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Development Status of Regulatory Infrastructure for Fusion Energy

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Abstract

The fusion energy development plan of Korea was established in 2005 to secure the design and construction capability of fusion power plant. A research tokamak KSTAR is under construction and KINS is reviewing the safety related documents for licensing. Korea participated in the ITER project for the cooperating development of fusion related technologies. In parallel with the participation in the ITER project, Korea plans to design a DEMO plant and licensing application for the DEMO construction is expected to be submitted toward the middle of 2020. For an effectiveness and efficiency of the parallel development for fusion related technology and regulation, KINS launched a project in May 2006 to establish the regulatory infrastructure including preparation of safety standards and revision of atomic energy act for fusion energy, to develop the technology roadmap for identification of key regulatory technologies and their development strategies, and also to cultivate human resources, etc. In this paper, the current status of fusion regulatory activities in KINS is introduced.

1. Introduction

The fusion energy development plan of Korea was established by the ‘Presidential Advisory Council on Science and Technology’ in 2005. The ultimate goal of the plan is to secure the design and construction capability of fusion power plant by sometime in 2030s. The development schedule is as follows:

• 1st stage (‘06~’10): Establish infrastructure for development of fusion energy
- Construct and operate KSTAR (Korea Superconducting Tokamak Advanced Research)
- Participate in the construction of ITER

• 2nd stage (‘11~’20): Progress in fusion technologies
- Upgrade KSTAR and participate in the operation of ITER
- Secure engineering design capability for DEMO plant

• 3rd stage ('21~'35): Secure construction capability for fusion power plant
- Construct DEMO plant and complete engineering design of fusion power plant

To support this plan, ‘Fusion Energy Promotion Act’ was legislated in November 2006. In this act, safety management of fusion energy was entrusted to the current atomic energy act. A set of revision of rules and regulations to incorporate the safety management features of fusion facilities is under development by KINS (Korea Institute of Nuclear Safety), which is a quasi-governmental institute fully dedicated to nuclear safety regulation.

KSTAR project was launched in December 1995 with the design goals of achieving steady state D-D fusion reactions up to 300 seconds and adopting a fully superconducting magnet system. KSTAR project team submitted a radiation safety report, a provision for safety control, etc. for the 'Permit'. KINS has been performing the licensing review and it is expected to be finished by this coming August. Then operation will start in September 2007 just after the facility inspection is completed.

Korea participated in the ITER project, which will demonstrate the scientific feasibility of fusion and key fusion technologies, to secure and to improve its fusion related technologies through it.

For an effectiveness and efficiency of the parallel development for fusion related technology and regulation when considering domestic and international fusion development trends, KINS launched a project to establish regulatory infrastructure for fusion energy in May 2006. Major activities of the project are as follows: establishment of the regulatory bases for fusion energy such as preparation of safety standards and revision of atomic energy act; development of strategic technology roadmap for identification of key regulatory technologies and their development strategies, and cultivation of human resources. The development schedule of regulatory infrastructure is as follows:

- 1st stage ('06~'08): Establish regulatory infrastructure for fusion experimental device such as ITER
  - '06. 5~'07. 1: Basic survey and setting-up of development strategies
  - '07. 2~'08. 1: Development of technology roadmap, development of safety standards for fusion experimental device, and revision of atomic energy acts
  - '08. 2~'09. 1 : Finalization of safety standards for fusion experimental device
- 2nd stage ('09~'20): Establish regulatory infrastructure for the DEMO plant
  - Extension of safety standards and reflection of up-to-date technologies identified in strategic technology roadmap.

2. Current Status of Fusion Regulatory Activities

2.1 Strategic Technology Roadmap Development

A Strategic Technology Roadmap (STR) has been developed to establish the contents, schedule, and strategies in developing regulatory technologies by considering the followings: the fusion facility will use materials currently under development and will operate in harsh conditions such as extreme vacuum, extremely low and high temperature, and extremely dense magnetic field, etc. These are new areas to be considered in safety regulation, compared to the present regulation on fission nuclear energy.

Thirteen (13) technical areas such as materials, system design, accident analysis, and radiation assessment, etc. composed of thirty nine (39) core regulatory technologies were identified in the STR. The followings were analyzed for each core regulatory technology:

- Key technology and its importance,
  - Maturity of the technology,
  - Trends and prospects in technology development,
  - Limiting factors of technology development and possible solutions,
- Strategies for technology development, and
  - Plan of securing required technology.

The developed STR will be modified in 2~3 years interval to improve its realization.

2.2 Cultivation of Human Resources

KINS has accumulated experiences and technologies for the safety regulation of fission reactors. For fusion facilities, a plan for the cultivation of human resources has been established to improve staffs' technical understanding for the fusion theory, systems, and current issues related to the fusion safety. Basic education for fusion energy and related technologies was conducted in 2006. For in-depth education, Fusion Information Conference was held in May 2007 to catch up with the current technical progress in the areas identified in the STR. It was open to KINS experts as well as outside researchers and experts interested in the fusion safety, and will be held periodically to pursue up-to-date technical development. Fusion Safety Experts Group, from universities and research institutes, was organized to periodically discuss the fusion related safety and technologies. In addition, KINS plans to recruit fusion experts or students who majored in fusion energy.

2.3 Revision of Atomic Energy Act

Korean government issued the Fusion Energy Promotion Act in 26 December, 2006. This Act prescribed research, development, production and utilization of fusion energy, and entrusted the safety management for fusion energy to the current Atomic Energy Act. Because the Atomic Energy Act does not fully include the safety management for fusion energy at this time, provisions of safety management for fusion energy should be developed. A draft revision of atomic energy act was made for fusion safety management and drafts for Enforcement Decree and Enforcement Regulation of the Atomic Energy Act were also developed. Drafts will be finalized by the end of this year.

2.4 Safety Standards Development

KINS started the development for safety standards in early 2007 with an aim to develop safety and regulatory requirements and guides for the fusion experimental device. A hierarchy of safety standards and format were established, and contents of each hierarchical tier are under development. The ultimate goal is the preparation of licensing review for the fusion power plant. For an effective step by step development, however, safety standards are being developed for the fusion experimental device such as the ITER. Further extension of safety standards for the licensing review of DEMO plant, which will generate the electricity, will be performed after completion of safety standards for experimental device and progressed technologies in parallel with DEMO design will be reflected in the extended version.

A detailed development program including strategy, work scope, and milestone was established in order to carry out the work in a systematic, effective, and consistent way.
The work is as follows:

- Establishment of hierarchy and format,
- Analysis and evaluation of domestic/foreign safety and regulatory documents for identifying requirements,
- Establishment of requirements (Safety Objectives, Safety Principles, General Safety Criteria, and Specific Safety Requirements), and
- Development of safety review guidelines.

The basic approach to the development of safety standards is to utilize and modify existing safety standards for fission reactors such as format, contents commonly applicable to the fission and fusion energy, and to incorporate the safety concepts specifically related to the fusion energy. Domestic and foreign documents associated with fusion safety are being surveyed, compared, and evaluated, and then safety standards will be developed based on the results of these evaluations. Experiences obtained from KSTAR safety review will also be reflected. An in-depth study is being performed for the followings:

- Safety and regulatory requirements and guides for fusion energy established by foreign regulatory bodies,
- Design requirements and features considered in ITER, and
- Safety issues raised by domestic or foreign organizations.

A comprehensive framework of safety standards was established, consisting of the following 5 tiers as shown in Fig. 1: Safety Objectives (SO), Safety Principles (SP), General Safety Criteria (GSC), Specific Safety Requirements (SSR), and Safety Review Guidelines (SRG). The framework of safety standards systematically provides a series of tiers; the upper four tiers (SO, SP, GSC, and SSR) cover compulsory requirements, while SRG, forming the understructure of the hierarchy, is not considered as mandatory requirements but as a guide.

Safety Objectives	• Ultimate aim which has to be achieved in fusion safety
Safety Principles	• Essential ingredients which have to be observed in achieving what is stated in safety objectives
General Safety Criteria	• Criteria for complying with safety principles in general aspects
Specific Safety Requirements	• Requirements for complying with safety principles in specific aspects
Safety Review Guidelines	• Internal guideline on review scope, review method, interface identification, etc.
Industrial Codes and Standards	

* Industrial Codes and Standards are not a part of the safety standards but they are shown as a reference.

Fig. 1 Hierarchy of safety standards

Safety Objectives

The utilization of fusion energy as other industrial activities, may cause detrimental effects to humans and the environment. In order to protect humans and the environment from hazards induced by the use of fusion energy, it would be desirable that a regulatory body provide objectives for which utilities and designers use to steer all the activities related to fusion safety. Safety Objectives are the top tier requirements in the hierarchy of safety standards, and provide objectives which should be ultimately achieved in the activities of using fusion energy.

Safety Objectives are currently composed of three objectives: General Safety Objective, Radiation Protection Objective, and Technical Safety Objective. General Safety Objective is the top objective supported by two complementary objectives dealing with radiation protection and technical aspects. Components of safety objectives are the same as those of fission energy, while the contents will be different and are under development.

• General Safety Objective	
• Radiation Protection Objective	• Technical Safety Objective

Table 1. Structure and Components of Safety Objectives

Safety Principles

As the second tier in the hierarchy of safety standards, Safety Principles provide the most essential elements which have to be observed in accomplishing the Safety Objectives.

Safety Principles consist of four areas as shown in Table 2: general considerations, siting, design, and operation. In the area of general considerations, six elements are considered. They shall be applied commonly to all the stages of licensing from siting to operation of fusion reactor. In the area of siting, design, and operation, six elements are being considered.

<table>
<tr><td colspan="3"><u>General Considerations</u>
• Safety management
• Establishment and Implementation of a Quality Assurance Program
• Consideration of Human Factors
• Assessment of Safety
• Preparedness for Emergency
• Protection from Radiation</td></tr>
<tr><td><u>Siting</u>
• Evaluation of Site-related Factors</td><td><u>Design</u>
• Defense-in-depth</td><td><u>Operation</u>
• Establishment of Limits and Conditions for Operation
• Establishment of Operating Procedures
• Maintenance, Testing and Inspection
• Technical Support Organization</td></tr>
</table>

Table 2. Structure and Elements of Safety Principles

General Safety Criteria

The Safety Objectives and the Safety Principles have characteristics of regulatory policy or philosophies to provide steering for regulations, rather than of requirements directly applicable to the actual regulation of the fusion energy. General Safety Criteria will be substantially the top tier requirements in the actual regulation of the fusion energy.

Specific Safety Requirements provide detailed and specific technical regulations. They will incorporate the technologies to date but do not cover issues not yet revealed or resolved. To therefore cope with the potential circumstances for which detailed requirements are not prepared, it is necessary to establish a tier of requirements in the hierarchy of safety standards, consisting of comprehensively and generally described requirements. Establishment of this tier will make it possible to carry out judicial enforcement under unexpected regulatory circumstances which can not be covered by detailed requirements or guides. The GSC is being developed based on the concept that they provide comprehensive and general standards and provide fundamental bases for developing Specific Safety Requirements.

The structure and components of the GSC are shown in Table 3. The GSC consists of 4 areas which are site/environment, design, operation, and quality assurance. This division of areas in the structure of the GSC is based on the licensing steps and regulatory activities. To date, drafts of the GSC in siting and design are being developed, and components and their key contents of the GSC in operation will be developed later. The existing GSC for quality assurance, which was developed for fission reactors, will be reviewed and modified if necessary.

Table 3. The structure and components of the GSC

I. Site/Environment		
1. Geological Features and Earthquakes 2. Limitations on Location 3. Meteorological Conditions	4. Hydrologic and Oceangraphic Conditions 5. Impact of Man-Made Accident 6. Feasibility of Emergency Plan	7. Assessment of Radiological Impacts
II. Design		
1. Consideration of fusion related features 2. Safety Classes and Standards 3. External Events Design Bases 4. Provision against Fire Protection 5. Environmental Effects Design Bases, etc. 6. Sharing of Structures, Systems, and Components 7. Fusion Reactor Design 8. Inherent Protection of Fusion Power 9. Instrumentation and Control System 10. Confinement (or Containment) 11. Electric Power System	12. Control Room, etc. 13. Protection System 14. Plasma Control System 15. Heat Removal System 16. Fusion Power Shutdown System 17. Ultimate Heat Sink 18. Processing and Storage Systems of Radioactive Wastes 19. Fuel Handling and Storage Facilities 20. Radiation Protection Provisions 21. Vacuum Vessel Pressure Suppression System 22. Alarm Devices, etc. 23. Prevention of Collapse of Steep Slope, etc.	24. Use of Qualified Equipment 25. Testability, Monitorability, Inspectability, and Maintainability 26. Design Basis Accidents 27. Reliability 28. Human Factors 29. Optimization of Radiation Protection 30. Emergency Response Facilities and Equipment 31. Establishment, Adjustment, etc. of Limiting Conditions for Operation 32. Initial Tests
III. Operation (To be developed later)		
IV. Quality Assurance (Current existing standards will be reviewed and modified if necessary)		
1. Organization for Quality Assurance 2. Quality Assurance Program 3. Design Control 4. Procurement Document Control 5. Instructions, Procedures and Drawings 6. Control of Purchased Items and Services 7. Identification and Control of Items 8. Control of Special Process 9. Inspection	10. Document Control 11. Test Control 12. Control of Measuring and Testing Equipment 13. Handling, Storage and Shipping 14. Inspection, Test and Operating Status 15. Control of Nonconforming Items 16. Corrective Action 17. Quality Assurance Records 18. Audits	

Specific Safety Requirements (SSR)

The SSR provides detailed rules necessary for complying with the General Safety Criteria (GSC), and forms the lowest tier of the mandatory requirements. All of the SSR will be established in conjunction with the GSC, and may further be linked with the industrial codes & standards where necessary.

The SSR is categorized into four areas; site/environment, design, operation, and quality assurance. The structure of the SSR is composed of 16 chapters for site/environment and design.

Table 4. Structure of the Specific Safety Requirements

Areas	Chapters	Components
I. Site/ Environment	1. Site	1.1 Meteorology 1.2 Hydrology ....(5 elements)
	2. Radiological Environment	2.1 Environmental Description 2.2 Environmental Effects of Radiation ....(5 elements)
II. Design	3. Design Common Requirements	3.1 Classification of Systems 3.2 Codes and Standards ....(14 elements)
	4. Structural Design	4.1 Geology and Foundation 4.2 Seismic Design ....(10 elements)
	5. In-Vessel System	5.1 Plasma Performance 5.2 Blanket 5.3 Diverter 5.4 Vacuum Vessel
	6. Ex-Vessel System	6.1 Magnetic System 6.2 Cryostat
	7. Fueling & Tritium System	7.1 Fueling 7.2 Tritium System
	8. Engineering Safety System & Confinement System	8.1 Control of Energy Sources 8.2 Engineering Safety System 8.3 Confinement System
	9. Instrument and Control System	9.1 Common Requirements 9.2 Safety Related I&C System
	10. Electric Power System	10.1 Offsite Electric Power System 10.2 Onsite Electric Power System 10.3 Coil Power Supply & Distribution System 10.4 Additional Heating Power Supplies
II. Design	11. Auxiliary System	11.1 Additional Heating & Current Drive 11.2 Cryoplant 11.3 Vacuum System 11.4 Thermal Shield 11.5 Tokamak Cooling System 11.6 Remote Handling System

		..... (13 elements)
	12. Power Conversion System	(To be developed later)
	13. Radioactive Waste System	(5 elements)
	14. Radiation Protection System	(4 elements)
	15. Human Factors Engineering	(2 elements)
	16. Accident Analysis	(6 elements)
III. Operation		(To be developed later)
V. QA	Quality Assurance	(To be Reviewed & Modified if necessary)

Safety Review Guidelines

Safety Review Guidelines provide the KINS' internal guideline on review scope, review method, interface identification, etc. It does not specify the additional regulatory requirements and will be developed after development of higher tiers.

3. Concluding Remarks

The current status of fusion regulatory activities in KINS was introduced based on the interim results.

The technology development in company with the regulatory preparation will result in better outputs. Therefore, in the development process of fusion related regulatory technology, interim results will be periodically open to domestic fusion societies to draw a broad consensus or comments.

In parallel with the domestic fusion regulatory activities, KINS is willing to cooperate with international regulatory societies to develop global safety standards or to discuss the technical issues for fusion energy in the regulatory point of view.