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Licensing Approach for New Fuel Design

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Abstract

A licensing approach for new fuel design is proposed. It includes the possible licensing options to be taken according to the level of significance of design changes. This approach can be applied on legal grounds of the AEA, Article 44.3 and Article 21, but implies that the related ERAEAs should be revised or other alternative regulatory guidelines should be prepared. However, it is not intended to invoke additional requirements but rather to streamline and formulate the current practice by using one of supplementary provisions of the AEA, Article 104.2 which is recently enacted for approval of the technical report on a special topic.

I. Background of Study

The Atomic Energy Act (AEA) [1] provides the bases on which the regulatory body can establish requirements directed toward protecting the health and safety of the public from the uncontrolled release of radioactivity. Protection of public health and safety is ensured through the engineered protection of physical barriers to guard against the uncontrolled release of radioactivity. Fuel clad, reactor coolant system boundary and containments are the representative three of the physical barriers. The Final Safety Analysis Report (FSAR) analysis demonstrates that the integrity of the first two barriers is maintained during normal operation and anticipated transients and, under the assumed accident conditions, the consequences of accidents challenging the integrity of the barriers will not exceed the criteria established in Minister's Notice 83-5 [2] or guidelines established in 10CFR100 of the US Nuclear Regulatory Commission (NRC) [3]. The demonstration assumes that changes in the nuclear characteristics will be within the range seen from cycle to cycle due to fuel management effects, which should be verified each reload cycle. The FSAR analysis serves as a reference safety analysis for reload cores.

A plant specific application of the new fuel design often leads to changes of the FSAR analyses, which are needed due to the change of the Fuel Design Criteria (FDC) or the evaluation methods as well as the changed core effects on reactor behaviors. The FDC are defined as a set of the acceptance limits of the fuel design parameters whose values should not be exceeded in any reactor conditions, i.e., normal operation, anticipated transients and accident conditions. The evaluation methods are the methods of demonstrating that the FDC are met for plant specific applications. They can be based on operating experience, experimental testing, or analytical predictions, depending on the established FDC. It is the current regulatory practice to confirm the acceptability of both the FDC and the evaluation methods prior to plant specific applications of the fuel design. Article 44.3 of the AEA [4] provides the legal ground for doing this by saying that matters concerning the design and fabrication methods shall be approved by the Minister of Science and Technology (MOST) prior to commencing the fabrication of nuclear fuels. However, the contents of Article 58 of the Enforcement Regulation of AEA (ERAEA) [5] are not only inconsistent with the current practice but also are liable to lead misunderstanding. For this reason the regulatory body is asked to answer the question on what is required for approval of the fuel design.

The FSAR analysis is generally performed by assuming a homogeneous core loaded with only one type of the approved fuel assemblies. Licensing review of the FSAR analysis is performed according to the requirements of the AEA, Article 21 [6] and the ERAEA, Article 6 [7] and 7 [8] that any change that affects the FSAR accident analyses and the operational technical specifications is required to obtain a prior permit by the MOST. However, the core experiences the transition cycles where the new and existing fuel assemblies co-resist until the existing fuel assemblies are completely discharged. For this period the FSAR analysis of a homogeneous core provides incomplete demonstration of plant safety and can not be a reference for evaluating reload safety. A compatibility study has been traditionally performed to examine the differences between the new and the existing fuel designs and to evaluate the effects of these differences on the cores during the transitions to an all new fuel assembly core. The Mixed Core Safety Report (MCSR), often called Reload Transition Safety Report (RTSR) results from the compatibility study and then serves as a reference safety evaluation/analysis report for the transition from the existing fuel assembly fueled core to an all new fuel assembly fueled core. Although the current regulatory practice considers the MCSR as a supplement of the FSAR, the regulatory body is often questioned on its legal effectiveness because no connection between the reference analysis and the reload evaluation is found in any of the Atomic Energy Laws (AELs) or the regulatory documents.

II. Criteria for Fuel Design Approval

In order to support customer needs and remain competitive, the fuel vendors are continually improving their fuel designs through changes of the mechanical design or constituent materials, which may lead to significant changes of the existing FDC and evaluation methods. Even without changes of the mechanical design or constituent materials, modification of the FDC or adjustment or improvement of fuel performance models can be called if the new data collected identify new mechanism or significant changes in fuel performance models. Besides, minor changes of the mechanical design have been made to utilize the new fabrication method. A standard regulatory procedure is to qualify and approve all these new designs or design changes. The ERAEA, Article 58 describes the regulations only against changes of the mechanical design or the design burnup limit. It does not provide appropriate technical criteria for fuel design licensing, considering that fuel performance and core safety are evaluated with use of the FDC and evaluation methods which are applicable for the design, regardless that any mechanical designs are proposed.

The FDC should be consistent with the plant specific requirements for the fuel system which are well generalized by the following paragraphs of Section 4.2 of US NRC Standard Review Plan (SRP): (1) the fuel system is not damaged as result of normal operation and anticipated transients, (2) fuel system damage is not never so severe as to prevent control rod insertion when it is required, (3) the number of fuel rod failures is not underestimated for accidents, and (4) coolability is always maintained. A licensing review confirms that the designer examines all the possible fuel system damage mechanisms during normal operation and anticipated transients, considers all the possible severe conditions that may affect control rod insertability and core coolability, and uses the method to conservatively predict fuel rod failures which must be accounted for in the dose analysis. Some examples of FDC are: that the internal pressure of the lead rod in the reactor is limited to a value below that which could cause the diametral gap to increase, that the minimum Departure from Nucleate Boiling Ratios (DNBR) during normal operation and anticipated transients does not exceed the specified limit, and that deformation of the fuel assembly grid under seismic and Loss of Coolant Accident (LOCA) loads is not severe enough to prevent effective core cooling, etc.

The evaluation methods include operating experience, experimental testing, or analytical predictions. Operating experience can be introduced to evaluate some design parameters such as fretting wear, hydriding, and crud buildup, etc. Adherence to the specific FDC of the fuel vendors requires to be conclusively demonstrated with operating experience. When operating experience is not available, as with the introduction of a design change, experimental testings such as out-of-reactor or in-reactor tests are to be performed. Out-of-reactor tests should be performed when practical to determine the characteristics of the new design. In-reactor testing of the new design is considered important because the core power history and the burnup have significant effects on the fuel performance. In-reactor testing of the new design features can be performed with irradiation of the Lead Test Assembly (LTA) in a real reactor core. The maximum burnup experience associated with the test should be considered in specifying the maximum burnup limit for the new design. The experimental tests are also needed to develop the empirical models involved in the analytical methods. The empirical models generally employ many calculational variables and expressions such as thermal conductivity, clad oxide and crud layer thickness, irradiation time, and empirical correlations, etc. They are used to calculate the values of the design parameters which are compared against the FDC in the FSAR analyses. The FDC-related design parameters such as fuel temperature, rod internal pressure, and metal and water reaction rate, etc. can only be evaluated with calculational procedures.

As it is well known, many parts of the AELs have been directly translated from the Japanese and directed towards the regulation against the hardwares themselves or operations of the facilities. For example, only the person who owns the fabrication facility and intends to fabricate a fuel can apply for the fuel design licensing. Considering this, distinction should be made between regulations against the two applicants: One is the regulation against the fabricator for fuel design itself, and the other, the regulation against the plant utility for plant specific applications. The FDC and evaluation methods are considered as the items which should be qualified prior to plant specific applications of the fuel design. In the stage of fuel design licensing, licensing review confirms that they are acceptable at promised reactor conditions.

III. Proposed Licensing Process

One of supplementary provisions of the AEA, Article 104.2 was recently enacted. The applicants can use Article 104.2 of the AEA optionally for expected repetitive applications of a specific topic and then licensing efforts required by general provisions of the AEA would be minimized within applicability of technical report on the topic. Fig. 1 shows how a new fuel design can be completed with the proposed licensing approach. Solid lines, and the numbers of the bracket, 1, 2, and 3 are explicitly required by the AELs, and dashed lines, and the alphabets of the bracket, A and A' are optional to applicants. The left side of the centered solid line with three lines designates the responsibility of the fuel designer or fabricator and the right side, the responsibility of the plant utility. In case where the fuel designer performs the reload safety evaluation of a specific core where the proposed fuel assemblies are to be loaded, the fuel design report (FDR) (A) and the MCSR (A') can be provided for licensing simultaneously by the fuel designer. In order to provide the possible licensing options to be taken by the applicants, new designs and design changes are divided into the following three cases according to the level of significance:

case (1): major change

- change of existing FDC based on new data showing new mechanism,
- change of the evaluation models affecting overall prediction of fuel behaviors such as change of correlation form, etc.,

- change of dimensions, materials and geometrical features exceeding the analysis range of neutron physics, mechanical and thermal-hydraulic design, or
- other change requiring the in-reactor testing such as extension of burn-up, etc.

case (2): moderate change

- adjustment of existing FDC based on new data supplementing existing data
- change of the evaluation models retaining overall prediction of fuel behaviors such as change of correlation coefficients, etc.,
- change of dimensions, materials, and geometrical features within the analysis range of neutron physics, mechanical and thermal-hydraulic design, or
- introduction of new fabrication method affecting the original design such as use of the welding method affecting the pressure loss, etc.

case (3): minor change

- minor change in dimension, material constituents, and geometrical features not affecting neutron physics, mechanical, and thermal-hydraulic design.
- use of new fabrication method not affecting the original design.

For cases (1), (2), and (3), the recommended licensing paths are A→1→(A')→2→3, 1→(A')→2→3, and 1→(2)→3 respectively. Here, the parentheses mean the step is applicable in a case-by-case. Although the step 1 is required according to the current AEA, it would be considered as a formal licensing step to be taken once the substantial licensing review was completed against the topical report of the fuel design (FDR): For example, if the design change corresponding to case (2) is proposed, it is deemed to be acceptable only if the design change does not have significant effect on the FDR. In this approach, the FDR can serve as a reference design report for the future fuel design changes as the MCSR can do as a reference safety analysis report for core changes during the transition from the existing fuel assembly fueled core to an all new fuel assembly fueled core.

V. Concluding Remarks

In this study a licensing approach for the new fuel design was proposed. It includes the possible licensing options to be taken according to the level of significance of design changes. This approach can be applied on legal grounds of the AEA, Article 44.3 and Article 21, but implies that the related ERAEAs should be revised or other alternative regulatory guidelines should be prepared. However, it is not intended to invoke the additional requirements but rather to streamline and formulate the current practice by using one of supplementary provisions of the AEA, Article 104.2 [10] which is recently enacted for approval of the technical report on a special topic.

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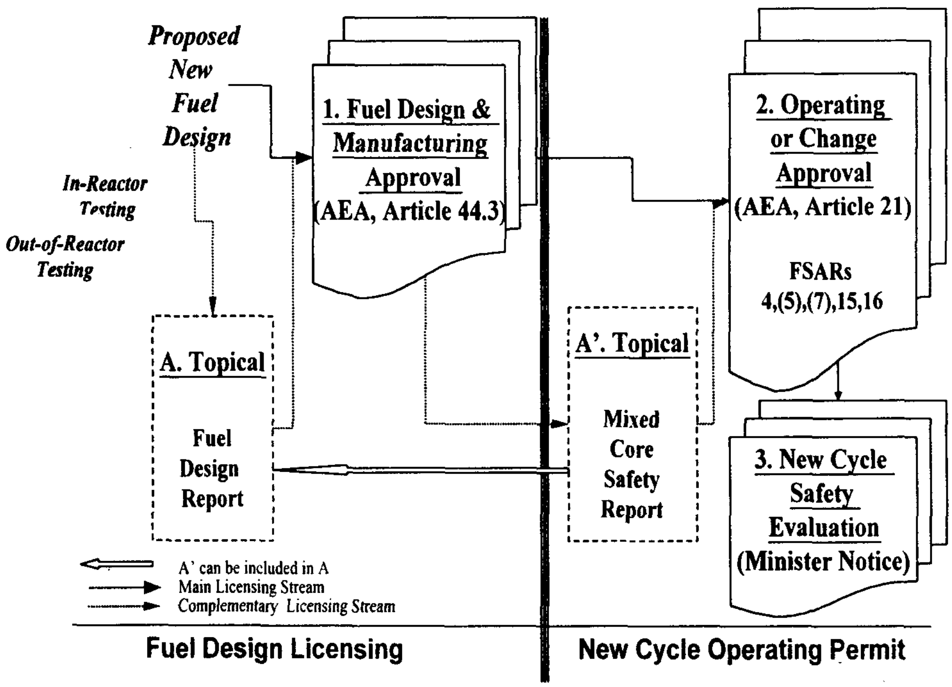

[Fig.1] Licensing Process for New Fuel Design