

# Radiological Protection Bulletin

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# Does X-ray Screening Work?

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Questions have been raised recently about the effectiveness of breast screening programmes. The issues require balanced and expert judgement.

The use of x-rays for medical diagnosis was one of the first beneficial applications of ionising radiation, and it is one of the most enduring. The potential benefits for many of those who are injured or ill are undeniable. An x-ray can help doctors make an accurate diagnosis of the problem and to decide on appropriate treatment. The range of medical x-ray diagnostic techniques has expanded tremendously, to include computed tomography (CT) scans, mammography and angiography. As well as being of use in diagnosis of symptomatic patients, x-rays have been used in health screening programmes for the general population. One of the first applications was the use of chest x-rays to screen people for tuberculosis. This practice became widespread in the UK in the 1950s, but as the incidence of TB declined, primarily because of the use of antibiotics and improving housing conditions, it gradually became clear that the screening programme was no longer cost effective. The costs were high and the benefits were minimal, in terms of detection of disease and lives saved, and large-scale mass screening using chest x-rays was stopped.

Today breast cancer screening using x-ray mammography is widespread, and in the UK it is available for all women between 50 and 70 years. The overwhelming medical/scientific consensus view is that breast cancer screening is beneficial. However the *Lancet* has published two papers recently from a Danish research centre questioning the value of breast cancer screening. After carrying out a systematic review of randomised trials of screening mammography, the work has raised questions about the quality of these trials. The authors (P Gotzsche and O Olsen) claimed that the best of the trials did not provide evidence of a reduction in either total or breast cancer mortality (*Lancet*, **355**, 129–34, 2000, and **358**, 1340–42, 2001). Furthermore, the authors claimed that early diagnosis could lead to more aggressive surgical treatment. They claim that screening identifies some slow growing tumours which may not develop into cancer in later life, as well as cell changes which are 'histologically cancer but biologically benign'.

Predictably these conclusions have caused controversy, not least in the Nordic Cochrane Centre where the authors work, and provided newspapers (and the *Lancet*) with an intriguing story, which is good for circulation and subscription figures. However, there is a need to go behind the headlines to get a broader perspective. For example, the NHS Breast Screening Programme claims that breast screening saves lives (*BMJ*, **323**, 1088, 2001) and the Nordic study has been criticised for studying old trials. Research in the UK shows that between 1990 and 1998 breast cancer mortality fell by 21.3% in women aged 55–69 years (*BMJ*, **321**, 665–9, 2000). Of this decrease in mortality, 6.4% was attributed to screening.

So far in this debate, issues concerning radiological protection have not been a primary consideration. The radiation risks from mammography are considered to be very low, such that the number of cancers detected far exceeds the number that might be induced. NRPB has given advice on the risks and uncertainties, but it would be inappropriate for NRPB to express an opinion on the value of breast screening programmes as a whole. The work reported in the *Lancet* has raised questions about the effectiveness of breast screening programmes, and such questions are relevant to any health screening programme involving people who are well. Is it better to test and to treat, rather than to leave well alone? In view of the effort and resources involved in mass screening programmes, their cost effectiveness should be assessed more or less continually. What is the prevalence of the disease? How accurate is the screening technique? Is there an effective treatment for the disease once it is detected? Are there any serious side effects from either the screening test or from the treatment? Expert and considered judgement needs to be applied to these difficult questions.

Michael Clark

## Lessons from Chernobyl

In an editorial for the *British Medical Journal* (*BMJ*, **323**, 643–4, 2001), Professor Sir Dillwyn Williams argues a strong case for improving the handling of major disasters, using the experience of Chernobyl as a guide. He is highly critical of how various organisations were involved in uncoordinated studies in the early years after the accident. The USA and EU signed separate research agreements with the governments involved, and various UN agencies carried out their own studies. Initially the EU and WHO played a major part in identifying the increase in childhood thyroid cancer, but then set up separate research studies. Eventually medical scientists established some sort of co-ordination and, 13 years after the accident, formal agreements were reached between the governments of affected areas, the USA, the EU, Japan and WHO, and thyroid tumour banks were created (see *Bulletin*, No. 227, 4, 2000, and *Science*, **289**, 2283, 2000). Many factors influenced the lack of co-ordination in the early years, not least the break up of the Soviet Union. Some historians claim that the Chernobyl accident was a major pre-cursor to this momentous political change. Williams is nevertheless highly critical of the in-fighting between and within various UN agencies which hampered international cooperation.

About 2000 cases of thyroid cancer have occurred in those exposed to isotopes of radioiodine as children or adolescents. Fortunately these have not led to many premature deaths, but it cannot be assumed that this will be the only observable health effect of the Chernobyl accident. Williams makes a strong plea for an international study of all long-term health effects of exposure to Chernobyl. Without such a study he says ‘... there will be no authoritative assessment of all the consequences, allowing some groups to accept uncritically the highest claims made, while others can say there are no proved long-term effects other than thyroid cancer’.

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## UVR and Prostate Cancer

A case-control study by Hanchette and Schwartz (*Cancer*, **70**, 2861–9, 1992) of 210 cases of prostate cancer adds to an earlier finding (Luscombe *et al*, *Lancet*, **358**, 641–2, 2001) that ultraviolet radiation (UVR) may be associated with a reduced risk of prostate cancer. The current study used patients attending a UK midlands hospital. The controls were 155 patients with benign prostatic hypertrophy. A self-administered questionnaire was used to elicit a lifetime history of chronic occupational and recreational sun exposure and acute episodes of sunburn.

The study found a significant negative correlation between prostate cancer and both chronic and acute UVR exposure indices. There was no relationship with skin type, hair or eye colour or vasectomy status. Patients in the lowest quartile of lifetime UVR exposure had an earlier presentation of prostate cancer.

Using patients with non-malignant prostatic disease as controls could be criticised. The authors did this because the controls had been investigated for their benign prostate disease. Therefore they were more certain than the general population to be free of covert prostate cancer.

Overall, the studies are of interest but it remains uncertain whether there is an aetiological association between lack of UVR exposure and risk of prostate cancer. UVR is known to promote skin synthesis of vitamin D and thus some UVR exposure may be

beneficial, especially to people with darker skins. However, only small exposures are needed to produce this beneficial effect. This study should not alter advice about the need to protect the skin and eyes against UVR, which is a known skin carcinogen and immune suppressant. It does serve as a reminder that more needs to be known about the biological effects of UVR to allow sound recommendations to be made about an optimal dose of UVR to the general public or people with particular risk factors.

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### **Sunburn and Melanoma**

Epidemiological studies have indicated that cutaneous malignant melanoma may arise as a consequence of exposure of the skin to ultraviolet radiation. In particular, studies have shown that intermittent and intense exposure of children to UVR may be a significant risk factor for melanoma incidence in later life. The Board gave formal advice on this topic in 1995 in light of the evidence, and highlighted the risk to children (*Doc NRPB*, 6(2), 1–6, 1995). Now scientists in the USA have developed a genetically engineered mouse model to show that a single dose of burning UVR to neonates, but not adults, is able to induce skin tumours similar to human melanoma (Noonan *et al*, *Nature*, 413, 272, 2001). They hope that further studies using the transgenic mice will help with the assessment of genetic and environmental risk factors for melanoma, as well as developing protection against sunburn and melanomagenesis in humans.

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### **UVR Sewage Treatment**

It is well known that exposure to ultraviolet radiation can have biological effects, and in some circumstances UVR can act as a disinfectant. Northumbrian Water has announced that it intends to install UVR disinfection equipment at more of its sewage treatment plants. The first plant was installed earlier this year and led to local bathing waters passing the most stringent EC guideline standards. Encouraged by this success, plans to build five new plants in the region have been announced, involving an investment of about £12 million. The system works by passing secondary treatment sewage water through a covered channel containing banks of UVR generators, suspended parallel to the direction of flow. As the water passes, the intense UVR destroys the vast majority of remaining bacteria and viruses.

Those interested in safety aspects of UVR might like to note that for the opening ceremony of the first installed system, normal fluorescent light tubes were used instead of UVR generators. This spared the prying eyes of journalists from exposure to UVR, and local dignitaries were protected from any risk during walkabouts.

(*Sources*: news.bbc.co.uk and www.nwl.co.uk, 7 November 2001.)

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### **Fermi Taken to Cleaners**

Enrico Fermi, the great Italian Physicist and Nobel Prize laureate, made one of his major discoveries with the help of a cleaning lady, according to a new book. While she washed floor tiles in the corridor outside Fermi's laboratory, Cesarina Marani routinely placed buckets of water inside the laboratory near an experiment where elements were being bombarded by neutrons. Two of Fermi's colleagues noticed that they obtained anomalously high radiation outputs when the buckets of water were present. They told

Fermi and he quickly realised the implications and postulated the mechanism of neutron moderation. We know now that the water moderated the fast neutrons in the beam giving larger yields of new isotopes in target materials. To confirm his hypothesis of moderating fast neutrons, Fermi performed the experiments directly over a bucket of water and registered dramatically improved yields of new isotopes.

The book, written by Fabio Cardone and Roberto Mignani, is entitled *Enrico Fermi and the Buckets of Cesarina* and published (in Italian) by Di Renzo Editore to coincide with the centenary of Fermi's birth (see [www.direnzo.it](http://www.direnzo.it)). Fermi was an exceptional man and this incident is a good example of how the scientific intellect can appreciate the importance of anomalous results.

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## Mobile Phones Monitor Asthma

The breathing sounds generated by patients with asthma are widely accepted as an indicator of the severity of the condition. Work done at a hospital in Kilmarnock and at the University of Glasgow, show that mobile phone recordings can be used to monitor asthma. The microphone of a normal mobile phone was applied to the neck over the trachea of patients and they were asked to breath through the mouth for a minimum of five breath cycles. Signals were recorded using a free internet voicemail service which, for each recording, sends a date stamped audio file to chosen recipients ([www.yac.com](http://www.yac.com)). When analysed in the laboratory, the audio files provided breath sounds that are of a quality equivalent to that achieved by a stethoscope (Anderson *et al*, *Lancet*, **358**, 1343–4, 2001). The readings could be easily converted into breath spectrograms and the paper gives some striking examples of the results obtained. The authors suggested that this could be used by doctors to monitor remotely occupational asthma and also larger populations during inclement environmental conditions such as smog.

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## Animal Magnetism

The question of how migratory animals find their way around the globe, some travelling vast distances, is the subject of scientific debate. A recent issue of *Science* contains a paper which indicates that sea turtles may be using the Earth's magnetic field to find their way around (**294**, 283–4, 2001). To test this hypothesis, Lohmann *et al*, at the University of North Carolina (UNC), collected 79 loggerhead turtle hatchlings, and fitted them with a tiny bathing suit tethered to a tracking system. The hatchlings were placed in a shallow laboratory tank which had a grid of external electric coils designed to simulate the Earth's magnetic field. The scientists presented each hatchling with one of three fields found at critical points on their known migratory route across the Atlantic from Portugal to Florida. At each magnetic field tested, the hatchling turtles swam preferently along the direction corresponding to their natural migratory path. For example, when the tank simulated the magnetic field of the north-east Atlantic gyre, the hatchlings chose to swim south. In the wild, this strategy takes them away from cold Atlantic waters. Lohmann *et al* claim that this response to a magnetic field enables hatchlings to make their way across the Atlantic, without prior migratory knowledge.

Written and compiled by Michael Clark,  
with contributions from Jill Meara & Colin Driscoll

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# ICRP Committee 1 Meeting in September 2001

ROGER COX & COLIN MUIRHEAD  
NATIONAL RADIOLOGICAL PROTECTION BOARD • CHILTON

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**This first meeting of the newly constituted ICRP Committee 1 in The Hague, NL, in September 2001 introduced seven new members to the work of ICRP on the biological effects of ionising radiation. This new membership (see *Bulletin* No. 228, p 29) reflected a need to supplement epidemiological input and replace previous members with expertise in deterministic effects and cell/molecular biology. A major topic for discussion was the expected input of Committee 1 to the formulation of ICRP recommendations for the 21st century.**

**T**he Committee received reports from the chairmen of three existing task groups reviewing, respectively, RBE in relation to radiation weighting; radiation effects on the embryo/fetus; and cancer risk at low doses. Discussion on the work of the first two of these task groups led to agreement that, with appropriate modifications/additions, the reports should be reviewed by the Committee and the Main Commission in 2002 with a view to publication. The report of the task group considering cancer risk at low doses was less fully developed and was likely to receive its final review in 2003. This delay would allow for interaction with the working party activities given below.

Much of the meeting was devoted to discussion on the work strategy that will serve to provide Committee 1 input to the Main Commission, in respect of the development of ICRP recommendations for the 21st century. With this in mind, it was agreed that the task group activities noted above were important but not sufficient. Accordingly, the Committee 1 work programme was reviewed and it was agreed that a new set of working parties should be formed in order to develop or re-confirm views on the following:

- cancer risk coefficients, organ-specific risks and the transfer of risks between populations,
- genetic susceptibility to cancer,
- comparative aspects of cancer risk after exposure to radiation or chemical agents,
- risk of heritable diseases,
- deterministic effects, including those after chronic exposures.

The Committee also discussed A-bomb data on the dose–response for non-cancer diseases. Developing a view on risks at low doses would be problematical and the Committee will seek to work with UNSCEAR which is appointing a consultant for this area of study.

Committee 1 working parties will be reporting on their topics over the next two years. In order to amalgamate these views with those from task group reports, it was agreed to form a new task group to draft a document that will act as a vehicle for Committee 1 advice to the Main Commission. This report, when published, would serve as one of the foundation documents in support of ICRP recommendations for the 21st century.

In concluding its work, Committee 1 reviewed new epidemiological data and discussed general developments in cell/molecular biology, tumorigenic mechanisms and genetics.

Committee 1 plans to hold its next meeting in Chapel Hill NC, USA, during September 2002.

## ICRP Committee 2 Meeting in September 2001

JOHN STATHER • NATIONAL RADIOLOGICAL PROTECTION BOARD • CHILTON

ICRP Committee 2 has the responsibility for calculating dose coefficients for the assessment of internal and external radiation exposure. The Committee appointed for the period 2001–2005 recently met with the Main Commission and the other three Committees in The Hague, NL, to consider the programme of work for the next four years. The main issues to be addressed by the Committee are summarised below.

The Main Commission has determined that the main thrust of its programme of work over the next four years will be to review the existing recommendations and supporting documentation with the aim of developing further advice for radiological protection at the start of the 21st century. Committee 2 has the responsibility for developing dose coefficients (doses per unit intake or unit exposure) for the assessment of internal and external radiation exposure. It is also involved in the development of reference biokinetic and dosimetric models for intakes of radionuclides and reference data for workers and members of the public. The Committee already has a programme of work in hand but has been given additional responsibilities related to the development of further recommendations by the Commission.

### Members of Committee 2

C Streffer ( <i>Germany</i> ) ( <i>Chairman</i> )	
M Balonov ( <i>Russia</i> )	J L Lipsztein ( <i>Brazil</i> )
B B Boecker ( <i>USA</i> )	H-G Menzel ( <i>Switzerland</i> )
A Bouville ( <i>France</i> )	H Métivier ( <i>France</i> )
G Dietze ( <i>Germany</i> )	H Paretzke ( <i>Germany</i> )
K F Eckerman ( <i>USA</i> )	A S Pradham ( <i>India</i> )
F A Fry ( <i>UK</i> )	J W Stather ( <i>UK</i> )
J Inaba ( <i>Japan</i> )	D M Taylor ( <i>UK</i> )
I A Likhtarev ( <i>Ukraine</i> )	Y Zhou ( <i>China</i> )

### FORTHCOMING PUBLICATIONS

In recent years, Committee 2 has developed a series of publications giving dose coefficients for intakes of radionuclides by members of the public of various ages from environmental exposures and by adults from occupational exposures<sup>1,2</sup>. These dose coefficients have been adopted in the International Basic Safety Standards<sup>3</sup> and in the European Basic Safety Standards Directive<sup>4</sup>. As a continuation of this programme of work, a new report on dose coefficients for the embryo and fetus following intakes of radionuclides by the mother has been completed and was issued as Publication 88<sup>5</sup>. This publication covers intakes by members of the public and workers of selected radionuclides of the 31 elements covered in the previous reports giving age-dependent dose

coefficients<sup>1</sup>. It gives dose coefficients for a range of intake scenarios by both inhalation and ingestion. For acute exposures, intakes are taken to occur at the time of conception and after 5, 10, 15, 25 and 35 weeks of the pregnancy and at six months and 2½ years before conception. For continuous intakes, exposures are taken to occur during the year of pregnancy, starting from conception and for one or five years up to the time of conception. This range of intake patterns should allow doses to the offspring to be calculated for any pattern of intake by the mother. Summary information on equivalent doses to selected tissues together with effective doses to the offspring to birth and to age 70 years are given in the report. The report will be accompanied by a CD-ROM giving more comprehensive information than is possible in the published report. It will give dose coefficients for a range of inhaled particle sizes and equivalent doses to a range of tissues at various times after the intake in addition to committed equivalent doses and committed effective doses.

Guidance on the practical application of the human respiratory tract model (HRTM) is to be given in a technical document. This covers situations for which information is available that enables more accurate dose assessments to be made than would be the case using the general default parameter values. It will cover examples of both occupational and public exposure and will give practical guidance on the development of material specific dose coefficients as well as the use of the HRTM in interpreting bioassay data. The report should be published early in 2002.

A task group on Reference Man (REM) has been preparing a report on reference values for anatomical and physiological data. This report will effectively supersede Publication 23<sup>6</sup> and provide the basic information on organ masses needed for dose calculations. The report is essentially finished and has been approved for publication by the Commission. It summarises information in recent ICRP publications (eg the respiratory system given in Publication 66<sup>7</sup> and the skeletal system in Publication 70<sup>8</sup>) and provides additional information on other organ systems not previously covered (eg the circulatory and urogenital systems). It will be posted on the ICRP website ([www.icrp.org](http://www.icrp.org)) at the end of 2001 prior to publication in the *Annals*.

#### COMMITTEE 2 TASK GROUPS

Committee 2 has three task groups which will continue their work. The first is concerned with the development of a new dosimetric model for the human alimentary tract (HAT) that will complement the HRTM<sup>7</sup>. The present model of the gastrointestinal tract, applied by ICRP in the calculation of dose coefficients, has provided an essential basis for dose calculations for more than 30 years. There is now a need to develop a new model which takes account of more recently published information and is age-specific. The programme of work covers:

- definition of the anatomical regions need for dosimetry,
- review and evaluation of information on the movement of materials through the whole of the alimentary tract, including the mouth,
- the possible retention of radionuclides in the gut wall and absorption from different regions,
- review of the information on the location of cells at risk, methods for estimating radiation doses and provision of reference parameters for the relevant biokinetic and anatomical parameters,

- determine of age-dependent parameter values,
- consideration of uncertainties in dose calculations.

It is expected that the report will be completed during 2002 and will be used as the basis for future dosimetric calculations for both ingested radionuclides and radionuclides passed through the throat and swallowed after inhalation.

A second task group on Internal Dosimetry (INDOS) is concerned with developing biokinetic models to describe the behaviour of radionuclides in the body following their entry by inhalation or ingestion. A report is presently being prepared covering the transfer of radionuclides to mother's milk. This will allow the calculation of doses to the offspring following intakes of radionuclides by the mother. The report will cover:

- the transfer of radionuclides to breast milk following inhalation or ingestion by the mother, considering intakes before or during pregnancy as well as during the period of breast feeding,
- dose coefficients for the infant ingesting radionuclides in breast milk for each of the scenarios considered.

It will give information on radioisotopes of the 31 elements covered in previous reports giving age-dependent dose coefficients, together with radioisotopes of some additional elements. This modelling approach may also be extended to cover some radio-pharmaceuticals in conjunction with Committee 3.

Over the next few years INDOS is to concentrate on a review of the biokinetic data needed to provide models that can be used both for dose calculations for people who are occupationally exposed and for the interpretation of bioassay data. The models will be used in the next generation of dose coefficients after the Commission has finalised the development of its recommendations. This will result in the publication of a report that will replace Publications 30, 54, 68 and 78<sup>2,9-11</sup>.

A third task group is on Dose Calculations (DOCAL). This task group implements in computer code the biokinetic models developed by INDOS and carries out the necessary dose calculations. A major task will therefore be preparation of the updated dose coefficients for workers. DOCAL also has the responsibility for calculating dose coefficients for external radiation exposure. The priority at present is for the preparation of dose coefficients for neutron energies above 30 MeV. These coefficients are needed for cosmic ray exposure and for occupational exposure of people to high energy neutrons. This work will complement the conversion coefficients for photons and neutrons given in Publication 74<sup>12</sup>.

A major priority of DOCAL is the development of more realistic phantoms for the calculation of dose coefficients. Phantoms are used to calculate the regional deposition of energy in different organs and tissues following exposure to internally deposited radionuclides and external radiation. The aim is to replace the current MIRD phantoms, which are based on simple geometric shapes of organs and tissues with realistic representations of organs and tissues based upon medical imaging data. These new phantoms are expected to be developed from voxel (volume pixel) phantoms in which the body can be represented by many millions of voxels each identified as a particular tissue type. Priority will be given in the first instance to the development of adult male and female phantoms. DOCAL will use the new phantoms to calculate doses from both internal and

external radiation sources once the Commission has finalised any revisions to tissue and radiation weighting factors. DOCAL will also revise Publication 38<sup>13</sup> which gives physical data on radionuclides. This revision will involve more than 1000 radionuclides and be carried out in collaboration with a number of other national and international organisations. These data will be made available in electronic format.

To complement the development of dose coefficients for workers, Committee 2 has set up a working party to give advice on the interpretation of bioassay data. The experience of some recent interlaboratory comparisons has been that the interpretation of monitoring data can be very variable with a wide range of results. The Commission considers that this is unsatisfactory and that there is a clear need to give advice on appropriate procedures to follow. The working party's objective is to provide guidance to those with responsibility for interpreting bioassay data from routine or special investigative monitoring programmes. It is intended that a technical document will be complete by the time that the new dose coefficients for workers are published.

### WORK WITH OTHER ICRP COMMITTEES

Some areas of work of Committee 2 are carried out in conjunction with other Committees. A joint task group with Committee 3 (Protection in Medicine) is concerned with providing biokinetic models and dose coefficients for radiopharmaceuticals commonly used in medicine. This is a continuing programme of work as, increasingly, new radiopharmaceuticals are becoming available for use by physicians. The task group has to be selective in identifying the most important new radiopharmaceuticals and in providing advice on dose coefficients. The most immediate materials being examined at present are <sup>99m</sup>Tc labelled depreotide, fatty acids labelled with <sup>123</sup>I and various dopamine transporter and receptor substances as well as PET substances.

A joint task group with Committee 1 is reviewing the radiobiological effectiveness of radiations of different quality and how the information relates to radiological protection. The task group has to date concentrated on a review of experimental and epidemiological data related to an assessment of the relative biological effectiveness (RBE) for neutrons of different energies. It will also consider other high LET particles, namely protons, alpha particles and heavy ions. This work may result in some changes to radiation weighting factors,  $w_R$ .

Two other issues are also being examined with Committee 1. Recent analysis of the development of bone tumours in people exposed to radium<sup>14</sup> has suggested that the sensitive cells for tumour induction may be located at distances in excess of 10  $\mu\text{m}$  from endosteal bone surfaces (the default distance for dose calculations). This information suggests that it may be more appropriate to calculate the dose to cells lying within the range of alpha particles deposited on bone surfaces (ie around 50  $\mu\text{m}$ ). A position paper is being developed for consideration by the Committees in 2002.

The HRTM is not at present readily applied to the dosimetry and hence risk assessment for exposures to radon and its decay products. The issues are complex and influenced by the reference values adopted for deposition and clearance in the respiratory system as well as the radiation weighting factor,  $w_R$ , for alpha-particle irradiation of the lung and the dose and dose rate effectiveness factor. At present, exposure limits for radon recommended by ICRP<sup>15</sup> are based on dose-response relationships from epidemiological studies. Committees 1 and 2 are reviewing the epidemiological and dosimetric approaches

to assessing the consequences of exposure to radon with the aim of harmonising the two approaches.

## SUMMARY

In conclusion, Committee 2 has a full programme of work over the next four years. It will need to work closely with other Committees in the development of its programme and in supporting the evolution of ICRP advice on radiological protection at the start of the 21st century.

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# ICRP Committee 3 Meeting in September 2001

CHRIS SHARP, GROUP MEDICAL ADVISER, AWG PLC • HUNTINGDON

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Radiation in medicine has brought enormous benefits to people and populations throughout the world, since the discovery of radioactivity and x-rays in the late 19th century. However, approximately two-thirds of the world's population has little or no access to these benefits. The burden of disease on the economic and social systems in countries without adequate access to diagnostic and treatment resources is substantial. A number of imaging and treatment modalities will need to be employed to address the problem but, for the foreseeable future, ionising radiation procedures will provide a significant proportion of the procedures. Consequently, a substantial increase in radiation exposure of populations is required, and urgently. For the maximal benefits to be realised, the risks need to be pragmatically controlled.

Procedures are becoming increasingly complex, often allowing faster, more accurate (and sometimes reduced cost) diagnosis and treatment. However, this complexity carries enhanced risks of error, with the very real possibility of severe detriment. Most physicians are unaware of the risks of ionising radiation exposures. Globally, physicians have a good understanding of benefits of medical procedures, but little understanding of many of the risks – this is for *all* interventions not just those involving radiation. Thus far, ICRP advice has had little impact on physicians who actually 'prescribe' radiation.

## STRATEGY

ICRP Committee 3 was reconstituted in 1997 to achieve a majority representation of practitioners from the relevant fields of medicine, reinforced by expertise from those medical professionals who support medical practice using ionising radiation. The new Committee 3 produced a mission statement and devised a strategy with the aim of reaching the practising physicians of the world. The main objectives were to:

- identify and prioritise the real protection problems in medicine,
- write single reports to address each specifically,
- direct reports to a target group of medical users,
- include colour pictures, main points and bold important messages,
- make reports widely available through routes other than traditional ICRP methods.

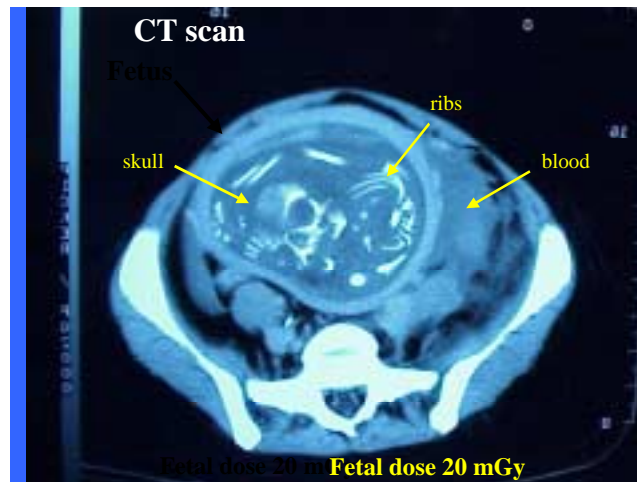
These objectives have been, and are being, pursued through the task group and working party format.

Members of Committee 3		
F Mettler (USA) (Chairman)	L K Harding (Secretary)	
J M Cosset (France)	J Linecki (Poland)	H Ringertz (Sweden)
C Cousins (UK)	S Mattson (Sweden)	M Rosenstein (USA)
M Guiberteau (USA)	P Ortiz (Spain)	C Sharp (UK)
I Gusev (Russia)	L V Pinillos-Ashton (Peru)	E Vano (Spain)
M Hiraoka (Japan)	M M Rehani (India)	W Yin (China)

## TASK GROUP PROJECTS

### Pregnancy

Lack of knowledge among medical practitioners leads to anxiety and probably unnecessary termination of pregnancy when pregnant patients and workers are exposed to ionising radiation. Some exposures are inappropriate resulting in unjustifiable increased risks to child, but many pregnant patients are exposed appropriately. This was the first issue addressed by the Committee and the resulting advice was published as Publication 84<sup>1</sup>, which gives practical guidance on addressing the commonly asked questions. Now published in English, it has also been translated into Chinese and French and will shortly be distributed, in abridged format, by WHO globally.



### Interventional radiology

Interventional radiology is increasingly used by practitioners in many specialties to reduce morbidity and mortality. However, most physicians using these techniques have had *no* radiation effects or safety training. There is a growing literature on serious skin injuries to patients and less serious injuries to staff. Although the techniques can often save life or substantially improve quality of life, patients are not routinely informed of the potential serious adverse effects, which can significantly impair the quality outcomes that the procedures seek to provide. Publication 85<sup>2</sup> has recently been published in English to provide practical guidance on the optimal use of these techniques. It is currently being translated into French and summaries will be published in specialist journals.



### **Accidental exposures in radiotherapy**

Devastating, fatal overdosages and significant underdosages continue to occur in radiotherapy. Radiotherapy usage is increasing world-wide and the potential for accidents is increasing concomitantly. The complexity of equipment and procedures is amplifying this risk and there is a need for robust quality systems to protect patients. Publication 86<sup>3</sup> provides practical radiological protection advice in radiotherapy.

### **Managing doses in computed tomography (CT)**

Absorbed doses from CT often approach or exceed levels known to increase cancer risk. CT frequency is increasing rapidly along with the doses for each procedure. In the UK, for example, CT represents 4% of procedures, but around 40% of the total population dose. The availability of rapid, comprehensive images have led to a problem with the justification and optimisation of these procedures – these issues are often ignored. However, there are many practical techniques available to reduce dose without compromising the clinical purpose. Publication 87<sup>4</sup> provides such practical advice.

### **Radiation doses from radiopharmaceuticals**

A standing task group with Committee 2 provides dosimetry advice on some of the large number of radiopharmaceuticals used in medicine. Reports are published as Addenda to Publication 53<sup>5</sup>, and Publications 62<sup>6</sup> and 80<sup>7</sup>. The emphasis recently has shifted to positron emission tomography (PET) with its ability to detail short-lived functional events and a task group is looking at an increasing number of substances used in this technique.



### **Release after therapy with unsealed sources**

Legislation and practice varies considerably between countries and there is a need to clarify the rationale and essential elements of discharge policies to protect carers, friends and the public after therapy. Ethical issues are an integral part of such policies. The task group has a target of 2002 to provide a draft to the Commission of a document to provide pragmatic advice on protection of those likely to be exposed.

### **Dose reduction in digital radiography**

Digital radiology has improved the quality and recall of images, but doses are often higher than in conventional procedures. There is a lack of awareness of this by many

clinicians. The Commission has been asked to approve the work to provide a report that will recommend dose optimisation techniques to both manufacturers and users. The objective is a draft by 2004.

## WORKING PARTY PROJECTS

### Paediatric exposures

In non-paediatric radiology facilities children are often handled like adults, resulting in unnecessarily high doses in a putative higher risk group. A poster and sticker have been designed to be located in examination rooms and on equipment to provide practical advice to radiographers and technicians. The International Society of Radiology has jointly sponsored these publications, but widespread distribution awaits a commercial sponsor.



### Diagnostic Reference Levels

There has been much misunderstanding of the concept of diagnostic reference levels, since the original recommendation in Publication 60<sup>8</sup> and further explanation in Publication 73<sup>9</sup>. The purpose of the guidance is to provide additional, clarified advice to national and local authorities and clinicians on the practical application of this tool in diagnostic radiology and nuclear medicine. A draft for comment is currently on the ICRP website ([www.icrp.org](http://www.icrp.org)). It is intended to publish the final version on the website, notifying regulatory authorities and medical and radiological journals of its location.

### Guide on radiation in medicine for medical practitioner

Medical practitioners are generally have inadequate knowledge about radiation: its benefits and risks; doses quantities and effects; typical procedure doses and sources; justification and optimisation; and special circumstances, eg pregnancy. This is extant in a setting where patients wish to know more about their investigation and treatment. The Committee 3 document provides advice in a 'frequently asked questions' format, to make it an indispensable aid in the consultation room. The Commission has decided to make this available on a dedicated education segment of the ICRP website with a download facility.

### Training requirements for practitioners using ionising radiation

There is growing concern in many countries about the ongoing demonstration of competency by medical practitioners. Knowledge, attitudes and behaviour are just as relevant in the use of radiation as in any other technique in medicine. The Committee has

put forward a working party proposal to prepare the way for a task group to develop a document to provide recommendations on training for radiological protection and safety for operators at all levels. Additionally, recommendations on potential authorisation networks are envisaged.

### **High dose rate brachytherapy (HDRB)**

HDRB is a new technology that has the potential for devastating effects from small errors. The working party proposal from the Committee is to prepare an outline of the aspects of this technology that are different from conventional radiotherapy, with the aim of producing guidance to facilitate the reduction of detriment.

### **Web-based PowerPoint presentations**

To achieve the Committee's strategic aims, it is proposed that the main points of its reports are provided in a format for teaching, downloadable from the Internet. This will exploit the medium of telemedicine, which has had a considerable impact on the practice of medicine in developing and remoter regions of the world. Internet connection is considerably cheaper than microwave and other higher quality communications links. Reproduction of presentations is also likely to be more cost-effective. Each presentation should be between 10 and 15 slides, with lecturer notes. The Commission has agreed this in principle. The presentation would be cross-referenced with the ability to order publications on line.

### **WATCHING BRIEFS**

#### **Genetic susceptibility**

The effects of genetic susceptibility on radiation exposure continue to be investigated. In medicine the effects are only likely to be significant for therapy. However, the ability to identify susceptible patients before treatment could significantly enhance the treatment of non-susceptible patients – therapy is already moderated to guard against serious effects in the small number of susceptibles – and reduce morbidity in those that are.

#### **Intravascular brachytherapy**

Intravascular brachytherapy is being used in some countries with reportedly mixed results. Doses to staff are of particular concern with some techniques.

#### **Gamma knife**

Gamma knife techniques are gaining 'market share' in neurosurgery as they reduce collateral brain damage. They are also extensively used in developing countries as cost-effective techniques.

### **FUTURE WORK**

#### **New ICRP recommendations**

Committee 3 has been asked to consider whether the proposed revision of ICRP recommendations has an impact on radiation in medicine. The Committee believes that the approaches taken in its strategy already anticipate the change in emphasis by ICRP, but will consider this issue further as new work arises from the Commission and the other Committees.

## Continuing problems

There are a number of current issues which the Committee consider to be major challenges to protection in medicine.

- Communication to clinicians remains the most fundamental challenge for ICRP. In providing recommendations and writing guidance, ICRP must understand the issues that drive physicians in their everyday work. By meeting their needs, when concerns arise (whether ICRP raises these concerns or they are raised by others) with easily accessed information, the objectives of protecting patients and staff will be served.
- Is patient protection globally a significant issue at doses below 10–50 mSv? Answering this question is fundamental to where limited effort is applied. The special issue of the use of effective dose for *in utero* and paediatric exposures is likely to be a contentious issue.
- Quantification of the risk–benefit ratio eludes most of medicine – but has it a provenance in low dose procedures?
- Human error is the cause of most accidents and despite good training, practical procedures and tight regulation they continue to occur in even industrialised countries – how can this be reduced?
- What is the level of unjustified practice, is it controlled by criteria and is audit working?

Although the Committee has tackled a number of problems, there is still much left to do and its members intend to address it!

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# ICRP Committee 4 Meeting in September 2001

JOHN COOPER • NATIONAL RADIOLOGICAL PROTECTION BOARD • CHILTON

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**ICRP Committee 4 deals with application of the Commission's recommendations. It interprets, expands and develops the recommendations, providing a forum for identification of issues stemming from the recommendations and, hopefully, a means for resolution. This inquiring approach has led to Committee 4 being termed 'the alternative Commission'.**

**T**he Committee comprises 18 members drawn from 15 countries (see *Bulletin* No. 228, p 29). About a third of the members are new this year. The chairman for a second term is Bert Winkler from South Africa. The positions of vice-chairman and secretary are both held by new members being, respectively, Ches Mason and Mary Clark. Observers from EC, NEA and IAEA also attend.

The Commission's development of 'recommendations for the 21st century' was not far from members' minds during the discussions. It had also provided an impetus for work the Committee had previously put in hand. Some of the week was taken up by discussing and finalising this work. Reports were received on the scope of the new recommendations, on the protection of the individual, on the principle of optimisation of protection, on potential exposures, intervention and emergency issues, on operational and regulatory matters, and on the rehabilitation of contaminated land. Some common issues emerged. One in particular was the involvement of stakeholders (interested and affected parties) in radiological protection decisions. This is an area that has not been touched upon in the Commission's recommendations but has come to the fore in a number of circumstances including rehabilitation after Chernobyl and the clean-up of contaminated sites related to nuclear weapons work in the USA. It is an area of further work for Committee 4.

Turning to the future, the chairman of the Main Commission, Professor Clarke, charged Committee 4, as he did the other Committees, with producing building blocks for the new recommendations. These could be issued in publications that supported and expanded upon the main recommendations. On the basis of the extensive amount of work that the Committee had already undertaken on this subject and on the Main Commission's latest thoughts on the new recommendations, the Committee drew up a list of topics for future work. The results of the Committee's deliberations on these topics could form building blocks for the future recommendations.

The work will be undertaken over the coming months in task groups and working parties. The distinction is that the former may have members drawn from outside the Commission's structure and is funded as necessary by the Commission; the membership of working parties is usually restricted to Committee members.

Three new task groups are to be set up. The first is reconsidering the definition of the individual in the context of public protection. Issues to be addressed include the concept of critical group, demonstration of compliance, monitoring and uncertainty. The

group will be chaired by John Till from the USA. The second task group, chaired by Wolfgang Weiss from Germany, is covering optimisation of protection. Stakeholder involvement will be an issue for discussion as will protective action levels (a possible new term encompassing constraints) and justification. The third task group has a slightly different emphasis, looking at radiological protection in space flight. This will be chaired by Toshiso Kosako from Japan.

Three working parties were also established. One will address issues of scope including the thorny questions of exclusion and exemption. Another will develop a glossary of terms used by the Commission and a third will develop ideas on potential exposure and regulatory issues.

The next meeting of Committee 4 is scheduled to take place in Paris in June 2002. Progress by the task groups will be reviewed and the outcomes from the working parties will be assessed. No doubt, more issues for deliberation by Committee 4 will emerge as the Commission moves closer towards its 'recommendations for the 21st century'.

Overall, Committee 4 has a well-developed, hefty workload that should provide building blocks for the future of radiological protection.

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## Dose and Radiation Quality Issues in Radiological Protection

ALAN EDWARDS • NATIONAL RADIOLOGICAL PROTECTION BOARD • CHILTON

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**ICRP is in the process of reviewing its recommendations on dose quantities and radiation quality for radiological protection purposes. It is therefore timely to give a broad overview and to stimulate discussion on a subject which in my experience has caused heated argument amongst honest, respectable scientists, commenting on what ICRP and ICRU should have done. The specific problems revolve around the 'quantities' which involve the words *dose equivalent* or *equivalent dose* and have the unit of Sv. I have deliberately put the word 'quantities' in quotation marks because not all such terms are quantities in the scientific sense.**

will not detail numerical and name changes that have taken place in the past 50 years, but I do wish to recall the original idea behind the specification of what is generically called radiation quality. In the early 1950s, perhaps earlier, it was recognised that neutrons and alpha particles (known as high LET radiation) were biologically more damaging than x-rays or gamma-rays (known as low LET). Conceptually, the biologically equivalent dose was that dose of low LET radiation, which gave the same biological effect as the given dose of the high LET radiation. The ratio of the two doses is termed radiobiological effectiveness (RBE) and is simply an expression of radiation quality, used in the generic sense. RBE is a dimensionless ratio, which varies with the endpoint (eg cancer or mutations), system (eg animal strain or cell line), dose and many other factors. Measured values of RBE for neutrons or alpha particles vary from less than one to infinity.

## RELEVANT RBE VALUES

For radiological protection purposes, it is the RBE for the induction of cancer in humans at low doses and low dose rates that is of most importance. There is a paucity of direct evidence. The assumption that differences between epidemiological data from Hiroshima and Nagasaki can be attributed to the differing neutron contributions to dose, leads to the conclusion that fission neutron RBE is probably less than 200. An analysis of lung cancer deaths in uranium miners leads to an RBE for alpha particles of 5 to 20 depending on how the lung dose is calculated, that is which cells are regarded as the target. In all these human estimates there is an implicit assumption that the method of extrapolation to low doses and low dose rates is known.

There is better evidence from exposure of laboratory animals to fission neutrons and gamma-rays or x-rays, observing cancer and life-shortening endpoints. However, extrapolation of data to low doses and dose rates is still a questionable part in the interpretation of these experiments. After neutron exposure it appears reasonable to extrapolate linearly from moderate doses because a dose rate effect is apparent only at higher doses. For photon exposure there is clear evidence that reduced dose rates cause a reduction in life-shortening and in the incidence of specific cancers. It is the measurement of effects at low LET and low dose rates that forms the major component of uncertainty in the measurement of RBE. Values for RBE are very variable (2 to 50 or more) but the higher values are associated with larger reductions due to dose rate for low LET exposures. A value of 10 for RBE is associated with a reduction factor of two for low dose rates and this appears only slightly dependent on animal strain, probably within a factor of two.

Effects in cellular systems, such as mutations, neoplastic transformations and chromosome aberrations give better defined dose response relationships such that an initial slope can be measured for all radiation qualities. Thus RBE values at low doses can be measured and so information on how RBE for these endpoints varies with neutron and photon energy is obtained. Broadly, these experiments show that lower energy photons (conventional x-rays) are possibly two or three times more effective than higher energy photons (cobalt-60). Low energy electrons such as those from tritium may be three to four times more effective than the higher energy photons. They also show that higher energy neutrons (15 MeV) are less effective than fission neutrons by a factor of four or five. There is very little evidence for measurements of RBE at the much higher neutron energies, which are typical of space radiation. For charged particles, the RBE can be related broadly to LET with a peak in the region of  $100 \text{ keV } \mu\text{m}^{-1}$ . High energy protons have the lowest RBE and the overall range is about one order of magnitude. The precise relationship is cell line and endpoint dependent. I am not aware of any charged particle response that gives a value of RBE greater than that obtained for fission neutrons.

## JUDGEMENTS

Somehow, this scientific information must be converted into a set of pragmatic choices, called judgements, for use in radiological protection. To take account of radiation quality, ICRP has chosen to multiply absorbed dose, a good physics quantity, by a factor dependent on radiation quality, which is a biologically based estimate. According to ICRP,

the latest recommendation for estimating risk in general terms is to use a set of tabulated judgements called radiation weighting factors, which depend on the radiation field incident on the body. Numerically the factor for all low LET radiation is set at 1. Neutrons are set at 5, 10 or 20 dependent on energy. Heavy charged particles and alpha particles are set at 20. Protons of energy more than 20 MeV are set at 5, although this is under review. A weighted sum of equivalent doses in all body organs and tissues is calculated and the resultant parameter is called effective dose. This parameter is regarded as most logically relatable to risk but it is not a quantity. It is not measurable. It can be calculated in specific circumstances but there is no unique relationship between any physical quantity of the radiation field and effective dose. If you and I were put in a given radiation field in a given orientation for the same time our effective doses would be different. The same would apply to activity inhaled or ingested.

Regulations, however, are developed in terms of limiting effective dose. To demonstrate compliance with legislation, effective dose has to be estimated and this is where instrumental quantities play their part. Ambient dose equivalent is an example and is used to calibrate area monitors. This quantity generally, but not always, overestimates effective dose, so that an ambient dose measurement that is numerically less than a dose limit can be taken legally as proof of compliance. The judgement made to convert Gy to Sv in order to compute ambient dose equivalent is called the quality factor and is defined rigorously in terms of LET, that is the Q-LET relationship. Ambient dose equivalent is a quantity in the scientific sense because the radiation field and the target phantom are specified precisely. This applies despite the use of a judged Q-LET relationship. This means that there is a unique relationship between the radiation field quantity, that is fluence, and ambient dose equivalent. The judged quality factors are, however, numerically different from the judged radiation weighting factors. It must be emphasised that, despite the appearance of precision, quality factors should not be regarded as more accurate or reliable judgements than radiation weighting factors.

The variability of the scientific data concerned with radiation quality cannot be emphasised enough but pragmatic choices have to be made. There are several different uses to which estimates of risk may be put. One is to make decisions about control of exposure and may be called a prospective use. Another may be for reassurance purposes or for calculating probability of causation when compensation is an issue. These might be termed retrospective uses. There is interest in cosmic ray particles, which become important for air travel and for astronauts. Generally these are exposures, which are difficult to control and it is not at all clear into which category these should fit or whether they should form a third category. There is a further category, the purpose of which is to provide measurable quantities which, as far as is practicable, match the imprecise parameter effective dose.

On the basis of this outline of radiation quality issues, I list below some questions that arise in my mind.

- Q1** Should legal limits be specified in terms of a personal parameter (which is how effective dose is defined at present) or should it be made into a scientific quantity by specifying the phantom and orientation with respect to the radiation field?

- Q2** Is it illogical to make different judgements concerning radiation quality for different purposes in radiological protection?
- Q3** Is it illogical to take account of a factor of four range in RBE for different neutron energies while ignoring a similar factor for photons? If not, to which application should it apply?
- Q4** When making judgements about radiation quality, should the aim be to make the effect of low and high LET radiation the same? Alternatively, should it be to estimate the high LET risk as accurately as possible by taking into account that, scientifically, RBE is related to the low dose and dose rate reduction factor at low LET? Might the aims be different for different applications?
- Q5** In choosing a quantity that matches effective dose (eg ambient dose equivalent) is it necessary to use the Q-LET relationship that was invented to match the radiation weighting factors?

In answering these questions, it should be borne in mind that paragraph 32 of ICRP Publication 60 limits the application of radiation weighting factors to the estimation of risk *in general terms*. It permits the selection of other RBE values in specific circumstances. I know of only one circumstance where the provisions of this paragraph have been used (*Documents of the NRPB*, 8(2)) and perhaps those with responsibility to advise on radiological protection matters should make more use of it.

In an article designed to stimulate discussion, I have probably said enough. However, to stimulate discussion even further I will give *my* answers to the questions above. They follow.

- A1** Pragmatically, I could accept either view. Setting dose limits in terms of a concept which is not a quantity offends my scientific instincts.
- A2** No.
- A3** Yes. Perhaps I would use the variation of RBE with neutron and photon energy for retrospective but single values for prospective purposes.
- A4** The alternative should not be ignored but could be used for retrospective purposes. For prospective purposes it seems logical to use the former but practical difficulties might arise if it can be shown that the risk for low LET is substantially overestimated.
- A5** No. It might be possible to obtain a better match between ambient dose and effective dose by dispensing with this restriction.

These answers are *my personal judgements* at present, but of course they can change in the light of further data and further argument. So, what is your view?

**EDITOR'S NOTE** We encourage letters on this subject for publication in the *Bulletin*.

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## New Computer Phantoms and Their Use in Internal Dosimetry

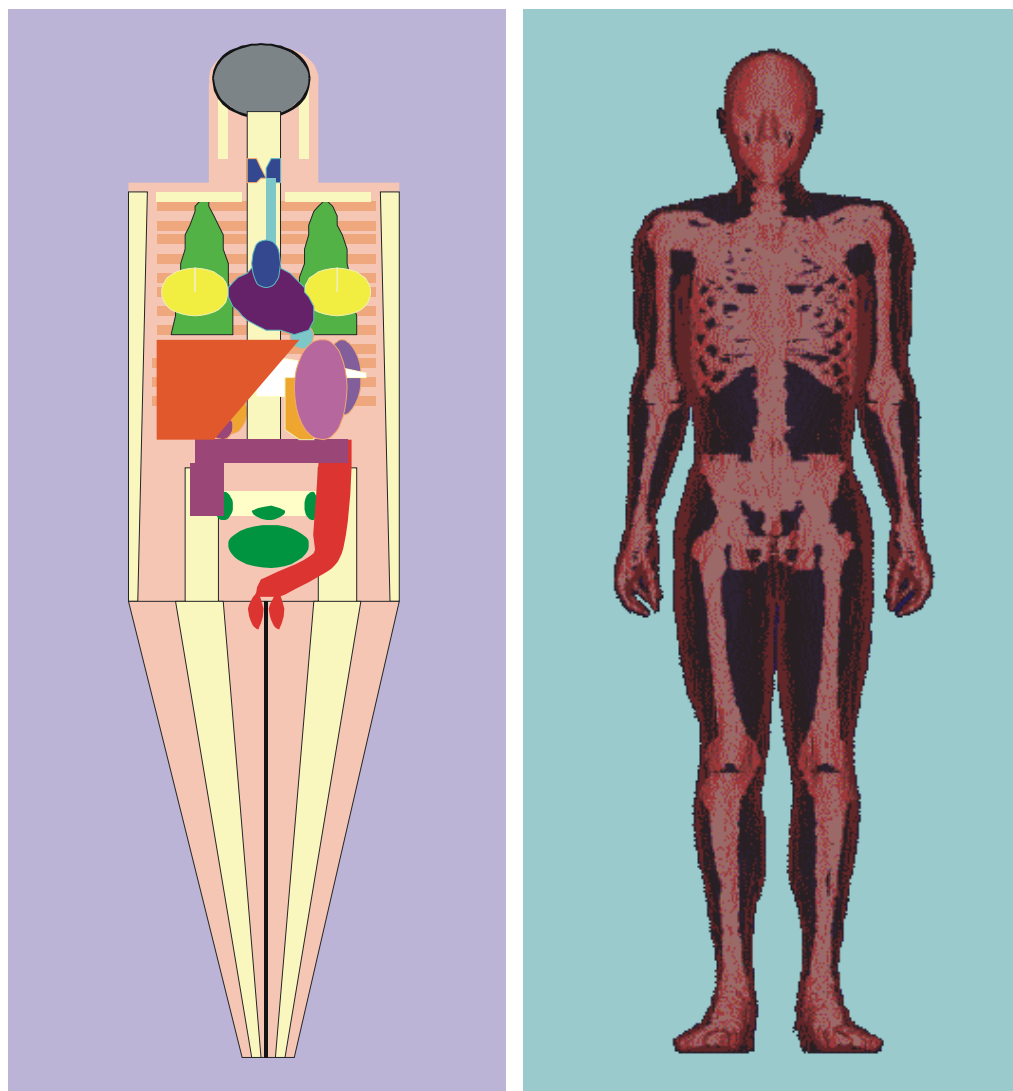
ALAN PHIPPS • NATIONAL RADIOLOGICAL PROTECTION BOARD • CHILTON • UK  
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The calculation of radiation dose from internally incorporated radionuclides requires a knowledge of how radioactivity in one organ or region of the body contributes to doses to other organs or tissues. This is quantified by a set of values known as specific absorbed fractions (SAF) which are usually calculated using computer models of the human body known as phantoms. In 1969 the Medical Internal Radiation Committee (MIRD) of the US Society of Nuclear Medicine developed a phantom in which organs were represented as simple mathematical shapes such as spheres, ellipses and cones. This phantom and its later derivatives, collectively known as MIRD-type phantoms, have served the radiation protection community well for over 30 years. Recently, however, a new generation of phantoms has become available which offer the prospect of increased realism and accuracy in dose calculations. These phantoms are based on computed tomography (CT) or magnetic resonance images (MRI) obtained from high resolution scans of individuals. They consist of a large number of volume elements known as voxels (a voxel can be envisaged as a three-dimensional equivalent of the familiar pixel, voxel = volume pixel) and are usually known as voxel phantoms.

This development began about 15 years ago and now a number of laboratories around the world have developed voxel phantoms. For example, NRPB has NORMAN (NORmalised MAN), GSF has, among others, Golem<sup>1</sup>, the US National Library of Medicine has developed the Visible Human Project (VIP), where the phantom is accompanied by colour visual images ([www.nlm.nih.gov/research/visible](http://www.nlm.nih.gov/research/visible)). The VIP phantom has potentially many applications but has been used by Xu and co-workers for both internal and external dosimetry<sup>2</sup>. Interest in voxel phantoms can be gauged by the recent steep increase in the number of publications in the field; one only has to scan the references of a typical recent paper in the field to see the frequency with which dates of 2000 and 2001 occur.

Clearly, the voxel phantoms are much more realistic than the MIRD-type phantoms (see the figure) and it is tempting to assume that much greater accuracy in doses will be obtained when using voxel phantoms. Caution should, however, be exercised. It must be remembered that a voxel phantom begins as a model, albeit an accurate one, of an individual person. Organisations such as NRPB and ICRP are usually concerned with reference doses, ie doses to people of average height and mass which are taken to be representative of doses to a whole population. An individual-specific model may not therefore be appropriate. The MIRD-type phantoms can be made to be hermaphrodite in that they can contain both sets of gonads, breasts and a uterus. Dose calculations could therefore be based on results from a single phantom; clearly this is not possible with a voxel phantom. Some authors have therefore aired the issue of how voxel phantoms can be used in reference dose calculations<sup>2,3</sup>.



**MIRD phantom (left) and NORMAN phantom (right)**

Fortunately, a practical way forward does seem to be emerging. A first step towards developing a reference voxel phantom is to change the dimensions of the original voxels, effectively stretching or shrinking the phantom in length or girth. While this technique is useful it does have its drawbacks. For example, an individual carrying a lot of muscle may well have an average sized liver. When voxels are reduced in size to obtain the required reference body mass, the liver will be smaller than the reference liver size. Investigations have shown that re-sizing of voxels should not be undertaken to too great an extent<sup>4</sup>. Another way of manipulating the phantom is to add or subtract layers of voxels to an organ, the latter can be pictured as removing a layer from an onion. Care is also required with this technique; clearly adding too many layers could allow one organ to encroach on another. Of course, each voxel can only be in one organ! In some cases organs which could not be resolved in the original data can be added in the voxel model after consulting anatomical texts. The NRPB phantom NORMAN was produced using the above techniques<sup>5</sup> and is therefore suited to reference calculations. A further manipulation

method is now being developed at GSF in Germany where organ shapes can be changed using familiar PC features such as dragging and dropping. With the aid of anatomy texts, other CT and MRI images, and perhaps also with the help of a consultant anatomist, ideal organ shapes can be achieved. In summary, starting with a voxel phantom which is reasonably close to the required reference person (male or female), a combination of re-sizing and the adding or subtracting of voxels, together with organ shape manipulation, when used with care, can produce good reference voxel models for radiation protection.

Another proposed method for deriving reference doses is to dispense with the manipulation of phantoms and to derive doses for many individual-specific phantoms and then apply some average of these doses to the general population. This method would require a great many phantoms to be available so that the average was truly representative of the general population. At present, the process of defining individual organs and tissues in the CT or MRI image, known as segmentation, is labour intensive and requires considerable experience<sup>6</sup>. Nor should the computational effort in calculating so many doses be underestimated. Thus this approach is unlikely to be practical over a timescale of the next two or three years, but may become viable in due course.

ICRP has stated that it intends to use reference voxel phantoms in the next revision of internal dose coefficients<sup>7</sup>. So, what changes to dose coefficients can be anticipated? Recent work compared over 3000 dose calculations using either the photon SAFs from the GSF voxel phantom, Golem, or those of the traditional MIRD-type adult phantom<sup>8</sup>. It was found that the choice of photon SAF dataset did not have a great impact on committed effective doses from internal emitters. However, some individual tissue doses were very sensitive to the choice of phantom. The main factors appear to be tissue mass and the mean separation of tissues, which is much more realistic in the voxel phantoms<sup>9,10</sup>. For example, doses to the thymus following intakes of isotopes of iodine (which concentrate in the thyroid) can be much higher (by as much as a factor of ten) using the voxel phantom. Jones<sup>10</sup> reported similar findings using NORMAN. Doses to the liver from activity in the stomach were about three to four times higher than those calculated from a MIRD-type phantom. In both cases, these findings are direct results of the greater proximity of the thyroid/thymus and stomach/liver pairs in the voxel phantom. While it is recognised that these studies investigated the effect on doses of SAFs from two separate voxel phantoms rather than a reference voxel phantom, the findings do suggest that if national or international bodies were to adopt voxel phantoms for future internal dosimetry calculations, prospective derived limits based on the effective dose would probably not change greatly. However, individual tissue doses could show much greater changes. This raises some interesting issues regarding the use of voxel phantoms in radiation protection systems that are based on tissue doses as well as effective doses, and in compensation schemes where the dose to a known cancer site is of interest.

Although this article has concentrated on the application of voxel phantoms in internal dosimetry, they can also be used in external dosimetry. In occupational exposure situations the aim is to relate internal doses in the body to external fluence or kerma. Jones<sup>11</sup> has used NORMAN to calculate doses for six different standard radiation geometries and compared his results with those obtained from the MIRD-type phantom. Petoussi-Henss *et al*<sup>3</sup> carried out similar work with, among others, Golem and the Visible Human. For these uniform, broad-beam, external exposures the deposition of energy within the body is much more homogeneous than for internal sources. Thus different

phantoms tend not to cause such large differences as those reported above for internal emitters. Jones reported differences in effective doses between the two types of phantoms as being less than 20% for photon energies over 100 keV, although differences can be as high as 100% for lower energies when the degree of heterogeneity in dose increases. Some interesting effects are reported both by Jones and by Petoussi-Henss *et al* for individual organs where the greater realism of the voxel phantom means that the amount of overlying tissue is often very different to that of the MIRD-type phantom. There are undoubtedly applications for reference voxel phantoms in the field of medical x-ray dosimetry, although here it is more difficult to assess potential differences in doses estimated by MIRD-type and voxel phantoms due to the highly non-uniform dose distributions of x-ray examinations.

Another application of voxel phantoms is in non-ionising radiation protection where interest centres on the calculation of induced current densities at low frequencies and energy absorption at RF and microwave frequencies. Indeed the NRPB phantom NORMAN was originally developed for this application<sup>5</sup>. All in all, voxel phantoms mark a major step forward in the realistic modelling of the human body. When manipulated to be close to reference size and shape they can provide a good basis for many reference dosimetry applications in the future.

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## Recent Passive Radon Detector Intercomparisons at NRPB

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Radon is the largest and most variable contributor to the radiation dose to the public. Surveys of radon levels in homes and other buildings have been carried out throughout Europe and elsewhere to determine the magnitude of average exposures and to identify situations where excessive exposures occur. These surveys have been carried out using a variety of passive radon detectors: etched-track, activated charcoal or electrets. In order to ensure the quality of these measurements, it is important to compare detectors from different laboratories exposed side by side in a known radon atmosphere.

NRPB has carried out intercomparisons of passive radon detectors since 1982 (see Table 1), mainly with funding from the European Commission. The exercises in 1982, 1984 and 1987 were broader in scope, as they also included intercomparisons of active radon gas and decay product concentrations. Since 1989, intercomparisons have been limited to passive detectors only, primarily due to the large increase in the number of participating laboratories. Table 1 shows how the scale of the intercomparisons has grown since 1982, this reflects the growing interest in radon measurement both within Europe and elsewhere.

In 1996 the European Commission agreed to sponsor a series of three annual intercomparisons to be held at NRPB. This contract also provided for a steering meeting to be held before the first intercomparison early in 1997 and a final meeting open to all participants after the third intercomparison in 1999. There has been no external funding since the end of this contract but the intercomparisons have continued on an annual basis funded entirely by fees charged to the participants. Many laboratories regard the

TABLE 1 Participation in NRPB passive radon detector intercomparisons	
YEAR	NUMBER OF LABORATORIES
1982	10
1984	19
1987	22
1989	24
1991	39
1995	48
1997	62
1998	51
1999	52
2000	47
2001	45

intercomparisons as an important check on the international comparability of their radon measurement results as well as their quality control procedures. The popularity of the intercomparisons can be gauged by the fact that the number of participating laboratories has remained broadly constant for the last four years, despite the increased cost of participation from 2000 onwards. In the last five intercomparisons from 1997 to 2001, a total of 99 laboratories have taken part, from 32 different countries including China, the USA, Mexico and South Africa. Many laboratories submit more than one set of detectors to each intercomparison, either different types of detector or multiple sets of the same type.

### TYPES OF PASSIVE RADON DETECTORS

Two types of passive etched track radon detector are commonly used, one consisting of a track detector within a closed container, which allows radon-222 to diffuse into it (closed) and the other which consists of naked track-detecting material exposed to the ambient atmosphere (open). The closed detector excludes radon decay products which are present in the ambient atmosphere, and records only those alpha particles generated by the radon entering the container and the decay products formed from it. This form of detector therefore provides a result which is related to the true average radon gas concentration during the time of exposure.

The open detectors, however, record alpha particles originating from both radon and its decay products in the ambient atmosphere. Their response to radon and its decay products as a function of equilibrium factor,  $F$ , depends on the detector material used. Open detectors made from Kodak LR-115 have a sensitivity as a function of  $F$  which is intermediate between that of a true radon gas detector and a true Equilibrium Equivalent Radon (EER) detector, being closer to the true radon gas response. Bare CR-39 (PADC) detectors have a response which depends strongly on  $F$ , and are not recommended.

Two types of detector which do not rely upon etched tracks were submitted by some laboratories: activated charcoal detectors and electret chambers. The charcoal detectors rely upon retaining adsorbed radon which is measured after the detector is returned to the originating laboratory. As they must be assessed before the radon they adsorb decays or desorbs, each set of detectors was returned at the end of an exposure. Electret radon detectors consist of an air chamber above an electret. Ionisation of air in the chamber by radon gradually discharges the electret. Measurement of the charge on the electret by the issuing laboratory before and after exposure to radon allows the average radon during exposure to be calculated. As electret radon detectors are also sensitive to gamma and cosmic rays, they are sometimes accompanied by additional detectors sealed in radon-proof bags to allow the gamma and cosmic ray dose rate to be estimated separately. If such extra detectors are not supplied, the combined gamma and cosmic ray dose rate is estimated on the basis of average gamma ray dose rates and the elevation of the measurement point above sea level. Alternatively, some laboratories have attached small thermoluminescent dosimeters (TLD) in order to determine the gamma exposure of the detectors.

### LABORATORY MEASUREMENT FACILITIES

NRPB maintains a 43 m<sup>3</sup> walk-in radon chamber<sup>1</sup>, shown in Figure 1. This facility has been the European regional reference laboratory for radon measurements under an intercalibration and intercomparison scheme organised by IAEA. The chamber is of the

static type: radon is continuously released inside the chamber by radon sources, so there is no need to ventilate the chamber. All of the exposures were carried out in this chamber.

The chamber contains a radon atmosphere which can be varied (and held stable) from around  $200 \text{ Bq m}^{-3}$  to  $8000 \text{ Bq m}^{-3}$ , depending on the use of various dry and liquid  $^{226}\text{Ra}$  sources. A radon concentration of about  $4000 \text{ Bq m}^{-3}$  is normally maintained in the chamber, and the concentrations of radon and its decay products are continuously monitored. The aerosol conditions and the equilibrium factor in the chamber are altered as required for different studies and calibrations. Table 2 shows the parameters measured and controlled in the chamber during the exposures.



**FIGURE 1 Radon chamber**

Three different values of the equilibrium factor,  $F$ , between radon and its decay products were obtained for the three laboratory exposures in each intercomparison. To obtain a high value of  $F$  in the chamber, the aerosol generator is used to maintain a high aerosol concentration. This reduces the plate-out of radon decay products on to room surfaces. A low equilibrium factor is obtained by running an electrostatic precipitator to remove aerosols and decay products. By running the precipitator fan at low speed an intermediate equilibrium factor was obtained. A standard desk type fan is also run continuously in the chamber in order to ensure thorough mixing of the air and an homogenous concentration of radon and its decay products.

**TABLE 2 Parameters measured and controlled in the radon chamber during intercomparisons**

PARAMETER	CONTROL	MEASUREMENT
Temperature	None	Platinum resistance thermometer
Humidity	None	Capacitive sensor
Aerosol concentration	Carnauba wax aerosol generator, electrostatic precipitator	Ultrafine condensation nucleus counter (TSI 3025)
Aerosol size distribution	Aerosol about 100 nm produced by aerosol generator	Diffusion battery with switching valve
Radon concentration	Dry and liquid radium sources	Ionisation chambers (Atmos 12 DPX and Alphaguard Professional)
Radon decay product concentrations	Use of aerosol generator, electrostatic precipitator with variable speed fan and mixing fans	Sampling on Millipore AA filter, spectrometry using Nazaroff method

The radon concentration in the chamber is continuously monitored using an ATMOS 12 ionisation chamber. This instrument is normally calibrated every six months using a radon gas source obtained from the UK National Physical Laboratory (NPL). Should one of these not be available the instrument is calibrated using a source supplied by Physikalisch Technische Bundesanstalt (PTB), Germany.

An Alphaguard ionisation chamber is used as a backup radon monitoring instrument. Radon decay products were sampled on a Millipore AA filter and their concentrations determined using an alpha spectrometry system<sup>2</sup>. All monitored data were automatically transferred to a database. Radon and radon decay product exposures were calculated after results had been received from participating laboratories.

The total ambient aerosol concentration and size distribution within the radon chamber were monitored using a condensation nucleus counter connected to a serial diffusion battery via a switching valve.

### LOGISTICAL ARRANGEMENTS

Participating laboratories were sent sets of 40 labels to attach to their detectors and were asked to send the detectors to NRPB, if possible in radon-proof bags. Each label carried a detector number from 1 to 40 and a set number. NRPB assigned ten detector numbers to the transit control group and the other 30 numbers at random to one of the three measurement groups. Charcoal and electret detectors were submitted in groups of 15, 20 or 30 rather than 40, using 5 or 10 detectors for each measurement group. No transit controls were used for charcoal detectors. Some laboratories submitting sets of electret detectors provided extra detectors to measure gamma and cosmic ray exposures.

On arrival at NRPB sets of detectors were divided up among the four groups and sealed in radon proof bags. The sealed detectors were stored in the laboratory until it was time for the exposure at which point the bags were opened and the detectors set up in trays outside the chamber. The trays of detectors were then taken into the chamber for the exposure. Setting up of the detectors normally takes up to half an hour. By doing this work outside the chamber in a well monitored low radon area the start time of the exposure was the same for all detectors. An additional benefit is a reduced radon exposure to staff.

At the end of each exposure the detectors were all removed from the chamber and placed in the laboratory for three days to allow radon to diffuse out of the holders after which the detectors were again sealed into radon proof bags.

After the final exposure of each exercise the detectors for each set of 40 were mixed together and returned to the originating laboratory for processing and reporting. As noted above, for technical reasons this did not apply to charcoal detectors, each batch of which were returned as soon as the exposure was complete.

## EXPOSURES

The steering meeting in 1997 decided that the format of the exposures would involve a total of three exposures at three different equilibrium factors, with two of the exposures of similar magnitude and one considerably higher. The final meeting in 1999 was open to all participants who were questioned about the format of the exposures and invited to offer suggestions. As a result the intercomparisons in 2000 and 2001 consisted of three very different exposures: low, medium and high. This would enable participants to compare the response of their detectors over most of the exposure range they would be likely to encounter in real surveys.

The exposures were carried out in the radon exposure chamber at NRPB. The appropriate conditions were obtained in the chamber before introducing the detectors. Detectors were placed on or above a table in the centre of the radon chamber (see Figure 2). Open detectors were placed with their sensitive surfaces exposed to the air. Detectors designed to hang in the air were hung from a rod above the table.

During the exposures the radon level was monitored continuously by the ATMOS 12 instrument. Measurements of radon decay products were made using the alpha spectrometric method at hourly intervals during the exposures. The radon concentration in the laboratory outside the exposure chamber was monitored during the exposures using an Alphaguard Professional monitor. Typical daily average concentrations ranged from 10 to 60 Bq m<sup>-3</sup>, with an overall average of approximately 20–25 Bq m<sup>-3</sup>. The estimated additional exposure of the detectors caused by leaving them exposed in the laboratory for three days to allow radon to diffuse out of them was less than 1% of the exposure in the chamber in all cases and was therefore neglected.

Thoron decay product concentrations were estimated by recounting some of the filter papers overnight, 24 hours after sampling. The highest thoron decay product concentration was found to be <1 Bq m<sup>-3</sup> equilibrium equivalent thoron during any exposure.

Monitoring of ambient aerosols during the intercomparisons showed concentrations typically ranged from 5 10<sup>3</sup> particles cm<sup>-3</sup> with a median thermodynamic diameter of 100 nm under very low equilibrium conditions, to 8 10<sup>4</sup> particles cm<sup>-3</sup> with a median thermodynamic diameter of 120 nm under high equilibrium conditions.

## DISCUSSION OF RESULTS

Participants in each intercomparison were asked to return results for each detector in terms of kBq m<sup>-3</sup> h exposure of radon. The results were received by NRPB before the participants were informed of the exposures given. With the exception of the charcoal detectors (which had to be returned immediately at the end of an exposure), participants did not know which detectors were exposed together.



**FIGURE 2** Detectors during exposure

To ensure that the results submitted by NRPB (as a participant in the inter-comparison) were reported blind as well, they were routed through a third party who renumbered the detectors. The exposures given to the detectors in each intercomparison were not calculated until after the results for NRPB detectors had been returned and the deadline for return of all results had been passed.

Many of the laboratories taking part in the intercomparisons do not use their own design of detector: often they use one of a number of common types of detectors. Table 3 shows the minimum standard deviations achieved by each of the common detector types, taking all five intercomparisons together. These results serve as reference points for each of the detector types. In all cases there were other laboratories using the same combination of holder and detector material which produced much higher standard deviations. The results demonstrate that many laboratories are not achieving the best possible results from

**TABLE 3 Minimum mean % standard deviations achieved by common detector types in the intercomparisons**

HOLDER	DETECTOR MATERIAL	MINIMUM MEAN % SD
Canister	Activated charcoal	1.0
E-Perm L	Electret	2.3
NRPB/SSI	CR-39/PADC	3.0
Karlsruhe FN	Polycarbonate	4.3
NRPB	CR-39/PADC	4.6
ANPA	Cellulose nitrate	4.7

their detectors. They also appear to show differences between the best possible results obtainable from each detector type.

It should be noted that errors of bias can in principle be corrected by more accurate calibration, but if there is a large standard deviation on a set of detectors exposed simultaneously this indicates problems which may be more difficult to identify and correct. There are many potential sources of error on individual results, including the effects of shock in discharging electrets and problems of proper recognition of etched tracks by automatic image analysers.

Large numbers of European and other laboratories continue to take part in these passive detector intercomparisons. Although the slightly different format for intercomparisons after 1999 makes comparison with previous years difficult, there continues to be a general trend of improvement in results which it is hoped will continue. These improvements can be attributed to several factors. One of the most important is that participants see their results ranked alongside those from other laboratories, so that they can tell immediately whether they are performing better or worse than others. Poor performance provides a strong incentive for improvement. Also the nature of the errors shown by the results allows a participant to identify what may be going wrong. For instance, high standard deviations indicate poor quality control, and possibly electrostatic effects. Consistent deviations from the reference value indicate a calibration error. Variable deviations from the reference value may indicate non-linearity of response. Hence participation in an intercomparison like the ones reported here allows a scientist to identify and correct sources of error.

Although not all laboratories take part in every intercomparison there is continued enthusiasm by all participants, with new laboratories expressing interest in joining every year. It is intended that the intercomparisons continue on an annual basis for the foreseeable future.

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# Uncertainty Analysis on the Probabilistic Accident Consequence Code COSYMA

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**This article summarises a project to analyse the uncertainty in the probabilistic accident consequence code COSYMA, undertaken with partial support from the European Commission. The study was carried out in two stages. The first used formal expert judgement elicitation to derive ranges to express the uncertainty on the parameter values for COSYMA. This part was also intended to provide ranges for the American code MACCS, and was undertaken jointly with the US Nuclear Regulatory Commission. The second stage used the ranges provided in an analysis for the COSYMA code. The full results of the project are published in a series of reports.**

**T**wo computer systems for use in probabilistic accident consequence assessments (COSYMA<sup>1</sup> in the European Union and MACCS<sup>2</sup> in the USA) were developed around 1990, and made generally available. There has been an interest in quantifying the uncertainty in the predictions of such systems, and analyses of the uncertainty on predecessors of both programs have been carried out (see, for example, Jones *et al*<sup>3</sup>, Fisher *et al*<sup>4</sup> and Ritchie *et al*<sup>5</sup>). An important feature of an uncertainty analysis is the derivation of a joint distribution on the values of the many parameters involved. In the earlier studies, the joint distribution\* was largely specified by the system developers, rather than experts in the many different fields involved in accident consequence modelling.

In 1991, both the European Commission (EC) and the US Nuclear Regulatory Commission (USNRC) were considering initiating studies to better quantify the uncertainty in the input parameter values and in the predictions of the systems. An essential aspect of these studies was to obtain distributions and information on the dependencies between parameter values using formal expert judgement elicitation techniques. The studies were combined into a single EC/USNRC project intended to develop credible and traceable uncertainty distributions for the respective system input parameters. The distributions have been propagated through COSYMA, and the uncertainty in the predictions has been quantified.

This paper describes both the elicitation of uncertainty ranges and the propagation of those uncertainties through COSYMA.

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\* The joint distribution assigns a probability to each feasible set of values of the input parameters.

## OBJECTIVES

The main aims of the study can be summarised as:

- to formulate a state-of-the-art methodology for uncertainty estimation which is capable of finding broad acceptance,
- to apply the methodology to estimate uncertainties associated with the prediction of the PRA code COSYMA,
- to provide an input into identifying future R&D priorities.

The first objective was met through the collaboration between research teams from the USA and Europe, and the development of agreed methods for the study. The second objective was met, at least for Europe, by eliciting information from experts and using the resulting joint distribution on the uncertain parameter values in an analysis using COSYMA. This analysis was undertaken for several combinations of source term and countermeasure strategy with the intention of deriving indicative levels of uncertainty should COSYMA be applied in other situations. It was intended that the levels of uncertainty obtained in this study would indicate the likely levels of uncertainty in other, similar situations. In addition to calculating the uncertainty on the model predictions, the study also identified the input parameters whose uncertainties make major contributions to the overall uncertainty. This could form an input into identifying research priorities, so fulfilling the third objective. In addition, this study has improved on earlier studies as the uncertainty has been better quantified because the distributions on the parameter values were determined from formal techniques of expert judgement.

## EXPERT JUDGEMENT ASPECTS OF THE STUDY

The expert judgement aspects of the study were undertaken jointly by USNRC and EC, using a combination of methods developed in earlier American<sup>6</sup> and European<sup>7</sup> studies. The formal use of expert judgement followed an agreed protocol<sup>8</sup>.

Accident consequence programs consider the various pathways by which people can be irradiated following a release to atmosphere, together with the calculation of doses and risks following intakes of radionuclides. The input parameters are drawn from many scientific fields. Obtaining information on the uncertainty in the parameter values from expert judgement therefore also requires experts from the different scientific fields covered by the parameters, and no one group of people would have expert knowledge about the whole set of parameters. Therefore a series of expert panels were formed, with each panel covering a particular aspect of the overall area. The panels covered

- atmospheric dispersion,
- deposition,
- transfer through terrestrial foodchains, split into two panels for soil and plant processes and for animal processes.
- external  $\gamma$  exposure from deposited material,
- internal dosimetry,
- risk of early health effects,
- risk of late health effects.

Each of the panels included about eight experts, chosen according to an agreed set of criteria, and included both European and American experts. However, for the foodchain study, separate panels of European and American experts were formed and some different

questions were posed to the two panels as some conditions and agricultural practices are different in Europe and the USA. The experts were introduced to the modelling used in accident consequence systems. They were also trained in assessing probability distributions. They were then asked for their views on the distributions of values for a number of parameters in the modelling area in which they are expert. In providing these distributions, the experts were free to use whatever models or information they wished. The parameters for which distributions were elicited using expert judgement were considered to be those whose uncertainty is likely to make large contributions to the overall uncertainty, within the area of expertise of the panel. Distributions were obtained for the other parameters using less formal methods.

Some of the parameters in accident consequence models represent quantities that can, in principle, be measured. Others, for example some transfer coefficients used in foodchain models, cannot and so must be derived from other measurable quantities. A fundamental aspect of the methodology of formal judgement elicitation is that experts should only be asked to give their views on values of quantities that can potentially be measured. For example, the atmospheric dispersion experts were asked for information on the air concentration at particular distances, rather than on the parameters used in the dispersion models. In this way a library of information can be obtained that can be of use to both the MACCS and the COSYMA systems, and also to other models and programs. In some cases, experts were asked for information on quantities that are not used in models currently included in either MACCS or COSYMA if this information might be of interest in other studies.

The procedures adopted for the panels are described in a series of reports jointly prepared by USNRC and EC<sup>9-15</sup>. These reports also contain the results obtained from the panels, but do not give distributions on the values of the COSYMA input parameters where these have been obtained from the experts' distributions on related quantities.

The panels provided information on a range of quantities as summarised below.

The *atmospheric dispersion panel*<sup>9</sup> provided information on the air concentration at a series of points and the standard deviation of the cross-wind distribution of activity at selected distances, for a number of atmospheric conditions. The distributions for the parameters of the COSYMA dispersion model have been derived from this information.

The *deposition panel*<sup>9</sup> provided information directly on dry deposition velocities to different surfaces for iodine and for a range of particle sizes. It also gave information that was used to derive the washout coefficient.

The *foodchain panels*<sup>10</sup> gave information on the foodchain model input parameters for strontium, caesium and iodine for transfer into crops and transfer into animals' meat and cows' milk. The distributions on the values for the parameters of the model used to generate the COSYMA foodchain libraries were derived from this information.

The *deposited material panel*<sup>11</sup> gave information on the dose and dose rate at different times following unit deposition of particular radionuclides. The information is given for the dose over a large uniform area of grass and for an average urban area. The panel also gave information on the shielding properties of various types of buildings, and on some aspects of population behaviour.

The *internal dosimetry panel*<sup>12</sup> gave information on the amounts of material deposited in different organs at a series of times following intake by inhalation and ingestion, for a range of nuclides. Distributions of values for the parameters in the model

to calculate dose coefficients used with COSYMA were derived from this information. They also gave distributions for the doses in selected organs for  $^{90}\text{Sr}$ ,  $^{131}\text{I}$ ,  $^{132}\text{Te}$ ,  $^{137}\text{Cs}$ ,  $^{144}\text{Ce}$  and  $^{239}\text{Pu}$ .

The *early health effects panel*<sup>13</sup> gave information on the  $D_{10}$ ,  $D_{50}$  and  $D_{90}$  doses for a series of dose rates, for both whole body exposure and for preferential exposure of particular organs. Distributions of values for the parameters of the dose response relationships adopted in COSYMA were derived from this information.

The *late health effects panel*<sup>14</sup> gave information on the numbers of cancers, and cancer deaths, in a population within different time periods after exposure at a high and a lower dose rate. Information was obtained for both an average population and for children.

A panel was also organised to consider some aspects of the *timings of countermeasures*<sup>15</sup>, although the contribution of this uncertainty was not included in the analyses of the uncertainty on the predictions of COSYMA.

Each member of the panel gave their views independently for each of the elicited quantities. The distributions from each expert were aggregated into a single distribution.

## QUANTITIES CONSIDERED

The uncertainty analysis of COSYMA was undertaken for three source terms encompassing a wide range of characteristics of those that have been postulated for Light Water Reactors (LWRs). These were taken from analyses of the Pressurised Water Reactor (PWR) proposed for the Hinkley Point site in the UK. The source terms considered were<sup>16</sup>:

- UK1, a very large release identified as the risk dominant source terms for early health effects,
- CB2, a smaller release which makes a major contribution to the overall risk of late health effects,
- DBA, a design basis release.

COSYMA gives information on a wide variety of consequences of an accident. It was not possible to consider all of these endpoints, and so the study evaluated the uncertainty on a selection of endpoints which can be summarised as follows:

- concentration in air and deposition of  $^{131}\text{I}$  and  $^{137}\text{Cs}$  at selected distances,
- individual dose integrated to seven days in bone marrow, thyroid and skin at selected distances,
- individual and collective risks of early fatal and non-fatal health effects,
- the areas with emergency actions for sheltering, evacuation and distribution of stable iodine tablets,
- individual and collective committed effective doses and doses in bone marrow and thyroid,
- individual and collective risks of fatal cancers and leukaemia,
- the areas and their time integral affected by relocation and by food restrictions.

The calculations of dose and risk were undertaken for a range of patterns of population behaviour, as considered in licensing procedures in various countries. The study considered potential doses and risks calculated assuming that people are outdoors for the whole period, consequences assuming normal living with no countermeasures and consequences if allowance is made for the effects of countermeasures. The intervention

levels adopted for these calculations were based on those suggested by the International Atomic Energy Agency (IAEA) for sheltering, evacuation, iodine tablets and relocation together with the EC levels for food restrictions.

The complete set of endpoints and behaviour patterns could not be considered for each of the three source terms because of the effort that would be required for such a study. Therefore the following set of situations was analysed:

- UK1 potential outdoor doses from inhalation and external exposure integrated to seven days and individual risks of early health effects,
- UK1 normal living with no countermeasures, for individual doses from inhalation and external exposure integrated to seven days and the individual and collective risks of early health effects,
- UK1 with countermeasures, for individual doses from inhalation and external exposure integrated to seven days and the individual and collective risks of early health effects,
- CB2 normal living with no countermeasures for individual and collective committed doses and individual and collective risks of late health effects,
- CB2 with countermeasures, for all endpoints selected,
- DBA potential outdoor individual committed dose and individual risks of late health effects,
- DBA with countermeasures for individual and collective committed dose and risks of late health effects, relocation and food restrictions.

Here 'potential dose' refers to the calculation of doses outdoors and with no countermeasures; this is adopted as the calculations giving the highest doses that could potentially be received after the accident. 'Normal living' refers to the situation with no countermeasures; the calculations include the effects of buildings in reducing exposure, allowing for average behaviour of the population and occupancy of buildings. 'With countermeasures' refers to calculations where it is assumed that all members of the population follow the adopted countermeasures strategy, but use the normal living assumptions for other aspects of the calculations.

### METHOD ADOPTED FOR UNCERTAINTY ANALYSIS

There are several hundred parameters in the models included in COSYMA or used to derive its data libraries. It was felt that it would not be possible to undertake a single analysis including all these parameters<sup>16</sup>. Therefore, four analyses<sup>17-20</sup> were undertaken on parts of the code to select the parameters for inclusion in the overall analysis. The number of uncertain parameters considered in each of these analyses, and the number selected for the overall analyses, are tabulated below<sup>21</sup>.

MODULE	NUMBER OF PARAMETERS CONSIDERED	NUMBER IDENTIFIED FOR OVERALL ANALYSIS
Atmospheric dispersion and deposition	28	24
Foodchain	162	35
Internal and external dosimetry	159	100
Health effects	27	27
Overall analysis	376	186

The results of a single run of a PRA code are generally presented in terms of the complementary cumulative distribution function (ccdf) which gives the probability that the consequence is greater than a particular value. This analysis considered the uncertainty on the mean value and 95th and 99th percentiles of the distribution. The uncertainty analysis involved running COSYMA many times, and so generated many different estimates of the ccdf and its mean value and percentiles. A probability distribution can be derived from these results for each endpoint and the uncertainty on the predicted consequences is then described by percentiles of that distribution. The uncertainty is generally expressed using the ratio of the 95th to 5th percentile of the uncertainty distribution on the mean value or the specified percentile of the ccdf; this quantity is designated the uncertainty factor in this report.

Some results are presented using diagrams that show the 5% and 95% envelopes of all the ccdfs from the analysis. This presentation distinguishes two forms of uncertainty in determining the probability of exceeding a particular number of effects. The first form of uncertainty reflects the range of atmospheric conditions that could occur at the time of the accident, while the second form of uncertainty reflects the uncertainty on the input parameter values. This form of presentation shows the extent to which the uncertainty could be reduced by increasing knowledge about the most appropriate values for the input parameters; the uncertainty arising from the range of possible atmospheric conditions at the time of the release cannot be reduced.

Some results are also presented as the average of all the ccdfs from the analyses, here termed the 'mean curve'. This form of presentation combines the uncertainties from the atmospheric conditions at the time of the accident and from the parameter values and describes the probability of exceeding a particular number of consequences allowing for both forms of uncertainty. However, this form of presentation does not include any information on the effects of reducing the uncertainty on the parameter values.

## RESULTS

Full results of the study are presented in Jones *et al*<sup>21</sup>, and summarised here.

### Individual doses and risks

The study showed that the uncertainty on individual doses to seven days, for the UK1 and CB2 releases, is generally between factors of about 10 and 100 for bone marrow and thyroid doses, but a few thousand for skin doses. The parameters whose uncertainties make large contributions to the overall uncertainty are those of the atmospheric dispersion model for bone marrow dose, the deposition velocities to skin for the skin dose, and some of the dispersion and deposition and internal dosimetry parameters for the thyroid dose.

The uncertainty factor on the individual risks of early fatalities, for the UK1 release, increases considerably with distance, ranging from a factor of about two at short distances to a value of more than 1000 at larger distances, where doses are close to the threshold for early effects for some values of the input parameters. The parameters whose uncertainties make large contributions to the overall uncertainties are some of those in the lung model together with some of the dispersion and deposition parameters.

The uncertainty factors on individual committed dose for the CB2 and DBA source terms depend to some extent on the organ, population behaviour and source term, with the uncertainty on the effective dose being lower than that on the doses in particular organs. The uncertainty factors lie between about ten and a few hundred. The parameters

whose uncertainties make major contributions to the overall uncertainty also depend on the situation considered, and are different for the two source terms considered. The important uncertainties are those on some of the parameters of the internal dosimetry models, particularly of the lung model, and of the foodchain models.

The uncertainty factors on the individual risks of fatal cancers, for the CB2 and DBA releases, range between about 50 and 100, with the uncertainties on the risk coefficients in remainder tissue, thyroid and lung being identified as important contributions to the overall uncertainty. Other parameters from the dispersion, dose or foodchain model are also identified as making important contributions in some situations. The uncertainty factors on the individual risks of thyroid cancer and leukaemia are very high, more than a hundred thousand, reflecting the large uncertainty assigned by the expert panel to the risk coefficients in these organs.

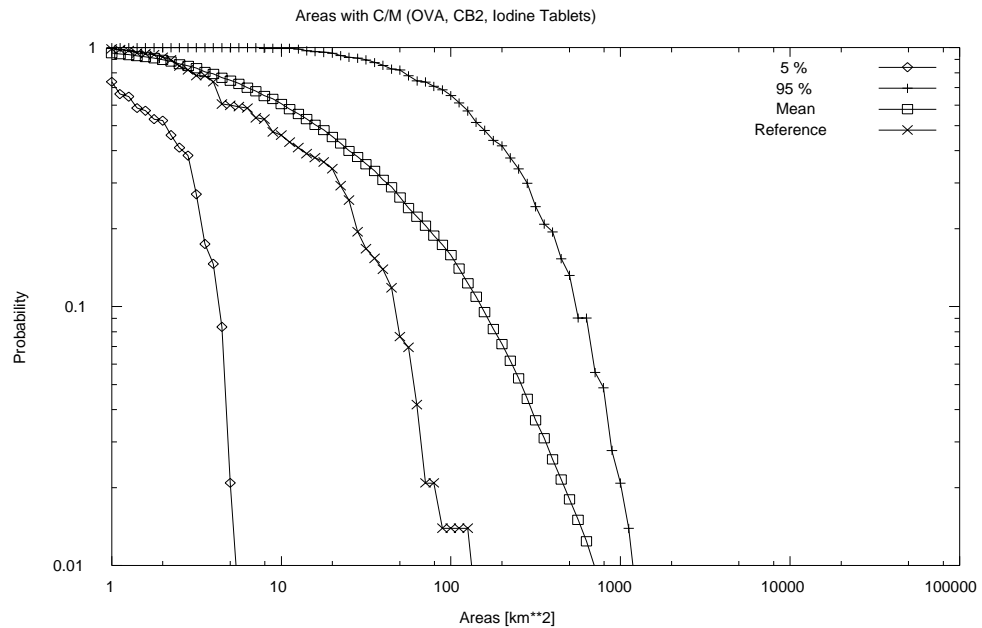
Some of the results are given in the following table, which presents uncertainty factors on the mean values of the doses and risks at the different distances considered.

QUANTITY	UNCERTAINTY FACTORS FOR MEAN VALUES, AT DISTANCES INDICATED			
	1 km	5 km	20 km	100 km
Dose to bone marrow in seven days, with countermeasures, for UK1	4.5	13	6.4	—*
Dose to thyroid in seven days, with countermeasures, for UK1	12	29	32	—*
Individual risk of early death, with countermeasures, for UK1	3.1	13	1100	—*
Individual risk of early morbidities, for potential exposures, for UK1	15	30	130	—*
Committed effective dose, with countermeasures, for CB2	—*	110	39	15
Committed effective dose, with countermeasures, for DBA	—*	44	33	37
Individual risk of fatal cancers, with countermeasures, for CB2	—*	100	85	64
Individual risk of fatal cancers, in normal living, for CB2	—*	96	75	65

\*Quantities related to short term doses and risks of early health effects were only considered at distances of 1, 5 and 20 km, while quantities related to committed dose and individual risk of late health effects were only considered at 5, 20 and 100 km.

### Extent of countermeasures

The study found that the uncertainties on the areas with early countermeasures (sheltering, evacuation and iodine tablets), for the CB2 release, are large, with uncertainty factors in the range from about 100 to about 300. To some extent this large uncertainty may reflect the small areas that are predicted to be affected for some values of the input parameters. The parameters whose uncertainties make large contributions to the uncertainty on the sheltering and evacuation areas are some of those in the lung model while those for the area in which iodine prophylaxis is indicated are the deposition velocity of iodine and the breathing rate. The results for the area where iodine tablets would be required are illustrated in Figure 1, which shows the 5th and 95th per cent envelopes, the mean curve and the reference curve. In this case, the reference curve is near the centre of the uncertainty band.



**FIGURE 1** Extent of the uncertainty on the area with iodine tablets for the CB2 source term

The uncertainty on the extent of the relocation area, for the CB2 source term, was found to be the same as that on the evacuation area. The uncertainty on the time integrated area is smaller, about a factor of 100. The parameters whose uncertainties make large contributions to the overall uncertainty are the deposition parameters for aerosols.

The study showed that the uncertainties on the areas with food restrictions are rather different for the two source terms considered, ranging from about 30 to about 500 for milk, green vegetables and beef, with somewhat larger values for grain where the areas affected are rather small. The uncertainty for the DBA source term, where the affected areas are small, tends to be larger than that for the CB2 source term. The parameters whose uncertainties make large contributions to the overall uncertainty come from the foodchain model.

Some of the results are given in the following table, which presents the uncertainty factors for the mean value and the 95th and 99th percentiles of the probability distributions for some of the endpoints considered.

QUANTITY	UNCERTAINTY FACTORS FOR		
	MEAN	95th PERCENTILE	99th PERCENTILE
Evacuation area, for CB2	230	300	300
Area with iodine tablets, for CB2	92	160	210
Time integral of relocation area, for CB2	88	81	130
Time integral of area subject to milk restrictions, for CB2	38	42	39
Time integral of area subject to green vegetable restrictions, for CB2	110	100	95
Time integral of area subject to milk restrictions, for DBA	190	170	180
Time integral of area subject to green vegetable restrictions, for DBA	60	68	65

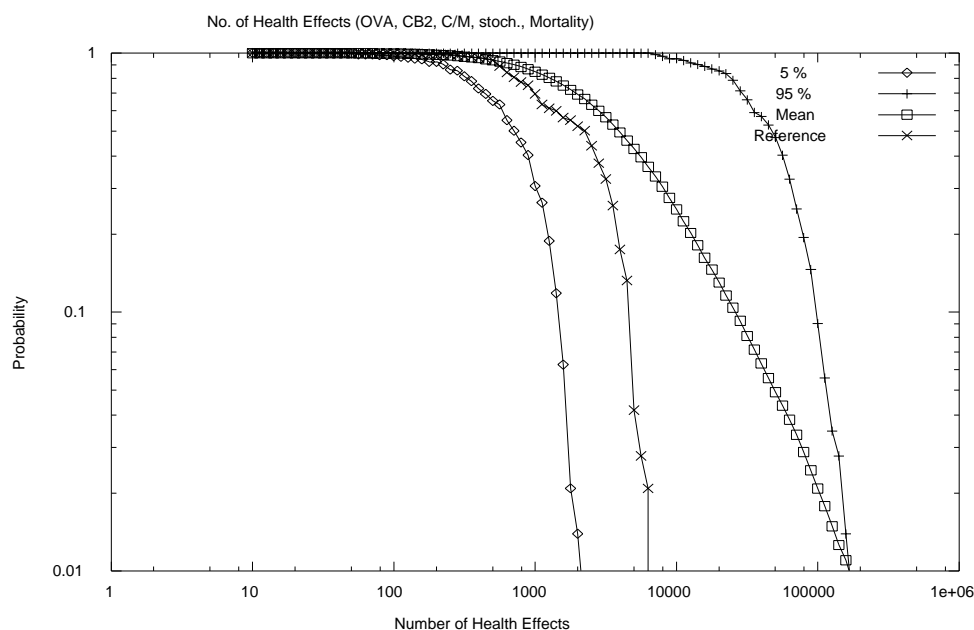
## Numbers of health effects

The uncertainty on the numbers of early fatalities in the population, for the UK1 release, ranges between about 30 and 60. The parameters whose uncertainties make large contributions to the overall uncertainty depend on the situation (ie source term and population behaviour pattern) considered, with the deposition velocity of iodine to skin and the fractions of material deposited in different parts of the lung identified for some situations.

The uncertain factors on the number of late health effects, for the CB2 and DBA releases, and the parameters whose uncertainties make large contributions to the overall uncertainty are similar to those discussed above for the individual risks of late health effects. The results for the numbers of fatal cancers with countermeasures for the CB2 source term are illustrated in Figure 2 which shows the 5th and 95th per cent envelopes, the mean curve and the reference curve. In this case, the reference curve is in the lower part of the uncertainty band.

Some of the results are given in the following table, which presents the uncertainty factors for the mean value and the 95th and 99th percentiles of the probability distributions for some of the endpoints considered.

QUANTITY	UNCERTAINTY FACTORS FOR		
	MEAN	95th PERCENTILE	99th PERCENTILE
Number of early mortalities, with countermeasures, for UK1	43	45	33
Number of early mortalities, in normal living, for UK1	65	58	51
Number of fatal cancers, with countermeasures, for CB2	23	23	26
Number of fatal cancers, in normal living, for CB2	18	20	27
Number of fatal cancers, with countermeasures, for DBA	28	26	32



**FIGURE 2** Extent of the uncertainty on the number of fatal cancers with countermeasures for the CB2 source term

## Applying the results in other situations

The study also considered the extent to which the results could be applied to other situations. The results for effects where there is a threshold (risks of early health effects, extent and duration of countermeasures) are considered likely to be more specific to the situations considered here than are those relating to other effects (doses and risks of late health effects). Results for the endpoints relating to the risk of early health effects and the extent of countermeasures are only available for one source term; those relating to the risk of late health effects are available for two source terms.

## SUMMARY

This paper has summarised a study to investigate the uncertainty in the predictions of the COSYMA probabilistic accident consequence code. The uncertainty ranges on the input parameters were derived from a formal expert judgement elicitation technique. The resulting distributions were processed through the COSYMA code, so that the uncertainty in its predictions could be assessed. The input parameters whose uncertainties made major contributions to the overall uncertainty have also been identified. These findings could be used to determine priorities for future research projects.

## ACKNOWLEDGEMENTS

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The study required contributions from a large number of people, namely the people who organised the expert panels, the members of the panels, and people who derived data files for use in the calculations.

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## Discussion of Current Radon Problems in Berlin

GERALD KENDALL • NATIONAL RADIOLOGICAL PROTECTION BOARD • CHILTON

The fourteenth 'Radonstatusgespräch' took place in Berlin in October 2001. These meetings, hosted by the German Environment Ministry, are designed primarily to discuss the latest state of research funded by the Ministry. However, in recent years, they have been broadened to include participants from other countries. A welcome innovation this year was the inclusion of a number of papers on epidemiology. This gave the meeting a focus while not detracting from the customary wide spread of interests.

There were a number of papers which discussed the problems of making maps of radon potential across Germany. By radon potential is meant the probability of a house having high radon levels. The processes involved are simple in principle. Radon in houses usually originates from uranium in the ground under the house. This uranium gives rise to radon in the soil gas. Various mechanisms, mostly pressure driven, cause radon in soil gas to enter the house. The first process, leading to radon in soil gas is a matter of geology. The second is one for building engineers, although they will need to know a great deal about the history of any particular house and the habits of its occupants.

The basic approach selected in Germany to these problems is to utilise both an extensive measurement programme and geological insights to map variations in radon concentration in soil gas. Good progress has been made in this area. The next step is to predict the transfer factor from soil gas to room air. This is proving very difficult, particularly if the problem is generalised to allow for the possibility that a second source (eg building materials) also contributes significantly to indoor radon levels. Klingel (Germany) reported some analyses of variance in which the most influential factors (whether a building had a cellar, the geological unit on which it was situated) contributed around 10% each, leaving 70% unexplained.

The UK has, of course, adopted a pragmatic approach in which radon potential maps are derived primarily from the results of radon in house measurements; geology can be used to help group potentially similar houses together. This may be less scientifically interesting than the German approach, and requires many measurement results, but in UK circumstances at least, provides a direct answer to the question.

The epidemiology section was introduced by Lothar Kreienbrock. He gave a lightning outline of epidemiological concepts for the uninitiated and went on to describe some of the major studies of radon and lung cancer. In the case of exposure of miners the link is well established and has been quantified, for example by the BEIR VI Committee. Attention is now directed towards direct investigations of the effects of domestic exposure to radon, usually by means of case-control studies.

Kreienbrock distinguished three stages in the development of these case-control studies, culminating in those with large sample sizes and good records of radon exposures covering the last 20 or more years of the experience for each individual. A current hot

topic is whether measurements of long lived  $^{210}\text{Pb}$  in the glass of, say, picture frames gives a better estimate of cumulative exposure than do contemporary measurements using track etch detectors. However, even good studies of this kind with a thousand or more cases, often lacked the power to conclusively demonstrate a trend in risk with exposure. Pooling exercises are underway to try to narrow the confidence intervals.

Oberaigner (Austria) reported the results of a new domestic radon case-control study. This also found an effect. This was at the higher end of the range usually reported, an odds ratio of 1.25 for a lifetime exposure at  $100 \text{ Bq m}^{-3}$ , whereas the European consensus was around 1.1. However, full allowance for measurement errors might change these numbers. Some confusion can arise if it is not recognised that these 'risk at  $100 \text{ Bq m}^{-3}$ ' figures describe the overall slope of the exposure-response relationship. There are not spot risk estimates at precisely  $100 \text{ Bq m}^{-3}$ .

Germany has a strong lobby against the linear no-threshold (LNT) hypothesis. The effects of radon exposure seem to be a favourite battleground. This may seem odd, given that there is a wealth of epidemiological evidence pointing, to put it no higher, to the fact that an effect exists and that control measures are introduced at radon concentrations around those where such an effect can be seen. In most areas of radiation protection there is not the slightest possibility of demonstrating the risk against which protective measures are being taken. Kreienbrock warned against trawling the results of individual epidemiological studies in search of data points which could be interpreted as a threshold. Inevitably there will be levels of exposure below which epidemiology cannot demonstrate an effect and interpolation must be guided by other evidence. We shall have to wait and see where the current pooling studies leave this threshold.

The spectrum of radon activities covered at these meetings is wide. Far away from the epidemiological research end of the spectrum, Minach (from Südtirol) described attempts to control radon levels in a number of dwellings where remedial measures were complicated by very high porosity of the ground or of the walls. One of these buildings had rubble-filled walls a metre thick within which there were reported to be not just drafts but gales. Even more mysteriously the flow of air into and out of the wall was found to reverse itself, 'breathing' with a periodicity of 20 seconds or so. Conventional remedial efforts with extraction fans often proved less effective than reversing the fan and blowing in clean air in such complicated buildings.

Poffijn (Belgium) reported on public attitudes to radon. The message was partly reassuring, with evidence emerging that public information campaigns could be very effective in getting across the basic facts about radon. However, the picture was not entirely rosy. It seemed that, after a lapse of a year, 90% of those questioned had managed to convince themselves that the radon level in their own house was significantly lower than the measurement had actually shown.

Schulz (Germany) described studies of factors affecting radon exhalation from capped-off spoil heaps. He argued that differences in the concentration of  $^{226}\text{Ra}$  and  $^{210}\text{Pb}$  were very revealing, despite the different mobilities of the two chemical species. This was a fascinating glimpse into a new field (perhaps, more strictly, a new hill) in which bioturbation through Durchwurzelung was of central importance. The conclusion, perhaps inevitably, was that a rather thicker cap was needed than optimistic predictions might have suggested.

## 37th Berlin Colloquium

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**The Berlin Colloquia are a well-established series of annual meetings for the informal exchange of practical experience on a wide variety of themes. In order to allow participants to talk freely there are no proceedings or formal written record. Nevertheless, the account below gives a flavour of the meeting.**

The 2001 Berlin Colloquium held in October attracted participants from 12 countries, plus the usual strong contingent from the host nation. A notable absence this year, and one which was regretted, was a representative of the European Commission. Five topics were selected for discussion:

- safety of radiation sources,
- monitoring of discharges from nuclear facilities,
- ultraviolet radiation and solaria,
- radioactivity in water,
- implementation of the European Medical Exposure Directive.

The first of these was introduced by Renata Czarwinski of the Bundesamt fuer Strahlenschutz. She reminded the meeting that since the end of the Second World War, there had been 400 significant accidents involving sources of radiation: 3000 people had been exposed, of whom 100 had died. Half of these fatalities had been a result of accidents in medicine. A study funded by the EU had estimated that over 500 000 sources had been produced. Of these, about 100 000 were still in use.

Keeping track of sources and safe disposal when they become surplus to requirements is the key to safety. *Bulletin* readers will know of the serious accidents which have sometimes followed when sources have fallen outside the normal system of control and come into the possession of people who did not recognise them for what they were. One of the problems is the potentially significant cost of disposal. Several participants spoke of a tendency in some quarters to declare surplus sources as reserves or as awaiting recycling rather than as waste to be disposed of. Current proposals to find a way of covering the disposal costs in the initial purchase price, or during its use, rather than at the end of its life look promising.

Lost sources often find their way to metal scrap yards for recycling. The operators of such plants have often introduced portal monitors in order to check incoming loads. They are notoriously reluctant to accept any material which registers as active. It was suggested that the famous German 'Reinheitsgebot' which forbids the addition of any material other than water, malt and hops in the production of beer was being adapted to the steel industry.

The discussion on monitoring discharges from nuclear installations was limited to participants from countries which had such installations. The UK was, of course, fully qualified. There was a general similarity of approach, although a comment was made that differences in modelling, choice of critical group etc meant that estimates of doses from nuclear installations were almost in different units, the German millisievert being different from the British, for example. Another observation, from those with power stations discharging low levels of activity into rivers, was that measured changes in activity concentrations in the water were just as likely to arise from differences in the flow of the

river as from changes in the power station. This point was often not recognised, and could cause confusion.

In contrast to the previous topic, everybody had something to report on the topic of ultraviolet and solaria. No country could say that its inhabitants were following expert advice and shunning solaria altogether. Precise estimates of the level of use were generally not available, but many participants could offer rough estimates. These were usually in terms of the total number of sunbed sessions per year. The totals often equated to more than one session per head per year. In practice, of course, there are likely to be a few heavy users, and others who rarely, if ever, use sunbeds. This enthusiasm is in the face of rising numbers of skin cancers and the fact that, from one country at least, 20% of sunbed users reported that they had experienced erythema.

All participants had radioactivity in their water, too, although not very much in most public supplies. Private water supplies from boreholes and mineral waters could be a different matter with high levels of natural radionuclides from the uranium and thorium decay chains sometimes being found. Radon, is of course, one such decay product. These problems were becoming recognised and countermeasures taken. A fascinating snippet emerged of mineral water producers, whose charter forbade processing the product, extracting water with high levels of say, radium, which had disappeared before bottling, clearly as a result of a non-processing process. 'More power to their elbow' was the general reaction. It was also noted that attention is usually focused on  $^{226}\text{Ra}$ , but that  $^{228}\text{Ra}$  gives higher doses per unit intake, and may be more important.

Some health-conscious parents have decided that it is more healthy for their infants to be fed on baby formula which has been made up with mineral water. At least one country had produced a special standard for water for this purpose to try to ensure that such good intentions were not counterproductive.

The final session was on implementation of the European Medical Exposure Directive, with especial reference to doses to volunteers in medical research and on the new duty to collect statistical data on patterns of exposure.

On the question of doses from medical research, all participants agreed that a sharp distinction should be drawn between exposures of patients who might be expected to benefit from the procedure, even if it were in some way non-standard, and exposures of healthy volunteers. It was suggested that many small volunteer studies in practice used the researchers themselves as volunteers, so the guinea pigs did gain some benefit in terms of professional advancement via published papers. There was a rather sharper exchange on the question of finding healthy volunteers for those few studies which need to be done on children. On the one hand, it was argued that the siblings of children with the disease under question would gain some indirect benefit from taking part in research. The counter-argument was that it was almost impossible to suggest such participation in a way which did not put pressure on the parents to agree.

There was general interest in the changes that were taking place in the nature of diagnostic radiology, in particular, the explosive growth of CT. Getting precise, quantitative information to document trends was less easy. Participants from countries where medical care was paid for by insurance schemes said that, in principle, payment records could provide information on the frequency of different types of examination. But it would be rather crude and, in particular, would give no indication of the doses involved. It was a common feeling that 5% of the diagnostic examinations gave rise to 50% of the dose.

Interventional radiology was notorious for the potential for high doses (and of course high benefits) to the patient. Examples of acute effects from such procedures were

not uncommon. It was noted that most accounts were more comfortable if they were at third hand.

Large inter-hospital variation in doses for ostensibly the same examination were again a general theme. There may be very good reasons for variations, and obtaining diagnostic information to guide the treatment of the patient requires that some dose be received. But there is, in many cases, also room for dose reductions without loss of information from which the patient will benefit.

One particular point concerning the effects of doses from medical radiology is that the patients, particularly for high dose examinations, tend to be old and may be seriously ill. An age-weighted risk factor can take account of the former. But it was also suggested that a new type of collective dose was required in which dose were discounted if the patient was going to die within the next five or ten years. The importance of the medical physicist in helping to carry out diagnostic examinations efficiently was also acknowledged. Several participants suggested that insufficient medical physicists was a problem in their country.

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## NERC Co-Ordinating Group on Environmental Radioactivity

FRANCES BURGE, ALISON JONES, JULIE MERCER, WAYNE OATWAY &  
LUCIA SINGER • NATIONAL RADIOLOGICAL PROTECTION BOARD • CHILTON

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**The twentieth open meeting of NERC Co-Ordinating Group on Environmental Radioactivity (COGER) was held at Imperial College, London, in September 2001. About 50 representatives from a diverse range of organisations with an interest in environmental radioactivity met to present and discuss their work. In traditional style, several members of the Environmental Assessments Department attended and gave presentations on their current work. In total, there were 23 presentations given and 11 posters.**

**T**he presentations included studies on the effects of taxonomic position on plant uptake of radionuclides (with results that may have implications on transfer factors used in compartmental radioecological models), the effects of tritium on embryo-larvae of marine invertebrates, and the ecological impact of radioactivity in the Chernobyl exclusion zone which now has enhanced biodiversity and population abundance.

The NRPB talks covered a geostatistical analysis of the Windscale fire data, the FARMING network, calculation of external gamma doses in urban areas and assessment of the future use of land previously contaminated with radionuclides. A poster was displayed on the current generalised derived limits being calculated by NRPB.

### PROTECTING OTHER SPECIES

A thought-provoking presentation was given on the impact of ionising radiation on wildlife. The ICRP presumption that 'if man is adequately protected from ionising radiation, then so are other species' is being increasingly challenged due to lack of supporting evidence and inconsistencies [*ICRP currently has a task group which is looking into this topic*]. The increasing realisation that the environment should be protected in its

own right has also been supported in international conventions, ie OSPAR. The outcome of this project is a spreadsheet which calculates doses to the average population of a set of biota for various radionuclides. This product is being used to devise guidelines for the Environment Agency when undertaking assessments for the authorisations to discharge radioactive waste into the environment.

In addition to this, presentations were given on laboratory studies being carried out to ensure the protection of the environment as a whole. For example, the effects of environmentally relevant tritium in invertebrates are being studied; species such as lug-worms and lobsters are also being investigated to see if they can be used as bioindicators.

## **SEDIMENTS**

A variety of studies were described on the interaction of radionuclides with sediments. A study on French coastal sediments as sinks for COGEMA La Hague discharges was presented. The results showed that low activity in the French marshes would indicate that they were not acting as major sinks for La Hague. This is thought to be reflected in part by the mineralogy of the suspended sediment, which are carbonate-rich, together with rapid dispersal by currents washing them eastwards to the southern end of the North Sea.

Another study had carried out an aerial gamma survey of the Dee Estuary sediments and had revealed elevated levels of  $^{137}\text{Cs}$ . Core samples of specific areas of the Estuary had been taken from salt marshes and analysed. High  $^{137}\text{Cs}$  concentrations were observed in the sub-surface of most cores reflecting the historical discharges of radiocaesium from the Sellafield processing plant. As part of other studies, offshore and deeper intertidal sediments were collected and analysed for their caesium content. Results concluded that the biological, physical and chemical processes affect distribution and transport of radionuclides in Irish Sea sediments.

## **GUEST SPEAKERS**

Finally, there were two guest speakers: David Coulston, former Environmental Health and Safety Director of BNFL and Sir Bernard Ingham from Supporters of Nuclear Energy (SONE). David interrupted his holiday in Spain to give a learned, witty and informative speech about the history and environmental effect of Sellafield. In contrast, Bernard gave a fervent polemic advocating the increased use of nuclear power, which provoked heated discussion amongst many of the audience. SONE was set up in 1998 following the partial privatisation of the nuclear energy companies. It currently has about 200 members whose main aim is to stop the government and the 'greens' writing off the nuclear industry.

## **THE FUTURE**

It is possible that some of the areas of research presented will have an impact on work done and models used by NRPB in the future. Overall, the conference provided a broad overview of the variety of research currently being undertaken in the field of environmental radioactivity. It was also a good opportunity to put our presentation skills into practice!

Next year the organisers are experimenting with a different format, the meeting will be merged with the CAPER conference on air pollution due to take place in Leeds in April 2002. It will be interesting to see what effect this change might have on the topics for discussion.

## Hylton Smith (1927–2001)

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**Hylton Smith, recently the Scientific Secretary of the International Commission on Radiological Protection (ICRP), died at home on 10 June 2001, after several years of struggle against cancer.**

Hylton came to radiological protection via biochemistry, pharmacology, and radiobiology, perhaps an unusual route, but one that made him a valuable colleague in his final profession. He graduated at Newcastle in 1951 and took his first appointment, as a clinical biochemist, at Edinburgh University, working particularly in paediatric biochemistry. He obtained his PhD while at Edinburgh. In 1959, he moved to the Medical School of the University of Newcastle-upon Tyne to work on the pharmacological action of anaesthetics.

In 1969, he moved to Scotland as a Principal Scientific Officer at the Chapelcross establishment of the UK Atomic Energy Authority. His work here introduced him to areas of radiological protection, including the radiochemistry analysis of environmental samples, biological indicators of radiation exposure, human metabolism of radioactive materials, notably strontium and the actinides, and the decorporation of such materials. After some years, he found that he was not altogether happy in the scientific environment at Chapelcross, which was predominantly a nuclear power plant, and in 1969, he returned to the more academic surroundings of Sunderland Polytechnic, where he was Principal Lecturer in pharmacology.

In 1971, the National Radiological Protection started operating and Hylton was tempted back to radiological protection. He joined NRPB in 1973 as the head of its Biological Department, covering the metabolism of radioactive materials, cytogenetic indicators of radiation damage, terrestrial ecosystems, and non-ionising radiations. Shortly before his retirement, NRPB released him to become the Scientific Secretary of ICRP.

This post has always included a wide range of responsibilities, many of them well outside the field of science. They included the organising and financing of meetings of the Commission, the Committees, and the Task Groups. Financing ICRP has also depended on contributions from international and national bodies and charitable organisations and it has been the task of the Scientific Secretary to extract these contributions and to manage its finances. Hylton worked hard and successfully to keep the Commission solvent. He also had to maintain the scientific and editorial standards of ICRP publications and to satisfy the commercial needs of the publishers by producing a reasonably steady output of reports for publication. In 1988, he negotiated the arrangements needed to register ICRP as a charity, with useful financial advantages.

Over the years, Hylton achieved a substantial international reputation. He served as a consultant to UNSCEAR, the United Nations Scientific Committee on the Effects of Atomic Radiations. He represented ICRP at the regular meetings of UNSCEAR and at *ad hoc* meetings developing the basic safety standards of the relevant UN bodies. He participated in the European Late Effects Project and in the co-ordination of European biology research programmes. He was a member of a Technical Assessment Group advising the Australian Government on the clean up of the sites used for British nuclear weapon tests. Until his death, he was member of an expert panel involved in the Compensation Scheme for Radiation-linked Diseases, which is operated by the British nuclear industry to provide compensation to radiation workers who develop cancer, possibly due to their employment. Throughout all this, Hylton found time to exercise his interests in fell walking, cycling, gardening, and bird watching.

Hylton Smith was a kind man. Faced with a professional conflict, his instinct was to act as a conciliator rather than a participant. But he was also determined and the conflicting participants often found, with some surprise, that they had been influenced by his quiet interventions. In retrospect, I can see that his policy was to take 'all reasonably practicable steps' to get things right. Radiological protection has lost a valuable practitioner.

**John Dunster**