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Development of fully coupled MARS-KS/FRAPTRAN code system for simulation of fuel behavior during LOCA

Hyochan Kim[a], Yongsik Yang[a], Changhwan Shin[a], Taewan Kim[b], Yongwon Choi[c]
[a]*Fuel Safety Research Division, Korea Atomic Energy Research Institute, 111 Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Korea*
[b]*Department of Safety Engineering, Incheon National University, 119 Academy-ro, Yeonsu-gu, Incheon, Korea*
[c]*Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon, 34142, Korea*
[*]*Corresponding author: hyochankim@kaeri.re.kr*

1. Introduction

The study of fuel behaviour under accidental conditions is a major concern in the safety analysis of the pressurized water reactors (PWRs). In particular, the consequences of design basis accidents (DBA) such as loss of coolant accident (LOCA) and reactivity initiated accident (RIA) have to be investigated and quantified in comparison to the related safety criteria already defined, in order to prevent from severe core damage that could result from fuel rods failure, fuel ejection into coolant, loss of core coolability and fission products release into the primary circuit. Those criteria have been established in the 70s on the basis of several experimental programs performed with fresh or low burnup irradiated fuel.

However, since the early 90s, economic concerns led utilities to consider the increase of the average burnup of the fuel subassemblies and the use of new types of fuel and cladding materials, in view of optimizing the fuel management. At the present time, the increased industrial competition and constraints result in more aggressive conditions for the fuel (higher burnup, higher power, load follow,..) and create incentive conditions for the development of advanced fuel designs with improved performance (new fuel types with additives, cladding material with better resistance to corrosion,…) [1] . These long anticipated developments involved the need for new investigations of irradiated fuel behaviour under reference accidents in order to check the adequacy of the current criteria, evaluate the safety margins, provide new technical bases for modelling and allow an evolution of these criteria.

Recently, revision of ECCS (emergency core cooling system) acceptance criteria (10CFR50.46c) will be performed in Korea [2]. In the revised criteria, safety analysis code system should incorporate fuel behavior models. During LOCA, the fuel rod undergoes thermo-mechanical deformation of cladding, exothermic high temperature oxidation, cladding burst and FFRD (fuel fragmentation, relocation and dispersion).

To simulate fuel behavior during LOCA, system code should incorporate transient fuel models in the view of the best-estimated calculation. Therefore, U.S. NRC developed the coupled TRACE/FRAPTRAN/DAKODA code system to study fuel rod behavior and uncertainty during LBLOCA [3]. However, its methodology was limited as one way coupling. IRSN developed DRACCAR code system which is a multirod 3D thermo-mechanics code, with mechanical and thermal interactions between rods, coupled with subchannel type two-phase flow codes [4].

In Korea, KAERI and INU has been developing fully coupled MARS-KS/FRAPTRAN code system to simulate fuel behavior during LOCA. In this study, its methodology was proposed in order to maintain each calculation method. Preliminary fuel results of the coupled code were also discussed.

2. Development of MARS/FRAPTRAN code system

For the development, MARS-KS V1.4 which KINS owns as audit system code was chosen. FRAPTRAN V1.4 was employed as fuel behavior code for transient [5].

2.1 Coupling methodology

To develop MARS-KS/FRAPTRAN code system, coupling methodology should be defined because each code system already was used and validated with their own methodology. As shown in Fig.1, we proposed coupling methodology of two codes for steady state and transient maintaining each calculation flow and I/O (Input/Output) system.

At the beginning of fully coupled calculation, MARS-KS performs steady state calculation with MARS' input file. For this calculation, MARS-KS employs its heat structure instead of fuel rod. We call the 1^{st} SS (steady state) calculation which performs null transient calculation without FRAPCON/FRAPTRAN. Once MARS-KS completes the 1^{st} SS, it calls S-fraptran (simplified-fraptran) which is modulized FRAPTRAN to be implemented into MARS-KS. For the first calling, S-fraptran initiates input variables and stores FRAPCON result file to apply burnup dependent variables. The s-fraptran starts fuel stabilization which increase power gradually to stabilize fuel thermo-mechanical behavior. We call the 2^{nd} SS for fuel stabilization. Once fuel stabilization is completed, fully coupled MARS-KS/FRAPTRAN is ready to start transient calculation for LOCA.

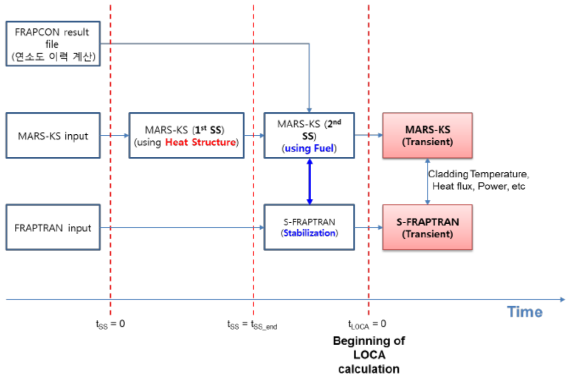

Fig. 1.Coupling methodology of fully coupled MARS/FRAPTRAN

Coupling variables between MARS and FRAPTRAN should be defined. Table I shows the coupled variables such as size of Time, LHGR, Coolant pressure, heat transfer coefficient, coolant temperature and so on. All variables except time increment are stored as array of axial node.

Table I: Coupled variables

Calling module	**Variable name**	**Content**
S-fraptran	Timeincrement	Size of Time step
	Power	Linear Heat Generation Rate (LHGR)
	CoolPress	Coolant pressure
	Htc	Heat transfer coefficient of cladding surface
	Tbulk	Coolant T
MARS-KS	Outdia	Cladding outer diameter (incl. oxide thickness)
	Heatflux	Cladding heat flux
	Tsurf	Cladding surface T

Fuel module requires power and thermal hydraulic boundary conditions at the surface of outer cladding to calculate thermo-mechanical behavior of fuel during LOCA. In addition, coolant pressure affects cladding deformation. System code requires cladding outer diameter and heatflux considering radial burnup distribution, gap conductance and metal water reaction energy. All variables are stored in the module and updated at each timestep.

2.2 Modulization of FRAPTRAN (S-fraptran)

FRAPTRAN code was modulized as S-fraptran to implement FRAPTRAN into MARS-KS. Basically, FRAPTRAN was modernized to F90. Its environment should be identical to MARS-KS V1.4 as Intel Visual Fortran Composer XE2013 Update2.

To couple variables of two codes, new module (MARSLINK) was created in the S-fraptran. When the subroutine uses this module, the subroutines are able to access the coupled variables.

In addition, new subroutines were added into S-fraptran to get new variables from MARS-KS. Some of subroutines were eliminated because thermal hydraulic calculation were carried out in MARS-KS. However, I/O system was maintained to easily use the I/O file for fuel code user and MARS-KS code user.

2.3 Preliminary results of fully coupled code

To evaluate the coupled MARS/FRPATRAN code system, it run LOCA input deck including system code and fuel input. The input decks include the followings ; hypothetical Hanul Units 3/4 plant, non-rezoning, PLUS7 fuel rod, Hot pin power, Time step size is 10^{-3}s, Begin of Life (BOL) fuel condition.

Fig. 2 shows cladding outer temperature of each axial node along time. For this scenario, peak cladding temperature (PCT) occurs during blowdown phase. Due to power, T/H condition and metal water reaction, PCT occurs at axial node 11. The biggest temperature difference among axial nodes is approximately 600K.

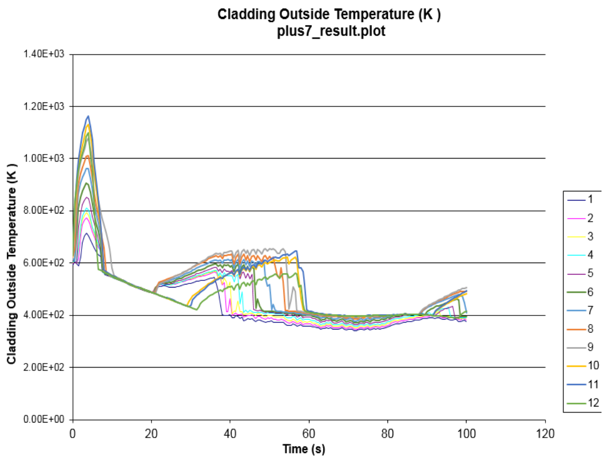

Fig. 2. Cladding outer temperature vs time calculated by fully coupled code.

Following the blowdown, refill and reflood begin. Cladding temperature for reflood state is not higher than that for blowdown. The coupled code demonstrates temperature fluctuation of cladding well due to complex T/H conditions during reflood. Hoop strain and gap conductance of the fuel were also analyzed during LOCA. As a result, it is determined that the fully coupled code system is performed correctly.

3. Conclusions

ECCS acceptance criteria will be revised to enhance reactor safety. To evaluate the revised criteria that incorporate the fuel models, fully coupled MARS/FRAPTRAN code system has been developed. We proposed the coupling methodology of two codes because basically two codes' methodology should be kept despite coupling. FRAPTRAN was modulized as S-fraptran to be implemented into MARS-KS. To evaluate the fully coupled code system preliminarily, hypothetical LOCA input deck was chosen. The coupled results demonstrate the fully coupled code system is performed correctly

For the future, the coupled code system will be evaluated with LOCA scenario for several types of PWR plants. The results also will be discussed in the view of T/H and fuel.

ACKNOWLEDGEMENT

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REFERENCES

[1] OECD NEA, Nuclear Fuel Behavior in Loss-of-coolant Accident (LOCA) Conditions: State-of-the-art Report, NEA No. 6846, 2009.
[2] Y.S. Bang et al., Technical Basis for the Revision of ECCS Acceptance Criteria of Domestic PWR Plants, KINS/RR-1686, 2017.
[3] K. Tien, Fuel Rod Behavior and Uncertainty Analysis by FRAPTRAN/TRACE/DAKOTA Code in Maanshan LBLOCA, NUREG/IA-0471, 2016.
[4] G. Repetto, F. Jacq, F. Barr´e, F. Lamare, and J. M. Ricaud, DRACCAR, a new 3D thermal mechanical computer code to simulate LOCA transients on Nuclear Power Plants, in Proceedings of the International Congress on Advances in Nuclear Power Plants (ICAPP '09), Tokyo, Japan, May 2009.
[5] K.J. Geelhood, W.G. Luscher, C.E. Beyer, J.M. Cuta, FRAPTRAN 1.4: A Computer Code for the Transient Analysis of Oxide Fuel Rods, NUREG/CR-7023, Vol.1, 2011.3