THE MONETARY VALUE OF THE MAN-SV FOR KOREAN NPP RADIATION WORKERS ASSESSED BY THE RADIATION AVERSION FACTOR

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Abstract: The monetary value of the man-Sv(man-sievert) for operators of Korean nuclear power plants (NPPs) was calculated using the radiation aversion factor analyzed based on a survey of NPP workers. Initially, the life expectancy in population of 79.4 years, average age of cancer occurrence of 60 years, average annual wage for electric worker of 56,000 $/year, and nominal risk coefficient induced by radiation of $4.2E^{-2}Sv^{-1}$ were used to evaluate the basic monetary value(α_{base}) resulting in 45.6 $/mSv. To evaluate the risk aversion factor, radiation workers were surveyed, of which 2,157 responded. The assessed risk aversion factor and the monetary value of the man-Sv from the calculated risk aversion factor were 1.26 and approximately 50 $ in the 0−1 mSv range, 1.38 and approximately 200 $ in the 1−5 mSv range, 1.52 and approximately 1,000$ in the 5−10 mSv range, 1.65 and approximately 4,000 $ in the 10-20 mSv range, and 1.74 and approximately 8,500 $ above 20 mSv.

Key Words: monetary value, NPP, radiation workers, risk aversion factor, man-Sv

INTRODUCTION

As of 2011, 21 nuclear power plants (NPPs) were in operation. Additionally, three units of OPR-1000(optimised power reactor, 1000 MWe), the Korean standard NPP, and four units of APR-1400(advanced power reactor, 1400 MWe), the next most common Korean nuclear reactor, are under construction.

The Korea Hydro & Nuclear Power Co., Ltd.(KHNP) has successfully carried out various design modifications, adoption of equipment, and process improvements for the realization of radiation protection optimization in accordance with the ALARA principle. Such efforts to reduce the radiation dose of radiation workers has resulted in the effective reduction of the collective dose of Korean NPPs' radiation workers from 1,975 man-mSv/unit in 1985 to 641 man-mSv/unit in 2007. This trend is predicted to be maintained steadily at a low level. [(1)]

However, there is no inherent monetary value of the man-Sv for operators of Korean NPPs that can quantitatively evaluate such efforts to realize radiation protection optimization is reasonable and economical. International practices and cases are referenced on a case by case basis. Therefore, setting a unique monetary value of the man-Sv of KHNP is necessary as an essential means of decision-making in radiation protection optimization.

The monetary value of the man-Sv, commonly referred to as the α-value, is widely used among NPP operators and state regulatory agencies as a secondary means of radiation protection optimization realization recommended by IAEA and ICRP. The Human capital

methodology(HCM) and willingness to pay methods(WTP) are utilized to calculate the unit monetary value per man-Sv($/man-Sv), which is different for every regulatory agency and NPP operator as the factors and parameters used take into consideration the domestic socio-economic condition and unique characteristics of the NPP. In this study, the risk aversion factor was analyzed based on a survey of NPP workers and the socioeconomic condition of Korea to evaluate the monetary value of the man-Sv that reflects the characteristics of NPP in Korea. The monetary value according to the radiation exposure level is presented.

MATERIALS AND METHODS

The monetary value of the man-Sv is established with reference to the potential health effects depending on the level of exposure. The effect on an individual's health from cancer or genetic effects can be expressed as the loss in the individual's life expectancy. The economic loss of the individual that follows such health detriments are directly related to the monetary value of human life. HCM and WTP is applied in assessing the monetary value of the life expectancy loss. In this research, the monetary value of the man-Sv of NPP operators was evaluated utilizing HCM. The basic equations presented in ICRP Pub. 101 and IAEA SRS No. 21 are shown below [(2) (3)].

$$\alpha_{ref}(d) = \alpha_{base} \quad \text{for} \quad d<d_0$$
$$\alpha_{ref}(d) = \alpha_{base}(d/d_0)^a \quad \text{for} \quad d\geq d_0$$

Here, $\alpha_{ref}(d)$ is the monetary value of the man-Sv according to the individual exposure level d, α_{base} is the basic monetary value of the health detriment due to a unit dose, d_0 is the lowest limit of individual exposure with exposure aversion applied, d is the annual level of individual exposure, and a is the degree of exposure aversion or the risk aversion factor.

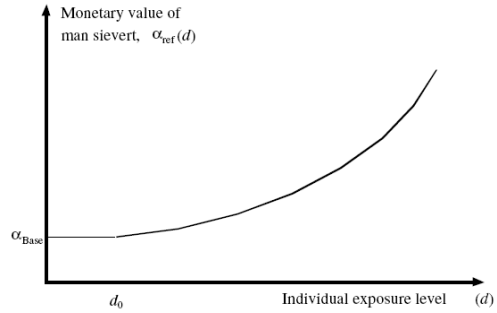

Figure 1. Model of monetary values of the man-Sv incorporating risk aversion and equity consideration

In September of 2010, a survey was distributed to all radiation workers of 20 NPPs and 2,157 responses were collected. Table 1 shows the company distribution of the respondents.

Table 1. Distribution of respondents for the survey

Surveyed company	Profession	No. of respondent	Percentage (%)
KHNP	Operation	1,115	51.7
KEPCO KPS*	Machine/electricity-Inspection & maintenance	469	21.7
Radiation Contractor	Radiation management service	312	14.5
Samchang	Instrumentation-Inspection & maintenance	161	7.5
The rest		100	4.6

* KEPCO Plant Service & Engineering Co., LTD

In the case of occupational exposure, ICRP Pub. 101 suggests a risk aversion factor between 1.2 and 1.8 while the Nuclear Protection Evaluation Centre(CEPN) of France suggests a value between 1.2 and 1.75. As shown in Table 2, the risk aversion factor evaluated by CEPN was a=1.2 when the exposure level was 1-5 mSv/year, a=1.5 when 5-15 mSv/year, and a=1.75 when above 15 mSv/year.[4]

Table 2. Risk aversion factor "a" value by dose level(CEPN)

"a"	1	1.2	1.6	1.75
Dose level (mSv)	0-1	1-5	5-15	15-50

On the other hand, the Korea Institute of Nuclear Safety(KINS), a regulatory agency of Korea, announced the real monetary value of man-Sv of Korea in 2009 as shown in Table 3 below.[5]

Table 3. Real monetary value of man-Sv in Korea (2006).

Gross domestic product per capita (current price 2006) (US$)	18,374
GDP Deflator	111.7
Gross domestic product per capita (constant price)	16,449
Life expectancy in the population (years)	78.5
Loss of life expectancy induced by a radiation health effect (years)	18.5
Monetary value of one health effect	16,449 × 18.5 = 304,306.5 (US$)
Probability of occurrence of health effects associated with 1 Sv (Sv)	5.6×10^{-2}
Risk aversion factor	
0 - 1.0 mSv	1.0
1.0 - 5.0 mSv	1.4

5.0 - 10 mSv	1.5
10 mSv and above	1.7
Monetary value of man-Sv exposure	(US$)
0 - 1.0 mSv	17,040
1.0 - 5.0 mSv	79,320
5.0 - 10 mSv	350,010
10 mSv and above	1701,620

RESULTS AND DISCUSSION

The value of α_{base}, the productivity loss due to life expectancy decrease, is shown in Table 4. In this research, the probabilistic risk factor of radiation was multiplied to the average annual wage of electric workers to reflect the characteristics of NPP radiation workers.[3] For the nominal risk coefficient of radiation, the value presented in ICRP 103 was used.

Table 4. Korean specific factors and basic monetary value(α_{base}) as of 2009

Life expectancy in population (A)	79.4 years[6]
Average age of cancer occurrence (B)	60.0 years[7]
Loss of life expectancy induced by radiation exposure (C = A-B)	19.4 years
Average annual wage for electric worker (W)	56,000$/year[8]
Nominal risk coefficient induced by radiation (P)	$4.2E^{-2}Sv^{-1}$[9]
Basic Monetary Value (α_{base} = C×W×P)	45.6 $/mSv

As observable in Table 5, a majority(79.52%) of NPP workers in 2010 were exposed less than 1 mSv. In the survey used in this study, a paired t-test was used to conduct a significance test on the difference between those with previous exposure and without. The significance was determined at a significance level of 5%. The statistical analysis system(SAS ver 8.2) was used for the paired t-test statistical analysis.[10] 69.46% of the respondents were found to have had exposure of 1 mSv. It was found that there were differences in sensation between respondents that were not exposed and those exposed to more than 1 mSv. On the other hand, there were no differences in sensation for those with or without exposure of 1 mSv.

Table 5. Radiation dose distribution of NPP workers in 2010

	Dose distribution(mSv); d					
	$0 < d \leqq 1$	$1 < d \leqq 5$	$5 < d \leqq 10$	$10 < d \leqq 20$	$20 < d$	Total
Exposed people	9,957	1,720	565	258	22	12,522
%	79.52	13.74	4.51	2.06	0.18	100

In order to take into consideration the socio-psychological factors regarding radiation exposure, the public dose limit of 1 mSv/yr was set as the d_0 value. The radiation risk aversion factor a, which represents the degree of aversion against radiation exposure, was determined for different dose levels through the survey. The resulting α_{ref} values are organized in Table 6.

Table 6. KHNP's Risk aversion factors and monetary values by dose level

	Dose level (mSv)				
	0 - 1	1 - 5	5 - 10	10 - 20	> 20
Aversion Factor	1.26	1.38	1.52	1.65	1.74
α_{ref} ($)	46	210	1,075	3,977	8,370

CONCLUSION

A comparison of the internationally and domestically managed monetary values of man-Sv reveals that most values used by NPP operators are 2-10 times greater than the values used by regulatory agencies. This finding is interpreted to be due to the regulatory agencies using the gross domestic product per capita and NPP operators using the average annual wage of employees in calculating the basic monetary value(α_{base}).

The risk aversion factors derived from the survey of NPP radiation workers are values based on the individual's radiation exposure and underlying perception of radiation. These risk aversion factors were used as an important basis in determining the monetary value of the man-Sv by the NPP operators.

Additionally, while ICRP and KINS provide the risk aversion factor value of "1" in the 0-1 mSv range, the value investigated through this study resulted in ″1.26″. The difference in the values represent a separate and additional aversion to radiation aside from the natural radiation dose even though this value is within the public dose limit.

The monetary value of the man-Sv is expected to contribute significantly in the NPP radiation protection optimization of KHNP. However, for convenient application in the NPP optimization of radiation protection, the values have been rounded up and down to provide a table of representative figures as shwon in Table 7.

Table 7. Representative figures of monetary values of man-Sv by rounding up and down

	Dose level (mSv)				
	0 - 1	1 - 5	5 - 10	10 - 20	> 20
α_{ref} ($)	50	200	1,000	4,000	8,500

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