CHAPTER 7: RADIATION RISKS

109. Australia's annual limits on the amount of ionising radiation (in 'doses') that can be absorbed for the public, workers and the environment are set on a precautionary basis. As people and the environment are constantly exposed to natural background radiation, the limits seek to minimise exposure to additional radiation from artificial sources.

All people are continuously exposed to ionising radiation from natural sources, or 'natural background radiation', throughout their lives.[1] Natural background radiation arises from a variety of sources, including rocks and soil (terrestrial radiation) and matter in outer space (cosmic radiation). People are exposed to the natural radiation present in their bodies, in the food they eat and in the radon gas they inhale, which comes from the ground.[2]

The level of natural background radiation that people will be exposed to depends on their location and the combination of radioactive sources present at that location.[3] On a worldwide basis, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has estimated that an individual's average annual exposure from natural background radiation is 2.4 millisieverts (mSv).[4] In Australia, the public is exposed to between 1.69 mSv and 3.79 mSv of natural background radiation per year.[5]

Figure 7.1 compares the additional doses that the public receives from artificial sources of radiation from medicine with the range of expected doses that the public in Australia and the United Kingdom receive from natural background radiation, and from nuclear facilities in the United Kingdom and Spain. In all cases, the additional doses to the public from nuclear fuel cycle facilities are many times lower than the annual regulatory limit fixed for those doses. It is also evident that doses from these facilities are much lower than natural background radiation and medical procedures.

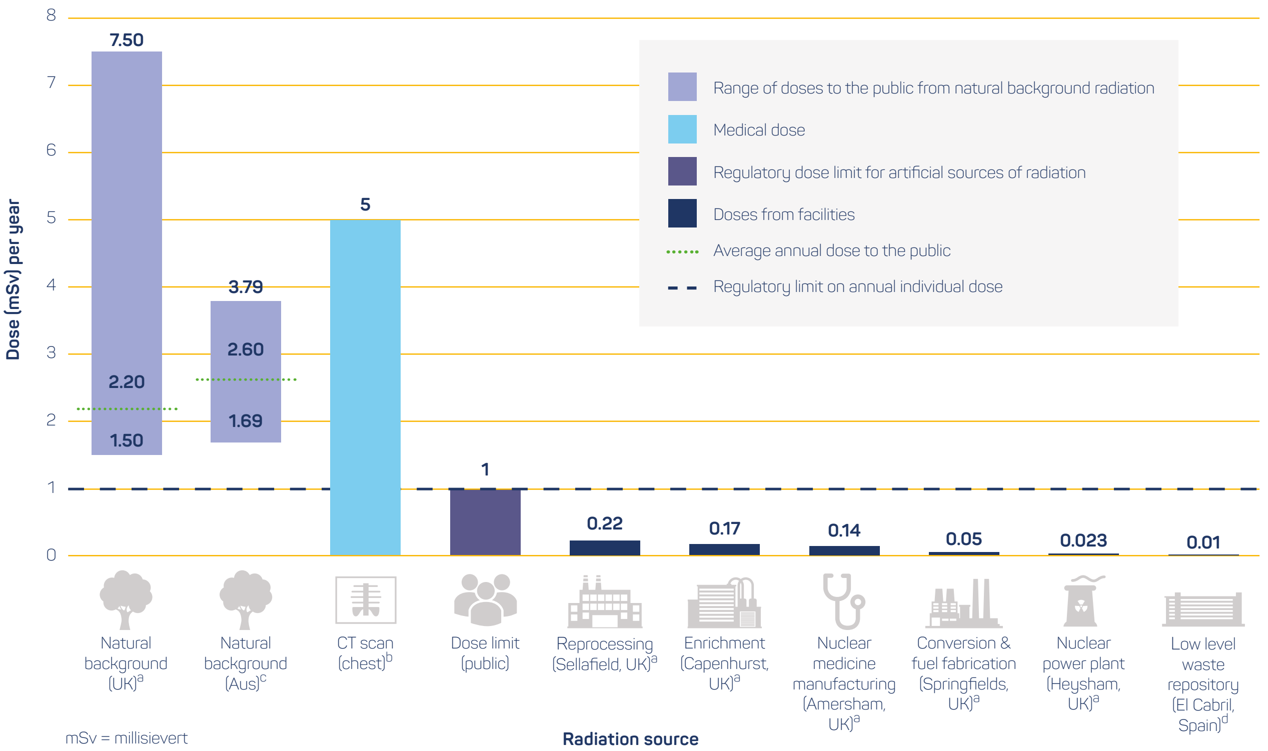


Figure 7.1: Expected radiation doses to the public from natural background radiation, medical sources and international nuclear fuel cycle facilities, and regulatory limit for doses of radiation to the public additional to natural background sources and medical procedures

a. Centre for Environment, Fisheries and Aquaculture Science (Cefas), on behalf of the Environment Agency, Food Standards Agency, Food Standards Scotland, Natural Resources Wales, Northern Ireland Environment Agency & Scottish Environment Protection Agency, *Radioactivity in food and the environment*, 2014 (RIFE – 20), Cefas, United Kingdom, October 2015, pp. 10, 12, 18–19

b. Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), *Ionising radiation and health*, fact sheet, ARPANSA, September 2015, http://www.arpansa.gov.au/RadiationProtection/Factsheets/is_ionising.cfm

c. SD Muston, 'Spatial variability of background radiation in Australia', master's dissertation, RMIT University, Melbourne, 2014, p. 38

d. E Neri (ENRESA), letter to the Nuclear Fuel Cycle Royal Commission, 21 December 2015

Radiation exposure often takes place for diagnostic or therapeutic purposes in medicine. For example, a computed tomography (CT) scan of the chest would give the recipient a radiation dose of 5 mSv, although CT scans can result in higher doses of up to about 10 mSv.[6]

In Australia, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) develops national standards for protecting the public, workers and the environment from the harmful effects of radiation based on international requirements.[7] These standards are uniformly applied in the states and territories. ARPANSA develops these standards in accordance with the principles of[8]:

- justification, which requires that the individual or society more generally receives a sufficient net benefit to offset the possible radiation harm caused by an exposure
- optimisation, which requires that all reasonable measures are taken to minimise the likelihood of exposures taking place, the number of people who are exposed and the magnitude of any exposures, including in accidents
- limitation, which requires that no individual is exposed to excessive radiation by reason of any radiation safety measures implemented to address risks to the broader community, unless the individual is receiving medical treatment.

In its application of these principles, ARPANSA sets limits on the permissible doses of radiation which the public and workers can receive from manmade sources, which are additional to natural background radiation.

For the public, the limits are significantly lower than what an average Australian might expect to receive from natural sources in any year. ARPANSA has specified that the effective dose limit for members of the public is 1 mSv a year.[9] This limit does not apply to radiation exposure in occupational or medical settings, where doses may exceed 1 mSv a year.

Although the limits are higher for workers, the principles that apply to public exposure also apply to minimise occupational exposure. For radiation workers, the limit is generally 20 mSv a year, averaged over five consecutive years, and no more than 50 mSv in any one year.[10] Radiation doses to workers are discussed in more detail later in this chapter.

In the case of the environment, operators of facilities that release radiation are required to optimise environmental radiation exposure. This involves determining an appropriate 'environmental reference level' (ERL) at which releases of radiation (above natural background radiation) would create little risk to the environment. Unlike dose limits for the public and workers, ERLs are calculated for specific projects to account for the diversity of flora and fauna present in nature.[11]

110. At very high levels of radiation exposure, adverse health impacts can be directly observed or inferred from statistical analysis; however, at low levels (in the range of ordinary exposures from natural background sources) there is ongoing scientific debate on the extent of any health risk. Despite this uncertainty, it is appropriate to apply a precautionary approach to radiation safety, even at low levels of exposure.

Over the past century, there has been extensive research into the effects of radiation on the human body. (See Appendix K: Radiation concepts, for more detailed information about the different types of ionising radiation and their biological effects on humans.)

While there is scientific consensus that human exposure to high doses of radiation will cause adverse health effects[12], there is disagreement about the health effects of radiation at low doses. It has been argued that any dose of radiation is unsafe and adverse health effects can result from natural background radiation alone[13], although no evidence was presented to the Commission that definitively supported these claims. Conversely, some studies have suggested that low doses of radiation could have positive health effects.[14]

This debate cannot be readily resolved. The health impacts of low levels of radiation are obscured as people are continuously exposed to natural background radiation and make other lifestyle choices that have adverse health effects. This makes it difficult to isolate the causes of those impacts with any certainty using current scientific methodologies.[15] Further, although it is known that radiation exposure can potentially cause cancer and other diseases, it is impossible to unequivocally attribute this to radiation or any other possible cause in an individual.[16]

Given these issues, the most conservative approach to managing radiation risks is to assume that any increase in radiation exposure will lead to a corresponding increase in risk to human health. That approach is known as the linear non-threshold (LNT) assumption and, in light of the ongoing debate, is the most prudent way to manage health risks from radiation exposure.[17] This is consistent with statements made by UNSCEAR and guidance by the International Commission on Radiological Protection.[18]

111. Any new nuclear facilities in South Australia would need to be designed and operated to ensure regulatory limits are not exceeded. The greater the radiation risk, the greater the level of engineered barriers, automation of processes and protective work practices required.

Australia's radiation safety regime adopts an approach in accordance with the LNT assumption.[19] Consequently, all facilities where radioactive substances are handled or produced must implement appropriate controls to ensure that doses of radiation are as low as reasonably achievable.[20] To that end, engineered control measures are designed and built into modern facilities before they begin operations. These measures include shielding to ensure there are low radiation areas and additional barriers to separate people from processes involving the greatest potential for radiation exposure.[21]

When planning a project to mine or mill uranium in South Australia, proponents are required to formulate a radiation management plan (RMP) and a radioactive waste management plan (RWMP), which outline the measures that would be in place to protect the public, workers and the environment from radiation during project operation and in managing wastes that are produced. Assessments must be undertaken of the potential pathways for radiation exposure, the controls that would apply to each pathway and how the effectiveness of those controls would be monitored.[22] The South Australian Environment Protection Authority (EPA) reviews and approves RMPs and RWMPs before any mining or milling operations start and, during operations, carries out quarterly inspections to ensure the plans are properly implemented.[23] It would be appropriate to undertake similar assessments in relation to any new nuclear facilities in South Australia.

112. Data from modern nuclear fuel cycle facilities demonstrates they operate well within the applicable regulatory limits for workers, the public and the environment. Doses of radiation to the local community from any new nuclear facilities in South Australia could be expected to be in the range of those estimated from the international nuclear facilities set out in Figure 7.1.

Internationally, operators and regulators of nuclear facilities undertake studies on radiation exposure to the public. For example, in the United Kingdom the various environmental and food safety regulators monitor radiation levels in food, and in land and marine environments near nuclear facilities. Radiation is released into the environment from nuclear facilities in the form of gaseous, liquid or particulate discharges. Some gamma radiation may also be released directly from the facility.[24] To assess the dose of radiation that the public might receive from a facility, regulators develop a 'representative person', who performs activities that could result in exposure to radiation from the facility, such as eating locally produced food and attending the local area for work or other purposes. These habits are determined on the basis of local survey data, with the representative person performing the activities that could cause exposure more frequently than the average person.[25] The estimated doses in Figure 7.1 relate to a representative person who carries out all the activities that have been identified as leading to radiation exposure.[26]

As Figure 7.1 indicates, the levels of radiation exposure to the public from international nuclear fuel cycle facilities are lower than what might be expected from natural background radiation. Keeping in mind the regulatory framework already in place, it is reasonable to envisage that any new nuclear facilities constructed in South Australia would be expected to give rise to doses in the range of those assessed at international facilities. Indeed, at the Open Pool Australian Lightwater (OPAL) research reactor operated by the Australian Nuclear Science and Technology Organisation (ANSTO) in New South Wales, the maximum potential dose to nearby residents from the facility's airborne emissions in 2014–15 was 0.0026 mSv, or less than 0.3 per cent of the 1 mSv annual dose limit for the public.[27]

113. The likely dose of radiation that members of the public would receive from a deep geological disposal facility has been estimated in assessments by overseas regulators. Even for the most conservative assumptions about future site conditions, radiation doses to the public are well below applicable regulatory limits.

The potential doses of radiation to the public from deep geological disposal facilities are estimated in 'safety cases' which are assessed by regulatory authorities. Estimates are made for both operations and after closure. Safety cases are discussed in more detail in Chapter 5 at Finding 69, with particular reference to long term safety.

With respect to operational safety at a disposal facility, the risks are similar to those that arise when loading dry casks at reactor sites. However, at the point at which used fuel is ready for disposal, though still highly hazardous, radiation levels are significantly lower than when dry storage of the used fuel began. The principal risk in used fuel storage and disposal operations is a used fuel assembly being physically damaged during on-site handling.

Once containers of used fuel have been placed in the disposal facility, it is closed by backfilling the tunnels to place it in a passively safe state. Assessments in Finland and Sweden are based on known characteristics of the materials throughout the first 10 000 years after closure. In the reference scenario, the used fuel containers will remain integral.[28] Despite the use of high-quality welding techniques, the reference scenario for Finland has conservatively assessed the consequences of a container with a small hole being emplaced.[29] Even in that unlikely scenario, the potential annual dose to the most exposed person will be less than 0.000001 mSv, which is a tiny fraction of the annual dose from natural background radiation.[30]

For other baseline scenarios, additional assessments have been made that take into account changes in groundwater conditions, container corrosion rates and the effects of climate change.[31] For these scenarios, potential annual doses to the most exposed person are still significantly less than 0.001 mSv.[32]

As geological disposal sites have not yet been identified in Belgium and Switzerland, their safety cases are at a more preliminary stage. Nevertheless, their reference scenarios show that annual doses during the first 10 000 years after closure will be significantly less than 0.0001 mSv.[33]

The safety cases also assess the potential doses that could arise from unlikely events, such as inadvertent intrusion after the facility's closure. Siting the facility at an appropriate depth, away from natural resources, and preserving records

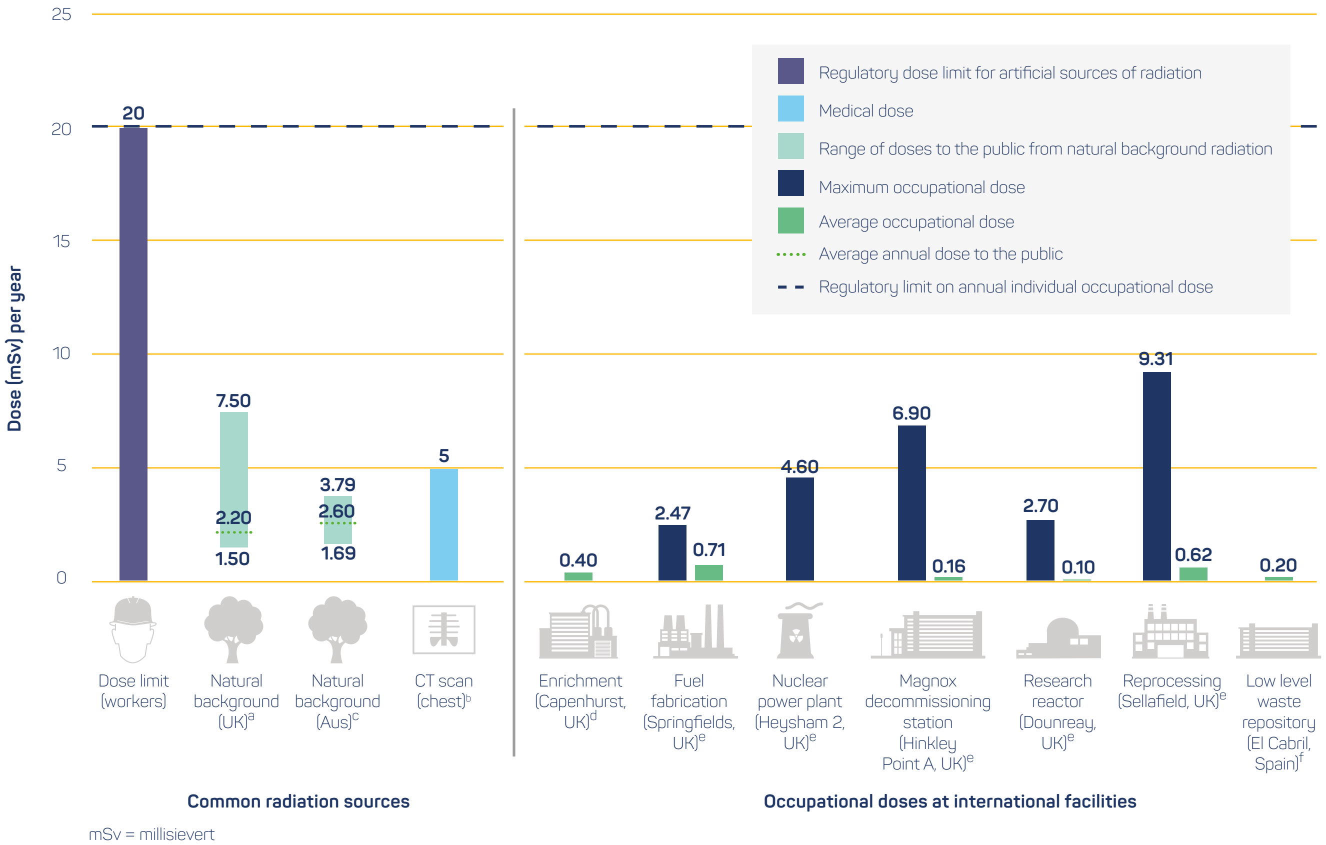
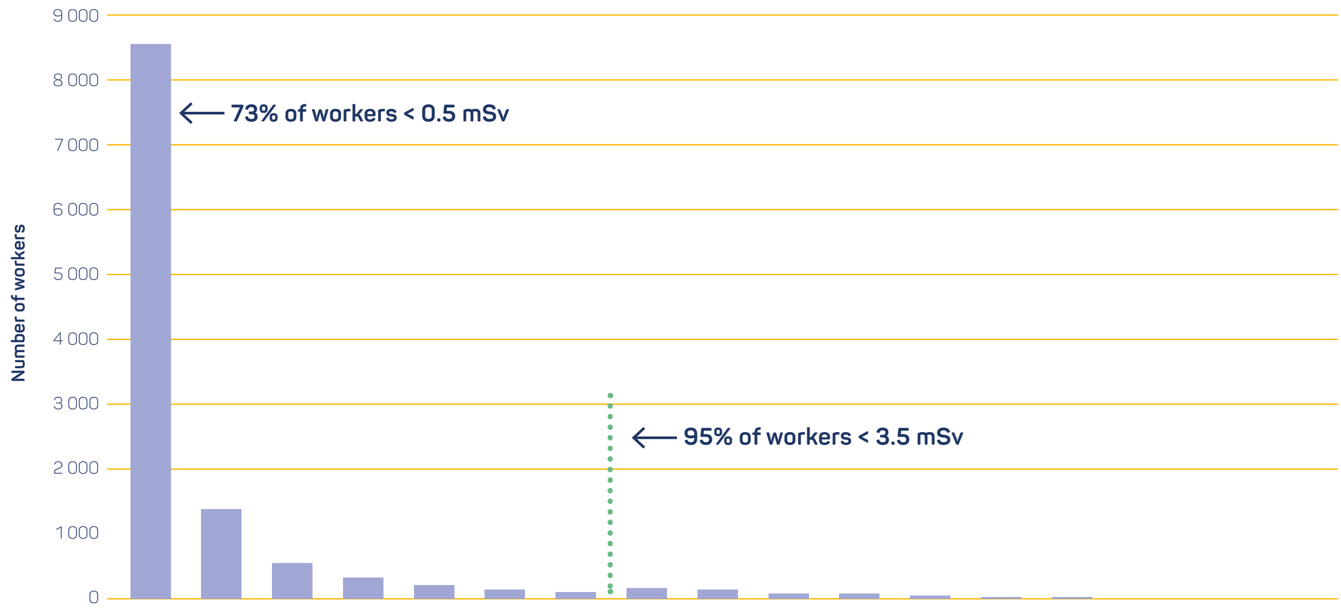


Figure 7.2: Expected radiation doses to workers from common sources, measured occupational doses at international nuclear fuel cycle facilities and regulatory occupational limit for doses of radiation additional to natural background sources

a. Cefas, *Radioactivity in food and environment*, p. 19
b. ARPANSA, *Ionising radiation and health*
c. Muston, 'Spatial variability of background radiation', p. 38
d. URENCO, *Sustainability report 2014*, URENCO Ltd, United Kingdom, 2015
e. Transcript: Fisher, p. 1789 and accompanying slides
f. E Neri (ENRESA), letter to the Nuclear Fuel Cycle Royal Commission, 21 December 2015



Effective dose (mSv)	0–0.5	0.5 –1	1–1.5	1.5–2	2–2.5	2.5–3	3–3.5	3.5–4	4–4.5	4.5–5	5–5.5	5.5–6	6–6.5	6.5–7	7–7.5	7.5–8	8–8.5
No. of workers	8 505	1 361	529	324	201	123	111	174	131	97	50	42	32	18	7	2	0

Figure 7.3: Annual dose distribution for all Australian uranium workers in 2014

Data sourced from ARPANSA, 'Analysis of ARPANSA data', *ANRDR in Review*, Issue 2, July 2015, p.5

of the site reduces the likelihood that this could occur while the used fuel presents a safety hazard.[34] The greatest potential doses from these unlikely scenarios would arise from drilling into a container of used fuel.[35] If that occurred soon after closure and parts of the fuel were brought to the surface, the driller would receive a significant radiation dose.[36] In addition, the most exposed member of the public could receive doses of a few tenths of a mSv a year, which is less than typical regulatory limits of 0.1 mSv per year for disposal facilities.[37]

Appendix I: Safety cases for geological disposal facilities provides a more detailed description of assessments of long term safety of geological disposal facilities.

114. For workers at nuclear facilities, the annual dose of radiation received varies depending on the nature of the tasks performed. The range of occupational exposures that might arise in South Australia from nuclear fuel cycle activities could be expected to be in the range of those recorded at the international nuclear facilities set out in Figure 7.2.

Given the implementation of the radiation management practices discussed earlier, exposures to workers at nuclear facilities could be expected to be in the ranges depicted in Figure 7.2. It can be seen that the average occupational dose received by workers is only a fraction of natural background radiation, and the maximum occupational dose received by any worker recently at those facilities is less than half of the annual occupational regulatory limit of 20 mSv.

At uranium mines in South Australia, radiation safety is already regulated by the EPA. It does so in accordance with ARPANSA's Radiation Protection Series, thereby maintaining national uniformity in radiation safety standards.[38] Operators of uranium mines are required to monitor the doses that workers receive to ensure that regulatory limits are not exceeded.[39]

Radiation exposure at uranium mines has not always been addressed in the way it is today. For example, at the Radium Hill mine, which operated from 1952 to 1961 in eastern South Australia, control measures for radiation safety were minimal and, at times, may even have been absent.[40] There is evidence that the lack of priority placed on radiation safety and the consequent exposure of miners to radiation led to an increased risk of developing lung cancer, although it is not known what impact smoking may have had.[41]

Modern uranium mines are required to be operated in accordance with the radiation safety principles outlined earlier, and operators need to demonstrate their ability to do this before receiving approval to proceed. Operators are required to provide information on worker radiation exposure to the Australian National Radiation Dose Register (ANRDR), which is a consolidated source of worker dose data administered by ARPANSA. A central source allows trends in occupational radiation exposure to be monitored, although the actual doses received by workers are likely to be lower than recorded as the data does not take into account the effect of protective equipment.[42] As the ANRDR data in Figure 7.3 shows, 73 per cent of workers in Australian uranium mines during 2014 received an annual dose of radiation of less than 0.5 mSv.[43] This is significantly less than the radiation doses received by miners in the past.[44]

115. The more significant radiation risks are created in the event of an uncontrolled release of nuclear or radioactive material during an accident at a nuclear power plant. The severity of those risks can vary depending on the extent of any such release. Authoritative international organisations have extensively evaluated the independent and peer-reviewed epidemiological data obtained by medical doctors and other scientists into the health effects of each accident. The credibility of these organisations and their findings is not open to doubt.

Other than the survivors of the Nagasaki and Hiroshima atomic bombs, the populations affected by the nuclear power plant accident at Chernobyl in 1986 have been the subject of the most extensive studies into radiation health effects. The most prominent is the study undertaken by the 'Chernobyl Forum', a joint study involving eight United Nations (UN) organisations and the governments of Belarus, the Russian Federation and Ukraine, which released its reports in 2006.[45] The most recent and comprehensive assessment of the available evidence, including the Chernobyl Forum reports, was published by UNSCEAR in 2011. Research into the effects of the Chernobyl accident is ongoing and society's understanding of its impacts will further improve.

The circumstances surrounding the nuclear accident at Fukushima Daiichi in 2011 are markedly different to those at Chernobyl. This difference led to very different levels of radiation release. The Fukushima accident, its causes and the measures taken in response, are discussed in more detail in Appendix F: The Fukushima Daiichi accident.

In its findings into the Fukushima accident, published in 2014, UNSCEAR estimated that the atmospheric release of the radioactive elements iodine-131 and caesium-137 (which contribute most to the radiation exposure to the public and the environment) were respectively about 10 per cent and 20 per cent of the levels released from the Chernobyl accident.[46] Further, the total dose of radiation to the Japanese public was about 10–15 per cent of the comparable dose to the European populations affected by radiation from Chernobyl.[47]

Despite its extensive studies into both accidents, UNSCEAR's standing as an authoritative source has been questioned. Claims were made in oral evidence to the Commission that the experts in UNSCEAR were not appropriately qualified and its investigations used data which was either incomplete or of poor quality, thereby excluding significant radiological impacts from its findings.[48] In addition, it was asserted that the World Health Organization (WHO) was prohibited by the International Atomic Energy Agency (IAEA) from undertaking its investigations appropriately and it did not physically examine the health effects of the Chernobyl or Fukushima accidents.[49]

UNSCEAR comprises 27 member states, including Australia, and its investigations are performed by teams of experts nominated by those states. In the case of the study into the Fukushima accident, a cohort of more than 80 scientific experts (including medical doctors) was assembled from specialists in 18 countries. They were organised into various expert groups which undertook independent investigations and reviewed data collected and provided by Japanese government agencies, UN member states, international organisations such as the Food and Agriculture Organization of the UN, and WHO, and non-governmental organisations.[50]

The WHO is the peak UN authority responsible for assessing current international health issues, including those arising in emergencies, and providing guidance about the appropriate management response. Its guidance, on topics including radiation, is developed independently of the IAEA.[51] Having led the comprehensive Chernobyl Forum studies in the past, it was directly involved in the assessment of health risks resulting from the earthquake, tsunami and nuclear power plant accident at Fukushima. After doing so over the course of two years, it produced a Health Risk Assessment in 2013 which estimated the future health impact of the accident on affected populations based on the available data at the time and using widely accepted methodologies and conservative assumptions.[52]

Both UNSCEAR and WHO draw similar conclusions from their independent investigations. Given their role, composition and the comprehensive nature of the investigations, they should be accepted.

116. The most serious consequences for human health caused by the radiation releases following the Chernobyl and Fukushima Daiichi accidents are well understood, although sometimes misreported. Given the latency of some less serious but potential consequences, ongoing health monitoring of affected areas and populations will continue. This will enhance understanding of health impacts of exposure. The detriment to mental health of persons affected by each accident and evacuation must also be acknowledged, particularly in future emergency response planning.

Despite the depth of research into the Chernobyl accident, there are very different views about the estimated health impacts asserted to be attributable to the radiation released. A paper by Yablokov, Nesterenko and Nesterenko concluded that 'the overall mortality rate for the period from April 1986 to the end of 2004 from the Chernobyl catastrophe was estimated at 985,000 additional deaths'.[53] That conclusion was reached using overly simplistic methodologies to analyse cause and effect, and without considering extraneous factors such as socioeconomic conditions and the impact of increased screening.[54] Such methodologies are known to give rise to erroneous conclusions and, given the additional difficulties in attributing health effects to low levels of radiation exposure, have been recommended against by UNSCEAR.[55] The publication, including its methodologies and conclusions, has been specifically criticised in the scientific literature.[56]

With respect to the presence of radioactive materials in the environment at Chernobyl, it has been claimed that the radioactivity in some places will increase over time.[57] Certain radioactive elements, known as 'hot particles', were released during the accident and the levels of one of those elements—americium-241—are increasing as it is a product of the decay of other radionuclides.[58] However, because these hot particles are 'heavier' than other elements, they do not travel far from the nuclear power plant site in the event of an accident.[59] Although these elements will remain radioactive in the long term, they will only be present in trace quantities.[60] Those quantities will not materially add to radiation from background sources.

UNSCEAR has identified several areas where uncertainties affect its ability to draw conclusions from the available evidence about the health effects of Chernobyl. As cancer and other stochastic effects are difficult to attribute to radiation given they have other potential causes, it is only possible to determine a probability that the effect was wholly or partly caused by radiation exposure. Each effect must be examined on its own merits and in light of other relevant factors. These limitations are even more pronounced in the populations that received low doses of radiation from the Chernobyl accident given the presence of natural background radiation.[61]

Bearing these uncertainties in mind, UNSCEAR made the following conclusions[62]:

- Of the plant staff and emergency workers who received very high doses of radiation, 134 people developed acute radiation syndrome (ARS), which caused the deaths of 28 of those people. Two other workers died in the immediate aftermath of the accident from causes unrelated to radiation exposure.
- Of the ARS survivors, a further 19 had died by 2006 (two decades later), although their deaths were not directly attributable to radiation exposure. The remaining ARS survivors experience skin injuries, cataracts and ulceration as a result of radiation exposure, the severity of which is consistent with the dose of radiation received. No other health conditions experienced by the ARS survivors have been attributable to radiation exposure.
- Among the public, who received much lower doses of radiation than the plant staff and emergency workers, there were no cases of ARS or associated fatalities. A significant increase in thyroid cancers was observed in members of the local population who were children or adolescents at the time of the accident. Doses of radiation to the thyroid were caused by the contamination of milk with radioactive iodine in the immediate days after the accident. Radiation is considered to have contributed to a large proportion of the 6848 cases of thyroid cancer reported between 1991 and 2005. Fifteen of these proved fatal.
- While those who received high doses of radioactive iodine or were exposed as children or adolescents are at increased risk of developing radiation-related conditions, it has not been possible to confirm whether any further health impacts were attributable to radiation. As the public were generally exposed to doses of radiation in the range of those from natural background sources, it is unlikely that any identifiable health impacts will be attributable to radiation released as a result of the accident.

In its assessment of the health impacts from radiation released at Fukushima, UNSCEAR reached the following conclusions[63]:

- No plant staff, emergency worker or member of the public died or developed acute health effects (such as ARS) as a result of radiation exposure. A small proportion of workers received higher doses during the accident and in the immediate clean-up period; however, these doses are understood to be a long way below the threshold for acute effects.
- In estimating potential health risks, including solid cancers, thyroid cancer, leukaemia, breast cancer and diseases associated with prenatal exposure, UNSCEAR considered the extent to which radiation exposure would affect the natural incidence of these diseases in the exposed populations. In general, it was concluded that it would not be possible to discern an increase in these diseases from that baseline level of risk.
- There may be an increased risk of cancer, particularly of the thyroid, and hypothyroidism in more vulnerable groups, including the 173 workers who received effective doses of 100 mSv or more, and infants and children in the evacuation zone. However, any such increase would be difficult to attribute to the accident, given the understood levels of exposure.

UNSCEAR stated that its findings do not preclude the possibility that health effects attributable to radiation from the Fukushima accident might be identified in future.[64] To that end, it has implemented a process of ongoing review of new information about radiation effects from Fukushima.[65] In the first of these reviews, in 2015, UNSCEAR concluded that its findings on the health implications for workers and the public 'remain valid and are largely unaffected by new information that has been published so far'.[66]

The health of the people exposed to radiation from the Fukushima and Chernobyl accidents will continue to be monitored by local authorities and the international community over the coming decades. Given the increase in thyroid examinations in Fukushima, it is expected that thyroid abnormalities not necessarily attributable to radiation will be identified that would not have been detected otherwise.[67] Further study since UNSCEAR's report has supported this view.[68] In the case of Chernobyl, the Chernobyl Tissue Bank has been established as a central data repository to assist in understanding how radiation induces cancers.[69]

Following the accidents at Chernobyl and Fukushima, evacuations and other response measures reduced the risk that radiation presented to local populations. However, these measures in themselves gave rise to other health implications.[70] Studies have found increased levels of depression and anxiety in populations affected by the Chernobyl accident.[71] In Japan, the comprehensive Mental Health and Lifestyle Survey indicated the presence of severe traumatic problems in adults from the Fukushima evacuation zone.[72] Mental conditions are also likely to lead to negative health effects and will have significant implications for public health.[73]

NOTES

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14 Submission: Sykes, p. 2; UNSCEAR, *Sources, effects and risks*, 2012 Report to the General Assembly, scientific annex A, UN, New York, 2012, pp. 8–9.

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37 ibid., pp. 749, 751.

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