Journal of Radiological Protection

Official journal of
the Society for
Radiological Protection

PAPER

Reflections on low-dose radiation, the misconceptions, reality and moving forward

To cite this article: M Lips *et al* 2021 *J. Radiol. Prot.* **41** S306

IOP Publishing | Society for Radiological Protection Journal of Radiological Protection

J. Radiol. Prot. **41** (2021) S306–S316 (11pp) https://doi.org/10.1088/1361-6498/ac1a5d

Reflections on low-dose radiation, the misconceptions, reality and moving forward

M Lips[1], E Anderson[2], T Nakamura[3], F Harris[4], G Schneider[5], J Zic[6], C Sanders[7], J Owen[8], J Hondros[9] and A de Ruvo[9,*]

[1] Kernkraftwerk Gösgen-Däniken, Postfach CH-4658 Däniken, Switzerland
[2] Radiation Safety & Control Services, Seabrook, NH, United States of America
[3] Japan NUS Co, LTD, Tokyo, Japan
[4] Rio Tinto, Brisbane, Australia
[5] Namibian Uranium Institute, Swakopmund, Namibia
[6] Mc Master University, Hamilton, Canada
[7] University of Nevada, Las Vegas (UNLV), Las Vegas, NV, United States of America
[8] BHP—Olympic Dam, Adelaide, Australia
[9] World Nuclear Association, London, United Kingdom

E-mail: alexandre.deruvo@world-nuclear.org

Received 2 June 2021; revised 13 July 2021
Accepted for publication 3 August 2021
Published 27 September 2021

Abstract

Low dose radiation has been widely accepted by the radiation protection community as presenting a very low risk to human health, if any. Over-conservatism in optimisation principles and regulations have resulted in a disproportionate fear of radiation amongst the general public and government authorities alike, overlooking the great benefits nuclear science and techniques have brought to society as a whole. As such, the World Nuclear Association advocates for a recontextualisation of the radiation hazards with regards to low dose radiation, and a greater awareness as to the absence of any discernible effects associated with it.

Keywords: low dose, LNT, collective dose, optimisation, all hazard approach

(Some figures may appear in colour only in the online journal)

* Author to whom any correspondence should be addressed.

1. Introduction

The World Nuclear Association (WNA) is the international organisation that represents the global nuclear industry. Its mission is to promote a wider understanding of nuclear energy among key international influencers by producing authoritative information, developing common industry positions, and contributing to the energy debate. The WNA is also the global nuclear industry's interface with the established international institutions (IAEA, ICRP, NEA-OECD, IRPA etc).

The Radiation Protection Working Group (RPWG) is a committee of the WNA and consists of experienced radiation protection professionals from a range of organisation involved in the nuclear fuel cycle. Areas of activity include uranium mining, fuel fabrication, electricity generation, education, research, plant construction, decommissioning and waste disposal. The RPWG, created in 2002, promotes worker, public and environmental protection through implementing robust radiation protection practices and develops and advocates scientifically policy and practice.

The RPWG has recently published a policy paper on 'Reviewing the Question of Low-Dose Radiation' (WNA 2021) and that paper is available from the WNA website. This current paper builds on the discussion in the position paper, providing a deeper consideration of low dose radiation (below 100 mGy) and low dose rate (below 0.1 mGy min^{-1}) (UNSCEAR 2012), together with a discussion on the impacts. It is worth noting that the dose and dose rate levels commonly found in the nuclear industry are well below the above mentioned levels.

The purpose of this paper is to provide informed opinions and practical perspectives on the system of radiation protection. As practitioners, the RPWG is concerned that misinformed radiation debate is occurring which marginalises the nuclear industry (Lindberg 2021). This debate tends to over emphasise minor radiation risks, resulting in an unnecessary fear of radiation (Slovic 2015). An additional purpose of the paper is to provide opinions and perspectives for the upcoming review of the 2007 Recommendations of the International Commission on Radiological Protection. A practical input to policy and standard setting provides a balance between a system which is overly sophisticated and complex and a system that can be implemented effectively, leading to worker, public and environmental protection.

This paper considers the following.

- Low-dose radiation and the evidence for impacts (LNT),
- How the systems of radiation protection inadvertently perpetuate misconceptions about optimisation and collective dose,
- Opportunities to move forward.

2. Background

The international nuclear industry is a significant contributor to the global society by supplying approximately 15% of the world's electricity demand, that is essentially carbon free. The industry maintains a strong focus on safety and continuous improvement and ensures that radiological impacts to workers, the public and environment have been optimised and well controlled. This is done by implementing robust internationally accepted radiation protection practices and controls that are based on the science of the impacts of radiation, which have developed and improved over the past decades. Industry also contributes to standard development and policy by supporting ongoing research, providing a practical perspective on radiation.

Despite the sustained focus, significant events (incidents of: Chernobyl, Fukushima, TMI) have occurred which focus the public's attention on the industry and, in particular, on the radiological impacts of the industry. While the radiological risks from such events are well documented and generally low, the negative focus on radiation constrains rational discussion on risk.

It is a fact that radiation is ever present in our daily lives with significant variations across different countries and within countries. This ever-present radiation exposure is seldom recognised, with the majority of people not considering it when making decisions in their everyday lives. On the other hand, most people accept the medical use of radiation, for example, in diagnostic application or cancer therapy. However, much of negative coverage of radiation focusses on the low doses delivered by nuclear installations which contribute the smallest fraction of the overall radiation dose to the public. Additionally, dramatised documentaries (e.g. HBO series: Chernobyl (HBO 2019)) distort the public perception of radiation impacts.

Popular media propagates the myth that the health risks associated with low doses of radiation are substantially greater than they actually are (Sanders 2017). This then re-enforces the public's perception that all radiation is dangerous and that the industries associated with radioactivity are therefore also dangerous. However, when considering the facts, this is far removed from the truth.

Current science shows that any risk associated with low doses and dose rates of radiation is extremely low, if it exists at all. Existing radiation protection regulations are designed to ensure that radiation exposures to workers, public and the environment are at levels that are well below the level where there is any demonstrated health impact.

There are numerous practical consequences that result from a distorted perception of radiation risks and some of these are shown as follows.

- Diverting attention and effort from other higher risks,
- Increased unnecessary and costly regulation,
- Overly conservative approaches, systems and decision making and
- Shifting from objective risk-based decision making to perception-based decision making.

The misconceptions about radiation directly affect the ability of the nuclear industry to provide clean, affordable and low-carbon electricity. While no action or practice is totally removed from any level of risk, the very low risks from nuclear energy production are massively outweighed by the benefits provided by the use of electricity produced by nuclear energy.

3. Industry performance

The radiation protection performance of the nuclear industry is excellent. Impacts to the environment through radioactive releases or waste are very well controlled and ongoing monitoring and studies show that radiological impacts remain well within acceptable regulatory standards.

Comprehensive industry performance data has been collated in UNSCEAR (2008) and (2016) and shows continuous improvement over many decades (see figure 1), with current average doses similar to the members of the public's dose limit and natural background levels. More recent occupational exposure data from the Nuclear Energy Agency (NEA 2017), confirms the ongoing improvement of the industry.

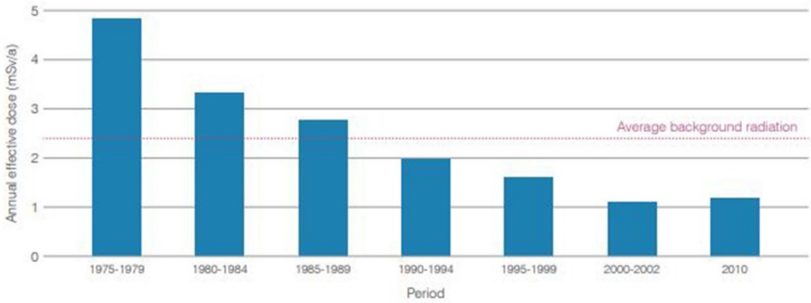

Figure 1. Estimated annual average effective dose (mSv a^{-1}) to workers in the nuclear industry worldwide (UNSCEAR 2008, 2016).

Uranium mining worker dose data largely depends upon the type of mining, which includes underground mining, open cut mining and *in situ* leaching. Australia shows average annual doses of approximately 1.5 mSv y^{-1} (averaged over the last ten years), with Australian uranium processing workers receiving on average 0.5 mSv y^{-1} for a similar period (ARPANSA 2019).

In Canada, the doses to workers are similarly low with annual averages from 2012 to 2016 being less than 1 mSv y^{-1} (CNSC 2018).

Despite the measured and verified performance of the nuclear industry, dose data can be misinterpreted leading to incorrect perceptions of the impacts from radiation. These misconceptions are sometimes supported by interest groups in an attempt to disrupt the growth of the nuclear industry. In some extreme cases, these false arguments can be used by anti-nuclear group to push the argument over closing existing nuclear facilities.

The measured and verified data do not support these arguments. For example, UNSCEAR (2015) notes the following.

> In general, increases in the incidence of health effects in populations cannot be attributed reliably to chronic exposure to radiation at levels that are typical of the global average background levels of radiation.

However, the conservative basis of the internationally accepted system of radiation protection and some of the terminology and definitions, allow misinterpretation, in particular the 'linear non-threshold' (LNT) model which implies that radiation doses, no matter how low, present a risk and that there is no safe level of radiation exposure.

These aspects are explored in section 4.

4. The low dose paradox

ICRP 103 confirmed that: 'assuming a linear response at low doses, the combined detriment due to excess cancer and heritable effects remains unchanged at around 5% per Sievert.' (ICRP 103). This radiation risk factor of 5% per Sv is a dose-response factor and has been derived from high dose and high dose rate situations. The system of radiation protection conservatively assumes that the risk factor applies for all doses down to zero dose and this approach is known as the LNT model (see figure 2). While there is evidence of radiation risks from doses greater than about 100 mSv, the situation at lower doses (where occupational and public exposure

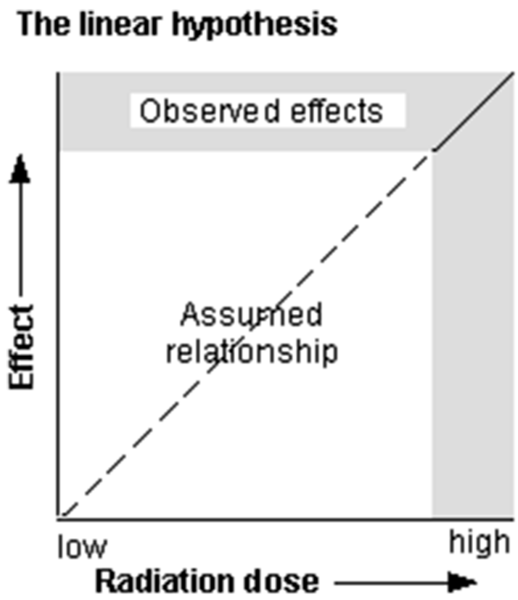

Figure 2. Simplified diagram of the LNT model.

occur) is much less certain. However, the LNT model applies this risk factor down to natural background radiation levels and even lower.

The LNT model hypothesises that radiation risk is proportional to dose at all dose levels. Therefore, the model says that even at low doses (of the order of a few mSv) there is assumed to be a small risk of cancer. This model has been adopted as the foundation of radiation protection practices and establishes a prudent response to the fact that the 'true' risks at low doses are not known. The LNT model forms the theoretical cornerstone of the system of radiation protection and regulations, including dose limits and key concepts such as ALARA (As Low As Reasonably Achievable) and collective dose.

In the very low dose region, it is practically impossible, by means of epidemiological studies, to show any link between radiation and any negative health impacts because of the relatively high incidence of natural occurring impacts (e.g. cancer) and the low incremental risk from radiation. In addition, the presence of a low, but quite variable exposure to natural background radiation further complicates the problem of determining the impact of radiation in the low dose region. A 2018 review of available epidemiologic data undertaken by the National Council of Radiation Protection (NCRP 2018), best summarises the difficulties with the practical application of the LNT model by stating the importance of recognising that

> the risk of cancer at low doses is small and might contribute only a very small, nondetectable fraction to an individual's overall risk.

The LNT as a model is a conservative oversimplification that has been in used for decades. Although, the NCRP concluded that the LNT model is the most prudent approach for radiation protection purposes, the controversy over its validity at low doses continue to raise voices amongst medical (AAPM 2018) and industry professionals. Because of the inadequate scientific evidence at low doses, interest groups may misuse the model to misinterpret radiation risks, leading to heightened levels of fear about the industry.

5. Misinterpretation of radiation protection concepts

From a practical perspective, there are two radiation protection concepts that have developed from the LNT model that, when used properly and as intended, are useful tools for radiation protection management. However, when used inappropriately, they can be used in an open-ended manner to undermine the formal and robust system for radiation protection. These concepts are optimisation and collective dose. A discussion on the practical aspects of the misuse of these important radiation protection concepts follows.

5.1. Optimisation in practice

In ICRP Publication 26 (ICRP 1977) the principles of optimisation were formalised. For the two decades preceding this document the idea of maintaining doses as low as possible was seen to be a prudent approach to radiation protection. In 1977 the adoption of the concept into the ICRP system of radiological protection meant that industry and users of radioactivity were required to formally consider optimisation as part of their management systems.

In ICRP Publication 42 (ICRP 1985) the concept of optimisation was broadened as policy makers grappled with its implementation. In this publication, the following three interpretations were considered to have the same meaning:

- ALARA (social and economic factors taken into account)
- Optimisation of radiation protection and
- Keeping exposures as low as reasonably achievable.

In later publications, the definition of optimisation by the ICRP in ICRP 2006b again shifted to the following:

> … the source-related process to keep the magnitude of individual doses, the number of people exposed, and the likelihood of potential exposure as low as reasonably achievable below the appropriate dose constraints, with economic and social factors being taken into account.

It is relevant to note that this change further limits optimisation to being below dose constraints. From a practical perspective, this provides another inferred limit where operators are required to

(a) comply with dose limits,
(b) establish lower dose constraints and
(c) optimise below the dose constraints.

This re-enforces the notion that optimisation is equal to minimisation and is generally the way implementers are applying the ALARA concept. ICRP stresses that: ‘the best option is not necessarily the one with the lowest dose’ (ICRP 101), and efforts should be pursued to convey that message and educate RP (Radiation Protection) professionals on this matter.

ICRP notes in the same publication that optimisation is part of a broader approach involving ‘individual equity, safety culture, and stakeholder involvement’. From a practical perspective, this embeds optimisation with the formal management structures of an operation. It is worthy to note also that in earlier publications, ICRP refers to the application of optimisation using the term ‘common sense’. This term was removed in later publications in favour of more prescriptive terminology.

At a practical level, ALARA is usually considered to be part of an organisation's continuous improvement culture, where the organisation is looking to always improve rather than simply achieving a target performance level. An example is switching off lights to save small amounts of energy.

The RPWG notes that the principle of optimisation is often misused because the broader social and economic factors not being properly taken into account in decision making. This leads to a perception that optimisation means 'as low as possible'. This incorrect application of the optimisation principle results in unnecessary costs for industry with negligible benefit. It is important to ensure that the proper intended application of optimisation is applied to ensure that benefits are achieved for the expenditure.

An example of the misuse of optimisation can be seen in the occasional excess attention being paid to a particular practice, resulting in more effort for radiation protection than would be considered reasonable to justify. This is usually about risk reduction rather than actual dose reduction. This results in additional measures being required to ensure that doses remain at their existing lower levels.

From an industry perspective, the difficulty is that optimisation can be used to imply that an unacceptable risk exists when in reality, it does not. From a practical perspective, this creates unnecessary cost or a diversion of finite resources. It places a burden on management systems to impose additional controls. Most importantly, it overemphasises the risk of radiation and potentially results in confusing staff and contractors about the key risks in a job. This also results in misinformation for public decision making such as the Fukushima Daichi incident where more than 2200 deaths resulting from evacuation stress and interruption to medical care were reported, while no radiation induced fatalities are reported to this day (Fukushima Pectural Government 2019, UNSCEAR 2020). Another example could be highlighted with the recent efforts aimed at strengthening the regulation on clearance for natural and artificial radionuclides. These measures, ultimately aimed at marginally lowering the dose and gaining public acceptance, will have no measurable health benefits, but will add yet another financial burden to the industry (Hattori 2019).

Radiation is one of a number of hazards that requires control within the nuclear industry and ensuring that the magnitude of the actual risk remains in perspective with the other hazards is important for effective safety management.

5.2. Collective dose

In ICRP Publication 26 (ICRP 1977), the term 'Collective Dose' was first described as a tool for decision making and comparing options. It is essentially the product of dose by the number of people potentially exposed and can be arbitrarily applied across a timescale. At the time, the ICRP warned about the uncertainties involved and noted that the concept should be used to 'appraise the detriment from a practice', suggesting that it can be used as a qualitative means of considering a particular practice.

In fulfilling its original intention as a tool to compare options, it has been useful when making decisions about technologies or long-term remediation options.

However, in practice, collective dose has also been inappropriately used to imply or calculate risks by multiplying very small average doses with a large population across a long time scale by the UNSCEAR risk factor, to produce alarming numbers of hypothetical fatalities. This approach was applied to the Chernobyl and Fukushima accidents and is regularly applied to operating nuclear facilities. When challenged, these estimates are shown to be misleading. The use of collective dose in this manner is inappropriate and not consistent with its original intention.

From the nuclear industry perspective, the primary difficulty with the inappropriate used of collective dose is that it enhances public fear and leads to misguided decision making by policy makers and regulators.

The inappropriate use of the collective dose concept is widely condemned by radiation protection professionals.

Gonzales (2014) highlights the problems caused by the concept of collective dose, noting that theoretical calculations have already caused much harm. He notes that UNSCEAR were moved to make the following statement:

> Therefore, the Scientific Committee does not recommend multiplying very low doses by large numbers of individuals to estimate numbers of radiation-induced health effects within a population exposed to incremental doses at levels equivalent to or lower than natural background levels.

Most recently, in 2016, UNSCEAR recommended that the use of collective dose should not be used to estimate alleged health effects:

'Collective dose is not intended as a tool for epidemiological risk assessment'. Moreover, the aggregation of very low individual doses over extended time periods is inappropriate for use in risk projections and, in particular, the calculation of numbers of cancer deaths from collective doses based on individual doses that are well within the variation in background exposure should be avoided.

The ICRP notes that it is inappropriate to use collective dose calculations for theoretical health impacts of radiation exposure as 'collective effective dose is not intended as a tool for epidemiological studies, and it is inappropriate to use it in risk projections' (ICRP 2007).

Health Physics News March 2013 reports, Misuse of Collective Dose: Multiplying tiny radiation doses by millions (or billions) of individuals to estimate numbers of radiation-induced cancers should not be done, yet such computations are still being performed.

From a practitioner's perspective, the concept remains useful when comparing repetitive tasks or procedures in order to optimise the potential exposures during on-site maintenance operations (e.g. change of valve in a contaminated environment). It is linked to optimisation and when comparing options or in health-risk assessment, collective dose is a useful tool for optimisation of decision making, however.

Although the ICRP and UNSCEAR comment on the correct use of the term, the damage has been done and editorial clarifications seem to not be able to change the broader misuse of the term. The RPWG advocates that the term collective dose be removed from policy and regulation and considered only as operational optimisation tool. Collective dose is an excellent operational tool, not a policy tool.

6. Discussion

The nuclear industry clearly understands that there are a range of reasons why nuclear power may not be acceptable to various groups and to various countries; however, the industry argues that radiation should not be among those reasons. Scientific evidence clearly shows that at low doses, the health effects of radiation exposure are not discernible. This is true for doses typically encountered in the nuclear industry and other application of radiation in society, where the benefits outweigh the small risks.

This is particularly true in the event of a nuclear accident. Like any major accident or incident, objective decision making in relation to emergency response or post closure remediation should be based on scientific evidence, rather than perception. In addition, other non-quantifiable data such as psychological and socio-economic factors will have to be taken into account by decision makers as part of their all-hazard approach. The totality of acute and chronic hazards and risks need to be considered in perspective, to ensure a proper response to the incident.

Additional constraints on radiation emissions would also impair the many beneficial uses of nuclear technology. Many fields have benefitted from radio-nuclear applications such as the medical, industrial and agricultural (e.g. sterilisation, mutation breeding for crops etc) fields, resulting in a rise in standards of living. For example, advanced diagnostic and treatment methods have saved millions of lives, and the use of nuclear energy provides clean, affordable and low-carbon electricity for many millions of people around the world.

Current science shows any risk associated with very low doses of radiation (as experienced in the nuclear industry) is extremely low, if it exists at all. However, misconceptions about radiation is limiting the willingness of society of more fully harness the benefits of nuclear power as a clean, affordable, and low-carbon source of electricity. In addition, the burden from excessive regulation imposes unnecessary costs to the global nuclear industry and society as a whole—while at most achieving minor decreases in exposure levels without any benefits.

Some examples which highlight the difficulties that the industry faces in regard to the over focus on radiation as a result of perceived risks and the impacts of misconceptions are as follows.

- The inability to demonstrate that deep geological disposal of radioactive waste is safe,
- Closure criteria and legal definitions of radioactive material becoming trade barriers,
- Regular changes in the system of protection (for example changes in dose limits or dose estimation methods) which suggest a lack of understanding of radiation effects,
- Risk inequality—maintaining risks in perspective when completing complex and difficult tasks (such as maintenance).

The RPWG notes that there are a number of potential practical improvement options, most of which are based on clarity and communicating as follows.

- Effective communication and stakeholder engagement about the low health risk from exposure to low levels of radiation may prevent adverse health effects associated with the fear of radiation,
- The RPWG strongly supports education as the basis for informed decision making and the importance of sound science as the basis of policy making,
- The RPWG advocates simplification of the system of dose limitation and proposes the following practical discussion points,
- Ensuring that radiological risks are considered alongside other hazards and risks
- Modifying the concept of collective dose to limit its use to an operational optimisation tool and
- Avoiding over conservatism in risk assessments.

7. Conclusions

This paper has aimed to provide a set of observations, based on the knowledge of nuclear industry practitioners through the WNA RPWG.

The key conclusions are as follows.

(a) Unnecessary fears of radiation are impacting on the viability of a sustainable solution to climate change.
(b) Many of the fears find their basis in the ultra-conservative nature of radiation protection and also in the misuse of radiation protection concepts and principles.
(c) The RPWG advocates an 'All-hazards' approach, where all hazards are considered in perspective, without prioritisation on one particular hazard.
(d) Clarity in communications of hazards and risks of radiation should remain a priority for all radiation protection professionals and practitioners.

ORCID iDs

M Lips https://orcid.org/0000-0001-5873-1912
A de Ruvo https://orcid.org/0000-0001-7857-2568

References

ARPANSA 2019 *Australian National Radiation Dose Register (ANRDR) in Review* Australian Radiation Protection and Nuclear Safety Agency
Canadian Nuclear Safety Commission 2018 *Regulatory Oversight Report for Uranium Mines and Mills in Canada: 2016* CNSC
Fukushima Prefectural Government 2019 Damage caused by the 2011—earthquake and tsunami (available at: www.pref.fukushima.lg.jp/site/portal-english/en03-01.html)
Gonzales A J 2014 Clarifying the Paradigm on Radiation Effects & Safety Management: UNSCEAR Report on Attribution of Effects and Inference of Risks *Nuclear Engineering and Technology* **46** 4
Hattori T 2019 *ICRP 2019, Conference abstract: trend of strengthening clearance regulation in Japan and concerns about its worldwide effects on regulations for natural and artificial radionuclides* (www.youtube.com/watch?v=8yIr0YDghqI)
HBO 2019 *Chernobyl, Directed by Johan Renck* (www.hbo.com/chernobyl)
ICRP 1977 ICRP Publication 26, Recommendations of the ICRP *Ann. ICRP* **1** 29
ICRP 1985 ICRP Publication 42, A compilation of the major concepts and quantities in use by ICRP *ICRP* **14** 10
ICRP 2006b ICRP, 2006. The optimisation of radiological protection—broadening the process. ICRP Publication 101b *Ann. ICRP* **36** 81
ICRP 2007 The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103
Lindberg J 2021 'J'accuse.!': the continuous failure to address radiophobia and placing radiation in perspective (https://doi.org/10.1088/1361-6498/abf9e2)
NCRP 2018 *Implications of Recent Epidemiologic Studies for the linear-Nonthreshold Model and Radiation Protection* Commentary No.27 National Council on Radiation Protection and Measurements
NEA 2017 *Occupational Exposures at Nuclear Power Plants* 27th Annual Report of the ISOE Programme, 2017 OECD-NEA
Sanders C L 2017 *Radiobiology and Radiation Hormesis: New Evidence and Its Implications for Medicine and Society* (Cham: Springer)
Shore R E American Association of Physicists in Medicine 2018 Commentary No. 27—Implications of Recent Epidemiologic Studies for the Linear-Nonthreshold Model and Radiation Protection (https://doi.org/10.1088/1361-6498/aad348)
Slovic P 2015 The perception gap: radiation and risk *Bulletin of the Atomic Scientists* (https://doi.org/10.1177/0096340212444870)
UNSCEAR 2008 United Nations Scientific Committee on the Effects of Atomic Radiation *Sources, Effects and Risks of Ionizing Radiation: United Nations Scientific Committee on the Effects of*

Atomic Radiation 2008 Report to the General Assembly, Volume I: SOURCES, Scientific Annexes A and B

UNSCEAR 2012 United Nations Scientific Committee on the Effects of Atomic Radiation *Sources, Effects and Risks of Ionizing Radiation: UNSCEAR 2012 Report*

UNSCEAR 2015 United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2015 White paper

UNSCEAR 2016 United Nations Scientific Committee on the Effects of Atomic Radiation *Sources, Effects and Risks of Ionizing Radiation: UNSCEAR 2016 Report, Scientific Annexes A, B, C and D*

UNSCEAR 2020 United Nations Scientific Committee on the Effects of Atomic Radiation *Sources, Effects and Risks of Ionizing Radiation: UNSCEAR 2020 Report, Scientific Annexe B*

WNA 2021 *Reviewing the question of low-dose radiation* (https://world-nuclear.org/our-association/publications/technical-positions/reviewing-the-question-of-low-dose-radiation.aspx) (Accessed 19 July 2021)