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Discussion on Safety Analysis and Regulatory Framework for the Future Fusion Reactors

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1. Introduction

K-DEMO is a colossal program and is going in the second phase planed for R&D from 2012 to 2021 [1]. As a part of K-DEMO program with domestic universities funded by National Fusion Research Institute of Korea (NFRI), Kyung Hee University has surveyed ITER licensing process and technical standards under the project entitled "Development, Operation, and Management of Core Technologies for ITER." This study aims to secure the core original technologies and expand the base of domestic specialist at a fusion area by pursuing and developing non-procurement technologies for ITER. From this project, the latest technical data and experiences have been recorded for the development of the safety regulation and safety-related design criteria of the future fusion reactors in Korea. In this context, this paper discusses on the progress of surveying the ITER licensing process and regulatory issues revealed.

2. French Regulation Process

The purpose of the French Nuclear Safety Authority (ASN) established as an independent administrative institution in 2006 is to provide nuclear supervision that is efficient, impartial, legitimate and credible, recognized by the citizens and which constitutes an international benchmark for good practices. Most of the safety regulations for nuclear-related facility in France follows non-prescriptive rules and requires the design provision sets specified by a risk level. Despite of that, several parts must follow the prescriptive design rules (ex. Fire prevention, Building design and construction). [2]

The French legal and regulatory framework has been established:

- to affirm that the licensee is responsible for nuclear safety;
- to provide full independence to the regulator in its decision making;
- to guaranty transparency of any decision related to nuclear safety. [3]

According to Devos [4], due to the diverse and large nuclear reactor fleet, France logically and inevitably uses non-prescriptive regulation leading more reasonable technical communication between the regulators and the licensees. This situation sounds like favorable to take benefits gained by using Probabilistic Safety Assessment (PSA). However, ASN considers that the results of PSA cannot be suitable as a decision making tool for the nuclear safety regulation since the PSA model has several intrinsic limitation: uncertainties from analysis results depending highly on input data and modelling, input data relying on experience feedback, practical impossibility to anticipate new safety issues, and less reliable level 2 and 3 PSA.

ASN has also studied the risk informed approach for the future regulation framework. The risk informed strategy was defined as the extended PSA with deterministic approaches. However, ASN allowed the result of PSA for only comparing risk between the same types of nuclear stations in risk informed strategy. The risk calculated for a certain nuclear facility cannot be compared with other industrial facility. Therefore the role of PSA is limited to support the deterministic approaches in identifying design vulnerabilities.

The French regulatory framework for all nuclear facilities including ITER is similar to that of conventional Pressurized Water Reactors (PWRs) but it is essentially a graded approach. ITER regulation has the same licensing process and design codes of PWR's based on the deterministic safety assessment. [5] Due to the threshold level for tritium (104 TBq) of the radioactive inventory in ITER, ITER has been classified as a Basic Nuclear Installation (INB) according to French Decree 2007-830 of 11 May 2007.

3. ITER Licensing Strategy

ITER Technical Basis and other related documents state 'the main goal of ITER is to demonstrate the safety and environmental potential of fusion and thereby provide a good precedent for safety of future fusion power reactors.' [6~8] The regulation on ITER in the early stage was required to accomplish the full range safety comprehensively considering changeable choices of design options. For that reason, the licensing strategy of ITER was focused on the adaptability for all member countries' requirements. This is a part of reason why France could be selected to be the construction site. French regulatory framework was so flexible and adaptable as to negotiate safety issues between a regulatory authority and a licensee [6]. Flexibility does not necessarily mean 'easiness.' The licensing process of ITER was and should be more than rigorous such that all member countries' requirements need to be reflected. At that moment, the following safety objectives were taken into account: general safety to protect individuals, society and the environment, no-evacuation, and reduction of radioactive waste hazards and volumes.

In 2007, ITER was classified as INB by French decree, and then ITER organization published "General Safety Principles" in 2010. The principles are globally based on international safety guidelines and rules, French rules, the specific design characteristics of ITER and the results of conventional studies. These principles covered the entire life-cycle including design, construction, and operating phases [9~11]. Eventually, in this document, the previous safety objectives were a bit adjusted. The following fundamental safety objectives are practically adopted for ITER licensing;

- to protect workers, the public and the environment from harm,
- to ensure in all situation that exposure to hazards within the premises and due to release of hazardous material from the premises is controlled, kept below prescribed limits and minimized to the extent reasonably achievable,
- to prevent accidents with high consequences,
- to ensure that the consequences of more frequent incidents, if any, are minor,
- to ensure that the consequences of accidents and incidents are bounded and that the likelihood is small,
- to demonstrate that the favorable safety characteristics of fusion permit a safety approach that limits the hazards from accidents such that in any event there is no need for public evacuation on technical grounds,
- to minimize radioactive waste hazards and volumes to the extent reasonably achievable.

In order to achieve these objectives, 'defense-in-depth', and 'radiation protection, as per the principle of optimization and the as low as reasonably achievable approach' are applied.

4. Status of Regulation Studies in Korea

In South Korea, safety objectives and principles for nuclear power reactors have been evolved along with technological development as well as public's concerns. The well-organized philosophy for nuclear safety will help to systematize the entire nuclear industry. Particularly, it contributes not only the design of the first-kind facilities such as Generation-IV reactors or K-DEMO but also their license.

Korea Institute of Nuclear Safety (KINS) carried out the project, "Establishment of advanced and future-oriented nuclear safety regulatory system" from 2007 to 2012 [12]. This project was the extensive research for the upcoming nuclear issues. It is worthwhile to focus two purposes of the project from authors' viewpoint: 1) to perform regulation activities based on safety significance and 2) to systematize reasonable graded regulation according to performance results. Especially, the 5th sub-project dealt with the technology-neutral licensing strategy and its rule-making draft which is applicable to any types of Generation-IV reactors.

In the meantime, KINS established the draft of safety philosophy for Generation-IV reactors in 2011 [13]. KINS surveyed and analyzed the safety philosophy reports published from a lot of different institutes and countries. KINS calculated the practical usability by the detailed investigation of those reports, and established safety philosophy for the advanced nuclear reactors on the basis of the collected opinions from national and international experts.

5. Discussion on Regulation Framework for Korean Fusion Reactors

Authors assume that regulation has to evaluate two aspects: Risk must not be under-calculated. At the same, risk should not be over-calculated because over-conservatism can waste the limited resource so other risk factors can be emerged ultimately. This is more important when we face an unforeseen safety-critical system such as a fusion reactor.

KINS is trying to introduce the recently developed safety philosophy and Korean technology-neutral regulatory framework for the licensing process of the advanced nuclear reactors. However, it is required to verify the consistency of adopting the new concept from the current and future fission-based reactors to fusion reactors.

As stated above, there have been differences of the regulatory framework between Korea and France. French regulation mainly follows non-prescriptive and deterministic approaches. On the contrary, future Korean regulation follows less-prescriptive and risk-informed approaches.

The prescriptive approach is a framework that a regulatory body determines whole set of safety requirements and licensee must demonstrate the requirements are met [14]. The regulatory philosophy based on the prescriptive approaches should provide sufficiently detailed regulations for licensees even before the licensee submits the application. In principle, although the most of responsibilities for the safety of NPP is liable to operator, the regulatory body with this approach can be seen as being in charge of the safety of Nuclear Power Plant (NPP) than operators. This approach relatively reduces the time and skills necessary to conduct the licensing process for both the regulatory body and the operator with clearly defined requirements, which is beneficial for the plant inspection and public communication. However, it is needed for the regulators to prepare detailed technical knowledge. Furthermore, the low flexibility leads to modify or replace the requirements harder when updating the latest technologies are demanded.

On the other hand, the regulatory body with non-prescriptive approach provides the general acceptance criteria or set the safety goals that licensees satisfy. With the full flexibility to the licensees, the regulator can be seen as sharing the responsibility of safety both the regulator and operator. This framework can comparatively have the more flexibility to reflect the new development and avoid the obstruction of licensees' creativity or self-activities for the safety related improvement. Nevertheless, it requires highly competent and proactive regulators and intensive verification processes.

As far as the safety design of fusion reactors is concerned, it is important to set the direction of licensing at this point. Regulatory approach influences to decide which safety assessment methodologies, such as deterministic, probabilistic, risk-informed, or risk-based safety assessment, are more profitable. Utilizing the same methodology of regulation framework directly contributes to K-DEMO licensing process. From the point of regulatory body's view, it allows licensees to provide the adequate information through sharing the angle of safety regulation. In fact, a regulatory body suffering from shortage cannot fully cover a massive system in the design stage. This can leads to a regulatory capture by information asymmetry or infringement [15]. In the development of regulation, the regulatory body relies upon the relatively specialized licensee's information, and reflects the licensee's opinions. If a country has given priority to technical development under the government, the regulatory should be alert to these areas in particular.

6. Conclusions

The regulation and licensing process for a fusion power plant has been expected to be quite different due to unique and unforeseen properties differently from the conventional nuclear facilities. To overcome this, not only various safety issues should be analyzed, but safety objectives, regulatory requirements, and design variables should also be established in detailed design phase. We expect our survey will contribute on the discussion to establish general and technical safety principles for national fusion power plant technology plans.

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