A model to establish the monetary value of the man-sievert for public exposure

T. Schneider¹, C. Schieber¹, L. Eeckhoudt², P. Godfroid²

¹Nuclear Protection Evaluation Centre (CEPN), BP48, 92263 Fontenay-aux-Roses, France
²Catholic University of Mons (FUCAM), 151 Chaussée de Binche, 7000 Mons, Belgium

INTRODUCTION

In order to select, among the range of possible protective actions, those which are consistent with the available resources and which ensure that the risks are distributed satisfactorily between individuals, the use of economic analysis (through cost-benefit analysis) was introduced in the early 1970s by the ICRP (1, 2, 3). In this perspective, the monetary value of the man-sievert appears to be a central element for the implementation of the optimisation of the radiation protection. For occupational exposures, a model to determine the monetary value of the man-sievert has been developed (4) and some operators of nuclear installations and authorities have gradually adopted monetary values as a decision-aiding tool for the evaluation of major protective actions. Recent reflections have pointed out the needs for differentiating the monetary values of the man-sievert according to the exposure situations under consideration (5). The aim of this paper is to propose a model for the determination of the monetary values to be applied for the evaluation of protective actions related to public exposures.

ROLE AND EVALUATION OF THE MONETARY VALUE OF THE MAN-SIEVERT

The aim of optimisation of radiation protection is to obtain an efficient allocation of protection resources. The efficiency criterion does not rely solely on the financial return on investments, but also on ethical and social dimensions related to the acceptability of risk according to the various exposure situations. As such, the monetary value of the man-sievert is a key element for the implementation of optimisation allowing to take into account the detriment as well as the benefits expected from activities in the allocation of protection resources. This allocation has notably to take into account the risk transfers between populations.

From the economic point of view, the monetary value of the man-sievert can be seen as a function reflecting the "utility" (or disutility) or individual and collective preferences associated with the level of exposures and the specific exposure situation. For this purpose, it has to integrate several dimensions:

- One dimension, which is independent of the exposure situation, is related to the potential health effects associated with the level of exposure. These health effects consist mainly in delayed cancers (fatal and non fatal) and severe hereditary effects. Within the economic theory, several methods already exist for the valuation of health detriment (Quality Adjusted Life Year, Value of Statistical Life based on Willingness to Pay Approach or Human Capital Theory). Therefore, the knowledge of the dose-effect relationship allows to determine the monetary value of the health detriment, which forms one component of the monetary value of the man-sievert. It has to be noted that the health detriment, when it occurs, is the same for public, workers or future generation individuals whatever exposure situation is considered.

- Besides the health detriment dimension, it is necessary to introduce social and equity dimensions which should allow to reflect the specificity of the various exposure situations: characteristics of the situation, distribution of individual exposures, individual and social risk perception, weighting of probabilities and consequences for potential exposure, aversion towards uncertainty when dealing with future generations etc…

METHODOLOGY DEVELOPED FOR THE EVALUATION OF PUBLIC EXPOSURES

Differences between public exposures and workers exposures

In the case of occupational exposure, a model for defining the monetary values of the man-sievert was developed a few years ago and has favour the adoption of monetary values by some operators of nuclear installations and authorities. Although the reference to the monetary value of the man-sievert is observed in a number of decisions related to the protection of workers, there was only a few discussions for public exposures.
It is notably considered that for these latter the monetary value of the man-sievert should be different.

In this perspective, the main differences between an individual exposure for a member of the public and for a worker have been considered in terms of their influence on the willingness to pay for a reduction of exposure (reduction of the probability of radiation induced cancer). After an analysis of a number of differences (level of initial exposure, age at exposure, compensation system...), the possibility to compensate the workers in case of radiation induced cancer was considered as the major difference between workers and public exposures from the economic point of view.

In practice, compensation systems have been implemented for the workers exposed to ionising radiations and having developed a cancer. In the case of public exposure, such systems do not exist, mainly due to the absence of a permanent individual monitoring of exposures and to the low level of exposures (6).

**Theoretical model for the monetary value of the man-sievert for public exposures**

In order to determine the monetary value of the man-sievert applicable for public exposure, the theoretical approach adopted consists in evaluating the willingness to pay for a reduction of exposure in case of public exposure compared with the same reduction for occupational exposure (7). Based on the expected utility approach, the following parameters have been considered in the model:

- the total wealth of an individual in the absence of radiation induced cancer;
- the loss associated with the occurrence of a radiation induced cancer (this parameter being less important when a compensation exists);
- the probability of occurrence of a radiation induced cancer according to the exposure level;
- the reduction of exposure.

In order to characterise the utility function reflecting the preferences of the individual, a relative risk aversion coefficient was considered. This relative risk aversion coefficient reflects the attitude of individuals towards risk.

This model leads to the conclusion that there is in general a negative influence of the level of the compensation on the value of the willingness to pay. Therefore, given the fact that the member of the public cannot be compensated if they declare a radiation induced cancer, the willingness to pay to reduce their probability of cancer (i.e. to reduce their level of exposure) should be higher than the willingness to pay applied to reduce the probability of cancer for the workers.

**PROPOSED MONETARY VALUES FOR PUBLIC EXPOSURES**

In order to determine a monetary value of the man-sievert for public exposure, a numerical application of the theoretical model has been proposed. For this purpose, the following parameters have been characterised: range of probabilities of radiation induced cancer for public and workers exposures, reduction of exposures, level of wealth and compensation system. On this basis, the evolution of the willingness to pay has been analysed for different levels of relative risk aversion (ranging from 1 to 3).

**Range of probabilities for public and workers**

The value of the initial probability of radiation induced cancer for public and workers has been evaluated on the basis of the dose-effect relationship associated with ionising radiation (8). The situations considered for assessing these probabilities refer to individual exposure levels reflecting current situations.

- If we assume a member of the public exposed at 0.1 mSv/year during 75 years, his lifetime dose is equal to 7.5 mSv, and, applying the dose-effect relationship, his lifetime risk (probability of occurrence of a radiation induced fatal cancer) is equal to $4 \times 10^{-7}$.

- If we assume a worker exposed at 5 mSv/year from age 18 to 65 years, his lifetime dose is equal to 240 mSv, and his lifetime risk is equal to $10^{-7}$. 

In both situations, the initial probability of a radiation induced cancer, considered in the numerical application, corresponds to the lifetime risk.

**Reduction of the exposure level**

For comparing the willingness to pay for a reduction of probabilities of radiation induced cancer for workers and public exposures, a reduction of exposure leading to a decrease in probability equal to $10^{-4}$ has been considered. Therefore, the probabilities after the reduction of the exposure level are respectively for public and workers: $3 \cdot 10^{-4}$ and $99 \cdot 10^{-4}$.

**Level of wealth and loss of wealth**

For evaluating the utility of the individual in the different exposure situations, the initial level of wealth, expressed in monetary terms, is considered. This wealth is supposed to be the same for a member of the public and a worker: 915 KEUROS (rounded value). It is based on two components: the monetary value of life (about 850 KEUROS) and the average individual financial wealth (estimated to 65 KEUROS).

The loss of wealth in case of occurrence of a radiation induced cancer is evaluated on the basis of its associated loss of life expectancy (GDP/capita x loss of life expectancy due to a radiation induced cancer): 305 KEUROS (rounded value).

**Compensation system for occupational radiation induced cancer**

Three situations have been considered for the levels of compensation for the workers: no compensation (just for the sake of comparison with the public situation), compensation of 50% of the loss of wealth or compensation of 75% of the loss of wealth.

In fact, one may consider that the compensation systems already implemented in the case of occupational diseases, and more specifically in the case of occupational cancers, generally cover expenses in the range of 50 to 75% of the loss of wealth.

**The main results**

From the numerical application, a ratio between the willingness to pay for a reduction of probability of radiation induced cancer for a member of the public and the one for the workers has been calculated. Depending on the level of compensation for workers and on the relative risk aversion coefficient for the utility function, the willingness to pay for a reduction of probability of developing a radiation induced cancer for a member of the public should be between 2 and 6 times higher than that of a worker.

Figure 1 summarises the results obtained for the different values of the relative risk aversion coefficient.
On this figure, one should notice that in the absence of a compensation system for workers, the willingness to pay for a reduction of probability of radiation induced cancer is similar between workers and public.

**Application to the monetary value of the man-sievert**

On the basis of the human capital approach, the monetary value of the health effects is given by valuing one year of loss of life expectancy with the Gross Domestic Product per capita per year. According to the dose-effect relationship for ionising radiation, it leads to a monetary value of the radiation health effects per man-sievert for the public equal to: 25 KEUROS/man.Sv.

Furthermore, a recent survey conducted in France to evaluate the willingness to pay to reduce the probability of a radiation induced cancer in case of occupational exposure in nuclear power plants allowed to obtained a monetary value of the human life in case of death by cancer equal to 450 KEUROS (9). According to this value, and using the probability of occurrence of a radiation induced health effect for the public presented above, the following monetary value of the man-sievert is obtained: 33 KEUROS/man.Sv.

Adopting a relative risk aversion coefficient between 1 and 3 for the utility function, and assuming that usually the compensation for a radiation induced cancer is in the range of 50 % to 75%, the following set of multiplying coefficients is proposed in order to derive the monetary values of the man-sievert for public exposures from the values related to occupational exposures: 2; 4 and 6.

Table 1 gives the resulting monetary values of the man-sievert for public exposures when the different multiplying coefficients have been applied.
Table 1. Proposal for the monetary values of the man-sievert in case of public exposure

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<tr>
<th>Basic monetary value of the man-sievert</th>
<th>Multiplying coefficient</th>
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The resulting monetary value of the man-sievert to be applied in optimisation studies for the reduction of public exposures ranges from 50 KEUROS/man.Sv to 200 KEUROS/man.Sv.

CONCLUSION

The theoretical model used to evaluate the monetary value of the man-sievert suggests a higher willingness to pay to reduce the probability of occurrence of a radiation induced fatal cancer for the public than for workers. This difference is mainly related to the non-existence of a compensation system for members of the public. For worker exposure, compensation systems are implemented in case of recognition of occupational diseases, including cancer potentially induced by radiations. The numerical application of the model shows that depending on the level of compensation for workers and on the relative risk aversion coefficient adopted for the utility function, the willingness to pay for a reduction of probability of developing a radiation induced cancer for a member of the public should be between 2 and 6 times higher than that of a worker. The resulting monetary value of the man-sievert to be applied in optimisation studies for the reduction of public exposures is ranged between 50 KEUROS/man.Sv and 200 KEUROS/man.Sv.

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REFERENCES