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Invited Article

Research and Development Methodology for Practical Use of Accident Tolerant Fuel in Light Water Reactors

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A R T I C L E I N F O

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A B S T R A C T

Research and development (R&D) methodology for the practical use of accident tolerant fuel (ATF) in commercial light water reactors is discussed in the present review. The identification and quantification of the R&D-metrics and the attribute of candidate ATF-concepts, recognition of the gap between the present R&D status and the targeted practical use, prioritization of the R&D, and technology screening schemes are important for achieving a common understanding on technology screening process among stakeholders in the near term and in developing an efficient R&D track toward practical use. Technology readiness levels and attribute guides are considered to be proper indices for these evaluations. In the midterm, the selected ATF-concepts will be developed toward the technology readiness level-5, at which stage the performance of the prototype fuel rods and the practicality of industrial scale fuel manufacturing will be verified and validated. Regarding the screened-out concepts, which are recognized to have attractive potentials, the fundamental R&D should be continued in the midterm to find ways of addressing showstoppers.

1. Introduction

Since the Fukushima-Daiichi Nuclear Power Plant Accident, the research and development (R&D) for improving the safety of light water reactors (LWRs) has been further activated in many countries. Accident tolerant fuel (ATF) is considered to be one of the most attractive concepts for improving safety. There are many candidate concepts of ATF. For example, in Japan, the R&D of accident tolerant cladding of SiC/SiC-composite or advanced stainless steel, advanced fuel based on coated particle concept, and accident tolerant control rods are mainly ongoing. Although there are no specific R&D projects of advanced or coated zircaloy, Mo-cladding, high density fuel, and improved UO_2-fuel in Japan, the R&D of these concepts are being progressed in other countries. A significant concern is pointed out on the technology screening toward the practical use of ATF in LWRs. That is, the potential targets of the accident tolerance, so-called ATF-attributes, obtained from one of these concepts is rather different from those obtained from the other concepts. Hence, a proper methodology is necessary to make consensus among stakeholders for selecting the practical use candidates, which should be clearly shown in the R&D roadmap after achieving a common understanding.

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Table 1 – General definition of practical use of accident tolerant fuel in light water reactors from viewpoints of fuel design and fuel manufacturing.

TRL		General definition for fuel design/fuel manufacturing
Proof of performance	9	Utilization of new fuel concept in commercial reactors
	8	Quality verification for commercial operation Full loading of new concept fuel in a commercial reactor, based on new approval/regulation & new specification/standard
	7	Establishment of final fuel design by vendors Establishment of fabrication technology for commercial fuel assembly Irradiation of lead use assembly (LUA)
Proof of principle	6	Verification of prototype fuel assembly performance Design & irradiation test of prototype fuel assembly (LTA: lead test assembly), based on new approval/regulation & new specification/standard concept Establishment of regulation criteria for safety analysis Design of fuel fabrication plant
	5	Validation of prototype fuel rod performance Finalization of fuel design & irradiation test of prototype fuel rod (LTR: lead test rod) Validation of process performance of fuel fabrication
	4	Establishment of conceptual design of prototype fuel Establishment of fuel design parameters Irradiation test of prototype fuel rod (without fuel, full or long-scale rod) Verification of component technology for fuel fabrication
Proof of concept	3	Verification of new fuel concept Determination of R&D objectives for industrial scale Sample irradiation tests
	2	Embodiment of new fuel concept Evaluation of upper limit to be achieved by new fuel concept Evaluation of technology options
	1	Proposal of new fuel concept Extraction of R&D subjects

R&D, research and development; TRL, technology readiness level.

In the US, a roadmap of the near- and mid-term R&D for ATF was already reported, in which the irradiation test of the prototype lead test rod (LTR) or lead test assembly (LTA) in a commercial reactor will be targeted in 2022 after the technology screening in 2016 [1]. Also, international collaboration between the United States and other countries like China, France, Japan, Korea, etc., is being actively advanced under the roadmap. In the Organization for Economic Co-operation and Development/Nuclear Energy Agency, an expert group of accident tolerant fuel for LWRs (EGATFL) was established in 2014 [2], and identification and quantification of the ATF-attributes are being performed for achieving international common understanding, which includes the recognition of the gap between the present R&D statuses and the targeting practical use for individual ATF-concepts. Publication of several state-of-art reports is planned by the end of 2016. In Japan, a R&D roadmap for the safety technology of LWRs and human resource development was reported in 2015 [3], in which the importance of the evaluation of the effect to various LWR-technologies was pointed out, as well as that of fuel design and fuel manufacturing, when considering the practical use of the ATF. Not only the R&D methodology for fuel design and fuel manufacturing process including the identification and the quantification of ATF-attributes but that for evaluating the effect to the present LWR-technologies like plant performance, core physics, safety analysis method, approval and regulation, quality assurance, transportation, storage, reprocessing, waste disposal, etc., should be clearly shown in the roadmap. The present article attempts to summarize the methodology, so-called R&D-metrics, based on these discussions.

2. Identification of the gap between the present R&D status of various ATF-concepts and practical use

The first step is the identification and the quantification of the gap between the present R&D status and the practical use of candidate ATF-concepts. National Aeronautics and Space Administration originally established the technology readiness level (TRL) methodology for maturity measurement in the technology development process [4], which is recognized as a proper manner for this purpose in many R&D fields. The guideline of the TRL for various advanced fuel concepts was reported in the United States [5]. The TRL is divided into nine steps of three stages and is used as a reference idea in many countries. Table 1 shows an example of the general definition of the TRL for ATF-utilization in the LWRs. The descriptions in the table are mainly from the viewpoints of fuel design and fuel manufacturing. Although the details of the definition for each step must be further discussed, the important point of the TRL is to achieve consensus among specialists on the definition for achievement of each step toward the final goal. The development starts from the proposal of a new ATF-concept and the extraction of the R&D subjects in TRL-1. The region of the practical use, which the new ATF-concept is potentially able to target, is also identified and proposed at the very beginning mainly by inventors of universities, institutes, or other organizations. The various fundamental R&Ds are activated in the proof of concept stage, especially for databasing of the fuel design and the fuel fabrication process. Then, the fundamental performance of the ATF-concept is