Radiation Protection Dosimetry (2009), Vol. 136, No. 2, pp. 136–138

Book Review

doi:10.1093/rpd/ncp162
Advance Access publication 20 August 2009

IONISING RADIATION EXPOSURE OF THE POPULATION OF THE UNITED STATES: NCRP REPORT No. 160

Published by: the National Council on Radiation Protection and Measurements, Bethesda, MD, USA
ISBN: 978-0-929600-98-7, 387 pp. (2008).US$120 (Hard cover)/US$100 (PDF)

This report is a long-awaited sequel to NCRP Report No. 93 (published in 1987) and provides a comprehensive re-evaluation of the exposure of the US population to all natural and man-made sources of ionising radiation in 2006—some 25 y after the previous assessment for the early 1980s. Over this period, the average annual effective dose per individual in the US population (E_{US}) from all sources has increased by a factor of 1.7 to 6.2 mSv, with the increase being almost entirely due to the dramatic growth of relatively high-dose medical imaging procedures using X-rays and radionuclides.

The report first considers exposures from ubiquitous background radiation, which contribute 50% of the E_{US} from all sources (3.1 mSv). They are divided into extra-terrestrial cosmic and solar radiation, terrestrial radiation from surface soil and rocks, internal exposures from inhaled radon and thoron seeping out of the ground and internal exposures from radionuclides in the body. As in most other countries, the majority of the population exposure from background sources (73% in the USA) comes from radon and thoron, but the estimated average annual effective dose per individual for the USA (2.3 mSv) is about 75% higher than that for the UK (1.3 mSv), despite using the same conversion coefficient of 10 mSv per WLM (Working Level Month) to relate effective dose to radon concentration. Radon exposures at work were included in this assessment of ubiquitous background radiation rather than as an occupational exposure, but were based on very limited data giving an assumed radon concentration in workplaces that was marginally lower than that used for outdoor radon. The potential impact of radon remediation measures in the USA over the past 20 y was not taken into account in this report due to only sketchy data on their effectiveness. It was estimated that by 2005 over 1.4 million homes had been built ‘radon resistant’ but only about 600 000 of them had been activated by the installation of a radon venting fan. Radon levels vary widely across the USA, with higher levels commonly found in the Appalachians, the upper Midwest and the Rocky Mountain states. Cosmic and solar radiation levels vary with altitude and geomagnetic latitude and terrestrial gamma rays vary with the geology of the underlying rocks, so the total level of exposure to ubiquitous background radiation can change considerably around the USA from the average value of 3.1 mSv. The report estimates that about 2.5 million Americans (0.8% of the population) receive annual background doses in excess of 20 mSv, but a very similar average value (3.0 mSv) was found in the early 1980s.

By 2006 the contribution of medical imaging to the exposure of the US population had risen to be almost the same as background radiation (E_{US} = 3.0 mSv or 48% of that from all sources). This is due to major developments in the diagnosis and treatment of cancer and heart disease over the past 20 y—predominately in the fields of computed tomography (CT), interventional radiology and nuclear medicine.

Since its introduction in 1972, CT has evolved into an essential diagnostic imaging tool capable of producing detailed images of organs and tissues in the body with a clarity far surpassing that of conventional radiography or fluoroscopy. Recent advances in CT technology involving helical scanning and multiple rows of detectors have enabled the rapid acquisition of imaging data over large volumes of the body from which two or three-dimensional images can be reproduced in any plane or from any direction with sub-millimetre spatial resolution.

Scans of the whole body can be completed in less than 30 s, or the beating heart can be scanned with ECG gating over just a few heartbeats to freeze the motion and obtain clear images of the coronary arteries. These developments have led to an ever-increasing growth in the number of clinical applications for CT and to a 10% increase per year in the number of CT examinations carried out in the USA over the past two decades, culminating in 62 million in 2006 which is equivalent to 207 CT examinations per 1000 population. This is over four times higher than the rate estimated for the UK for 2006 ($\sim$50 per 1000 population). CT examinations involve relatively high effective doses (average 7 mSv per examination estimated for the USA) leading to an E_{US} of 1.5 mSv for CT alone, which amounts to 50% of that for all medical exposures and 24% of that from all natural and man-made sources combined.

In interventional radiology, fluoroscopy is used to guide the positioning of catheters or needles in the body that may be used for diagnostic or therapeutic purposes. In this report 'interventional fluoroscopy' is taken to cover both uses, so that purely diagnostic examinations that require the fluoroscopic guidance of needles or catheters for the injection or passage of contrast media to the organ or vessel to be imaged (e.g. myelography, urethography, coronary angiography, etc.) are included as well as those that involve a therapeutic intervention such as a stent insertion, embolisation, angioplasty or drainage. This broad interpretation of 'interventional fluoroscopy' to include diagnostic as well as therapeutic techniques has not always been followed in population dose surveys in other countries, so its contribution to the population exposure in this report may be higher than that reported elsewhere. Nonetheless the number of interventional fluoroscopy procedures has been increasing in the USA over the past decade at about 5% per year and those involving therapeutic interventions were very rare at the time of the previous NCRP report in the early 1980s. During these procedures dose rates at the skin can exceed 100 mGy per minute and for complex procedures involving intricate manipulation of catheters can last for tens of minutes. Effective doses for procedures involving stent insertions can exceed 20 mSv and serious skin burns have been reported when the X-ray beam remains stationary over the same area of skin for long periods. About 17 million interventional fluoroscopy procedures were performed in the USA in 2006 resulting in an E_{US} of 0.43 mSv, which is about 14% of that from all medical exposures.

In nuclear medicine unsealed radionuclides are administered to patients in a particular chemical form that will be taken up by the organ or tissue under study for diagnosis or treatment. Only diagnostic nuclear medicine procedures are considered in this report since they are far more common than therapeutic procedures and the high doses associated with treatments cannot be sensibly evaluated with the quantity effective dose. By displaying the distribution of a selected radiopharmaceutical in the body, diagnostic nuclear medicine procedures are used to assess *in vivo* biological processes such as organ function, cellular metabolism and regional blood flow rather than to provide the purely anatomical information of X-ray radiography and CT images. However, tomographic imaging techniques have also been developed in nuclear medicine to improve image resolution and by 2006 SPECT (single photon emission CT) and PET (positron emission tomography) scanners were widely available in the USA. Moreover, PET scanning was frequently performed in conjunction with a CT scan to combine physiological and anatomical information into a single fused image, but not without a combined effective dose of some 20 mSv.

About 18 million nuclear medicine procedures were performed in the USA in 2006 (60 per 1000 population), which is about twice the number carried out in the early 1980s and five times the rate estimated for the UK in 2006 (12 per 1000 population). As well as this much higher frequency for nuclear medicine examinations in the USA compared with the UK, the activities administered and the corresponding effective doses appear to be at least twice as high for all those procedures that make a significant contribution to the total collective dose. Moreover, relatively high-dose cardiac investigations make up 57% of the number of nuclear medicine examinations conducted in the USA and 85% of the collective effective dose, compared with only about 17 and 34%, respectively, in the UK. These three factors combined, lead to the E_{US} for all diagnostic nuclear medicine procedures in the USA (0.77 mSv) being a remarkable 25 times higher than the corresponding figure (0.03 mSv) for the UK. Consequently, nuclear medicine contributes 26% of the population dose from all medical exposures in the USA, but only 7% in the UK (and recent estimates in six other European countries range from 4 to 14%).

Between them CT, interventional fluoroscopy and nuclear medicine contributed 2.7 mSv to E_{US} in 2006, which is 90% of that from all medical exposures, the remaining 10% being due to conventional radiography and fluoroscopy. These conventional procedures accounted for 68% of the E_{US} from all medical exposures back in the early 1980s when it was 5.7 times lower than in 2006. A rough estimate was made of the contribution of external beam radiotherapy to population exposure, by considering only doses to organs which lay outside the treatment volume, but it was not included in this analysis because those exposed represent a small fraction of the US population ($<$3%) with life-threatening illnesses, receiving doses to organs and tissues surrounding the treatment volume that often exceed 1 Sv. Effective dose was not considered a suitable quantity in these circumstances.

The remaining 2% of the population exposure for the USA in 2006 (apart from natural background and medical exposures) comes mainly from consumer products and activities with a further very small contribution (about 0.1%) from doses to the general public and to radiation workers from industrial, medical, commercial, educational and research activities that involve the use of ionising radiation or contact with radioactive material. Three consumer products or activities are particularly important—building materials, cigarette smoking and commercial air travel—each accounting for about 30% of the population exposure from this source. Doses to the general public are dominated by exposures to those who have come into contact with nuclear medicine patients rather than with the nuclear power programme—a reflection of the rapid rise in nuclear medicine and the decline in nuclear power over the past two decades in the USA. Despite the recent introduction of X- or gamma-ray security inspection systems for detecting contraband at air, sea or land ports-of-entry in the USA, exposure levels are very low and the collective dose to the public is considered negligible.

Those occupationally exposed are likely to receive higher doses than general members of the public from industrial, medical, commercial, educational and research activities, with the average annual effective dose to the 1.2 million radiation workers in the USA (0.4% of the population) being about 1 mSv, but all workers were estimated to receive doses significantly below regulatory limits. Workers in the medical sector and those who fly as aircrew in commercial aviation are responsible for 39 and 38%, respectively, of the annual collective effective dose from all occupational exposures. The largest number of occupationally exposed individuals (735 000) work in the medical sector with an average annual effective dose of 0.8 mSv, whereas 173 000 are employed as aircrew with an average dose of about 3.0 mSv a year from the elevated levels of cosmic and solar radiation at flying altitudes. With the numbers of medical procedures using ionising radiation and the numbers of aircrew and high-altitude flights increasing at the time of this report, occupational exposures in medicine and aviation are likely to increase in the future, but at less than 0.1% they both still pale into insignificance compared with the contributions to E_{US} from natural background radiation and medical exposures of patients (~50% each).

The report issues a caution about interpreting relative contributions to population exposure in terms of relative health detriment, since the populations exposed to the different sources are not the same. For example, those exposed to ubiquitous natural background radiation represent the entire US population in age, gender and health status, whereas groups of patients exposed to medical radiation are often skewed towards the elderly and the infirm for whom the lifetime risks of radiation-induced cancer and hereditary effects will be much reduced. Any attempts to quantify health risks or to specify the actions to be taken in the light of these latest data on population exposure were considered to be outside the scope of this report. So the intriguing question as to whether the explosive growth in medical imaging over the past 25 y is justified by a net health benefit to the US population or is merely the result of the irresistible forces of technology, marketing and physician reimbursement in the American healthcare system, remains unanswered.

Barry F. Wall
Radiation Protection Division
Health Protection Agency, UK