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From scientific evidence to radiation protection: A perspective of four decades

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Abstract

I have had the good fortune to have been involved in a wide spectrum of radiation protection activities - instrument development, dosimetry and biokinetics, environmental radioactivity and biological effects (these four, the "evidence" side of my title), and developments in practical radiological protection. In this short presentation, I shall highlight just some of these involvements. First will be the measurements of fallout and natural radioactivity that in 1959 started me in the business of radiological protection; second will be the R&D on tritium-related matters that occupied much of my hands-on research career through the 1960s and 1970s with AECL at Chalk River; and the final topic will be the studies involving the application of collective dose in radiological protection. The first two are examples of the R&D around the world that now supports the complex system of protection recommended by the ICRP. The third raises fundamental issues in the protection system, related to the assumption of linearity of response to dose, to individual variability and to the uncertainties in predictions of exposures and doses over long times. The current rapid advances in biological understanding of genetics and disease, while resolving some of these issues, may well lead to a more complex approach to protection, with a concomitant need for new directions in R&D.

Introduction

In the late 1950s, concern about radioactive fallout from nuclear weapons testing in the atmosphere was prompting research on methods for measuring radiation and radionuclides, on environmental transport of radionuclides, and on their biokinetics and health effects. There was also great interest in the development of atomic power plants that would, it was realised, lead to many more people being occupationally exposed. The incidence of leukaemia was recognized as being significantly increased in radiologists, as was that of bone tumours in groups contaminated with bone-seeking radioactive substances. There was insufficient information to estimate a threshold for these effects; it was thought that the permitted lifetime dose of the 1950s (7.5 Sv) would likely exceed it, particularly for some susceptible individuals. Genetic damage was seen as the main concern for populations and it was seen as highly desirable to keep the exposure of large populations at as low a level as practical. In 1958, the first report of UNSCEAR, whose formation in 1955 had been prompted by concerns about the effects of fallout from nuclear weapons, provided some early estimates of the doses from fallout and natural radionuclides in the environment [1]. In 1960 a committee of the UK Medical Research Council revised the fallout doses downward but continued to express misgivings about the behaviour and impact of fallout and noted the likely usefulness of learning more about the natural radiation environment [2].

Fallout and natural radioactivity

When I went to work as a graduate student in the Institute of Cancer Research in London in 1959, the search for fission products and fissile materials in the environment was bringing a much greater awareness of the ubiquity of natural radionuclides in the biosphere and of the high exposures that there could be from some materials and in some areas. Professor W.V. Mayneord's department in the Institute was taking a leading role in these explorations. One challenge was to distinguish the weapons-related plutonium-239 from the naturally-occurring alpha-emitter polonium-210, that was held up by the longer-lived lead-210 in most environmental materials. I was faced with either a lot of chemistry or with designing a spectrometer that could achieve the resolution needed with sources of very low concentrations of activity. With a physicist's natural disinclination to do any chemistry and following Kit Hill's lead in alpha spectrometry, I built a large-area, gridded ionization chamber with 50 keV resolution, sufficient to resolve these radionuclides [3], and was able to follow the 1962 spring peak in plutonium fallout [4]. With the results from measurements I made on human lungs (where I did have to do some chemistry), I was able to verify that the "standard man" model of the time for plutonium inhalation was reasonably consistent with observations.

The spectrometer design found its way around the world. Merril Eisenbud and Bob Drew of the Institute of Environmental Medicine at NYU applied it in their work in the high natural background area of Brazil. Also, I was astonished to find a replica of the design in Crocodile Dundee country, near Darwin, Australia, in 1988, in the uranium mining district.

In the early 1960s there was not much known about doses to soft tissues from natural radionuclides so, turning myself off eating mixed grills for life, I obtained and assayed human kidneys and other soft tissues to measure polonium-210 and lead-210. The results led to some early estimates of the biokinetics and doses to soft tissues from these radionuclides [5]. The values published in Nature were in the range of the many values later measured by others such as Richard Holtzman at the Argonne National Laboratory in the 1970s.

Now, nearly 40 years later, the dominant contribution that natural radioactivity and radiation makes to most people's exposures is well documented. The radiation doses received from natural background have provided – and I suspect always will – a helpful perspective in managing small, man-made, increments in radiation doses, given the continuing uncertainty in their biological consequences.

Tritium

Developments in instrumentation, in describing environmental processes, and in biokinetics and radionuclide metabolism continued apace around the world through the 1960s and 1970s, particularly in well-funded national nuclear research laboratories – of which Chalk River was one and where I arrived in 1963. These were the halcyon days of

R&D related to radiological protection. Semiconductor technology enabled great strides to be made in the portability and capabilities of instruments, and these improved measurement capabilities led to sounder protection practices as well as enabling many tracer experiments to be carried out in the environment, in animals and in people. The result was that by the end of the 1970s, there were extremely detailed biokinetic models available for internal dosimetry and there were local, regional and global models for estimating the environmental transport of radionuclides. Many types of radiation instruments that earlier had been only of the homemade variety had become commercially available.

At Chalk River through this period, prompted by Art Marko and George Cowper, my interest shifted from fallout and natural background radiation to tritium. We set out to define the hazard from tritiated water vapour (HTO) – and here I certainly depended on many of my colleagues who volunteered, not only to be subjected to exposures to HTO vapour in a small instrumented chamber, while near-naked or in a variety of protective garbs, but also to producing urine samples serially for the next few hours [6]. The volunteers can be pleased that the permeation properties of their skins are reflected in the ICRP model for tritium.

The skin is remarkably well behaved in its permeation properties. Fickian diffusion kinetics are closely followed, with a lag time through the skin of about 10 to 20 minutes. I obtained these estimates from the whole person exposures and also from a series of exposures of small areas of various volunteers' skin, where the lag time could be obtained from an analysis of the desorption curves after the end of an exposure [7]. One question was whether increased blood flow in the skin capillaries would enhance tritium intake. I sought to find this out on myself by exposing part of my arm to HTO vapour under conditions of high vaso-dilation, brought about pharmaceutically. I did not have the nerve to seek a volunteer for this. I can remember being incredibly beet-root red all over for some time afterwards, to the consternation of colleagues who saw me running between the lab and the washroom to provide urine samples. The answer, incidentally, was that it did not make any difference to the eventual intake.

We were able to get a measure of the protection provided by various non-ventilated suits in this exposure chamber. One suit we tried, a sandwich of a wet cotton coverall between two thin plastic layers, provided by far the highest protection. We had to use exposures to many thousands of DACs (or MPCs as they were then) for an hour to get a measurable intake [6]. I have always been disappointed that we never managed to exploit this idea.

Operating experience at NRU, at NPD, and then at Douglas Point NGS, brought home to us the need for portable and fixed tritium-in-air monitors that could work in gamma backgrounds and could discriminate against radioactive noble gases, and the need for tritium-in-water monitors for effluent and for bioassay. Of course, this is still a perceived need. Why it is so provides a useful lesson.

George Cowper, Doug Simpson and Bill Merritt in the late 1950s and early 1960s had tried ionization chambers and proportional counters for monitoring tritium in air [8, 9]. Through the next two decades Art Coveart, Norm Tepley, Mike Wood, Ric Surette, Bob McElroy and I designed and built a variety of devices – with varying degrees of success. Gamma-compensated ionization chambers have the advantage of simplicity and they can achieve moderate gamma compensation - and they have proved to be reliable, as indicated by some of the original models [10] still being in operation at Chalk River after more than 33 years. Noble gases, if present, mask the tritium signal and one solution, employed at Douglas Point to combat the argon-41 interference, was to have a second pair of ionization chambers that measured the sampled air after the HTO had been removed by dryers [11]. We also put this one on wheels as a transportable monitor [12]. In another design, HTO vapour was captured in a water stream and the tritium detected in a flow cell containing sheets of plastic scintillator [13]. A similar flow design was used for monitoring tritiated water streams directly in the early CANDU-6 stations [14]. We also tried semi-permeable membranes to separate HTO from noble gases [15] and also tried detection cells with a mixed flow of tritiated water and liquid scintillator [16]. Liquid scintillator detection was also the basis of the automatic urine analyzer that saw extended service in NPD but only a brief one in Pickering NGS [17,18].

The difficulty we had – and I think is still a difficulty – was in keeping fluid processing systems clean when these instruments were deployed in generating stations. Regular preventive maintenance was essential – to change filters, to clean sampling lines, to maintain insulators in ionization chambers, and to keep good optics in scintillation detectors. At Douglas Point, Ranjit Mohindra was a local champion for the ionization chamber-based design and ensured it was looked after. Similarly, the complex urine analyzer at NPD was well maintained by a succession of local champions, but at other stations we never managed to get preventative maintenance routines in place for any of the instruments and most devices in these places eventually plugged up and became in-operable.

My younger colleagues have continued with new detection methods, taking advantage of the computer chip technology of the last decade. Detector signal processing can now achieve far more than used to be possible and the greater control possibilities that this technology offers means that far more in the way of self-diagnosis and even self-cleaning is possible. Nevertheless, I believe that unless there are local champions for these necessarily-complicated instruments in nuclear power stations, future designs may not be that much more successful.

The most successful of the suite of designs we produced in the 1960s and 1970s has been the simplest one. Despite being pushed for more sensitivity and better gamma compensation than was provided by an early design of portable ionization chamber-based instrument [19], I decided we would aim for low cost and reliability with a no-frills, lightweight device, that would measure an MPC_a (as it was then) with reasonable gamma compensation. Art Coveart and I went on to develop the prototype of such an instrument [20] and, brought into commercial production by Scintrex, it continues to be a best-seller

as their Model 209. The unusual orange colour that it still has, by the way, is a carry over from the prototypes that we painted to match the battery pack that we used; one that was available from Black and Decker for its range of power tools.

Practical applications of ICRP recommendations; the collective dose problem

We have seen an enormous increase since the early 60s in our ability to measure our radiation environment, to estimate the distribution of doses in tissues from internal and external sources, and to predict the behaviour of radionuclides, both in the environment and in people. An important part of that ability has been an appreciation of the magnitude of uncertainty in predictions, gained particularly in the last decade through programs such as BIOMOVS (and more recently in the IAEA's BIOMASS) that we and the AECB strongly supported from its initiation, and in which Peter Barry and his colleagues at Chalk River have had leading rôles. I think it was something of a shock to some modellers to find out just how disparate predictions by reputable modellers could be, both from one another and from actual observations. The reappraisal of models and implicit assumptions has led, now, to much better definition of the envelopes of uncertainty in predictions.

The envelope of uncertainty between small increments of radiation dose and consequences to health remains frustratingly large though, despite the extremely detailed insights that we now have about cellular processes (and carcinogenesis in particular) and about the influence of genetics on disease. Radiation protection for decades has been predicated on the concept that, for practical purposes, an increment in dose, albeit with many modifying factors, is the appropriate quantity to estimate as a measure of impact on health. There have always been caveats on this and it is the ignoring or misunderstanding of these caveats that has led often to misapplication of protection principles and also to unjustified criticism of the principles of protection enunciated by the ICRP.

In 1962, UNSCEAR provided estimates of the average dose to populations from various sources, most notably nuclear weapons fallout that was the then big concern as noted above [21]. It was very cautious in doing this, recognizing that if average dose was to be a measure of comparative risk from sources, there was an implicit assumption of linearity between dose and effect on health. UNSCEAR argued that there was good evidence for linearity in the relationship for genetic effects (that is, effects that would be inherited), which at that time were of greater concern than were somatic effects for which it acknowledged linearity was much more uncertain. In its 1972 report, UNSCEAR introduced the quantity "man-rad" as a measure of comparative risk, although it stressed that it did not intend to imply that "man-rad" was a measure of total harm because of non-linearities in response, non-uniformities in exposures, time distribution of irradiation and radiation quality [22]. By 1977, the ICRP felt there was enough evidence from accumulating epidemiological data on humans to justify, for protection purposes, continuing the assumption of linearity between incremental dose and somatic effects, which were, by then, seen as the more important. It launched a more comprehensive system of radiological protection with its Publication #26 [23]. By introducing tissue

weighting factors and the concept of detriment, ICRP formally set collective dose as a measure of impact on public health. This led to many attempts to apply collective dose in optimizing protection and, unfortunately, to many misapplications.

While it was realised that the collective dose associated with long-lived, globally dispersed radionuclides could be large, it was not evident how practical it would be to employ this quantity in cost-benefit or other types of formal analyses in the management of such radionuclides. I became involved with a group convened by the Nuclear Energy Agency (of OECD) to examine the implications of global collective doses in the management of tritium, carbon-14, krypton-85 and iodine-129 arising from the nuclear fuel cycle, which reported in 1980 [24], and with another one concerned with wastes from uranium mining and milling, which reported in 1984 [25,26]. These studies made very evident the large uncertainties involved in global and regional modelling and in the long-term performance and costs of retention technologies, and the difficulties of dealing with doses far into the future. The overall conclusion, written in the latter report in the circumspect language of international agencies, was that "the cost-benefit approach to optimising radiation protection can only provide limited inputs to decisions on tailing management." Note that this was irrespective of any inappropriateness of collective dose as a measure of health detriment. The Canadian Radiation Protection Association's workshop on collective dose in 1985 came to much the same conclusion on the difficulties of applying collective dose [27].

There is now a much better understanding of the application of the principle of optimisation to practices (for example, in controlling effluents from a nuclear power station) and the rôle that collective dose can play in it (some may disagree), reflected by the more cautious wording in ICRP 60 [28]. There remain difficulties and misunderstanding, though, when it comes to what the ICRP calls interventions – for example managing the evacuation from, remediation of, or return to a contaminated area. Dose limits intended for protection against new practices are inappropriate in these circumstances, optimization being the recommended approach, but they are often applied and lead to unnecessary worry – and inappropriate decisions. Why is there a problem?

One reason for the problem is the tension between basic ethical approaches – one that puts the individual well-being first and one that puts societal interests first, the so-called utilitarian ethic. This was apparent in the group I chaired for ICRP on protection against radon and progeny in homes and at work (excluding uranium mines). We recommended decisions on remediation in homes or workplaces should be based on levels of individual exposure despite this not necessarily being the most cost-effective way to reduce collective exposures. It was a pragmatic recommendation – if there were high exposures, then you fixed up the home or the workplace; if the exposures were not above a recommended action level, then you did not worry about them. This was very much an "individual-related" approach and was incoroporated into the broader ICRP recommendations on radon-222 [29].

The confusion in dealing with interventions and the difficulties associated with the utilitarian approach, has led the ICRP to ask whether there may be a better way to ensure protection of the public; one that puts greater emphasis on the individual and perhaps reflects more the totality of an individual's exposure from radiation. I am currently chairing a working party on this topic. The intention here is not to bring about a change in the level of protection currently afforded by the present system; rather, it is to provide a way of protecting against exposures to radiation that is more understandable and better accepted by those involved. It is not directly connected to the current arguments over the appropriateness of linearity as a model for radiation protection purposes. Nevertheless, any de-emphasis of the application of collective dose that may come about in such an approach will reduce the temptation to carry out nonsensical estimations of global health effects over millennia.

A final comment

The next decade is likely to produce a leap in our understanding of the genetic control of biological processes and of disease, and of the spectrum of perturbations in this control that radiation damage can produce. This is because of the unprecedented power of the molecular biological tools that are now available. It is unlikely that there will be found any single simple relationship between a measure of initial damage such as dose and an overall effect on health – beneficial or deleterious. Whether a practical model for protection purposes can be derived that more accurately reflects the actual response of any individual or of a hypothetical composite individual in a population than does the current linear model will be a continuing question. A linear model may remain the best compromise as Norman Gentner and I have suggested elsewhere [30]. We need to be clear that radiation measurements, dosimetry, and environmental modelling would become much more complicated with a departure from an assumption of linearity of dose and response for protection purposes. The instruments and models would need to be much more clever than the ones with which I have been involved in my near four decades. Operational protection, too, would be much more complicated.

Whatever the outcome, it promises to be an exciting time. I hope that my former colleagues at Chalk River will be able to continue to contribute to these advances. We have, there, a fine animal and irradiation facility in which to ask many of the pertinent radiobiological questions, we have the expertise in dosimetry and instrumentation to meet the measurement challenges that the new biology is likely to bring, and we have the environmental expertise, based on decades of field research, to continue to develop and establish the credibility of the more complex environmental models that will be needed over the next decade.

I acknowledge my indebtedness to all my former colleagues through these four decades. I retain my enthusiasm in the R&D that we undertook and I feel proud of our accomplishments. I hope that those still in R&D will continue to enjoy the support of the industry so that we can be assured of a sound base for radiological protection in the Canadian nuclear industry.

References

[1] Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, General Assembly, A/3838, 13th Session, Suppl. No. 17 (1958)

[2] The Hazards to Man of Nuclear and Allied Radiations, A Second Report to the Medical Research Council, Her Majesty's Stationery Office, London (1960)

[3] High Resolution Alpha Particle Spectroscopy at Very Low Specific Activities, R.V. Osborne & C.R. Hill, Nucl. Instr. & Methods 29: 101-106 (1964)

[4] Plutonium-239 and other Nuclides in Ground-level Air and Human Lungs during Spring 1962, R.V. Osborne, Nature 199 (4889): 143-146 (1963)

[5] Lead-210 and Polonium-210 in Human Tissues, R.V. Osborne, Nature 199 (4980): 295 (1963)

[6] Absorption of Tritiated Water Vapour by People, R.V. Osborne, Health Phys. 12: 1527-1537 (1966) [AECL-2469]

[7] Diffusion Kinetics of Tritiated Water through Human Skin, R.V. Osborne, Proc. IAEA/OECD Int. Symp. on the Behaviour of Tritium in the Environment, San Francisco, USA, 1978 October 16-20: 509-520, IAEA, Vienna (1979) [AECL-6618]

[8] System for Counting Tritium as Water Vapour, W.F. Merritt, Anal. Chem. 30: 1745-1747 (1958)

[9] A Monitor for Airborne Tritium, G. Cowper & S.D. Simpson, AECL-1049 (1960)

[10] The Detection of Tritium in Air with Ionization Chambers, R.V. Osborne & G. Cowper, Atomic Energy Of Canada Limited, Report AECL-2604 (1966)

[11] Monitoring Reactor Effluents for Tritium: Problems and Possibilities, R.V. Osborne, Proc. Tritium Symposium (Eds. A.A. Moghissi & M.W. Carter), Las Vegas, Nevada, 1971 August 30-September 2: 496-511 (1971) [AECL-4054]

[12] A Transportable Monitor for Tritiated Water Vapour, R.V. Osborne & A.S. Coveart, Proc. IVth IRPA Congress, Paris, France, 1977 April 24-30: 805-808 (1977) [AECL-6097]

[13] Central Tritium Monitor for CANDU Nuclear Power Stations, R.V. Osborne, IEEE Trans. on Nucl. Sci. NS-22(1): 676-680 (1975) [AECL-5098]

[14] Detector for Tritium in Water, R.V. Osborne, Nucl. Instr. & Methods 77: 170-172 (1970) [AECL-3433]

[15] Application of Membranes to Monitoring for Tritiated Water Vapour, R.V. Osborne & R.G.C. McElroy, Proc. Int. Symp. on the Management of Gaseous Wastes from Nuclear Facilities, IAEA, Vienna, Austria, 1980 February 18-22: 393-407 (1980) [AECL-7263]

[16] Developments in Tritium Monitoring, R.G.C. McElroy & R.V. Osborne, Proc. American Nuclear Society, Meeting on Tritium Technology in Fission, Fusion and Isotopic Applications, Dayton, Ohio, 1980 April 29-May 1: 169-174 (1980)

[17] Automatic Urinalyser for Tritium, AEP5216, R.V. Osborne, Atomic Energy of Canada Limited, Report AECL-2702 (1968)

[18] Performance of an Automatic Analyser for Tritium in Urine, R.V. Osborne, Health Phys. 18: 87-89 (1970) [AECL-3403]

[19] A Portable Monitor for Tritium in Air, R.V. Osborne & A.S. Coveart, Nucl. Instr. & Methods 106: 181-187 (1973) [AECL-4320]

[20] A Personal Tritium Monitor, R.V. Osborne & A.S. Coveart, Proc. Vth IRPA Congress, Jerusalem, Isreal, 1980 March 9-14, Vol. 2: 303-306 (1980) [AECL-6730]

[21] Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations, General Assembly, A/5216, 17th Session, Suppl. No. 16 (1962)

[22] Ionizing Radiation: Levels and Effects, Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly, Volume 1: Levels , A/8725, 27th Session, Suppl. No. 25 (1972)

[23] Recommendations of the International Commission on Radiological Protection, ICRP Publication 26, Annals of the ICRP 1 (3), Pergamon Press (1977)

[24] Radiological Significance and Management of ^{3}H, ^{14}C, ^{85}Kr and ^{129}I Arising from the Nuclear Fuel Cycle, Report by a Group of Experts, Organization for Economic Cooperation and Development, Nuclear Energy Agency, Paris (1980)

[25] The Long-Term Radiological Aspects of Management of Wastes from Uranium Mining and Milling, Report by a Group of Experts, Organization for Economic Cooperation and Development, Nuclear Energy Agency, Paris (1984)

[26] Long-Term Management of Uranium Mill Tailings: Results of the OECD/NEA Study, J-P. Olivier, R.V. Osborne, & P.J. Rafferty, Proc. Int. Conf. on Radioactive Waste Management, IAEA, Vienna, Austria: 121-133 (1984) [AECL-8499]

[27] CRPA Workshop on Radioactive Waste Management Criteria, Ottawa, 1985 February-March 01, Canadian Radiation Protection Association (1985)

[28] 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Annals of the ICRP 21 (1-3), Pergamon Press (1991)

[29] Protection against Radon-222 at Home and at Work, ICRP Publication 65, Annals of the ICRP 23 (2), Pergamon Press (1993)

[30] Linear versus Non-Linear: A Perspective from Health Physics and Radiobiology, N.E. Gentner and R.V. Osborne, Proc. 11th Pacific Basin Nuclear Conference, Banff, Canada, 1998 May 3-7: CD-ROM, CNA/CNS (1998)