

R&D Activities for NPP Life Management in Korea

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Abstract. Many R&D activities related to PLiM have been carried out and implemented to Korean NPP for the long term operation. Those activities include ageing management study, periodic safety review, steam generator management programme, materials reliability programme, thinned pipe management programme, study on dissimilar metal welds, etc. Based on the R&D activities, long term operation of Kori Unit 1 was successfully started from January 17, 2008 for next 10 years beyond its original design life. In this paper, all the activities and their results of the R&D programmes are briefly introduced.

1. INTRODUCTION

Long term operation (LTO) of a nuclear power plant (NPP) becomes the recent worldwide trend because of unstable oil price and the green house effect. To make LTO possible, first of all the plant safety should be maintained in its extended operation period and then the economical benefits should be also expected. For the plant safety, it can be confirmed through periodic safety review (PSR) system recommended by IAEA[1]. The economical benefits may be achieved by the plant life management (PLiM) as well as structural integrity of the critical components of NPP.

Systems, structures and components (SSC) of NPP are designed to have safety margins in design stage, and being operated with operational margins. As the plant gets older and older, however, ageing of SSC occurs and some of SSC may be sometimes failed due to the unexpected ageing mechanisms in design stage. Most countries which have operated NPP have their own R&D programmes to establish proper countermeasures against the ageing and degradation of SSC [2]. We also have our own R&D programmes for the plant life management in Korea. Some of them were done and some are still on-going.

In this paper, the present status of the R&D projects relevant to life management will be presented. On-going projects relevant to PLiM in KEPRI are listed in Table 1.

2. PLANT LIFE MANAGEMENT STUDY

2.1. Life Management Study for PWR

PLiM study for PWR was started in 1993 to investigate the feasibility and possibility of LTO for Kori Unit 1 which is the oldest PWR in Korea. In phase-I study, the critical 13 SSC's including reactor pressure vessel chosen based on the safety significance were evaluated with the documents for design, manufacturing, operation, inspection records, etc. As the result of the evaluations, it was confirmed that the continuous operation of Kori Unit 1 beyond its original design life of 30 years (1978~2007) would be technically feasible, economically beneficial and possible to get operating license. In the second phase of the study (1998.7~2001.6), we have developed the life assessment methodology for PWR, done the detailed life evaluation for critical SSC's, established ageing management programmes (AMP), developed monitoring and diagnostic technologies, and constructed PLiM data base[3].

Table 1. On-going R&D projects relevant to PLiM in KEPRI

No.	Project Name	Schedule
1	Development of Boiler Tube Inspection Technique by Computed Radiography	'07.3~'10.2
2	Development of the Test Facility for Large Capacity Valves and Pumps	'06.9~'11.8
3	Technical Development of the Prognostics and Diagnostics for Principal Active Components in NPPs	'07.4~'10.2
4	Development of a NPP simulator for the Integrated Performance Verification Facility	'07.8~'10.7
5	Development of Mechanical Analysis and Crack Management Technology for the Dissimilar Metal Welds	'07.4~'10.2
6	Development of the Integrity Evaluation Technique for the BOP Heat Exchangers in NPPs	'06.7~'09.6
7	Development of Visual Inspection Device of SG Flow Distribution Plate Bolts	'06.9~'09.7
8	Research for Developing Key Technologies in Fatigue Monitoring for Major Components & Pippings in NPP	'07.3~'09.2
9	A Study on the Effect of Grain Boundary Segregation of Phosphorous and Sulfur on the Crack Initiation and Growth of a Carbon Steel	'07.7~'09.6
10	Improvement of Structural Life Management System (SLMS) for NPP Structure	'07.6~'09.6
11	Development of Risk-Informed Piping ISI Program for Ulchin Unit 3	'07.4~'09.3
12	Establishment of Performance Demonstration System of Ultrasonic Test for Dissimilar Welds in NPP Piping (Phase 1)	'07.4~'11.2
13	Study on Application of LBB Technology for Primary Loop Piping of Ulchin Units 1 and 2	'07.7~'10.6
14	Development of Non-destructive Aging Evaluation Technique for Nuclear Cable	'08.4~'10.6

2.1.1. Detailed Life Evaluation of Critical SSC's for LTO

Critical SSC's for PLiM were selected based on the screening criteria in 10CFR54.21[4], NUREG-1800[5] and NUREG-1801[6]. The selected SSC's were categorized into 12 groups for the detailed life evaluation, such as reactor pressure vessel, reactor internals, pressurizer, safety class 1 piping, non-safety class 1 piping, safety class 1 supports, pressure vessels, heat exchangers, cables, electrical facilities and distributors, concrete and steel structures, and underground facilities. The result of detailed life evaluation is shown in Table 2.

As the original design life (30 years) of Kori Unit 1 was ended in 2007, many activities have been done for its LTO, such as PLiM study [3] and PSR [7, 8]. In addition, the detailed life evaluation of critical components for the extended operation period of 10 years (2005.9~2008.12) was required including the time limited ageing analysis, review on AMP [9] and radiological impact on environment report.

2.1.2. Establishment of Ageing Management Programmes

To effectively manage ageing of SSC, ageing management programme (AMP) should be in place. AMP's were prepared for the 12 groups. Fig. 1 shows typical procedure for preparation of AMP.

Each AMP consists of 10 attributes such as the scope of AMP, preventive action, parameters monitored or inspected, detection of ageing effects, monitoring and trending, acceptance criteria, corrective actions, confirmatory procedure, administrative control and operational experience, etc. The prepared AMP's for 12 groups are summarized in Table 3.

Table 2. Result of detailed life evaluation for critical SSC's of Kori Unit 1

Item	SSC's group	Evaluation result	Remark
1	RPV	60 years based on neutron embrittlement and fatigue	
2	RI	50 years for LSS based on fatigue 60 years for the others based on ISI	
3	PZR	60 years based on fatigue	
4	SC-1 piping	Less than 40 years for SI nozzle	Fatigue monitoring needed
5	Non SC-1 piping	60 years based on preventive maintenance and corrosion control	
6	SC-1 supports	60 years based on ISI	
7	Pressure vessels	60 years based on corrosion	
8	HX	Less than 40 years for HX tube 50 years based on body wall thinning 60 years for some HX based on AMP	
9	Cables	50 years for some cables	EQ needed
10	Elec. facilities and distributors	60 years based on condition assessment and maintenance	
11	Concrete & steel structures	60 years for concrete structure related to safety	
12	Underground facilities	40 years for cables based on ISI 60 years for the others	Some trench piping needed to replace

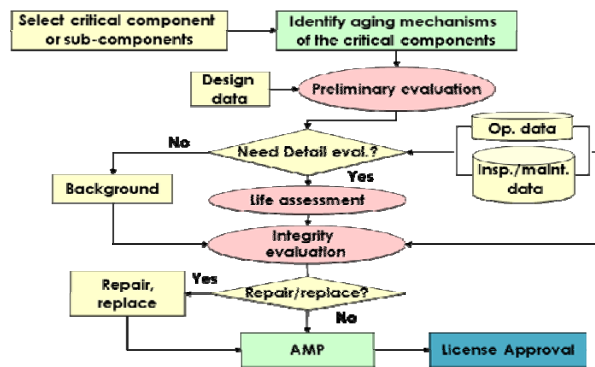


Fig. 1. Typical procedure of preparation of AMP

Table 3. AMP's for critical SSC's of Kori Unit 1

Item	SSC's group	AMP
1	RPV	Installation of ex-vessel dosimeter Alloy 600 programme, etc.
2	RI	Installation of loose part monitoring system Improvement of ISI programme
3	PZR	Boron acid corrosion monitoring programme PWSCC inspection programme, etc.
4	SC-1 piping	Fatigue monitoring programme Fracture mechanics assessment for thermal embrittlement, etc.
5	Non SC-1 piping	Boron acid corrosion monitoring programme Erosion and corrosion assessment programme

6	SC-1 supports	Boron acid corrosion monitoring programme Improvement of ISI programme
7	Pressure vessels	Boron acid corrosion monitoring programme Improvement of preventive maintenance programme
8	HX	Thermal performance monitoring programme Improvement of ISI programme, etc.
9	Cables	Condition monitoring programme
10	Elec. facilities and distributors	Periodic visual inspection
11	Concrete & steel structures	Structural integrity monitoring programme
12	Underground facilities	Short term and long term ageing management programme

2.1.3. Time-Limited Ageing Analyses

Ministry of Education, Science and Technology (MEST), nuclear regulatory body in Korea, requires licensee to submit time-limited ageing analysis (TLAA) report for the continued operation [10]. In case of Kori Unit 1, four(4) general TLAA items and six(6) specific TLAA items were identified and reviewed. The general TLAA items for Kori Unit 1 included reactor vessel neutron embrittlement analysis, metal fatigue analysis, environmental qualification of equipment, and containment liner plate, metal containment and penetration fatigue analysis.

The specific TLAA items for Kori Unit 1 included wear of neutron flux detector tube, crane load cycle limit, reactor coolant pump flywheel, spent fuel pool liner, components and piping subsurface indication and thermal ageing embrittlement of cast austenitic stainless steel.

In TLAA of metal fatigue of main components (reactor vessel, control rod drive mechanism, reactor internals, reactor coolant pump, steam generator, reactor coolant system piping, safety injection tank), for instance, the cumulative usage factor was found to be less than 1.0 (acceptance criteria) even with the occurrence of transients conservatively predicted at the end of extended operation, 40 years. It was subsequently confirmed that the integrity of the main components is maintained until the end of continued operation of Kori Unit 1. Furthermore, fatigue monitoring system was installed in Kori Unit 1 to ensure the operational safety for another 10 years operation, as shown in Fig. 2.

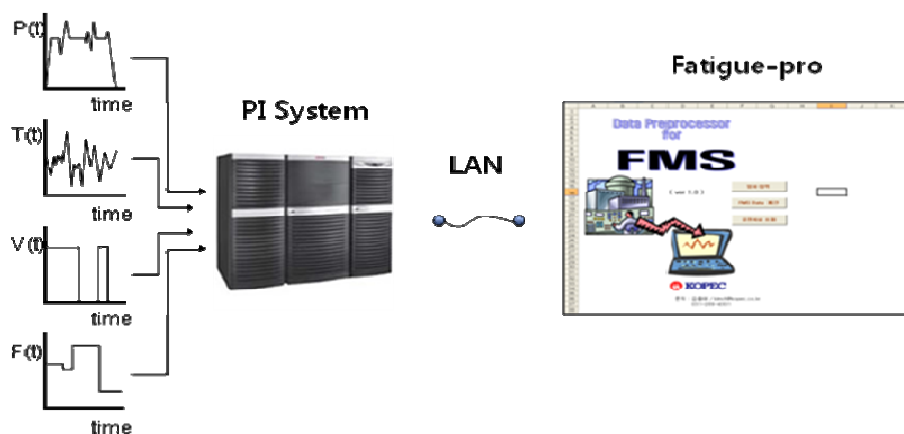


Fig. 2. Fatigue monitoring system installed in Kori Unit 1

2.1.4. Review on Ageing Management Programme

As mentioned earlier, another regulatory requirement for continued operation of NPP is the review on ageing management programme (AMP) being used in the plant. Review on the AMP includes the

assessment of the present monitoring/management procedures and maintenance activities to confirm that the existing AMP in present does easily and effectively manage the various ageing phenomena, or otherwise a new AMP should be prepared.

39 AMP's in total were selected for review in Kori Unit 1 based on NUREG-1801, such as inservice inspection of safety class 1,2,3, one-time inspection, reactor vessel surveillance, loose part monitoring, neutron noise monitoring, bus ducts, fuse holders, electrical cables and connections not subject to environmental qualification requirements.

It was found that most of the existing AMP can properly and effectively manage the ageing phenomena shown in the critical SSC. But some of them, e.g. one-time inspection and selective leaching of materials, were found necessary to be revised. Accordingly 13 AMP's in total were revised or newly prepared [11]. Particularly implementation of AMP for one-time inspection and selective leaching of materials was successfully completed by the active cooperation of the plant personnel. These AMP are the leading ones in the world, which means that Korea acquires experience and knowhow on these AMP prior to other NPP's in oversea still staying at the implementation planning stage.

In addition, AMP for nickel-alloy nozzles and penetrations was established to ensure that integrity of nickel-alloy nozzles and penetrations is maintained against the primary water stress corrosion cracking (PWSCC) which recently becomes the worldwide hot issue. The AMP includes the survey of all Alloy 600 dissimilar metal welds in Kori Unit 1 and the assessment of integrity of components highly susceptible to PWSCC. In case of CRDM nozzle penetration in reactor upper head which is known to be very susceptible to PWSCC, for an example, re-analysis of stress distribution was done as shown in Fig. 3 for the structural integrity.

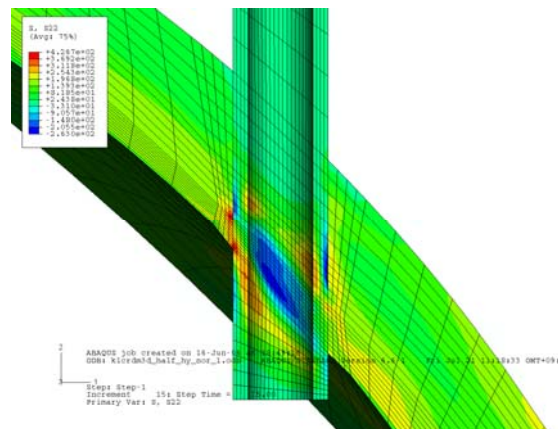


Fig. 3. Stress distribution due to welding and operating condition at CRDM penetration

2.1.5. Construction of PLiM Database

Web-based PLiM DB was developed for easy access of PLiM related researchers and organization. PLiM DB includes general methodology and technical references, operating transient history and experience, component design specification and manufacturing data, in-service inspection, surveillance & maintenance data, AMP and implementation schedules, etc.

Fig.4 shows the initial screen of the PLiM DB. This database can be open to public in the future.



FIG. 4. Initial screen of PLiM DB

2.1.6. Economical Benefits of LTO of Kori Unit 1

Economical benefit of LTO of Kori Unit 1 was evaluated for the extended operation period of 10 years beyond its design life. IAEA data and some experience precedent were utilized for cost estimation needed in the extended operation. The benefit of LTO was calculated based on the present value method and the generation cost. It was found that the economical benefit of about \$300 million was expected on the assumption of conservative cost.

2.2. Life Management Study for PHWR

PLiM study for PHWR was also started to investigate the feasibility and possibility of LTO for Wolsong Unit 1 which is the oldest PHWR(CANDU) in Korea. In the PLiM study, the validity of replacement of pressure tubes and feeder pipes were reviewed, and the remaining life of some components was evaluated. As a result, it was confirmed that the continuous operation of Wolsong Unit 1 beyond its original design life of 30 years would be technically feasible, economically beneficial and possible to get operating license. In the second phase of the study, we have evaluated the detailed lives of critical SSC's and established AMP's needed for LTO [12].

2.2.1. Detailed Life Evaluation for Critical SSC's

Critical SSC's for PLiM were selected based on the screening criteria in 10CFR54, NUREG-1800 and CANDU experience. The result of detailed life evaluation for the selected SSC's is summarized in Table 4.

Table 4. Result of detailed life evaluation for critical SSC's of Wolsong Unit 1

Item	SSC's group	Evaluation result	Remark
1	Fuel channel	Less than 30 years based on pressure tube ageing	Pressure tube to be replaced in 2009.4
2	Calandria assembly	60 years	
3	Reactivity control units	50 years based on performance monitoring	
4	Moderator system	More than 50 years based water chemistry control	
5	Primary heat transport system	50 years based on flow accelerated corrosion	
6	Feeder	Less than 30 years based on flow	Feeder to be replaced

		accelerated corrosion	in 2009.4
7	Steam Generator	50 years based on SGMP	
8	Cables	50 years for some cables	EQ needed
9	Concrete & steel structures	50 years based on AMP	
10	Underground piping	50 years based on periodic inspection	

2.2.2. Establishment of Ageing Management Programmes

The AMP's presently used in Wolsong Unit 1 were also reviewed and revised or newly prepared if necessary. Table 5 listed the AMP status in Wolsong Unit 1.

Table 5. AMP's for critical SSC's of Wolsong Unit 1

Item	SSC's group	AMP
1	Fuel channel	No additional AMP required Pressure tube to be replaced in 2009.4
2	Calandria assembly	No additional AMP required
3	Reactivity control units	Vertical control guide to be inspected Gap between calandria tube and liquid injection nozzle be inspected
4	Moderator system	Performance of heat exchanger be inspected
5	Primary heat transport system	Pipe wall thinning be monitored
6	Feeder	Pipe wall thinning be monitored Feeders to be replaced in 2009.4
7	Steam Generator	No additional AMP required
8	Cables	Environmental qualification required
9	Concrete & steel structures	No additional AMP required
10	Underground piping	Periodic inspection required

3. DEVELOPMENT OF STEAM GENERATOR MANAGEMENT PROGRAMME

Steam generator is one of the most trouble making components in NPP, because it consists of many thin tubes where the heat transfer is accomplished between primary and secondary coolant system. We have tried to develop a performance-based steam generator management programme (SGMP) since 2002. In the phase 1 (2002.3~2003.2) of a project entitled "Development of Integrated SG Management System", we established a plan for the development of SGMP. In the second phase (2003.3~2005.2), an overall SGMP guideline was prepared and implemented to a leading plant [13]. A government-supported complementary project entitled "Development of Technology to Improve Steam Generator Integrity (2000.9~2008.2)" has been carried out at the same time to develop essential technologies for steam generator management. In this project, particularly, the retired steam generator from Kori Unit 1 in 1998 was very usefully utilized to develop robot technology for withdrawal of tubes, to improve the detecting technology by using its natural defects [14]. In the third phase (2005.3~2008.2), the developed SGMP was implemented to all NPP in Korea.

3.1. Steam Generator Management Programme

SGMP is an integrated guideline for overall operation and maintenance of steam generator based on its performance criteria according to NEI 97-06 [15] and EPRI guideline. For the purpose, standardized procedures relevant to NDE of tubes, integrity assessment, in-situ pressure testing, leakage monitoring, water chemistry control and maintenance were prepared as shown in Fig. 5 including plant specific performance criteria, the tube failure status and trend classified by each nuclear plant.

After implementing the developed SGMP, NDE of tubes was quite improved by making the inspection performance with probability of detection and sizing capability quantified, and by making the inspection scope and period linked with integrity assessment. Integrity assessment newly adopted in this SGMP is accomplished in three steps at every outage, such as degradation assessment, condition monitoring and operation assessment. Procedures for leakage monitoring and water chemistry control were also prepared according to the latest version of EPRI guideline. For the integrity of secondary system, the procedure was revised to evaluate the structural ageing, sludge and cleansing plan of steam generator.

The developed SGMP was approved by MEST in 2005 for its implementation in all NPPs in Korea. Development and implementation of SGMP based on the performance criteria must be a landmarking step in the operation and maintenance of steam generator.

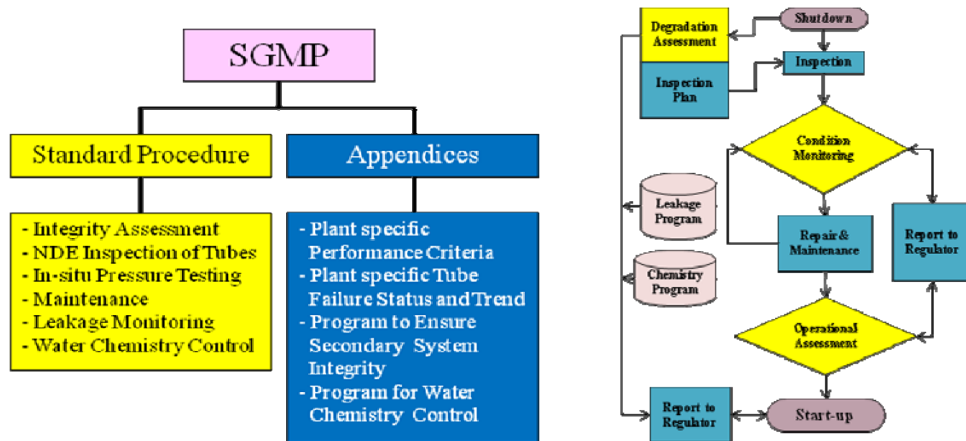


Fig. 5. SGMP contents

3.2. Programme for Integrity Assessment of Steam Generator Tube

In the government-supported project, a programme for integrity assessment of steam generator tube, PIAT[®], was developed by KEPRI. PIAT[®] is a comprehensive wear assessment programme including thermal-hydraulic data base, mode analysis, flow-induced vibration and wear assessment. Fig. 6 shows flow chart and initial screen of PIAT[®] [16].

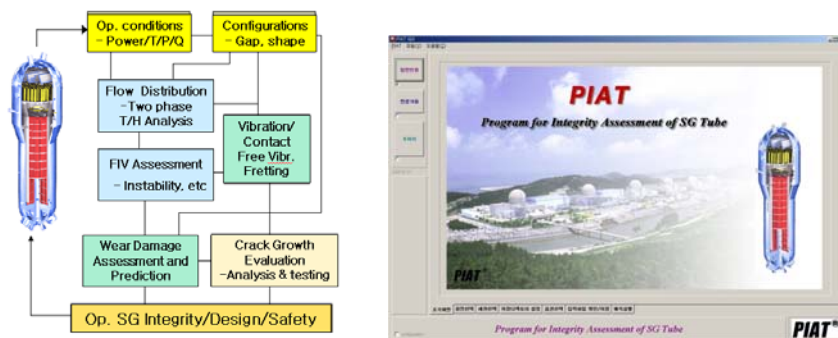


Fig. 6. Flow chart of PIAT[®]

4. DEVELOPMENT OF MATERIALS RELIABILITY PROGRAMME

A project entitled “Development of Materials Reliability Programme in NPP” was launched for the integrity and management of all materials except steam generator, which was a very similar project to MRP in EPRI. Phase 1 (2005.6~2008.5) was completed [17] and the next phase 2 (2008.12~2011.11) was just started. In phase 1, we reviewed all deliverables of EPRI’s MRP, analyzed the susceptibility

of nickel-alloy (Alloy 600) to PWSCC which has recently been a hot issue worldwide, and prepared an AMP for nickel-alloy nozzles and penetrations.

4.1. AMP for nickel-alloy nozzles and penetrations

Many efforts have been trying to properly manage the PWSCC issues in nickel-alloy nozzles and penetrations which have often occurred from 2000 in the world. As mentioned earlier, AMP for nickel-alloy nozzles and penetrations was prepared to ensure their integrity against PWSCC. The AMP includes the survey of all Alloy 600 components in Korean NPPs and the safety assessment of components highly susceptible to PWSCC as shown in Fig.7. The first PWSCC case in Korea was occurred at the drain nozzle of steam generator in Yonggwang Unit 3 in 2007, but the probability of detecting is expected to gradually increase.

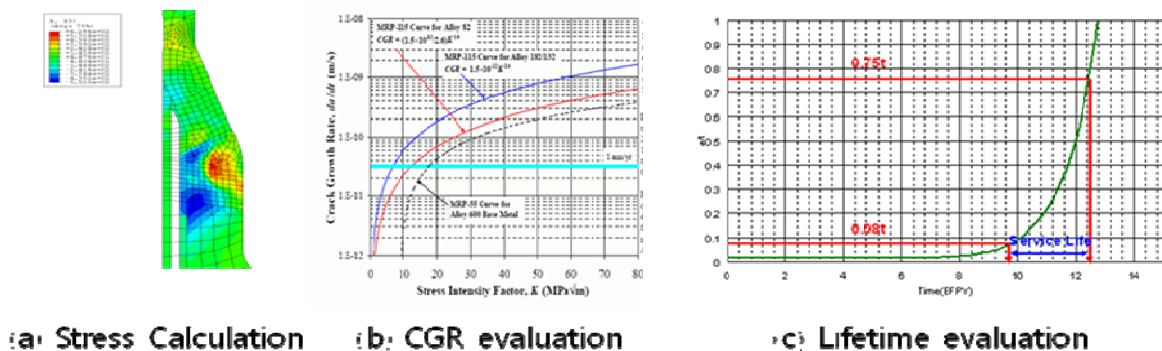


Fig. 7. Safety assessment for pressurizer nozzle

4.2. Development of MRP for CANDU type Reactor

In phase 2 of “Development of Materials Reliability Programme in NPP”, ageing management programmes for CANDU type reactor will be established. Pressure tubes and feeder pipes are the most critical components in CANDU reactor. The major ageing mechanisms are creep, delayed hydride cracking and embrittlement for pressure tube, while wall thinning due to the flow accelerated corrosion for feeder pipes. In this project, we are going to develop the methodology to assess the structural integrity of those critical components, and guidelines for AMP of pressure tubes and feeder pipes.

5. DEVELOPMENT OF THINNED PIPE MANAGEMENT PROGRAMME

Local wall thinning and integrity degradation caused by flow accelerated corrosion (FAC) is a main concern in carbon steel piping systems of nuclear power plant in terms of safety and operability. ASME code case N-597 [18] is the most frequently used criterion at present for the integrity evaluation of the thinned piping. However, the code case was originally issued to apply to safety related piping system, so we should be careful when applying the code case to secondary piping system. In addition, the code case has some limitations in evaluation of elbow and branch connection. And we found somewhat large discrepancy between thickness criteria in code case for repair and the actual thickness at limit load obtained from tests. Therefore it is necessary to develop alternative integrity evaluation criterion which is applicable to secondary piping system and possible to reduce the excessive conservatism.

A project entitled “Development of Management Programme for Thinned Pipe in NPP Secondary System” was completed in 2003, and its successive project to optimize the programme as also completed in 2007 [19].

5.1. Establishment of Plant Specific Prediction Models

Predictive plant models of wall thinning had been established for 20 operating units in Korea using CHECWORKS programme [20]. Long term strategies to manage the thinned pipe component of each unit were prepared and applied, which were reflecting plant specific design, operation and inspection history, so that the structural integrity of piping system can be efficiently managed.

5.2. Development of Web-based Management System

Web-base management system (iPiManager, integrated pipe manager) was developed to monitor and manage the vast data related to thinned pipe management. As illustrated in figure 5, this system provides the objects of thinned pipe management and the history of thickness measurement as well as integrity evaluation results for each unit and for each outage. The design information such as piping design table, P&IDs, isometric drawings and the technical information such as susceptibility evaluation for each unit, documentations from EPRI, NRC, WANO, INPO, etc., are provided for the purpose of information shearing.

5.3. Development of Alternative Engineering Evaluation

An alternative integrity assessment criterion using limit load equations were developed by KEPRI, which is directly applicable to the secondary piping system of nuclear power plant [21]. A lot of finite element analyses were done to set up the limit load equations for straight pipe, elbows, reducer, T-branch with reinforcement, etc. Mockup tests (pressure and bending) were also performed to verify the equation. For easy implementation of the alternative criterion to plant operation, a computer programme (PiTEP[®], Pipe Thinning Evaluation Programme) was developed. Fig. 8 shows the deformed mockup in closing mode bending test, initial screens of PiTEP[®] and the application result of the alternative criterion

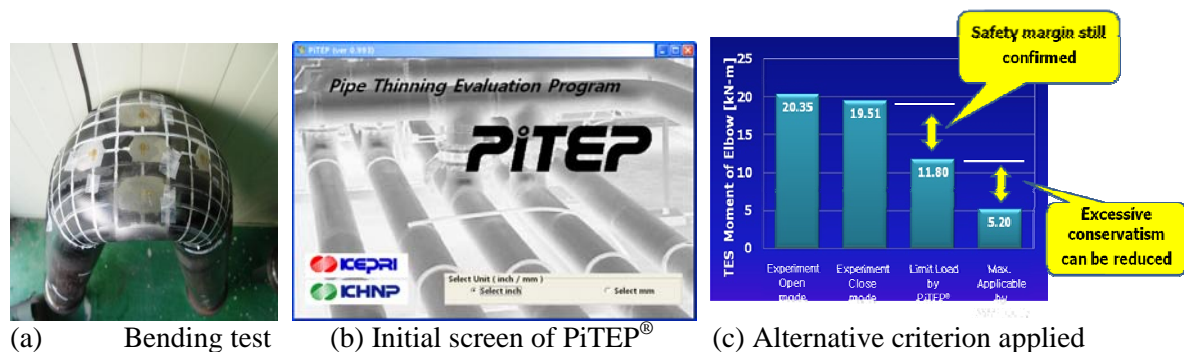


Fig. 8. Initial and result screens

6. STUDY ON DISSIMILAR METAL WELDS

Recently PWSCC in dissimilar metal welds (DMW) have often occurred worldwide, e.g. cold leg crack in V.C.Summer, CRDM penetration crack in Davis Besse and BMI penetration crack in STP-1. The first PWSCC case in Korea was occurred at the drain nozzle of steam generator in Yonggwang Unit 3 in 2007. The probability of detecting is expected to gradually increase. Subsequently AMP for nickel-alloy nozzles and penetrations was already prepared to ensure their integrity against PWSCC. In addition, research to develop the technologies for analysis and measurement of the residual stresses induced by butt welding is on going. Comprehensive assessment and maintenance technologies for the DMW will be developed sooner or later.

6.1. Development of Technologies for Residual Stresses Analysis and Measurement

Although many researches for residual stresses analysis and measurement in DMW have been done worldwide, the reliability of the analysis and measurement result is still doubtful. In a government-

supported project of “Development of Analysis Technology for Crack Management of Dissimilar Metal Welds (2007.4~2010.2)”, a guideline for residual stresses analysis in DMW was developed by using finite element methods. To obtain the reliable analysis result for DMW in actual pressurizer nozzle, round robin analyses by 5 participants were performed. In addition, residual stresses were measured by using hole drill method, X-ray method and indentation method. The measured data was compared with the analyzed results as shown in Fig. 9.

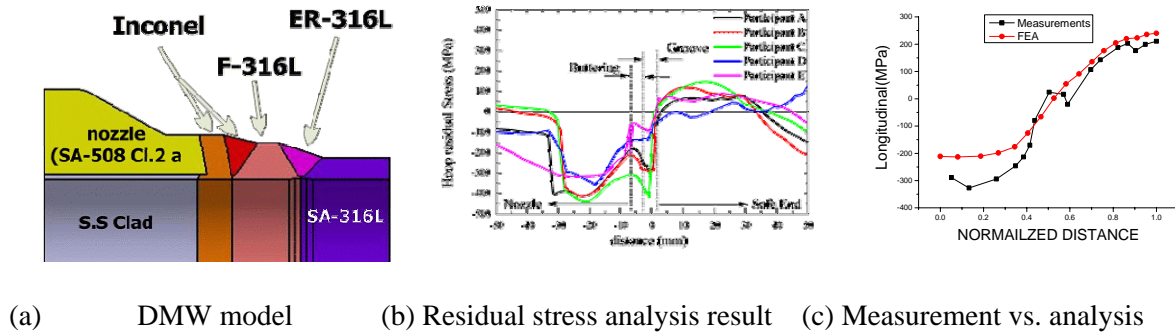


Fig. 9. Residual stresses analysis and measurement results

6.2. Performance Demonstration of NDE for Dissimilar Metal Welds

Performance demonstration is very important in qualification of NDE system (personnel, equipment, technology) to warrant the capability of detection and sizing of cracks. Accordingly a project of “Establishment of Performance Demonstration System for NDE in NPP (2000.8~ 2004.1)” was completed by KEPRI to establish PD system for UT of piping/bolt/stud and ECT of steam generator tubes. Accordingly, KEPRI has been nominated as a PD center in Korea since 2004.

From 2007, KEPRI has been carrying out a project of “Development of Performance Demonstration System for Dissimilar Metal Weld, Phase 1 (2007.4~2010.2)” to establish PD system for UT of butt welds in nuclear piping. Fig. 10 shows the PD test specimens and test room in KEPRI.



Fig. 10. PD tests in KEPRI

6.3. Development of Comprehensive Assessment and Maintenance Technologies for DMW

To encounter PWSCC issues in CRDM penetration, reactor nozzles, BMI penetration and small nozzles connected to pressurizer and steam generator, some projects to develop comprehensive assessment and maintenance technology are about to launch. In addition to R&D activities, reactor vessel head of Kori Unit 1 is planned to replace and the pressurizer nozzles are planned to have preventive maintenance (weld overlay).

7. CONCLUSION

Long term operation of a nuclear power plant is one of the goals that the plant wants to achieve, which may be possible as long as the plant safety is maintained and the economical benefits is expected. The economical benefits may be achieved by the plant life management (PLiM) activities.

Many R&D activities related to PLiM have been carried out and implemented to Korean NPP, Kori Unit 1 and Wolsong Unit 1 in particular, for the long term operation beyond their original design lives. Those activities include PLiM study, PSR, SGMP, MRP, thinned pipe management programme, study on dissimilar metal welds, etc.

With the results of R&D activities, continued operation of Kori Unit 1 was successfully started from January 17, 2008 for next 10 years beyond its design life. It must be a landmark of 30 years history of nuclear power generation in Korea. Subsequently Wolsong Unit 1 is also expected to start its continued operation when the replacement of pressure tubes and feeders are completed in 2009.

So called the worldwide ‘Nuclear Renaissance’ is coming. Many countries have plans to build new reactors or to extend the life of operating plants. We are going to continue our R&D activities for ensuring the safety and economical competitiveness of operating NPP in Korea.

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