Transactions of the Korean Nuclear Society Spring Meeting
Gwangju, Korea, May 30-31, 2013

Study on Fusion Safety Infrastructure using ISAM

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1. Introduction

The purpose of safety regulations related with nuclear facilities is legal, technical, institutional, and administrative measures to protect public and environment against radiation disaster. For this reason, construction and operation of Korean Fusion DEMO Plant (K-DEMO) have to satisfy these safety regulations because of use radioactive isotope [1]. The regulation of nuclear facilities have checked and managed safety throughout the entire process from design, construction, operation and decommissioning. Also, the same meaning as the regulatory requirements and design requirements, it will be important indicators for detailed design of K-DEMO.

K-DEMO has many uncertainties because it is in conceptual design phase. Also, there is no reference material because demonstration scale fusion power plants were not operated yet in overseas. So, hazard that threaten the integrity of K-DEMO have to be defined preferentially to define regulatory or design requirements.

This study proposed method that educe regulatory or design requirements and introduce web-based cloud infrastructure to perform renewal and sharing of information related with safety that is required in the study rapidly as a part of the R&D program funded by National Fusion Research Institute of Korea (NFRI).

2. ISAM for Korean Fusion DEMO Plant

In Korea, regulatory framework and safety requirements related with nuclear facilities is well organize through the operating and design experience of Light Water Reactor (LWR) since 30 years. However, existing regulatory framework is focused on just LWR. In case of development of new reactors or plants, it may be inadequate to apply existing safety requirements, due to difference in coolant, fuel, and inherent safety feature of LWR. So, methodology for definition of regulatory requirements should be developed.

In case of new reactor or plants, regulatory requirements are considered through definition of safety goal/principle and risk/safety analysis of entire systems in the early phase. And, it is applied in design requirements of system. Development of Generation IV fission power plant (Gen IV) in Korea is one example. Currently, safety requirements which are adequate to Gen IV have been developed by using Integrated Safety Assessment Methodology (ISAM) as a tool [2].

The ISAM is used to develop a more detailed understanding of safety related design vulnerabilities, and resulting contributions to risk. Based on this detailed understanding of safety vulnerabilities, new safety provisions or design improvements can be identified, developed, and implemented previously. Fig.1 shows the structure that defines regulatory requirements using ISAM. The ISAM consists of five analytical tools. These are Qualitative Safety features Review (QSR), Phenomena Identification Ranking Table (PIRT), Objective Provision Tree (OPT), Probabilistic Safety Assessment (PSA), and Deterministic & Phenomenological Analysis (DPA). Each tool is intended to address specific kinds of safety-related issues at different design phases. The resultant of each analysis tool support or relate to inputs or outputs of other tools. The ISAM is a PSA-based safety assessment methodology for Gen IV. Use of ISAM to establish safety requirements for Korean Fusion DEMO Plant (K-DEMO) may be possible because it is able to analyze the technical issues of varying complexity. Risk analysis or QSR is performed using design value in the early phase as input data. Using the result of risk analysis or QSR, PIRT is performed to identify a spectrum of safety-related phenomena or scenarios that could affect systems, and to rank phenomena or scenarios on the basis of their importance. OPT focuses on identifying design provisions intended to prevent, control, or mitigate the consequences of PIRT. Its purpose is to inform the design process and to help structure inputs that will eventually make their way into the PSA. Finally regulatory requirements are defined through detailed analysis for failure mode using results of ISAM.

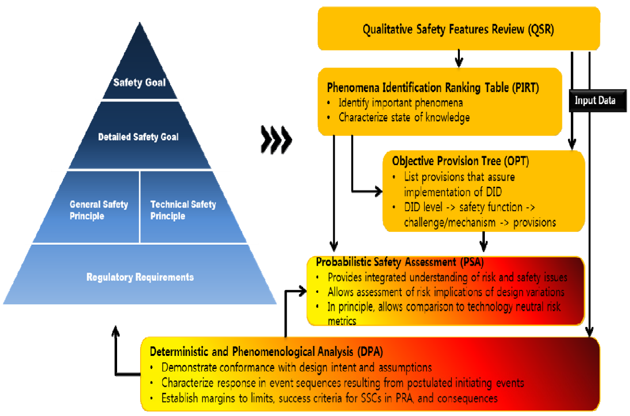

Fig. 1. Structure of ISAM for Korean Fusion DEMO Plant

Table 1. Example of Expert & Extant Safety related Information Table (omitted)

WBS No	Fields	Safety Class	Code & Standard (Design/Manufacture/Inspection/Test)	Computation Code (ITER/DEMO)	
1.1-1.3	Magnet systems	Not Safety Class RCC-MR,SEP-Manifold (equipment&pipes)	Magnetic Structure Design Rules, Manufacture - Technical specification (based on ASME allowance- ASME XI)	MAGS(modular code system set up to analyze the 3D quench behavior of forced flow cooled super-conducting coils)	•••
1.5	Vacuum Vessel & VVPS system	Some equipment (SIC Level) ESPN (Pressure III&IV, Nuclear N2&3)	Design - Design Rules(SDC00) : ASME VIII Div. 2 / Material: SS 304L, ASTM, ASME VIII Div. 2 Manufacture - ASME VIII Div.2 & ASME IX Inspection - Procurement Specification (Design Rules), ASMEVIII Div2 for weld inspections(GSSR) Test - Procurement Specification	- MELCOR (Accident pressurization and thermal hydraulic calculations for 1st and 2nd boundaries) / INTRA(Transient thermal hydraulics-system-level,1-D)/ ATHENA(Transient thermal-chemical calculations2-Din-vessel) / TRAC-PF1(Transient thermal hydraulics-system-level,1-D)/ NUMA(Aerosol behavior)	

3. Expert & Extant Safety related Information

Existing nuclear power plants' safety characteristics and fusion power plants' are quite different and, the demonstration scale permit has never been issued abroad yet. It is a substantial cause of the problem that there is not much material to refer.

Korea Institute of Nuclear Safety(KINS) analyzed ITER's licensing progress judged to be the most advanced and developed the 'strategic technology roadmap for nuclear fusion safety management infrastructure development' in 2007 and the revised version of' strategic technology roadmap for nuclear fusion safety management infrastructure development' in 2009 due to various environmental changes. Despite of the limitation that this roadmap is written based on the perspective of the regulators to regulate the existing nuclear power plant, this roadmap is evaluated as an important milestone because KINS expected to be a competent regulatory authority in the future DEMO fusion power plant initiatively suggested it. Accordingly, we have analyzed the roadmap.

Development of fusion DEMO plant is a huge and complex research that is required for the latest technologies of various field including mechanical, material, chemistry, etc. With the introduction of such research techniques in the above mentioned fields the economics as well as safety and reliability will increase rapidly. For these processes, it will have to be preceded by a review of technology for the most advanced in the field of nuclear fusion.

However, it is required that the groups working on safety, regulation and licensing should understand every field's newest technologies related safety although it is very hard to gather, manage, and share all of that information for the research group at first hand. For that reason we have applied a Closed Cloud Infrastructure (CCI) based on World Wide Web (WWW), and it has following merits: a) building a sustainable, consistent and comprehensive research infrastructure, b) sharing the updated data immediately, and c) simplifying to consult domestic and foreign experts.

Table 1 shows an example written in cloud environment. The y-axis represents the fusion power plant classified in accordance with ITER's Work Breakdown System (WBS). Column titles as WBS No, Fields, Safety Class, Code & Standard (Design/Manufacture/Inspection/Test), PIE, Event Frequency, Consequence, Method (Prevention/Mitigation), Computation Code (ITER/DEMO) and Note. These distinctions continue to be expanded with various possibilities by considering that fusion research is in the early stage. For example, the horizontal axis will be added to the requirements of each of the tools mentioned above the ISAM technique and the vertical axis will be added with the DEMO unit.

4. Conclusions

We have been performing QSR and PIRT in accordance with development of fusion DEMO plant, and preparing OPT, PSA and DPA for regulation requirements. This study introduces our recent research activities about ISAM for fusion and CCI built for expert and extant safety related information.

Unlike fission, nuclear fusion's safety goal is non-evacuation of the public during an accident. To satisfy this goal not only various safety issues should be analyzed, but safety objectives, regulatory requirements, and design variables should also be established in detailed design phase. The web-based cloud infrastructure proposed in this paper will be able to offer input data of future studies and, it is expected to contribute on general and technical safety principles for national fusion power plant technology plan.

Acknowledgments

This work as supported by R&D Program through the National Fusion Research Institute of Korea (NFRI) funded by the Government funds.

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