WORLDWIDE EXPOSURES TO IONIZING RADIATION

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Abstract

All of mankind is exposed to ionizing radiation from natural sources, from human practices that release natural and artificial radionuclides to the environment, and from medical radiation procedures. This paper reviews the assessment in the UNSCEAR 1993 Report of the exposures of human populations worldwide to the various sources of ionizing radiation.

Introduction

Exposure to ionizing radiation is a constant and inescapable phenomenon for all human populations. The main component of exposures arises from natural sources: from cosmic rays that originate in outer space, from radionuclides in the earth's crust that become distributed throughout the environment in air, water, soil, foods and the human body and from radon and its decay products that accumulate in indoor closed spaces.

A second component of exposures to ionizing radiation arises from man-made sources and practices. Radioactive materials are released from installations associated with the nuclear fuel cycle used for the generation of electrical energy. Accidents have occurred at these sites or in the transport of nuclear materials that have allowed additional amounts of radionuclides to become widely distributed. The testing of nuclear weapons in the atmosphere caused relatively large releases of radioactive materials, but since 1980, this practice has stopped. An additional cause of exposure of human populations is from medical radiation examinations and treatments.

Natural Radiation Exposures

The UNSCEAR assessment of the annual effective dose from natural sources of ionizing radiation in areas of normal background has not changed from the previous estimate of 2.4 mSv. One third of this is due to external exposure to cosmic rays and terrestrial radionuclides and two thirds to internal exposure. The largest component of this exposure, half of the total, is from radon and its decay products.

Exposures to cosmic rays depend on altitude and to a lesser extent on latitude. The exposures increase at higher elevations and at higher latitudes. At sea level the annual effective dose is 0.27 mSv. Most populations live at or near sea level, but for those who live at high altitudes, the cosmic ray annual dose may reach 2 mSv. The world average annual dose to cosmic rays is 0.38 mSv.

Cosmic ray interactions in the atmosphere result in the formation of several radionuclides, including ^{3}H, ^{7}Be, ^{14}C and ^{22}Na. These cosmogenic radionuclides become evenly distributed and cause equal and relatively low exposures to all human populations. The annual effective dose from ^{14}C is 0.012 mSv, and it is much less from the other radionuclides.

Exposures to terrestrial radionuclides are mainly from ^{40}K and radionuclides of the ^{238}U and ^{232}Th series. These radionuclides cause both external and internal exposures. The dose rate in air in areas of normal background averages 57 nGy h^{-1} outdoors and 83 nGy h^{-1} indoors. The indoor-to-outdoor ratio is thus 1.5, but the ratio can vary from less than one for lightweight houses to around two when the construction materials make substantial contributions to exposures. Taking account of indoor (0.8) and outdoor (0.2) occupancy and using the conversion factor 0.7 Sv Gy^{-1} from dose in air to effective dose, the average annual effective dose from external irradiation is 0.48 mSv.

Internal exposures are caused by ingestion of radionuclides in foods and water and from inhalation, primarily of radon gas and its decay products. The annual exposure from ingestion of ^{40}K is relatively constant at 0.17 mSv, since this element is homeostatically controlled in the body. The radionuclides of the ^{238}U and ^{232}Th series cause annual internal exposures of 0.052 mSv from ingestion, mainly of ^{210}Pb-^{210}Po, and 0.010 mSv from inhalation (not including radon).

Exposure from inhalation of radon (^{222}Rn) and its decay products is considered separately, since this is the dominant and most variable component of exposure to natural sources. The concentration of radon is typically 10 Bq m^{-3} outdoors and 40 Bq m^{-3} indoors. In tropical areas with houses of lightweight construction and high ventilation, there should be little difference in indoor and outdoor levels. There are, however, too many factors that determine the concentrations, and measurements are necessary in all areas.

The dosimetry of radon is presently under review. UNSCEAR has retained the assumptions used previously, namely equilibrium factors of 0.4 indoors and 0.8 outdoors and a dose conversion factor of 9 nSv h^{-1} per Bq m^{-3} of equilibrium equivalent concentration (EEC) of radon. With these parameters the average annual effective dose from radon and its decay products is estimated to be 0.13 mSv for exposures outdoors and 1.0 mSv for exposures indoors. The average annual effective dose from inhalation of thoron (^{220}Rn) and its decay products is 0.07 mSv.

All of the exposures to natural sources of radiation can vary by significant amounts at specific locations. Factors of 5 to 10 are common variations for most components of exposure and several orders of magnitude for exposures to radon. UNSCEAR has made use of survey data from many countries and will continue to compile such measurement results to determine the average exposures to populations and the range of values throughout the world.

The extraction, processing and use of earth materials affect the exposures of people to natural radiation, especially when the materials contain above average concentrations of natural radionuclides. UNSCEAR has assessed the exposures resulting from energy production from coal, oil, peat, natural gas and geothermal energy, the use of phosphate rock in fertilizers and building materials and the processing of mineral sands for various uses. The highest exposures result from the use of phosphate by-products in buildings, the domestic use of coal for cooking and heating and the use of phosphate fertilizers. The overall annual effective dose from all such sources averaged over the world's population is 0.02 mSv.

Man-made Radiation Exposures

The assessments by UNSCEAR of the radiation exposures from man-made sources have been based on evaluations of the collective effective dose committed by the annual practice or by the events. The doses to individuals have been variable in both space and time. In many cases the amounts of radionuclides released result in relatively low concentrations in environmental media. Models have then been used to describe the dispersion, transfer and doses to local, regional and global populations.

Atmospheric testing of nuclear weapons resulted in the largest releases of radionuclides into the environment from man-made sources. Most of the testing occurred in 1952-1958 and 1961-1962. The last atmospheric test was conducted in 1980. From the many measurements that have been made throughout the years, UNSCEAR has evaluated transfer coefficients relating the input of radionuclides into the atmosphere to the resulting dose to humans. Transfer coefficients for 20 radionuclides for the ingestion, inhalation and external irradiation pathways are listed in the UNSCEAR 1993 Report. Exposure from two additional radionuclides, ^{3}H and ^{14}C, have been evaluated from comparisons with natural production and dose rates.

The collective effective dose to the world's population from atmospheric nuclear testing is estimated to be 30 million man Sv. Of this total, 86% is due to long-term, low-level exposure from ^{14}C. The contributions to dose in decreasing order of importance are ^{14}C, ^{137}Cs, ^{95}Zr, ^{90}Sr, ^{106}Ru, ^{144}Ce and

^{3}H. Only residual irradiation from ^{14}C, ^{137}Cs, ^{90}Sr and ^{3}H remains to be received by the present and future world population. The collective dose from this practice is equivalent the 2.4 years of exposure of the present world population to natural radiation sources.

Another man-made source of radiation exposures that has been assessed in some detail by UNSCEAR is that due to nuclear power production. There has been an increasing trend in electrical energy generation by nuclear reactors since the practice began in 1956. The expansion of the industry has slowed somewhat recently, primarily due to economic considerations, and the consequences of accidents have caused some countries to reconsider their energy programmes. Nevertheless, nuclear power production is extensive. At present, about 20% of the world's electrical energy is generated by nuclear means. At the end of 1992 there were 424 reactors operating in 32 countries. Additional reactors are planned or under construction in other countries.

During routine operation of installations associated with the nuclear fuel cycle (uranium mining and milling, fuel fabrication, reactor operation, reprocessing and waste disposal) radionuclides are released to the environment. The data on radionuclides released are quite extensive and complete, especially for reactor operations. It is possible to derive representative release quantities normalized to the amount of electrical energy generated or served by the activity for each stage of the fuel cycle. From the total amount of electrical energy generated each year, the total releases of radionuclides worldwide have been estimated. The trends in releases can be analysed in detail for the entire period in which the generation of electrical energy by reactors has taken place.

There have been generally decreasing trends in normalized releases of radionuclides from nuclear fuel cycle installations as operating practices have improved. This has meant that the trend in collective dose to the world population has been increasing somewhat less than the trend in electrical energy generated. The estimate of collective dose from nuclear power production was 43,000 man Sv during 1990 and 400,000 man Sv for the entire period 1956-1990. Even when the collective dose caused by the Chernobyl accident (600,000 man Sv) is added, the total collective dose has been just 1% of that which the world's population receives in one year from natural radiation sources.

Other man-made sources of radiation exposures caused by releases of radionuclides to the environment that have been assessed by UNSCEAR include exposures to local populations near the Semipalatinsk, Nevada, Australian and Pacific nuclear test sites, exposures from underground nuclear testing, exposures from nuclear weapons fabrication, exposures from radioisotope production and use and exposures from accidents at the Three Mile Island and Chernobyl reactors, Kyshtym and Windscale plutonium production plants, crashes of airplanes carrying nuclear weapons, satellite re-entries and lost or mishandled radiation sources, as at Goiania. The contributions to the total collective effective dose to the world population are sometimes minor, but the analysis has been made as complete as possible.

Medical Radiation Exposures

The use of x rays and radiopharmaceuticals for diagnostic examinations and therapeutic treatments is quite common throughout the world. Most of the equipment and the procedures performed are in industrialized countries, in which 25% of the world's population is located. For individuals living in less developed countries, the medical radiation facilities are less available, and the examinations and treatments are much less frequent than would be justified by the illnesses and injuries in the population.

UNSCEAR has assessed the exposures from medical radiation exposures from information obtained in a questionnaire distributed to all countries. Four regions of health care have been designated, based on availability of facilities, and the data have been extrapolated to the world's population. The variations in medical radiation exposures among individuals are great, ranging from no dose to those not examined or treated to high doses to those receiving therapeutic treatment. The largest portion of the total dose from medical radiation sources arises from diagnostic examinations due to their relatively high frequency. At the highest level of health care the annual effective dose averaged over the population from all diagnostic examinations is 1.1 mSv. The comparable value is 0.05 mSv at the lowest level of health care. The population-weighted world average is 0.3 mSv, and the annual collective effective dose is 1.8 million man Sv. The collective effective dose from medical radiation usage has been evaluated to allow comparisons among countries and the evaluation of trends. Much, and optimally most, of the collective dose from medical uses of radiation is offset by direct benefits to the examined or treated patients.

Conclusions

Exposures to ionizing radiation occur from both natural and man-made sources. For most individuals, the dose from natural background radiation is the most significant exposure that they receive. The average annual effective dose to the world's population from natural sources of radiation is estimated to be 2.4 mSv. Wide variations may occur, depending on local conditions, such as altitude and soil composition and especially building construction and ventilation that determine the levels of radon indoors.

Man-made environmental radiation sources generally contribute minor doses to most individuals. The collective doses from the practices have been evaluated by UNSCEAR. The largest collective dose resulted from atmospheric nuclear testing, but this practice has now ceased. Exposures from nuclear power production have been evaluated from the beginning of the practice to the present. Accidents at Chernobyl and other locations involving nuclear installations, transport of nuclear materials and satellite reentries have been evaluated. Except to individuals directly involved in these events, the exposures have been minor.

Medical radiation exposures make a greater contribution to the collective dose to the world population because of the frequencies of the examinations and treatments. These doses are offset by the direct benefits to the patient. Although the doses per procedure should be optimized, there is a general need to make medical radiation services more widely available throughout the world. The contributions to the collective effective dose to the world's population from the various sources of radiation are summarized in Table 1.

Table 1 Worldwide exposures to sources of ionizing radiation

Source	Annual effective dose (μSv)	Collective effective dose (man Sv)	
		Annual	Long-term committed
Natural radiation background	2,400	12,700,000	
Natural mineral utilization	20	100,000	
Man-made environmental exposures			
Atmospheric nuclear testing			30,000,000
Chernobyl accident			600,000
Nuclear power production	0.1	700	400,000
Radioisotope production and use	0.02	100	80,000
Nuclear weapons fabrication			60,000
Kyshtym accident			2,500
Satellite re-entries			2,100
Windscale accident			2,000
Other accidents			300
Underground nuclear testing			200
Medical radiation exposures	300	1,800,000	

Reference: United Nations. Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation. 1993 Report to the General Assembly, with annexes. United Nations, New York (1993).