SPACE Code Development and Assessment Plans

Chang-Keun Yang [a*], Dong-Hyuk Lee [a], Yo-Han Kim [a], Sang-Jun Ha [b]
[a] *KEPCO Research Institute, 65 Munji-Ro, Yuseng-Gu, Daejeon, 305-760 KOREA*
[*] *Corresponding author: yanaki@kepri.re.kr*

1. Introduction

The Korea Electric Power Co. Research Institute (KEPRI) has been developing a thermal-hydraulic analysis code, SPACE (**S**afety and **P**erformance **A**nalysis **C**od**e** for Nuclear Power Plant), for PWR (Pressurized Water Reactor) safety analysis with co-workers. The SPACE code adopts advanced physical modeling of two-phases flows, two-fluid, three-field models which are comprised of gas, continuous liquid and droplet fields and has a capability to simulate 3D effects by the use of structured and/or non-structured meshes using the C/C++ language. As a result of the first phase project for SPACE code, the demo version was released on March 2010. V&V (verification and validation) work is currently being processed for making advanced SPACE code. In this paper, main features of SPACE code and a summary of the first phase project activities are presented.

2. Main Features of SPACE Code

2.1 Hydraulic Solver

The SPACE code has two-fluid, three-field governing equations in one-dimensional or three-dimensional geometry. The effects of one phase on another are accounted for by interaction terms appearing in the equations. Dividing the liquid phase into two fields is a convenient and physically reasonable way of handling flows where the liquid can appear in both film and droplet form, because the thermal and hydraulic behaviors of the droplets can be quite different from those of the film. When modeling in 3D, Cartesian or cylindrical coordinate system is used.

2.2 Mesh System

The SPACE code uses staggered mesh and semi-implicit discretization method, which are widely used in existing LOCA analysis codes. The staggered mesh system in SPACE code is based on the orthogonal hexahedral shape of cell and its surrounding faces. All of the geometric quantities are described in terms of cell volume, face area, and face center, so that Cartesian and cylindrical mesh systems can be expressed in the same manner. With these sub-faces, one-dimensional or three-dimensional branches are easily modeled in the SPACE code staggered mesh system. Generally curved pipes can be also represented by providing a inclined angle to each scalar cell.

2.3 Models and Correlations

The models and correlations are composed of the source terms for the governing equations. The physical models and correlations of the SPACE code are categorized into five packages; i) a flow regime selection package, ii) a wall and interfacial friction package, iii) an interfacial heat and mass transfer package, iv) a droplet entrainment and de-entrainment package and v) a wall heat transfer package.

2.3.1 Flow regime selection package

All the interfacial interaction properties, such as an interfacial heat and mass transfer rate and an interfacial drag force are highly depend on a flow regime. The SPACE code has two basic flow regime maps: horizontal and vertical flow regime maps.

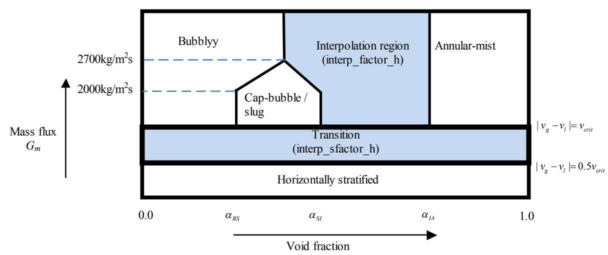

Fig. 1. Horizontal Flow Regime Map

The vertical flow regime map is applied in cells with inclined sine angle, $2/3 \le |\sin\phi| \le 1$ and the horizontal map is applied in cells with inclined sine angle, $0 < |\sin\phi| \le 1/3$. Interpolation is used in cells with inclined sine angle, $1/3 < |\sin\phi| \le 2/3$. A horizontal flow regime is determined according to the void fraction and relative velocity (or mass flux for vertical flow regime map) as shown in Fig. 1.

2.3.2 Wall and interfacial friction package

An interfacial friction factor accounts for an interfacial force that can occur as a result of a momentum interchange between phases. Using flow regime information and interfacial area concentration, an interfacial friction factor is calculated. The interfacial area concentration for Taylor bubbles used in interfacial heat transfer calculation cannot be used for a friction factor calculation since the area concentration for a drag model is the projected area of a Taylor bubble. For bubbly and slug flow conditions in a vertical channel, the drift flux model is used as a default model.

2.3.3 Interfacial heat and mass transfer package

An interfacial heat transfer is determined by multiplying the temperature difference at an interface with the product of an interfacial area concentration and an interfacial heat transfer coefficient. Interfacial heat transfer coefficient is determined by degree of a superheating or subcooling, and a flow regime. For slug flow, interfacial heat transfer coefficients for small and Taylor bubbles are calculated seperatedly. The large constant heat transfer coefficient is applied for the physically unstable states like a subcooled vapor or superheated liquid phase to avoid the sustaining of an unstable state.

2.3.4 Droplet entrainment and de-entrainment package

Droplet entrainment from a continuous liquid and de-entrainment to a continuous liquid can occur in annular-mist and horizontal stratified flows. The prediction of a droplet behavior may affect an accurate calculation of the reflood phenomena. Pan-Hanratty model is chosen to calculate the entrainment rate for a horizontal annular-mist flow because no proper model has been found.

2.3.5 Wall heat transfer package

The wall-to-fluid heat transfer modes consist of a liquid phase natural convection, a liquid phase forced convection, a nucleate boiling, a critical heat flux, a transition boiling, a film boiling, a vapor phase convection and a condensation heat transfer. A total of 12 heat transfer modes have been determined.

2.4 Special Models

Special models cover operation characteristics of a component or physical phenomena that applies to certain components. An example of component model is the pump model where pump performance curves are used to calculate pump speed, head and torque. The list of special models included in SPACE is as follows:

• Component Models : Pump, Safety Injection Tank, Pressurizer, Separator, ECC Mixing, Valve, Steam Turbine.

• Special Phenomena Models : Critical Flow, Counter Current Flow Limit, Abrupt Area Change, Level Tracking, Off-take

2.5 Heat structure and Kinetics Model

The heat structure model of SPACE code includes transient heat conduction in rectangular or cylindrical geometry. For fuel rod sections, reflood model with fine mesh feature and 2D conduction equation has been developed. Radiation heat transfer effects can also be modeled. The neutron kinetics model is used to calculate core power. The neutron kinetics model in SPACE code will be point kinetics with ANS decay heat models. If 1D or 3D neutron kinetics calculation is needed, a separate neutronics code will be linked with SPACE code to provide core power.

3. Code Assessment

The code assessment activity in Phase 1 is limited to conceptual problems and separate effect test problems. 20 conceptual and separate effect test problems were selected. SPACE input files were written and calculations were performed. The results were compared with analytic or experimental data. Basic code assessment shows that the SPACE code is correctly predicting physical phenomena. Further assessment using integral test data and plant calculation is planned for Phase 2.

4. Conclusions

The Korea nuclear industry has been developing SPACE thermal-hydraulics code PWR safety analysis. The phase 1 activity of SPACE code development has been completed and demo version of SPACE code has been released. The SPACE code can solve 2-fluid, 3-field governing equations. The SPACE code has many component models required for modeling a PWR, such as pump, safety injection tank, etc. Code assessment using conceptual problems and separate effect test problems were performed and show good results. Further code assessment is planned for phase 2 of SPACE code development.

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