Proposal of Basic Principles of Maintenance Management for Prototype Reactors

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Abstract. Basic principles of maintenance management for prototype reactors are proposed in this paper. One of main missions of prototype reactors is R&D for commercializing advanced reactors, which shall be appropriately considered in maintenance management for prototype reactors. Development of maintenance programs suitable to the reactor types is one of key features of the proposed basic principles of maintenance management for prototype reactors. It is important to identify risks specific to the reactor type, and maintenance grade of structures, systems and components should be determined considering the risks by applying the Graded Approach. Degradation mechanisms specific to the reactor type shall be also taken into account in the maintenance programs. Progressive development of maintenance programs by accumulation of operation experiences is another key feature of the proposal. Maintenance programs have to be modified and improved timely by reviewing results and knowledge obtained during operations. The Graded Approach will be useful to control risks corresponding to revisions of maintenance programs. Standardization is one of effective ways to utilize operation experiences for maintenance of prototype reactors and also development of commercial reactors.

Key Words: Fast Reactors, Graded Approach, Risk Insight, Operational Experience

1. Introduction

MONJU is Japan's prototype fast breeder reactor with an output of 280 MWe (714 MWt), following an experimental reactor, JOYO [1]. It is fueled with mixed oxides of plutonium and uranium, and cooled by liquid sodium. Its construction was started in 1985, and the first criticality was attained in 1994. It pasts over 20 years since then, but trial operation before full scale operation has not finished yet due to several hardware troubles including sodium leakage from a secondary circuit in 1995 and a drop of in-vessel transfer machine (IVTM) in 2010 [2]. In addition, repeated revisions of plant operating schedule related to the trouble of IVTM and the great east Japan earthquake in 2011 caused exceedance of planned maintenance intervals for around 10 000 items. Non-conformance controls for them were also not proper. Japan's Nuclear Regulation Authority (NRA) deemed that restructuring of maintenance management and quality assurance systems was needed, and ordered JAEA, the operator of MONJU, to suspend preparation of trial operations in 2013. Furthermore, NRA issued a recommendation on replacement of operators of MONJU in 2015.

One of important technical backgrounds inviting such a severe situation of MONJU is considered that basic principles of maintenance management appropriate for prototype reactors have not been discussed sufficiently so far. Regulatory requirements for quality assurance and maintenance management are the same between commercial Light Water Reactor (LWR) power plants and MONJU [3, 4]. NRA endorsed voluntary consensus standards, JEAC4111-2009 “Quality Assurance Rules for Safety in Nuclear Power Plants” [5] and JEAC4209-2007 “Code for Maintenance at Nuclear Power Plants” [6] providing specific provisions for quality assurance and maintenance activities, and they are used in not only commercial LWR power plants but also MONJU. JEAC4111-2009 is based on ISO9001:2000 “Quality Management Systems” [7], and is conceptually the same with IAEA GS-R-3 “The Management System for Facilities and Activities” [8]. JEAC4209-2007 was developed as a fruit of discussion on inspection regimes suitable to commercial LWR power plants. Both the codes do not mention any considerations needed to apply them to prototype reactors.

IAEA issued several documents for research reactors, including safety requirements [9] and a report on implementation of a management system [10]. It is noted that requirements are to be applied in accordance with the potential hazards associated with the reactor by means of a graded approach, thereby ensuring safety in the design and operation of research reactors. This point is certainly considered to be also applicable to prototype reactors. However, unfortunately, nuclear reactors used for the production of electricity are out of scope in the documents, and there are no detailed discussions on maintenance management for prototype reactors.

NQA-1 “Quality Assurance Requirements for Nuclear Facility Applications” provided by the American Society of Mechanical Engineers (ASME) [11] is other recognized standard in the world. The standard uniquely includes a guidance on graded application of NQA standard for research and development activities. Applicability of each requirement of NQA-1 to basic research, applied research and development work is explained in detail. It is very useful information for progressive construction of maintenance programs discussed later, but it would be difficult to apply this guidance directly to maintenance management for prototype reactors. For instance, control of nonconforming items is not required in the guidance because the results of R&D activities are not expected to meet predetermined requirements. However, control of nonconforming items related to the safety must be necessary even for prototype reactors.

Therefore, in this study, we discuss on maintenance management suitable to prototype reactors. At first, key points to be considered are sorted out, and then basic principles are proposed.

2. Definition and Purpose of Prototype Reactors

It is essential at first to clarify the definition of the term of “Prototype Reactors”, before starting discussion on suitable maintenance management for them. In Japan’s regulatory rules, the term of “R&D-Level Nuclear Power Plants” is used instead of “Prototype Reactors”. It is mentioned that fast breeder reactors and heavy water boiling reactors with electric power generation systems are included in R&D-Level Nuclear Power Plants, but any further information on definition of the term cannot be found in the rules. A definition in IAEA Advanced Reactors Information System (ARIS) reports is “In which much of the scaling up required for a commercial station in terms of both overall size and individual components has been incorporated” [12]. Other definition can be found in United States Nuclear Regulatory Commission (U.S. NRC) regulations 10 CFR §50.2 [13] and is as follows: “Prototype plant means a nuclear reactor that is used to test design features, such as the testing required under

§50.43(e). The prototype plant is similar to a first-of-a-kind or standard plant design in all features and size, but may include additional safety features to protect the public and the plant staff from the possible consequences of accidents during the testing period” where 10 CFR §50.43(e) provides conditions for approval of applications for a design certifications, combined license, manufacturing license, or operating license that propose nuclear reactor designs which differ significantly from LWR designs that were licensed before 1997, or use simplified, inherent, passive, or other innovative means to accomplish their safety functions. It is one of important points that prototype reactors have significantly different features from conventional and commercial reactors in parts or overall. It is also important that prototype reactors are used to demonstrate performance, reliability, and other related aspects of new technologies at plant scale for future industrial use. Therefore, in this study, we defined the term of “Prototype Reactors” as “New type reactors with electric power generation systems during R&D toward commercial use”.

Based on the definition, a purpose of prototype reactors is to conduct R&D required for implementation of the practical use, which is different from commercial reactors of which purpose is steady electric power supply (*FIG.1*).

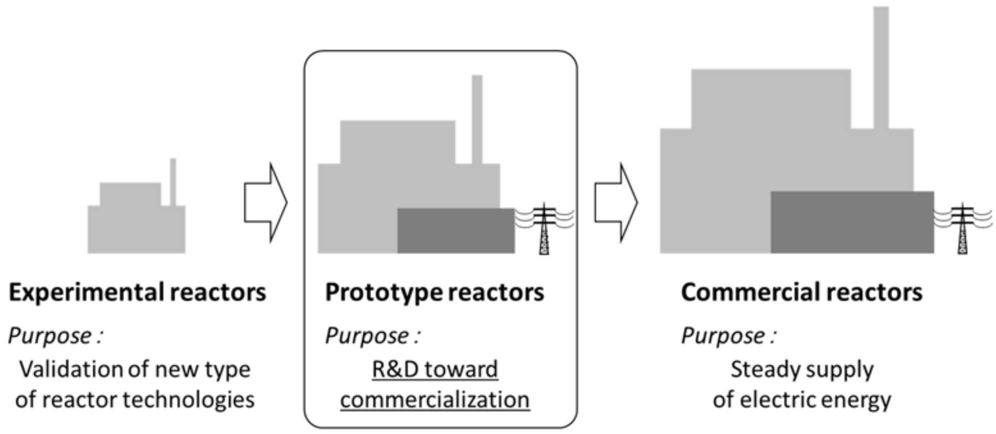

FIG. 1. Change of Purposes of Operating Reactors as Progress of Development

3. Key Considerations for Maintenance Management for Prototype Reactors

There are two main differences between commercial LWRs and MONJU that are examples of existing commercial reactors and prototype reactors, respectively, as shown in *FIG.2*: difference of reactor types, and that of operational experiences. Although a lot of rules and methods employed in maintenance management at existing commercial reactors would be also useful for prototype reactors, sufficient cares are required on these differences before actual application.

As mentioned above, basic requirements for maintenance management at commercial LWR are provided in JEAC4209-2007 in Japan. The workflow in JEAC4209-2007 includes multiple Plan-Do-Check-Action cycles, which is expected to contribute to continuous improvement. Such a workflow of maintenance management inducing continuous improvement could be also applied to prototype reactors which need R&D toward practical use, but specific contents of implementation shall be determined by considering features of prototype reactors appropriately.

In terms of difference of reactor types, maintenance programs of existing commercial reactors cannot be directly applied to prototype reactors even if the systems and components of prototype reactors have similar names with those of existing commercial reactors because their safety significances and potential degradation mechanisms could be different. In terms of difference of operational experiences, maintenance programs of prototype reactors shall be optimized progressively as accumulation of knowledge and findings on object components and maintenance technology. Therefore, prototype reactors have to be constructing maintenance programs suitable to the type of reactor by themselves for implementation of the practical use, with ensuring the safety of the plants.

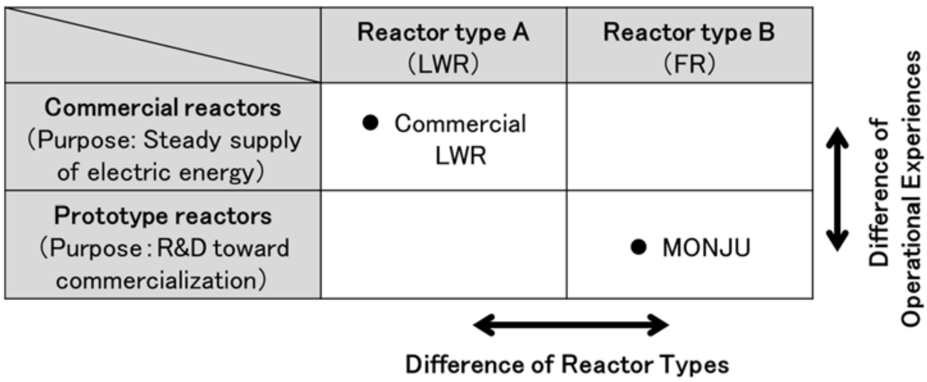

FIG. 2. Comparison between Commercial reactors (Commercial LWR) and prototype reactors (e.g., MONJU).

4. Basic Principles of Maintenance Managements for Prototype Reactors

4.1. Construction of Maintenance Programs Suitable for the Reactor Type

First, features of safety design are different by reactor types and thus risk profiles also change. In light of ensuring the safety of plants, it is important to reveal risk profiles typical of the reactor type by identifying dominant accident sequences resulting in severe situations such as core damages, and selecting critical systems and components in those sequences using risk analysis methods. In addition, a graded approach in which the stringency of requirements are determined to commensurate with significances of components and activities [8,11,14] should be widely used in maintenance management for prototype reactors. The extent of maintenance activities including analysis, inspection, evaluation, and repair, and the level of rigor of related control and verification efforts should be determined on the basis of risk relevant to systems and components. More careful maintenances are applied to significant systems and components selected by considering risk insight results, which contributes to effective utilization of human and financial resources, and enables efficient construction of maintenance programs toward commercialization without sacrificing the safety of the plants.

Specific and practical conditions of maintenance such as methods and intervals of inspections are to be determined by taking account of degradation mechanisms, but degradation mechanisms to be considered in a prototype reactor could change from those of existing commercial reactors because of different service conditions. At an initial stage with limited operational experience, degradation mechanisms should be determined based on scientific knowledge, design knowledge, and experience in test facilities and experimental reactors by referring ways in conventional reactors. Then, the adequateness of assumptions should be examined through operation in order to construct maintenance programs suitable to plants of the reactor type.

4.2. Progressive Development of Maintenance Programs with Accumulation of Operational Experience

In an early stage after commencement of operations, surfacing of problems regarding design, fabrication, construction, and operation is one of main concerns. Prediction of problems in advance is relatively difficult, so it is effective to conduct maintenance aiming early detection of problem occurrences according to the risks of systems and components. Object systems and components, and detection methods should be reconsidered properly as appropriateness of design, fabrication, construction and operation is confirmed by accumulation of operational experience.

Next, it is important to examine if knowledge obtained through R&D so far and used as technical bases for maintenance programs of prototype reactors, including degradation mechanisms, is valid in actual plant conditions. Obtained results should be arranged so that they can be used effectively for R&D activities toward commercialization and also operation after commercialization. Standardization is one of promising ways. Results might affect not only maintenance programs but also designs of object components. It is needed to evaluate its influence widely, correct items if necessary and sort out issues to be solved in successors.

In addition, it is necessary to clarify procedures to modify maintenance programs in advance so that knowledge newly obtained by accumulation of operation experience can be reflected on maintenance programs timely. Levels of requirements for modification must correspond to risks of object systems and components or risks induced by modification of items in maintenance programs according to the graded approach.

Finally, introduction of quantitative indices will be useful to measure safety levels of plants and matured levels of current maintenance programs compared to that of commercial reactors. Potential index in terms of the safety is the number of unplanned scram, while those in terms of effectiveness of maintenance programs are the number of working days and personal exposure dose. Steady development of maintenance programs is expected by updating maintenance programs with aiming improvement of indices related to effectiveness of maintenance programs while keeping of safety-related indices.

5. Conclusions

In maintenance management for prototype reactors, it is important to develop maintenance programs suitable for own reactor types by improving effectiveness of maintenance activities while maintaining safety of plants.

Usage of risk profiles, proper distribution of human and financial resources based on the graded approach, and introduction of quantitative indices in terms of plant safety and effectiveness of maintenance activities will implement such development of maintenance programs in prototype reactors.

In addition, it is important to examine adequateness of degradation mechanisms assumed based on scientific and design knowledge in early stage by accumulation of operational experience, and to standardize degradation mechanisms to be considered in the type of reactor.

Examples that the proposed basic principles in this paper are applied to MONJU can be found somewhere [15,16].

It is expected that the proposed principles will contribute to implementation of maintenance management in prototype reactors with conducting R&D toward commercialization, one of main missions of prototype reactors, in safer and smoother ways.

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