Improvement of Fuel Performance and Safety Codes for Regulatory Research

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1. Introduction

The KINS and KAERI are using FRAPCON[1]/FAMILY[2] code for regulatory research on fuel safety purpose.

Over the past 10 years, as ECCS rulemaking has emerged as the most important issue, the FAMILY code, which combines FRAPTRAN[3] and MARS-KS[4], has been developed and utilized for fuel research.

Recently, due to an introduction of new cladding materials (HANA-6, Coated ATF), LWR-SMR development and new operation strategy such as full-scale load-following operation, various new fuel-related researches for regulatory purpose have been started.

This paper introduces research progress and plans of fuel regulatory R&D including fundamental changes to the FAPCON/FAMILY code system to effectively respond to recent fuel-related issues.

2. Overview of code system

The majority of fuel performance code consists of three main modules :

Module 1: Material property (including failure criteria) model determined by primary factors such as temperature, irradiation, and stress

Module 2: Performance model that is more dependent on operating conditions, including primary factors, and has a feedback effect between factors. (Fission gas release, rod internal pressure and FFRD, etc.)

Module 3: An algorithm for evaluating the feedback effects between various phenomena. (Gap temperature iteration, explicit creep calculation, etc.)

2.1 Material properties

Generally, the material property module of the fuel code adopts a test-based correlation models and the MATPRO[5] has been widely used.

However, because direct applying current MATPRO correlations to new materials such as HANA/ATF is limited, the material property model of FRAPCON and FAMILY are significantly revised.

Table 1 summarizes the material property models of FRAPCON/FAMILY that have been changed for HANA cladding.[6]

Table I: Cladding Model Change

Thermal expansion
Irradiation growth
Phase transform temperature
Irradiation factor on property
Creep
Waterside corrosion
Hydrogen pickup
High temperature oxidation
High temperature rupture (Stress)
High temperature rupture (Strain)

Some material properties, including thermal properties, can leverage data from Zr-4, Zirlo, etc., but some models which greatly affected by alloying elements and heat treatment have been modified

Compared to HANA cladding, ATF cladding is expected to require more significant modifications, and research is actively being conducted not only on material properties but also on developing a model to replace FRACAS and redefining failure/safety criteria to evaluate the effects of the multilayer characteristics.

2.2 Performance models

The most remarkable changes in the performance model of the FRAPCON/FAMILY are FFRD and PCI analysis modules.

2.2.1 FFRD research

According to FFRD module, the QT model[7] included in FAMILY is being modified and a sensitivity analysis performed to reflect the latest research results of NRC-RES.(Office of Nuclear Regulatory Research)[8]

The important change of QT model is :
- Pulverized particle size
- Axial relocation threshold strain
- Packing fraction of crumbled fuel

Although, a default value of pulverized particle size of QT model is assumed 100μm, various FFRD test results show that a pulverized particle size have wide range scattering from 10 to 200μm. Figure 1(left) shows the sensitivity study results that as pulverized particle size decrease from 100μm to 20μm, a mass of crumbed fuel in ballooned region increase by up to 1%. This results means the effect of particle size on axial power shape is not significant. [9]

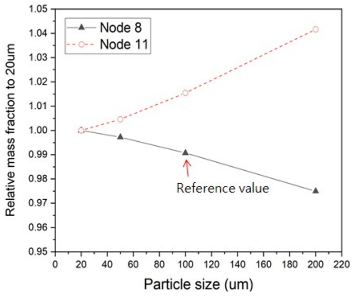

Fig. 1. Effect of particle size on mass fraction change

Figure 2 shows the effect of cladding threshold strain that can affect to axial relocation. As a threshold strain increase from 3.7% to 5.4%, a mass of crumbed fuel in ballooned region decrease by up to 20%.[9]

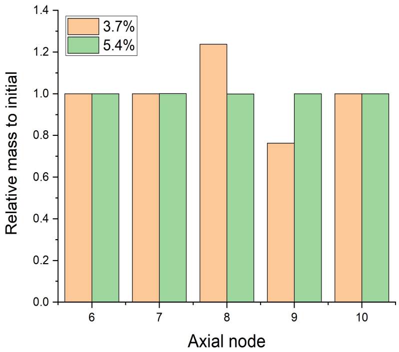

Fig. 2. Effect of cladding strain threshold on mass fraction change by FFRD

In addition to existing QT model change in FAMILY code, a new FFRD models are also being developed to simulate azimuthally non-uniform phenomena observed in many FFRD tests, along with technologies for integration with sub-channel scale CUPID.

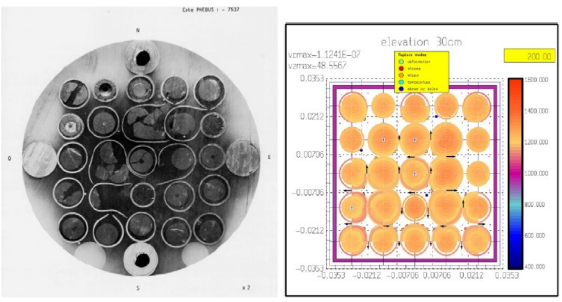

Fig. 3. Azimuthally non-uniform FFRD behavior [10]

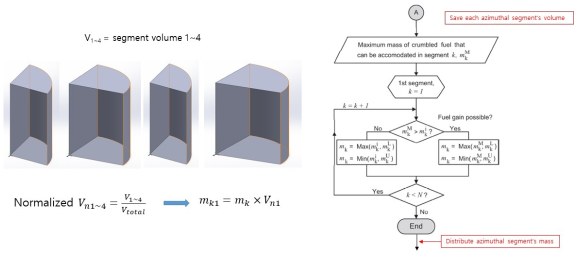

Fig. 4. Azymuthal FFRD model

Research has also been initiated to obtain a more fundamental understanding of the FFRD phenomenon and develop an advanced FFRD analysis technology[11], with a hot-cell test using high burnup fuel. The advanced FFRD model is composed of:

Operation history based HBS model including new FGR, bubble behavior modeling
High fidelity pulverization model based on accumulation of irradiation damage and microstructure change in HBS during LOCA
More systematic axial relocation model including transient FGR and axial gas communication.
Empirical and semi-empirical dispersal model

2.2.2. PCI research

The need for a change of existing PCI analysis module has arisen due to the emergence of iSMR and changes in the PWR reactor operation strategy. The load-following operation technology, which has been used in a limited manner in PWR reactors, is now being actively studied as a primary operation mode of iSMR and PWR reactors; consequently, PCI phenomena have become an even more important issue

Therefore, the need has arisen for improvement in the useful methodology that has been used for PCI analysis in fuel performance analysis for a long time.

More specially, some modifications are required to various assumptions (rigid pellet, explicit algorithm, etc.) used in the FRCAS module included in the FRAPCON code.[12]

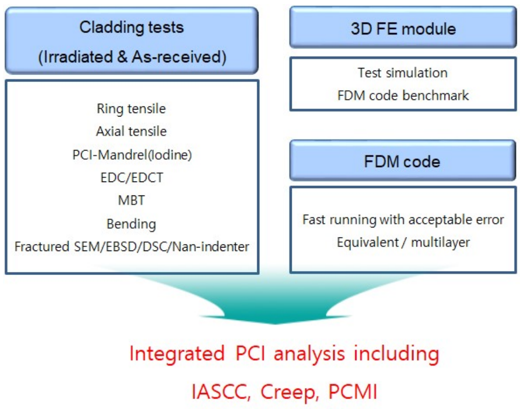

Fig 5. PCI evaluation structure

Since the PCI phenomenon is a very local phenomenon and requires a lot of computing power, the development of PCI analysis module is being conducted by dividing it into three major areas, as detailed in Figure 5.

As mentioned above, the main role for PCI analysis in regulatory studies will be carried out using FDM method. However, for detailed evaluation of cladding failure criteria or sensitivity analysis of various uncertainty factors, the 3D FE analysis technique will be used together.

2.3 Extension to Domestic Regulatory Fuel Code

As a results of previous fuel research projects, most aspects of the regulatory fuel code FRAPCON have been changed, excluding a small fraction of material properties such as UO_2 thermal properties.

Further studies are underway to consolidate the findings from past regulatory fuel research in preparation for the release of the domestic fuel code system and its validation database

To improve the quality of the code, additional research is also being performed or planed such as establishment of Level 1 and 2 QA, code shape refactoring and further validation using domestic hot-cell test results.

3. Conclusions

Various regulatory fuel studies are progressing due to the introduction of new reactor designs, changes in operation strategies and strengthening of nuclear safety. New fuel models/codes development project is started and changes in analysis methodology is also being considered to effectively utilize the new models and code systems. In particular, regulatory fuel research is planned to extended to directly apply hot cell tests that are actively being conducted domestically and internationally.

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[11] Will be published in 2025 KNS Spring meeting

[12] Will be published in 2025 KNS Spring meeting