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PERIODIC SAFETY REVIEW ON KORI UNIT 1

Tae-Ryong Kim
Korea Electric Power Research Institute
Korea Electric Power Corporation

Abstract

Periodic safety review on Kori Unit 1 has been successfully done for the first time in Korea. 11 safety factors of the review were fully evaluated in accordance with the domestic legal system. Although it is the oldest nuclear power plant in Korea, Kori Unit 1 was found to have maintained good operating conditions and continuously enhanced its safety by implementing post-TMI action plans and other safety issues, such as replacing steam generators and process/control system. It can be therefore confirmed that safe operation of Kori Unit 1 is guaranteed until next periodic safety review. Nevertheless, some corrective action items were recommended to enhance further its safety level, such as equipment qualification, additional ageing management program, strengthening of some procedures related to administration and human factor. The results of PSR can be utilized for the continued operation beyond the design life as long as the plant safety is maintained and improved. Experiences of the PSR on Kori Unit 1 can be also applied to PSR on other plants.

1. Introduction

International Atomic Energy Agency (IAEA) recommends its member countries to introduce Periodic Safety Review (PSR) system for the maintenance and enhancement of the safety level of old nuclear power plants in operation[1]. The purpose of PSR is to determine to what extent the plant meets current safety standards and practices and whether adequate arrangements are in place to maintain plant safety. According to the recommendation of IAEA, the Korean government decided to adopt the Periodic Safety Review System in 1999. Korea Hydro & Nuclear Power Cooperation (KHNP) operating 18 nuclear power plants at present established accordingly a strategic plan to do PSR of the operating nuclear power plants in May of 2000 and set to the first PSR on Kori Unit 1, the oldest one in Korea, in the same time. Description of Kori Unit 1 under the PSR is

shown in Table 1. In this paper, the results of the review are briefly summarized and the corrective actions to enhance the plant safety to a higher level are recommended.

2. Periodic Safety Review on Kori Unit 1

2.1 Scope and Content of the Review

The legal basis of periodic safety review on Kori Unit 1 is as follows:

- Article 23 of Atomic Energy Act (Jan.16, 2001): PSR
- Article 42 of Enforcement Decree of the Act (July 16, 2001): Content of PSR, method and applicable safety standards for PSR
- Article 19 of Enforcement Regulations of the Act (July 25, 2001): Details of PSR

Scope of the review shall include all nuclear safety aspects, including all facilities and equipment on the site covered by the operating licence and their operation, together with the staff and its organization.

A comprehensive assessment of overall plant safety is a complex task. Experience shows that it can be facilitated by dividing it into a number of elements. These are so called 'safety factors' as listed in Table 2. IAEA guide has recommended 11 safety factors[2] and Paragraph 3 of Article 42 of Enforcement Decree of Atomic Energy Act has adopted them[3], such as actual physical condition, safety analysis, equipment qualification, management of ageing, safety performance, use of experience from other nuclear power plants and research findings, procedures, organization and administration, human factors, emergency planning, radiological impact on environment.

The operating period to be reviewed in PSR on Kori Unit 1 is from the first criticality of the plant to Dec. 31, 2000 when PSR on the plant started.

2.2 Safety Standards for the Review

For the successful accoplishment of PSR, proper safety codes and standards to be applied to the PSR should be identified based on the current national standards and practices. In the paragraph 4 of Article 42 of Enforcement Decree of Atomic Energy Act, it is required that PSR be done by 'utilizing the currently valid codes and standards for the nuclear facility under the review at the time of PSR'.

Cutoff date of the currently valid codes and standards for Kori Unit 1 is therefore so determined as 6 months prior to the completion of the Review (May 31, 2002) that more recent codes and standards could be applied in the review.

Other detailed technical codes and standards to be applied in the review are based on decree of Ministry of Science & Technology (MOST)[4], those specified in FSAR[5], etc.

Additional criteria regarding to safety enhancement or continued operation beyond

the design life (e.g., fire protection, SBO, ATWS) are not required, but applied in the review.

2.3 The Review Methodology and Procedure

PSR is conducted as reviewing 11 safety factors by using current method and the findings are compared to current safety standards and practices. The review methodology is based on deterministic analysis. The deterministic analysis includes review and analysis of all documents related to operation, maintenance, inspection and test of the plant together with on-site investigation and interview, and also includes the remaining life calculation of equipment and re-analysis if needed.

It is known that probabilistic safety assessment (PSA) can provide useful insights into the safety of a nuclear power plant and is consequently a useful contributor to PSR. But in this case, the probabilistic analysis was thought to be a complementary method since PSA on Kori Unit 1 has been separately conducting.

When the actual review work on safety factors is done, the results are summarized and reported to MOST for review. In the report, not only the present status of plant safety but also corretive action items for safety enhancement shold be included.

The corrective action items identified will be prioritized considering the significance of safety, urgency, cost-benefit, etc. and actually implemented at post-PSR stage.

The procedure of typical PSR as recommended by IAEA is shown in Figures 1 and 2.

2.4 Project Management System

Since PSR is a very complicated task, it is necessary to setup a project management system on computer network for the real time communication and easy access to common plant data. Accordingly a PSR project management system based on web browser form was established for Kori Unit 1.

Although quality assurance (QA) is not considered as an independent safety factor, it should be included as an integral part of every activity affecting safety. In the PSR on Kori Unit 1, therefore, QA plans and procedures for PSR were developed and applied.

3. Results of the Review

The review tasks for 11 safety factors were categorized into 4 groups based on the characteristics of the safety factors and the efficiency of project management, such as present status of the plant, safety assessment, radiation safety and plant management.

The factor, 'use of experiences from other plants and research findings' was commonly evaluated in all groups. Results of the review and the corrective action items recommended to enhance safety are summarized here.

3.1 Present Status of the Plant (actual physical condition, management of ageing, equipment qualification)

(a) Actual Physical Condition of the Nuclear Power Plant

After reviewing all documents related to plant operation (including maintenance, inspection and test records), Kori Unit 1 was found to have maintained good operating conditions. There had been 115 shutdowns (including scheduled outage for maintenance) from the beginning of the commercial operation to the end of 2000. All shutdowns were considered as normal operation of no impact on safety such that 114 shutdowns were classified as grade 0 except only one insignificant failure (grade 1).

Many facilities have been replaced or refurbished to improve the reliability of the equipment and to ensure safety. Followings are the representative examples of major maintenance records or equipment improvements.

- Implementation of post-TMI actions: installation of reactor coolant off-gas facility, accident condition monitoring facility, post-accident sampling facility and operation support computer facility, etc.
- Replacement of steam generator: old SGs were replaced by Delta 60 type SGs with improved corrosion resistance.
- Replacement of low pressure turbine rotor
- Replacement of control equipment: analog-type was replaced by latest digital type.
- Installation of remote shutdown panel: two trains of panel installed in emergency diesel generator room.
- Replacement of aged pipes about 1,200m long.

(b) Management of Ageing

For the review on ageing management, the potential ageing mechanisms and their effects were identified and evaluated for system, structures and components (SSCs) of Kori Unit 1. The actual physical conditions of SSCs were also found being in good condition.

For instance, it was confirmed from the detailed review on irradiation embrittlement and fatigue as the ageing mechanism of the reactor pressure vessel (RPV) that the integrity of the RPV can be maintained for 40 operating years or beyond. Even though the existing ageing management programs can properly manage the ageing effects of RPV, the followings were recommended to enhance further the safety of the RPV of Kori Unit 1 and its subcomponents.

- Installation of ex-vessel dosimetry
- Installation of transient counting or fatigue monitoring system

- Implementation of Alloy 600 program

(c) Equipment Qualification

Equipment qualification for Kori Unit 1 was done in accordance with the codes and standards specified in FSAR. But it was found that the details of the code and standards used in Kori Unit 1 were insufficient comparing with those of the later versions applied to other nuclear power plants. To satisfy the equipment qualification of Kori Unit 1 according to the requirements of the current codes and standards, the followings should be implemented:

- Preparation of equipment qualification plan (listing of equipment to be qualified, qualification procedure, acquisition of the qualification test reports) according to the the latest codes and standards
- Accident analysis (e.g., main steam line break and small bore LOCA) for environmental qualification
- Screening verification, seismic walkdown and establishment of seismic retrofit for outliers.

In order to satisfy the requirement for the equipment qualification per latest safety standards, two projects entitled "Development of environmental qualification system" and "Re-evaluation of seismic qualification" have been already started.

3.2 Safety Assessment (safety analysis, safety performance, design safety)

(a) Safety Analysis

The current safety analysis was reviewed to confirm that its scopes, methods and assumptions satisfy the current safety standards. It was found that the accident analysis on core design, thermal-hydraulic design, transients, loss of coolant accident, and radioactive release from a subsystem or component satisfied the standards. Three transient analyses originally not applied to Kori Unit 1 were additionally analyzed according to the current safety standards, such as:

- Single rod cluster control assembly (RCCA) withdrawal accident
- Boron dilution accident during operation modes 3, 4, 5 and 6
- Failure of small lines carrying primary coolant outside containment

From the accident analysis of single RCCA withdrawal, with assumption that a RCCA of the highest rod worth was withdrawn during the full power operation, it was confirmed that the results satisfied the current safety standards. The computed number of fuel rods experiencing departure from nucleate boiling (DNB) was 0.29% of full core, which is much less than the safety criterion of 5% of fuel failure.

It was found from the boron dilution accident analysis that the results based on the existing analytical methods did not meet the requirements of the current safety standards. The boron dilution accident at operation modes 3, 4, 5, and 6 is being re-evaluated by using the variable shutdown margin method in order to resolve the situation.

Results from the analysis on failure of small lines carrying primary coolant outside containment showed that requirements of the current safety standards were met.

(b) Safety Performance

According to the review on safety performance indicators, there were a number of unplanned reactor scrams and unplanned power changes in the early stage of commercial operation of Kori Unit 1. However, with the continuous facility improvement, revision of procedure and training of employees, safety performance indicators have been stabilized as 'green code' since 1992. Nevertheless, it was recommended to develop a management procedure enabling systematic management of safety system unavailability to secure the reliability.

(c) Design Safety

Review on the design safety has confirmed that the safety-related matters (common cause failure, cross-linking effect, single failure criteria, redundancy, independency and diversity) have been properly taken into consideration in the process of design. However it was recommended to revise the test ranges of safety class pumps for agreement with to the safety analysis assumption as follows:

- Revision of technical specifications and test procedures for residual heat removal pump, high pressure safety injection pump, containment spray pump, and motor operated auxiliary feedwater pump.
- Due to the insufficient conservatism in the flow rate used in safety analysis assumptions, the suitable flow rate of turbine-driven auxiliary feedwater pump shall be decided for safety analysis and then the affected accidents shall be re-evaluated.

3.3 Radiation Safety (radiological impact on environment, radwaste management, radiation protection)

(a) Radiological Impact on Environment

It was confirmed from the review on release records and its limit in the possible release path that the site boundary concentrations of gaseous and liquid radioactive material satisfied the standards for release control of the Notices of the MOST. In addition, the warning system against the unexpected release is also properly installed

and maintained.

Environment monitoring plan was found properly established and carried out according to the Notice No. 2001-25 of the MOST. Comparing the monitored result of environment radiation before and after plant operation, it was confirmed that there was no radiological impact of Kori Unit 1 on environment.

It was also confirmed that the off-site dose to the public around the nuclear facilities satisfied the expected limit per unit and per site specified in the Notice No. 2002-1 of the MOST. In addition, no radiological impact is expected to the public in case of simultaneous operation of several units including Shin-Kori Unit 1 and 2 in the future.

Nevertheless, environment monitoring and dose evaluation for radioactive carbon (C-14) was recommended to be implemented to enhance the reliability and the accuracy of the evaluation of radiological impact to public, based on the agreement between MOST and KHNP.

(b) Radwaste Management

From the review on radwaste management system and radiation monitoring system of Kori Unit 1, it was found that the related codes and standards were satisfied. It was also confirmed that the radioactive concentration of reactor coolant, the amount of liquid and gaseous radwaste effluent, and the amount of low- and mid-level solid radwaste have satisfied the related criteria of the relevant codes and standards specified in FSAR. However, the alarm setpoint of process and effluent radiation monitor is recommended to revise according to the Notice No. 2002-1 of the MOST.

(c) Radiation Protection

For radiation protection, a radiation exposure reduction program was established. The program was found to be very effective for maintaining the exposure dose of radiation workers as low as reasonably achievable and for satisfying the requirements specified in Enforcement Regulation of Atomic Energy Act.

The measures for dose assessment for internal exposure and to reduce the person-rem exposure in response to the application of International Committee of Radiation Protection (ICRP)-60 should be established.

3.4 Plant Management (organization and administration, procedures, human factors, emergency planning)

Plant management factors should not be overlooked in PSR, since they play a significant role in defining safety culture of the plant. There are many research results on the safety culture, but no specific safety standard is established yet. Survey with

questionnaires, interviews, field investigations and basic job/task analysis as well as document review was used as the main review method.

(a) Organization and Administration

In the safety factor of organization and administration, the following detailed items as described in Article 19 of Enforcement Regulations of the Act were reviewed.

- Safety system with safety goal and policy taking precedence over generation
- Documented roles and responsibilities of individuals or groups.
- Management program to make the plant systematically being operated.
- System for utilizing specialists and experts outside the plant.
- Training facilities and programs for the plant staffs and operators.
- QA program and QA regular audits by independent auditors.

It was found that the above items were properly maintained. But it was recommended that a specific safety goal be established and that a safety policy taking precedence over all other matters including electricity generation be maintained.

(b) Procedures and Human Factors

The review of procedures and human factors consists of the following detailed items:

- Management of human resources
- Qualification of the plant operators
- Basic job and task analysis.
- Style of procedures and man-machine interface (MMI).

Total 641 procedures being used in Kori Unit 1 were reviewed for their completeness, procedure management, suitability of structure and format, human factor. It was found that the procedure management system (including preparation, revision, accuracy, human factor) was well maintained. There were no problem to be urgently improved in procedures and human factors, but 'human factors management program' as a long-term plan was suggested to improve the procedures.

MMI devices in main control room, remote shutdown panel and safety parameter display system were verified to be proper in viewpoint of availability, suitability and effectiveness except minor corrective items.

(c) Emergency Planning

For safety factor of emergency planning, the detaied items were reviewed such as the emergency strategy and organization, the suitability of devices, facilities and communication for emergency treatment, training and exercises against emergency, post-training actions, and the cooperation between participating organizations. As a

result, it was confirmed that the strategy, manpower, organization, facilities, devices, accident evaluation and training and exercises in Kori Unit 1 were sufficient to respond to radiation emergency. It was recommended, however, that calculation method of the time required to evacuate inhabitants around the plant be developed for the promotion of the effectiveness of emergency plan.

Totally 73 corrective action items were identified from PSR on Kori Unit 1. These items will be categorized and prioritized considering the significance of safety, urgency, cost-benefit, etc. and actually implemented at post-PSR stage.

4. Conclusions

The conclusions of PSR on Kori Unit 1 can be summarized as follows:

- The general design criteria of US AEC(Atomic Energy Committee) were applied in design of Kori Unit 1. Therefore, the fundamental design concept of Kori Unit 1 is similar to that of the later NPPs, though the details of the design might differ.

- The safety of Kori Unit 1 has been continuously enhanced by implementing post-TMI action plans and other safety issues, replacing steam generators and process/ control system. The latest codes and standards have been applied in safety analysis for major equipment replacements.

- Kori Unit 1 has maintained good operating records such that the number of transient occurrence like reactor trip remained less than 40% of the design number of occurrence since the first criticallity.

- The actual physical conditions of the SSCs including reactor pressure vessel are in good condition. The safety function and enough safety margin will be maintained. However, to enhance the safety, some of the current ageing management program should be supplemented, equipment qualification system reflecting the revised standards should be established, and timely replacement of some individual components would be needed.

- Accident analysis like thermal-hydraulic design, transient analysis meets the latest technical standards. Also, the assumptions used in accident analysis and the analysis results, diversity and independency of design meet the latest technical standards.

- Facilities, treatment capacity, and radioactive exposure management of radioactive waste management and monitoring system satisfy the relevant standards. Also, there is sufficient capability of the response strategy for radioactive emergency, emergency organization and facility. But the measures for dose assessment for internal exposure and the reduction of person-rem exposure in response to the application of

ICRP-60 should be established.

- Administrative systems of the plant such as organization structure, training, QA activity, use of experience of other plants and research findings, are generally well managed. However, some of the procedures should be supplemented, organizations for safety management and engineering should be strengthened.

Although it is the oldest nuclear power plant in Korea, Kori Unit 1 was found to have maintained good operating conditions and continuously enhanced its safety by implementing post-TMI action plans and other safety issues, such as replacing steam generators and process/control system. It can be therefore concluded that safe operation of Kori Unit 1 is guaranteed until next periodic safety review.

5. Future Works

The next PSR on Kori Unit 1 is expected to start at the year of 2010, since the period of PSR legally required is 10 years. In Korea, operating license for a nuclear power plant is issued with unlimited term. But the design life of Kori Unit 1 is reportedly 30 years, which means the year of 2008 is the last year of the design life. In this particular case, therefore, the results of PSR can not help directly connecting to the continued operation beyond the design life as long as the plant safety is maintained and improved.

Experiences on the PSR planning, methodologies, procedures, project management, documentation, etc from Kori Unit 1 can be applied to PSR on other plants. At present, in Korea, PSR programs for Kori Unit 2, 3 and 4, and Wolsong Unit 1 are on going.

References

[1] IAEA, Convention on Nuclear Safety, Vienna, 1996.

[2] IAEA, Safety Series 50-SG-012, Periodic Safety Review of Operational Nuclear Power Plants, 1994.

[3] MOST, Paragraph 3 of Article 42 of Enforcement Decree of Atomic Energy Act (Content of PSR), July 16, 2001

[4] MOST, Paragraph 2 of Article 19 of Enforcement Regulations of Atomic Energy Act (Details of PSR), July 25, 2001

[5] KHNP, Final Safety Analysis Report of Kori Unit 1, 2000.

[6] KHNP, The Periodic Safety Review of Kori Unit 1 (Summary Report), November 30, 2002.

Table 1. Description of Kori Unit 1 under periodical safety review

Reactor Type / Power	PWR / 587 MWe
NSSS Supplier	Westinghouse
Turbine Generator	GEC
Total Electricity Generated (at Dec. 31, 2000)	89.2 billion KWh
Capacity Factor	95% (2001)
Period of PSR	May 30, 2000 – Nov. 30, 2002
Period to be Reviewed	First Criticality(1977.6.19) – 2000.12.31

Table 2. Safety factors to be reviewed in PSR

Safety Factors in Atomic Energy Act and IAEA guide	
1	Actual condition of the nuclear power plant
2	Safety analysis
3	Equipment qualification
4	Management of ageing
5	Safety performance
6	Use of experience from other plants and research findings
7	Procedures
8	Organization and administration
9	Human factors
10	Emergency planning
11	Radiological impact on environment

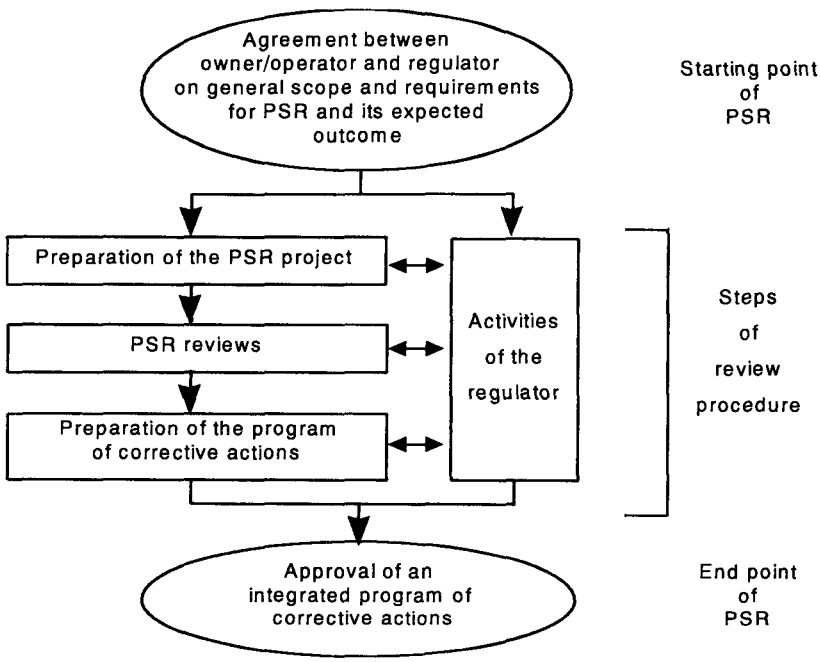

Fig. 1 Typical Overall Procedure of Periodic Safety Review (IAEA Guide)

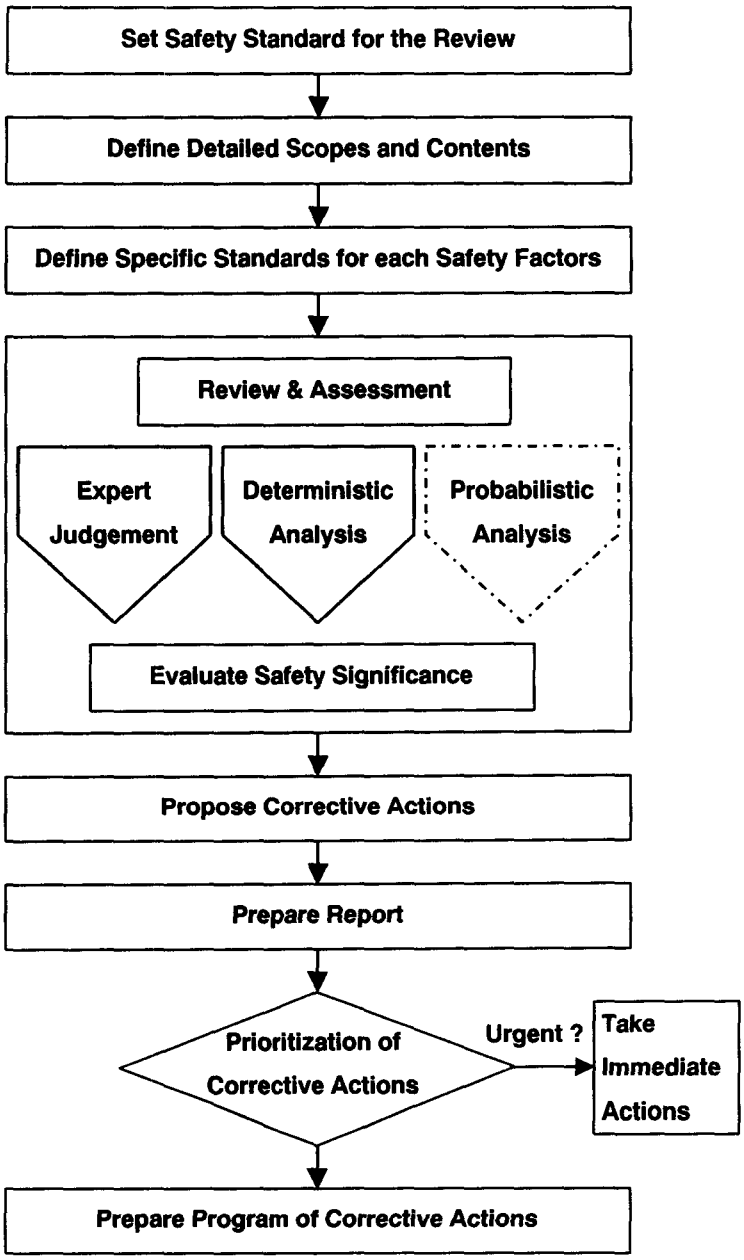

Figure 2. Method and procedures of the Review