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Classification of Radiation Work in Korean Nuclear Power Plants

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Abstract The classification of the radiation work performed in Korean nuclear power plants (NPPs) must be understood to provide workers with more comprehensive radiation protection. This study used annual reports on occupational exposure to investigate and analyze the similarities and differences in the radiation work performed in Korean NPPs with pressurized water reactors (PWRs) and pressurized heavy water reactors (PHWRs). The results showed that the radiation work performed in Korean NPPs could be classified into three categories. Category 1 contains work at the highest level. This work can be divided into individual tasks belonging to Category 2, which enables the evaluation of the radiation dose during the work. The work in Category 2 consists of tasks from Category 3, which contains basic detailed tasks that are not further subdivided. This study emphasized the need for the systematic management of the radiation work performed in both Korean PWRs and PHWRs, such as the tasks in Category 3, which are similar, with similar working conditions, for PWRs and PHWRs. It also suggested the need to establish a list of radiation work for decommissioning because Kori Unit 1 and Wolsong Unit 1 are currently in permanent shutdown and preparations are being made for their decommissioning.

Key words: Radiation work, Classification, Nuclear power plants, Pressurized water reactors, Pressurized heavy water reactors

1. INTRODUCTION

Currently, 22 pressurized water reactors (PWRs) and three pressurized heavy water reactors (PHWRs) are in operation in Korea. In addition, one PWR and one PHWR have been permanently shut down. Table 1 summarizes the current status of each nuclear power plant (NPP) in Korea [1]. Furthermore, with the increasing number of NPPs, the number of NPP radiation workers has also increased (Table 2) [2]. The growing number of NPP radiation workers requires more comprehensive radiation safety management [3]. The International Commission on Radiological Protection (ICRP) introduced three key principles of radiological protection in its 1977 Recommendations: justification, optimization of protection, and dose limits (ICRP Publication 26). These principles were maintained in the 2007 Recommendations (ICRP Publication 103). However, the 2007 Recommendations place greater emphasis on the principle of optimization compared to the previous recommendations. In particular, the ICRP recommends the application of dose constraints to optimize radiological protection [4]. The introduction of such dose constraints will reduce individual doses to as low as reasonably achievable (ALARA), considering economic and societal factors. To apply dose constraints, it is necessary to characterize the exposure situation and work toward reducing or avoiding exposure. In addition, radiation work must be classified prior to the characterization of the exposure situation. Korea Hydro & Nuclear Power

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Table 1. Nuclear Power Plant Status in Korea

NPP	Reactor type	Electric power output capability (MWe)	Commercial operation date
Kori 1[a]	PWR	608	1978-04-29
Kori 2	PWR	650	1983-07-25
Kori 3	PWR	950	1985-09-30
Kori 4	PWR	950	1986-04-29
Shin Kori 1	PWR	1,000	2011-02-28
Shin Kori 2	PWR	1,000	2012-07-20
Saeul 1	PWR	1,400	2016-12-20
Saeul 2	PWR	1,400	2019-08-29
Shin wolsong 1	PWR	1,000	2012-07-31
Shin wolsong 2	PWR	1,000	2015-07-24
Wolsong 1[b]	PHWR	688	1983-04-22
Wolsong 2	PHWR	700	1997-07-01
Wolsong 3	PHWR	700	1998-07-01
Wolsong 4	PHWR	700	1999-10-01
Hanbit 1	PWR	950	1986-08-25
Hanbit 2	PWR	950	1987-06-10
Hanbit 3	PWR	1,000	1995-03-31
Hanbit 4	PWR	1,000	1996-01-01
Hanbit 5	PWR	1,000	2002-05-21
Hanbit 6	PWR	1,000	2002-12-24
Hanul 1	PWR	950	1988-09-10
Hanul 2	PWR	950	1989-09-30
Hanul 3	PWR	1,000	1998-08-11
Hanul 4	PWR	1,000	1999-12-31
Hanul 5	PWR	1,000	2004-07-29
Hanul 6	PWR	1,000	2005-04-22
Shin Hanul 1	PWR	1,400	2022-12-07
Total	27	25,946	

[a]Permanent Shutdown (2017.06.18)
[b]Permanent Shutdown (2019.12.24)

(KHNP), the state-run NPP operator, classifies NPP radiation work and applies their classifications to all NPPs. The differences between PWRs and PHWRs result in a difference in the radiation work based on the reactor type. This study had the goal of analyzing the similarities and differences in the radiation work performed in Korean PWRs and PHWRs using annual reports on NPP radiation control.

2. MATERIALS AND METHODS

KHNP classifies the radiation work performed in Korean NPPs based on annual reports on NPP radiation control. Annual reports on NPP radiation control consist of two main parts: radiation dose management and radioactive waste management. This study used information on radiation dose management from annual reports to investigate

Table 2. Number of nuclear power plant workers over ten years (2012~2021)

Years	Number of operating reactors			Number of workers		
	PWRs	PHWRs	Total	PWRs	PHWRs	Total
2012	19	4	23	18,100	3,395	21,495
2013	19	4	23	18,136	3,259	21,395
2014	19	4	23	17,155	3,285	20,440
2015	21	4	25	19,214	3,587	22,801
2016	21	4	25	19,153	3,536	22,689
2017	21	4	25	18,633	3,482	22,115
2018	21	4	25	21,299	3,589	24,888
2019	22	4	26	21,472	3,542	25,014
2020	22	4	26	20,601	4,470	25,071
2021	22	4	27	22,019	3,579	25,598

the radiation work performed in Korean NPPs [2,5]. These reports contain information on the radiation doses for workers based on NPP operational conditions, including internal and external occupational doses, occupational dose distributions, and collective doses for specific jobs. The radiation work differs between PWRs and PHWRs. The radiation work was classified into three categories. The work in Category 1 was determined based on the radiation work area, and this criterion was the same for both the PHWRs and PWRs. Category 2 contains jobs that combine multiple detailed tasks from Category 3. For example, the work in Category 2 related to nozzle dams includes steam generator (SG) nozzle dam installation, SG nozzle dam removal, and other work on SG nozzle dams. Category 3 contains detailed tasks with work codes. In general, it is difficult to determine the starting and ending points of each detailed radiation task because they are conducted consecutively. It is also difficult to separate detailed work and calculate the radiation dose at the level of a specific detailed task. Thus, the radiation dose during work was typically calculated for Category 2 work. This study analyzed annual reports on NPP radiation control and compared the radiation work performed for PWRs and PHWRs to identify similarities and differences.

3. RESULTS AND DISCUSSION

3.1. Classification of Radiation Work in Korean PWRs

The radiation work performed in Korean PWRs has been classified using 21 subcategories for Category 1, 38 for Category 2, and 214 for Category 3 [2]. The subcategories for Category 1 include refueling, reactor vessel or internal, SG primary side, SG secondary side, residual heat removal and safety injection systems, chemical and volume control system and coolant pump seal water system, pressurizer (PZR), reactor water clean-up system, reactor coolant system pump, primary circuit, valve work, routine inspections, general work, scaffolding, insulation, control rod drive, extra, large tasks, SG replacement, reactor head replacement, and decommissioning work. The criterion for the classification of the radiation work in Category 1 is the location where the radiation work was performed. The subcategories used for Category 1 are further divided and used for Category 2, which enables the calculation of the radiation dose during the work. The work in Category 2 is comprised of detailed radiation tasks listed in Category 3. The tasks in Category 3 are grouped together and placed into Category 2 because usually one task immediately follows another, which makes it challenging to evaluate the radiation dose for each detailed radiation task. Category 3 contains the individual tasks performed by radiation workers, which cannot be further subdivided. For example, the SG nozzle dam work in Category 2 includes the individual tasks of SG nozzle dam installation, SG nozzle dam removal, and other tasks for the SG nozzle dam. For Korean NPPs, the subcategories for Category 3 have their own codes. The classification of the radiation work performed in Korean PWRs is presented in Appendix 1, which includes the three categories [2].

The classification of the radiation work performed in

Korean PWRs is updated annually whenever new tasks are created. For example, in 2012, there were 24 tasks in Category 3, which belonged to the "other work" subcategory of Category 2. This, in turn, belonged to the "general work" subcategory of Category 1. These included instrument calibration and operation, and chemical and water quality control. In 2021, the total number of Category 3 tasks for the "other work" subcategory of Category 2 (and the "general work" subcategory of Category 1) increased to 26 with the addition of jobs such as hydrogen monitoring system installation and recirculation sump filter replacement. In 2012, the "extra work" subcategory of Category 2 (in the "extra" subcategory of Category 1) included 10 tasks for Category 3, including visitor guidance, containment vessel vents, and drain line work. In 2021, hold-up tank recovery work was added to the list of tasks, resulting in an increase in the number of tasks in Category 3 to 11. Furthermore, reactor head replacement in Category 1 did not exist in 2012 but was newly added to the subcategories of Category 1, with seven detailed tasks in Category 3. It was also found that decommissioning in Category 1 only includes the single task of decommissioning. In other words, there is no classification of the radiation work performed to decommission a PWR because the current tasks for PWRs focus on the maintenance and inspection of operating NPPs. However, it is essential to establish detailed work for decommissioning in Category 1 because Kori Unit 1 is scheduled to be decommissioned in the near future [6].

3.2. Classification of Radiation Work in Korean PHWRs

Currently, the radiation work performed in Korean PHWRs is classified into 20 subcategories in Category 1, 53 in Category 2, and 163 in Category 3 [2]. Category 1 includes refueling, reactor vessel or internal, SG primary side, SG secondary side, residual heat removal and safety injection systems, chemical and volume control system and coolant pump seal water system, PZR, reactor water clean-up system, reactor coolant system pump, primary circuit, valve work, routine inspections, general work, scaffolding, insulation, control rod drive, extra, large tasks, decommissioning, and pressure pipe replacement. The criteria for the classification of the radiation work performed in Korean PHWRs are the same as those used for Korean PWRs. The radiation work in Category 1 is classified based on the area in which the radiation work is performed. Tasks from Category 3 are grouped together in Category 2 and used to evaluate the occupational dose during the performance of the work, with the tasks in Category 3 at a basic level that can no longer be subdivided.

Most of the subcategories in Category 2 for Korean PHWRs contain only a relatively small number of tasks from Category 3 compared with those for Korean PWRs. In particular, the radiation work performed in Korean PHWRs includes tasks related to heavy water and tritium, owing to the characteristics of the CANDU reactor system. For example, general work in Category 1 includes heavy water systems, passive autocatalytic recombiner installations, and hydrogen monitoring installations in Category 2. Appendix 2 lists the three categories used in the classification of the radiation work performed in Korean PHWRs [2].

Similar to the updates on the radiation work performed in Korean PWRs, the classification of the radiation work performed in Korean PHWRs is updated whenever new tasks are created. For example, in 2012, the reactor vessels or internals in Category 1 included FCVI, SLARette, pressure tube equivalent hydrogen concentration measurement, end-fitting lapping, fuel channel fixed end change work, replacement of the old ionization chamber of the reactor system, and other reactor work in Category 2. In 2021, the replacement of the old ionization chamber of the reactor system was removed as a subcategory of Category 2 and changed to detailed work in Category 3 in the "other work" subcategory of Category 2. The pressure tube material property test was newly added as part of Category 2. In addition, the CT/LIN interval measurement task was added to Category 3 as part of the "other work" subcategory of Category 2 (in the reactor water cleanup system subcategory of Category 1), compared to the radiation work in 2012. Furthermore, the number of subcategories in Category 2 in the "general work" subcategory of Category 1 increased from 11 in 2012 to 15 in 2021 with the addition of pump work, dousing tank work, PAR installation, and hydrogen monitor installation. Similar to Kori Unit 1, Wolsong Unit 1 is currently in permanent shutdown, and preparations are being made for its decommissioning. Therefore, it is necessary to provide radiation work lists for Categories 2 and 3 for the "decommissioning" subcategory of Category 1.

3.3. Comparison of Radiation Work Classifications between Korean PWRs and PHWRs

Three categories are used to classify the radiation work

performed in Korean PWRs and PHWRs. For Korean PWRs, Category 1 contains 21 subcategories, with 38 for Category 2 and 214 for Category 3. For Korean PHWRs, Category 1 includes 20 subcategories, with 53 for Category 2 and 163 for Category 3. The radiation work performed in Korean PWRs and PHWRs can be compared based on the individual tasks in Category 3 because these are at a basic level of work and can no longer be subdivided.

Although the subcategories of Category 1 for Korean PWRs and PHWRs are similar, there are a few differences owing to their maintenance histories and designs. For instance, SG replacement is included in Category 1 for PWRs but is not included in the list of work for PHWRs. SGs have been replaced in Korean PWRs, with the SGs in Kori Unit 1, Hanul Unit 2, Hanul Unit 1, Hanul Unit 4, Hanul Unit 3, Hanbit Unit 4, Hanbit Unit 5, Hanbit Unit 6, and Hanbit Unit 3 replaced in 1998, 2011, 2012, 2013, 2014, 2019, 2020, 2021, and 2022, respectively [7]. In contrast to Korean PWRs, there is no experience with steam generator replacement in Korean PHWRs; thus, steam generator replacement is not included in the work for Korean PHWRs. From the perspective of reactor design, unlike Korean PHWRs, reactor head replacement is included in Category 1 for Korean PWRs. Pressure tube replacement is included in Category 1 for Korean PHWRs. The pressure tube, which is a unique component of a PHWR, surrounds the nuclear fuel and is installed with a horizontal orientation. Owing to its structure, the pressure tube is stretched horizontally with decreasing thickness and increasing inner diameter to withstand the high pressure and heat from the nuclear fuel during reactor operation. If the length of the pressure tube exceeds a certain limit, it can detach from the support plate, causing serious defects in the nuclear fuel; thus, pressure tube replacement is performed to prevent fuel defects in PHWRs [8].

While the subcategories of Category 1 are similar between Korean PWRs and PHWRs, the actual work differs because of the characteristics of the reactors. Korean PWRs and PHWRs use different nuclear fuels, reactor structures, coolants, and moderators. For example, the Category 1 refueling subcategory has a single task (refueling) in Category 2 for Korean PWRs, whereas in Korean PHWRs, there are two tasks in Category 2, including FHM system maintenance and the inspection of other nuclear fuel-related facilities. However, there are some common subcategories in Category 2 for both reactors, such as manway and ECT work on the primary side of the SG in Category 1.

The number of subcategories in Category 2 for Korean PHWRs is greater than that for Korean PWRs; however, the total number of radiation tasks in Category 3 for Korean PHWRs is lower than that for Korean PWRs. Even though relatively more work is included in Category 2 for Korean PHWRs than Korean PWRs to control the occupational dose during radiation work, the number of actual radiation tasks for Korean PHWRs is smaller than that for Korean PWRs. For example, the pressurizer subcategory in Category 2 (in the PZR subcategory of Category 1) for both Korean PWRs and PHWRs includes seven detailed tasks in Category 3 for PWRs: PZR manual work, PZR inspection, PZR external work, PZR internal work, PZR upper piping overlay, PZR lower surge line overlay, and PZR other work. However, there is only a single Category 3 task, PZR inspection and maintenance, for PHWRs. This indicates that the radiation work performed in Korean PWRs is classified in greater detail than that performed in Korean PHWRs. It is necessary to match certain similar Category 3 radiation tasks, with similar working conditions (structures), between Korean PWRs and PHWRs to manage radiation work more systematically.

4. CONCLUSION

This study analyzed annual reports on occupational exposure in Korean NPPs to examine the classification of radiation work in Korean PWRs and PHWRs and compare the similarities and differences in the radiation work performed in PWRs and PHWRs. The radiation work is classified into three categories. For Korean PWRs, Category 1 includes 21 subcategories, with 38 for Category 2 and 214 for Category 3. For Korean PHWRs, Category 1 includes 20 subcategories, with 53 for Category 2 and 163 for Category 3. The subcategories of Category 1 are based on the locations where the radiation work is performed. The subcategories of Category 1 are further divided into subcategories for Category 2. The occupational dose during a specific task is evaluated based on the work listed in Category 2. Each subcategory of Category 2 comprises detailed radiation tasks in Category 3. The tasks in Category 3 are at a basic level and have work codes. The radiation work performed in Korean PWRs and PHWRs is updated whenever new tasks are created.

The results of the analysis revealed that the radiation subcategories of Category 1 for Korean PWRs and PHWRs are similar because they are determined based on the locations where the radiation work is performed. However, there are a few differences in the subcategories of Category 1 between PWRs and PHWRs owing to the maintenance histories and reactor designs. The work in Category 1 for Korean PWRs includes steam generator and reactor head replacement, whereas the work in Category 1 for Korean PHWRs includes pressure tube replacement. Categories 2 and 3 differ between Korean PWRs and PHWRs because of the characteristics of the reactors, including differences in the nuclear fuel, reactor structure, coolant, and moderators.

This study suggested that it is necessary to find the correspondence between the radiation tasks for Korean PWRs and PHWRs in Category 3, based on similarities between the tasks and working conditions, to manage radiation work more systematically. In addition, Kori Unit 1 and Wolsong Unit 1 are currently in permanent shutdown and are waiting for decommissioning approval from the regulatory body. Thus, it is also necessary to establish a list of radiation tasks in Categories 2 and 3 for the "decommissioning" subcategory of Category 1. Finally, the analysis results of this study could be used to identify high radiation exposure in Korean NPPs for further study.

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부 록 - ABBREVIATIONS

ALARA: As Low As Reasonably Achievable
AOV: Air Operated Valve
CHG: Charge
CIGAR: Channel Inspection & Gauging Apparatus for Reactors
CLP: Containment Liner Plate
CT: Calandria Tube
CV: Containment Vessel
CVCS: Chemical & Volume Control System
DACS: Diffuser Adapter Cap Screw
DN: Delayed Neutron
ECT: Eddy Current Testing
EQ: Environmental Qualification
FCVI: Fuel Channel Volumetric Inspection
FHM: Fuel Handling Machine
FOSAR: Foreign Object Search And Retrieval
GTSP: Guide Tube Support Pin
HPSI: High Pressure Safety Injection
HUT: Hold-Up Tank
HVAC: Heating, Ventilating, and Air Conditioning
ICRP: International Commission on Radiological Protection
ILRT: Integrated Leakage Rate Test
LAC: Local Air Cooler
LIN: Liquid Injection shutdown system Nozzles
LLRT: Local Leakage Rate Test
LPMS: Loose Parts Monitoring System
LPSI: Low-Pressure Safety Injection
LZC: Liquid Zone Control system
MOV: Motor Operated Valve
OSG: Old Steam Generator
PAR: Passive Autocatalytic Recombiner
PHT: Primary Heat Transport
PSR: Periodic Safety Review
PZR: Pressurizer
RB: Reactor Building
RCP: Reactor Coolant Pump
RCS: Reactor Coolant System
RHR: Residual Heat Removal System
RSG: Recirculating Steam Generator
RTD: Resistance Temperature Detector
SDS: Shut-Down System
SFB: Spent Fuel Bay
SG: Steam Generator
SGR: Steam Generator Replacement
SI: Safety Injection
TRF: Tritium Removal Facility
TVCS: Turning Vane Cap Screw
UBHC: Upper Bundle Hydraulic Cleaning
UBIB: Upper Bundle In-Bundle

Appendix 1. Classification of radiation work in Korean pressurized water reactors

Division	Category 1	Category 2	Category 3	
			No. of tasks	Task
A	Refueling	Nuclear fuel replacement	7	1. Preparation for fuel change 2. Unloading 3. Fuel inspection 4. Fuel loading 5. Refueling machine inspection and maintenance 6. Control rod ECT and visual fuel examination 7. Refueling other work
B	Reactor vessel or internal	Disassembly or assembly	5	1. Reactor disassembly 2. Lifting reactor internals 3. Mounting reactor internals 4. Reactor assembly 5. Stud bolt work
		Inspection	2	1. Reactor and internal inspection 2. Mechanical ultrasonic testing
		Nuclear instrumentation system work	12	1. In-core detector works 2. Replace the In-core thermocouple 3. Replace the In-core guide tube and seal the nozzle 4. In-core time-hopping impulse modulation work 5. In-core other work 6. In-core seal housing replacement work 7. Reactor vessel head penetration inspection 8. Reactor vessel head penetration visual examination 9. Reactor vessel head penetration volumetric examination 10. Installation and inspection of reactor lower insulation plug 11. Control rod visual examination 12. EX-Core detector work
		Other work	7	1. Reactor vessel head vent pipe maintenance 2. Reactor lower other work 3. Foreign material investigation and removal operation 4. Reactor cladding maintenance activities 5. Reactor vessel replacement monitor replacement 6. Polar crane driving current collecting facility replacement work 7. Other work related to nuclear reactors
C	SG primary side	Man-way work	3	1. SG man-way open 2. SG man-way close 3. SG man-way other work
		Nozzle dam work	3	1. SG nozzle dam installation 2. SG nozzle dam removal 3. SG nozzle dam other work

Appendix 1. Continued

Division	Category 1	Category 2	Category 3	
			No. of tasks	Task
C	SG primary side	ECT work	4	1. Installation and removal of SG ECT equipment 2. SG ECT 3. Inspection and maintenance of SG ECT equipment 4. SG ECT other work
		Tube work	4	1. SG tube preparation work 2. Installation and removal of SG tube equipment 3. SG tube plugging & sleeving 4. SG tube other work
		Other work	1	1. SG primary side other work
D	SG secondary Side	Man-way/ Hand-hole	2	1. SG secondary man-way open & close 2. SG hand-hole & eye hole work
		Lancing	1	1. SG lancing work
		Foreign object search and retrieval	1	1. SG secondary foreign object search and retrieval (FOSAR)
		Other work	3	1. SG UBIB work 2. SG UBHC work 3. SG secondary other work
E	RHR & SI SYS	Residual heat removal· Safety injection system	13	1. RHR P/P inspection and maintenance 2. RHR P/P disassembly and assembly 3. RHR other work 4. LPSI P/P inspection and maintenance 5. LPSI P/P disassembly and assembly 6. LPSI other work 7. HPSI P/P inspection and maintenance 8. HPSI P/P disassembly and assembly 9. HPSI other work 10. SI P/P work 11. SI V/V work 12. SI heat exchanger work 13. Other SI work
F	CVCS & Coolant pump seal water system	Reactor coolant system	8	1. CHG P/P inspection and maintenance 2. CHG P/P disassembly and assembly 3. CHG P/P other work 4. CVCS filter work 5. CVCS heat exchanger work 6. CVCS V/V work 7. CVCS other work 8. Coolant pump seal water system

Appendix 1. Continued

Division	Category 1	Category 2	Category 3	
			No. of tasks	Task
G	PZR	Pressurizer	7	1. PZR man-way work 2. PZR inspection 3. PZR external work 4. PZR internal work 5. PZR upper piping overlay 6. PZR lower surge line overlay 7. PZR other work
H	Reactor water clean-up system	Reactor coolant system	1	1. Reactor water clean-up system work
I	RCS pump	Reactor coolant pump	7	1. RCP inspection and maintenance 2. RCP disassembly and assembly 3. RCP seal work 4. RCP motor replacement 5. RCP internal inspection and replacement 6. RCP chemical decontamination 7. RCP other work
J	Primary circuit	Reactor coolant system	5	1. RCS V/V work 2. Snubber inspection and replacement 3. Snubber replacement 4. Snubber other work 5. Primary circuit other work
K	Valve work	Valve work	5	1. MOV work 2. AOV diagnostic service 3. Valve actuator refurbishment maintenance work 4. Safety class MOV maintenance work 5. Other V/V work
L	Routine inspections	Inspection	7	1. P/P patrol inspection 2. PM 3. On-site inspection and supervision 4. Quality control activities 5. IAEA inspection and on-site inspection by the resident officer 6. Firefighting equipment inspection 7. Other daily inspection
M	General work	In-service inspection	3	1. In-service inspection 2. Authorized nuclear in-service inspector 3. In-service inspection other work
		Other inspection	2	1. External integrity inspection of steel containment 2. IRWST (in-containment refueling water storage tank) leak test

Appendix 1. Continued

Division	Category 1	Category 2	Category 3	
			No. of tasks	Task
M	General work	ILRT, LLRT	3	1. ILRT 2. LLRT 3. Other leak test
		System operating	1	1. System operating
		Radiation safety, Laundry	2	1. Radiation safety 2. Decontamination and laundry
		Waste management	2	1. Radwaste disposal 2. Drum temporary storehouse work
		Vitrification equipment	2	1. Vitrification equipment operation 2. Vitrification equipment maintenance
		Other work	26	1. Instrument calibration and operation 2. Chemical and water quality control 3. Communication 4. P/P work 5. Tank work 6. Sump work 7. Pipe work (includes insulation, support fixture) 8. Heat exchanger work 9. Filter work 10. Evaporator work 11. Fan work 12. Painting work 13. C/V cooling water pipe work 14. Replacing old non-safety small bore pipe 15. Improvement of the cooling channel in the charge pump room 16. Air distribution system work for safety class instruments 17. Fire protection material installation 18. Cable fire protection paint insulator 19. Firewall penetration improvement and reinforcement 20. Follow-up measures for environmental qualification 21. EQ follow-up air conditioning equipment reinforcement work 22. Heating, venting & air conditioning system (HVAC) fire damper work 23. A/B activated charcoal air cleaning unit fire extinguishing system work 24. Hydrogen monitoring system installation 25. Recirculation sump filter replacement 26. Other general work
N	Scaffolding	Scaffolding	1	1. Scaffolding
O	Insulation	Insulation work	2	1. RCS pipe shielding material installation and removal 2. Other insulation work

Appendix 1. Continued

Division	Category 1	Category 2	Category 3	
			No. of tasks	Task
P	Control rod drive	Control rod work	2	1. Guide tube support pin (GTSP) replacement 2. Control rod other work
Q	Extra	Extra work	11	1. Visitors guidance 2. CV vent & drain line work 3. Borated water system leakage test 4. Process protection and control monitoring facility improvement work 5. Nuclear power plant life management research 6. RSG eddy current test 7. LPMS (loose parts monitoring system) 8. PSR related work 9. HUT recovery work 10. Air conditioning equipment improvement replacement work 11. Other work
R	Large task	Specialized work	8	1. Dense storage rack work 2. RCP DACS and TVCS 3. RTD bypass line replacement work 4. SG replacement 5. Removal of obstacles in the dense rack storage tank (underwater work) 6. Dense storage rack salvage and decontamination 7. Cutting and wasting the existing storage rack of dense rack 8. Other work related to dense storage (preparation/relocation/installation)
S	SGR	Steam generator replacement	33	1. SGR SG support 2. SGR reactor cavity decking 3. SGR temporary load support 4. SGR SG platform modification 5. SGR temporary runway cart 6. SGR polar crane modification 7. SGR removal and replacement of interfere 8. SGR haul route 9. SGR SG rigging and transport 10. SGR OSG vessel work 11. SGR RSG vessel work 12. SGR RCS piping work 13. SGR RCS clamping activities and supports 14. SGR RCS cutting and machining 15. SGR RCS decontamination 16. SGR RCS templating 17. SGR RCS welding and NDE 18. SGR RCS FOSAR 19. SGR main steam 20. SGR feedwater

Appendix 1. Continued

Division	Category 1	Category 2	Category 3	
			No. of tasks	Task
S	SGR	Steam generator replacement	33	21. SGR blowdown 22. SGR shell drain 23. SGR level instrumentation 24. SGR sample system 25. SGR wet layup system 26. SGR whip restraint 27. SGR insulation 28. SGR OSG storage facility 29. SGR temporary utilities 30. SGR thermal expansion gaps 31. SGR radiation safety 32. SGR interference 33. SGR other work
T	Reactor head replacement	Reactor head replacement	7	1. Disassembling and taking out the old reactor head 2. Transporting the old reactor head 3. New reactor head transport and assembly 4. Containment building temporary penetration installation 5. Containment liner plate (CLP) incision and recovery 6. Temporary platform installation and recovery 7. Disassembly and restoration of internal/external interference in the containment building
U	Decommissioning	Decommissioning	1	1. Decommissioning

Appendix 2. Classification of radiation work in Korean pressurized heavy water reactors

Division	Category 1	Category 2	Category 3	
			No. of tasks	Task
A	Refueling	Fuel handling machine (FHM) system maintenance	3	1. FHM system 2. FHM inspection 3. FHM bridge
		Inspection of other nuclear fuel-related facilities	9	1. Refueling work 2. New fuel transfer and storage system work 3. FHM heavy water supply and control system 4. FHM filter replacement work 5. Shield door work 6. FHM other work 7. Spent fuel system work 8. SFB filter replacement work 9. Refueling other work
B	Reactor vessel or internal	Fuel channel volumetric inspection (FCVI)	1	1. Channel inspection & gauging apparatus for reactors (CIGAR) and maintenance
		SLARette	1	1. SLARette
		Pressure tube equivalent hydrogen concentration measurement	1	1. Pressure tube equivalent hydrogen concentration measurement
		End fitting lapping	1	1. End fitting lapping
		Fuel channel fixed end change work	1	1. Fuel channel fixed end change work
		Pressure tube material property test	1	1. Pressure tube material property test
		Reactor other work	12	1. Feeder grayloc 2. Channel shift 3. Reactor assembly component inspection 4. Reactor face insulation related work 5. Start-up instrument work 6. In-core detector system work 7. 1st shutdown system flow meter work 8. Replacement of the old ionization chamber of the reactor system 9. Radiation dose measurement in front of the reactor 10. Reactor header nuclide analysis 11. Inspection of feeder pipe 12. Reactor other work

Appendix 2. Continued

Division	Category 1	Category 2	Category 3	
			No. of tasks	Task
C	SG primary side	Man-way open & close	1	1. SG man-way open & close
		ECT	2	1. Installation and removal of SG ECT equipment 2. SG ECT
		SG other work	4	1. SG man-way remodeling 2. SG plugging 3. SG partial expanding tube ultrasound 4. SG 1st other work
D	SG secondary side	Remodeling work and lancing	1	1. G remodeling work and lancing
		SG other work	4	1. SG 2nd internal work 2. Installation and removal of SG lancing equipment 3. SG secondary manway gasket replacement 4. SG 2nd other work
E	RHR & SI SYS	Shutdown cooling system	1	1. Shutdown cooling system
		Other work	2	1. Emergency core cooling system (ECCS) 2. RHR & SI other work
F	CVCS & Coolant pump seal water system	Reactor coolant system (RCS)	2	1. CVCS & coolant pump seal water system 2. D2O feed P/P work
G	PZR	Pressurizer	1	1. PZR inspection and maintenance
H	Reactor water clean-up system	Moderator auxiliary system	4	1. Moderator auxiliary system maintenance 2. Moderator cleanup system filter work 3. Moderator cleanup system RD, STR work 4. Moderator deuteration/de-deuteration (D/DD) work
		Coolant auxiliary system	3	1. Coolant auxiliary system maintenance 2. Coolant deuteration/de-deuteration (D/DD) work 3. PHT filter work
		Other work	4	1. Moderator cleanup system rupture disc and IX overhaul 2. Low-grade heavy water tank pressure vessel replacement 3. CT/LIN interval measurement task 4. Heavy water cleaning system and other work
I	RCS pump	Moderator pump, sealing device	3	1. Moderator pump work 2. Moderator motor work 3. Moderator pump sealing device inspection and vibration damping work

Appendix 2. Continued

Division	Category 1	Category 2	Category 3	
			No. of tasks	Task
I	RCS pump	Coolant pump, sealing device	3	1. PHT pump work 2. PHT motor work 3. PHT sealing device inspection
		Other work	1	1. RCS P/P other work
J	Primary circuit	Moderator auxiliary system	3	1. Moderator checks valve disassembly 2. Moderator upper gas system overpressure protection rupture disc replacement 3. Main moderator system inspection and maintenance
		Other work	4	1. Replacing aging instrumentation equipment for moderators 2. Snubber inspection and maintenance 3. Replacing aging instrumentation equipment for coolant 4. Primary circuit other work
K	Valve work	Valve	2	1. V/V work 2. 1st M/V work
L	Routine inspections	In-service inspection and feeder thickness measurement	2	1. In-service inspection 2. Feeder thickness measurement
		ILRT, LLRT	2	1. ILRT 2. LLRT
		Inspection and audit related	3	1. On-site inspection and supervision 2. Quality control activities 3. IAEA Inspection and on-site Inspection by the resident officer
		Other work	4	1. Heavy water (H3) leak inspection 2. Vibration, oil inspection 3. Reinforcement inspection of general structures (painting, welding, ladders, etc.) 4. Other daily inspection
M	General work	DN tube work	2	1. DN tube work 2. DN coil assembly work
		Heavy water system	3	1. Heavy water system 2. Heavy water cleaning and upgrading system 3. Heavy water vapor recovery system
		Operator daily inspection	2	1. Daily inspection of generator operators 2. Daily inspection of nuclear fuel operators

Appendix 2. Continued

Division	Category 1	Category 2	Category 3	
			No. of tasks	Task
M	General work	Other regular inspections and call-up related work	5	1. Electrical installation inspection and repair 2. Instrument calibration and operation 3. Chemical and water quality control 4. Inspection and maintenance of communication facilities 5. IAEA surveillance camera cable maintenance
		Radiation safety	1	1. Radiation safety
		Survey	2	1. Cold survey 2. Hot survey
		Decontamination and laundry	1	1. Decontamination and laundry
		Waste management	4	1. Radwaste disposal 2. Liquid waste storage tank work 3. Radioactive waste temporary storehouse work 4. OGMS
		Pump work	1	1. P/P work
		Dousing tank work	1	1. Dousing tank work
		Insulation	1	1. Pipe work (includes insulation, support fixture)
		Air cleanup system	4	1. Air cleanup system work 2. HVAC filter work 3. Ion exchange resin work 4. LAC inspection
		Passive autocatalytic recombiner (PAR) installation	1	1. Passive autocatalytic recombiner (PAR) installation
		Hydrogen monitor installation	1	1. Hydrogen monitor installation
		Other work	22	1. Feeder cabinet work 2. 3410-3460 auxiliary system 1 3. 3480-3490 auxiliary system 2 4. 7000 auxiliary system 3 5. R/B access, shielding, sealed doors 6. Radiation control area epoxy liner work 7. Rupture disc work 8. Strainer work 9. Annulus gas system work 10. TRF: Heavy water supply/product system work 11. TRF: LPCE system work

Appendix 2. Continued

Division	Category 1	Category 2	Category 3	
			No. of tasks	Task
M	General work	Other work	22	12. TRF: CD system work 13. TRF: TGHS system work 14. TRF: air cleanup system 15. TRF: deuteration/de-deuteration system work 16. TRF: deuterium supplementation system work 17. TRF: off-gas and recombine system work 18. TRF: tritium monitoring system work in the air 19. TRF: other work 20. 3D laser scanning 21. Passive autocatalytic recombiner (PAR) inspection 22. Other general work
N	Scaffolding	Scaffolding work	1	1. Scaffolding work
O	Insulation	Insulation work	1	1. Insulation work
P	Control rod drive	Control rod work	5	1. Shutdown rod (SDS #1) work 2. Poison system (SDS #2) work 3. Regulating work 4. Absorption rod work 5. LZC work
Q	Extra	Extra work	4	1. Visitors guidance 2. Commissioning the robot 3. Waste liquid decontamination facility improvement 4. Other work
R	Large task	Specialized work	1	1. Large task
S	Decommissioning	Decommissioning	1	1. Decommissioning
T	Pressure pipe replacement	Pressure pipe replacement work	13	1. Preparing for pressure pipework 2. Dismantle the shield plug and feeder connection 3. Feeder removal 4. End fitting removal 5. Pressure pipe removal 6. Calandria tube insert and calandria tube removal 7. Calandria tube inspection 8. Calandria tube installation 9. Pressure pipe and end fitting installation 10. Feeder installation 11. Finishing work 12. Pressure pipe replacement work radiation safety 13. Pressure pipe waste transport