Multi-dimensional Code Development for Safety Analysis of LMR

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1. Introduction

A liquid metal reactor loaded a metallic fuel has the inherent safety mechanism due to the several negative reactivity feedbacks. Although this feature demonstrated through experiments in the EBR-II, any of the computer programs until now did not exactly analyze it because of the complexity of the reactivity feedback mechanism.

Korea Advanced LIquid MEtal Reactor (KALIMER) is a pool-type sodium cooled reactor that uses metallic fuels. SSC-K code has been used for the reactor safety analysis by several simplified reactivity feedbacks. To apply a detailed reactivity models, a multi-dimensional program (MDP) developed through the International Nuclear Energy Research Initiative(INERI) from 2203 to 2005. This paper includes the numerical coupling SSC-K code and the multi-dimensional program. The coupled code has been proved by comparing the analysis results using the code with the results using SAS-SASSYS code of ANL for the UTOP and ULOF applied to the safety analysis for KALIMER-150.

2. Method and Results

2.1 Hydrodynamic models of SSC-K

SSC-K simulates single phase flow and the flow is assumed to be incompressible. The axial distributions of coolant pressure in all channels of core are determined by following momentum equation.

$$\frac{dW}{dt}+\frac{d}{dz}(W\cdot v)+A\frac{dP}{dz}+\frac{f_k}{D_{H_k}}\frac{\rho v^2 A}{2}+\rho g=0 \qquad (1)$$

Here, 'W' is the flow rate in a coolant channel 'k', 'v' is the velocity, 'ρ' is the coolant density, 'P' is the pressure, 'D_{Hk}' is the hydraulic diameter, 'f' is the friction factor, and 'A' is the flow area. Solving of the equation uses the fully-implicit finite difference scheme.

The integration of Eq. (1) for the parallel channels gives the pressure drop occurred in the core.

$$\Delta P_k=\left(\frac{\Delta z}{A}\right)_k\frac{\delta W_k}{\delta t}+\left(\frac{W}{A}\right)_k^2\left(\frac{1}{\rho_t}-\frac{1}{\rho_b}\right)+W_k|W_k|\cdot(I_{f,k}+I_{K,k})-g\cdot I_{g,k} \qquad (2)$$

$$I_{f,k}=\left.\frac{f\cdot\Delta z}{2\rho DA^2}\right|_{inlet}+\left.\frac{f\cdot\Delta z}{2\rho DA^2}\right|_{outlet}+\frac{1}{2DA^2}\sum_j\left.\frac{f\cdot\Delta z}{\rho}\right|_{j=1,N} \qquad (3)$$

$$I_{K,k}=\left.\frac{K}{2\rho A^2}\right|_{inlet}+\left.\frac{K}{2\rho A^2}\right|_{outlet} \qquad (4)$$

$$I_{g,k}=\rho\cdot\Delta z|_{inlet}+\rho\cdot\Delta z|_{outlet}+\sum_j\rho\cdot\Delta z|_{j=1,N} \qquad (5)$$

2.2 Hydrodynamic models of the MDP

The multi-dimensional program can compute steady-state and transient fuel, cladding and coolant temperatures in each fuel pin and coolant sub-channel of a subassembly. Duct wall temperatures can also be calculated for each of the six flats of a hexagonal subassembly. The detailed three-dimensional temperature and flow distributions can be calculated for each subassembly as in Fig. 1 in the whole-core.

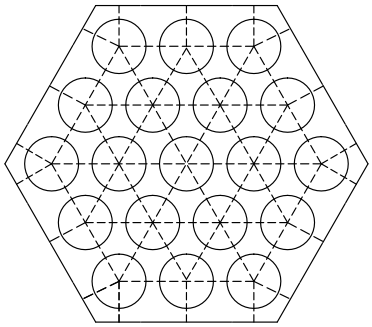

Fig. 1. Coolant subchannels in a 19-pin Hex

The basic equations for the program are continuity, energy, and axial and horizontal momentums. Eqs. (6) and (7) describe momentums for the axial and horizontal directions. Numerically, a time step approach is used both for the steady-state null transient and for the regular transient. The equations are linearized about values at the beginning of the time step, and fully implicit finite differencing in time is used for the basic conservation equations. This leads to N linear equations in N unknowns. The unknowns are solved for by iteration.

Here, i = sub-channel number, j = axial node number, k = sub channel number of a connecting subchannel, K_{or} = orifice coefficient, Δp_{frji} = friction pressure drop in the bottom half of node j and the top half of node j-1, S_{wjik} = 1 if $w_{Ljik} \geq 0$, 0 otherwise. w_{Ljik} = lateral flow from sub-channel i to sub-channel k at node j, S_{jik} = 1 if $\overline{p}_{ji} \geq \overline{p}_{jk}$,-1 otherwise, K_{sik} = wire wrap sweeping factor.

$$\frac{1}{2}\left(\frac{\Delta z_j}{A_{ji}}+\frac{\Delta z_{j-1}}{A_{j-1,i}}\right)\frac{dw_{ji}}{dt}=\bar{p}_{j-1,i}-\bar{p}_{ji}-\frac{\bar{w}^2_{ji}}{\bar{\rho}_{ji}A^2_{ji}}+\frac{w^2_{ji}}{\rho_{ji}A^2_{ji}}-\frac{w^2_{ji}}{\rho_{ji}A^2_{j-1,i}}$$
$$+\frac{\bar{w}^2_{j-1,i}}{\bar{\rho}_{j-1,i}A^2_{j-1,i}}-\Delta p_{frji}-\frac{w_{ji}\,|w_{ji}|\,K_{orji}}{2\rho_{ji}A^2_{ji}}-\frac{\rho_{ji}g(\Delta z_j+\Delta z_{j-1})}{2} \quad (6)$$
$$-\frac{1}{2}\sum_k\{S_{wjik}\frac{w_{Ljik}w_{ji}}{\bar{\rho}_{ji}A^2_{ji}}-(1-S_{wjik})\frac{w_{Ljik}w_{jk}}{\bar{\rho}_{jk}A_{jk}A_{ji}}$$
$$+S_{wj-1,ik}\frac{w_{Lj-1,ik}w_{j-1,i}}{\bar{\rho}_{j-1,i}A^2_{j-1,i}}-(1-S_{wj-1,ik})\frac{w_{Lj-1,ik}w_{j-1,k}}{\bar{\rho}_{j-1,k}A_{j-1,k}A_{j-1,i}}\}$$

$$w_{Ljik}=K_{sik}\frac{(w_{ji}+w_{j+1,i})}{2}+S_{jik}\sqrt{\frac{2\rho A^2_{Lik}\,|\bar{p}_{ji}-\bar{p}_{jk}|}{K_{Lik}}} \quad (7)$$

2.3 Coupling of SSC-K and MDP

The multi-dimensional program was coupled with SSC-K for the detailed treatment of core region. For a time step the subassembly coolant inlet and outlet flows are approximated as

$$w_{sain}(t+\Delta t)=c_1+c_2\Delta p_{in}+c_3\Delta p_x \quad (8)$$

$$w_{sax}(t+\Delta t)=c_4+c_5\Delta p_{in}+c_6\Delta p_x \quad (9)$$

where $\Delta p_{in}=$ change in inlet pressure during the time step and $\Delta p_x=$ change in outlet pressure during the time step. The coefficients $c_1 \ldots c_6$ are calculated in the SA coolant calculations for each time step.

2.4 Simulation results using the coupled code

Unprotected postulated accidents for KALIMER-150 have been simulated to validate the coupled code (SSC-MDP). The simulation results were compared to those of SAS-SASSYS which developed at ANL. KALIMER-150 is a 150 MWe pool-type sodium cooled reactor that uses metallic fuels. The reactor is composed of 168 subassemblies. The MDP simulates the 1/12 of the reactor core (14 SAs) because of the symmetry configuration. Fig. 2 represents the nodalization for the typical SA. The total number of channels is 696 and axially divided into the 42 elevations.

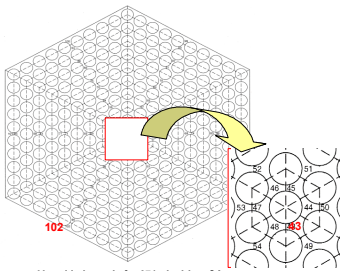

Fig. 2 Node of Single subassembly for the MDP

The results using the coupled code are well agree with the those of SAS-SASSYS. The slightly different results are mainly due to the difference of the coolant inventory of primary heat transport system. For the second cause, the total system pressure drop is differed because of the different wall friction factor models and the properties of sodium and structures. However the whole system behaviors are well agreed with each other.

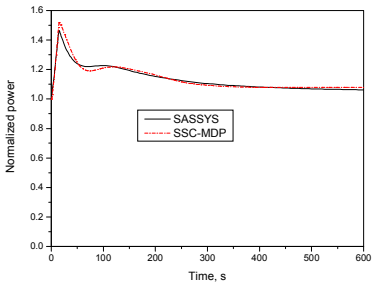

Fig. 3 Power behavior for the UTOP

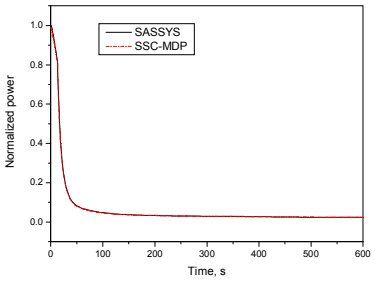

Fig. 3 Power behavior for the ULOF

4. Conclusion

For the application of detailed reactivity models, SSC-K and multi-dimensional program has been numerically coupled. The coupled code has been proved by comparing the analysis results using the code with the results using SAS-SASSYS code for the UTOP and ULOF applied to the safety analysis for KALIMER-150. The results are well coincided with each other.

ACKNOWLEDGMENTS

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