown, the primary pumps are in a low flow operation mode, providing about 13% of the rated primary flow. Although this would normally result in a scram due to a high flux-to-flow ratio soon after the initiation of the coastdown, it is assumed that either the RPS fails to detect the mismatch or the control rods fail to insert. The Uranium metal core which have been analyzed do not have Gas Expansion Modules (GEMs). Adoption of GEMs in the core would increase the safety margin for the loss of primary flow events by the rapid introduction of a large negative GEM worth with the primary flow coastdown. The results of performance analysis for UTOP ans ULOF events are summarized in Table 1.

Table 1. Summary of ATWS Performance of KALIMER Uranium Metal Core

		Temperatures, ^0F	
Events	Peak Power, %	Peak Fuel	Peak Coolant
Temperature Limits		1880	1750
100% Power	100	1445	1131
$0.20 UTOP	169	1767	1391
ULOF	100	1609	1544

5. Conclusions

Improvement of the KALIMER design and assurance of the enhanced safety can be achieved by the preliminary evaluation of ATWS performance of KALIMER core options from the initial concept study phase. The temperature limits are met with margins for the Uranium metal core whose performance would improve with a core design optimization and the introduction of passive features such as RVACS and GEMs. KALIMER Uranium metal core has inherent passive means of negative reactivity insertion, sufficient to place the reactor system in a safe stable state for these ATWS events without significant damage to the core or reactor system structure.