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Perspective on Utilizing SAS4A/SAYYS-1 Code as Severe Accident Analysis Code for Metal Fueled SFR

Yong Won Choi*, Andong SHIN, Moo-Hoon BAE and Namduk SUH
Korea Institute of Nuclear Safety, Goosong-dong, Yusong-gu, Daejeon
**Corresponding author: k722cyw@kins.re.kr*

1. Introduction

SAS4A was developed at Argonne National Laboratory for analysis of severe accidents in liquid metal cooled reactors. And SAS4A was designed to analyze the initiating phase of core disruptive accidents resulting from under-cooling or overpower conditions. This code contains mechanistic models of transient thermal-hydraulic, neutronic and fuel-pin mechanical effects. In the US, SAS4A severe accident models were validated with results from fuel tests run in the TREAT facility.[1] Then, since 1990, the FZK/IPSN/JNC consortium have developed improved oxide fuel severe accident models for SAS4A, and have completed validation analyses of tests performed in the French CABRI reactor. However, the development of the metal-fuel severe accident models had not been completed at the time when the ANL focus shifted to inherent, passive safety phenomena. Therefore, further development and validation of the existing metal-fuel models will be needed in order to accurately describe the outcomes of postulated severe accidents in a metal-fuel fast reactor. The purpose of this study is to review the capability of SAS4A/SASSYS-1 code for severe accident analysis of metal-fueled SFR.

2. Review of SAS4A/SASYYS-1 Models

In this chapter, a brief introduction concerning models implemented in the SAS4A/SASYYS-1 code is given. [1],[2]

2.1 SAS4A fuel pin heat transfer model

This model describes one-dimensional, radial heat transfer at many axial locations. And the convective boundary condition to the axially flowing coolant from the cladding and the structure, steady state conditions for the coolant mass flow and the axially-dependent channel power, and steady state channel pressure drop in all channels are calculated by this module.

2.2 Coolant boiling model

Coolant boiling model in SAS4A (Fig.1) predicts single and two-phase sodium coolant flow in pin bundles. Thus, the behavior of low-pressure liquid sodium boiling (multiple slug/bubble flow regime) and cladding wetting (liquid sodium film on cladding and hexcan wall) are predicted by this model.

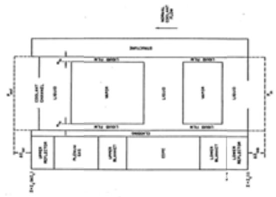

Fig. 1. SAS4A sodium boiling model

2.3 DEFORM-4 oxide-fuel pin mechanics model

Mechanistic simulation of oxide fuel and stainless steel cladding behavior during irradiation and in a transient are described by DEFORM-4. Fig.2 shows DEFROM-4 fuel/cladding deformation model.

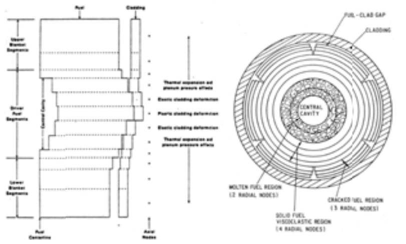

Fig. 2. DEFROM-4 fuel/cladding deformation model

2.4 DEFORM-5 metal-fuel cladding mechanics model

For stainless steel clad metallic fuel pins, DEFORM-5 predicts margins to cladding failure in DBA and BDBA transient and cladding failure time and location in severe accident transient

2.5 SSCOMP metal-fuel pre-transient characterization

SSCOMP calculates U-Pu-Zr migration and zone formation during pre-transient irradiation. The metal-fuel properties as a function of composition are calculated by this model. SSCOMP has correlation of Integral Fast Reactor (IFR) program metallic fuel properties database such as enthalpy, specific heat, density, thermal expansion, and thermal conductivity for metallic fuel. Also SSCOMP performs automated data interpolation among experimental data for composition correlation.

2.6 FPIN2 metal-fuel transient pin behavior model

FPIN2 was developed to analyze the thermal-mechanical phenomena that control the fuel behavior during fast reactor transients.

2.7 PINACLE in-pin fuel relocation model

PINACLE describes the pre-failure in pin fuel melting, leading to the formation of an internal cavity. Also the in-pin hydrodynamic relocation of the molten fuel and fission gas mixture is described by this model.

2.8 CLAP cladding melting and relocation model

CLAP model describes the cladding melting and relocation following dryout of sodium film, motion due to coolant vapor flow and gravity, and molten cladding freezing and blockage formation.

2.9 PLUTO2 fuel/coolant interaction model

PLUTO2 describes conditions characteristic of transient over-power (TOP) accident sequence. Thus, the objectives of this model are prediction of reactivity effect of material relocation, and prediction of end-state coolability.

2.10 LEVITATE fuel pin disruption model

LEVITATE is the model for fuel pin disruption in voided coolant channels. The model involves fuel (in- and ex-pin), fission gas, cladding, and coolant vapor dynamics following cladding failure and disruption in a channel voided of coolant.

2.11 PRIMAR-4 coolant system thermal/hydraulics model

PRIMAR-4 is the thermal and hydraulic model for primary and intermediate sodium coolant loops. And this model is arranged by volumes connected by segments. PRIMAR-4 has the special models for pumps, valves, heat exchangers, and steam generators. Fig.3 shows PRIMAR-4 model of a small pool-type reactor.

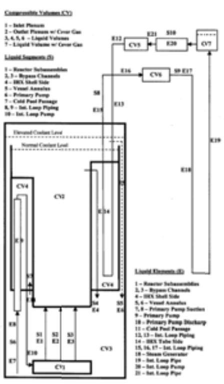

Fig.3 PRIMAR-4 model of a small pool-type reactor.

3. Extension & limitation of Metal-fuel Model of SAS4A/SASSYS-1 code

The SAS4A oxide-fuel models have undergone extensive development, testing, validation, and application, whereas the development and validation for SAS4A metal-fuel models have not been completed yet. So, in this chapter, the extension and limitation of metal-fuel model of SAS4A are evaluated.

3.1 SSCOMP Model

SSCOMP model simulates the in-pin diffusion-driven material migration during steady state irradiation of metal fuel. However, SSCOMP is not yet fully integrated with the fuel relocation models. The presence of the variable-composition fuel zones requires the extension of these models.

3.2 SAS4A Metal-Fuel Pin Behavior Modules

The transient metal-fuel pin behavior is described by the DEFORM-5 and FPIN2 models. The extension of the DEFORM-5 metal fuel pin behavior model to include advanced metal-fuel FPIN2 models and other metal-fuel behavior models is necessary. Thus, it is needed to integrate with SSCOMP. And the review and extension of transient fuel and cladding response models such as fission gas behavior model, pin swelling and axial expansion models, fuel/cladding eutectic formation and associated material migration and fuel component (U-Pu-Zr) migration during the transient are needed.

3.3 PINACLE Module

PINACLE module describes the in-pin molten fuel relocation prior to cladding failure. And the extension of the PINACLE model to track the relocation of each of the molten U-Pu-Zr metal-fuel components and associated fuel composition changes is necessary in order to accurately model the metal-fuel severe accident phenomena. Also the extension of the PINACLE model may be needed to allow the tracking of the in-pin relocating-fuel composition changes due to eutectic formation and melting.

3.4 LEVITATE Module

LEVITATE module describes the physical processes that occur in a subassembly after pin failure. LEVITATE module is also needed to extend for tracking the relocation of each of the molten U-Pu-Zr metal-fuel components and fuel composition changes. And the formation of fuel-cladding eutectic and subsequent cladding relocation requires the extension of the LEVITATE model to allow the tracking of the molten cladding/eutectic composition changes and their effect of the cladding/eutectic freezing, re-melting, and other thermal-hydraulic phenomena that can affect the outcome of metal-fuel severe accident.

4. Conclusions

In this study, the models of SAS4A/SASSYS-1 code are reviewed. As the result, additional SAS4A metal-fuel model development and validation is needed to further improve the description of metal-fuel accident phenomena and reliably assess the consequences of postulated severe accidents in a metal-fuel SFR. Thus, priority areas of model development and validation include:

1) The extension of the PINACLE and LEVITATE models to track the relocation of each of the molten U-Pu-Zr metal-fuel components, fuel composition changes, and associated phenomena
2) The extension of the DEFORM-5 model to include advanced metal-fuel FPIN2 models and other relevant metal-fuel behavior models

Therefore, the utilizing SAS4A/SASSYS-1 code for severe accident analysis of metal fueled SFR is premature. SAS4A metal-fuel model extensions should be guided by a careful review of metal-fuel phenomenology and a sustained validation effort.

REFERENCES

[1] J.E. Cahalan and T.H. Fanning et al., "The SAS4A/SASSYS-1 Safety Analysis Code System", ANL/NE-12/4, 2012.

[2] A.M Tentner., "SAS4A/SASSYS-1 Overview Severe Accident Models", ANL, 2013.