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Uses and Risks of DU

In view of its wide topical interest, a Q&A brief on depleted uranium (DU) has been placed on the NRPB website, and some extracts from this are included in this issue of the *Bulletin* (see page 19). It may come as a surprise to some, but DU was commonly used in dental porcelains until the publication of NRPB-R25 in 1974.

In one of the early NRPB reports (NRPB-R25, 1974), authored by Michael O’Riordan and John Hunt, the practice of putting radioactive fluorescers in false teeth and crowns (not fillings) was examined in some detail. Natural teeth fluoresce brilliant white in ultraviolet light and artificial porcelain teeth always looked very different until the 1940s when a mixture of trace amounts of uranium and cerium was added to dental porcelain to make artificial teeth look natural. Uranium salts fluoresced yellow and cerium fluoresced blue, and the combination gave a natural looking white. This led to wide exploitation in the 1950s and 1960s and, increasingly, depleted uranium (DU) was used rather than natural uranium. This had two benefits – it was cheaper and it was less radioactive. NRPB-R25 contained calculations and measurements of doses to soft tissue in the mouth assuming DU was used. The doses were nearly 30 mSv per year to the basal layer of the epithelium in the mouth, and this was in breach of the Medical and Dental Code of Practice in the 1970s. This code set a limit of 15 mSv per year averaged over any organ, for practices with no obvious therapeutic or diagnostic benefit. The authors of NRPB-R25 therefore recommended that the practice be discontinued – and it was soon afterwards, especially as there were other methods available for making artificial teeth look natural.

DU has had a number of uses, especially as radiation shielding, counterweights in helicopters and aircraft and in anti-armour weapons. The last has produced an enormous amount of publicity recently and inevitably a lot of anxiety in soldiers and others who suspect they may have been exposed to DU. Since the Gulf War in 1991 there has been a great deal of information released on DU. NRPB staff have contributed to various studies looking at the potential hazards, including those of working groups set up by the Royal Society, the European Commission and the World Health Organization. It is interesting to note that in a recent ten-year review of the evidence for Gulf War illness in *Science* (291, 812–17, 2001) the possible risks from DU are put in the context of the many other hazards soldiers had to face. It is also significant that a recent update of the epidemiological study of UK veterans of the Gulf War showed they had fewer fatalities from disease (including cancer) than a similar group of veterans who did not serve in the Gulf War. (*Hansard*, Written Answer, WA4, 22 January 2001)

DU is radioactive and doses from inhalation of dust or from handling bare spent rounds need to be assessed properly. However, the scientific consensus at present is that the risks are likely to be small and easily avoidable, especially compared to the other risks the armed forces have to take in war.

Michael Clark

Doses from CT Fluoroscopy

Computed tomography fluoroscopy (CTF) is increasingly used for difficult biopsy procedures on patients. CTF has considerable benefits medically. However, the technique can deliver high radiation doses to patients and to medical staff.

A recent paper from scientists at the Department of Radiology, Columbia University (*Health Physics*, **79**(6), 675–81, 2000) has reported dose measurements using patient phantoms and ionisation chambers. The measured patient doses were in the range 3–10 mGy s⁻¹ and, for a group of 78 patients, the clinically utilised imaging times varied from 13 to 407 seconds, with a mean time of 96.6 seconds (\pm 78.9 seconds). The scattered x-ray radiation at the position of the radiologist's hands when performing biopsy procedures were 10–25 μ Gy s⁻¹. Thin leaded gloves provided only minimal protection from doses to the hand, but floor-mounted radiation shields reduced doses from scattered radiation by up to 99%.

CTF delivers high dose rates due to the high voltage and current settings, and the rotation geometry. It is clear from this study, that the medical benefits of this technique needs to be balanced against the high doses to patients and staff. A clear case for ALARA studies in medical physics departments?

New RERF Genetic Study

To date, the Radiation Effects Research Foundation (RERF) has found no long-term genetic effects in the 80 000 children (known as the F_1 population) born between 1946 and 1984 to survivors of the atomic bombings at Hiroshima and Nagasaki. There is still, however, the possibility that genetic effects could appear as late onset multifactorial disorders that were not visible in infancy. To evaluate this hypothesis, RERF is carrying out a new study of the F_1 population, which will look at health records and some clinical examinations will also be carried out. (*Nature*, **409**, 5, 2001, and www.rerf.or.jp)

Plutonium Smuggling

Over 300 plutonium plate sources have been discovered in a forest in Greece. These source are thought to originate from Eastern Europe or from Russia, where such sources are used in industry as static eliminators. The plates were found after an anonymous tip off to the Greek police and were taken to the Greek Atomic Energy Commission for analysis. GAEC scientists detected plutonium-239 with traces of americium-241 and the calculated total inventory was about 3 g of plutonium-239. This is hardly enough to make a nuclear weapon (kilogram quantities are required), but sufficient to alarm authorities and regulators about the effectiveness of safeguards and radioactive source control.

The International Atomic Energy Agency was called in to advise on decontamination measures in the forest where the plates were found. Precautionary measures have been taken, including the removal of potentially contaminated soil and sealing local drinking water supplies. IAEA has offered to analyse the precise radionuclide composition of the source plates which may reveal their origin. (*Nature*, **409**, 653, 2001, and www.iaea.worldatom.org)

Clouds Affected by Cosmic Rays

A major greenhouse gas is water vapour, and clouds are a significant influence on the energy budget at the Earth's surface. Clouds can reflect solar light, but they can also absorb outgoing long-wave thermal radiation. Solar cosmic rays can influence global cloud cover because the ionised secondary particles in the atmosphere tend to act as condensation nuclei for cloud droplet formation.

A recent study by Marsh and Svensmark (*Physical Review Letters*, **85**, 5004, 2000) has looked at monthly cloud anomalies in the troposphere and correlated them with changes in solar cosmic ray flux. They report that cloud cover at altitudes less than 3.2 km shows a correlation with solar cosmic ray fluxes between 1980 and 1995. In contrast, there is no correlation for cloud cover at higher altitudes. This is at first surprising, but given the extensive showers of ionising particles that cosmic rays produce in the atmosphere, one explanation is that there is likely to be a greater number of condensation nuclei at lower altitudes.

Radon and Lung Cancer in Germany

Results from a case-control study of radon and lung cancer in various regions of Germany have recently been published by Kreienbrock *et al* (*American Journal of Epidemiology*, **153**, 42-52, 2001). There were about 1450 hospital cases diagnosed with lung cancer, during 1990-96, of whom more than 80% were male, and 2300 population controls who were matched for gender, age and region. A subsample of about 370 cases and 600 controls from radon-prone areas was also studied.

On average, subjects in all groups had resided in their current home for 23 years. Average residential radon concentrations were estimated on the basis of one-year measurements to be 50 and 60 Bq m⁻³ for the entire study and radon-prone areas, respectively. The analysis adjusted for smoking and occupational exposure to asbestos.

Although the results did not demonstrate a risk associated with residential radon exposure in the entire study area, a significant radon risk was observed in the radon-prone areas. A large number of houses with low exposure and small variation in radon concentrations could explain the difference in results between the radon-prone areas and the full study area. The excess relative risk for an increase of 100 Bq m⁻³ was estimated to be 0.13 (95% CI -0.12, 0.46) in radon-prone areas; this is similar to that found in other case-control studies of radon and lung cancer, such as that in South West England. These results support findings from previous studies that have illustrated a link between residential radon exposures and lung cancer.

Radon to the Rescue

An Icelandic study reported excess malignant melanoma amongst pilots flying over five time zones (*Occupational and Environmental Health*, **57**, 175-9, 2000). The natural explanation is that globe trotting increases the chances of unwise sunbathing, but another possibility is that disturbance of the circadian rhythm is responsible. A letter in the same journal (*ibid*, **57**, 843) reports a case-control study which found no excess of melanoma amongst those whose circadian rhythm had been disrupted by working night shifts. This argues against the theory advanced above.

Why 'Radon to the Rescue'? The lead author of the letter is Dr Katja Radon.

Cosmic Uranium Dating

The age of the universe is estimated to be between 9×10^9 and 15×10^9 years by a variety of methods. The best known technique pioneered by the famous astronomer Hubble is to use the observed expansion rate of the Universe. A lesser known technique is that of 'radioactive cosmochronometry' which looks at the age of thorium-232 (half-life, 14.1×10^9 years) in stars.

Ground-based knowledge of nuclear fusion and observations of stars have led to the conclusion that average sized long-lived stars, such as the Sun, can only produce elements up to carbon, nitrogen and oxygen. The heavier nuclei must be produced by supernova explosions in short-lived super-massive stars. These explosions produce a hugely neutron-rich environment which leads to the formation of heavy, neutron-rich nuclei, which subsequently rearrange themselves to stable configurations by radioactive decay. Supernova explosions are a regular occurrence in galaxies and therefore stars like the Sun (and the planets) contain the debris of many such explosions over time. So radioactive cosmochronometry applied to radionuclides in the Sun or Earth is not a revealing exercise.

However, in the galactic halo, far from the centre of the galaxy, there are some very old stars which are assumed to be formed from the debris of the very first supernova explosions. These stars are very 'metal poor' compared to the Sun, which supports the basic hypothesis. Observations of these stars show that despite being depleted in metals, neutron-capture elements exist in relatively high proportions, and their absorptions can be seen easily in the star's light spectrum. A recent paper by Cayrel *et al* (*Nature*, **409**, 691–2, 2001) reports the first observation of both thorium-232 and uranium-238 (half-life 4.5×10^9 years) in a very old metal poor star, and the estimated age of the star is 12.5×10^9 years ($\pm 3.3 \times 10^9$ years). The authors expect that observations of other stars in the galactic halo with new generation telescopes will reduce the uncertainties considerably.

Radiotherapy to Keep Coronary Arteries Open

The *New England Journal of Medicine* (**344**, 243–56, 2001) reports two studies of intracoronary brachytherapy (radiation sources placed inside the coronary arteries) to help prevent the artery re-blocking. Blocked coronary arteries can be successfully re-opened with balloon catheters, introduced through leg vessels and guided to the blockage under x-ray control. In some cases a small metal mesh scaffolding (stent) is inserted to keep the artery open. In up to 40% of cases the artery re-blocks (restenoses) because of an overgrowth of the cells lining the artery.

Radiation is known to slow cell growth. The two studies reported add to the small body of evidence about the role of intracoronary brachytherapy in preventing restenosis. These are the first randomised studies in the field and bring the total number of patients reported in the literature to nearly 600. The first study used a beta source and followed 181 patients for six months after the procedure. Four doses between 9 and 18 Gy were used. The second study used gamma radiation (average dose within 2 mm of the source, 13.5 Gy) and followed 252 patients for nine months after the procedure.

Frustratingly, none of the studies uses exactly the same outcome measures, so direct comparison of the results is difficult. However, there is an emerging consistency to

the findings. Intracoronary radiotherapy leads to a significant reduction in the restenosis rate, but can increase the risk of coronary thrombosis (clot) at the operated site several months after the procedure.

All the published studies are reviewed in an editorial in the same issue. The editors sound a note of caution. More patients need to be studied for much longer to define the safety of the procedure. Clinical outcomes (what the patient can do afterwards) must be considered as well as the diameter of his/her coronary arteries. The best and safest way to use this new technology must be defined before it becomes part of routine practice and is used without the rigorous evaluation of a randomised trial. This history of medical technology suggests that it may be adopted long before the answers to these questions are known.

Cancer Research Merger?

The trustees of the Cancer Research Campaign (CRC) and the Imperial Cancer Research Fund (ICRF) are considering a merger (*Nature*, **409**, 4, 2001). CRC tends to fund research at various institutions, while ICRF does a major amount of research at its own institutes. A merger would combine these extramural and intramural research capabilities, and both types of work would continue in parallel.

Nuclear Liabilities

The UK Atomic Energy Authority is presently undergoing a five yearly review of its activities. For some time now UKAEA has concentrated its efforts on decommissioning civil nuclear sites, having sold off its commercial arm as AEA Technology. One plan being considered in the government review is to set up a new body called the Liabilities Management Authority. LMA would be charged with providing a clear view on the total costs and timescales of decommissioning all nuclear sites in the UK. The ownership of the liabilities would remain with the government, but control of them would reside with UKAEA. (*Nuclear Engineering International*, p 9, December 2000)

Wireless Capsule Endoscopy

A letter in the *New England Journal of Medicine* (**344**, 232–3, 2001) reports on pictures ‘from mouth to colon’ taken by a capsule swallowed by patients with small-bowel bleeding. The capsule, about 25 mm long and 12 mm in diameter, contains a TV camera and LEDs to illuminate the scene. Aerials taped to the patient’s body receive the images. The authors, from the Royal London Hospital, reported that useful diagnostic information was obtained.

Antibiotic Resistance

An editorial in the *New England Journal of Medicine* (**343**, 1961–3, 2000) draws attention to what it describes as ‘the relentless rise of antibiotic resistance’ amongst important bacteria. The authors note that, in the USA, 160 million prescriptions for antibiotics are written per year and over 20 million kg are prescribed, only half of which are for human use. This tremendous proliferation encourages the selection of resistant strains of bacteria.

The authors advocate much greater use of vaccination against pneumococcal infections and the avoidance of inappropriate use of antibiotics for conditions such as viral infections of the upper respiratory tract.

Depressing News

A short article in *Cancer Causes and Controls* (**11**, 759–64, 2000) reports a clear correlation between increasingly sedentary jobs and incidental prostate cancer. Your first thought might be that social class could be confusing the analysis. But prostate cancer levels were, if anything, lower in those with higher educational levels. So, after your PhD, you should aim to be a navvy. Bad news for those of us who spend our lives behind a desk.

A Sweaty Business

An article in the *New England Journal of Medicine* (**343**, 488–93, 2001) discusses a new approach to axillary hyperhidrosis. Your reviewer would have passed on to the next article if the authors had not helpfully explained that this meant excessive sweating. This was defined as production rates in excess of 50 mg per minute, although the mean production by the patients concerned was almost four times this.

A randomised, double-blind multicentre trial seemed to demonstrate clearly that injection of botulinum toxin A into an armpit greatly reduced sweat production. The reduction in the armpit receiving the toxin was by a factor of eight or so, against less than a factor two for the placebo. The frequency with which injections would be needed is variable, but six months might be typical. The patients tolerated the treatment well and 98% would recommend it to others.

Bed Rest Scare

There has been some fascinating correspondence in the *Lancet* about the dangers of bed rest. A reader pointed out that a review of the potentially harmful effects of staying in bed too long, omitted to mention an item by Asher over 50 years ago in the *BMJ* (**ii**, 967–8, 1947). Long periods of convalescence were common then, and Asher's description of the health impact of too much 'bed rest' is masterly.

'The blood clotting in his veins, the lime draining from his bones, the scybala stacking up in his colon, the flesh rotting from his seat, the urine leaking from his distended bladder, the spirit evaporating from his soul.'

So much for beauty sleep. However, rumours that the Department of Health is planning to ask manufacturers to put health warnings on beds, have been discounted by sources close to Whitehall.

Written and compiled by Michael Clark,
with contributions from
Nezosh Hunter, Gerald Kendall and Jill Meara

The Ups and Downs of Medical and Dental Radiology

BARRY WALL • NATIONAL RADIOLOGICAL PROTECTION BOARD • CHILTON

NRPB has recently completed a long awaited re-assessment of the number and pattern of medical and dental x-ray examinations performed in the UK*. The study covers all diagnostic and interventional procedures using x-rays, both within and outside the National Health Service (NHS) and is the first such national survey conducted by NRPB since 1983. One of the most significant findings is that where as the total number of medical x-ray examinations per head of population has remained substantially constant, the number taken by dentists has increased by nearly 50% since 1983, to the extent that dental x-rays now comprise 30% of all x-ray examinations. However, despite their large number, the impact of dental x-rays on the collective dose to the population is small. Of far more importance is the increasing clinical exploitation of new high dose imaging modalities such as computed tomography (CT) and digital fluoroscopy and the rapid expansion of medical imaging from pure diagnosis to the guidance of therapeutic interventions.

SURVEY METHODS

To discover the latest trends in hospital radiology practice, the survey made use of the detailed data now available from computerised radiology information systems at a selected sample of 38 English NHS hospital trusts. Details were requested on the numbers of every different type of x-ray examination carried out in the financial year 1997/98. The data returned from the 38 trusts covered 16% of all the x-ray examinations performed in England in that year. The multitude of different classifications of x-ray examination used by the trusts were re-arranged into 62 standardised categories, based on the anatomical region under examination and whether they were conventional, computed tomography (CT) or interventional procedures. The numbers of examinations performed in each of the 62 categories were extrapolated from the survey sample to the whole of England, using the broad radiology workload statistics that are collected from every NHS trust by the Department of Health each year.

Statistical data were also obtained on recent NHS radiology practice in Wales and Northern Ireland from the respective Health Departments. They demonstrated a remarkably similar provision to England, in terms of the total number of x-ray examinations of all types per head of population. In the absence of any contemporary radiology statistics for Scotland, the same rate per head of population as seen in the rest of the UK was assumed to apply, and the English data were scaled up to the whole of the UK accordingly. Sufficient information was also obtained for x-ray imaging practice outside NHS hospitals to make fairly reliable estimates of the contribution from dentistry, independent and military hospitals, chiropractic clinics and other fringe practices.

* Tanner R J, Wall B F, Shrimpton P C, *et al.* Frequency of medical and dental x-ray examinations in the UK – 1997/98. Chilton, NRPB-R320.

RESULTS

Overall numbers

A total of about 42 million medical and dental x-ray examinations were conducted in the UK in 1997/98, corresponding to 704 examinations per 1000 inhabitants (see the table). X-rays remain the predominant type of radiation used for medical imaging, accounting for 79% of all imaging procedures, with ultrasound, radioisotopes (diagnostic nuclear medicine) and magnetic resonance imaging (MRI) responsible for 17%, 2.6% and 1.7%, respectively.

Annual frequency of diagnostic x-ray examinations from all health care sectors in the UK in 1997/98			
SECTOR	NUMBER OF EXAMINATIONS (THOUSANDS)	PERCENTAGE OF TOTAL	NUMBER PER THOUSAND POPULATION
NHS hospitals	26 558	64.0	450
Independent hospitals	853	2.1	14.5
Mammography screening	1 400	3.4	23.7
MOD hospitals	105	0.25	1.78
Chiropractic clinics	75	0.18	1.27
Other	50	0.12	0.85
Total excluding dentistry	29 041	70.0	492
Dentistry (primary care)	12 500	30.0	212
TOTAL (medical and dental)	41 541	100	704

NHS hospitals performed 64% of the x-ray examinations and 30% (12.5 million per year) are now carried out by dentists. Independent (private) hospital provision of diagnostic radiology services has risen slightly since the last survey in 1983 but is still only 2.1% of the total, whereas mammography screening under the NHS Breast Screening Programme, which did not exist in 1983, now comprises 3.4% of all x-ray examinations. The contribution from armed service hospitals and medical units has fallen to about 0.25%, reflecting recent reductions in the numbers of service personnel and military medical establishments. Chiropractors are estimated to conduct about 75 000 x-ray examinations per year (0.18% of the total) and all other practices, such as podiatry, chiropody and the prison service, are thought to be responsible for no more than about 50 000 examinations altogether (0.12% of the total).

The increase since 1983 of 5% in the total number of x-ray examinations conducted in NHS hospitals has just kept pace with the increase in the population, whereas in primary care dental radiology the number of examinations has increased by 50%, despite a marked decrease in the incidence of dental decay.

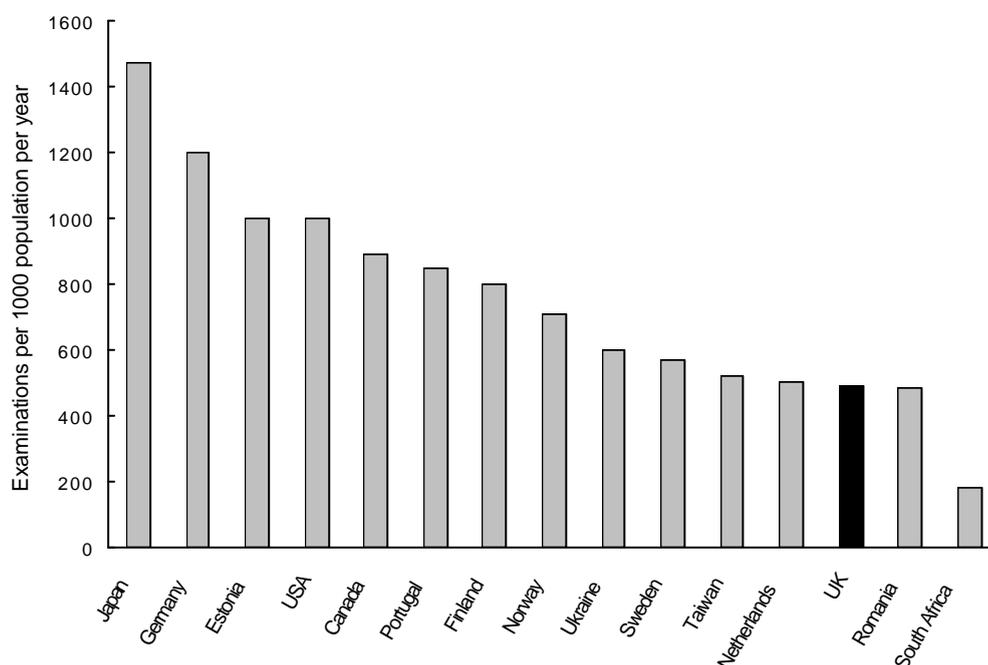
The frequency of medical x-ray examinations in the UK is similar to recent estimates for the Netherlands, Romania and Taiwan but less than one-half of those for Germany, the USA and, rather surprisingly, Estonia (see Figure 1). Japan continues to hold its place as the top provider of high technology health care with an x-ray examination frequency three times that of the UK and 50% higher than that of the USA. The relatively

low frequency of x-ray examinations in the UK is probably associated with a number of factors including:

- the comparatively low percentage of gross domestic product (GDP) spent on health care in 1997/98 (6.8% for UK compared to 10.7% Germany, 9.6% France, 8.6% Sweden and a European national average of 8%),
- the low number of radiologists per head of population compared to most other developed countries (eg about one-half of the average and one-third of the maximum for 12 European and North American countries in the 1980s and relatively lower still in the 1990s),
- the provision of detailed guidance for doctors in the UK from the Royal College of Radiologists on the correct indications for x-ray examinations,
- the low prevalence of private practice in UK radiology (only about 2%) compared to many other European countries (eg 81% of French radiologists work entirely in the private sector and 15% of radiological procedures in Belgium are performed in private offices).

A combination of rigorous clinical justification and financial stringency would appear to be responsible for the comparatively restrained use of medical x-ray imaging in the UK.

FIGURE 1 Comparison of medical x-ray examination frequency in different countries



Pattern of examinations

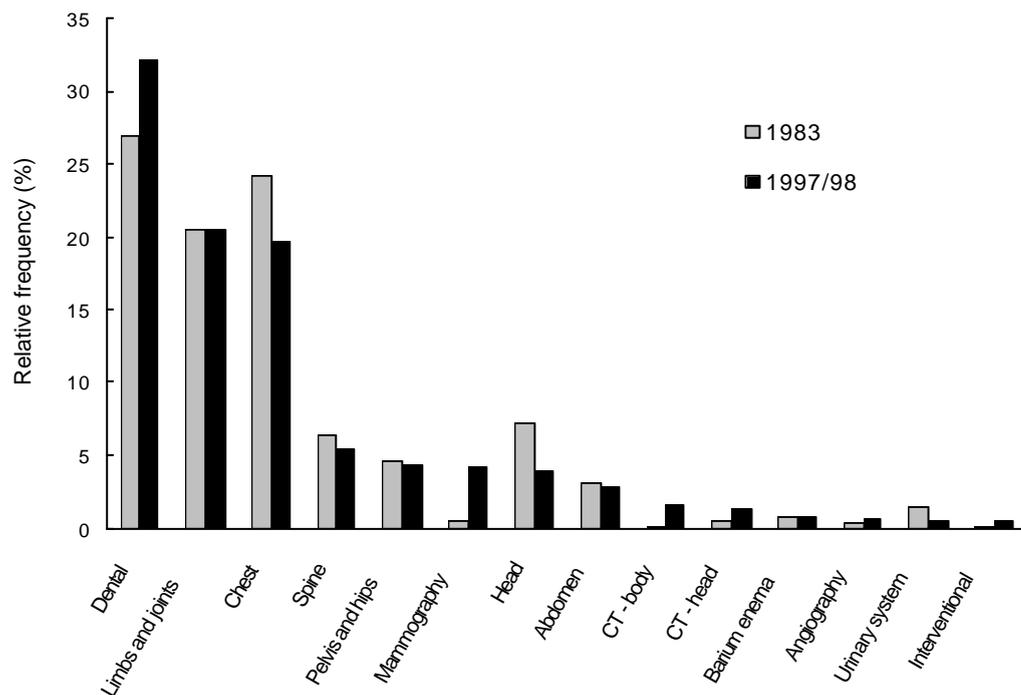
X-ray examinations of the teeth, limbs and chest remain by far the most frequent, accounting for about 75% of all examinations in 1997/98 compared to about 70% in 1983. Fortunately, the radiation exposure is very low for these types of examination, with individual effective doses rarely exceeding 20 μ Sv. Examinations of the spine, pelvis and hips are just as common now as 15 years ago, comprising about 15% of all examinations,

whereas conventional radiographs of the head and neck have fallen slightly, some probably being replaced by CT. There have, however, been significant changes in the relative frequencies of some other examinations over the past 15 years, as new imaging technologies have been developed and introduced into clinical practice. Those showing large increases in frequency involve mammography, angiographic procedures, CT and interventional radiology.

Mammography screening has increased from a very low level in 1983 – which, as mentioned before, was prior to the setting up of the UK Breast Cancer Screening Programme – to an estimated 1.4 million examinations per year in 1997/98. About 332 000 mammographic examinations are also carried out on symptomatic women in the UK, giving a total of about 1.73 million mammographic examinations altogether, which comprise about 6.5% of all x-ray examinations conducted in NHS hospitals. There was consequently an eight-fold increase in the number of mammographic examinations (screening and symptomatic) between 1983 and 1997/98.

The number of CT examinations has increased by over a factor of five since 1983 (see Figure 2) and CT now comprises about 5% of all x-ray examinations performed in NHS hospitals. These are relatively high dose examinations, with effective doses ranging from 2 to 20 mSv, and are probably contributing as much as 40% of the collective dose from all diagnostic radiology procedures in the UK. Nearly one-half of CT examinations are of the head and neck, one-third of the abdomen and pelvis, and one-seventh (14%) are of the chest. Over the past couple of years since the survey, further technological developments have occurred in CT in the shape of multi-slice helical scanning. This allows larger volumes of the patient to be scanned more rapidly, leading for the first time to the possibility of ‘real-time’ moving CT images (‘CT fluoroscopy’), high resolution

FIGURE 2 Relative frequency of different types of medical and dental x-ray examination in the UK



three-dimensional imaging and 'virtual endoscopy'. A further explosion of CT scanning into angiographic and interventional procedures has probably already begun.

Interventional radiology, which comprises image-guided, minimally invasive therapeutic interventions, can also involve high radiation doses when x-ray fluoroscopy or, more recently, CT, provide the guidance. About half of the interventional procedures carried out in 1997/98 were related to the heart, being mostly coronary artery angioplasties or pacemaker insertions. Drainage, dilatation, stenting and stone extraction in the biliary and urinary tracts comprised 20% of the interventional procedures, while biopsies accounted for a further 11%. Unavoidable complications frequently arise with the positioning of catheters and guide wires, and the need to continue until the therapeutic intervention is completed can lead to very prolonged exposures. However, the avoidance of potentially more hazardous surgery and reduced hospitalisation time have meant that these procedures are becoming increasingly popular, rising some ten-fold in frequency since 1983 to nearly 250 000 procedures (1% of all x-ray examinations) by 1997/98. This high rate of increase shows no sign of abating and interventional radiology may soon be competing with CT as a major contributor to collective dose.

The examinations showing large reductions in frequency are mainly those which are being superseded by other imaging modalities such as endoscopy (barium meals) or ultrasound (biliary, urinary and obstetric examinations). Endoscopy does not appear to have made an impact on the frequency of barium enema x-ray examinations of the colon, but its use for imaging the oesophagus and stomach has reduced the frequency of barium meals to the extent that they no longer feature in the top 14 types of examination shown in Figure 2. The increase in the number of MRI examinations to just over 2% of all x-ray examinations may have partially held down the numbers of some conventional x-ray and CT imaging procedures but there was no clear evidence for this from the survey results.

CONCLUSIONS

While bread and butter radiography of the teeth, limbs and chest remains at the top of the nation's x-ray shopping list, technological advances in medical imaging have begun to make a significant impact on clinical practice at the high quality end of the market. However, high quality images generally come at a high price, in terms of both money and dose. The adoption of these new imaging technologies requires a double-justification, involving careful selection of patients for whom both the financial costs and the radiation risks are clearly compensated by overwhelming clinical benefits. The UK remains comparatively restrained in its use of medical imaging compared to many other developed countries – a result of clinical prudence and financial stringency in the past – but it will be interesting to see which way things develop in the future.

NRPB is currently assessing the impact of these changes in the pattern of radiology practice on the collective dose to the population. Preliminary results suggest that modest reductions in the dose per examination for the bulk of the conventional radiographic and fluoroscopic examinations might have balanced the increased, but still relatively uncommon, use of the new higher dose imaging modalities. It is still too early to say whether the collective dose will go up or down, but NRPB is never likely to have the temerity to suggest which direction is desirable.

Application of the ICRP HRTM to Uranium Compounds Produced During the Manufacture of Nuclear Fuel

ALAN HODGSON • NATIONAL RADIOLOGICAL PROTECTION BOARD • CHILTON

With the introduction of the human respiratory tract model (HRTM) in 1994¹, the International Commission on Radiological Protection (ICRP) provided a means by which material-specific information could be used to derive dose coefficients and interpret bioassay measurements for inhaled materials². Previously published biokinetic data, obtained after exposure of rats to a variety of industrial uranium compounds formed during the fabrication of nuclear fuels, were re-evaluated. Values of the HRTM parameters which describe absorption from the lungs to the blood were derived, and then used to calculate dose coefficients and predict the lung retention and urinary excretion kinetics for each compound. Results were compared with predictions using the ICRP default values³.

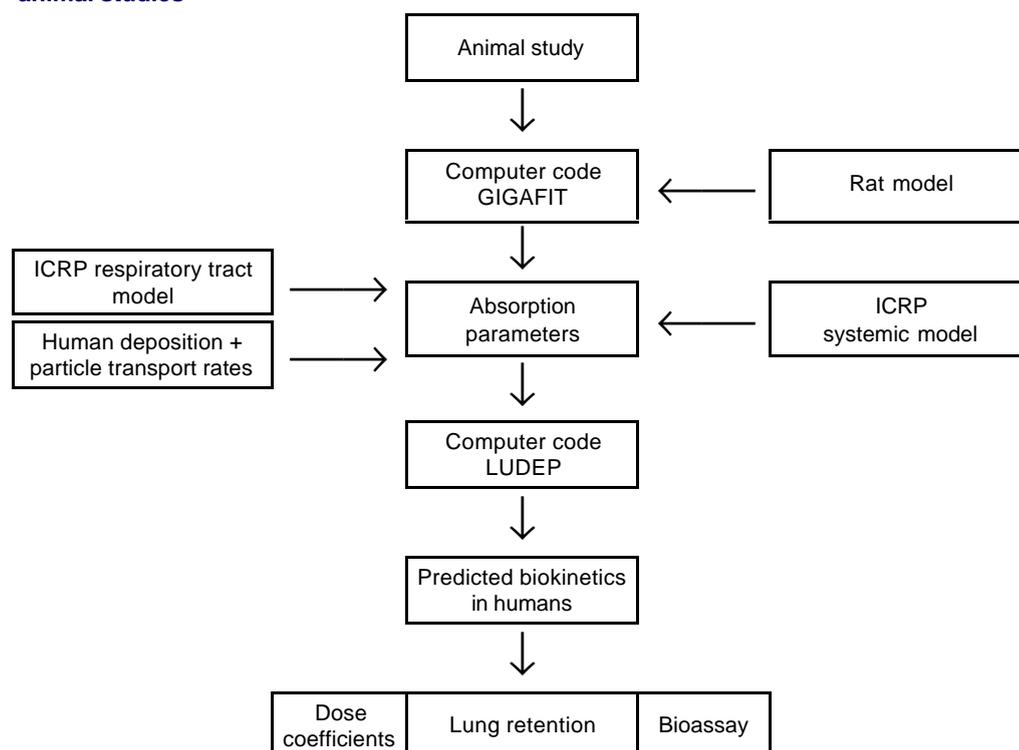
The methodology used for interpreting the results from the animal studies and assessing the radiological implications for human exposure is shown schematically in Figure 1. Essentially, the material-specific absorption parameter values derived from the animal studies are combined with human particle deposition and transport parameter values from the HRTM (which are independent of the material) and the human systemic model for uranium.

The HRTM absorption parameters cannot be measured directly but are derived from measurements of the radionuclide retained in the respiratory tract and other organs, and in excreta. For this purpose a biokinetic model for the rat was developed to describe the deposition and clearance of material in the respiratory tract, and the systemic behaviour of the radionuclide after uptake.

This rat model and the biokinetic data were used with the NRPB parameter fitting program GIGAFIT⁴ to derive absorption parameter values for each compound. In the HRTM the absorption of uranium is represented by a fraction (f_r) which dissolves rapidly at a rate (s_r) and the remaining fraction ($1 - f_r$) which dissolves at a slower rate (s_s). The results are summarised in the table, in order of decreasing absorption represented by f_r . The absorption parameter values were then used to extrapolate from rats to humans and to model intakes. The rates of absorption to blood after inhalation of a given material are assumed to be independent of mammalian species.

The table shows that in all cases the value of s_r was much lower than the ICRP default value of 100 d^{-1} . It is suggested therefore that in the absence of material-specific information, a value of 1 d^{-1} should be assumed for s_r for compounds of uranium. Uranyl nitrate, UO_3 and ADU have large rapid fractions (f_r) but also a slow component with a dissolution rate similar to that of Type M. UF_4 has a rapid fraction that is midway between Types F and M and a slow dissolution rate (s_s) that is similar to that of Type M. The more insoluble compounds, UO_2 and U_3O_8 , have dissolution kinetics (f_r and s_s) intermediate between Type M and Type S, but closer to Type S.

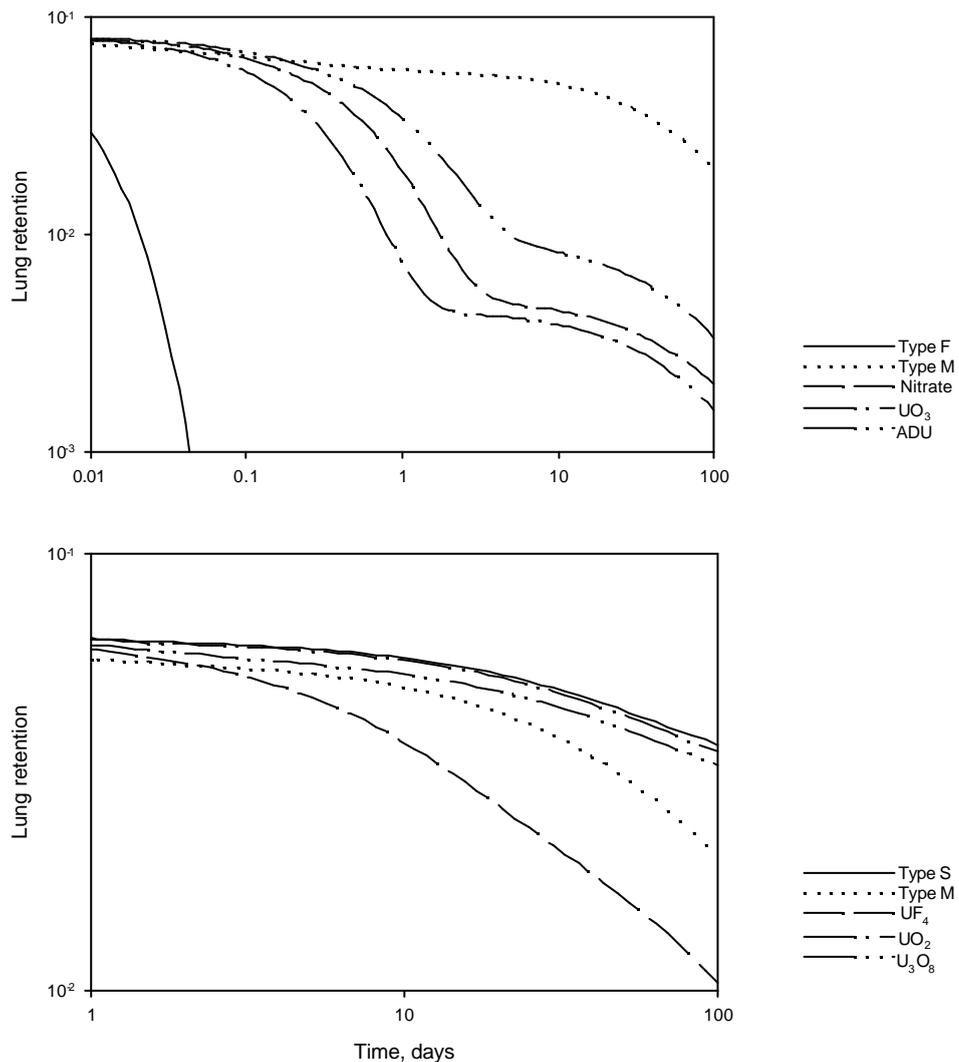
FIGURE 1 Methodology for assessing consequences of human exposure based on animal studies



Summary of absorption parameter values, assigned absorption Type and dose coefficients ($\mu\text{Sv Bq}^{-1}$) for 'natural uranium'						
COMPOUND	ABSORPTION PARAMETERS			ASSIGNED ABSORPTION TYPE		DOSE COEFFICIENT ($\mu\text{Sv Bq}^{-1}$)
	f_r	s_r (d^{-1})	s_s (d^{-1})	ICRP 30/68 DEFAULT	ICRP 71 CRITERIA	
Uranyl nitrate	0.93	3	0.005	F	F	0.4
UO ₃	0.92	1.4	0.0036	M	F	0.4
ADU	0.85	0.78	0.005	N/A	F	0.5
UF ₄ – kiln	0.51	0.10	0.0074	M	M	1.2
UF ₄ – fluid bed	0.52	0.11	0.0039	M	M	1.3
U ₃ O ₈	0.044	0.49	0.00035	S	S	4.9
UO ₂ – non-ceramic	0.011	0.95	0.00061	S	S	4.4
UO ₂ – ceramic	0.008	1.3	0.0026	S	S	5.4
<i>Defaults (ICRP Publication 68)</i>						
Type F	1	100	–			0.6
Type M	0.1	100	0.005			1.9
Type S	0.001	100	0.0001			6.3
<i>Notes</i>						
N/A not applicable. ADU (ammonium diuranate) is not assigned to a default Type in ICRP Publication 68.						
'Natural uranium' defined as:						
	²³⁴ U	²³⁵ U	²³⁸ U			
by mass (%)		0.005	0.72	99.27		
by activity (%)		48.9	2.2	48.9		

In the absence of material-specific information a default absorption type would be used. Hence, it is important to compare the derived absorption parameter values, and the implications for doses and bioassay, with the HRTM default values (Type F, M or S). In ICRP Publication 68⁵, uranyl nitrate is assigned to Type F, UO_3 and UF_4 are assigned to Type M, and U_3O_8 and UO_2 are assigned to Type S (see the table). ICRP Publication 71⁶ briefly reviewed recent information on the biokinetics of inhaled uranium compounds and reported that the behaviour of UO_3 and UF_4 was complex, with some studies indicating Type F behaviour and others Type M according to the criteria proposed in ICRP Publication 71. Similarly, it reported that considerable variation in the behaviour of U_3O_8 was observed, with some studies indicating Type M behaviour and others Type S. It did, however, support the assignment of UO_2 to Type S. Applying the ICRP Publication 71 criteria to the rat biokinetic data, UO_3 and ADU are assigned to Type F, both forms of UF_4 are assigned to Type M, and U_3O_8 and both forms of UO_2 assigned to Type S. These assignments (see the table) support those in ICRP Publication 30⁷ and 68⁵, for all materials except UO_3 . The material studied here would be assigned to Type F rather than Type M.

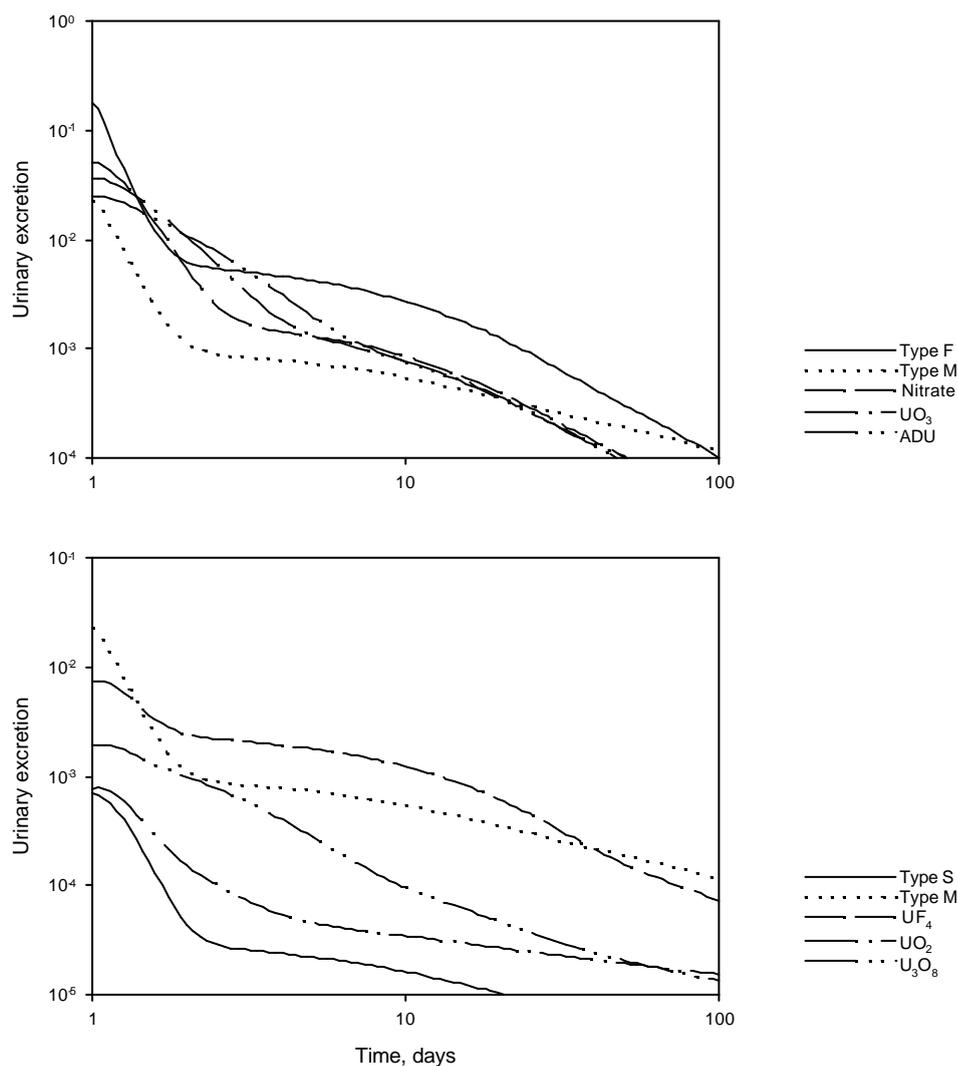
FIGURE 2 Predicted lung retention and daily urinary excretion for workers exposed to uranium compounds



A modified version of the NRPB software LUDEP⁸ was used to calculate dose coefficients ($\mu\text{Sv Bq}^{-1}$), using the material-specific absorption parameter values with ICRP reference conditions for occupational exposure ($5 \mu\text{m AMAD}$ aerosol inhaled by a reference worker as used to calculate dose coefficients in ICRP Publication 68). The effective dose was calculated using the HRTM, ICRP Publication 60 tissue weighting factors⁹ and the ICRP Publication 69 systemic model for uranium¹⁰ for the three uranium isotopes of interest (^{234}U , ^{235}U and ^{238}U) and combined to give dose coefficients for 'natural' uranium forms of each compound (see the table). The dose coefficients calculated using the material-specific absorption parameter values were within 60% of the corresponding default values (Type F, M or S) for all compounds.

Figure 2 shows the predicted lung retention and daily urinary excretion rate of uranium for some of the compounds studied using the material-specific absorption parameters. An acute exposure of 1 Bq for a $5 \mu\text{m AMAD}$ aerosol inhaled by a reference worker⁴ is modelled. It is worth noting that for an aerosol of this size the fraction deposited in the lungs is only about 8% of the inhaled material.

FIGURE 2 Continued



The predicted lung retention and daily urinary excretion curves show that most of the compounds studied are not well described by any default absorption Type, confirming the need for material-specific data in these cases. These results will provide an important input into the optimisation of monitoring procedures, a subject currently being addressed by NRPB and other European organisations under the Fifth Framework Programme of the European Commission.

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Depleted Uranium

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This article contains some edited information from the question and answer brief on depleted uranium that is also on the NRPB website.

BASIC PROPERTIES

Depleted uranium is a byproduct of the industrial process to obtain an 'enriched' form of uranium. In this process the ^{235}U concentration is enhanced and the remaining uranium mixture (after the enriched uranium is removed) has reduced concentrations of the ^{235}U and ^{234}U isotopes: this is known as depleted uranium (DU). Typically, DU used in munitions, contains by weight:

- ^{234}U , 0.001%, half-life 2.5×10^5 y,
- ^{235}U , 0.2%, half-life 7×10^8 y,
- ^{238}U , 9.8%, half-life 4.5×10^9 y,

All the above isotopes have progeny with significant beta emissions.

If the DU is partly derived from reprocessed reactor fuel, then it may also contain

- ^{236}U , 0.0003% (approximately),
- plus trace amounts of plutonium, neptunium, americium and fission products.

Since the radioactivity per gram of each uranium isotope is different, the ratios of isotopes in natural and depleted uranium are different if expressed by radioactivity (see Table 1) rather than by mass.

DU is less radioactive than natural uranium because it has less of the more radioactive isotopes, ^{234}U and ^{235}U , per unit weight. The International Atomic Energy Agency defines DU as a low specific activity material. (Specific activity – the activity in becquerels per unit mass – is used as a measure of radioactivity.) The specific activity of uranium in DU is about 15 Bq mg^{-1} compared with 25.4 Bq mg^{-1} for natural uranium. If the activities of the decay products are also included, then the value for specific activity is higher. Plutonium (eg ^{239}Pu) has a much higher specific activity of about $2.3 \times 10^6 \text{ Bq mg}^{-1}$, while granite has an activity of 5×10^{-5} to $5 \times 10^{-4} \text{ Bq mg}^{-1}$.

	NATURAL URANIUM	DEPLETED URANIUM
^{234}U	48.8%	15.2%
^{235}U	2.4%	1.1%
^{238}U	48.8%	83.7%

DU OUTSIDE THE BODY

For DU outside the body, the potential effects are limited to those of radiation and not chemical toxicity. The radiation exposure depends on how much DU is present, how close it is, and how long it is there. It is relatively straightforward to calculate (or measure) such radiation exposures and to assess their effects. DU emits three types of ionising radiation: alpha particles, beta particles, and photons (x-rays and gamma rays). Alpha

particles are stopped by a sheet of paper, and most will be stopped by the inert outer layer of skin. Beta particles can travel about a centimetre in the body. Photons are more penetrating and can pass straight through the body.

The radiation dose rate to the skin, which comes mainly from the beta particles, can be up to 2.5 mSv h^{-1} , if a lump of DU were held in the hand. It is easily reduced by wearing gloves, or if the DU is encased in some other material. Furthermore, skin is relatively insensitive to radiation, so that even continuous contact (keeping a piece in a pocket or wearing it as jewellery) is unlikely to produce a radiation burn or other short-term effect. Such effects require doses of a few thousand millisieverts delivered over a short time, but at 2.5 mSv h^{-1} the DU would need to be in contact for months to give such doses. However, a small increase in the risk of skin cancer would be expected.

The theoretical maximum whole body gamma dose rate from external exposure, for someone surrounded by DU, has been calculated to be 0.025 mSv h^{-1} . The highest exposures likely to arise in practice are in a vehicle fitted with DU armour and carrying DU ammunition. According to US Army measurements, the whole body dose rate in a tank fully loaded with DU munitions is typically less than 0.002 mSv h^{-1} . Thus driving such a tank for 1000 hours gives a dose similar to the average annual dose from natural background radiation in the UK. Such exposures are readily measured and controlled.

DU IN THE BODY

If DU enters the body, it can potentially cause damage from the inside (internal exposure) either through irradiation or by chemical action. It can enter the body by inhalation (breathing in fine dust), ingestion via the mouth, contamination of an open wound, or – on the battlefield – by the embedding of shrapnel fragments. Uranium has been used extensively as a nuclear fuel, and many workers involved in processing uranium have been potentially exposed to dusts containing uranium, over many years, so many studies have been carried out on the behaviour of uranium in the body. In particular, there have been numerous studies conducted to determine the behaviour of uranium in the body, after deposition in the lungs of a wide range of different uranium compounds, including the various oxides produced by the use of DU munitions.

Inhaled DU particles may enter the body through the nose and/or the mouth. Depending on their sizes, some particles will be exhaled, some will deposit in the upper airways (the nose, mouth and bronchial tree), and some will deposit in the deep lungs. Most particles larger than a few micrometres in diameter are filtered out in the upper airways and so do not reach the deep lungs: the nose is quite an effective filter. (The cells that make up the body are typically about $10 \mu\text{m}$ across). Most particles that deposit in the upper airways are trapped in mucus that moves to the throat and are swallowed within a few hours. Most particles that deposit in the deep lungs are quickly captured by mobile cells called macrophages, rather similar to white blood cells. They may move the particles to the bronchial tree, to be carried away in mucus and swallowed, but this is a slow process, and some particles may remain in the lungs for years. A very small fraction of particles deposited in the lungs will be transferred to lymph nodes, where they would probably remain if they did not dissolve. However, whether in lungs or lymph nodes, uranium oxide particles will gradually dissolve and the dissolved uranium will be absorbed into the blood. Even materials generally regarded as ‘insoluble’ will dissolve to some extent in the lungs: particles small enough to deposit there have a large surface area per unit mass, which makes them accessible to cellular liquids.

It is generally found that when dusts are inhaled and deposit in the lungs, a fraction of the material dissolves rapidly and the rest at a fairly steady rate. Tests have been carried out on DU oxides, which simulated dissolution in the lungs. These show that for the particles formed when lumps of DU are heated in a fire, a few per cent dissolves rapidly, but the rest very slowly. For the particles formed when a DU penetrator impacts on armour plate, a larger fraction, about 25%, dissolves quickly. Other tests have shown that in both situations, the particles consist mostly of U_3O_8 , with some UO_2 , both of which are relatively insoluble. Experiments carried out on industrial forms of U_3O_8 and UO_2 indicate a long-term dissolution rate in the lungs of the order of 0.1% per day.

When uranium compounds are ingested, uranium is not readily absorbed into blood from the gut. Even for soluble forms of uranium only a few per cent is absorbed (2% is usually assumed for radiation protection purposes). For the uranium oxides formed from DU impacts or fires, the fraction is likely to be much less. For relatively insoluble compounds, such as UO_2 and U_3O_8 in workplaces, 0.2% is usually assumed.

Most of the uranium absorbed into blood is rapidly excreted, mainly in urine. About 65% is excreted during the first day, another 10% during the rest of the first week. There is a continuing slow excretion, about 0.002%, of the original uptake to blood per day after a year. That is why measurements are often made on urine to estimate the amount of uranium in the body. The uranium that is not rapidly excreted deposits in various organs. In particular, about 10% is deposited in the kidneys. Since the kidneys are relatively small (about 300 g in an adult), the concentration will be higher than in other organs. However, most of the uranium deposited in the kidneys does not stay for long. By 3 months, the amount retained is only about 0.1% of the original uptake to blood. About another 15% deposits in bone, but since the mass (5000 g) is much greater than that of the kidneys, the concentration is lower. Uranium does stay much longer in the bone, so there will still be a few per cent left after 5 years and about 1% after 25 years.

LIMITS ON INTAKE

Regarding chemical toxicity, the kidneys are considered to be the most susceptible organ. In many countries, the current occupational exposure limits for soluble uranium compounds are related to a maximum concentration of $3\ \mu\text{g}$ uranium per gram of kidney tissue. Any effects caused by exposure of the kidneys at these levels are considered to be minor and transient. Current practices, based on these limits, appear to protect workers in the uranium industry adequately. In order to ensure that this kidney concentration is not exceeded in the UK, HSE legislation restricts long-term (8 hour) workplace air concentrations of soluble uranium to $0.2\ \text{mg m}^{-3}$ and short-term (15 minute) to $0.6\ \text{mg m}^{-3}$.

It is more difficult to define a safe limit for radiation exposure since the risk of developing a cancer is assumed to be proportional to the dose received. Limits for radiation exposure are recommended by the International Commission on Radiological Protection (ICRP) and have been adopted by the European Union. The annual limit on effective dose for a member of the public is 1 mSv, while the corresponding limit for a radiation worker is 20 mSv. The additional risk of fatal cancer associated with a dose of 1 mSv is assumed to be about 1 in 20 000. This small increase in lifetime risk should be seen in the context of the 1 in 4 people who die from cancer.

Limits on intake depend on the route of intake into the body, and on various assumptions about the size of the aerosol and solubility in the lungs and gut and its distribution in the body. For insoluble compounds, the material will tend to remain in the

lungs for longer, and so the principal damage would be irradiation of the lungs. For more soluble material, the DU would be absorbed more quickly from the lungs into the blood stream where about 10% of it would initially concentrate in the kidneys.

Table 2 shows how much would have to be inhaled or ingested to give an effective dose of 1 mSv (radiation dose limit) or, alternatively, a kidney concentration of 3 µg per gram of kidney (chemical toxicity limit). These values have been calculated with the biokinetic models currently recommended by ICRP.

TABLE 2 DU intakes required to reach limits		
ROUTE OF INTAKE	INTAKE (mg)	
	FOR A KIDNEY CONCENTRATION OF 3 µg PER GRAM	FOR A DOSE OF 1 mSv
Inhalation of a reference 'moderately soluble' aerosol	230	32
Inhalation of a reference 'insoluble' aerosol	7400	11
Ingestion of a reference 'moderately soluble' DU compound	400	1500
Ingestion of a reference 'insoluble' DU compound	4000	8800

In order to express these amounts in becquerels, it should be noted that 1 mg of DU typically corresponds to about 15 Bq. It should also be borne in mind that the amounts required to give a kidney concentration of 3 µg per gram would be larger if the intake was given over a longer time since it would give the kidneys more time to excrete the DU. It can be deduced from the table that, for ingestion of DU, the chemical toxicity limit of 3 µg per gram of kidney tissue needs a smaller intake than the radiological limit (for a member of the public) of 1 mSv. For inhalation of a DU aerosol, the reverse is the case.

PRACTICAL LIMITS ON INHALATION

DU is a low specific activity material, so a large mass has to enter the body to give even a moderate radiation dose. In this context, it has been pointed out that to inhale 1 g of any dust in a short time is almost impossible. Even over a long time it is not easy. An air concentration of 10 mg m⁻³ is regarded as noticeably and unpleasantly 'dusty'. An adult breathes about 1 m³ h⁻¹ during normal daytime activities, so would have to inhale dusty air continuously 8 hours a day for nearly 2 weeks to inhale 1 g. The dust would have to be very contaminated to be even 10% DU: generally, away from the immediate site of a DU weapon attack the concentration in dust will be far less. Hence in almost any normal situation it is unlikely that anyone would inhale even 100 mg DU. The radiation dose from this would be up to about 10 mSv, similar to the average annual dose from radon in parts of the UK. Thus, even if many people inhaled that amount (which is even more unlikely), the effects would be too small to observe.

With regard to chemical effects, HSE legislation in the UK restricts long-term (8 hour) workplace air concentrations of soluble uranium to 0.2 mg m⁻³ and short-term (15 minute) to 0.6 mg m⁻³. It is unlikely that more than 25% of the DU is soluble or that dust to which people are exposed is more than 10% DU. On this basis, 0.2 mg m⁻³ corresponds to a dust concentration of 8 mg m⁻³, which people would not normally be able to tolerate for long.

Discussion of Radon Problems in Berlin

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A tradition has emerged of an annual meeting of those engaged in radon research funded by the German Environment Ministry (BMU). This year's event was the thirteenth in the series and took place during October in Berlin. The traditional format was broadened with speakers from other European countries invited to present a status report on their radon programmes. The meeting is held in German which left the visitors scrabbling for vocabulary ('subfloor depressurisation?'). Twenty-eight papers were presented in two busy days. Proceedings will appear in due course, what follows are some personal impressions.

Sweden and the UK have arguably the most developed radon programmes in Europe. In both countries, measurements have been made in around 400 000 houses. Comparable numbers have been identified where remedial action is recommended (50 000 in Sweden and 40 000 in the UK). But the Swedes have been much better than the British at persuading such households to remediate: about half have taken action in Sweden compared to an estimated 10%–20% in the UK. The reason for the difference is easy to understand: the Swedish government will pay half the cost of remediation. The UK radon programme has recently been re-directed in order to encourage higher levels of remediation, but by advice and information rather than by grants. Nevertheless initial indications are that this more economical approach will also help to increase the remediation rate.

Germany has taken a completely different approach to developing its domestic radon programme from Sweden and the UK. Instead of massive measurement programmes, the Germans have adopted an approach led by geological modelling. Of course, radon in room air largely originates from uranium in rocks and soils (building materials rarely contribute much) and the uranium content of such materials is certainly a matter of geology. Transfer of radon gas to the soil gas beneath a house involves factors such as the porosity of soils and fracturing of rocks which also belong to geology. The final stage – entry of soil gas into the house – may be a matter for building engineers but geologists are irresistibly drawn to the general question of predicting radon levels. There is no doubt that, in a general way, they can do so, particularly when geological information is used in conjunction with house measurement data. However, the geological processes involved are extremely complex. The Germans have attempted to short-circuit many of these difficulties by relying heavily upon radon in soil gas measurements.

In the UK, promising results have been obtained by grouping radon in house measurements according to the geological unit on which the houses stand. This is certainly more logical than the traditional grid square. However, the geological maps from which 'geological units' are deduced were not developed with radon in mind and it sometimes

happens that house measurement data demonstrate that what appears to be a uniform geological unit is not homogeneous so far as radon is concerned.

A wide range of work was discussed including some relating to occupational exposures. One striking account involved attempts to reduce doses during maintenance at a water works. The initial attempts to improve ventilation lowered radon concentrations from 400 000 Bq m⁻³ only to 300 000 Bq m⁻³. Radon is funny stuff and pumping in clean air proved vastly more effective than extracting the high radon air. Finally, a regime of continuous blowing in of clean air (not just during the working day) and care to prevent turbulence in the water, reduced levels to 'only' a few thousand Bq m⁻³.

Mention must also be made of a fascinating, if slightly peripheral, paper. One contributor had responsibility for training mining engineers. He had awakened the interests of his students to the point that they had undertaken radiological surveys of most of Berlin's 320 railway stations. They had found a number with slightly elevated levels of radiation caused by granite facings. But the plums were a couple where ceramic tiles incorporated uranium glaze. Dose rates of well over a microsievert per hour could be found at hotspots.

Keep Taking the Tablets?

EDITOR – The time over which thyroid blocking with KI is effective is commented on under the heading 'Taking the Tablets' in *Bulletin* No. 227. A recent study (Zamzonico and Becker, *Health Physics*, **78**(6), 660–67, 2000) found blocking was effective only if oral KI was administered within two days and less than eight hours after radioiodine intake. It is commented that this imposes severe constraints on the provision of tablets for affected populations, and that prophylaxis would have been of little value for the populations exposed to the plume from the Chernobyl accident.

This view may be somewhat pessimistic. While in the case of people living close to the reactor, such as residents of Pripjat, the thyroid doses primarily arose from inhalation, for people at rather greater distances inhalation during passage of the plume was less important than milk ingestion. The UNSCEAR 2000 Report notes, for example, that in the contaminated region around Bryansk in the Russian Federation about 80%–90% of iodine-131 intake appeared to be derived from milk consumption, and only 10%–20% from vegetables and inhalation. For ingestion from the milk intake pathway, at least 24 hours are usually available to consider intervention measures. However, effective intervention would seem to require pre-planning and stockpiling of tablets.

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