NUCLEAR REGULATORY RESEARCH IN KOREA: ACHIEVEMENTS AND FUTURE DIRECTION

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For efficient and effective nuclear regulation, regulatory organizations must establish consistent and rigorous regulatory positions on safety matters. These positions should be based on high technical expertise and relevant ordinances, standards, and guidelines reflecting policy changes governing nuclear regulations. The Korea Institute of Nuclear Safety, a regulatory expert organization in Korea, has developed regulatory requirements, guidelines and analytical tools that provide regulatory technical bases for ensuring nuclear safety. The nuclear regulatory research also contributes to regulatory decision making by providing resolution for current and future safety issues. In this article, we introduce nuclear regulatory research and its main achievements in the past 10 years. Also, suggested here are future directions of nuclear regulatory research.

KEYWORDS : Regulatory Research, Safety Issues, Nuclear Regulation

1. INTRODUCTION

The Korea Institute of Nuclear Safety (KINS) is an independent regulatory expert organization that implements safety regulations according to the Atomic Energy Act. Its purpose is to protect the public and environment from undue radiation hazards that arise from the production and utilization of nuclear energy. To ensure efficient and effective nuclear regulation, the regulatory organization must establish a consistent and rigorous regulatory position on safety matters, and these positions should be based on high technical expertise and relevant ordinances, standards, and guidelines reflecting policy changes governing nuclear regulations both in Korea and overseas. Through nuclear regulatory research, KINS has been developing a regulatory framework necessary for making independent decisions regarding regulations. The framework entails assessment methods and analyses models. Furthermore, KINS is preparing the necessary framework not only for nuclear facilities that are currently in operation but also facilities that will be built in future.

KINS nuclear regulatory research is funded by the Ministry of Education, Science and Technology, which operates medium and long term plans for research and development of nuclear energy. Since the formulation of the "Medium and Long Term Plans for Research and Development of Nuclear Energy for the 21st Century" in June of 1997, KINS has actively conducted nuclear regulatory research. At present, KINS keeps in step with the direction of the 3rd stage plan of providing "International Leadership for Regulation Technology" from 2007 to 2012 by implementing specific research programs for development of nuclear and radiation regulation technologies.

Through conducting regulatory research, KINS has broadened the scope of mutual understanding of relevant technological fields among experts in nuclear safety by encouraging information exchange. Also, to set the direction of research, KINS has organized several technical symposiums in the area of safety analysis, integrity assessment of nuclear components, and radiation safety assessment technology. In addition, KINS has organized various technical seminars and research forums not only to exchange information on technological development but also to discuss various safety issues. Besides these efforts, KINS holds exhibitions highlighting their nuclear regulatory research so that they may promote a better understanding of the stakeholders, including the general public.

Due to the rapidly changing nuclear environment, the nuclear field now faces new challenges and opportunities. For instance, while there is a continuous need to maintain the safety of existing nuclear power plants, the introduction of advanced water reactors requires safety assurances for new design features and technologies. Along with this, national development projects were implemented for designing sodium-cooled fast reactors and very high temperature gas-cooled reactors according to the "Action Plan for Developing Future Nuclear Energy System" approved by the Nuclear Energy Commission in December, 2008. Accordingly, KINS nuclear regulatory research also requires significant restructuring in preparation for the fundamentally different technologies that are to be incorporated. In relation to this, preliminary research and development is currently underway to develop both a regulatory framework and licensing strategies.

In the following sections, we introduce the implementation system for nuclear regulatory research. We then address key achievements of the past 10 years in this field. Finally, we suggest future directions for nuclear regulatory research.

2. IMPLEMENTATION SYSTEM OF NUCLEAR REGULATORY RESEARCH

The objectives of nuclear regulatory research are as follows: 1) development of the criteria, requirements, and guidelines that serve as measures for regulation; 2) enhancement of technical capabilities for making timely regulatory decisions; 3) development of technologies to resolve safety issues and assure safety; and 4) preparation of a program for constructing an efficient and effective regulatory system. To accomplish these objectives efficiently, KINS has created an organizational structure (Figure 1) that will enable networking with internal organizations to achieve such objectives.

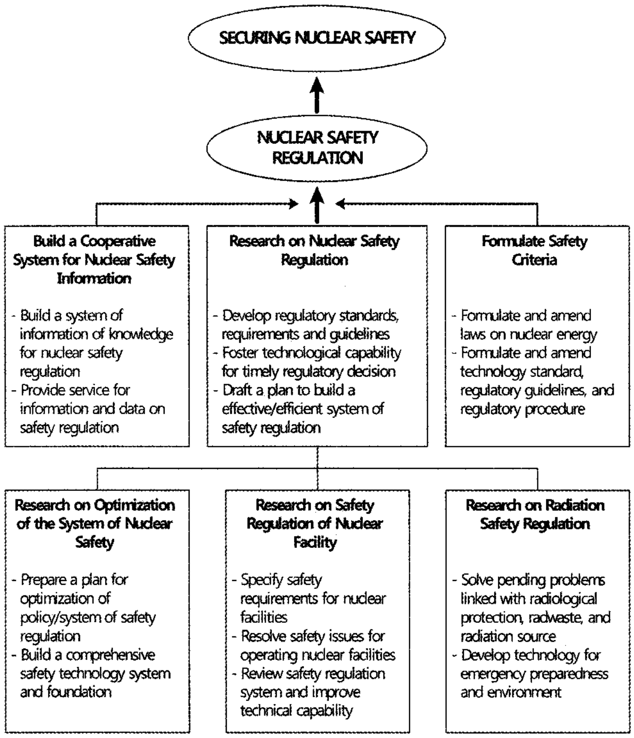

Fig. 1. Plan for Implementing Nuclear Regulatory Research

The subject of nuclear regulatory research consists of three areas: streamlining regulatory systems for nuclear safety, regulating nuclear facilities, and researching issues pertaining to radiation regulations. First, KINS formulated a plan to streamline the regulatory framework. KINS built a system for integrated safety assessment specific to reactor types, especially heavy water reactors. Second, research has highlighted safety requirements for nuclear facilities and explored methods of solving safety issues derived from operational experience. Further, research has borne out methods of analyses necessary for independent evaluation during the licensing process. Research has also highlighted plans, and the implementation thereof, to improve technical capabilities of regulatory personnel. Research has also secured technologies required to resolve safety issues related to radiation protection, radioactive waste, radiation sources, and required to respond to nuclear and radiation emergencies linked with the environment.

In addition to the above research focused on foundations of regulatory technology, there was a need for thorough investigation and systematic management of urgent safety issues that had been revealed through accidents at domestic and overseas nuclear facilities. KINS administered a nuclear safety issues program to investigate and identify potential safety issues relating to new and existing nuclear facilities and drafted a plan for finding solutions via technological assessments. Through this, KINS secured technologies for preventive regulation designed to lower the possibility of incidents and accidents.

KINS operates an open system that allows experts from the regulatory departments to participate directly and indirectly in research together with various research departments. This increases the utility and applicability of results obtained from research. Moreover, to obtain comprehensive research results for large-scale system projects, KINS implemented some key projects selected in terms of the degree of urgency. In addition, KINS has encouraged collaboration among research teams via research cooperation with the Korea Atomic Energy Research Institute (KAERI) for the purpose of information exchange among the research fields related to nuclear safety.

3. ACHIEVEMENT OF RESEARCH ON NUCLEAR SAFETY REGULATION

The following key research areas on nuclear safety regulation were conducted by KINS: 1) streamlining of verification systems for nuclear safety; 2) development of regulatory technologies for nuclear safety; 3) development of regulatory technologies for radiation safety; 4) development of safety assessment technologies for seismic events at nuclear power plants; 5) research on safety issues for operating nuclear facilities; and 6) research on regulatory framework for advanced reactors. In what follows, the major research results are described.

3.1 Streamlining of the Verification System for Nuclear Safety

With respect to the development of policy and systems for nuclear safety regulation, research objectives have focused on streamlining the verification system for efficient implementation of safety regulations. The following four subsidiary programs have been implemented.

- Reorganization of the nuclear legislation system
- Optimization of the structure and system of nuclear regulations
- Systemization of risk-informed and performance-based regulations
- Fostering of public understanding of and participation in safety regulations

3.1.1 Research on Reorganization of Nuclear Legislation System

KINS carried out research focusing on restructuring nuclear energy ordinances and on improving technological requirements of nuclear safety regulations. For the first area, KINS analyzed problems associated with ancillary ordinances associated with nuclear energy and came up with a basic methodology for categorizing such ordinances as follows: a system of enforcement ordinance for basic laws; a system of technological standards for nuclear facilities and materials; and a system of enforcement ordinances for radiation protection. Moreover, KINS conducted research on specific safety issues linked with nuclear energy legislation and formulated programs for resolutions.

For building a system of technological requirements for safety regulations, KINS analyzed safety principles and operation and management standards as well as technological requirements, which include ancillary standards and guidelines. The system was based on analyses of domestic and foreign regulatory requirements. In addition, KINS systematically reflected the International Atomic Energy Association (IAEA) safety requirements and guidelines associated with nuclear reactors for power generation, nuclear reactors for research, and nuclear fuel cycle facilities.

3.1.2 Research on Optimization of the Structure and System of Nuclear Safety Regulation

KINS developed a program that improved the regulatory system for each licensing step associated with nuclear power plants. They also developed several programs targeted at enhancing inspections prior to construction, improving periodic safety reviews, supervising programs for nuclear power plant operations, and setting up and operating onsite regulation offices. In addition, KINS suggested a systematic verification program for nuclear power plants beyond their design life. The program conforms to international trends in nuclear safety.

The program of improving inspections prior to construction entails supplementing weak areas, found during regulatory inspections, in the design, manufacture, and performance testing of key equipment. With respect to the program of enhancing the system of periodic safety review, operating experiences gained from Kori Unit 1 and Wolsong Unit 1 and the amended safety guidelines of IAEA have been reflected. The supervising program for nuclear power plant operations was developed to raise the efficiency of the regulatory system dealing with increased numbers of operating nuclear power plants. This was accomplished by examining the regulatory inspections and operational status for specific nuclear power plants. The program for operating onsite KINS offices was recommended to activate regulatory activities at reactor sites. The program to systemize safety verification beyond design life of nuclear power plants was developed as a regulatory system to ensure safety for continued operation of nuclear power plants beyond their design life, which factors in the expiration of the lifespan of Kori Unit 1 (2008). In response to domestic and overseas trends in nuclear safety, KINS explored various measures based on an analysis of the prospect of global nuclear safety regime, such as multinational design evaluation program (MDEP), currently underway in the international nuclear community.

3.1.3 Research on Systemization of Risk-informed and Performance-based Regulation

KINS drafted a policy on risk-informed and performance-based regulations that includes basic directions and implementation principles for introducing risk-informed and performance-based regulations. The draft also includes an implementation model that incorporates three stages: infrastructure preparation, execution, and optimization. This draft was intended to be used for the government policy statements. The basic guidelines necessary for enforcing policy statements includes selection criteria, basic consideration factors, and essential details that must be considered for application of risk-informed and performance-based regulations. The developed policy statements and basic guideline draft can be utilized in activities relating to future risk-informed and performance-based regulations, as anticipated.

3.1.4 Research on Public Understanding of and Participation in Safety Regulation

KINS developed subjective safety indicators, which are made up of four factors and twelve items, to aide in public understanding of nuclear safety. KINS gauged the level of safety felt by residents near a nuclear power plant using subjective safety indicators. The utility and regulatory bodies can better understand the mindset of residents adjacent to nuclear power plants by examining these indicators. They can also recognize details that must be considered prior to communicating with such residents. Moreover, to strengthen public trust, KINS clarified the basic direction for promoting public disclosure of information on safety regulation. To improve the clarity of information disclosure to the public, KINS prepared an easy-to-understand glossary of terms relating to nuclear safety and regulation.

In reference to increasing public participation, KINS recommended a program for polling resident opinion and for changing the attitude of nuclear workers toward resident opinions. The program also includes discussions and debates involving all concerned parties, increased transparency surrounding the policymaking process, and long term perspectives and strategies when collecting opinions. Based on the results of research of programs that were meant to enhance interest of residents in nuclear safety regulations, KINS has recommended a multi-faceted system for conversation with residents, consolidation of autonomous civilian oversight organizations, increasing information disclosure. This larger program also includes training programs to adjust the attitudes of nuclear workers (including regulators) toward public opinion as well as the establishing of regional information committees. KINS examined the level of safety consciousness of the residents near nuclear power plants by surveying their awareness of nuclear safety and regulations. Additionally, KINS made the research results available for social science research.

3.2 Development of Regulatory Technology for Nuclear Safety

The development of regulatory technology for nuclear reactor facilities seeks to optimize the safety regulation standards twofold: first so that they conform to international standards, and second to bring the technological capacity of safety regulations up to globally advanced level. As such, research is being conducted on key technological safety issues associated with nuclear facilities. These areas include the following:

- Operational performance of nuclear power plants
- Integrity of reactor components
- Reactor thermal-hydraulic and safety analysis
- Assessment of mitigation capability during a severe accident
- Digital instrumentation and control systems
- Safety of nuclear power plant structures

3.2.1 Development of Regulatory Technology for Operational Performance Evaluation of Nuclear Power Plants

KINS conducted research on five specialized areas. They included risk-informed regulation, risk monitoring technologies, performance-based maintenance, performance of power operated valves, and performance of key systems.

With respect to foundational technologies for risk-informed regulation of nuclear power plants, KINS developed a probabilistic safety assessment (PSA) model meant for regulatory review/assessment in order to evaluate risk-informed licensing applications of the utilities. Moreover, KINS developed a general reliability data platform for major nuclear power plant equipment using a web-based format. KINS also established a system of quality assurance for PSAs as a basis for applying risk-informed regulation. Furthermore, KINS developed assessment guidelines for domestic programs in reference to risk monitoring (RM). These technological developments on risk-informed regulations provide support for the construction of various risk-informed regulatory systems in Korea. In relation to performance-based maintenance, KINS developed detailed guidelines on specific items such as safety significance classification and performance monitoring.

In relation to the assessment of the design basis for air operated valves, KINS clarified its regulatory position and developed a system for diagnosing performance and malfunctions. They also developed regulatory guidelines for periodic safety review for motor operated valves. KINS built a knowledge database of the impact of malfunctions of emergency diesel generator systems. Based on this, KINS developed a prototype monitoring system to diagnose these malfunctions. Based on technical standards for nuclear reactor facilities, KINS issued a ministry notice on fire protection planning and fire risk analysis for fire protection systems. Additionally, KINS established guidelines for reviewing fire protection programs which must be submitted by the operators.

3.2.2 Development of Regulatory Technology for Integrity of Reactor Components

This study developed a regulatory technology for verification of the integrity of reactor components of nuclear power plants. The main contents include the construction of a technical basis of assessing integrity for long-term operation, the development of a method of assessing the integrity of major components, and the establishment of a system to evaluate the integrity of major components in nuclear power plants.

Several results were derived from this research. First, in terms of constructing the technical basis of assessing integrity for long term operation, KINS developed a Regulatory Aging Assessment Program (RAAP), a database for that program, and drafted a revised ministry notice for monitoring tests and inspections during reactor operation. Also, KINS drew up guidelines for fracture mechanics analysis of reactor-vessel heads and built a database containing piping failures. Second, in reference to the development of a method of assessment of the integrity of major components, a component integrity assessment program based on probability analysis (PROBie) was developed. KINS also developed regulatory guidelines for leaks-before-breaks and constructed a web-based database for the material properties of thermally embrittlement regions and dissimilar-metal welds. Third, in terms of the construction of an assessment system for integrity of major components of nuclear power plants, KINS developed ultrasonic examination (UT) simulators, intelligent eddy current testing (ECT) signal analyzers, and a real time integrity monitoring system (R-TiMEs).

The above results can be utilized for assessment of material degradation in operating nuclear power plants, periodic safety reviews, and continued operation safety reviews.

3.2.3 Development of Regulatory Technology for Reactor Thermal-hydraulic and Safety Analysis

This study developed a safety code and methodology that can assess major nuclear power plant accidents and explored ways of resolving safety issues. More specifically, based on the Code Assessment and Maintenance Program (CAMP), KINS assessed the best-estimated thermal-hydraulic system assessment code (RELAP 5 and TRACE), and the three dimensional neutronics analysis code (PARCS). KINS participated in the international joint research project for assessing the performance of high burn-up nuclear fuels (CABRI) and developed a technology for best-estimate assessment of large-loss-of-coolant accidents.

For an analysis of thermal hydraulic behaviour of direct vessel injection, one of the prerequisites for licensing of the APR1400, KINS developed the interfacial drag model and film off-take model of the downcomer region for the newly developed thermal-hydraulic safety analysis code (MARS). Based on this research, KINS performed a realistic safety assessment for the performance of the emergency core coolant system of the APR1400.

To clarify the regulatory standards for high burn-up nuclear fuel associated with long term operation, KINS analyzed the material characteristics of high burn-up nuclear fuel, and evaluated the experimental data obtained from the CABRI test. KINS then constructed a domestic and international technology infrastructure which enables assessment of the impact made upon the safety standard and accident analysis of high burn-up nuclear fuel resulting from a long term operation.

3.2.4 Development of Regulatory Technology for Assessment of Mitigation Capability during a Severe Accident

To confirm the utility's compliance with government policy ("Policy on Severe Accidents of Nuclear Power Plants, Ministry of Education, Science and Technology; Aug. 2001"), KINS developed a technology that enables assessment of both severe accident management programs of operating nuclear power plants and new design features for responding to severe accidents in an advanced pressurized water reactor (APR1400). Also, by participating in the Steam Explosion Resolution for Nuclear Application (SERENA) program organized by OECD/NEA, KINS analyzed loads from steam explosions that can occur during severe accidents in nuclear power plants. Based on the analytical conditions, KINS assessed the APR1400 reactor cavity using the Integral Fuel Coolant Interaction (IFCI) code. Further, KINS analyzed hydrogen dynamics by developing a detailed analytical model of the APR1400 inside refueling water storage tank (IRWST). KINS also developed a simulator for visual observations of assumed severe accidents. This simulator can be utilized to develop technologies to diagnose real time progress of severe accidents at nuclear power plants. In order to evaluate the management strategy for severe accidents at nuclear power plants, KINS used the severe accident analysis code (MELCOR) and developed a technology for assessing the validity of key strategies that can be applied to Kori Units 3 and 4. As a result, KINS discovered that the vessel retention of the molten corium using external reactor vessel cooling could not be employed as a strategy.

3.2.5 Development of Regulatory Technology for Digital Instrumentation and Control System

As digital equipment gradually replaced their analog counterparts in both existing and newly constructed nuclear power plants, there arose a need for new perspectives on safety review. KINS conducted research on risk assessment and environment verification of digital instrumentation and control equipment and evaluated safety performance of the improved information display system and safety related cables. In relation to risk assessment, by analyzing precedents of failure of digital instrumentation and control equipment in domestic and foreign nuclear power plants, KINS developed a regulatory technology to predict failure. In the field of software safety assessment, KINS developed regulatory guidelines for quality assurance for programmable controllers and safety grade software. In assessing the safety of the improved information display system, KINS developed a support system for safety evaluation of cathode-ray tubes (CRTs) and computer-based procedures (CBPs). Additionally, KINS drew up guidelines for assessing the safety of composite-type control rooms. With respect to the development of regulatory standards for assessing the performance of cables related to safety, KINS revised the guidelines for monitoring the condition of cables and for evaluating their remaining life.

3.2.6 Development of Regulatory Technology for Safety of Nuclear Power Plant Structures

For the development of regulatory technologies for safety assessment of nuclear power plant structures, KINS conducted research in five different areas: safety assessment for aircraft crashes, safety assessment for artificial disasters, assessment of containment resistance to extreme internal pressure, assessment of earthquake resistance and structural safety associated with material degradation, and development of regulatory requirements and guidelines related to the safety of nuclear power plant structures.

With respect to the safety assessment for aircraft crashes, KINS developed an assessment technology for the containment resistance capacity. The research highlighted the damage modes inflicted on containment buildings as borne-out by nonlinear dynamics. The research also recommended a method to suppress damage from aircraft crashes. By investigating domestic and foreign technologies for assessment of hazardous facilities nearby nuclear power plants, KINS conducted a precedent-assessment on the dangers resulting from various accidents. This entailed defining the concentration of various poisonous materials that could leak from hazardous facilities and assessing risks of chlorine leakage and liquefied petroleum gas (LPG) vapour cloud explosions from moving vehicles. KINS developed guidelines and procedures for responding to the worst possible leakage scenarios, which have been drawn upon in accordance with the Industrial Safety and Health Act. KINS formulated a program of assessing containment resistance to extreme internal pressure for heavy water reactors. For this, the results of the existing Gentilly-2 model test were compared with those of the axi-symmetric two dimensional model analyses. Moreover, in preparation for periodic safety review and long term operation of nuclear power plants, KINS secured basic data for analyzing the characteristics of material degradation of non-metallic liners.

KINS established the procedures for assessing degradation factors of nuclear power plant structures, the methods of repair and reinforcement and for assessing the structural integrity of adhesion-type tendon systems. KINS also developed guidelines for management of material degradation in operating nuclear power plants and clarified methodologies for evaluating structural integrity of containment using adhesion-type tendon systems. In addition, KINS drafted regulatory guidelines for reassessment of seismic safety. The guidelines include a program to reduce the seismic response of equipment, and a method to generate the response spectrum of a structure.

3.3 Development of Regulatory Technology for Radiation Safety

The KINS research objective for the project focused on the development of regulatory technologies for radiation safety is centered on the development of regulatory technology for radiation safety that meets international standards while reflecting specific domestic conditions. The goals of technological development for radiation safety regulation include the following: 1) establishment of technologies for the verification of radiation protection; 2) establishment of comprehensive verification systems for radioactive waste; 3) development of advanced techniques for assessing environmental impacts and monitoring environmental radiation; 4) establishment of emergency response technologies; 5) construction of a database containing radiation risks for the public; and 6) establishment of safety assessment technologies for the handling of radiation sources.

3.3.1 Development of Regulatory Technology for Radiation Protection

To introduce regulations that meet international standards on radiation protection, KINS established a program to improve the current system of radiation protection. After collecting and analyzing expert testimony, KINS drafted a proposal for legislation and standards of radiation protection guidelines. KINS developed assessment guidelines for operational management at nuclear power plants to assess radiation protection programs of nuclear facilities. To develop assessment technologies for personal effective dose, KINS clarified items and requirements for maintaining a quality assurance program for internal dose assessment (indirect method) while also specifying the requirements for design approval of personal dosimeter. As a way of developing a technology to assess transportation safety of radioactive materials, KINS established safety analysis procedures, including assessment requirements for each test, in relation to the transportation vessel accidents assumed in the design. To set up a quantitative As Low As Reasonably Achievable (ALARA) assessment system, KINS analyzed domestic and overseas trends in occupational radiation exposure and developed guidelines for optimization assessment. At the same time, they set monetary values on exposure according to the range of annual exposures.

3.3.2 Development of Regulatory Technology for Radioactive Wastes

As part of the development of safety verification technologies for the decommissioning of nuclear facilities, KINS developed guidelines for reviewing decommissioning plans. Also, KINS established guidelines for investigation of radiation characteristics of nuclear facilities scheduled for decommissioning and restoration. KINS reviewed general safety factors for dry storage of spent nuclear fuel to develop assessment methods for spent fuel storage facilities. Further, focusing on the CANDU dry storage facility for spent nuclear fuel to be constructed on the Wolsong site, KINS developed safety verification methodologies that included safety analyses, radiation safety assessments, and heat and shielding analyses. In terms of radioactive waste disposal, KINS also drafted regulatory guidelines for examination of the radionuclide inventory included in the wastes and prepared guidelines for assessment of those inventories. Moreover, KINS specified technological requirements relating to the operation, closure, and post-closure of low- and intermediate-level radioactive waste repositories. They also drew up operation criteria for low- and intermediate-level radioactive waste repositories in compliance with regulations on technology standards of radiation safety management.

3.3.3 Development of Regulatory Technology for Emergency Preparedness and Environment Assessment

For efficient environmental radioactivity monitoring, KINS developed analytical methods that can quickly assess ^{129}I contamination during emergencies by devising rapid analysis methods of ^{129}I using Multi-Collector Inductively-

Coupled Plasma Mass Spectrometry (MC-ICP-MS). Also, KINS confirmed the reliability of that method by manufacturing measurement systems for a number of effluent ß nuclide monitors. Furthermore, KINS established technological standards for verification capabilities of environmental dose assessment. These standards are based on the performance of environmental dosimeters and on the evaluation results of the irradiation facilities of low level dose rate. Also, based on comparative research on optimal measurement conditions for analysis of gamma radionuclides in environmental samples in an underground cave facility, KINS laid foundations for ensuring efficiency in gamma radionuclide analysis. KINS secured basic data for interpreting the impact of Pu on oceans using data from the research on Pu origins and on dissolved and particulate Pu distributions in the seas surrounding the Korean Peninsula. This was done via an assessment of the fallout and close-in of Pu in seawater of the Pacific Ocean. For emergency preparedness, KINS established a procedure for comprehensive assessment of decision making for protection during radiological accidents. KINS also developed emergency monitoring techniques of environmental radioactivity using monitoring vehicles in contaminated areas. This would serve to rapidly implement measures to protect local residents.

3.3.4 Development of Regulatory Technology for Radiation Source Safety

KINS drew up safety requirements, related regulatory guidelines, and technical standards intended to secure radiation safety when using radioisotopes and radiation generators (RIs) that can be applied to Korea's technological and industrial sectors. In particular, for developing assessment techniques and application methodologies for risk assessment of RIs, KINS selected six systems that included three from the field of nuclear medicine and three from radiation oncology as medical RI systems that are either currently in use or have potential for use in Korea. KINS then performed the risk analysis for this system by utilizing the status data that were secured via surveys and onsite visits. Also, KINS analyzed problems linked to the systems of safety regulations in such fields as authorization, periodic inspection, and design approval for radiation equipment and drew up a system improvement plan. Further, safety regulation guidelines were drafted by putting together standard handling procedures and structural standards, design standards, performance standards, and radiation protection standards which were drawn up by analyzing specific design and safety features of radiation generators and large-scale irradiation facilities.

3.3.5 Radiation Risk Assessment for the Public

By investigating the air gamma dose rate and the environmental factor for the interior of 320 houses located in Daegu, Busan, Ulsan, Gwangju, Gyeongnam, Gyeongbuk, Jeonnam, and Jeju, KINS drew up the contour map of the air gamma dose rate and the concentration of radon and thoron. Then, KINS assessed the dose of the thoron in relation to the radon concentration inside buildings located in areas where a high concentration of radon was detected. By examining the concentration of thoron and thoron daughter nuclides inside buildings, KINS evaluated the correlations both between air gamma dose rates and radon concentration and between thoron and radon concentrations. Moreover, to assess radiation exposure doses due to food intake, KINS analyzed natural radionuclides such as U, Ra, and Th from 100 food samples taken from fish, shellfish, and vegetables. Further, KINS assessed the total dose derived by weighing the number of population to the results of indoor air gamma dose, radon concentration in residential areas and outdoor air, and natural and artificial radioactivity in foods. Then, KINS built a database to store this statistical information.

3.4 Development of Seismic Safety Assessment Technology for Reactor Sites

KINS conducted this research in cooperation with twelve institutes including the Korea Institute of Geosciences and Mineral Resource, the Korea Electric Power Research Institute, and several universities. The overall purpose of the research was to develop technical criteria for capable faults specific to the Korean peninsula and various relevant fundamental technologies based on geological environments upon which nuclear power plants are constructed. The detailed research objectives were as follows: 1) development of technical criteria and guidelines for investigation and assessment of capable faults; 2) mapping of quaternary faults near nuclear power plants; and 3) construction of database housing geological information for assessing seismic safety of nuclear power plants.

KINS established technical criteria for capable faults and draft guidelines for assessments applicable to the Korean peninsula. This was done after taking into consideration the background of technical standards relating to assessment criteria for capable faults from overseas such as the United States, Japan, and the International Atomic Energy Agency. KINS analyzed the geological environment for the area surrounding nuclear power plants. In respect to fault materials and surrounding geological strata, KINS estimated the occurrence time of fault movement by using the quaternary age dating methods, such as electron spin resonance (ESR) and the optically stimulated luminescence (OSL). In addition, by analyzing the reliability of quaternary age dating methods, KINS laid foundations for establishing methodologies that can be utilized in the future for age analysis of Korea's quaternary fault.

For the purpose of evaluating the likelihood of earthquakes near domestic NPP sites, KINS suggested reliability criteria for input data through comparative analyses, which have been used hitherto for analyzing earthquake hazards at nuclear power plants. Also, by analyzing data derived from the approximately 60 geographical positioning systems operating in Korea, KINS prepared foundations for the geodetical analysis necessary for prediction of future crustal displacement.

KINS developed a detailed fracture map for the quaternary fault region adjacent to the Wolsong, Kori, Uljin, and Younggwang nuclear power plants. Also, KINS investigated the geological features and assessed the maximum earthquake potential of the fault. Furthermore, based on an analysis of the background of foreign technical criteria for capable faults, KINS built an integrated database on geological information relating to the setting of the Korea specific technical standard.

3.5 Research on Resolution of Safety Issues for Operating Nuclear Facilities

3.5.1 Implementation of Safety Issues Program

To ensure the safety of nuclear power plants, it is essential to secure regulatory technologies in advance to reduce the potential of accidents. This is accomplished by identifying and resolving potential safety issues through technical assessment activities. When a safety issue is identified, it is necessary to perform timely root-cause analyses to establish corrective actions that can prevent its recurrence. In order to systematically manage safety issues at nuclear facilities, KINS established and implemented a safety issues program.

The safety issues program was established in 2006. It includes the following steps: proposal, selection, classification, research on resolution, and completion. Ten safety issues were selected and addressed from a research perspective. The selection was made based on domestic and overseas case studies, foreign safety issues, and proposals by regulatory and research staff. KINS analyzed root causes of the selected safety issues in detail and established preventive measures for regulation. Root-cause analyses were performed for thermal hydraulic transients in the main steam line of Kori Unit 1, for the depleted Uranium pyrophoricity incident at the KAERI research reactor fuel processing shop, and for thermal sleeve separations of safety injection lines of pressurized water reactors. Further analyses focused on air-ingression into the emergency core cooling pump from refuelling water storage tank during loss of coolant accidents. CANDU feeder pipes, which are susceptible to wall thinning due to flow accelerated corrosion, were assessed and the results were reflected in the in-service inspection plan of Wolsong Unit 1. Also, regulatory actions were established to prevent reverse flow of the coolant at the sump into the spay tank during the operational mode of low pressure safety injection of Wolsong Unit 1. Furthermore, guidelines for assessing the structural integrity of major piping systems subjected to thermally stratified flow were developed and utilized in the safety review of the life extension of Kori Unit 1.

3.5.2 Construction of a Research Infrastructure for Securing Steam Generator Safety

The purpose of this project was to establish a domestic research system for preventing steam generator tube ruptures. The project was set following four objectives: 1) construct a steam generator database; 2) construct a web-based network for steam generators; 3) analyze technical status on steam generators; and 4) assess accident factors and research vulnerabilities inherent in steam generator.

Main results include the following: a glossary of terms relating to the rupture of steam generator tubes; an analysis of the cause of steam generator tube ruptures of Uljin Unit 4; an analysis of overseas steam generator tube ruptures; and an analysis of domestic steam generators. Based on these results, KINS drew up items of recommendation for preventing similar ruptures. In addition, to analyze current technological trends in steam generator design, a technology map of steam generators was drawn up. It has eight categories which include design, manufacture, inspection, maintenance, operation and monitoring, water chemistry, damage assessment, and regulation. These were then subdivided into 26 intermediate categories and 87 sub categories. Furthermore, in order to measure the level of domestic steam generator technology, KINS prepared an analysis report on current technologies with cooperation of the Steam Generator Research Council. Those results were utilized to pinpoint research demands and ranking prioritization.

To make for efficient research efforts focused on steam generators, sharing of databases belonging to the various organizations was essential. For this, KINS built a database composed of 11 areas including design, manufacture, inspection, maintenance, operation and monitoring, water chemistry, damage assessment, regulation, general data, research data, and general status. To realize this sharing philosophy, KINS operates a website that is built on the concept of an operation experience feedback system. The database is available on the website.

3.5.3 Development of Technology for Addressing Open Safety Issues of Pressurized Heavy Water Reactor (PHWR)

KINS conducted research to build a system of verifying the safety and to develop regulatory technologies for safety issues peculiar to PHWR, a Canada Deuterium Uranium (CANDU) reactor. Safety verification system requires core neutronics analysis codes, thermal hydraulic analysis codes, and containment thermal hydraulic analysis codes. KINS secured regulatory technologies for CANDU reactors through an assessment of key safety issues and a development of relevant regulatory guidelines.

KINS developed several codes including a three dimensional core analysis code (SCAN) for evaluating the kinetics of the core of heavy water reactors, a system safety analysis code (RELAP/CANDU) for evaluating thermal hydraulic characteristics, and a containment safety analysis code (CONRAIN/CANDU) for evaluating the thermal hydraulic power features inside a containment building in the case of accidents. Moreover, to set up a system for continuous monitoring of the safety performance of heavy water reactors, KINS developed a CANDU-integrated safety assessment system (CISAS). For detailed assessment of the thermal hydraulic characteristics of the systems peculiar to heavy water reactor, KINS developed a three dimensional thermal hydraulic code for nuclear fuel channel assessment (CHAN/CANDU) and for moderator analysis (MOD/CANDU). Additionally, to improve the system safety analysis code (RELAP/CANDU), KINS modified the model using data from an experiment studying liquid entrainment in fuel channels. To examine the thermal hydraulic characteristics of the moderator system, KINS carried out experiments to verify heat removal capabilities of the moderator system.

As part of efforts to improve methodologies for safety assessment of CANDU reactors, KINS developed technologies to address key safety issues associated with operating CANDU reactors: preservation of moderator heat sink during a loss of coolant accident (LOCA) and simultaneous failure of Class IV power with a LOCA. This enabled KINS to secure an independent assessment capability for CANDU reactors. In accordance with periodic safety reviews (PSRs) for operating nuclear power plants, KINS completed assessment guidelines of PSR for CANDU reactors.

3.6 Research on Development of Regulatory Infrastructure for Advanced Reactors

3.6.1 Development of Regulatory Technologies for Small and Medium Integral Reactors

Amidst global trends in designing and developing advanced reactors in 1996, KINS commenced the development of a pressurized light water integrated reactor (330 MWt) for the dual purposes of seawater desalination and small scale electricity production. Its conceptual design was completed in 1999, and by 2002, the basic design was prepared. For the purpose of verifying the safety and performance of the integral reactor, Korea Atomic Energy Research Institute (KAERI) pursued a plan to construct a scaled-down prototype of the integral reactor, SMART-P (65 MWt). Also, to prepare the application for its construction permit, KINS executed a research project to develop regulatory technologies for the prototype integral reactor. The ultimate purpose of the project was to develop safety requirements and related regulatory technologies for the prototype integral reactor. The key areas of the research were as follows: 1) development of licensing procedures for a prototype reactor meant to demonstrate the safety and performance of integral reactors; 2) development of regulatory technologies to resolve safety issues associated with the prototype integral reactor; 3) development of safety requirements for the prototype integral reactor; and 4) development of regulatory confirmatory technologies for the safety of the prototype integral reactor.

The research was multi-faceted in that it surveyed domestic and overseas licensing procedures for nuclear reactors, developed a draft of licensing procedures for a prototype reactor to demonstrate safety and performance of new commercial reactors, and revised a draft for supplementation and amendment of the current regulation for nuclear reactor facilities. Also, the research identified safety issues, developed technologies to resolve them, and established safety requirements for the prototype reactor. Moreover, as regulatory technologies for the prototype reactor, the following was accomplished: development of assessment technology for the structural integrity of major systems and equipment; development of regulatory computational codes for core safety analysis; and establishment of regulatory assessment systems for accident analyses. Further, it surveyed overseas verification tests and experiences relating to demonstration of integral reactors and passive safety systems. KINS confirmed test items required for demonstration of safety and performance of the prototype, and evaluated test results performed by the designers.

3.6.2 Research on Regulatory Infrastructure for High Temperature Gas-cooled Reactor for Hydrogen Production

The purpose of this project was the development of regulatory technologies for very high temperature gas-cooled reactors (VHTR) for hydrogen production, which was developed by KAERI. As an initial step, the project established a foundation for developing technical standards for safety regulation of the VHTR and for identifying safety issues. Then, the project reviewed the status on the design and regulatory technologies for the VHTR. The key areas of this research were as follows: 1) survey of regulatory status on innovative nuclear reactors; 2) analysis of regulatory characteristics of VHTR for hydrogen generation; 3) examination of design and safety requirements for VHTRs; and 4) establishment of regulatory infrastructure for development of safety requirements and for identification of safety issues.

The focus of the research was the establishment of infrastructure to develop safety requirements and to identify safety issues by understanding the characteristics of the design of VHTRs and the hydrogen production facilities coupled to them. In particular, the research explored general regulatory features of VHTRs by analyzing VHTR licensing in various countries around the world. Moreover, by evaluating the applicability of the current safety requirements, which are based on safety regulation of pressurized water reactors, a plan to develop safety requirements for VHTRs was established.

4. DIRECTION OF FUTURE RESEARCH ON NUCLEAR SAFETY REGULATION

Nuclear regulatory research must be conducted in a manner such that its results can be directly utilized for regulatory activities, such as safety review and inspection. Therefore, starting from the planning stage of research programs, safety regulation staff at the nuclear facilities should opine often and participate in the research activities so that it may be directly utilized in regulatory activities. For this, it is necessary to explore regulatory research needs raised by both regulatory organizations and industry and to consider them in the research scope. Moreover, confronting with the nuclear renaissance, nuclear community becomes rapidly global to meet worldwide demands for nuclear power plants. With respect to nuclear regulation, there are activities, such as multinational design evaluation program (MDEP), not only to assess design of newly build nuclear power plants program but also to harmonize technical standards and safety objectives of individual countries. Therefore, when selecting the topics of nuclear regulatory research, those that are important in international joint research or international activities must be included.

The direction of future nuclear regulatory research is explored in two ways: research meant to enhance operating nuclear facility safety and the establishing of regulatory infrastructure aimed at confirming design safety of advanced reactors to be built in future. Since the safe operation of existing nuclear facilities is a prerequisite for the utilization and development of nuclear energy, there is a need to take preventive measures for potential safety issues in operating nuclear facilities, and research and development for this must be conducted continuously. In terms of operating nuclear power plants, there is a need first of all to conduct safety research for identifying safety issues from operational experiences and for resolving them and taking necessary measures to rectify or prevent them. Further research is needed to reduce the possibility of accidents and malfunctions that can be caused by aging of system, structures, and components (SSCs). This research should also confirm the safety of new equipment (e.g., digital instrumentation and control system) that replaces the old one.

For the development of safety regulation technologies for future nuclear systems including sodium-cooled fast reactors (SFRs), very high temperature gas-cooled reactors (VHTRs), and pyro-processing of spent fuels, focus must be on understanding design features of relevant systems, on establishing frameworks to develop safety requirements and technical standards, and on identifying safety issues. Also, feasibility studies for technology-neutral safety requirements are planned for Generation IV reactors. The applicability of current safety requirements for pressurized water reactors will be assessed for development of new safety requirements meant for Generation IV reactors. Furthermore, there are plans to survey the safety issues identified hitherto for Generation IV reactors, to develop technologies to resolve the safety issues, and to establish technologies to perform confirmatory assessment needed an independent safety reviews.

KINS will continue to perform the research not only relating to the assurance of the safety for nuclear facilities described above but also for streamlining the current licensing system to make it more efficient and effective.

5. CONCLUSION

Nuclear regulatory research plays an important role not only in producing information necessary for establishment of safety requirements, and guidelines, but also in performing independent safety assessment by regulatory bodies. Furthermore, the results of regulatory research contribute to supporting regulatory activities meant to enhance the safety of nuclear facilities and to improve the confidence in regulation for both the public and operators. To enhance the effectiveness of nuclear regulatory research, many things are necessary including the providing of financial resources in a stable manner, the carrying out of research focused on achievements, and the promoting of utilization of results garnered from nuclear regulation research. KINS, under the awareness of the common objective of securing nuclear safety technology, will continue its efforts to ensure that nuclear regulatory research contributes to securing the safety not only of operating nuclear facilities but also of future nuclear facilities. These efforts are at present, and will be in future, supported by mutual cooperation between industry, academia, research and government sectors.

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