

Development Status of GIFT-2.0: An Extended Fuel Performance Code for Burnup-Dependent Transient and Accident Analysis

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1. Introduction

Fuel performance analysis plays a central role in nuclear reactor design and operation. Accurately predicting the thermal and mechanical behavior of fuel rods is essential for verifying rod integrity and evaluating compliance with regulatory requirements. In recent years, growing demands for enhanced safety regulations during operation, safety analysis for design basis accidents (DBAs), and reassessment of safety margins have increasingly required the capability to predict fuel behavior not only under normal operating conditions but also under transient and accident conditions. Furthermore, advances in computing power have enabled the implementation of more precise predictive models, and there is growing interest in multi-physics analysis that accounts for real-time core deformation.

Against this background, rapid changes in the nuclear fuel field including the introduction of new fuel concepts such as accident tolerant fuel (ATF) and increasing interest in high burnup operation have highlighted the need to develop an independent domestic fuel performance code, free from dependence on foreign codes. Establishing a domestically developed code in the nuclear materials field also carries significant importance in terms of advancing nuclear safety regulatory technology.

In response to this need, development of GIFT, a fuel performance code for light water reactors, has been underway since 2021 [1]. GIFT-1.0 was designed to improve the accuracy and fidelity of light water reactor simulations by incorporating enhanced models based on previously developed physical and mathematical models, and to support the establishment of regulatory standards for new fuel types by adding independent models suitable for ATF simulation.

GIFT-2.0, presented in this paper, was developed on the foundation of GIFT-1.0, integrating steady-state and transient analysis capabilities into a unified code framework. The transient analysis module directly utilizes results from the steady-state simulation, ensuring seamless coupling between normal operation and accident condition analyses while effectively capturing burnup-dependent effects in fuel behavior and material properties. With its integrated models, GIFT-2.0 is designed to analyze fuel behavior under major design basis accident (DBA) scenarios, including reactivity

initiated accidents (RIA), loss-of-coolant accidents (LOCA), and station blackout (SBO) events.

In this paper, the transient analysis capabilities of GIFT-2.0 are presented with particular focus on the newly developed models and their application to accident scenario analyses.

2. Structure of the GIFT-2.0 transient module

As a fuel performance code, the transient part of GIFT-2.0 is structured around the following key components.

2.1. Algorithm

The execution flow of GIFT-2.0 is illustrated in Fig. 1. The code begins by initialization using steady-state analysis results as input. For each time step, an iteration loop is performed, with the convergence of internal pressure serving as the primary criterion. Within each step, the process sequentially involves setting the fuel rod temperature distribution, calculating pellet deformation, determining cladding deformation, and evaluating internal pressure and fission gas release. Once the internal pressure converges, the code proceeds to calculate cladding oxidation and assess potential ballooning or rupture before moving to the subsequent time step.



Fig. 1. Flowchart of GIFT-2.0 transient module

2.2. Main models

The main models constituting the transient analysis module of GIFT-2.0 are summarized in Table 1.

Table 1. Key physical models in the GIFT-2.0 transient analysis module

Model	Description
Thermal	External input (default); 2D FDM (developer option)
Pellet deformation	Thermal expansion and fixed permanent deformation; QT model (FFRD) [2]
Cladding structural analysis	2D FDM (default); [3] FDM-FEM hybrid model (ballooning, large deformation)
Rod internal pressure	Ideal gas equation
Fission gas release	FRAPFGR model [2]
Cladding oxidation	TRANOX-2.2 [4]
Cladding rupture	Temperature-dependent empirical model [5]
Material property	MATPRO [6]

As shown in Fig. 1, the thermal module uses external input for the fuel rod temperature distribution by default. A 2D FDM heat conduction solver is also available as a developer option.

Pellet deformation during transient scenarios is divided into thermal expansion and other permanent deformation; the former is calculated according to temperature changes, while the latter is fixed at values from the steady-state simulation, and pellet deformation due to fuel fragmentation, relocation, and dispersal(FFRD) phenomena is calculated separately using the QT model.

For cladding structural analysis, GIFT-2.0 adopts the 2D FDM structural analysis function used in the previous version as its default model, and is designed to apply the FEM model selectively only to the cladding regions where ballooning or large deformation occurs; a hybrid model integrating the FDM and FEM formulations has been developed for this calculation, aiming to ensure both computational efficiency and accuracy simultaneously.

Rod internal pressure is calculated using the ideal gas equation, and the amount of fission gas released is computed by the FRAPFGR model from the fission gas distribution within the fuel pellet transferred from the steady-state calculation module.

TRANOX-2.2 is embedded in GIFT-2.0 as the cladding oxidation model, which precisely calculates the oxygen concentration and phase distribution within the cladding based on a 1D diffusion equation, supporting two-sided oxidation calculations and Cr-coated ATF analysis.

Finally, for cladding rupture assessment, an empirical model is applied in which the burst pressure or stress is dependent on the burst temperature.

3. Results

GIFT-2.0 simulations were performed for RIA and LOCA scenarios.

3.1. RIA

The fuel rod design parameters and transient power history used in this simulation are presented in Table 2 and Fig. 2, respectively. For the short duration of the RIA, a single coolant condition was maintained.

Table 2. Rod design parameters for RIA simulation with GIFT-2.0

Geometry	
Rod diameter [m]	0.00914
Rod length [m]	0.149
Pellet	
Pellet diameter [m]	0.00756
Pellet dish	None
Enrichment [%]	4.4
Cladding	
Cladding thickness [m]	0.000717
Cladding material	Zr-1%Nb
Void	
Gap size [m]	0.000075
Gap pressure [Pa]	2100000
Plenum volume [m ³]	0.00000358
Coolant	
Coolant pressure [Pa]	101325
Inlet temperature [K]	298

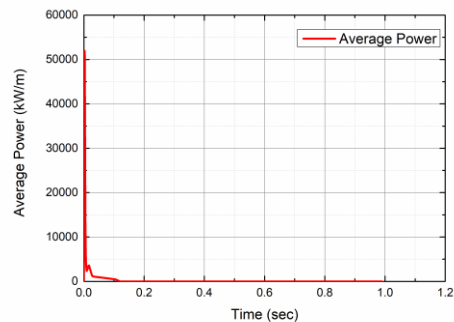


Fig. 2. Rod average power for RIA simulation with GIFT-2.0

Fig. 3 shows the cladding hoop stress and hoop strain derived as results of the RIA simulation.

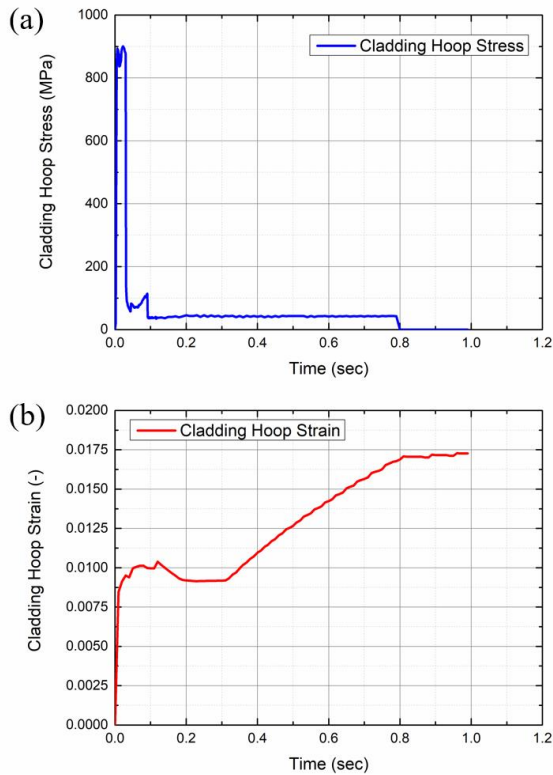


Fig. 3. RIA simulation results; (a) cladding hoop stress and (b) cladding hoop strain

In Fig. 3 (a), a spike in stress due to the initial power surge and the subsequent stress relaxation caused by plastic deformation can be observed. In (b), two distinct stages are visible: a sudden increase in strain immediately after the accident, followed by a relatively gradual increase with a reduced slope. The decrease in strain around 0.2 seconds is due to the change in the thermal expansion coefficient as the cladding temperature induces a phase transformation of material.

3.2. LOCA

The fuel rod design parameters and coolant temperature used in this simulation are presented in Table 3 and Fig. 4, respectively [7]. Fig. 4 illustrates the coolant temperature variations according to the blowdown (before 100 s) and the scram (after 400 s). Here, a single average rod power condition was maintained.

Table 3. Rod design parameters for LOCA simulation with GIFT-2.0

Power	
Rod average power [kW/m]	2.4
Geometry	
Rod diameter [m]	0.0107
Rod length [m]	0.48
Pellet	

Pellet diameter [m]	0.00913
Pellet dish diameter [m]	0.00673
Pellet dish height [m]	0.000279
Enrichment [%]	3.5
Cladding	
Cladding thickness [m]	0.000721
Cladding material	Zr-4
Void	
Gap size [m]	0.0000805
Gap pressure [Pa]	2000000
Plenum volume [m ³]	0.0000145

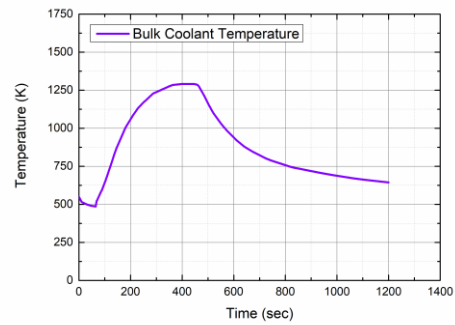


Fig. 4. Average coolant temperature for LOCA simulation with GIFT-2.0

Fig. 5 shows the cladding hoop stress and hoop strain calculated as results of the LOCA simulation, at the ballooning node.

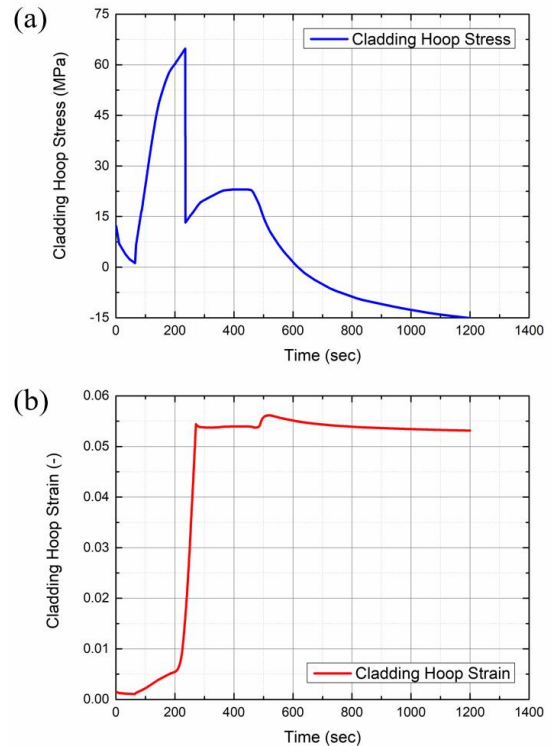


Fig. 5. LOCA simulation results; (a) cladding hoop stress and (b) cladding hoop strain

Fig. 5 shows that once ballooning initiates, the stress drops sharply while the strain rises rapidly. Ballooning is determined to have occurred when the cladding plastic strain obtained from the structural analysis exceeds a threshold value; after that point, cladding deformation is calculated either using a FEM based structural analysis model or the BALON2 model [8], depending on the specified input option.

Fig. 6 presents the cladding oxidation calculation results during the LOCA transient. Following ballooning and cladding failure, two-sided oxidation occurs on both the outer and inner walls of the cladding. As oxygen diffuses at the interface between the outer oxide and the Zircaloy, the outer oxide thickness decreases; nevertheless, the overall equivalent cladding reacted (ECR) continues to increase.

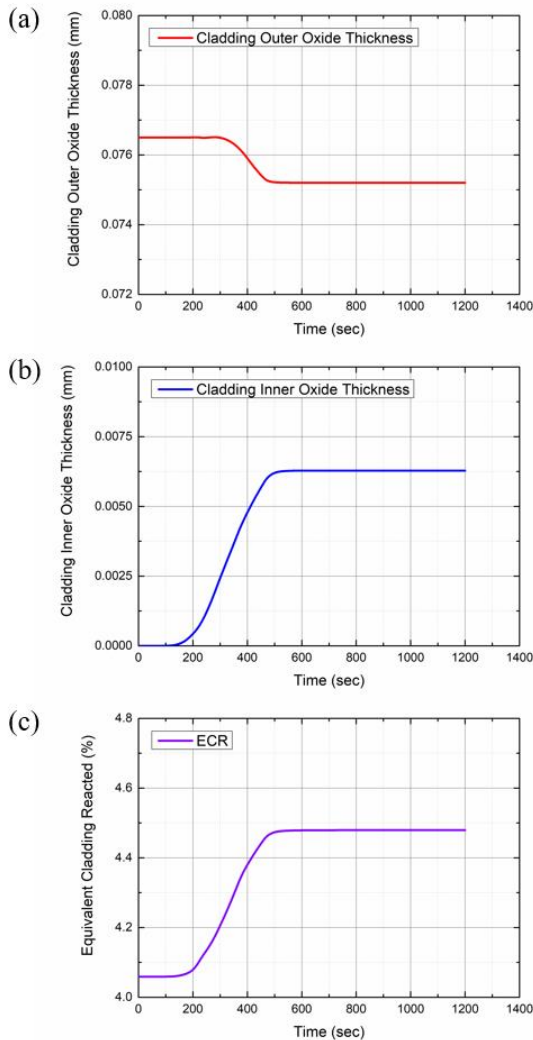


Fig. 6. LOCA simulation results; (a) cladding outer oxide thickness, (b) inner oxide thickness and (c) cladding total ECR

4. Conclusion

GIFT-2.0, a fuel performance code integrating steady-state and transient analysis capabilities into a unified

framework, has been presented. The transient analysis module of GIFT-2.0 directly utilizes results from the steady-state simulation, enabling seamless coupling between normal operation and accident condition analyses while capturing burnup-dependent effects in fuel behavior and material properties.

The key physical models constituting the transient module were described, including the thermal model, pellet deformation model, FDM-FEM hybrid cladding structural analysis model, rod internal pressure and FGR model, TRANOX-2.2 cladding oxidation model, and the temperature-dependent empirical cladding rupture model.

Preliminary simulations were performed for RIA and LOCA scenarios. The simulation results demonstrated that GIFT-2.0 is capable of capturing main transient phenomena.

Further validation and application of GIFT-2.0 to a broader range of accident scenarios including SBO will be pursued in future work to strengthen the code's predictive capabilities and contribute to the advancement of domestic nuclear safety regulatory technology.

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