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The Optimization Experience of Occupational Exposure during Nuclear Power Plant Outage

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Abstract - By optimizing the radiation protection the collective dose and individual dose could be reduced during YGN #4 5th outage in 2001. The collective doses for the two high radiation jobs decreased to 85% and 65% of expected doses. The proportion of workers with low dose (below 1mSv) exposure increased 4% while the proportion of workers with over 3mSv and 5mSv exposure are decreased to 2%, 1% respectively. But none is exposed over 8mSv for the annual dose.

To aid decision of utilizing the robot, cost-benefit analysis was performed and reasonable point was proposed to use the robot. For the first time job, repeated ALARA meeting and mock up training were implemented to set up working procedure by identifying the trouble. To easily set up standard procedure, mockup process was videotaped and reviewed during ALARA meeting.

Monitoring is a good approach to chase radiological working condition such as working time, dose rate, behavior of workers, especially for high radiation work. Those data were estimated and adjusted from the stage of work planning to mock up. At the stage of actual work the monitoring data were compared to the estimation and recorded to database. This database will not only be used as a powerful tool for dose optimization at the following outage but also as a guideline to dose constraint set up for optimization for each specific situation.

Key word: optimization, cost-benefit analysis, collective dose reduction, personnel dose reduction, monitoring

INTRODUCTION

Occupational exposure should be optimized to keep as low as reasonably achievable for personal and collective dose being taken into account economic and social factors, according to ICRP recommendation[1]. Korean Nuclear Act adopted this optimization concept and setting a detail procedure for optimization of occupational exposure is in progress.

YGN #2 station constructs the database[2,3] for occupational exposure and field survey data. This database can be variously used for radiation protection and control to lower the level of dose. Occupational exposure in the nuclear power plant is mainly come from the exposure during outage. The occupational dose during outage reached over 90%[4] of annual collective dose in YGN #2 station. And approximately 40% of outage dose came from S/G maintenance works[5].

Unit 4 of YGN #2 station set up the plan to plug & sleeve the worn S/G tube and replaces the damaged In Core Instrument seal table during the 5Th outage. These works open to the high radiation and should be carried out difficult working condition. The number of S/G tubes to be plugged is continuously increased with repeated outage.

Optimization process should be necessary for these high radiation exposure jobs to specifically evaluate the work plan and assess the exposure situation of working area. The reactor type, design & operating specification, etc should be considered to optimize occupational exposure. The expectancy of health and economic state are also taken into account to optimization. Therefore the dose constraint that prescribed in ICRP, the goal of optimization, is varying for different plants and countries. The annual collective dose for YGN #2 station is lower than other plants in Korea because it was designed to strengthen radiation protection such as shield design; facility lay out, easy maintenance, etc.

Thus optimization was preceded with analyzing the YGN #2 stations dose history and radiation condition. Even though the monetary value of man-Sv to avert adverse health effect is varied widely with the utilities of each country or institutes accessed[6]. A cost-benefit analysis is the powerful and effective tool of optimization among the various optimization processes. And for the first tried job there is a lot of uncertainty to achieve the original intention or goal. A repeated mock-up and ARARA meeting is best way to fix the procedure. Through the repeated mock-up and ARARA meeting identified the predicted trouble and solved it.

In this report experimental optimization process is brought forward that evaluate cost-benefit analysis to determine alternative work procedure and implement mock-up & ARARA activities to set up working plan procedure before start of working.

Analysis of the collective dose and dose history of major activity

YGN unit 3 & 4 are commercially operated since Mar. 1995 and Dec. 1996 respectively. Up to now, outages had been completed 6 and 5 times respectively. Outage had been executed every 12 month up to 5^{th} cycle; from 6^{th} outage the cycle is extended to 18 months. The 6^{th} cycle had been completed for unit 3; 6^{th} outage of unit 4 is scheduled to Oct. in this year. Table 1. shows the annual exposure history during YGN unit 3 & 4 outage and normal operation. There is exposed 450man-mSv ~ 480man-mSv on the average during outage except 1^{st} and 2^{nd} cycle of unit 4. The annual exposure derived from normal operation is recorded 50man-mSv/year on the average, which makes up 5% of annual total dose. Most of the exposure is concentrated on the exposure during outage. It implies that radiation protection has to be concentrated on the activities implemented during outage at nuclear power plant.

During outage a lot of maintenance works are performed such as refueling, S/G tube eddy current test, tube plugging and sleeve, and inspection & examination of pumps, valves and welding points including reactor coolant pump. Major activities exposed to high radiation are S/G maintenance, refueling, and several special projects planned during outage.

The proportion of the average dose between the major activities throughout outage is shown on Fig. 1. The dose from S/G maintenance is ranked 1^{st} with 37%, and dose from refueling is following with 21%. The dose from S/G maintenance

Table 1. Annual exposure during YGN#3 & 4 outage

	1996	1997	1998	1999	2000	2001	2002	AVG
YGN #3	433.00	432.00	482.72	455.74	478.17		417.30	449.82
YGN #4	240.00	210.00		574.93	423.80	445.13		481.29
Nor. Op.	20.00	40.00	41.68	59.20	42.34	107.53		51.79
SUM	693.00	682.00	524.40	1089.87	944.31	552.66	417.30	982.90

activities are consisted of the nozzle dam installment & removal, tube eddy current test, S.G tube plugging & sleeve, and man-way open & close. The works for S.G tube plugging & sleeve and nozzle dam installment & removal are supposed to expose high radiation and poor working condition because these jobs are performed in the chamber of S/G. The collective doses of these jobs are approximately 40 man-mSv ~ 70 man-mSv for nozzle dam and around 100man-mSv for S/G tube plugging. The dose from S/G tube plugging is dependant on spots of plug or sleeve.

During YGN #4-5th outage, ICI Seal Table is plan to replace. To replace it, the workers are expected to expose to high radiation in short period in the reactor cavity. The number of S/G tube plug & sleeve is anticipated to be 150~180 spots of S/G tubes. The collective doses for the S/G tube plug and ICI seal table replacement are expected to be over 390 man-mSv and 189 man-mSv, respectively.

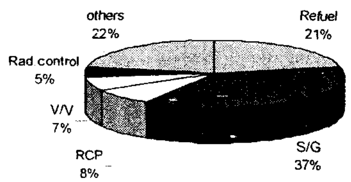

Fig. 1. Exposure distribution for major activities during outage.

Individual dose distribution

ICI seal table is replaced for the first time, while S/G tube plugging has dose records of 4 times in unit 3,4 of YGN station. Dose record is analyzed for optimization and extended cost-benefit analysis is assessed according to the IAEA safety report, NRPB R-120[7], and CEPN-R-2548[8]. The monetary value of the collective dose (man-Sv) and monetary value of the collective dose depending on the level of annual individual dose are adopted for calculation.

In 1999 and 2000, 38 and 50 spots of S/G tube respectively had been plugged. The dose from these jobs are 185 man-mSv and 112 man-mSv, workers to carry out are 96 and 60 workers, respectively.

Individual dose is mainly distributed in the range of 3 mSv ~ 5 mSv as shown on Table 2. The workers for S/G tube plugging were trained several times with mock-up according to the following procedure: marking-cleaning-sizing-rolling. To implement this job a lot of workers recruited from other jobs were exposed to high radiation released from the S/G chamber. And the other works were influenced to proceed because of vacancy of workers. When collecting a work force, it should be considered personal dose history and individual dose distribution among the collected workers.

The work for In-Core Instrument seal table replacement was to remove damaged seal housing

Table 2. Personal dose distribution of dose level in YGN#4 tube plugging

	Indi. & Collective dose				Dose distribution (person)						
Year	Avg.ind. (mSv)	Max.ind (mSv)	CD (man-mSv)	Workers (persons)	~ 1mSv	~ 3mSv	~ 5mSv	~ 8mSv	~ 10mSv	~ 12mSv	12mSv ~
1996	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1997	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1998	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1999	1.94	7.04	185.88	96	13	70	12	1	·		
2000	1.87	4.68	111.98	60	16	35	9				

Table 3. Dose distribution in YGN#4 Refueling

Indi. & Collective dose								Dose distribution (person)				
year	Avg.ind. (mSv)	Max.ind (mSv)	CD (man-mSv)	Working time (hr)	Amb. dose rate (mSv/hr)	Workers (persons)	~ 1mSv	~ 3mSv	~ 5mSv	~ 8mSv	~ 10mSv
1996	0.41	2.56	39.9	4857.4	0.0082	98	85	13			
1997	0.75	3.15	73.9	4289.8	0.0172	99	68	30	1		
1998	0.23	0.73	9.39	598.05	0.0157	40	40				
1999	0.92	3.85	62.36	3499.9	0.0178	68	42	21	5		
2000	0.68	3.56	70.67	4261.7	0.0166	104	79	23	2		

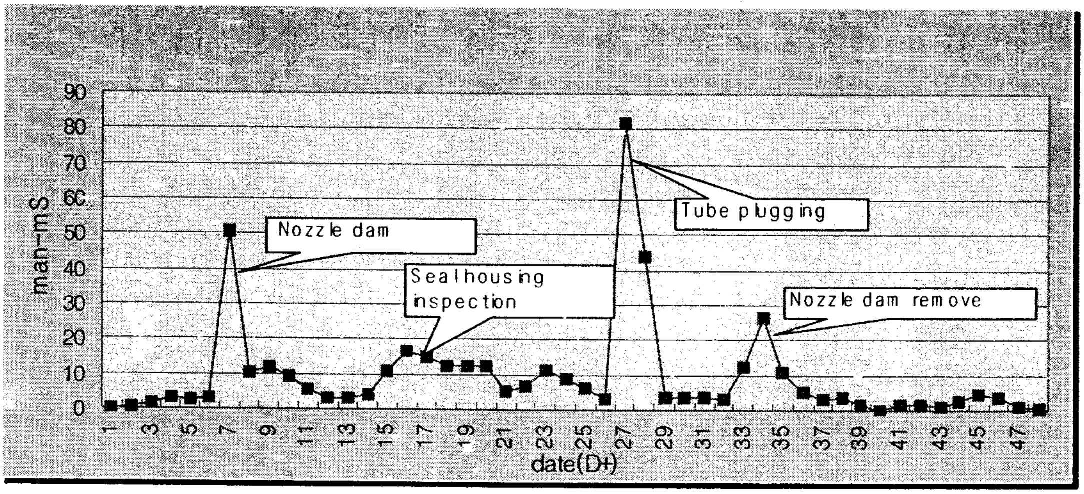

Fig. 2. Daily collective dose during YGN#4-4 Outage

to guide in-core thimble and seal table to support seal housing. The working condition was very poor, working space was narrow, and dose rate was very high due to the radiation from Upper Guide Support and reactor cavity. The workers were not accustomed to the work because it was a first time job. And it was worried about radiological contamination by spreading the ground particles produced from welding point cutting, as shown on fig. 3-1, 3-2. The dose to complete this job is expected to be 189 man-mSv.

Refueling is tedious, lasting for 40 days. The workers engaged in this work are exposed a little day by day and evenly. Average individual dose is under 1 mSv and maximum dose does not exceed 3.8 mSv as shown on Table 3.

Among the refueling activities the stud loosening & tightening is carried out on high radiation field, reactor cavity, but this is to be done by engineering tool, Multi Stud Tensioner.

The high radiation works can be identified by daily exposure chart as shown on Fig. 2. It shows exposure history implemented everyday during outage. The jobs finished for a short period and carried on high radiation field have peak values such as installing & removing the Nozzle dam, S/G tube plugging, and special project. These works should be optimized to alleviate high-rise. According to the Fig. 2 the installing & removing nozzle dam should be optimized. Hence it was searched for alternative method or engineering tool substituted but until now it was hard to find. Thus optimization of this job put off till next time.

S/G Tube plugging dose optimization

Radiological optimization is to allocate reasonably human and physical resources of work implementation and accomplish the radiation protection so as to maintain an occupational exposure as low as reasonably achievable. Now various method of optimization presented, cost-benefit analysis among them is powerful and economic tool of decision aiding technique.

Cost-benefit analysis is to calculate financial cost of implementing protective measures and associated collective dose. Extended cost-benefit analysis is considering collective dose and individual dose distribution as well. It is based on the higher an individual is exposed, the higher the risk he has and the detriment cost has a value dependant on individual dose level. It is possible to assess the cost of detriment of collective dose and the sum of individual dose level group. Cost-benefit analysis is performed to decide the application of robot, which is brought forward to the optimization means of occupational exposure for S/G tube plugging.

Extended cost-benefit analysis is applied to consider collective dose and personal dose distribution presented in IAEA safety report[6]. The utilities or authorities recommend the different monetary values for the unit collective dose & group individual dose depending on the level. In this evaluation the value of utilities is adopted. The equation for calculation is as follows

$$Y = \alpha \times S + \sum_i \beta_i \times S_i$$

α : a cost assigned to unit collective dose ($/man-Sv)

β : the additional value assigned to a unit collective dose in the i th group to take into account the subjective aspects of health detriment

Si : the collective dose originating from the i th group

To evaluate the radiation risk due to the radiation exposure during S/G tube plugging, average exposure was evaluated by analyzing exposure history. At first average working time for 1 spot plug (to plug 1 tube of S/G 2 end spots, hot leg and cold leg, should be plugged) and dose rate at working place were calculated from past database. And a brief report for average working speed, dose rate and individual dose distribution for dose level is presented in Table 4.

To calculate the collective dose multiplying the average dose rate and working time for spot of plug. And maintenance group presented the number of workers for the number of spots plug. Individual dose distribution of workers for the number of spots was calculated by applying the past average distribution. The result of calculation is presented in Table 5.

Now cost of radiation exposure risk was assessed for the number of tubes to be plugged, which depended on collective dose and individual dose distribution. The cost of risk exposed to radiation analyzed and presented in Table 6. The cost of risk is different from the country because each country has different monetary values of the unit collective dose & individual dose depending on the level. Even in the same country the utility or authorities recommend different monetary value.

In this evaluation utility value was adopted. As a result of cost-benefit analysis Spain had the highest cost among the other countries. U.S.A and Canada had about the same cost.

Suppose the Robot was utilized, the collective dose of S/G tube plugging was expected to be about 35man-mSv. The cost of radiation exposure risk falls on around U.S $60,000. And the rental fee of the Robot for S/G tube plugging is approximately U.S $140,000. Then the beneficial cost utilized the robot for S/G tube plugging has to exceed U.S $200,000.

The point should be identified which the cost of risk exposed to radiation for plug is equal to the benefit of alternate tool or changing working procedure. In this evaluation the monetary value was U.S $200,000, corresponds to 40 ~ 45 spots of tube. But reasonable point has to be under 40 ~ 45 spots of tube, because other factors to be attributed should be taken into account by virtue of using the robot.

Table 4. Average working speed, dose rate and individual dose distribution for dose level

Spots	Spot/min	Dose rate (mSv/hr)	Dose distribution (%)				
			~1mSv	1~3mSv	3~5mSv	5~8mSv	8~10mSv
avg	3.54	0.73	21	65	12	1	1
avg dev.	0.31	0.08					

Table 5. Collective dose and Individual dose distribution of workers for spots plug

Spot	Working time (min)	Collective dose (man-mSv)	No. of workers	Dose distribution (person)				
				~1mSv	1~3mSv	3~5mSv	5~8mSv	8~10mSv
20	70.8	51.68	38	8	25	5	0	0
40	141.6	103.37	52	11	34	6	1	0
60	212.4	155.05	76	16	49	9	1	0
80	283.2	206.74	96	20	62	12	1	0
100	354	258.42	124	26	81	15	1	0
120	424.8	310.10	160	34	104	19	2	1
140	495.6	361.79	180	38	117	22	2	1

Table 6-1. Radiation protection cost per number of spots plug

Spot	Canada	Spain	USA
20	US$97,166	US$137,841	US$87,863
40	US$194,332	US$275,682	US$175,726
60	US$291,498	US$413,524	US$263,588
80	US$388,664	US$551,365	US$351,451
100	US$485,830	US$689,206	US$439,314
120	US$582,996	US$827,047	US$527,177
140	US$680,161	US$964,889	US$615,040
160	US$777,327	US$1,102,730	US$702,902
180	US$874,493	US$1,240,571	US$790,765

For example the number of work force could be reduce to 35 workers and the reliability of working quality can be upgraded by using the robot. The labor cost cut down (about 60man-day), shortening term of work (1~2 day), and improvement of working quality has to be worthy of a few million U.S $. Then to optimize exposure of S/G tube plugging, the point of tube to be plugged has to be decided to be fewer than 40 spots of tube.

Optimization for ICI Seal table replacement

ICI seal table was replaced to new one, which is binding seal housing & housing assembly. This work had continued about 15 days and expected to expose about 180 man-mSv to accomplish. After the withdrawal of ICI thimble, damaged seal hosing& seal table was cut out with grinding and substituted to new one with automatic welding.

The workers are open to high dose rate with maximum 20 mSv/hr at the reactor cavity, and hot particle produced during cutting process, which is induced to internal exposure. And workers are not accustomed to this work procedure, which lead to increase the working time. To identify & eliminate the problem repeated ARARA meeting and Mock up trainings were performed and the work plan & procedure were set up. Considerations for radiation protection are as follows:

1. Minimize the staying time at work place.
2. Minimize the contaminated material production during progress
3. Prevent contaminated material from spreading

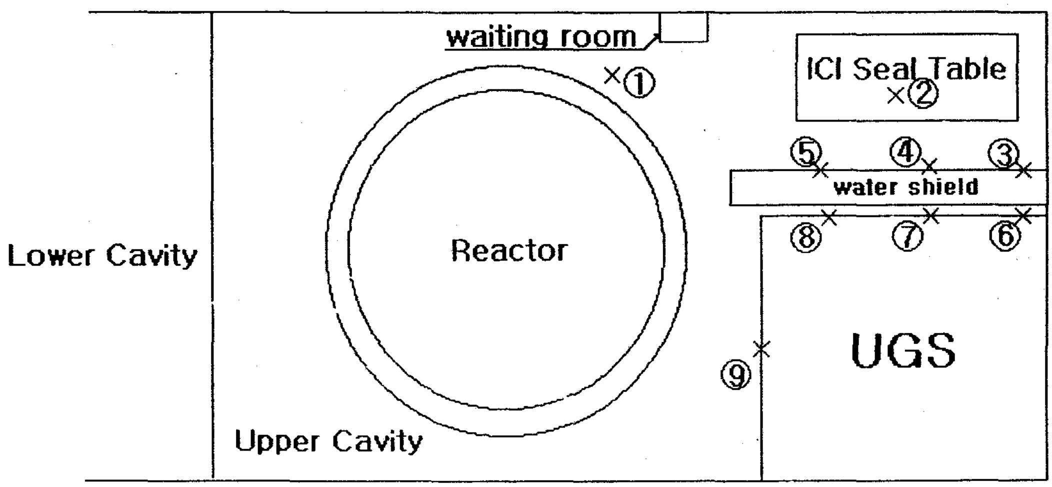

Fig. 3-1. A front view of ICI Seal Table Replacement during YGN#4-4 Outage

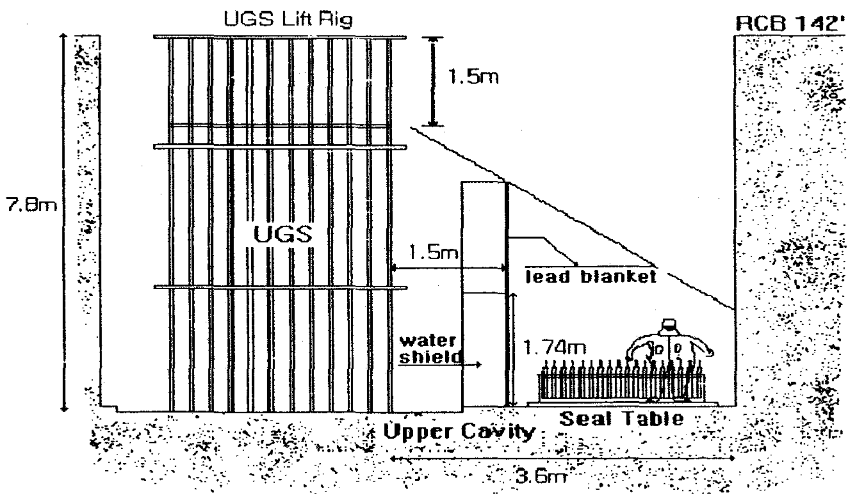

Fig. 3-2. A side view of ICI Seal Table Replacement during YGN#4-4 Outage

4. Minimize the dose rate at work place.

For these requirement,

1. Use automatic tool for welding and cutting.
2. Perform mock-up training at least 3 times.
3. Making and carrying out the standard work program and evaluating level from recording
4. Installing the tent to prevent the contamination.
5. Shielding work place with water and lead, setting the waiting room for workers at low radiation area.

During the mock-up training, a lot of spatter was produced during grinding the weld point and environment was contaminated by spread out. And lots of time was spent to finish cutting. Therefore plasma-cutting was adopted as a substitute for grinder and contaminated material was removed by installing continuous vacuum pump.

For shielding work place, water & lead shield were made site specifically. Water shield was filled with 4 tons of water. Double lead shield was erected on top of the water shield. After shield dose rate is decreased to 80% as shown on Table 6, a temporary tent was built with lead blanket to wait for a while before committing cutting or welding in low radiation area.

The optimized collective dose and individual dose distribution

During YGN #4-5 outage, S/G tube to plug is about 75 each(150 spots). The dose expected to be 390 man-mSv and the workers need more than 200 person, if it is worked manually. But collective dose decreased to 38.71 man-mSv and most of the workers were exposed were below 1mSv when a robot was used as shown the table 8.

ICI seal table was replaced for the first time in this station. So there have been many discussions about work procedure within maintenance departments from the early stage. And there were many mock-up trainings to qualify and get accustomed.

Table 6-2. Dose rate around the place of ICI Seal Table Replacement during YGN#4-4 Outage.

Point		1	2	3	4	5	6	7	8	9
Dose rate	Before shield	865	1,980	1,970	2,040	1,530	2,130	3,740	3,040	742
	After shield	180	550	438	365	215	-	-	-	-
Shielding rate		79	72	78	82	86	-	-	-	-

Table 7-1. Standardized working process for ICI Seal Table Replacement during YGN#4-4 Outage.

Process	Description	Dose rate (mSv/hr)	Working time (man-hr)	Exp. Dose (man-mSv)	Spot (set)	Personal dose(mSv)	
						Name	Dose
10	Nut Seal Weld cutting	0.1	16.80	1.68	16	H.H. PARK	3.94
20	Seal table Weld cutting(plasma)	0.1	15.75	1.58	45	J.S.Kim	39.83
30	Seal table lift out	0.1	0.35	0.04	1	P.S.Suh	39.83
40	Foreign mat'l covering	0.53	18.00	9.54	45	H.J.Kim	16.38
50	Setup cutting tool	0.53	43.20	22.90	45	W.C.Cha	16.38
60	Cutting Seal Hous.tube weld	0.53	29.70	15.74	45	Y.K.Jung	4.10
70	Lift out ICI Seal Hous.	0.53	29.70	15.74	45	Y.G.Jung	4.10
80	Decon. Tube weld	0.53	29.70	15.74	45	A	10.40
	Sum		488.37	189.76		SUM	189.76

Table 7-2. Monitoring sheet for ICI Seal Table Replacement during YGN#4-4 Outage

Description	Dose rate (mSv/hr)	Working time (man-hr)	Dose (man-mSv)	workers	Activity monitoring
Nut Seal Weld cutting	0.15	14.10	1.68	H.H.PARK	
Seal table Weld cutting (plasma)	0.15	14.75	1.58	J.S.Kim	
Seal table lift out	0.2	0.5	0.04	P.S.Suh	
Foreign mat'l covering	0.60	18.00	9.54	H.J.Kim	
Setup cutting tool	0.60	50.20	22.90	W.C.Cha	
Cutting Seal Hous.tube weld	0.60	35.70	15.74	Y.K.Jung	
Lift out ICI Seal House.	0.65	25.00	15.74	Y.G.Jung	
Decon. Tube weld	0.50	25.50	15.74	A	

Table 8. Collective dose and personal dose distribution of dose level after optimization for S/G tube plugging

Year	Indi. & collective dose				Dose distribution (person)						
	Avg.ind. (mSv)	Max.ind (mSv)	CD (man-mSv)	Workers (persons)	~ 1mSv	~ 3mSv	~ 5mSv	~ 8mSv	~ 10mSv	~ 12mSv	12mSv ~
1996	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1997	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1998	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1999	1.94	7.04	185.88	96	13	70	12	1			
2000	1.87	4.68	111.98	60	16	35	9				
2001	1.11	6.10	38.71	35	25	7	2	1			

As a consequence of this effort the collective dose for ICI seal table replacement reduced to 57.52 man-mSv, maximum and mean individual dose to 6.6 mSv and 1.4 mSv respectively. The individual dose distribution for ICI seal table replacement was kept 50% below 1 mSv, 36% below 3 mSv, and 13% below 6 mSv.

Through optimizing the radiation protection, annual collective dose and personal dose distribution of dose level are reduced and transferred to low dose level as shown on Table 9. The proportion of workers below 1 mSv exposure increased 4 % while the proportion of workers over 3 mSv and 5 mSv are decreased to 2%, 1% respectively. And none is exposed over 8mSv.

Conclusion

Collective dose and personal dose were reduced by optimization process during YGN #4 outage on 2001. For optimization alternative engineering tool was utilized by analyzing the cost-benefit analysis. This method was introduced to assist decision. And for the first time job, repeated ALARA meeting and mock up training were implemented to set up working procedure (standard process) and identify the trouble. These activities were recorded with report and video and reviewed to make it best procedure at the ALARA meeting.

Monitoring is the good approach to chase working time, dose rate, behavior of workers,

Table 9. Annual Collective dose and personal dose distribution of dose level after optimization

Year	Indi. & collective dose(TLD)				Dose distribution (person)						
	Avg.ind. (mSv)	Max.ind (mSv)	CD (man-mSv)	Workers (persons)	~ 1mSv	1~ 3mSv	3~ 5mSv	5~ 8mSv	8~ 10mSv	10~ 12mSv	12mSv ~
1996	0.62	21.30	458.99	743	606	92	30	11	3		1
1997	0.55	8.60	625.88	1138	948	121	46	21	2		
1998	0.45	7.70	605.88	1334	1132	155	36	11			
1999	0.74	17.51	1008.49	1354	1049	208	54	36	3	1	3
2000	0.70	11.22	944.29	1343	1066	161	83	28	3	2	
2001	0.44	7.90	552.66	1266	1080	141	31	14			
AVG (before 2001)					81%	12%	4%	2%	0.2%	0.1%	0.1%
2001					85%	11%	2%	1%			

which was estimated at the stage of work planning. During mock up the monitoring is the way of adjusting to set up those data, procedure and identify the trouble. At the stage of actual work the monitoring is the way of verification the job is in accordance with the procedure. The monitored data is recorded to database.

This database will not only be used as a powerful tool for dose optimization at the following outage but also as a guideline of dose constraint set up for optimization for each specific situation. These data can be applicable for the guideline of dose constraint for specific working condition.

Dose constraint, the tool of optimization of individual and collective dose, is different from dose limit. Therefore ICRP recommend that it should be determined as low as reasonably achievable relying on the various conditions. Even though the specific guideline of dose constraint has not been settled in Korea, determination and operation of dose constraint, based on database which built in past work history, could be an alternative method.

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