Identification of risk aversion factor for radiation workers in Korea

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1. Introduction

Radiation aversion factor reflects the degree of avoidance of radiation exposure which is considered a fundamental element in the optimization of radiation protection and a key factor in determining the real monetary value of the man-Sievert (Sv). In the optimization process, questioning of the cost-benefit analysis is essential in main decision-making process.

This study provides an adjusted risk aversion factor, which was prescribed by the Korea Institute for Nuclear Safety (KINS), a regulatory body in Korea. Specifically, the Korea Hydro and Nuclear Power Co., Ltd. (KHNP) evaluated the monetary value of the man-Sv for Korean Nuclear Power Plants (NPPs) workers. This monetary value was assessed by the radiation aversion factor [1]. However, no studies have focused on medical and industrial facilities in Korea. Therefore, the real monetary value of the man-Sv in these sectors has not been confirmed. Consequently, identifying the monetary value of the man-Sv in this study will enhance not only the effectiveness of optimization of radiation protection in Korea but also contribute to reduce doses to As Low As Reasonably Achievable (ALARA) when accounting for economic and societal aspects.

The primary purpose of this study is to obtain the risk aversion factor for radiation workers in medical and industrial facilities in Korea. The secondary purpose is to evaluate the real monetary value of the man-Sv.These objectives will be accomplished by collecting data from surveys that consider a variety of socio-economic conditions.

2. Materials and Methods

Originally, the Nuclear Protection Evaluation Centre of France (CEPN) has recommended that the radiation aversion factor be between 1.2 and 1.75. Furthermore, KINS developed the step function model and recommended the risk aversion factors for the different steps of exposure as follows:
1.0 For 0–1.0 mSv, 1.4 For 1.0–5.0 mSv, 1.5 For 5.0–10 mSv, and 1.7 for 10 mSv and above [2].

Thereafter, the International Commission on Radiological Protection (ICRP Publication 101) suggests that the value stay between 1.2 and 1.8. For practical considerations, the degree of aversion to the level of the individual dose must be greater than 1 to satisfy the objectives of radiation protection. In addition, ICRP indicated that it is more appropriate to assume a constant monetary value for the unit of the collective dose below a certain level of individual dose. Above this level the monetary value of a man- Sv increases with the level of the individual dose taking into account the degree of aversion and the dose levels as shown in Figure 1 .

In order to identify the risk aversion factor for radiation workers, a simplified questionnaire was developed and distributed in Korean hospitals and Non-Destructive Test (NDT) companies. For simplicity, the questionnaire involved 12 clear and understandable queries to effectively achieve the objectives of this study.

2.1 Development of questionnaire

Initially, KHNP developed detailed questionnaires to investigate the degree of radiation aversion among the workers from 10 NPPs in Korea. KHNP's questionnaires included general information regarding the psychological dimensions and detailed queries related to distribution of individual doses.

In this study, the questionnaire was developed based on psychological aspects regarding radiation work, and it included: age distribution, academic qualifications, and work experience. Also, familiarity with radiation work, individual dose distribution, and the degree of acceptance and satisfaction with radiation work.

A sensitivity analysis of key parameters of risk aversion was performed using the linear interpolation method. Thus, the degree of the risk aversion feeling of various responders was observed at different levels of exposure (0-1mSv, 1-3mSv, 3-8mSv, and >15mSv).

The survey, uniquely, has focused on psychological dimensions for radiation workers, therefore, the risk aversion feeling has been quantified for different levels of relative risk aversion with a slightly lower upper value from the one suggested by ICRP. The proposed

aversion factor was ranged from 1.2 to 1.70 as shown below in Table I.

Table I. Quantification of the risk aversion feeling

Risk aversion feeling	Original response	Risk aversion value
None	1	1.20
little	2	1.32
Median	3	1.45
Keep working with salary increasing (%)	4	1.57
Resign from the job	5	1.70

2.2 Target groups

In order to obtain risk aversion factor, 10 hospitals and 10 NDT facilities were selected. A total of 200 questionnaires were distributed to radiation workers in these sectors. Responses from 66 NDT radiographers and 81 radiation medical practitioners were obtained in August 2016.

2.3 Evaluation of the monetary value of the man-Sievert

According to the International Atomic Energy Agency (IAEA), the degree of aversion according to the exposure level is integrated into the monetary value of the man-Sievert, using the following simple model:

$$\alpha_{\mathrm{ref}}(d) = \alpha_{\mathrm{base}} \quad \text{for } d < d_0 \qquad (1)$$

$$\alpha_{\mathrm{ref}}(d) = \alpha_{\mathrm{base}} \left(\frac{d}{d_0}\right)^a \quad \text{for } d \geq d_0 \qquad (2)$$

In this model:
$\alpha_{ref:}$ the monetary value of unit collective dose for level of exposure.
$\alpha_{base:}$ baseline monetary value of unit collective dose for exposure arising at levels of individual dose lower than $d_{o.}$
$d_{0:}$ upper band of the range of individual dose for which α_{base} is applicable.
$d_{:}$ level of individual dose ($d > d_o$).
a: exponent representing the degree of aversion [3].

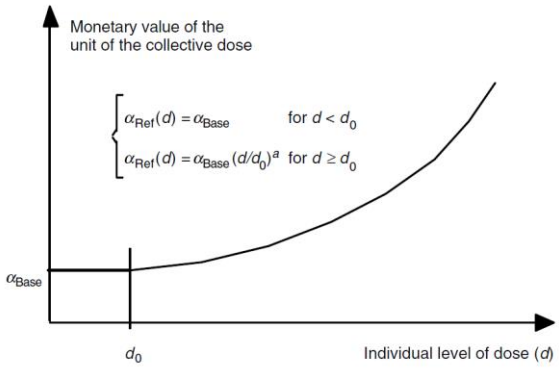

Figure 1. Modal of monetary values of the man-Sv.

The monetary value of health effects (α_{base}) can be changed with the increment of the Gross Domestic Product (GDP) per capita per year using the human capital approach as shown below.

$$\alpha = M \times P, \qquad (3)$$

$$M = GDP \times A, \qquad (4)$$

where M is the monetary value of a radiation induced health effect, P is the probability of the occurrence of a radiation-induced health effect with 1 Sv, for the Korean model 5.6 x 10^{-2} Sv^{-1} [2], A is the average loss of life expectancy associated with a radiation-induced health effect (18.5years in Korea), and GDP per capita – constant price in 2010 is US$ 25,000[4, 5].

3. Results and Discussion

A quantitative analysis to determine the risk aversion factor for each group was applied. It is evident from results that the majority (45.4 %) of NDT radiographers represented the median value of the risk aversion feeling which was 1.45 in the 3-8 mSv range, while most interventional radiologists (71.2 %) kept working with incremental salary increases which is represented by 1.57 in the 8-12 mSv range. The distribution of the responses can be observed in Figure 2.

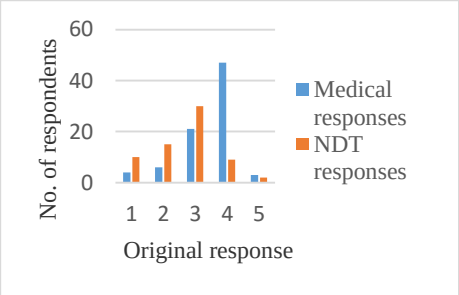

Figure 2. NDT and Medical responses

It is important to reiterate that KINS step function model indicated the following values of the risk aversion factors: 1.4 for 1.0–5.0 mSv, 1.5 for 5.0–10

mSv, which are generally applied to hospitals and NDT sectors. However, the upper values 5.0–10 mSv, and 1.7 for 10 mSv and above of this model shall rarely occurred during NPP work. According to Figure 2, it was observed that most of the worker responses were 3 and 4 which indicated the levels of exposures at 3-8 mSv, and 8-12 mSv, respectively.

Noticeably, the value of risk aversion factors was slightly higher than the suggested value, in particular among medical practitioners, while it was slightly lower than the previous values of NDT workers. The real monetary value of the man-Sv increases due to the increment of GDP and the magnitude of individual doses. After applying the values of the risk aversion factors (a) of the exposure levels to the model of monetary values, different monetary values (α_{ref}) were calculated. Table II. consists of these values with different levels of exposures and quantitative values of the aversion factors.

Table II. Calculated values of radiation aversion factors and monetary values.

Dose level (mSv)					
	0 -1	1 - 3	3 - 8	8- 12	>15
a	1.20	1.32	1.45	1.57	1.70
α_{ref} ($)	25900	110,433	528,178	1,281,192	2,586,157

Table III. KINS's radiation aversion factors (a) and monetary value by radiation dose level.

Dose levels (mSv)	0-1.0	1.0-5.0	5.0-10	≥ 10
a	1.0	1.4	1.5	1.7
α_{ref} ($)	17,040	79,320	350,010	1701,620

According to equations (3) and (4), the baseline monetary value (α_{base}) was 25,900 US$ which was applied directly to the model to obtain the real values for each level of exposure and the corresponding aversion factors.

4. Conclusion

Most importantly, the radiation aversion factors derived from the questionnaire were based on psychological dimensions related to distribution of individual doses.

The value of 1.45 represents considerable avoidance of radiation risk for the majority of NDT radiographers due to familiarity and work experience with radiation hazards. On the other hand, the value 1.57 indicates that most of radiation medical practitioners, in particular, interventional radiologists have a strong will to avoid radiation risk. However, they will accept more risk with incremental salary increases. According to the results, the monetary value of the unit of the collective dose at the reference individual dose (α_{base}) resulting in $_{25,900}$ $ mSv^{-1}, which is significantly increased compared with the value prescribed by KINS. As shown in Table II., the risk aversion factors are slightly increased as compared with former values which are suggested by KINS (Table III.), while the monetary values are significantly increased than the previous values due to increment of GDP.

For international comparison, the concept of Purchasing Power Parity (PPP) should be adopted to obtain the alpha values in real term.

Certainly, this monetary value of the man-Sv is expected to contribute effectively in optimization of radiation protection in both medical and industrial fields. The findings of this study will be useful as a basis for further research in different radiation fields.

Acknowledgements

The authors would like to thank the Korea Institute for Nuclear Safety (KINS) for research fund.

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