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Thermal Hydraulic Analyses for KALIMER Reactor Pool during Loss of Normal Shutdown Cooling Event

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Abstract

The thermal hydraulic calculations have been made for the KALIMER during the loss of normal shutdown cooling event from full power condition using the COMMIX-1AR/P code (Garner, 1992). The PHTS (Primary Heat Transport System) and surroundings of the KALIMER have been modeled using the cylindrical geometry option in COMMIX-1AR/P. The radial extent of the model is bounded by the centerline of the reactor vessel (RV) and the air separator, which is the outer boundary of the air riser portion of the PSDRS. Axially, the model begins at the bottom of the reactor vessel and extends to the top of hot pool sodium level. Results for the transient calculation over its early part of transient are presented. The transient analyses showed a smooth transition to natural convection without excessive fuel temperature peaks. The temperature response histories at various points in the reactor are used for structural evaluations.

1. Introduction

In the KALIMER, normal shutdown heat removal is done by condenser cooling through the steam generator. If the condenser is not available, the SGACS (Steam Generator Auxiliary Cooling System), which is a back-up non-safety grade decay heat removal system, is used for heat removal. In the case of malfunction in both non-safety grade system, the PSDRS (Passive Safety Decay heat Removal System) will remove heat directly from the reactor vessel by using natural air circulation flow. The PSDRS transient is characterized by a reactor trip followed by primary and intermediate pumps coastdown. Sodium flow in the IHTS (Intermediate Heat Transport System) is assumed to drop to zero in a short time period resulting in no heat removal through the IHX (Intermediate Heat Exchanger) at later times. Subsequent heat removal is done by the PSDRS only. This transient is expected to produce thermal loads due to thermal shock and coolant stratification within the pool.

During normal operation the free surface of the sodium within the annulus formed by the reactor vessel and the reactor baffle is about 5 m below the hot pool free surface due to the IHX primary side pressure drop. As primary pump coast down, the annulus gap will be filled with sodium instead of helium gas, and both free surface of the sodium of hot and cold pool will have the same elevation. Since the temperature of the surface of the hot pool is not expected to experience a large variation for the early part of the transient, it is assumed that the top surface has the same heat transfer rate as that of free surface of the hot pool during normal operation.

Calculation models and performance results of a short term transient from the COMMIX analysis are presented in the following.

2. COMMIX Calculation models

Figures 1 and 2 show the reactor structures and components of the pool. The PHTS and surroundings have been modeled using the cylindrical geometry option in the code. The IVTM(In-Vessel Transfer Machine) of the UIS(Upper Internal Structure) is ignored. A 90 ° sector is assumed by symmetry considerations, spanning the space between the centerline of the IHX's. The radial extent of the model is bounded by the centerline of the reactor vessel (RV) and the air separator, which is the outer boundary of the air riser section of the passive safety decay heat removal system (PSDRS) ; the air downcomer of the PSDRS has not been modeled, as it is separated from the riser by the insulating barrier. Axially, the model begins at the bottom of the RV and extends to the top of the free surface. The hemispherical shape of the bottom of the RV is ignored.

There are 21 nodes in the radial direction (IMAX=21): nodes 1 through 15 contain the sodium within the RV, nodes 16 and 17 contain the argon between the RV and the CV, node 18 and 19 contain the air between the CV and air separator, node 20 contains no fluid cells, and node 21 contains the sodium in the intermediate side of the IHX. There are 11 nodes in the azimuthal direction (JMAX=11): nodes 1, 2 and 10, 11 contain half of each IHX, nodes 5 through 7 contain the pump. There are 28 nodes in the axial direction (KMAX=28): node 28 is used for the expansion cells of the sodium and argon region. The expansion cells are used to circumvent numerical instability during heating (cooling) when incompressible fluids are located in completely enclosed spaces. Calculation cell sizes along the each axis are as follow;

- DX=0.2236, 0.1448, 0.1457, 0.1858, 0.3387, 0.3414, 0.3414, 0.125, 0.2043, 0.39, 0.4, 0.3093, 0.2725, 0.025, 0.0375, 0.1, 0.0875, 0.1125, 0.18, 0.035, 0.3,
- DY=11*0.1428,
- DZ= 0.4, 0.4, 0.4, 0.4, 0.275, 0.3829, 1.1176, 1.2, 1.1245, 0.2, 0.2509, 0.6491, 0.5, 0.225, 0.7375, 0.7375, 0.7, 0.7, 0.7, 0.7, 0.8, 0.44, 0.26, 0.24, 0.56, 0.6, 0.7, 1.0

Several views of the grid system for this study are shown in Figure 3 through Figure 5. In all figures, solid lines are used to denote boundary surfaces; dotted lines are used to denote cell faces which are pervious but not on boundary surfaces. An elevation view is provided in figure 3 and 4, showing two azimuthal locations : figure 3 contains the pump and figure 4 contains the IHX. Figure 5 is a plan view at the axial level of the separation plate. This shows the location of the pump duct and the return pipes. The core system is designed to generate 392.2 MWt of power. The core adopts a heterogeneous configuration in the radial direction that corporates annular rings of internal blanket and driver fuel assemblies. There are no upper and lower axial blankets surrounding the core. The core has an active core height of 120 cm and core structural material is HT9.

3. Operation and boundary conditions

Steady-state calculation at 100% power has been made for the initial condition of the transient calculation. Its boundary conditions are as follows (Sim, 1998).

- Tube side inlet velocity of IHX : 3.15 m/sec
- Tube side inlet temperature of IHX : 338.8 ℃
- Air inlet velocity : 3.18 m/sec
- Air inlet temperature : 40 ℃
- Heat loss from the top surface of the pool : 2314 W/㎡

The boundary conditions for the transient calculation are the product of an initial value times a transient scaling factor called the transient function. There are six transient functions; the FVAL(1) is for the normalized flow rate of the intermediate side of the IHX : the FVAL(2) is for the normalized inlet temperature of the intermediate side of the IHX : the FVAL(3) is for the normalized heat sources of the fuel, blanket, shielding, reflector : the FVAL(4) is for the normalized heat sources of pumps: the FVAL(5) is for the normalized pump coastdown flow rate : the FVAL(6) is for normalized air flow rate in PSDRS and is the function of the temperature of reactor vessel outer wall: FVAL's for this study are shown in Figure 6 through Figure 9. It is assumed IHX inlet temperature of the intermediate side is constant and no heat is generated from pumps during the transient. IHX inlet sodium flow of the intermediate side is assumed to drop to zero within 2 seconds.

4. Results

The steady state calculation is terminated when the changes of the velocity components and enthalpy per step devided by the maximum magnitude in the entire field are less than $1x10^{-5}$.

Results for the calculation over its first 20 minutes are presented. It is important to verify that transition to natural condition without flow reversal is predicted for the coastdown of primary pump and temperature distribution. The transient anaylses of this evaluation showed the transition from forced flow to natural convection flow is smooth without excessive fuel temperature peaks.

The driver fuel and blanket fuel outlet temperature are shown in Figure 10, 11. The blanket fuel outlet temperature decreases to 410 ℃ at about 50 seconds and then increases to 560 ℃

at approximately 800 seconds. The cooldown rate is about 2.2 ℃/s. The driver fuel outlet temperature response is similar to the blanket fuel response. It decreases to 410 ℃ at about 25 seconds and then increases to 560 ℃ at approximately 800 seconds. The cooldown rate is more rapid than that of the blanket fuel during 25 seconds and is about 4.8 ℃/s. This is due to a larger thermal capacity of blanket fuel assemblies. Temperature variations at the core inlet and hot pool above the core are shown in Figure 12. The core inlet temperature is steadily increasing from the beginning of the transient. The temperature of hot pool above the core decreases to 413 ℃ at 40 seconds and then smoothly increases. Figure 13 shows the IHX inlet and outlet temperatures. The IHX outlet temperature increases rapidly to 512 ℃ at about 55 seconds due to the loss of IHTS flow. Figure 14 shows hot pool surface temperature at mid location in the radial direction and cold pool temperature below reactor support .

5. Conclusions

Thermal hydraulic calculations have been made using the multi-dimensional thermal hydraulic code COMMIX-1AR/P. Results for the transient calculation over its early part of transient are presented. The transient analyses showed a smooth transition to natural convection without excessive fuel temperature peaks. The cooldown rates of the blanket fuel and driver fuel assembly during early transient were about 2.2℃/s and 4.8 ℃/s. The temperature responses at other points in the reactor are used for structural evaluations.

Acknowledgement

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References

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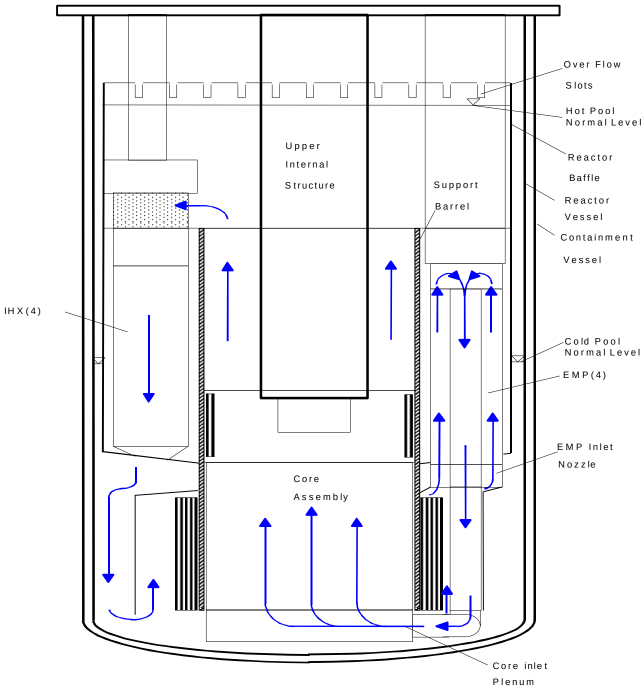

Fig.1 Primary system of the normal sodium flow path

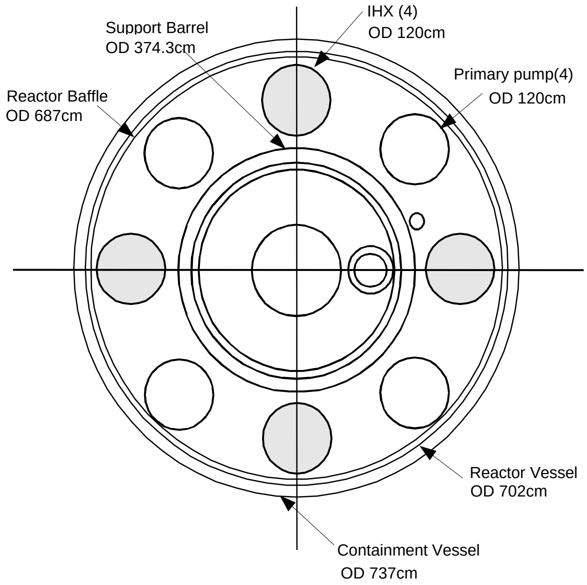

Fig.2 Horizontal arrangement of the primary pumps and IHXs

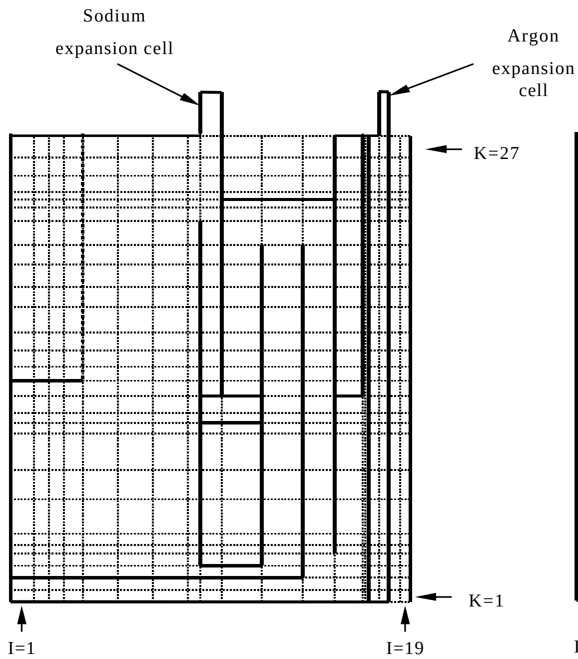

Fig. 3 Elevation view of the COMMIX model (J=6)

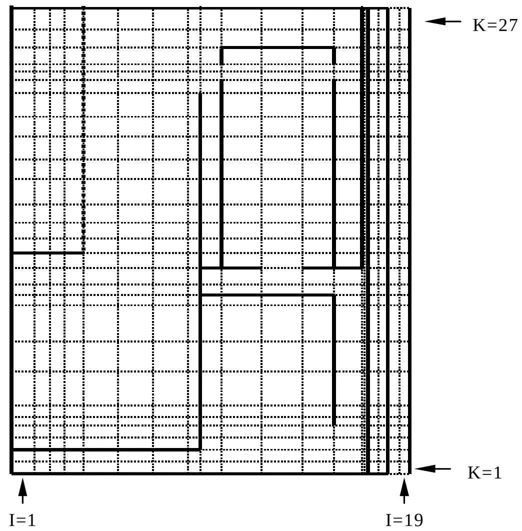

Fig. 4 Elevation view of the COMMIX model (J=1, 11)

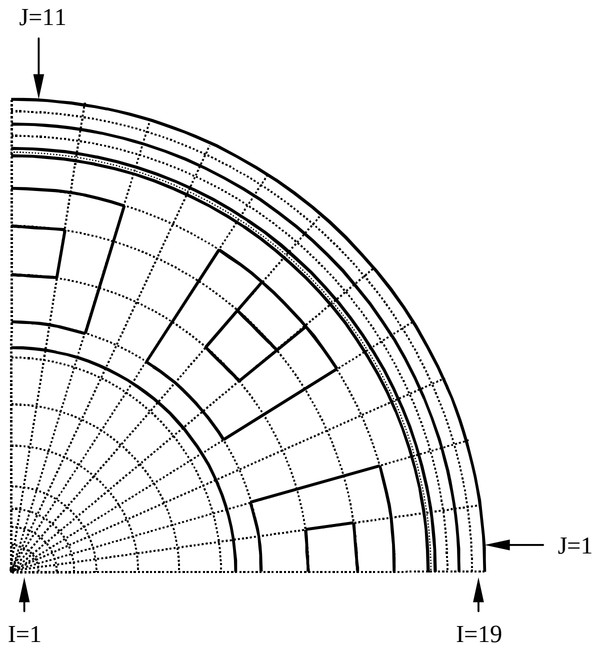

Fig.5 Plan view of the COMMIX model

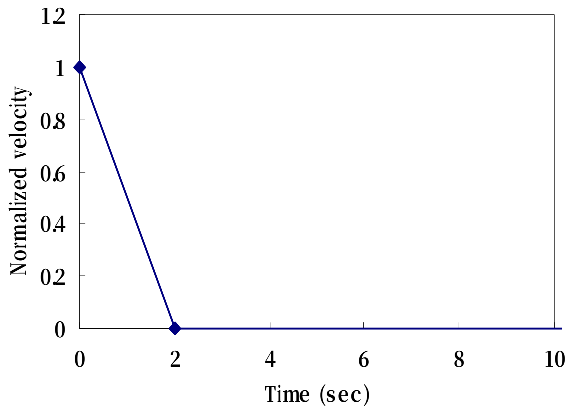

Fig. 6 Intermediate IHX flow coastdown

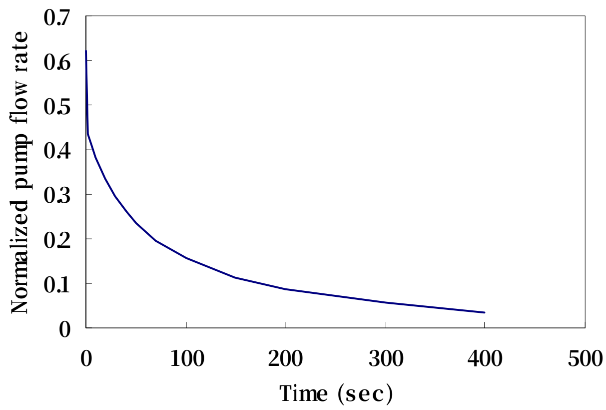

Fig. 7 Primary pump flow coastdown

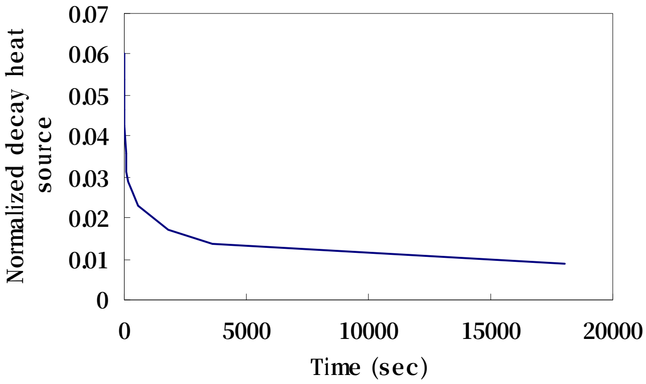

Fig. 8 Normalized decay heat source

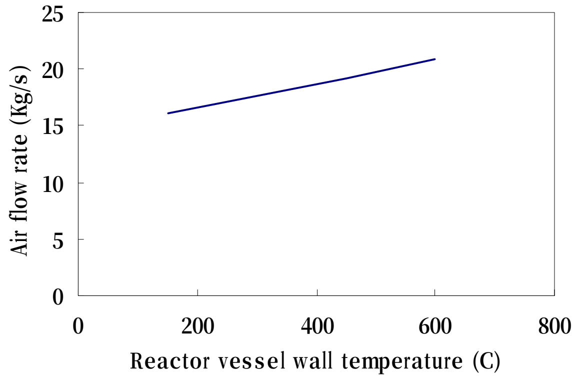

Fig. 9 PSDRS air mass flowrate

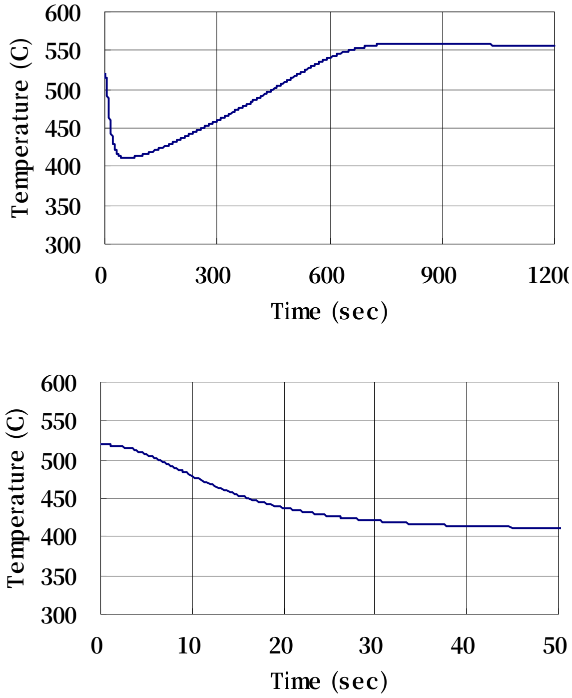

Fig. 10 Blanket fuel outlet temperature

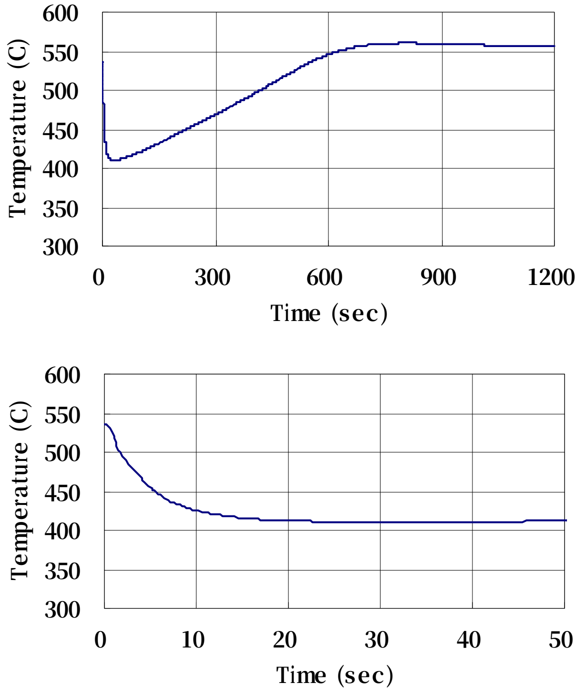

Fig. 11 Driver fuel outlet temperature

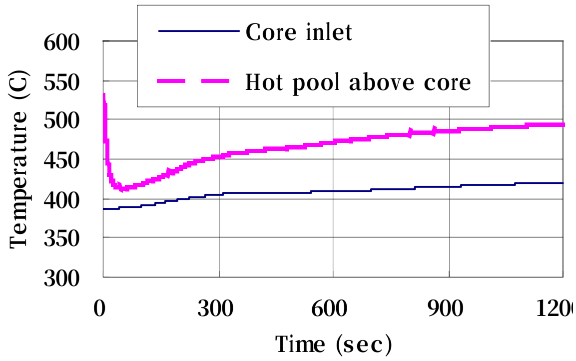

Fig. 12 Core inlet/outlet temperature

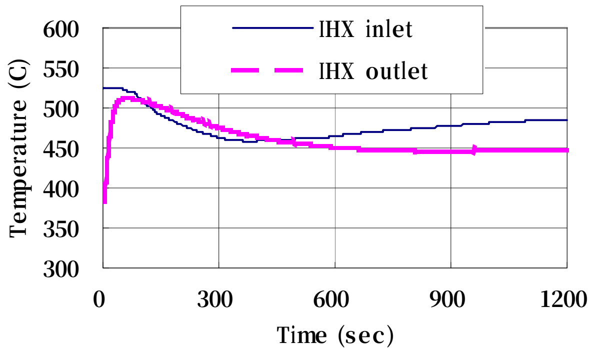

Fig. 13 IHX inlet/outlet temperature

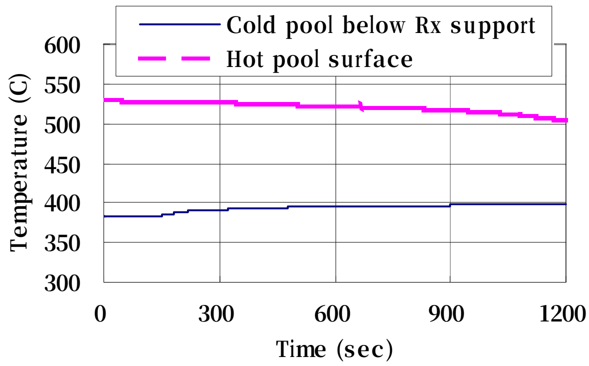

Fig. 14 Hot pool/cold pool temperature