Radiation Dose Distribution for Workers in South Korean Nuclear Power Plants


Abstract—A total of 33,680 nuclear power plants (NPPs) workers were monitored and recorded from 1990 to 2007. According to the record, the average individual radiation dose has been decreasing continually from it 3.20 mSv/man in 1990 to 1.12 mSv/man at the end of 2007. After the International Commission on Radiological Protection (ICRP) 60 recommendation was generalized in South Korea, no nuclear power plant workers received above 20 mSv radiation, and the numbers of relatively highly exposed workers have been decreasing continuously. The age distribution of radiation workers in nuclear power plants was composed of mainly 20-30-year-olds (83%) for 1990 ~ 1994 and 30-40-year-olds (75%) for 2003 ~ 2007. The difference in individual average dose by age was not significant. Most (77%) of NPP radiation exposures from 1990 to 2007 occurred mostly during the refueling period. With regard to exposure type, the majority of exposures were external exposures, representing 95% of the total exposures, while internal exposures represented only 5%. External effective dose was affected mainly by gamma radiation exposure, with an insignificant amount of neutron exposure. As for internal effective dose, tritium (^3H) in the pressurized heavy water reactor (PHWR) was the biggest cause of exposure.

Keywords—Dose distribution, External exposure, Nuclear power plant, Occupational radiation dose

I. INTRODUCTION

When Kori unit 1 began commercial operation on April 29, 1978, South Korea’s nuclear power generation was born. As of 2008, 20 nuclear power plants, with 16 units of pressurized water reactors (PWRs) and four units of pressurized heavy water reactors (PHWRs), have operated. And it is the world’s sixth largest nuclear power plant.

Additionally, four units of OPR-1000 (optimized power reactor 1,000 MWe), the Korean standard nuclear power plant, and four units of APR-1400 (advanced power reactor 1,400 MWe), the next most common Korean reactor, are under construction. The Korean domestic generation capacity of 70.5 GWe in 2006 is expected to grow to 88 GWe in 2017. Nuclear power generation is anticipated to be 26.6 GWe (30%), supplying 47% of demand (214 TWh). At the end of 2006, the nuclear capacity was 17.7 GWe net (28% of total), supplying 39% of demand (141 billion kWh net in 2006)[1].

To promote the ALARA (As Low As Reasonably Achievable) principle and to comply with the dose limits for radiation workers, the national authorities arranged for the collection, analysis, and discussion of radiation dose statistics. Consequently, high-quality monitoring systems, registration, and control of individual occupational exposure are required.

II. MATERIALS AND METHODS

A. Quality Assurance Procedures

The normal dose limit according to Korean national nuclear law is 100 mSv. During any given five-year period, the effective dose is not allowed to exceed 50 mSv in any single year.

The Korean National Dose Registry, managed by the Korea Radio-Isotope Association (KRIA) entrusted by the Ministry of Education, Science and Technology (MEST), maintains records of occupational dose due to ionizing radiation. The registry publishes a quarterly external effective dose report and a yearly internal effective dose report. These numbers are reported to the KRIA[2].

The Korea Hydro & Nuclear Power Co. (KHNP) follows the ICRP 60 recommendation and national nuclear law regarding dose limits. The doses obtained from the assessment of occupational exposures from external radiation and radioisotope intake are combined to determine the total effective dose. Total effective dose for demonstrating compliance with dose limits is calculated by

\[ E = H_p(10) + E(50), \]

where \( E \) is the total effective dose, \( H_p(10) \) is the personal dose equivalent from external exposure, and \( E(50) \) is the committed effective dose from internal exposure[3].

The deep dose, \( H_p(10) \) for NPPs workers is estimated using a Thermoluminescent Dosimeter (TLD). Radiation workers can be exposed to inhomogeneous radiation during the maintenance of reactor coolant pumps, pressurizer, and water chambers of steam generators during NPP overhaul. In inhomogeneous radiation fields, radiation workers are required...
to wear an additional TLD badge on the back as well as one on
the chest, if any body part is expected to receive a total
exposure exceeding 2 mSv, or 1.3 times the chest dose, and
the dose rate of the working area is expected to exceed 1
mSv/hr. In this case, the whole body effective dose is
calculated according to the following NCRP 55/50
algorithm[4]-[5].

\[
H_E = 0.55[H_P(10)]_{\text{chest}} + 0.50\ [H_P(10)]_{\text{back}},
\]  

(2)

where HE is the whole body effective dose, \([H_P(10)]_{\text{chest}}\)
is the deep dose \([H_P(10)]_{\text{chest}}\) of the chest, \([H_P(10)]_{\text{back}}\) is the
deep dose\([H_P(10)]\) of the back, and 0.55 and 0.50 are
weighting factors for TLD locations.

Radiation workers also wear additional extremity TLDs if
the hands and/or feet are expected to receive an exposure
exceeding 4 mSv or two times that of the whole body effective
dose[6].

TLDs of NPP workers are read monthly with quality
assurance manual authorized by the MEST. When an alarm
dosimeter is lost or destroyed, when one displays an over-
range reading, or when a radiation worker is exposed to a
higher-than-normal dose, the TLDs are read promptly. Every
two reactors of an NPP have a TLD reading facility, which is
audited yearly by the MEST to confirm the implementation of
the quality assurance manual. This manual covers information,
including the quality controls of the dose reading system, the
performance criteria appropriate for evaluating the dose from
ANSI N13.11, the technical skills of the person in charge of
the system, the dose reading procedures, the lower limits of
detection (LLD), the calibration periods, and the methods[7].

All NPP radiation workers are tested for internal exposure
once per year using a whole body monitor (WBM); if a worker
performs a potential high-exposure job, internal exposure
examination is performed promptly. In facilities with PHWRs,
when exiting from a radiation control area (RCA), every
worker should submit a urine sample for an internal exposure
evaluation to identify any possible tritium (\(^3\text{H}\)) intake. A
liquid scintillation counter (LSC) is used to determine the
activity of tritium in a liquid sample.

Every nuclear power plant having two reactors and an
internal dose assessment facility adheres to the nuclear
guidelines regarding internal dosimetry, measurement method
and procedure, requirement of workers to undergo bioassay,
bioassay system requirements, and management of
documentation. Measurement procedures cover the operation
method of the system, the technical skills of the person in
charge of the system, the system surveillance and calibration
methods, the evaluation method for intake of radioactive
material, and the committed effective dose. Facilities are
audited yearly by the MEST[8]. Korea Hydro & Nuclear
Power Co. has implemented a radiation safety management
system, including a dose registry of NPPs radiation workers,
in order to execute effective radiation management. The
company maintains the dose registry, and the application for
the system has been continuously renewed. In the year 2003,
this system was renewed under what is called a radiation
management (RAM) system, based on enterprise resource
planning (ERP). A radiation management system tracks and
manages the names of the designated radiation workers, the
issue of radiation work permits, control of RCAs, any release
of radioactive materials, and various external/internal radiation
dose registries. The national dose registry system, however,
tracks only the external and internal effective doses of the
NPP radiation workers.

A previous South Korean study on occupational radiation
dose did not provide a specific radiation dose distribution for
NPP radiation workers. The objective of this study, therefore,
was to investigate the detailed distribution and trend of
occupational radiation exposure to workers at NPPs using
doses recorded by the RAM of KHNP.

A. Registry information

The dose registry of the KHNP maintains records of
occupational doses by ionizing radiation for NPP radiation
workers. The registry contains radiation dose records for
33,680 persons tested between 1990 and 2007, with 11,435 of
them monitored in the year 2007. The information in the
registry includes individual worker exposure history, including
the worker's name, gender, date of birth, identification number,
job classification, monthly external and internal dose data, the
beginning and end date of measurement, work group, and
plant location. External dose information includes the deep
dose, shallow dose, skin dose, alarm dosimeter dose for \(\beta\) and
\(\gamma\) radiation, and neutron dose. The RAM system also includes
internal dose information as a result of whole body analysis
for \(\gamma\) emitters and liquid scintillation counts for tritium. The
radiation workers at nuclear power plants were grouped into
four occupational categories: operation, inspection and
maintenance, research and audit, and radiation management
service. All monitored workers were individuals to whom a
dosimeter was issued, while measurably exposed workers are
those who received an average annual effective dose higher
than 0.1 mSv. All dose data were based on measurements
from the TLDs for external exposures and the WBM/LSC for
internal exposures. All of the instruments used at the facilities
were calibrated semiannually.

B. Calculation of Dose distribution

We calculated two radiation dose variables based on the
following algorithms from the United Nations Scientific
Committee on the Effects of Atomic Radiation (UNSCEAR)
report[9] to investigate their distributions: 1) the average
annual effective dose, 2) the annual collective effective dose.
These were estimated for all monitored workers. We analyzed
the exposure data with respect to worker age, occupational
group, operation state, and exposure type[10]-[13].

III. RESULTS AND DISCUSSION

A total of 33,680 NPP workers were monitored from 1990
to 2007, with the number continuously increasing over time.
The average annual effective doses have been continuously
decreasing for all monitored workers.

The detailed data on occupational dose are presented in
The Korea Hydro & Nuclear Power Co. initiated ALARA activities for its radiation workers in order to comply with the new occupational exposure limit proposed by the ICRP in 1990. For example, both short- and long-term comprehensive grades are being performed in order to improve equipment, such as steam generators and reactor coolant pumps, reactor head open-close tools, the removal or minimization of snubbers and reactor coolant loop RTD (resistance temperature detector) bypass lines, and remote control device installations, which are known to result in high worker exposure [14].

As a result of those activities, the number of radiation workers receiving relatively high exposure doses has been decreasing since 1990. After 2000 when the ICRP 60 recommendation was adopted in Korea, no NPP worker received a dose above 20 mSv/yr. Moreover, the number of NPP workers who received doses greater than 15 mSv/yr and 10 mSv/yr also decreased.

In the case of NPPs, it is not easy to classify occupational groups in detail, unlike in other fields of industry. The dose registry system (RAM) of KHNP also does not classify workers by occupational group. Instead, starting with the data from 1990, we classified the workers using allocated company codes and statistically processed the significant data. We grouped people into four occupational groups of Operations, Inspection & Maintenance, Research & Audit, and Radiation Management Services. All of the KHNP plant workers were classified into the Operations group. The mechanical, electrical, and maintenance contractor workers were placed into the Inspection & Maintenance group, people from external institutes and regulatory bodies who inspected and audited facilities were assigned to the Research & Audit group. The Radiation Management Services group consisted of all special contractors in radiation control occupations, such as health physics, radiation protection, decontamination, and radioactive waste treatment.

Figure 1 indicates the average effective dose value by occupational group during the period from 1990 to 2007. The average dose for the Operation group was 0.46 mSv, that of the Inspection & Maintenance group was 2.27 mSv, the Research & Audit group was 0.18 mSv, and the Radiation Management Services group was 2.44 mSv. The individual average effective dose has also been continuously decreasing in all occupational groups, although the two groups Inspection & Maintenance and Radiation Management Services received relatively higher doses when compared with the other two groups, Operations and Research & Audit.

Analyzing the 2007 individual average effective dose

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</table>

As a result of those activities, the number of radiation workers receiving relatively high exposure doses has been decreasing since 1990. After 2000 when the ICRP 60 recommendation was adopted in Korea, no NPP worker received a dose above 20 mSv/yr. Moreover, the number of NPPs who received doses greater than 15 mSv/yr and 10 mSv/yr also decreased.

Table I, II and III. The Korea Hydro & Nuclear Power Co. initiated ALARA activities for its radiation workers in order to comply with the new occupational exposure limit proposed by the ICRP in 1990. For example, both short- and long-term comprehensive grades are being performed in order to improve equipment, such as steam generators and reactor coolant pumps, reactor head open-close tools, the removal or minimization of snubbers and reactor coolant loop RTD (resistance temperature detector) bypass lines, and remote control device installations, which are known to result in high worker exposure. Table I shows the number and average annual effective dose of NPP workers by calendar year. Table II shows the collective effective dose by exposure type. Table III shows the radiation dose distribution of NPP workers by calendar year.

<table>
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<th>Year</th>
<th>Monitored workers</th>
<th>Annual collective effective dose (man-mSv)</th>
<th>Average annual effective dose (mSv)</th>
<th>Monitored workers</th>
<th>Measurably exposed workers</th>
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distribution by age shows that the workers in their 20s had the highest average exposure of 1.35 mSv, followed by the 1.32 mSv of those in their 30s, the 1.00 mSv of those in their 40s. Finally, the group aged 50 and older had the lowest individual average effective dose of 0.69 mSv. There was little difference in average exposure by age.

In contrast, the average annual individual dose has been showing a constant downward trend due to the radiation protection activities of KHNP that have been implemented to assure compliance with the ALARA reinforcement policy to optimize radiation protection. Included in these protective acts are the recommendation of a decreased dose limit and the dose constraint guidelines established by the ICRP.

Actually, KHNP has performed a substantial amount of equipment improvements, design changes, and procedure amendments in order to meet the dose limitations of the ICRP recommendation. In addition, new plants are being constructed with an enhanced design based on the experiences of the existing plants.

From the software point of view, training, procedure development and exposure reduction plants are constantly being updated.

Because of these proactive measures, the Korean annual average individual radiation exposure dose is expected to remain low.

IV. CONCLUSION

The number of radiation workers in Korea has been increasing steadily since Kori-1 started commercial operation in 1978 and is expected to increase continuously in the future. Korea currently has 20 functioning nuclear reactors, with eight more under construction as of 2008. Additionally, the Korean government plans to increase nuclear power from its current generation rate of 35.5% to one of 59% by 2030.

![Fig. 1 The mean average annual effective doses of NPP workers by occupational group from 1990 to 2007.](image)

Representing 39.94% of the total NPP workforce, workers in their 30s were the largest age group of NPPs workers, followed by the 31.92% of workers in their 40s, 14.23% in their 20s, and 13.91% aged 50 years or older. The 30s and 40s are the predominate age groups among all NPP workers. As the number of women working at NPPs was too small to process, we did not analyze the data with respect to gender. For instance, only 30 of the 11,435 people working in nuclear power plants in 2007 were women.

Most radiation exposure occurred during refueling. When averaging the collective effective doses of 1990-2007, the percentages of exposure occurring during normal operations and refueling were 23% and 77%, respectively.

The detailed dose distributions by exposure type are presented in Table 2. As shown, external exposure accounted for 95% of exposures, and internal exposure occurred in only 5% of exposures. The external effective dose was affected mainly by gamma radiation, with insignificant amounts due to neutron exposure. The biggest contributor to internal effective dose for PHWR workers was tritium \(^{3}\text{H}\), and the internal effective dose of PWR workers was induced by the intake of gamma radioisotopes, such as \(^{58}\text{Co}\) and \(^{60}\text{Co}\).

According to the data provided by the World Association of Nuclear Operators, the annual collective effective dose per unit in South Korea has continually been lower than that of the world average[15]-[16].

**REFERENCES**