

HEALTH PROTECTION AGENCY

ASSESSMENT OF DOSES FROM MEASUREMENTS OF POLONIUM-210 IN URINE

INTRODUCTION

This note provides information on the methods that have been used by the Health Protection Agency (HPA) to assess radiation doses to individuals who have provided the organisation with urine samples for analysis. This has followed the recent poisoning incident in London in which Mr Litvinenko had an intake of polonium-210 (^{210}Po), as has been widely reported in the media. The exact circumstances of his exposure are not yet clear but ^{210}Po contamination associated with it has been found in a number of locations as well as in aircraft and other vehicles. Some contamination has also been found in other countries. This event resulted in HPA requesting urine samples from those potentially at risk of intakes of ^{210}Po for dose assessment purposes.

The measurement of a urine sample provides the amount of ^{210}Po excreted in the urine per day. From this, well-established methods are used to calculate the amount of ^{210}Po that originally entered the body, and hence the resulting radiation dose. The dose that is calculated is normally the committed effective dose. This is the sum of the doses to the organs and tissues of the body, weighted for their sensitivity to radiation and also weighted for the *effectiveness* of the radiations involved. Because radionuclides taken into the body can result in radiation exposure for many weeks, months or even years, depending upon their physical and biological half-lives, the dose is normally calculated over 50 years after the intake, hence the term *committed* effective dose. (Further details are given in the Annex). The International Commission on Radiological Protection (ICRP) developed this definition of dose, which is used around the world. The committed effective dose calculated from an intake of ^{210}Po provides a measure of the risk associated with the intake.

Many hundreds of samples have had to be analysed, and results were required promptly, for reassurance purposes and in case follow-up measures were needed. Account also had to be taken of the fact that ^{210}Po occurs naturally in the diet, and so people normally excrete low levels of it in their urine. A categorisation system was therefore developed by HPA by which rapid assessments would be made for those individuals whose urine measurements indicated that their intakes and doses were negligible, while more comprehensive "special" assessments would be made for those individuals likely to have received greater intakes and doses. The main consideration within the special assessments is the route of intake. The radiation dose resulting from an intake of ^{210}Po in a relatively insoluble form, as assumed here, is substantially higher for intakes by inhalation than by ingestion (see e.g. ICRP, 1996). Similarly, the dose assessed retrospectively from a urine sample is considerably greater if the intake is assumed to be by inhalation of ^{210}Po than by ingestion.

The following notes summarise the dose assessment procedure used by the HPA in this incident. It also explains the rationale adopted for presenting the results to the individuals

who provided samples. An Annex gives a more detailed explanation of how effective doses are assessed from measurements of ^{210}Po in urine.

DOSE ASSESSMENT CATEGORIES

The HPA has based the assessment procedure on three Categories. Results are assigned to Category 1 when the excretion of ^{210}Po in urine is less than a "Reporting Level" of 30 mBq per day. HPA has judged this level of 30 mBq per day to be one at which there will certainly be some activity above the natural background ^{210}Po level, which published data suggest falls in the range of about 5-15 mBq per day. For urine ^{210}Po concentrations at or below this Reporting Level HPA does not undertake any dose assessment. Results are assigned to Category 2 when activities of ^{210}Po in urine greater than 30 mBq per day are found. An assessment is then undertaken on the assumption that all of the intake has been by inhalation. This will overestimate the dose if the intake was actually by ingestion, or partly by inhalation and partly by ingestion. If this dose assessment gives a dose of <1 millisievert (mSv), the assessed dose is reported as "<1 mSv". If the dose is 1 mSv or higher it is treated as Category 3 and a special dose assessment is carried out. For this assessment a judgement needs to be made about the potential for exposure of the individual by both the inhalation and ingestion routes, using information obtained from each individual when they are invited to give the urine sample.

PRESENTATION OF RESULTS OF THE DOSE ASSESSMENT TO MONITORED INDIVIDUALS

Considerable thought has had to be given on presentation of the information on assessed doses to the individuals who provided urine samples.

For those in Categories 1 and 2, for which assessed doses are less than 1 mSv, advice is given that doses are of no concern. This is equivalent to the annual dose limit recommended by ICRP in Publication 60 for controlled routine exposures of members of the public (ICRP, 1991) and can apply to doses from intakes over a number of years. This dose limit does not apply in the case of the London poisoning incident as the presence of polonium-210 was as a result of a malevolent act and not as a result of a controlled situation. Nevertheless it does provide a perspective on this level of dose. A dose of 1 mSv is also about half the dose received from natural background radiation by most people each year. Natural background radiation includes contributions from naturally occurring radionuclides in soils and air as well as cosmic radiation – natural polonium-210 is a small component of the total. Furthermore, the ^{210}Po exposure is considered to be a "one off" incident, and so the risk is considerably lower than that from exposure at 1 mSv every year.

For those individuals in Category 3 it was decided to consider those whose doses are assessed to be below 6 mSv separately from those few individuals whose assessed doses are equal to or greater than 6 mSv.

For doses of below 6 mSv (Category 3a) HPA has calculated, from the risk factors given by ICRP in Publication 60 (1991), that any increase in the risk of cancer, which is the main concern, will be less than about 0.03%. This compares with the risk of dying of fatal cancer of about 25% for the population as a whole. It is considered that this is a very small increase and therefore HPA can advise people that the dose received is of no concern. The risk factors in the new ICRP Recommendations, to be published later this year, give a similar result.

For those with doses equal to or greater than 6 mSv (Category 3b) the results are reported as being of "some concern" and further follow up is advised. In setting this level of ≥ 6 mSv for reporting, the view has been taken that the exposure must be considered as a "one off" incident and it was necessary to determine a level of dose above which further medical surveillance was indicated. Guidance in the choice of this level was obtained from UK national guidance on the radiological protection of workers. In the UK, control of exposures to radiation is regulated by the Ionising Radiations Regulations (IRR 1999).

HPA took into account the fact that many of the higher exposed individuals were likely to be workers. It was also noted that, where a worker is routinely exposed to ionising radiation, medical surveillance would be required where exposures exceed 3/10th the dose limit of 20 mSv in a year (i.e. 6 mSv). It was therefore judged that this level of dose could provide a valuable guide to handling the unique circumstances of the ^{210}Po incident in London.

For those individuals with doses ≥ 6 mSv (Category 3b) it was, therefore, decided that this should prompt further surveillance and measurements. HPA is giving individual advice on the consequences of such doses to those so exposed. The approach adopted is to counsel those with assessed doses ≥ 6 mSv and to obtain follow up urine samples for analysis at 3-monthly intervals for as long as worthwhile measurements can be obtained. This will act as reassurance that the ^{210}Po is decreasing and also allow a more accurate dose assessment to be made from the individual's retention function, although it will not provide any more information on the route(s) of intake.

HPA has taken the view that this proportionate approach to reporting the dose assessment balances the concern not to cause quite unnecessary anxiety at low levels of exposure with the need to properly inform those few people with higher assessed doses.

CONCLUSIONS

Handling the consequences of the London poisoning has presented enormous challenges to HPA, including dealing with large numbers of people who could have been exposed to ^{210}Po . HPA developed a rational approach to the dose assessment procedure and to communicating the information to people it identified as needing urine measurements.

REFERENCES

International Commission on Radiological Protection (1996). ICRP Publication 72. Age-dependent Doses to Members of the Public from Intakes of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients. *Annals of the ICRP*, **26**(1).

International Commission on Radiological Protection (1991). 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. *Annals of the ICRP*, **21**(1-3).

IRR 99. Working with Ionising Radiation. Ionising Radiations Regulations 1999. Approved Code of Practice and Guidance. Health and Safety Commission, 2000. ISBN 0 7176 1746 7.

ANNEX

POLONIUM-210 IN URINE MEASUREMENTS AND THEIR INTERPRETATION BY DOSE ASSESSMENT

Direct assessment of the exposure of individuals that may have occurred as a result of the polonium-210 (^{210}Po) poisoning incident in London is reasonably straightforward through measurement of its excretion in urine.

Part of HPA's overall public health response strategy has been to try to obtain urine samples from those who have the greatest potential for exposure from the incident, based on their being in particular locations at particular times. This is important:

- to confirm whether or not the individuals who provided the urine samples had intakes of concern with regard to possible health effects;
- to provide information about the potential exposure of other people who were in a similar exposure situation; and
- to provide reassurance to people with lower potential exposures (typically being at a contaminated location, but at a later time).

MEASUREMENTS OF ^{210}Po IN URINE

Measurement of a 24-hour urine sample provides the amount of ^{210}Po present in it. The method adopted at HPA for measuring ^{210}Po in urine samples has been described in an accompanying note on the web site:

http://www.hpa.org.uk/polonium/measurement_Po210_in_urine.pdf.

Amounts of radioactivity are usually measured in becquerels (symbol Bq).

One Bq of ^{210}Po produces, on average, one radioactive decay per second. However, radioactive decay is a random process, so if 1 Bq is measured for 100 seconds, the number of decays measured would probably be between about 80 and 120. If the measurement was repeated many times, the average result would be close to 100.

The measurement methods that HPA and other laboratories use can measure very small amounts of ^{210}Po . Most results obtained as a result of the London incident are much less than 1 Bq, and so it is more convenient to report them as millibecquerels (mBq; 1 Bq = 1000 mBq). The methods of analysis used are capable of measuring natural excretion rates of ^{210}Po from intakes in diet and tobacco, which are typically in the range 5-15 mBq per day.

The mass of polonium-210 measured in a urine sample through its activity is *extremely* small. The activity of 1 gram of ^{210}Po is 1.7×10^{14} Bq (170,000 Gigabecquerels GBq; 1 GBq = 1,000,000,000 Bq)¹. Hence the mass of 1 Bq of ^{210}Po is 5.9×10^{-15} g, (0.0059 picogram, pg; 1 gram = 1,000,000,000,000 pg) and the mass of 10 mBq, the amount typically excreted naturally per day, is about 1×10^{-16} g (0.0001 pg).

Historically, radioactivity was measured in curies (Ci), and these units are still used by some organisations, especially in the USA. The curie was based on the activity of 1 gram of radium, and is a very large amount of radioactivity: 1 Ci = 37 GBq. Hence, if these

¹ The number of atoms in 1 gram-molecular weight of any compound is given by Avogadro's number: $N_A = 6.023 \times 10^{23}$. Thus for pure ^{210}Po , 210 grams = 6.023×10^{23} atoms, and 1 gram = 2.9×10^{21} atoms. The decay rate (the probability that an atom will decay during 1 second), $\lambda = \ln(2)/t_{1/2}$, where $t_{1/2}$ is the radioactive half-life = 138 days = $138 \times 24 \times 3600$ s = 1.19×10^7 s. Hence $\lambda = \ln(2)/t_{1/2} = 5.8 \times 10^{-8} \text{ s}^{-1}$ and the number of decays per second from 1 gram is $(2.9 \times 10^{21}) \times (5.8 \times 10^{-8}) = 1.7 \times 10^{14}$.

units are used, the ^{210}Po in a urine sample will probably be reported in picocuries (pCi):
 1 pCi = 37 mBq.

DOSE ASSESSMENT

There is the potential for people to be irradiated as a result of intakes of a wide range of radionuclides in many chemical forms. In only a few cases, such as inhalation of radon and its radioactive decay products, do epidemiological studies enable a direct assessment to be made of the risks to people from exposure. For all other cases (e.g. caesium-137, plutonium-239, uranium-235, polonium-210, etc.) “dose assessment” provides a systematic method for assessing the hazards based on calculated radiation doses to tissues. The dose assessment methods generally adopted for use around the world are those developed by the ICRP over the last half-century or so. Except at very high doses the hazards of concern are mainly radiation-induced cancers.

Stages in assessment process

For an individual dose assessment based on one or more measurements, the process consists of two basic stages, (i) assessment of the intake (ii) assessment of the dose resulting from that intake. The latter involves several steps, and so the process may be summarised as follows:

- From the measurement (in this case the daily excretion of ^{210}Po in urine), calculate the amount of ^{210}Po activity that entered the body by inhalation and/or ingestion at the assumed time of intake (see below).
- For that intake, calculate the amount of ^{210}Po in each body tissue as a function of time. The amounts generally decrease with time because of both radioactive decay (physical half-life is 138 days) and biological excretion (biological half-life in the body is 50 days). In the case of ^{210}Po the amount in the body reduces by half in a few weeks, and there will be very little left after about 1 year.
- Calculate the number of radioactive decays that take place in each tissue.
- Calculate the radiation “absorbed dose” to each tissue, i.e., the energy (in the form of ionising radiation) deposited per unit mass of tissue as a result of the decays. The absorbed dose resulting from the intake of a radionuclide is known as a “committed dose”, because although it is received over a period of time after intake, the person is “committed” to receiving it at the time of intake. By convention, committed doses are usually calculated for 50 years after intake. However, in the case of ^{210}Po , because the physical and biological half-lives are short, nearly all the committed dose is received within a few months of the intake.
- Calculate the committed “equivalent dose” to each tissue. Some forms of radiation are known to be more effective at inducing cancers than others for the same absorbed dose. To take account of this, the absorbed dose from alpha particle irradiation (as in the case of ^{210}Po) is multiplied by a “radiation weighting factor” of 20 to give an equivalent dose, i.e., the dose of x-rays that would give essentially the same effect (risk). The equivalent dose is measured in sievert, symbol Sv.
- Calculate the committed “effective dose”: an estimate of the uniform whole-body dose of x-rays that would give the same overall effect on the person as the various tissue doses from the ^{210}Po (i.e., the same cancer risk). Some tissues (e.g. lungs, stomach) are known to be more sensitive to radiation-induced cancer than others (e.g., muscle, kidney) for the same equivalent dose. To take account of this, the “equivalent dose” to each tissue is multiplied by a “tissue weighting factor”, and the results summed to give the effective dose. The effective dose is also measured in sievert, symbol Sv, but in practice the millisievert (mSv; 1000 mSv = 1 Sv) is more often used.

The effective dose thus gives a broad estimate of the risk of a fatal cancer, which is typically taken to be about 0.005% per millisievert, and to increase/decrease in proportion to dose. This means that if 20,000 people each received an additional effective dose of

1 mSv a single additional radiation-induced cancer death would be expected to occur in this group of the population. For 6 mSv the risk to an individual of death from a radiation-induced cancer would be $0.005\% \times 6 = 0.03\%$.

Behaviour of radionuclides in the body

In order to calculate the tissue distribution and excretion, detailed knowledge is required of how radioactive materials in general, and polonium in particular, behave in the various organs and tissues of the body after intake and how they are excreted (known as "biokinetics"). This knowledge is summarised in the form of equations and the equations implemented in computer programs. The set of equations that describes the behaviour of a material in the body is known as a "biokinetic model". A "dosimetric model" is applied to calculate the doses resulting from the distribution of activity in the body. For several decades the ICRP has, through its Committee 2 and associated Task Groups, developed biokinetic and dosimetric models which are almost universally used around the world. Using these models, ICRP provides tables of dose coefficients (committed effective doses for the intake of 1 Bq), for all radionuclides of practical interest, by inhalation and ingestion, and for both workers and members of the public.

Generally it has been found convenient to have separate models for the systems through which activity enters the body and is absorbed into blood (the respiratory tract and digestive tract), and those for the behaviour of each element after it has been absorbed into the blood ("systemic model"). These models have become increasingly realistic, sophisticated and, as a result, complex over the years. A brief (and approximate) outline follows to provide an overview of polonium behaviour in the body and its application in this incident.

Application to polonium-210

When polonium is *ingested* in a range of chemical forms about 10% is absorbed into the bloodstream, and the rest excreted in faeces within a few days. (If polonium is biologically incorporated in food absorption can be higher.) Polonium that has been absorbed into blood (the "systemic activity") is widely distributed through soft tissues, but with somewhat higher than average concentrations in kidneys and liver. It is also excreted, mainly in faeces, but also in urine, and to some extent in sweat. The biological retention half-time of the systemic activity is about 50 days, which means that about 1.5% of it is excreted per day. About one-third of this is excreted in urine i.e., about 0.5% of the remaining systemic activity per day. Hence if 50 mBq per day were excreted in urine, the systemic activity would be about 200 times higher, at 10 Bq. If the intake was a few weeks earlier, the original systemic activity would have been about twice that (20 Bq). Since about 10% of the amount ingested is absorbed, the intake is assessed to be about 200 Bq. The dose coefficient for ingested polonium in a relatively insoluble inorganic form is $2.4 \times 10^{-7} \text{ Sv Bq}^{-1}$ and so the assessed dose in this example is about 0.05 mSv.

For *inhalation* the approach is similar but the situation more complex. As for ingested material the current ICRP model assumes that about 10% of material deposited in the respiratory tract is rapidly absorbed into blood. Some of the inhaled material deposits in the upper respiratory tract, and is quickly cleared in mucus and swallowed, from which point it behaves as ingested material. Some polonium however deposits in the deeper lungs from which it is cleared relatively slowly. The relative proportions deposited in the upper and lower respiratory tract depend on the assumed size distribution of the airborne material that has been inhaled. The main effect however, is that the equivalent dose calculated to the lungs (which are considered to be of high sensitivity to radiation induced cancer) makes a large contribution to the overall effective dose to the whole body. As a result, the effective dose assessed from a given measurement of ^{210}Po in urine is about 10 times higher if inhalation rather than ingestion is assumed to be the route of intake.