RADON DAUGHTER PERSONAL DOSIMETRY AND EXPOSURE ESTIMATION FOR URANIUM MINERS

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Presented to the meeting concerned with an R & D review and state-of-the-art discussion on personal dosimetry and exposure estimation (for radon daughters and gamma radiation) for uranium miners.

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1. OVERVIEW

The aim of radiation protection for workers in uranium mines and for other Atomic Radiation Workers can be summarized in a few words, namely, that exposure should be kept "as low as reasonably achievable, economic and social factors taken into account" (ALARA). This is a statement advocated by the International Commission on Radiological Protection and one which can only be endorsed and adopted by all those involved in uranium mining: the industry, the workers and their union, and government agencies at both the federal and provincial levels. It is the striving to achieve this lofty principle that leads us to the questions: how can this principle be achieved and how can a measuring and reporting system be developed that will be accurate, not only for the regulatory bodies concerned, but also and more importantly for the workers who must be confident that the measuring and reporting system be a true representation of their exposure to internal and external radiation.

2. BACKGROUND ON PERSONAL DOSIMETRY FOR RADON DAUGHTERS

At this point and before reviewing some of the history of personal radon daughter dosimetry in Canada, let us give some of the factors which influence the accuracy of radon daughter measurements in personal dosimeters. Each of these factors has an uncertainty associated with it. The convolution of these uncertainties gives rise to the total uncertainty. It is the end result of all our R & D efforts to minimize these uncertainties such that each measurement of personal exposure is the most accurate attainable.

Let me list some of these factors:

1. volume of air pumped
2. effects of plate-out
3. efficiency and self-absorption of filters
4. pump performance
5. sensitivity of filter or detector to humidity, and water or dust loading
6. mechanical reliability and integrity of pumps, valves, turbines, filters, detectors and housings
7. electrical reliability of motors, batteries
8. sensitivity to orientation, positioning
9. efficiency and geometry of the detector in relation to the source.
10. reliability of processing and read-out mechanism for each detector type
11. approximation of air sampled to breathing zone of wearer
12. knowledge of what radionuclide(s) is (are) being sampled (for example radon daughters and/or thoron daughters and/or other radioactive substances).
13. interference of gamma radiation or other types of "background" (in some devices).

These are the major uncertainties in exposure estimation by personal dosimetry, but by no means all of them.

Personal dosimetry for radon daughter exposure estimation is but one means to achieve the desired end. Personal dosimetry is not a panacea but is fraught with difficulties if measurements of acceptable accuracy are to be achieved. This is the reason that vigorous efforts by the AECB and the Department of Energy, Mines and Resources are being put forward to fund private research and development in order to increase our understanding not only of the fundamentals of radon daughter attachment and the general behaviour of these daughters in mine atmospheres, but also of what the personal dosimeter is actually recording. In other words, does the dosimeter record the amount (and quality) of radon daughters which a miner, in fact, breathes or
is the exposure so determined merely **proportional** to this amount? How do the exposure estimates from personal dosimeters agree with those obtained from conventional grab-sampling techniques? Which, if any, is the "fundamental" estimate? Do all investigators keep in mind that different radioactive species are being measured by the different techniques?

At this point there are more questions posed than answers given.

3. **HISTORY OF PERSONAL DOSIMETRY IN CANADA**

For a few minutes let us go back over the history of personal dosimetry that bears directly on our research and development efforts in Canada.

The first serious attempt to measure radon daughters in Canada using an integrating device was in 1975 when Mr. A.C. George of the former Health and Safety Laboratory, (of the old U.S. Atomic Energy Commission) was invited to make measurements in one of the mines in Elliot Lake by the Ontario Ministry of Natural Resources. The so-called MOD dosimeter used in these mine trials was indeed a modification of earlier designs developed independently at Colorado State University and at the Massachusetts Institute of Technology. The detection principle of the sensitive chip was thermoluminescent dosimetry or TLD. An improved pump with uniform flow rate and a sturdier outer case were the features of the MOD dosimeter that helped assure its improved performance in the harshness of mine atmospheres. Despite the improvements, however, the outer case proved to be penetrable by dirt which in time rendered the pump unreliable. Moreover, in this early version of the MOD dosimeter, no compensation was made for gamma radiation to which the TLD chips were sensitive.
Aside from the difficulties just mentioned, the MOD working level dosimeters showed good agreement, generally, with a series of grab-samples using the Kusnetz method. As expected, the agreement was poorest at the lowest concentrations of radon daughters. Still, this first mine trial of a personal dosimeter in Canada was a milestone of sorts.

In the summer of 1976, the AECB engaged Mr. G.R. Yourt on contract to extend the initial mine test program carried out the previous year by Mr. George, using eleven of the same type of MOD dosimeters. However, of the eleven MOD dosimeters only three were used at any one time and in the end, data was acquired for only six of these eleven. In addition, two pumps were constructed by H & H Custom Work, of Toronto, to which MOD dosimeter heads could be attached. Finally, one pump and dosimeter assembly was purchased from duPont for this mine trial.

The two principal objectives of the 1976 mine trial were:

(1) To obtain, if possible, a closer correlation between frequent conventional radon daughter measurements (using the Kusnetz method) and those obtained from the MOD and the other personal integrating dosimeters.

(2) To develop an arrangement for wearing a personal dosimeter that would be acceptable to the miner and would also be reliable in terms of appropriately sampling his breathing zone.

Comparing the dosimeter readings worn by the miner with the grab-samples taken by an accompanying technologist, one could only conclude that the agreement was inconclusive. About half of the compared readings were in reasonable agreement while the other half differed significantly. No single or simple explanation was adequate to explain these discrepancies.
On the other hand a number of the MOD dosimeters suffered from electrical and/or mechanical problems. Of those MOD dosimeters which endured the testing program, the pump performance was acceptable. Anyone familiar with personal dosimeters will recognize that maintaining a constant air flow is one of the essential factors in obtaining a reliable measure of the working level. Both of the pumps manufactured by H & H Custom Work displayed acceptable pump performance. The single du Pont pump suffered from an electronic malfunction and was not used in the actual mine tests.

Encouraged by the initial performance of the H & H personal dosimeter the AECB engaged Mr. Yourt once again in the summer of 1977 to carry out a more intensive mine trial with the lighter-weight H & H pumps. The du Pont pump was repaired, as well, and incorporated into this trial. Once again the main objective of this contract was to examine whether a reliable correlation between dosimeter readings and frequent conventional samples could be achieved.

The main conclusion of this contract was that correlation between readings from these radon daughter dosimeters (using Li F chips) and frequent conventional grab-sampling (using the Kusnetz method) and time weighting was fair at high radon daughter concentrations but poor at low concentrations. In similar measurements using the more sensitive Ca F₂ chips, dosimeter readings were substantially lower than those indicated by the grab-sampling technique.

The reasons for the poor correlation are still not clear. It was acknowledged that difficulties existed at the time in the calibration, processing and interpretation of TLD chips when applied to radon daughter dosimetry. The quantitative significance of plate-out of radon daughters, the effects of moisture and other aerosols and the contribution of thoron daughters were not determined. (Efforts to try to resolve some of these uncertainties are now underway).
Despite the lack of conclusive findings referred to above, there was some comfort to be found in the performance of the two H & H pumps and the du Pont pump. Each of the pumps operated as required, maintenance free throughout the test period, the H & H pumps for five months and the du Pont for three months. Moreover, the airflow records showed that the volume of air pumped remained acceptably constant throughout the daily shifts. The variation was generally only a few percent from start to finish as measured on a daily basis.

At this time we should pause in the historical review of personal dosimeters based on the TLD principle to look at the concurrent development of another type, the so-called track-etch film device manufactured by CEA, the Atomic Energy Commission of France. In 1976 the AECB purchased five of the turbine-driven dosimeters and, early in 1977, entered into a contract with Professor C.R. Phillips at the University of Toronto. The project had the joint sponsorship of the Department of Energy, Mines and Resources (financial) and the AECB (scientific). The objectives of this contract were the evaluation (in the laboratory and in a series of mine trials) of the five personal dosimeters. The advantages of the CEA device in measuring the working level are:

1. there is essentially no background
2. no gamma interference
3. no temperature or humidity sensitivity
4. the working level is computed directly from the number of alpha particles from Ra A and Ra C'.
5. alpha-particle energy discrimination is achieved through appropriate absorption and etching conditions.
Details of the laboratory and mine trials of the CEA dosimeter in the Canadian experience will be given later by Prof. Phillips in his presentation. Mme. Chapuis, of the CEA, will, in addition, inform us of the progress which has been achieved in evaluations carried out in France.

The qualified success of the earlier dosimeter programs (the H & H TLD and the CEA track-etch) with which the AECB has been involved, has led to the obvious need to conduct a more intensive investigation of both dosimeter types in order to acquire more instrument-months of experience. Such an intercomparison is now underway involving about ten H & H Custom Work personal dosimeters and about twenty modified CEA track-etch personal dosimeters. Once again the contract is with Professor Phillips at the University of Toronto.

A final report on this contract is expected by the end of the year.

4. **FUTURE DEVELOPMENTS**

What are the future possibilities and directions with respect to personal dosimetry for radon daughters in Canada?

As a result of our previous and ongoing R & D efforts, one of the following may emerge:

1. Either the H & H Custom Work or CEA track-etch personal dosimeter will outperform the others in terms of reliability, endurance, accuracy, handling, readout and in terms of other key factors. If, in addition, AECB performance criteria are met, adoption for use in Canada will likely follow for the outstanding performer.

2. Both types of personal dosimeters will operate, although neither may perform outstandingly well compared to the other.
In this case modification and more testing may be indicated in order to meet AECB performance criteria.

3. Neither type will perform well in which case modification or abandonment of both may be in order.

This short list of possibilities is not exhaustive but merely indicative of future scenarios. Certainly other possibilities exist.

The future directions become even more obscure as new questions and problems arise out of our current efforts. The more we look into the fundamentals of radon daughter dosimetry, the more we worry about the validity of our previous assumptions. For example,

1. How well known are the uncertainties connected with TLD readers and readout systems when applied to alpha particle dosimetry?

2. How do we handle the situation when the alpha-attributable dose from a TLD chip is the small difference between the total \((\alpha + \gamma)\) chip and the compensating \((\gamma)\) chip?

3. What are the plate-out effects for each dosimeter and how do they vary as functions of geometry and positioning of dosimeter head design, flow rates, and so on?

4. What role do the size and activity distributions of aerosols play and what are the parameters affecting the size of the unattached fraction of radon daughters?

5. How important are the effects of the unattached radon daughters?

6. How do we account properly for thoron daughters? Do we make use of the energy discrimination of a CEA-type dosimeter head or do we design and build an exclusive thoron daughter personal dosimeter?

7. What overall uncertainty do we accept for radon daughter exposure estimation based on personal dosimetry? Should the allowable uncertainty be smaller because personal dosimetry is a "better" means of measurement than grab-sampling?
The list of crucial and vexing questions goes on and on. Many of the questions can only be addressed when the answers to others have been determined so that in many cases we can only treat problems consecutively rather than concurrently. At the same time, unlimited funds for R & D activities do not exist at the AECB or elsewhere, and priorities must always be developed as to the best use of such funds. We and other government agencies want to be responsive, as well, to new ideas and to new devices to better accomplish traditional ends.

The entry of new types of personal dosimeters need not negate the work that has gone before toward developing older or more conventional types. Indeed, we must encourage the manufacturers, the universities, private contractors, government agencies, the mining companies and the unions to work together to encourage innovation, to improve accuracy, to seek even greater reliability in the estimation of radon daughter exposures so that in the end no worker will be exposed beyond regulatory limits.