Radioprotection 2020, 55(3), 207–214

https://doi.org/10.1051/radiopro/2020058

Available online at:
www.radioprotection.org

ARTICLE

The values and the uses of the reference monetary value of the man.sievert. Results of an international survey

S. Andresz[1,*], T. Jobert[2] and C. Schieber[1]

[1] Centre d'étude sur l'évaluation de la protection dans le domaine nucléaire (CEPN), 96260 Fontenay-aux-Roses, France.
[2] Électricité de France, Direction technique de la DIPNN, Groupe Radioprotection, 69007 Lyon, France.

Received: 7 April 2020 / Accepted: 2 July 2020

Abstract – For complex radiation protection project, decision-aiding techniques, such as Cost-Benefit Analysis can be used. In 1973, the International Commission on Radiological Protection introduced the "reference monetary value of the man.sievert" to convert the benefit of a radiation protection option (averted exposure) in monetary term for comparison with it is cost. In 2017, an international survey has collected the reference monetary values of nuclear utilities and regulatory authorities. This article presents the data collected and analyzes them. Over the 220 reactors who answered, 176 (80%) are using the concept, expressing its longevity and relevance for optimization purposes. The utilities can use single value or set of reference values varying with the level of exposure. This survey also highlights the emergence of mixed and flexible systems. The collected values are largely spread (ratio 1:10 at least) and this is the opportunity to discuss the influence of the method used to calculate the reference value and notably the related concept of the Value of a human Statistical Life (VSL).

Keywords: reference monetary value of the man.sievert / ALARA / Cost-Benefit Analysis (CBA) / Value of a human Statistical Life (VSL)

1 Introduction

The optimization principle is one of the three principles of the radiological protection system lay down by the International Commission for Radiation Protection (ICRP) and is defined as the process "*to keep the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures* [...] *as low as reasonably achievable* [ALARA[1]], economic and social factors being taken into account" (ICRP, 2007).

For the practical implementation of optimization, ICRP suggested in 1973 to use decision-aiding techniques (Cost-Benefit Analysis [CBA]) to help find the optimum option (or scenario) among the variants (ICRP, 1973). Later, ICRP provided additional guidance on CBA for optimisation purposes (ICRP, 1977, 1983, 1985, 2001).

When performing a CBA, the benefit of the radiation protection option in averted exposure needs to be converted into monetary term to be compared with the cost of the option. Therefore ICRP introduced the "*monetary cost assigned to the unit of the collective dose*" (§24, ICRP, 1973) in monetary term per man.sievert (*e.g.* €/man.Sv). This conversion factor is often referred as "*the reference monetary value of the man sievert*" or even simpler '*the alpha value*' (because ICRP also introduced beta values). More information on these concepts and how to use the alpha (and beta) values in a CBA are shown in Appendix 1.

Since 1973, this concept has been adopted by many nuclear regulatory authorities and utilities worldwide. For example, Électricité de France (EDF) adopted in 1992 a system of reference monetary values (Berthet *et al.*, 1992) and updated it in 2002. Recently, EDF was considering a new update and contacted the Nuclear Protection Evaluation Centre (CEPN) to investigate the values in other organizations.

The CEPN had already conducted surveys to collect data about reference monetary values and how it is used *via* the Information System on Occupational Exposure (ISOE[2]) (ISOE, 1998, 2003, 2012). However, these data were old and subject to evolution, so it appeared advisable to conduct a

* Corresponding author: sylvain.andresz@cepn.asso.fr

[1] ICRP emphasized that "optimization of radiation protection" and "ALARA" are synonymous and interchangeable (ICRP, Pub 42).

[2] The ISOE system was created in 1992 and is a forum for radiation protection professionals from nuclear electricity utilities and national regulatory authorities worldwide to share dose reduction information, operational experience and information to improve the optimization of radiological protection at nuclear power plants. CEPN is the ISOE European Technical Centre.

new survey. The survey was conducted in 2017 and the purpose of this article is to present the values collected and an analysis of the answers received. The discussion part is the opportunity to talk about evolutions since the previous surveys, and the current trend for calculating the reference monetary value.

2 Methodology

The survey was made from May to July 2017 with two questionnaires sent by email to selected ISOE contacts. One questionnaire was designed for the nuclear regulatory authorities and one for the nuclear utilities.

The first question aimed to check if a reference monetary value is used in the organisation. If yes, the respondent was invited to answer a series of questions about:

– the value;
– its regulatory status (question addressed to regulatory authorities only);
– if document about its calculation and use exist;
– the users and the frequency of use (question addressed to utilities only);
– the decision under the scope (asking for examples);
– the benefits and the limits of the concept.

If no, the respondent was directed to detail why the concept is not introduced.

Several respondents were contacted later by email for clarification and documentation.

For the purpose of data comparison, the collected values have been converted in $€_{2017}$/man.mSv using the money exchange rates in July 2017 and rounded at the exact Euro using the usual rounding.

3 Results

3.1 Number of answers received

Answers originating from 21 countries have been collected: 18 regulatory authorities (from the 26 contacted) and 14 utilities (from the 44 contacted) answered directly to CEPN (Tab. 1). Additional information coming from all the 10 Japanese's utilities have been sent by the ISOE Asian Centre and a set of data covering 70 Nuclear Power Plants (NPPs) has been sent by the ISOE North American Centre.

Table 1. Origin of the answers.

Country	Nuclear regulatory authority	Nuclear utility and/or Nuclear Power Plant (NPP)
Belarus	X	
Belgium	X	X (Electrabel: 2 NPPs)
Canada	X	
China	X	
Czech Republic	X	
Finland	X	X (Loviisa NPP)
France	X	X (Électricité de France: 19 NPPs)
Germany	X	
Japan	X	X (from 10 utilities: 42 NPPs[a])
Lithuania	X	
The Netherlands	X	
Republic of Korea		X (Korea Hydro & Nuclear Power: 4 NPPs)
Romania		X (Cernavoda NPP)
Slovakia	X	
Slovenia	X	X (Krško NPP)
Spain	X	X (Cofrentes NPP)
Sweden	X	X (Forsmark NPP and Ringhals NPP)
Switzerland	X	X (Leibstadt NPP)
Ukraine	X	
United Kingdom	X	X (Sizewell B NPP)
United States of America		X (Exelon (13 NPPs), Palo Verde NPP, Cook NPP and 55 other NPPs[b])

[a] The ISOE Asian Technical Centre has collected 10 questionnaires from Chubu Electric Power Co., Chugoku Electric Power Co., Hokkaido Electric Power Co., Hokuriku Electric Power Co., Japan Atomic Power Co., Kansai Electric Power Co., Kyushu Electric Power Co., Shikoku Electric Power Co., Tokyo Electric Power Co. and Tohoku Electric Power Co.

[b] The ISOE North American Technical Centre has provided a set of data collected in 2015 and covering 70 NPPs. Exelon utility, Palo Verde and Cook NPPs were included in the set of data and have also answered directly to the survey in 2017.

3.2 Answers from the nuclear regulatory authorities

3.2.1 Reference monetary values of the man.sievert

The answer rate of the authorities is high (70% of those contacted), but only a small proportion of those (17%) are using or recommending a reference monetary value: only the British Office for Nuclear Regulation (ONR), the Slovak Public Health Authority (UVZSR) and the Czech State Office for Nuclear Safety (SÚJB).

The other authorities accounted that the utilities in the country have already adopted a value and/or are sole in charge of using it, so it is not necessary for the authority to explore the subject. Besides, some authorities have knowledge of the reference values used by the utilities in the country and provided reference to these.

The ONR does not explicitly recommend a value and advices to derive one from the recommendation of ICRP and the Health and Safety Executive (HSE). UVZSR and SÚJB both reported a set of values, varying with the level of individual exposure (expressed as fraction of the dose limit for workers) and the exposure situation. The two sets are quite comparable, although the categories and the values are not identical (Tab. 2). Both authorities consider public exposure received during medical treatment and exposure to natural sources (radon and naturally occurring radioactive material are reported examples).

3.2.2 Regulatory status and uses by nuclear regulatory authorities

The values reported by UVZSR are used in-house and has no regulatory nor guidance status. On the opposite, the values

Table 2. Set of reference monetary values reported by the Slovak Public Health Authority and the Czech State Office for Nuclear Safety.

Situation of exposure	Slovak Public Health Authority (UVZSR)	Czech State Office for Nuclear Safety (SÚJB)
Planned exposure situation (workers)		
Exposure <1/10th of annual dose limit	α = 33 €/man.mSv	α = 19 €/man.mSv
Exposure between (1/10th–3/10th) of annual dose limit	α = 50 €/man.mSv	α = 38 €/man.mSv
Exposure >3/10th of annual dose limit	α = 200 €/man.mSv	α = 95 €/man.mSv
Occupational exposure between 20–50 mSv on average on a year	α = 660 €/man.mSv	*Not addressed*
Emergency situation		
Occupational exposure	α = 150 €/man.mSv	α = 95 €/man.mSv
Other exposure situations		
For medical treatment	α = 40 €/man.mSv	α = 38 €/man.mSv
Exposure from natural source of radiation	*Not addressed*	α = 19 €/man.mSv

reported by SÚJB are inserted in the regulation[3], and a licensee shall consider them when performing a CBA (the licensee can use other values, but this should be justified).

SÚJB and UVZSR have used the reference monetary values, either directly for optimization analysis under their watch (example: calculation of shielding thickness in medical installation), or as a tool to evaluate licensee's decision (the example was the decontamination of circuits in NPP) and in "*some activities with natural sources*".

All authorities insist that the result of a CBA "*cannot be the whole argument in the decision*" and is an "*additional tool*" that help to drive the optimization. The reference monetary value is also regarded as a manner to hold a dialogue between the authority and the utility.

3.3 Answers from nuclear utilities

3.3.1 Reference monetary values of the man.sievert

Over the 14 utilities that directly answered the survey, eight (60%) are using a reference monetary value. And taking into account the answers sent by the other ISOE Technical Centres, 176 of the 220 reactors covered by the survey (80%) have reported having adopted the concept. The collected values are presented in Table 3 and Figure 1.

3.3.2 Users and uses of the reference monetary values

The prime (and sometimes the only) user is the Radiation Protection Department. Additional users are mentioned: other departments (*e.g.* maintenance, chemistry) and management. The frequency of use is generally 1–10 times a year, sometimes less (once a year) and never more than 10 times a year. Several examples of uses have been collected:

- decision on large-scale modifications ("*large/important projects*" is a common wording and reported six times): installation of a microfiltration system in the circuit or the renewal of parts of the waste system;
- to decide to perform the decontamination of circuits and also the size (reported three times);
- installation/removal of permanent shielding and scaffolding (two times);
- power reduction (two times);
- building a facility with radiation protection impact (one time);
- ranking modifications for the medium terms (one time).

However, indications on the rationale to calculate the reference value and how to use it are rarely documented.

There is consensus to say that CBA is not the sole support of the decision and is part of a broader process ("*one item of the optimization analysis*"). It is not uncommon that a project is implemented even if the reference value is exceeded.

3.3.3 Reasons for not using a reference monetary value

Nuclear utilities in Belgium, Finland, South Korea, United Kingdom and the majority of Japanese's have not adopted a reference monetary value. Nevertheless, all these utilities are congruent to say that ALARA is always applied in their organisation.

The arguments for not having a value are:

- such value simply does not enter in the decision-making process (this is mentioned by several utilities in Japan);
- there is no pressure from the authority to introduce the concept;
- the reference monetary value is a simplistic tool and each project is so different that it is not possible to have one standard criterion.

In the United Kingdom, the utility explained that the application of the optimization can be judged at the light of other tools (notably good practices) and that having no value provide more flexibility in decision-making. In South Korea, the utility is considering to introduce a value.

4 Discussion

4.1 Users and uses

The reference monetary value is more commonly used by utilities compared to authorities. This is not surprising given

[3] Section 7, § 6 of SÚJB, 2016.

Table 3. Reference monetary values of the man.sievert reported by utilities.

Country	Utility or NPP	Reference monetary values of the man.sievert (in $€_{2017}$/man.mSv)
Belgium	Engie – Electrabel	*No*
Finland	Loviisa NPP	*No*
France	Électricité de France	Set of values based on the individual annual exposure of the workers (last update: 2002) – [1–10] mSv/y: 650 €/man.mSv – [10–16] mSv/y: 1,300 €/man.mSv – [16–20] mSv/y: 1,800 €/man.mSv
Japan[a]	Chubu Electric Power Co.	*No*
	Chugoku Electric Power Co.	*No*
	Hokkaido Electric Power Co.	*No*
	Hokuriku Electric Power Co.	*No*
	Japan Atomic Power Co.	*No*
	Kansai Electric Power Co.	*No*
	Kyushu Electric Power Co.	*No*
	Shikoku Electric Power Co.	*No*
	Tokyo Electric Power Co. (apply to Fukushima NPP only)	Set of values (adopted in 2015) based on the average individual exposure for the task under consideration – ~1 mSv: 44.5 €/man.mSv – [1–5] mSv: 445 €/man.mSv – [5–10] mSv: 890 €/man.mSv – [10–20] mSv: 4,450 €/man.mSv – >20 mSv: 8,900 €/man.mSv
	Tohoku Electric Power Co.	*No*
Republic of Korea	Korea Hydro and Nuclear Power	*No*
Romania	Cernavoda NPP	Single value: 570 €/man.mSv (last update: 2010)
Slovenia	Krško NPP	Set of values based on the collective exposure of the population concerned by the task – If <50 man.mSv: 1,000 €/man.mSv – If >50 man.mSv: 2,600 €/man.mSv (2013 values)
Spain	Cofrentes NPP	Single value: 5,000 €/man.mSv (last update: 2012)
Sweden	Forsmark NPP	Single value: 1,100 €/man.mSv
	Ringhals NPP	Single value: 1,203 €/man.mSv (last update: 2015)
Switzerland	Leibstadt NPP	Set of values based on the individual annual exposure of the workers concerned by the investment – [1–10] mSv: single value equal to 273 €/man.mSv – [10–20] mSv: alpha value is increasing linearly up to 2,730 €/man.mSv (at 20 mSv)
United Kingdom	Sizewell B NPP	*No*
United States of America	From 43 NPPs[b]	Single value for the plant and ranging from 446 €/man.mSv to 3,570 €/man.mSv
	Cook NPP	Single value: 2,014 €/man.mSv
	Exelon utility	Mixed system: single value for the plant, based on the INPO radiation protection ranking – NPP in the 1st quartile: 1,780 €/man.mSv – 2nd quartile: 3,560 €/man.mSv – 3rd quartile: 5,340 €/man.mSv – 4th quartile: 7,120 €/man.mSv
	Palo Verde NPP	Single value: 2,739 €/man.mSv (last update: 2011)

[a] Data collected by the ISOE Asian Technical Centre.
[b] Over the 70 NPPs covered data set sent by the ISOE North American Technical Centre: the data from Exelon utility (13 NPPs), Cook and Palo Verde NPPs have been excluded because these interlocutors provided information directly through the survey in 2017 (cf. Tab. 1); eight NPPs have reported "*no longer* [using] *a value*"; one NPP has indicated being under decommissioning; and three NPPs have reported no information.

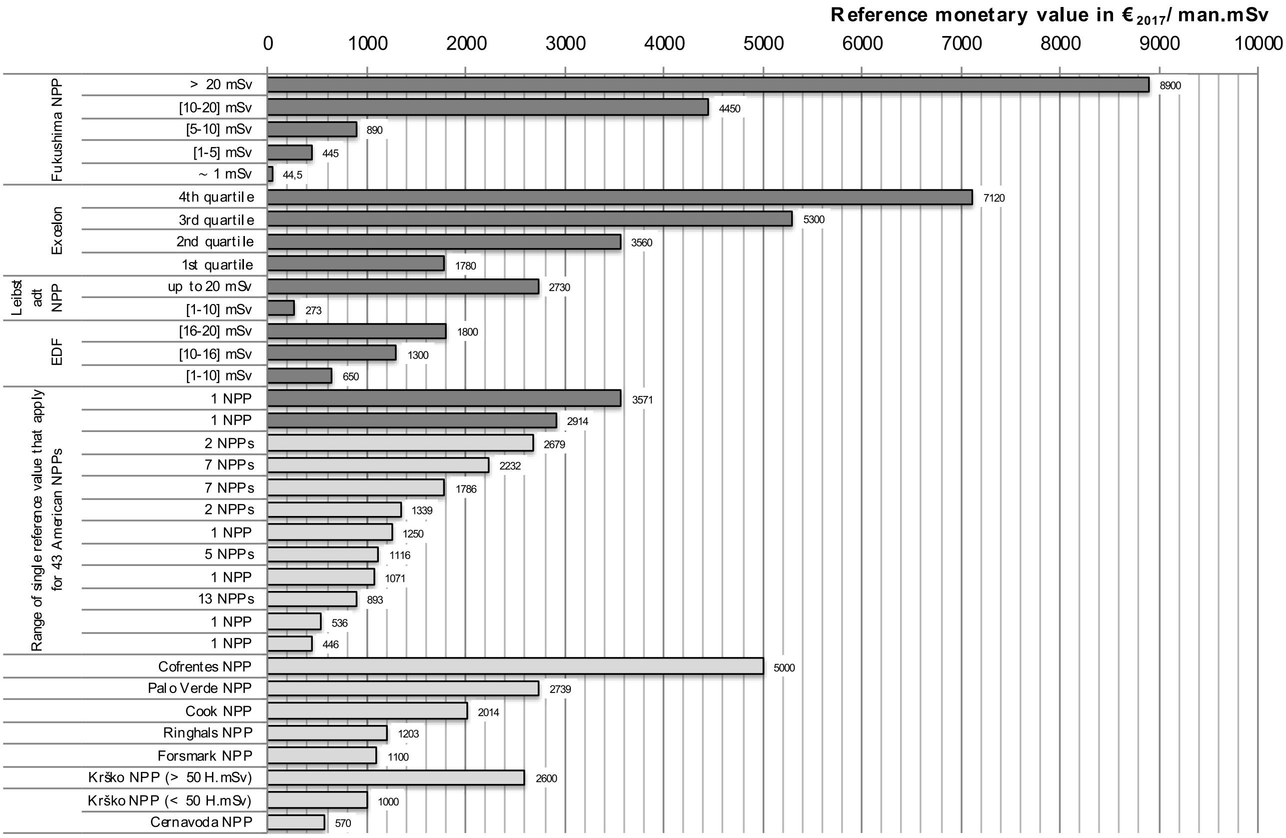

Fig. 1. Reference monetary values of the man.sievert reported by utilities.

that the concept has been designed firstly for utilities and practical radiation protection. In addition, the application of ALARA is the responsibility of the employer/utility and this was mentioned several times by authorities.

However, recent reflections at a SFRP-IRPA workshop on the reasonableness in ALARA pointed out that "[for the better search of the reasonableness] *it is necessary to establish a dialogue between the utility and the nuclear regulatory authority to set and share the criteria used in the optimization process*" (Schneider *et al.*, 2017). The results of the survey illustrate a potential point of weakness in the dialogue between authority and utility.

Considering the frequency of use and the examples, the reference monetary value is clearly not a day-to-day tool but is used for major projects having potential impacts on radiation protection, costs, safety, operation, etc. From the examples, the reference monetary value can be used twofold: to assess the "reasonableness" of a given project and to prioritize several scenarios/projects between each other's.

4.2 Single *versus* set of reference values

Half of the utilities who directly answered the survey has reported using a single monetary reference value when the other half has reported a set of values.

The single values range from 446 €/man.mSv to 5,000 €/man.mSv; hence more than a factor 10 between the lowest and the maximum (average and median are respectively 1,540 €/man.mSv and 1,200 €/man.mSv).

The second half of utilities is using a set of reference values increasing with the level of exposure of the workforce and this offers the possibility to adjust the effort with regard to the exposure of the individuals. The higher the individual risk, the higher the will to spend more to protect these individuals (this is "risk aversion"). Yet, the level of exposure of the workforce is expressed differently: individual annual dose, individual or collective doses associated with the project, quoted as exact value, band of values, etc. The number of values in a set is limited to 2–3 in general (5 maximum in the survey), certainly for practicality. No mathematical model linking the reference values with the level of exposure has been reported (the question was not explicitly asked). Leibstadt NPP is visibly using a linear model and Berthet *et al.* (1992) presented in *Radioprotection* the convex function used by EDF.

There is no consensus among utilities between the two systems. Both have advantages and disadvantages: single values are simpler to set up and use but are a crude tool and does not allow for adjusting the effort with regard to the exposure of the individuals. Set of values integrates collective and individual exposures, however, this requires a discretization of the (predicted) exposure of the workforce; a task that radiation protection specialists know to be challenging because predicted exposure changes individually, with time (depending on recent jobs) and is subject to uncertainties.

Exelon and other American utilities are using a mixed-system: a set of reference monetary values is calculated by the utility, and each NPP is allocated with a single value, based on plant-specific radiation protection conditions such as the total collective exposure from previous years.

4.3 Evolutions of the answers since previous surveys

The former ISOE surveys (ISOE, 1998, 2003, 2012) used a similar questionnaire so the results over time are comparable.

When it comes to the authorities, the results have barely changed: a reference monetary value is rarely set and the consensus is to report that optimization is in the hands of the utilities.

When it comes to utilities, eight American NPPs have answered in this new survey that they are "*no longer using a reference monetary value per advice of their legal department*". On the opposite, the concept has been introduced at Fukushima-Daiichi NPPs in 2015. This is the only NPP in Japan using the concept and this adoption was certainly driven by the specific context of the plant where the potential for elevated exposure has increased and the utility need to order all the radiation protection works and allocate economical and human resources at best.

The equilibrate balance between single *versus* set of reference values users has not changed over time. Still, two evolutions are noteworthy: Cofrentes NPP reported using a set of two values increasing with the collective and the individual doses of the workforce (ISOE, 2003), then reported using a set of two values increasing with the individual dose only (ISOE, 2012), and reported a single value in this survey. On opposite, Krško NPP reported using a single value of 1,000 €/man.mSv in 2003 and reported the same value in 2017, but added now the possibility to sharply increase it (up to 2,600 €/man.mSv) for job with elevated collective dose prognosis.

4.4 Methods to calculate the reference monetary values

As illustrated in Section 3.3.1, the spread of reference monetary values is striking. This observation incites to discuss the methods used to calculate a reference monetary value.

The alpha term of the reference monetary value of the man.sievert is the "reasonable" financial amount to spend for a reduction in collective dose. The collective dose is associated with a level of risk *via* the concept of *radiological detriment*[4]. At low dose and low dose rate, the detriment is the late occurrence of cancers (stochastic effect). A reduction in collective dose will thereby prevent death due to radiation-induced cancers. These prevented deceases can be evaluated in monetary term with the Value of a Statistical Life (VSL).

The concept of the VSL was first formulated by Drèze (1962) and has been the focus of many discussions since (Dionne and Lebeau, 2010). A key point is that the VSL is not the actual value of the life of an individual but the amount the individuals (or the society) are ready to spend to decrease a certain risk of decease.

The simplest method is the Human Capital (HC) where the VSL is valued in the light of the individual economical production, generally the gross domestic product per year and capita. An alternative is the implied or revealed preference method, which is based on the retrospective assessment of how much has been paid in past investments to avoid a certain risk. More recently, the Willingness-To-Pay (WTP) approach has been developed and this one is based on designed questionnaires addressed to the relevant individuals.

The HC was mostly used by utilities when they introduced a reference monetary value in the 1990s. Indeed, it is a simple method, and at the time recommended by IAEA (1985) and leading to consistent values (Hardeman *et al.*, 1998). But the HC is regarded as shortcoming because the VSL is valuated only by considering a loss in the country's economic production and excludes all other considerations. The HC is no longer the state-of-the-art and literature shows that the WTP is the most favoured methodology today (Baumstark, 2008). A recent congress of the French Society for Health and Environment (SFSE, 2018) showed that CBA using the WTP is now of standard application in health and safety sectors or for environment-related decisions.

When embedding other considerations and detriments, the alpha value will increase. In 1995, when the American authority (NRC) switched from HC to WTP, the reference value doubled. And 20 years later, another doubling is expected following a proposed reassessment of the VSL (NRC, 2015).

In France, Quinet (2013), under the aegis of the Commissariat général à la stratégie et à la prospective, performed a meta-analysis of hundreds of WTP studies valuating the VSL and concluded that a unique and statutory VSL of 3 million $€_{2010}$ can be recommended for France. In the technical recommendation, Quinet recommends a general update of the VSL used by organizations, noting that a doubling of the VSL should be expected.

These elements show that the reference value is very sensitive to the methodology and the VSL attached to its calculation. In addition, other inherent factors such as national radiation protection standards, local conditions and circumstances can explain the spread of values.

5 Conclusion

Despite the adoption of different reference monetary value of the man.sievert, there is strong consensus from users that the concept is a useful tool to help to sort out the options of complex radiation protection projects, for the better search of the optimization of the exposure. Albeit it is not the sole support of decision.

In addition, using the concept generally drives to identify and valuate "all" the implications of a project (also safety, planning, etc.), so it helps to foster discussions and dialogue between the concerned departments (radiation protection, maintenance, etc.) and the management. Using it also requires to write down and document the decision and the rationale behind and this provide objectivity and transparency in the decision, which can be justified to the authority and the workforce.

[4] "*The expectation of the harm incurred from a radiation dose*", ICRP (1973), § 21 The concept of detriment as well as the associated risk coefficients have changed several times and an overview of these changes has been provided by Vaillant and Schneider (2012) and Cléro *et al.* (2019). ICRP is currently in the process of reviewing the bases of radiation protection detriment calculation (Zhang *et al.*, 2020).

References

Drèze JH. 1962. The social utility of a human life. *Revue française de recherche opérationnelle* 123: 93–118.

Baumstark L, *et al.* 2008. Mesures de la valeur de la vie humaine. Usages et enjeux comparés dans les secteurs de la santé et des transports. *Les Tribunes de la santé* 21(4):41–55. https://doi.org/10.3917/seve.021.0041.

Berthet A, Boussard P, Lochard J, Brissaud A, Rollin P, Lefaure C. 1992. Valeurs de référence de l'unité de dose collective professionnelle pour la mise en œuvre de la politique « ALARA » dans les centrales nucléaires d'Électricité de France. *Radioprotection* 27(4): 411–421.

Cléro E, Vaillant L, Hamada N, Zhang W, Preston D, Laurier D, Ban N. 2019. History of radiation detriment and its calculation methodology used in ICRP publication 103. *J. Radiol. Prot*. 39(3).

Dionne G, Lebeau M. 2010. Le calcul de la valeur statistique d'une vie humaine. *L'Actualité économique* 864: 487–530.

Hardeman F, Pauwels N, Van de Walle B, Deboot P, De Meester P. 1998. The monetary value of the person-sievert: a practical approach in case of occupational exposure. *Health Phys.* 74(3): 330–336.

IAEA. 1985. *Assigning a value to transboundary radiation exposure*. IAEA Safety Series 67, Vienna.

ICRP. 1973. *Implications of commission recommendations that doses be kept as low as readily achievable*. ICRP Publication 22. Oxford: Pergamon Press.

ICRP. 1977. Recommendations of the ICRP. ICRP Publication 26. *Ann. ICRP* 1(3).

ICRP. 1983. Cost-benefit analysis in the optimization of radiation protection. ICRP Publication 37. *Ann. ICRP* 10(2–3).

ICRP. 1985. A compilation of the major concepts and quantities in use by ICRP. ICRP Publication 42. *Ann. ICRP* 14(4).

ICRP. 2001. The optimization of radiological protection – broadening the process. ICRP Publication 101b. *Ann. ICRP* 36(3).

ICRP. 2007. The 2007 recommendations of the International Commission on Radiological Protection. ICRP Publication 103. *Ann. ICRP* 37(2–4).

ISOE ETC Information Sheet 18. 1998. *The use of the man-sievert monetary value in 1997*. http://www.isoe-network.net/publications/pub-resources/pub-info-sheet/etc-information-sheets/200-etc-18/file.html.

ISOE ETC Information Sheet 34. 2003. *Man-sievert monetary value survey, 2002 update*. http://www.isoe-network.net/publications/pub-resources/pub-info-sheet/etc-information-sheets/215-etc-34/file.html.

ISOE ETC Information Sheet 55. 2012. *Man-sievert monetary value survey, 2009 update*. http://www.isoe-network.net/publications/pub-resources/pub-info-sheet/etc-information-sheets/2186-etc-55/file.html.

Quinet E. 2013. L'évaluation socio-économique des investissements publics. Commissariat général à la stratégie et à la prospective, septembre 2013.

Schneider T, Lecomte J-F, Schieber C, Andresz S, Chambrette V, Le Guen B, Vaillant L. 2017. Synthesis of reflections and conclusions of the SFRP-IRPA workshop on the reasonableness in the practical implementation of the ALARA principle. *Radioprotection* 52(4): 259–263.

SFSE. 2018. Congrès SFSE 2017 - Tout a un coût ! L'apport des analyses économiques en santé environnement. *Environ. Risques Sante*, special issue 17(5): 368–410.

NRC. 2015. *NUREG 1530-1, reassessment of NRC's dollar per person-rem conversion factor policy, draft report for comment*. Office of Nuclear Reactor Regulation.

SÚJB. 2016. *Decree 422/2016 on radiation protection and the security of a radioactive*. https://www.sujb.cz/fileadmin/sujb/docs/legislativa/vyhlasky/422_Radiation_safety_fin.pdf.

Vaillant L, Schneider T. 2012. Évaluation du détriment associé à l'exposition aux faibles doses et faibles débits de dose dans le système de radioprotection. *Environ. Risque Sante* 11(2): 149–159.

Zhang W, Laurier D, Cléro E, Hamada N, Preston D, Vaillant L, Ban N. 2020. Sensitivity analysis of parameters and methodological choices used in the calculation of radiation detriment for solid cancer. *Int. J. Radiat. Biol.* 96(5).

Appendix 1 The reference monetary value of the man.sievert in cost-benefit analysis.

To help the selection of the optimal radiation protection option (or scenario), ICRP proposed in Appendix II of Publication 22 (ICRP, 1973) to use "*quantitative decision-aiding techniques to help inform the finding of the optimum radiation protection scenario in the context of optimization analysis*" and published later two reports (ICRP, 1983, 1985) that describe the techniques that can be used and CBA was put forward.

In CBA, the benefit are to be compared with the cost and the reference monetary value of the man.sievert is the conversion factor to translate the benefit of the option in monetary terms. The alpha term converts a collective exposure in monetary terms (*e.g.* α in €/man.mSv). Different methods to calculate a reference monetary value have been suggested in Section 4.4.

In a CBA, the spared collective dose S_i of option i is transformed with the reference value: $Y_i = \alpha \times S_i$ and this is add it to the cost X_i of the option. The optimum scenario i^* is the one with the lowest total cost: $min(X_{i*} + Y_{i*})$. An alternative is the differential CBA where the increase in cost between options is compared with the associated saving of dose. The options have to be ranked by order of increasing cost X_i and the ratios $\Delta X_i/\Delta S_i = (X_i - X_{i-1})/(S_{i-1} - S_i)$ between two adjacent options are calculated. The optimum is the one with the highest ratio, but below (or equal) to α: $\Delta X_{i*}/\Delta S_{i*} \leq \alpha$. The two methods provide the same result.

The comparison of costs with collective dose might be simplistic, notably if the distribution of individual exposure is spread among the workers. So ICRP introduced the concept of *risk aversion* to take into consideration the repartition of risks in an exposed population (ICRP, 1983). ICRP proposed to use "beta" terms ("β", *e.g.* in €/man.mSv), associated with specific group of individuals, with the objectives of optimizing in parallel the collective exposure, the spread of individual exposures, and giving priorities to the highest exposures. In practice, β is to supplement the benefit of averted exposure:

$$Y_i = \alpha \times S_i + \Sigma_i \beta_i \times S_{i,j},$$

where $S_{i,j}$ is the collective dose for the jth group of individuals in scenario i and β_j the additional monetary values assigned to the group j. ICRP recommends to distinguish the groups with individual dose criteria and proposed individual annual dose ranges. The extended formulation of Y_i can be used for CBA and differential CBA. However, no ISOE survey has reported β values so its usage has probably not disseminated well. To take into account risk aversion, utilities have preferred introduced set of several "alpha" values or have provided flexibility to single "alpha value system (mixed system as in the United States or possibility to increase the value in specific cases).

Cite this article as: Andresz S, Jobert T, Schieber C. 2020. The values and the uses of the reference monetary value of the man.sievert. Results of an international survey. *Radioprotection* 55(3): 207–214