Guidance on Screening People for Internal Radioactive Contamination

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ABSTRACT

Following an incident where members of the public are contaminated with radioactive material, it is important to identify people quickly who may have inhaled or ingested sufficient material to require medical assessment. This guidance gives procedures for achieving this for five radionuclides using hand-held instruments. For a further eight radionuclides it was found that the hand-held instruments were not sufficiently sensitive to identify people who may require medical assessment. Although for these radionuclides it may be possible to use more sensitive detectors, the availability of suitable instruments is very limited and it is likely that analysis of urine samples would be used to identify people who require medical assessment. Consequently information is also given on measurement sensitivity and analysis times applicable to a large screening programme utilising urine sample analysis.

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EXECUTIVE SUMMARY

Following an incident in which radioactive material is released to the environment it is likely that people will need to be monitored for contamination on the skin or clothing and for internal contamination following inhalation or ingestion of radioactive material. For internal contamination monitoring, the principal aim is to identify people who could have internal contamination levels high enough to require medical assessment. It is important that these people are identified as quickly as possible so it is likely monitoring would commence at a Radiation Monitoring Unit (RMU) set up close to the incident. In the early stages of the response to an incident it is likely that only simple hand-held instruments would be available for monitoring of people.

At times soon after an incident, little or no information will be available on the physical and chemical properties of the radionuclides (e.g. particle size distribution and solubility of the material). This guidance assumes worst case values for parameters describing these properties with the objective of ensuring that everyone who requires medical assessment is identified.

For some radionuclides it is possible to identify people who require medical assessment using simple hand-held instruments, but for others more sensitive techniques are required such as the collection and measurement of a urine sample. This guidance presents detailed monitoring procedures for 13 radionuclides. These are cobalt-60 (^{60}Co), selenium-75 (^{75}Se), strontium-90/yttrium-90 (^{90}Sr/^{90}Y), iodine-131 (^{131}I), caesium-137 (^{137}Cs), iridium-192 (^{192}Ir), radium-226 (^{226}Ra), thorium-228 (^{228}Th), thorium-232 (^{232}Th), neptunium-237/protactinium-233 (^{237}Np/^{233}Pa), plutonium-238 (^{238}Pu), americium-241 (^{241}Am) and californium-252 (^{252}Cf). For the radionuclides ^{60}Co, ^{75}Se, ^{131}I, ^{137}Cs and ^{192}Ir, the reading from a hand-held instrument can be compared with tabulated action levels to decide if the person could have received a dose indicating that medical assessment is required. In the situation where the radionuclide has not yet been identified a procedure is given to make an initial identification of people who may require medical assessment. Following radionuclide identification the results of the measurements can be compared with the appropriate action levels. If the identified radionuclide is not ^{60}Co, ^{75}Se, ^{131}I, ^{137}Cs or ^{192}Ir the measurements using hand-held instruments can be used to prioritise people for measurements using systems capable of gamma-ray spectrometry.

For the radionuclides (^{90}Sr/^{90}Y, ^{226}Ra, ^{228}Th, ^{232}Th, ^{237}Np/^{233}Pa, ^{238}Pu and ^{241}Am) more sensitive external detectors would be required to measure internal contamination. However, the availability of suitable equipment for these measurements is very limited and so the most suitable method of screening large numbers of people is to use measurements of urine samples. This guidance provides detailed procedures for the collection and analysis of urine samples. For analysis of urine samples, the use of methods which are more rapid than routine methods was investigated. The use of rapid analysis methods for ^{90}Sr/^{90}Y, ^{237}Np/^{233}Pa and ^{241}Am in 24-hour urine samples is sensitive enough to identify people who require medical attention for samples taken up to at least 30 days after the incident. Rapid methods can also be used for analysis of ^{228}Th, ^{232}Th, ^{238}Pu and ^{252}Cf, but there are limitations as these methods may not be

sensitive enough to ensure that everyone who requires medical assessment is identified. This may be the case for younger people and for longer times between the incident and sample collection. Typical analysis times for rapid methods are between 12 and 30 hours from receipt of the sample at the laboratory. Analysis of 24-hour urine samples using routine methods should be sufficiently sensitive to identify everyone who requires medical assessment for the radionuclides ^{228}Th, ^{232}Th, ^{238}Pu, and ^{252}Cf for samples taken up to 30 days after the incident. Typical analysis times are 5 to 10 days. At present no suitably validated rapid method for the analysis of ^{226} Ra in urine exists. Routine methods for this radionuclide may only be sensitive enough to identify people who require medical assessment if samples are taken within about 10 days of the incident for people aged 20 years or older. For children, the ^{226} Ra analysis method may only be sensitive enough if samples are taken within a few days of the incident. If, during the response to an incident, more information becomes available on the properties of the contamination then it may be possible to reduce analysis times while still being able to identify everyone who needs medical attention.

Under some circumstances it may be necessary to collect a single voiding urine sample, rather than a 24-hour sample. This would be the case if there is a high probability that the person has received a high dose, perhaps because of the presence of very high levels of external contamination on the person's skin or clothing. In this situation the bladder must be emptied as soon as possible after the incident and the second (or subsequent) voiding collected. The sample should not normally be collected within 4 hours of the incident to allow sufficient time for biokinetic processes to produce a representative sample. If urine samples are collected within 4 hours of the incident, care is needed in the interpretation of the analysis results as the measured activity will produce a less reliable estimate of intake. In most situations it is recommended that 24-hour urine samples are collected as it is more likely that measurement of the sample will then be sensitive enough to identify people who require medical assessment.

Also included in this guidance are instructions for people providing a urine sample, an information leaflet for people who are asked to provide a urine sample and a sample record form.

For the radionuclides where urine sample measurements are required, nose blow sample and face wipe sample measurements can be used to indicate if inhalation of radioactive material has occurred. These methods can be used to prioritise people for urine sample analysis.

CONTENTS

1 INTRODUCTION

Following an incident in which radioactive material is released to the environment it is likely that monitoring of internal contamination levels in people will be required. The immediate aim is to identify people who could have internal contamination levels high enough to require medical assessment. Monitoring to identify these people should be carried out as soon as possible. To achieve this it is expected that the monitoring would be done at a Radiation Monitoring Unit (RMU) set up close to the location of the incident.

For some radionuclides it is possible to identify people who require medical assessment by making measurements with hand-held radiation monitors. The advantage of this is that suitable monitors should be available locally and so measurements can begin soon after the incident is confirmed.

For other radionuclides, measurements with these hand-held radiation monitors are not sufficiently sensitive. For some of these radionuclides more sensitive detectors could be used following their transport to the incident location, or alternatively people could be sent to laboratory based facilities. The number of systems available for these measurements is very small, and therefore the number of measurements which could be carried out is limited. Where measurements with hand-held instruments do not provide adequate sensitivity it is probable that measurement of activity in a urine sample will be used.

This guidance presents detailed monitoring procedures for 13 radionuclides. For those where screening with hand-held radiation monitors can be used, action levels are tabulated which, if exceeded, indicate that the person will require medical assessment and that arrangements must be made for accurate measurements to be made.

For the remaining radionuclides, for which screening with hand-held monitors cannot be used, alternative methods are described which can be used at an RMU to identify people who may have inhaled radioactive material. Procedures are given for the collection of urine samples and information about the analysis of urine samples is provided, including limits of detection, expected analysis times and the estimated UK capacity. Action levels are also tabulated for activity in a 24-hour urine sample which if exceeded indicate the person will require medical assessment. The action levels have been calculated using deliberately cautious assumptions so if a person does not exceed the action level it is very unlikely that they will require medical assessment.

For all incidents where people have been contaminated with radioactive material, the removal of significant contamination on the skin and clothing is more urgent than monitoring for internal contamination. Furthermore, decontamination procedures should not be delayed by monitoring for either contamination on the skin and clothing or internal contamination.

2 SCOPE

This guidance should be used in conjunction with relevant health emergency planning guidance, the NHS Emergency Planning Guidance (Department of Health, 2010) and the National Health Service in Scotland Manual of Guidance (NHS, Scotland, 2010).

Procedures are described for monitoring of radionuclides within the body. Procedures are not given for monitoring for radionuclides on the skin or clothing.

Action levels are tabulated only for the radionuclides in Table 1.

Table 1 Radionuclides covered by this guidance

Radionuclide		Radiation types emitted	Screening possible with hand-held instruments?
Cobalt-60	^{60}Co	beta, gamma	Yes
Selenium-75	^{75}Se	gamma	Yes
Strontium-90/Yttrium-90	^{90}Sr/^{90}Y	beta	No
Iodine-131	^{131}I	beta, gamma	Yes
Caesium-137	^{137}Cs	beta, gamma	Yes
Iridium-192	^{192}Ir	beta, gamma	Yes
Radium-226	^{226}Ra	alpha, beta, gamma	No
Thorium-228	^{228}Th	alpha, beta, gamma	No
Thorium-232	^{232}Th	alpha, beta, gamma	No
Neptunium-237/Protactinium-233	^{237}Np/^{233}Pa	alpha, gamma	No
Plutonium-238	^{238}Pu	alpha	No
Americium-241	^{241}Am	alpha, gamma	No
Californium-252	^{252}Cf	alpha	No

The procedures described in this guidance assume use of one of the hand-held radiation monitors listed in Table 2. These radiation monitors were selected as they should be available locally and are relatively simple to operate. Table 2 also shows the organisations that have access to particular instruments. Table 1 indicates for which radionuclides screening with hand-held monitors could be used, although it should be noted that not all of the hand-held radiation monitors can be used for all of the radionuclides indicated in Table 1. For those radionuclides listed in Table 1 for which screening with hand-held instruments is not possible, analysis of urine samples has been considered.

Table 2 Hand-held radiation monitors

Radiation Monitor Name	Organisation(s) holding stocks of each radiation monitor
APTEC-NRC ADM-300 with BSP-100 probe	Military
RADOS RDS 200 with GMP-11 probe	Fire Service and Military
ROTEM RAM Gene-1	A&E Departments
Thermo Mini 900 with 44A probe	NHS, Medical Physics Departments
TSA systems PRM-470CS	Police
SAIC Exploranium GR-135	Fire Service and Police

It has generally been assumed that only single radionuclides are present in the contamination. If other radionuclides are present in significant quantities then using this guidance may not identify everyone who requires medical assessment. For example, if the radioactive material contains ^{137}Cs and also ^{238}Pu which was not identified, then using the procedures in this guidance for ^{137}Cs would only take account of the dose contributed by ^{137}Cs and therefore there is a chance that not everyone who requires medical assessment would be identified. Therefore it is important that all of the radionuclides present are identified so that the dose contributed by each can be considered. Methods for combining the dose contributions from two or more radionuclides are given in this guidance.

The hand-held instruments, used as described in this guidance, are unable to identify which radionuclides are contributing to the measured count rate. Therefore if any of the radionuclides ^{60}Co, ^{75}Se, ^{131}I, ^{137}Cs or ^{192}Ir are present in any combination, or with any other high energy and high yield gamma-ray emitting radionuclide, then the procedures in this guidance can not be used to identify people who require medical assessment. However, it would be possible to identify people who have the highest intakes by using one of the instruments included in this report and recording the net count rate for each person. Moreover, by using this method, if any high energy and high yield gamma-ray emitting radionuclides is present either by itself or with any other radionuclide(s) then it would be possible to identify people with the highest intakes.

If combinations of high energy and high yield gamma-ray emitting are present then to identify those people who require medical assessment, systems capable of gamma-ray spectrometry are required (Youngman, 2002 and Youngman, 2008).

For the radionuclides ^{90}Sr/^{90}Y, ^{226}Ra, ^{228}Th, ^{232}Th, ^{237}Np/^{233}Pa, ^{238}Pu and ^{241}Am the most appropriate method of screening large numbers of people is to use measurements of urine samples. If one of the radionuclides ^{60}Co, ^{75}Se, ^{131}I, ^{137}Cs or ^{192}Ir is present in the contamination together with one (or more) of the radionuclides ^{90}Sr/^{90}Y, ^{226}Ra, ^{228}Th, ^{232}Th, ^{237}Np/^{233}Pa, ^{238}Pu, ^{241}Am and ^{252}Cf then the procedures in this guidance can be adapted and used to identify people who require medical assessment (details are given in Appendix F). If two or more of the radionuclides ^{90}Sr/^{90}Y, ^{226}Ra, ^{228}Th, ^{232}Th, ^{237}Np/^{233}Pa, ^{238}Pu, ^{241}Am or ^{252}Cf are present in the contamination then the procedures in this guidance can also be adapted and used to identify people who require medical assessment (Appendix F).

Monitoring with hand-held radiation monitors, as described in this guidance, is intended for large groups of people and to identify anyone who could have received a dose high enough to require medical assessment. This is done by comparing the indicated reading of the monitor with Action Levels which are directly related to dose. It should be noted that the numerical value of the Action Levels are dependent on the monitor being used, as the sensitivity of each type of radiation monitor is different. The methods described for the use of hand-held radiation monitors should not be used for dose assessment purposes.

Measurement of 24-hour urine samples as described in this guidance is intended to identify anyone who could have received a dose high enough to require medical assessment. The measured activity in a 24-hour urine is compared to tabulated Action Levels which if exceeded indicate that the person requires medical assessment. For the measurement of urine samples, consideration has been given to the use of methods which are more rapid than those routinely used.

The action levels have been calculated assuming that the suspected intake is by acute inhalation or ingestion. These action levels can be used for intakes via a wound or when people are likely to have inhaled or ingested the radionuclide over a long period, for example if contaminated food were consumed over an extended period. In these situations care would be required in the interpretation of results. However, using the procedures in this guidance will allow the most contaminated people to be identified.

The action levels are deliberately cautious, and have been calculated assuming physical and chemical characteristics of the radionuclide that results in the maximum dose estimates. If information becomes available on the physical characteristics then these action levels may prove to be overly cautious and higher action levels could be adopted. In the determination of action levels both deterministic effects and stochastic risk were considered. For all but one of the radionuclides considered the stochastic risk is more limiting and the action levels correspond to a committed effective dose of 200 mSv. For ^{131}I, in people aged less than 20 years risk of deterministic effects are more limiting and the action level corresponds to a RBE weighted absorbed dose to the thyroid of 2 Gy. A value of 200 mSv was chosen for the committed effective dose criterion as this value has been proposed as the upper limit above which medical treatment to reduce dose should be considered (Menetrier et. al., 2005). Similarly, the RBE weighted dose values adopted in this guidance have been proposed as values which if exceeded the person should be refereed immediately for medical assessment. Details of the calculation of action levels are given in Appendix I.

The emphasis of this guidance is on techniques which can be used soon after the incident when few monitoring facilities will be available. However, it is recognised that it may be some while before the incident is discovered so action levels for using hand held radiation monitors are tabulated for the period up to 30 days after the contamination event. If measurements with hand-held monitors are made more than 30 days after the incident or urine samples are taken more than 30 days after the incident then the results can still be used to identify people who have received the highest intakes.

In order to use the action levels in this guidance, external contamination present on individuals must be low enough not to affect measurements using external detectors

(Rojas-Palma et al., 2009). Measurements with external detectors cannot distinguish between internal and external contamination and if significant external contamination is present the internal contamination level will be overestimated.

Following a release of radioactive iodine, stable iodine tablets may be administered to people who are likely to have inhaled significant amounts. If administered quickly enough, this stable iodine can block uptake of some of the radioactive iodine by the thyroid. In order to avert 50% of the thyroid dose the stable iodine must be administered within 4 hours of exposure (Kovari and Morrey, 1994). The action levels in this guidance for ^{131}I measurements of the thyroid assume stable iodine has not been administered. If stable iodine is administered then the action levels in this document is likely to be cautious as uptake by the thyroid will be reduced and excretion will be enhanced. If the stable iodine is administered more than 12 hours after the intake then it can be assumed to have been ineffective and the action levels in this guidance should be reliable (Kovari and Morrey, 1994).

It is intended that this guidance should be used by staff who have received some training in the use of hand-held contamination monitors (e.g. staff who have been trained to use the RAM Gene-1 monitors or staff from NHS medical physics departments).

HPA can provide specialist support to the emergency services and NHS staff. Specialist advice for a radiation incident can be obtained by telephoning 01235 834590.

3 TRIAGE

Triage is the use of simple procedures for rapidly sorting people into groups based on (a) their degree of physical injury and (b) actual or potential effects on health. Detailed guidance on triage procedures is contained in the TMT Handbook (Rojas-Palma et. al., 2009). The following is a summary of the most important points covered by the TMT Handbook. Triage is a multi-staged process. Following a radiological incident it may first be necessary to sort people on their degree of physical injury and then to identify people who require medical assessment on the basis of their exposure to radiation or radioactive materials (termed radiological triage in the TMT Handbook). Before monitoring equipment is available, radiological triage can be done, using for example, location at the time of the incident or on the basis of clinical signs and symptoms. It is important that people who are most likely to be internally contaminated should be given priority for screening for internal contamination. When monitoring equipment is available the results of measurements can then be used to identify people who require medical assessment. It is this stage of triage that is covered by the procedures in this guidance. People can also be prioritised for internal contamination measurements using the results of external contamination surveys, as people who are externally contaminated are more likely to be internally contaminated.

4 MONITORING LOCATIONS AND PRECAUTIONS

Monitoring of people for internal and external contamination would normally be carried out at a temporary Radiation Monitoring Unit, set up close to the incident (Department of Health, 2010). Information on setting up and running a radiation monitoring unit is contained in a HPA document (HPA, 2010). This is a summary of the most important points covered by this reference. The RMU should be located in a covered area large enough to deal with the demand. There must be adequate separation of people waiting for monitoring, being monitored, and awaiting transfer for further assessment. It may be necessary to monitor people for external contamination as well as internal contamination. If it is possible that external contamination could be present on people then decontamination facilities should be made available.

The monitoring should be carried out at a location where the levels of natural background radiation are not unusually high, and where levels have not been significantly enhanced by contamination from the incident.

The monitoring area in particular should be kept free of contamination. Chairs and floors should be covered so that they can be easily decontaminated.

Staff carrying out monitoring should wear suitable Personal Protective Equipment (PPE). In all but extreme cases, the use of disposable coveralls, gloves and overshoes should provide adequate protection of staff carrying out monitoring of people.

The TMT Handbook (Rojas-Palma et. al., 2009) and a report by the National Council on Radiation Protection and Measurements (NCRP, 2010) contain additional information on monitoring of people following a radiological incident.

5 MONITORING INSTRUCTIONS

5.1 Introduction

Before internal contamination monitoring procedures can commence the procedure shown in the flow diagram in Figure 1 should be followed. This flow diagram should be used as soon as any incident involving radiation or radioactive materials has been declared. It will always be necessary to monitor for external contamination and to carry out decontamination procedures when the results of external contamination monitoring indicate they are required. Detailed procedures for external contamination monitoring can be found in the TMT Handbook (Rojas-Palma et al., 2009) and the HPA RMU document (HPA, 2010). Decontamination procedures are published in the TMT Handbook (Rojas-Palma et al., 2009).

Radionuclides can be released to the environment in several different ways; as an airborne contaminant (e.g. in an explosion) or added to foodstuffs or water supplies. It is important to identify the radionuclide(s) released to the environment as a matter of urgency as this guidance cannot be used to identify people who require medical

assessment until this has been done. However, if it is known that a high energy gamma-ray emitting radionuclide is present then an initial screening can be made using hand-held instruments to identify those people who have received the highest intakes (Section 5.1.1). When the radionuclide has been identified these measurements can then be compared with the tabulated action levels to identify people who need medical attention. In this situation it is recommended that only the instruments with the highest sensitivity should be used (i.e. SAIC Exploranium GR-135 or TSA systems PRM-470CS). If the presence of radioiodine is suspected, because activity is concentrated in the thyroid, then a procedure for monitoring for thyroid should also be followed. If iodine-131 is subsequently identified, the results of these measurements can be used to identify people who need medical assessment.

Radionuclide identification must only be carried out by a suitably qualified radiation expert such as a Radiation Protection Advisor (RPA). For advice on radionuclide identification HPA can be contacted by telephoning 01235 834590.

Section 5.2 gives monitoring procedures for each of the radionuclides included in Table 1 which are intended to be used to identify people who require medical assessment. Section 5.2.1 gives a monitoring procedure to follow when a gamma-emitting radionuclide is present, but has not yet been identified.

Medical assessment must be carried out by a medical practitioner. The assessment should include a brief case history, basic physical examination and blood sampling as detailed in section J4 of the TMT Handbook (Rojas-Palma et. al., 2009). For radionuclides for which screening measurements with hand-held radionuclides have been made, arrangements for more accurate measurements must also be made. More accurate measurement systems could be deployed to the RMU or it may be necessary for the person to be taken to a laboratory. Arrangements for these measurements can be made through the HPA.

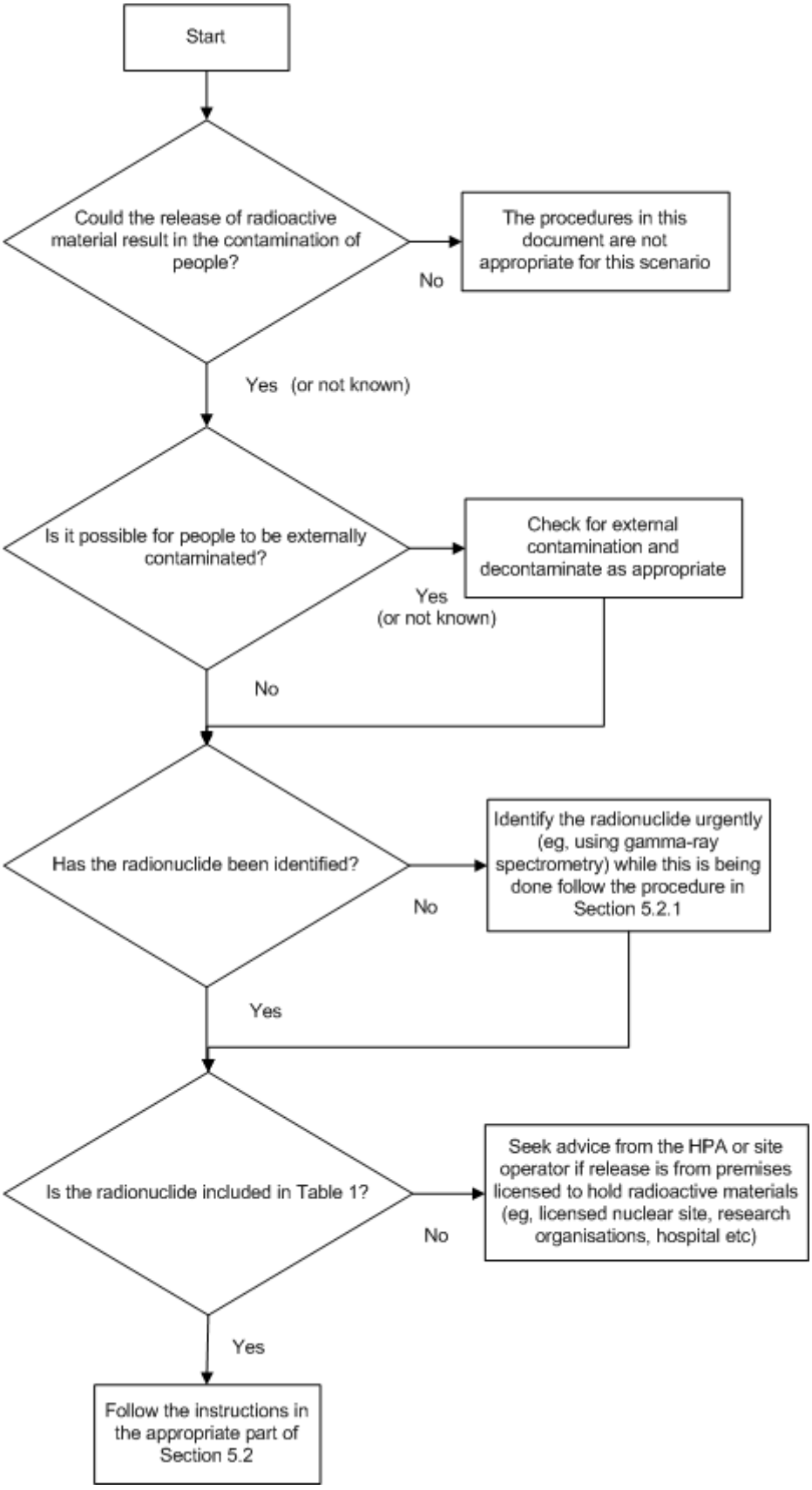

Figure 1 Flow diagram to be used prior to commencing internal contamination monitoring procedures

5.2 Monitoring Instructions for Individual Radionuclides

5.2.1 Unidentified Gamma-Ray Emitting Radionuclide(s)

This procedure should be used if a gamma-ray emitting radionuclide or radionuclides are present, but have not yet been identified. It will enable the most contaminated people to be identified, but it will not be possible to compare the measurement values with action levels to decide if the person needs medical assessment. As soon as the radionuclide is identified, the measurements previously made can be compared with appropriate action levels. For subsequent monitoring the procedure for the identified radionuclide should be followed providing the radionuclide is included in Table 1. If the identified radionuclide is not in Table 1, this procedure should continue to be used at least until additional monitoring facilities become available.

If the presence of radioiodine is suspected then in addition to the procedure in section 5.2.1.1 the procedure in 5.2.1.2 should also be followed. The presence of radioiodine in the thyroid can be detected by using a Thermo Mini 900 with 44A probe. If the neck of a contaminated person is monitored and the instrument reading reaches a maximum over the lower neck (Appendix C) then the presence of radioiodine is confirmed.

5.2.1.1 Unidentified Gamma-Ray Emitting Radionuclide

1. Has the presence of a gamma-emitting radionuclide been identified? Hold a scintillator based detector (e.g. SAIC Exploranium GR-135, TSA systems PRM-470CS or Thermo Mini 900 with 44A probe) approximately 30 cm from a contaminated person. If the instrument reads significantly above background then the presence of a gamma-ray emitting radionuclide has been confirmed (see instruction 7 in this section).

2. **Urgently obtain expert help to identify the radionuclide positively.** Help should be sought from a nuclear site operator, research organisation, university or similar local organisation with radiation protection expertise.

3. Obtain a suitable radiation monitor. Obtain either a SAIC Exploranium GR-135 or TSA systems PRM-470CS. If neither of these instruments is available then obtain a Thermo Mini 900 with 44A probe.

4. Perform battery check and check source measurement. Turn on your radiation survey monitor, and perform a check of the detector battery function (see Appendix A). If the detector has multiple display settings, select those given in Appendix A. If a portable radioactive check source is available, move that source closer to and farther away from the front of the detector surface to ensure that the registered count rate increases and decreases accordingly. The procedure in Appendix B can also be used to check that individual radiation monitors are working properly.

5. Establish the background count rate for your detector and monitoring location**.** Take an initial monitor reading of the environment in the general vicinity of where you will be surveying people. This reading should be obtained prior to the introduction of any potentially contaminated individuals into the monitoring location. Record this value as your Background Count Rate (BCR) in units of counts per second (cps) or counts per minute (cpm).

6. Ensure adequate distance between person being monitored and people waiting. Each person should be taken individually to the monitoring area maintaining a distance of about 5-10 m between the person being monitored and other potentially contaminated people. In the case of young children a parent or guardian can be closer than this, but the parent or guardian should be monitored first to ensure their presence will not affect the measurement of the child.

7. Position the detector. Hold the detector 30 cm from the centre of the chest (see Figure C1 and C2 in Appendix C). The orientation of the detector should be as detailed in Appendix A.

8. Record the measurement. Wait for about 10 seconds for the reading to stabilise and record the highest indicated detector count rate. Note the units (cps or cpm). The background count rate or BCR (see Step 5 above) must be subtracted from the Total Count Rate (TCR) measurement, to yield a Net Count Rate (NCR):

Net Count Rate (NCR) = Total Count Rate (TCR) – Background Count Rate (BCR)

9. Record results of each measurement. For each person monitored, sufficient information should be recorded to allow the person to be uniquely identified. This must include full name, date of birth and postcode. As a minimum, the instrument used, NCR and BCR must be recorded. A template record form is shown in Appendix D.

10. Compare the NCR to the action levels. When the radionuclide has been identified, the Net Count Rate (NCR) from Step 8 should be compared with the tabulated action level values from that particular radionuclide. Select the table for the appropriate age group and the column for the instrument used. Read off the action level for the number of days since intake. If the NCR is greater than or the same as this value then do the following:

(1) Urgently refer the person for medical assessment

(2) Arrange for accurate measurements to be made

11. Radionuclide not included in table 1. If the radionuclide, when identified, is not included in Table 1, then continue to follow this procedure until additional monitoring facilities become available. People found to have the highest Net Count Rate (NCR) values should be prioritised for measurements using these facilities.

12. Additional information. Additional information regarding the use of hand-held radiation monitors is given in Appendix E.

5.2.1.2 Radioiodine present in the thyroid

1. **Is radioiodine present?** Using a Thermo Mini 900 with 44A probe monitor around the neck of a person known to be contaminated. If the instrument reading reaches a maximum over the thyroid (see instruction 7 in this section) then radioiodine is present in the thyroid and this procedure should be followed. In addition to following this procedure the procedure in section 5.2.1.1 should be followed in case other radionuclides are also present.

2. ***Urgently obtain expert help to identify the radionuclide positively.*** Help should be sought from a nuclear site operator, research organisation, university or similar local organisation with radiation protection expertise.

3. ***Obtain a suitable radiation monitor.*** Obtain a Thermo Mini 900 with 44A probe.

4. ***Perform battery check and check source measurement.*** Turn on your radiation survey monitor, and perform a check of the detector battery function (see Appendix A). If the detector has multiple display settings, select those given in Appendix A. If a portable radioactive check source is available, move that source closer to and farther away from the front of the detector surface to ensure that the registered count rate increases and decreases accordingly. The procedure in Appendix B can also be used to check that individual radiation monitors are working properly.

5. ***Establish the background count rate for your detector and monitoring location.*** Take an initial monitor reading of the environment in the general vicinity of where you will be surveying people. This reading should be obtained prior to the introduction of any potentially contaminated individuals into the monitoring location. Record this value as your Background Count Rate (BCR) in units of counts per second (cps).

6. ***Ensure adequate distance between person being monitored and people waiting.*** Each person should be taken individually to the monitoring area maintaining a distance of about 5-10 m between the person being monitored and other potentially contaminated people. In the case of young children a parent or guardian can be closer than this, but the parent or guardian should be monitored first to ensure their presence will not affect the measurement of the child.

7. ***Position the detector.*** Hold the detector close to the skin at the base of the front of the neck (see Figure C3 and C4 in Appendix C).

8. ***Record the measurement.*** Wait for about 10 seconds for the reading to stabilise and record the highest indicated detector count rate. The background count rate or BCR (see Step 5 above) must be subtracted from the Total Count Rate (TCR) measurement, to yield a Net Count Rate (NCR):

Net Count Rate (NCR) = Total Count Rate (TCR) – Background Count Rate (BCR)

9. ***Record results of each measurement.*** For each person monitored, sufficient information should be recorded to allow the person to be uniquely identified. This must include full name, date of birth and postcode. As a minimum, the instrument used, NCR and BCR must be recorded. A template record form is shown in Appendix D.

10. ***Compare the NCR to the action levels.*** If the presence of iodine-131 is confirmed, the Net Count Rate (NCR) from Step 8 should be compared with the action level values in Tables 15-17. Select the table for the appropriate age group and the column for the instrument used. Read off the action level for the number of

days since intake. If the NCR is greater than or the same as this value then do the following:

(1) Urgently refer the person for medical assessment

(2) Arrange for accurate measurements to be made

If stable iodine has been taken by the person either before or within 12 hours after intake then these action levels must not be used. The NCR can be converted to activity of ^{131}I in the thyroid using the calibration factor given in Appendix A. If stable iodine was taken by the person more than 12 hours after the intake it will not be effective and it can be assumed that stable iodine has not been taken (Kovari and Morrey, 1994).

11. Radionuclide not included in table 1. If the radionuclide is not iodine-131, but another iodine radionuclide then continue to follow this procedure until additional monitoring facilities become available. People found to have the highest Net Count Rate (NCR) values should be prioritised for measurements using these facilities.

12. Additional information. Additional information regarding the use of hand-held radiation monitors is given in Appendix E.

5.2.2 Cobalt-60 (^{60}Co)

1. Has ^{60}Co been identified with a high degree of confidence? If not urgently obtain expert help to identify the radionuclide positively. Help should be sought from a nuclear site operator, research organisation, university or similar local organisation with radiation protection expertise. Until the radionuclide is identified follow the procedure in Section 5.2.1

2. Estimate the elapsed time since intake of radioactive material. It is important to have an estimate of the time between the original contamination event and the time that measurements are made which is as reliable as possible. The day that the incident is discovered may not be the day of intake.

3. Obtain a suitable radiation monitor. Choose a monitor from Table 3. Appendix A shows photographs and gives operating instructions for each radiation monitor. If these monitors are not available then choose one from Table 4.

Table 3 Recommended Radiation Monitors for cobalt-60

Radiation Monitor	Range of times between intake and measurement when monitor is suitable (days)
SAIC Exploranium GR-135	0-30 (0-20 for children aged up to 10 years)
Thermo Mini 900 with 44A probe	0-30 (0-6 for children aged up to 10 years)
TSA systems PRM-470CS	0-30 (0-9 for children aged up to 10 years)

Table 4 Alternative Radiation Monitors for cobalt-60[1]

Radiation Monitor	Range of times between intake and measurement when monitor is suitable (days)
APTEC-NRC ADM-300 with BSP-100 probe	0-6
ROTEM RAM Gene-1	0-4

[1]These instruments are very sensitive to beta activity and as the maximum range of beta radiation from ^{60}Co in air is approximately 50 cm then if activity is present on the skin or clothing this would have a large effect on the Net Count Rate.

4. Perform battery check and check source measurement. Turn on your radiation survey monitor, and perform a check of the detector battery function (see Appendix A). If the detector has multiple display settings, select those given in Appendix A. If a portable radioactive check source is available, move that source closer to and further away from the front of the detector surface to ensure that the registered count rate increases and decreases accordingly. The procedure in Appendix B can also be used to check that individual radiation monitors are working properly.

***5. Establish the background count rate for your detector and monitoring location*.** Take an initial monitor reading of the environment in the general vicinity of where you will be surveying people. This reading should be obtained prior to the introduction of any potentially contaminated individuals into the monitoring location.

Record this value as your Background Count Rate (BCR) in units of counts per second (cps) or counts per minute (cpm).

6. Ensure adequate distance between person being monitored and people waiting. Each person should be taken individually to the monitoring area maintaining a distance of about 5-10 m between the person being monitored and other potentially contaminated people. In the case of young children a parent or guardian can be closer than this, but the parent or guardian should be monitored first to ensure their presence will not affect the measurement of the child.

7. Position the detector. Hold the detector 30 cm from the centre of the chest (see Figure C1 and C2 in Appendix C). The orientation of the detector should be as detailed in Appendix A.

8. Record the measurement. Wait for about 10 seconds for the reading to stabilise and record the highest indicated detector count rate. Note the units (cps or cpm). The background count rate or BCR (see Step 5 above) must be subtracted from the Total Count Rate (TCR) measurement, to yield a Net Count Rate (NCR):

Net Count Rate (NCR) = Total Count Rate (TCR) – Background Count Rate (BCR)

9. Compare the NCR to the action levels. The Net Count Rate (NCR) from Step 8 should be compared with the action level values in Tables 5-7. Select the table for the appropriate age group and the column for the instrument used. Read off the action level for the number of days since intake. If the NCR is greater than or the same as this value then do the following:

(1) Urgently refer the person for medical assessment

(2) Arrange for accurate measurements to be made

Table 5 Action Levels for Children aged up to 10 years for cobalt-60

Time between incident and measurement (days)	Action Level				
	APTEC-NRC ADM-300/BSP-100 (cpm)	ROTEC RAM Gene-1 (cps)	SAIC Exploranium GR-135 (cps)	Thermo Mini 900 with 44A probe (cps)	TSA systems PRM-470CS (cps)
0	1400	6	340	35	430
1	1400	6	330	35	420
2	1300	5	300	30	380
3	1200	5	300	30	350
4	1100	5	270	30	340
5	900	-	210	25	260
6	480	-	110	10	140
7	-	-	60	-	80
8	-	-	40	-	55
9	-	-	35	-	45
10	-	-	30	-	-
11-12	-	-	30	-	-
13-14	-	-	25	-	-
15-16	-	-	25	-	-
17-18	-	-	23	-	-
19-20	-	-	23	-	-
21-30	-	-	-	-	-

Values for recommended radiation monitors are highlighted.
A '-' means that the monitor is not suitable for the combination of radionuclide, age group and time between intake and monitoring

Table 6 Action Levels for ages 10 years to 19 years for cobalt-60

Time between incident and measurement (days)	Action Level				
	APTEC-NRC ADM-300/BSP-100 (cpm)	ROTEC RAM Gene-1 (cps)	SAIC Exploranium GR-135 (cps)	Thermo Mini 900 with 44A probe (cps)	TSA systems PRM-470CS (cps)
0	2500	7	530	60	670
1	2400	7	520	60	650
2	2200	6	460	55	590
3	2100	6	430	50	550
4	2000	6	420	50	530
5	1800	-	380	45	490
6	890	-	190	20	240
7	510	-	110	-	140
8	-	-	73	-	90
9	-	-	61	-	75
10	-	-	55	-	70
11-12	-	-	50	-	63
13-14	-	-	47	-	59
15-16	-	-	45	-	56
17-18	-	-	42	-	53
19-20	-	-	40	-	50
21-30	-	-	36	-	45

Values for recommended radiation monitors are highlighted.
A "-" means that the monitor is not suitable for the combination of radionuclide, age group and time between intake and monitoring

Table 7 Action Levels for age 20 years and older for cobalt-60

Time between incident and measurement (days)	Action Level				
	APTEC-NRC ADM-300/BSP-100 (cpm)	ROTEC RAM Gene-1 (cps)	SAIC Exploranium GR-135 (cps)	Thermo Mini 900 with 44A probe (cps)	TSA systems PRM-470CS (cps)
0	2700	11	750	140	920
1	2700	11	750	140	920
2	2500	10	680	130	840
3	2300	9	630	120	780
4	2200	9	610	110	750
5	2000	8	560	100	690
6	1000	-	290	55	360
7	600	-	160	30	200
8	-	-	110	20	140
9	-	-	95	15	120
10	-	-	85	15	110
11-12	-	-	80	15	100
13-14	-	-	75	14	92
15-16	-	-	75	14	92
17-18	-	-	68	13	84
19-20	-	-	66	12	82
21-30	-	-	59	10	72

Values for recommended radiation monitors are highlighted.

A "-" means that the monitor is not suitable for the combination of radionuclide, age group and time between intake and monitoring

10. ***Record results of each measurement.*** For each person monitored, sufficient information should be recorded to allow the person to be uniquely identified. This must include full name, date of birth and postcode. As a minimum, the instrument used, NCR, BCR and whether the action level has been exceeded must be recorded. A template record form is shown in Appendix D.

11. ***Additional information.*** Additional information regarding the use of hand-held radiation monitors is given in Appendix E.

5.2.3 Selenium-75 (^{75}Se)

1. Has ^{75}Se been identified with a high degree of confidence? If not, urgently obtain expert help to identify the radionuclide positively. Help should be sought from a nuclear site operator, research organisation, university or similar local organisation with radiation protection expertise. Until the radionuclide is identified follow the procedure in Section 5.2.1.

2. Estimate the elapsed time since intake of radioactive material. It is important to have an estimate of the time between the original contamination event and the time that measurements are made which is as reliable as possible. The day that the incident is discovered may not be the day of intake.

3. Obtain a suitable radiation monitor. Choose a monitor from Table 8. Appendix A shows photographs and gives operating instructions for each radiation monitor.

Table 8 Recommended Radiation Monitors for selenium-75

Radiation Monitor	Range of times between intake and measurement when monitor is suitable (days)
ROTEC RAM Gene-1	0-30
SAIC Exploranium GR-135	0-30
Thermo Mini 900 with 44A probe	0-30
TSA systems PRM-470CS	0-30

4. Perform battery check and check source measurement. Turn on your radiation survey monitor, and perform a check of the detector battery function (see Appendix A). If the detector has multiple display settings, select those given in Appendix A. If a portable radioactive check source is available, move that source closer to and further away from the front of the detector surface to ensure that the registered count rate increases and decreases accordingly. The procedure in Appendix B can also be used to check that individual radiation monitors are working properly.

5. Establish the background count rate for your detector and monitoring location. Take an initial monitor reading of the environment in the general vicinity of where you will be surveying people. This reading should be obtained prior to the introduction of any potentially contaminated individuals into the monitoring location. Record this value as your Background Count Rate (BCR) in units of counts per second (cps) or counts per minute (cpm).

6. Ensure adequate distance between person being monitored and people waiting. Each person should be taken individually to the monitoring area maintaining a distance of about 5-10 m between the person being monitored and other potentially contaminated people. In the case of young children a parent or guardian can be closer than this, but the parent or guardian should be monitored first to ensure their presence will not affect the measurement of the child.

7. ***Position the detector.*** Hold the detector 30 cm from the centre of the chest (see Figure C1 and C2 in Appendix C). The orientation of the detector should be as detailed in Appendix A.

8. ***Record the measurement.*** Wait for about 10 seconds for the reading to stabilise and record the highest indicated detector count rate. Note the units (cps or cpm). The background count rate or BCR (see Step 5 above) must be subtracted from the Total Count Rate (TCR) measurement, to yield a Net Count Rate (NCR):

Net Count Rate (NCR) = Total Count Rate (TCR) – Background Count Rate (BCR)

9. ***Compare the NCR to the action levels.*** The Net Count Rate (NCR) from Step 8 should be compared with the action level values in Tables 9-11. Select the table for the appropriate age group and the column for the instrument used. Read off the action level for the number of days since intake. If the NCR is greater than or the same as this value then do the following:

(1) Urgently refer the person for medical assessment

(2) Arrange for accurate measurements to be made

Table 9 Action Levels for Children aged up to 10 years old for selenium-75

Time between incident and measurement (days)	Action Level			
	ROTEC RAM Gene-1 (cps)	SAIC Exploranium GR-135 (cps)	Thermo Mini 900 with 44A probe (cps)	TSA systems PRM-470CS (cps)
0	120	12000	4800	16000
1	120	12000	4800	15000
2	110	12000	4600	15000
3	110	11000	4500	15000
4	110	11000	4300	14000
5	100	10000	4200	14000
6	100	10000	4000	13000
7	100	9800	3900	13000
8	100	9600	3800	13000
9	90	9400	3700	13000
10	90	9200	3700	12000
11-12	90	8900	3600	12000
13-14	90	8500	3400	11000
15-16	80	8200	3300	11000
17-18	80	7900	3200	10000
19-20	80	7700	3100	10000
21-30	65	6500	2600	8600

TABLE 10 Action Levels for ages 10 years to 19 years for selenium-75

Time between incident and measurement (days)	Action Level			
	ROTEC RAM Gene-1 (cps)	SAIC Exploranium GR-135 (cps)	Thermo Mini 900 with 44A probe (cps)	TSA systems PRM-470CS (cps)
0	180	24000	7600	28000
1	180	23000	7300	27000
2	170	22000	7000	26000
3	160	21000	6800	25000
4	160	20000	6500	24000
5	150	20000	6200	23000
6	150	20000	6200	23000
7	140	19000	5900	22000
8	140	18000	5700	21000
9	140	18000	5700	21000
10	130	17000	5400	21000
11-12	130	17000	5400	20000
13-14	120	16000	5100	19000
15-16	120	15000	4900	18000
17-18	110	15000	4900	18000
19-20	110	15000	4600	17000
21-30	100	13000	4000	15000

Table 11 Action Levels for age 20 years and older for selenium-75

Time between incident and measurement (days)	Action Level			
	ROTEC RAM Gene-1 (cps)	SAIC Exploranium GR-135 (cps)	Thermo Mini 900 with 44A probe (cps)	TSA systems PRM-470CS (cps)
0	440	42000	18000	48000
1	430	41000	18000	47000
2	410	39000	17000	45000
3	390	37000	16000	42000
4	380	36000	16000	41000
5	360	35000	15000	38000
6	350	33000	15000	37000
7	340	33000	14000	37000
8	340	32000	14000	37000
9	330	31000	14000	36000
10	320	31000	13000	35000
11-12	310	29000	13000	34000
13-14	300	28000	12000	32000
15-16	290	28000	12000	31000
17-18	280	26000	12000	30000
19-20	270	26000	11000	29000
21-30	230	22000	9500	25000

10. ***Record results of each measurement.*** For each person monitored, sufficient information should be recorded to allow the person to be uniquely identified. This must include full name, date of birth and postcode. As a minimum, the instrument used, NCR, BCR and whether the action level has been exceeded must be recorded. A template record form is shown in Appendix D.

11. ***Additional information.*** Additional information regarding the use of hand-held radiation monitors is given in Appendix E.

5.2.4 Strontium-90/Yttrium-90 (^{90}Sr/^{90}Y)

The hand-held radiation monitors described in this guidance cannot be used as their sensitivity to ^{90}Sr/^{90}Y internal contamination is inadequate. The sensitivity is inadequate because this radionuclide produces weakly penetrating radiation which is absorbed before reaching the detector.

External Contamination Monitoring

If external contamination monitoring using hand-held instruments has been carried out then people found to be contaminated should be given a high priority for internal contamination measurements. People could be prioritised for internal contamination measurements based on the level of external contamination found. If activity is detected on the face then this could indicate intake by inhalation has occurred.

Face Wipe and Nose Blow Samples

For suspected intakes by inhalation, these samples can be used to give a qualitative indication of whether an intake has occurred providing samples are taken soon after the incident. Absence of measurable activity must not be taken to imply the absence of an intake. Samples may be measured using hand-held instruments (thin end-window GM detector based[*]) and kept for laboratory analysis or if available measured with portable sample (total beta) counting equipment. Appendix E gives additional information on the collection and use of face wipe and nose blow samples.

Measurements using External Detectors

Measurements of internal contamination are possible using external detectors with some portable and laboratory based facilities, although the availability of suitable equipment is very limited. These measurement facilities are able to detect the radiation produced by the interaction of high energy beta particles with materials. (Bremsstrahlung radiation) Contact HPA for more details.

Urine Measurements

Urine measurements can be used to quantify internal contamination. Instructions on how to provide a 24-hour urine sample are given in Appendix G. Information for laboratories who might conduct the urine sample analyses is given in Appendix H. The measured 24-hour urine activity should be compared with the action level values in table 12. Select the column for the appropriate age group and read off the action level for the number of days between the incident and sample collection. If the measured activity is greater than or the same as this value then the person should be urgently referred for medical assessment.

It is unlikely that more than 100 samples per day could be analysed in the UK using adapted routine methods. This capacity could be maintained for many months and could be increased by sending samples to laboratories outside the UK.

[*] Other detector types which are suitable for beta contamination monitoring can be used, see Burgess (2001).

Analytical methods are available which are more rapid than routine methods for the analysis of $^{90}Sr/^{90}Y$ in urine (Appendix H). For the method utilising extraction chromatography, the time required for the analysis of an individual sample is up to 1 day from receipt of the sample at the laboratory, and the limit of detection is approximately 1 Bq/24-hour sample. A more rapid direct counting method is also available with an analysis time of approximately 6 hours and a limit of detection of 50 Bq /24-hour sample (Appendix H). The extraction chromatography method can be used to identify people of all ages who require medical assessment for samples taken up to at least 30 days after the incident. If more information becomes available on the properties of the contamination, it may be possible to increase the action levels so that the direct counting method can be used to identify everyone who requires medical assessment for samples collected up to at least 30 days after the incident.

Table 12 Action Levels for strontium-90/yttrium-90 in urine

Time between incident and sample collection (days)	Action Level (Bq/24-hour sample)		
	Age up to 10 years	Ages 10 years to 19 years	Age 20 years and older
1	16	38	97
2	9.2	22	57
3	7.8	18	40
4	7.2	16	32
5-6	6.4	14	28
7-8	5.9	13	24
9-10	5.7	12	22
11-12	5.3	11	20
13-14	4.9	10	19
15-16	4.7	10	19
17-18	4.4	9.6	18
19-20	4.4	9.3	17
21-30	3.7	8.1	15

5.2.5 Iodine-131 (^{131}I)

1. Has ^{131}I been identified with a high degree of confidence? If not, urgently obtain expert help to identify the radionuclide positively. Help should be sought from a nuclear site operator, research organisation, university or similar local organisation with radiation protection expertise. Until the radionuclide is identified follow the procedure in Section 5.2.1

2. Estimate the elapsed time since intake of radioactive material. It is important to have an estimate of the time between the original contamination event and the time that measurements are made which is as reliable as possible. The day that the incident is discovered may not be the day of intake. Iodine-131 in thyroid measurements must not be made in people until 8 hours after the incident to allow time for the radionuclide to reach the thyroid.

3. Obtain a suitable radiation monitor. Choose a monitor from Table 13. Appendix A shows photographs and gives operating instructions for each radiation monitor. If these monitors are not available then choose one from Table 14.

Table 13 Recommended Radiation Monitors for iodine-131

Radiation Monitor	Range of times between intake and measurement when monitor is suitable (days)
Thermo Mini 900 with 44A probe	0-30

Table 14 Alternative Radiation Monitors for iodine-131[1]

Radiation Monitor	Range of times between intake and measurement when monitor is suitable (days)
RADOS RDS 200 with GMP-11 probe	0-20 (0-8 for children aged up to 10 years, 0-20 for ages 10 to 19 years)
ROTEM RAM Gene-1	0-30 (0-12 for children aged up to 10 years)

[1]These instruments are very sensitive to beta activity and as the maximum range of beta radiation from ^{131}I in air is approximately 200 cm then if activity is present on the skin or clothing this would have a large effect on the Net Count Rate.

4. Perform battery check and check source measurement. Turn on your radiation survey monitor, and perform a check of the detector battery function (see Appendix A). If the detector has multiple display settings, select those given in Appendix A. If a portable radioactive check source is available, move that source closer to and further away from the front of the detector surface to ensure that the registered count rate increases and decreases accordingly. The procedure in Appendix B can also be used to check that individual radiation monitors are working properly.

5. Establish the background count rate for your detector and monitoring location. Take an initial monitor reading of the environment in the general vicinity of where you will be surveying people. This reading should be obtained prior to the

introduction of any potentially contaminated individuals into the monitoring location. Record this value as your Background Count Rate (BCR) in units of counts per second (cps) or counts per minute (cpm).

6. Ensure adequate distance between person being monitored and people waiting. Each person should be taken individually to the monitoring area maintaining a distance of about 5-10 m between the person being monitored and other potentially contaminated people. In the case of young children a parent or guardian can be closer than this, but the parent or guardian should be monitored first to ensure their presence will not affect the measurement of the child.

7. Position the detector. Hold the detector close to the skin at the base of the front of the neck (see Figure C3 and C4 in Appendix C).

8. Record the measurement. Wait for about 10 seconds for the reading to stabilise and record the highest indicated detector count rate. Note the units (cps or cpm). The background count rate or BCR (see Step 5 above) must be subtracted from the Total Count Rate (TCR) measurement, to yield a Net Count Rate (NCR):

Net Count Rate (NCR) = Total Count Rate (TCR) – Background Count Rate (BCR)

9. Compare the NCR to the action levels. The Net Count Rate (NCR) from Step 8 should be compared with the action level values in Tables 15-17. Select the table for the appropriate age group and the column for the instrument used. Read off the action level for the number of days since intake. If the NCR is greater than or the same as this value then do the following:

(1) Urgently refer the person for medical assessment

(2) Arrange for accurate measurements to be made

If stable iodine has been taken by the person either before or within 12 hours after intake then these action levels must not be used. The NCR can be converted to activity of ^{131}I in the thyroid using the calibration factor given in Appendix A. If stable iodine was taken by the person more than 12 hours after the intake it will not be effective and it can be assumed that stable iodine has not been taken (Kovari and Morrey, 1994).

Table 15 Action Levels for Children aged up to 10 years for iodine-131

Time between incident and measurement (days)	Action Level		
	RADOS RDS 200 with GMP-11 probe (cps)	ROTEC RAM Gene-1 (cps)	Thermo Mini 900 with 44A probe (cps)
0	5	9	400
1	10	17	800
2	10	18	900
3	9	16	800
4	8	15	700
5	8	13	600
6	7	12	600
7	6	10	500
8	5	9	400
9	-	8	400
10	-	7	350
11-12	-	6	300
13-14	-	-	200
15-16	-	-	200
17-18	-	-	150
19-20	-	-	120
21-30	-	-	40

Values for recommended radiation monitors are highlighted.

A '-' means that the monitor is not suitable for the combination of radionuclide, age group and time between intake and monitoring

Table 16 Action Levels for ages 10 to 19 years for iodine-131

Time between incident and measurement (days)	Action Level		
	RADOS RDS 200 with GMP-11 probe (cps)	ROTEC RAM Gene-1 (cps)	Thermo Mini 900 with 44A probe (cps)
0	18	32	1600
1	32	55	3000
2	34	59	3000
3	32	55	3000
4	29	50	2500
5	28	48	2500
6	26	44	2500
7	23	40	2000
8	22	38	2000
9	21	36	2000
10	18	32	1500
11-12	16	27	1400
13-14	13	23	1200
15-16	12	20	1000
17-18	10	17	800
19-20	8	14	700
21-30	-	6	300

Values for recommended radiation monitors are highlighted.
A '-' means that the monitor is not suitable for the combination of radionuclide, age group and time between intake and monitoring

Table 17 Action Levels for age 20 and older for iodine-131

Time between incident and measurement (days)	Action Level		
	RADOS RDS 200 with GMP-11 probe (cps)	ROTEC RAM Gene-1 (cps)	Thermo Mini 900 with 44A probe (cps)
0	17	30	1600
1	30	53	3000
2	32	55	3000
3	30	52	2500
4	28	48	2500
5	26	45	2000
6	24	42	2000
7	22	39	2000
8	21	36	2000
9	19	33	1500
10	18	31	1600
11-12	15	26	1500
13-14	13	23	1200
15-16	11	20	1000
17-18	9	17	800
19-20	8	14	700
21-30	-	6	300

Values for recommended radiation monitors are highlighted.
A '-' means that the monitor is not suitable for the combination of radionuclide, age group and time between intake and monitoring

10. ***Record results of each measurement.*** For each person monitored, sufficient information should be recorded to allow the person to be uniquely identified. This must include full name, date of birth and postcode. As a minimum, the instrument used, NCR, BCR and whether the action level has been exceeded must be recorded. A template record form is shown in Appendix D.

11. ***Additional information.*** Additional information regarding the use of hand-held radiation monitors is given in Appendix E.

5.2.6 Caesium-137 (^{137}Cs)

1. Has ^{137}Cs been identified with a high degree of confidence? If not, urgently obtain expert help to identify the radionuclide positively. Help should be sought from a nuclear site operator, research organisation, university or similar local organisation with radiation protection expertise. Until the radionuclide is identified follow the procedure in Section 5.2.1

2. Estimate the elapsed time since intake of radioactive material. It is important to have an estimate of the time between the original contamination event and the time that measurements are made which is as reliable as possible. The day that the incident is discovered may not be the day of intake.

3. Obtain a suitable radiation monitor. Choose a monitor from Table 18. Appendix A shows photographs and gives operating instructions for each radiation monitor.

Table 18 Recommended Radiation Monitors for caesium-137

Radiation Monitor	Range of times between intake and measurement when monitor is suitable (days)
SAIC Exploranium GR-135	0-30 (0-6 for children aged up to 10 years; 0-7 for ages 10 to 19 years)
Thermo Mini 900 with 44A probe	0-30 (0-6 for children aged up to 10 years ; 0-14 days for ages 10 to 19 years)
TSA systems PRM-470CS	0-20 (0-5 for children aged up to 10 years; 0-7 for ages 10 to 19 years)

4. Perform battery check and check source measurement. Turn on your radiation survey monitor, and perform a check of the detector battery function (see Appendix A). If the detector has multiple display settings, select those given in Appendix A. If a portable radioactive check source is available, move that source closer to and further away from the front of the detector surface to ensure that the registered count rate increases and decreases accordingly. The procedure in Appendix B can also be used to check that individual radiation monitors are working properly.

5. Establish the background count rate for your detector and monitoring location. Take an initial monitor reading of the environment in the general vicinity of where you will be surveying people. This reading should be obtained prior to the introduction of any potentially contaminated individuals into the monitoring location. Record this value as your Background Count Rate (BCR) in units of counts per second (cps) or counts per minute (cpm).

6. Ensure adequate distance between person being monitored and people waiting. Each person should be taken individually to the monitoring area maintaining a distance of about 5-10 m between the person being monitored and other potentially contaminated people. In the case of young children a parent or guardian can

be closer than this, but the parent or guardian should be monitored first to ensure their presence will not affect the measurement of the child.

7. ***Position the detector.*** Hold the detector 30 cm from the centre of the chest (see Figure C1 and C2 in Appendix C). The orientation of the detector should be as detailed in Appendix A.

8. ***Record the measurement.*** Wait for about 10 seconds for the reading to stabilise and record the highest indicated detector count rate. Note the units (cps or cpm). The background count rate or BCR (see Step 5 above) must be subtracted from the Total Count Rate (TCR) measurement, to yield a Net Count Rate (NCR):

Net Count Rate (NCR) = Total Count Rate (TCR) – Background Count Rate (BCR)

9. ***Compare the NCR to the action levels.*** The Net Count Rate (NCR) from Step 8 should be compared with the action level values in Tables 19-21. Select the table for the appropriate age group and the column for the instrument used. Read off the action level for the number of days since intake. If the NCR is greater than or the same as this value then do the following:

(1) Urgently refer the person for medical assessment

(2) Arrange for accurate measurements to be made

Table 19 Action Levels for Children aged up to 10 years for caesium-137

Time between incident and measurement (days)	Action Level		
	SAIC Exploranium GR-135 (cps)	Thermo Mini 900 with 44A probe (cps)	TSA systems PRM-470CS (cps)
0	150	20	230
1	150	20	200
2	130	20	180
3	130	15	170
4	120	15	160
5	120	15	150
6	100	12	-
7	-	-	-
8	-	-	-
9	-	-	-
10	-	-	-
11-12	-	-	-
13-14	-	-	-
15-16	-	-	-
17-18	-	-	-
19-20	-	-	-
21-30	-	-	-

Values for recommended radiation monitors are highlighted.
A '-' means that the monitor is not suitable for the combination of radionuclide, age group and time between intake and monitoring

Table 20 Action Levels for ages 10 to 19 years for caesium-137

Time between incident and measurement (days)	Action Level		
	SAIC Exploranium GR-135 (cps)	Thermo Mini 900 with 44A probe (cps)	TSA systems PRM-470CS (cps)
0	260	35	330
1	250	35	310
2	230	30	290
3	210	30	260
4	210	30	260
5	200	25	250
6	170	25	220
7	110	15	140
8	-	10	-
9	-	10	-
10	-	10	-
11-12	-	10	-
13-14	-	10	-
15-16	-	-	-
17-18	-	-	-
19-20	-	-	-
21-30	-	-	-

Values for recommended radiation monitors are highlighted.
A '-' means that the monitor is not suitable for the combination of radionuclide, age group and time between intake and monitoring

Table 21 Action Levels for age 20 years and older for caesium-137

Time between incident and measurement (days)	Action Level		
	SAIC Exploranium GR-135 (cps)	Thermo Mini 900 with 44A probe (cps)	TSA systems PRM-470CS (cps)
0	320	70	390
1	320	70	380
2	290	65	350
3	270	60	320
4	260	60	320
5	250	60	310
6	230	50	280
7	170	40	200
8	140	30	170
9	130	30	160
10	130	30	150
11-12	120	30	150
13-14	120	30	150
15-16	120	25	140
17-18	120	25	140
19-20	120	25	140
21-30	110	25	-

Values for recommended radiation monitors are highlighted.
A '-' means that the monitor is not suitable for the combination of radionuclide, age group and time between intake and monitoring

10. ***Record results of each measurement.*** For each person monitored, sufficient information should be recorded to allow the person to be uniquely identified. This must include full name, date of birth and postcode. As a minimum, the instrument used, NCR, BCR and whether the action level has been exceeded must be recorded. A template record form is shown in Appendix D.

11. ***Additional information.*** Additional information regarding the use of hand-held radiation monitors is given in Appendix E.

5.2.7 Iridium-192 (^{192}Ir)

1. Has ^{192}Ir been identified with a high degree of confidence? If not, urgently obtain expert help to identify the radionuclide positively. Help should be sought from a nuclear site operator, research organisation, university or similar local organisation with radiation protection expertise. Until the radionuclide is identified follow the procedure in Section 5.2.1

2. Estimate the elapsed time since intake of radioactive material. It is important to have an estimate of the time between the original contamination event and the time that measurements are made which is as reliable as possible. The day that the incident is discovered may not be the day of intake.

3. Obtain a suitable radiation monitor. Choose a monitor from Table 22. Appendix A shows photographs and gives operating instructions for each radiation monitor. If these monitors are not available then choose one from Table 23.

Table 22 Recommended Radiation Monitors for iridium-192

Radiation Monitor	Range of times between intake and measurement when monitor is suitable (days)
SAIC Exploranium GR-135	0-30
Thermo Mini 900 with 44A probe	0-30
TSA systems PRM-470CS	0-30

Table 23 Alternative Radiation Monitors for iridium-192[1]

Radiation Monitor	Range of times between intake and measurement when monitor is suitable (days)
ROTEM RAM Gene-1	0-8 (0-3 days for children aged up to 10 years; 0-6 for ages 10 to 19 years)

[1] These instruments are very sensitive to beta activity and as the maximum range of beta radiation from ^{192}Ir in air is approximately 200 cm then if activity is present on the skin or clothing this would have a large effect on the Net Count Rate.

4. Perform battery check and check source measurement. Turn on your radiation survey monitor, and perform a check of the detector battery function (see Appendix A). If the detector has multiple display settings, select those given in Appendix A. If a portable radioactive check source is available, move that source closer to and further away from the front of the detector surface to ensure that the registered count rate increases and decreases accordingly. The procedure in Appendix B can also be used to check that individual radiation monitors are working properly.

5. Establish the background count rate for your detector and monitoring location. Take an initial monitor reading of the environment in the general vicinity of where you will be surveying people. This reading should be obtained prior to the introduction of any potentially contaminated individuals into the monitoring location. Record this value as your Background Count Rate (BCR) in units of counts per second (cps) or counts per minute (cpm).

6. Ensure adequate distance between person being monitored and people waiting. Each person should be taken individually to the monitoring area maintaining a distance of about 5-10 m between the person being monitored and other potentially contaminated people. In the case of young children a parent or guardian can be closer than this, but the parent or guardian should be monitored first to ensure their presence will not affect the measurement of the child.

7. Position the detector. Hold the detector 30 cm from the centre of the chest (see Figure C1 and C2 in Appendix C). The orientation of the detector should be as detailed in Appendix A.

8. Record the measurement. Wait for about 10 seconds for the reading to stabilise and record the highest indicated detector count rate. Note the units (cps or cpm). The background count rate or BCR (see Step 5 above) must be subtracted from the Total Count Rate (TCR) measurement, to yield a Net Count Rate (NCR):

Net Count Rate (NCR) = Total Count Rate (TCR) – Background Count Rate (BCR)

9. Compare the NCR to the action levels. The Net Count Rate (NCR) from Step 8 should be compared with the action level values in Tables 24-26. Select the table for the appropriate age group and the column for the instrument used. Read off the action level for the number of days since intake. If the NCR is greater than or the same as this value then do the following:

(1) Urgently refer the person for medical assessment

(2) Arrange for accurate measurements to be made

Table 24 Action Levels for Children aged up to 10 years old for iridium-192

	Action Level			
Time between incident and measurement (days)	ROTEC RAM Gene-1 (cps)	SAIC Exploranium GR-135 (cps)	Thermo Mini 900 with 44A probe (cps)	TSA systems PRM-470CS (cps)
0	11	1300	300	1700
1	11	1200	300	1600
2	7	860	200	1100
3	5	650	150	850
4	-	560	100	740
5	-	500	100	660
6	-	360	70	480
7	-	260	60	340
8	-	200	40	270
9	-	180	30	230
10	-	180	30	230
11-12	-	160	30	210
13-14	-	160	25	200
15-16	-	150	25	200
17-18	-	140	25	190
19-20	-	140	25	180
21-30	-	120	20	160

Values for recommended radiation monitors are highlighted.
A '-' means that the monitor is not suitable for the combination of radionuclide, age group and time between intake and monitoring

Table 25 Action Levels for ages 10 to 19 years for iridium-192

Time between incident and measurement (days)	Action Level			
	ROTEC RAM Gene-1 (cps)	SAIC Exploranium GR-135 (cps)	Thermo Mini 900 with 44A probe (cps)	TSA systems PRM-470CS (cps)
0	26	3300	600	4300
1	24	3000	600	3900
2	18	2300	400	3000
3	15	1900	400	2500
4	13	1700	300	2200
5	11	1400	300	1800
6	6	740	150	950
7	-	480	100	620
8	-	390	80	510
9	-	350	70	460
10	-	330	65	420
11-12	-	310	60	400
13-14	-	300	60	390
15-16	-	290	60	380
17-18	-	280	55	360
19-20	-	270	55	350
21-30	-	230	45	300

Values for recommended radiation monitors are highlighted.
A "-" means that the monitor is not suitable for the combination of radionuclide, age group and time between intake and monitoring

Table 26 Action Levels for age 20 years and older for iridium-192

Time between incident and measurement (days)	Action Level			
	ROTEC RAM Gene-1 (cps)	SAIC Exploranium GR-135 (cps)	Thermo Mini 900 with 44A probe (cps)	TSA systems PRM-470CS (cps)
0	38	4400	1300	5200
1	35	4000	1200	4800
2	27	3100	900	3700
3	23	2600	700	3100
4	20	2300	700	2700
5	19	2200	650	2600
6	10	1200	400	1400
7	7	790	200	930
8	6	640	200	750
9	-	570	150	670
10	-	540	150	630
11-12	-	520	150	600
13-14	-	510	150	580
15-16	-	490	140	550
17-18	-	470	140	540
19-20	-	450	130	520
21-30	-	380	100	450

Values for recommended radiation monitors are highlighted.
A "-" means that the monitor is not suitable for the combination of radionuclide, age group and time between intake and monitoring

10. ***Record results of each measurement.*** For each person monitored, sufficient information should be recorded to allow the person to be uniquely identified. This must include full name, date of birth and postcode. As a minimum, the instrument used, NCR, BCR and whether the action level has been exceeded must be recorded. A template record form is shown in Appendix D.

11. ***Additional information.*** Additional information regarding the use of hand-held radiation monitors is given in Appendix E.

5.2.8 Radium-226 (^{226}Ra)

The hand-held radiation monitors described in this guidance cannot be used as their sensitivity to ^{226}Ra internal contamination is inadequate. The sensitivity is inadequate because this radionuclide produces weakly penetrating radiation which is absorbed before reaching the detector.

External Contamination Monitoring

If external contamination monitoring using hand-held instruments has been carried out then people found to be contaminated should be given a high priority for internal contamination measurements. People could be prioritised for internal contamination measurements based on the level of external contamination found. If activity is detected on the face then this could indicate intake by inhalation has occurred.

Face Wipe and Nose Blow Samples

For suspected intakes by inhalation, these samples can be used to give a qualitative indication of whether an intake has occurred providing samples are taken soon after the incident. Absence of measurable activity must not be taken to imply the absence of an intake. Samples may be measured using hand-held instruments (zinc sulphide scintillation detector or dual phosphor detector[*]) and kept for laboratory analysis or if available measured with portable sample (total alpha) counting equipment. If decay products of ^{226}Ra are known to be present, then measurements with instruments which are sensitive to beta or gamma radiation should be considered. Appendix E gives additional information on the collection and use of face wipe and nose blow samples.

Measurements using External Detectors

Measurements of internal contamination using external detectors are possible using laboratory based facilities, although the availability of suitable equipment is very limited. These facilities are able to make measurements using low energy and low yield gamma-ray emissions. Contact HPA for details of where these measurements could be carried out.

Urine Measurements

Urine measurements can be used to quantify internal contamination. Instructions on how to provide a 24-hour urine sample are given in Appendix G. Information for laboratories who might conduct the urine sample analyses is given in Appendix H. The measured 24-hour urine activity should be compared with the action level values in Table 27. Select the column for the appropriate age group and read off the action level for the number of days since intake. If the measured activity is greater than or the same as this value then the person should be urgently referred for medical assessment.

It is unlikely that more than 20 samples per day could be analysed in the UK. This capacity could be maintained for many months and could be increased by sending samples to laboratories outside the UK.

[*] Other detector types which are suitable for beta contamination monitoring can be used, see Burgess (2001).

For the routinely used method for analysis of ^{226}Ra in urine the time required for the analysis of an individual sample is approximately 10 days from receipt of the sample at the laboratory, and the limit of detection is approximately 5 mBq/24-hour sample. There are no alternative more rapid methods currently available (Appendix H). The routine method can be used to identify people who require medical assessment when the following conditions are satisfied:

- People are aged 20 years and older and samples collected within 10 days of the incident
- People are aged from 10 years to 19 years and samples collected within 4 days of the incident
- People are aged up to 10 years and samples collected on the day after the incident

For samples collected outside these periods it is not possible to ensure everyone who requires medical assessment is identified. If more information becomes available on the properties of the contamination it may be possible to increase the action levels so that the routine method can be used to identify everyone who requires medical assessment for samples collected up to at least 30 days after the incident.

Table 27 Action Levels for radium-226 in urine

Time between incident and sample collection (days)	Action Level (mBq/24-hour sample)		
	Age up to 10 years	Ages 10 years to 19 years	Age 20 years and older
1	6.7	21	59
2	3.5	9.5	22
3	2.7	7.1	14
4	2.4	6.1	11
5-6	2.0	4.8	8.3
7-8	1.7	4.1	6.8
9-10	1.6	3.6	5.6
11-12	1.4	3.3	4.8
13-14	1.3	3.0	4.4
15-16	1.2	2.7	4.1
17-18	1.1	2.5	3.9
19-20	1.0	2.3	3.7
21-30	0.8	1.9	3.1

5.2.9 Thorium-228 (^{228}Th)

The hand-held radiation monitors described in this guidance cannot be used as their sensitivity to ^{228}Th internal contamination is inadequate. The sensitivity is inadequate because this radionuclide produces weakly penetrating radiation which is absorbed before reaching the detector.

External Contamination Monitoring

If external contamination monitoring using hand-held instruments has been carried out then people found to be contaminated should be given a high priority for internal contamination measurements. People could be prioritised for internal contamination measurements based on the level of external contamination found. If activity is detected on the face then this could indicate intake by inhalation has occurred.

Face Wipe and Nose Blow Samples

For suspected intakes by inhalation, these samples can be used to give a qualitative indication of whether an intake has occurred providing samples are taken soon after the incident. Absence of measurable activity must not be taken to imply the absence of an intake. Samples may be measured using hand-held instruments (zinc sulphide scintillation detector or dual phosphor detector[*]) and kept for laboratory analysis or if available measured with portable sample (total alpha) counting equipment. If decay products of thorium-228 are known to be present, then measurements with instruments which are sensitive to beta or gamma radiation should be considered. Appendix E gives additional information on the collection and use of face wipe and nose blow samples.

Measurements using External Detectors

Measurements of internal contamination using external detectors are possible using laboratory based facilities, although the availability of suitable equipment is very limited. Contact HPA for details of where these measurements could be carried out.

Urine Measurements

Urine measurements can be used to quantify internal contamination. Instructions on how to provide a 24-hour urine sample are given in Appendix G. Information for laboratories who might conduct the urine sample analyses is given in Appendix H. The measured 24-hour urine activity should be compared with the action level values in Table 28. Select the column for the appropriate age group and read off the action level for the number of days between the incident and sample collection. If the measured activity is greater than or the same as this value then the person should be urgently referred for medical assessment.

It is unlikely that more than 20 samples per day could be analysed in the UK using adapted routine methods. This capacity could be maintained for many months and could be increased by sending samples to laboratories outside the UK.

[*] Other detector types which are suitable for alpha contamination monitoring can be used, see Burgess (2001).

For the analysis of ^{228}Th in urine both a routine method and a more rapid method are available. For the rapid method the analysis time is approximately 24 hours from receipt of the sample at the laboratory and the limit of detection is 2 mBq/24-hour sample (Appendix H). The rapid method can be used to identify people who require medical assessment when the following conditions are satisfied:

- People are aged 20 years and older
- People are aged from 10 years to 19 years and samples collected within 2 days of the incident
- People are aged up to 10 years and samples collected on the day after the incident

For samples collected outside these periods it is not possible to ensure everyone who requires medical assessment is identified if the rapid method is used. If more information becomes available on the properties of the contamination, it may be possible to increase the action levels so that the rapid method can be used to identify everyone who requires medical assessment for samples collected up to at least 30 days after the incident.

For the routinely used method the time required for the analysis of an individual sample is up to 10 days from receipt of the sample at the laboratory, and the limit of detection is approximately 0.2 mBq/24-hour sample. It may be possible to reduce this analysis time by up to 50% depending on number of samples, and by using a 24-hour shift pattern; however this could not to be maintained for long. The routine method can be used to identify people of all ages who require medical assessment for samples taken up to at least 30 days after the incident.

Table 28 Action Levels for Thorium-228 in urine

Time between incident and sample collection (days)	Action Level (mBq/24-hour sample)		
	Age up to 10 years	Ages 10 years to 19 years	Age 20 years and older
1	3.9	9.8	23
2	1.1	3.0	7.1
3	0.73	1.9	4.5
4	0.62	1.7	3.9
5-6	0.52	1.4	3.3
7-8	0.46	1.3	3.0
9-10	0.42	1.2	2.8
11-12	0.40	1.1	2.7
13-14	0.38	1.1	2.6
15-16	0.36	1.1	2.5
17-18	0.35	1.0	2.4
19-20	0.34	1.0	2.4
21-30	0.29	0.89	2.1

5.2.10 Thorium-232 (^{232}Th)

The hand-held radiation monitors described in this guidance cannot be used as their sensitivity to ^{232}Th internal contamination is inadequate. The sensitivity is inadequate because this radionuclide produces weakly penetrating radiation which is absorbed before reaching the detector.

External Contamination Monitoring

If external contamination monitoring using hand-held instruments has been carried out then people found to be contaminated should be given a high priority for internal contamination measurements. People could be prioritised for internal contamination measurements based on the level of external contamination found. If activity is detected on the face then this could indicate intake by inhalation has occurred.

Face Wipe and Nose Blow Samples

For suspected intakes by inhalation, these samples can be used to give a qualitative indication of whether an intake has occurred providing samples are taken soon after the incident. Absence of measurable activity must not be taken to imply the absence of an intake. Samples may be measured using hand-held instruments (zinc sulphide scintillation detector or dual phosphor detector[*]) and kept for laboratory analysis or if available measured with portable sample (total alpha) counting equipment. If decay products of thorium-232 are known to be present, then measurements with instruments which are sensitive to beta or gamma radiation should be considered. Appendix E gives additional information on the collection and use of face wipe and nose blow samples.

Measurements using External Detectors

Measurements of internal contamination using external detectors are possible using external detectors using laboratory based facilities, although the availability of suitable equipment is very limited. Contact HPA for details of where these measurements could be carried out.

Urine Measurements

Urine measurements can be used to quantify internal contamination. Instructions on how to provide a 24-hour urine sample are given in Appendix G. Information for laboratories who might conduct the urine sample analyses is given in Appendix H. The measured 24-hour urine activity should be compared with the action level values in Table 29. Select the column for the appropriate age group and read off the action level for the number of days since intake. If the measured activity is greater than or the same as this value then the person should be urgently referred for medical assessment.

It is unlikely that more than 20 samples per day could be analysed in the UK using adapted routine methods. This capacity could be maintained for many months and could be increased by sending samples to laboratories outside the UK.

[*] Other detector types which are suitable for alpha contamination monitoring can be used, see Burgess (2001).

For the analysis of ^{232}Th in urine both a routine method and a more rapid method are available. For the rapid method the analysis time is approximately 24 hours from receipt of the sample at the laboratory and the limit of detection 2 mBq /24-hour sample (Appendix H). The rapid method can be used to identify people who require medical assessment when the following conditions are satisfied:

- People are aged 20 years and older and samples taken within 10 days of the incident
- People are aged from 10 years to 19 years and samples collected within 2 days of the incident
- People are aged up to 10 years and samples collected on the day after the incident

For samples collected outside these periods it is not possible to ensure everyone who requires medical assessment is identified if the rapid method is used. If more information becomes available on the properties of the contamination, it may be possible to increase the action levels so that the rapid method can be used to identify everyone who requires medical assessment for samples collected up to at least 30 days after the incident.

For the routinely used method the time required for the analysis of an individual sample is up to 10 days from receipt of the sample at the laboratory, and the limit of detection is approximately 0.2 mBq/24-hour sample. It may be possible to reduce this analysis time by up to 50% depending on number of samples, and by using a 24-hour shift pattern; however this could not to be maintained for long. The routine method can be used to identify people of all ages who require medical assessment for samples taken up to at least 30 days after the incident.

Table 29 Action Levels for Thorium-232 in urine

Time between incident and sample collection(days)	Action Level (mBq/24-hour sample)		
	Age up to 10 years	Ages 10 years to 19 years	Age 20 years and older
1	3.1	7.1	16
2	0.9	2.2	4.9
3	0.58	1.4	3.1
4	0.50	1.2	2.7
5-6	0.41	1.0	2.3
7-8	0.37	0.93	2.1
9-10	0.34	0.87	2.0
11-12	0.32	0.83	1.9
13-14	0.31	0.80	1.8
15-16	0.29	0.78	1.8
17-18	0.28	0.76	1.7
19-20	0.28	0.74	1.7
21-30	0.24	0.67	1.5

5.2.11 Neptunium-237/Protactinium-233 (^{237}Np/^{233}Pa)

The hand-held radiation monitors described in this guidance cannot be used as their sensitivity to ^{237}Np/^{233}Pa internal contamination is inadequate. The sensitivity is inadequate because this radionuclide produces weakly penetrating radiation which is absorbed before reaching the detector.

External Contamination Monitoring

If external contamination monitoring using hand-held instruments has been carried out then people found to be contaminated should be given a high priority for internal contamination measurements. People could be prioritised for internal contamination measurements based on the level of external contamination found. If activity is detected on the face then this could indicate intake by inhalation has occurred.

Face Wipe and Nose Blow Samples

For suspected intakes by inhalation, these samples can be used to give a qualitative indication of whether an intake has occurred providing samples are taken soon after the incident. Absence of measurable activity must not be taken to imply the absence of an intake. Samples may be measured using hand-held instruments (zinc sulphide scintillation detector or dual phosphor detector[*]) and kept for laboratory analysis or if available measured with portable sample (total alpha) counting equipment. If ^{233}Pa is known to be present then a hand-held instrument sensitive to gamma radiation should be used. Appendix E gives additional information on the collection and use of face wipe and nose blow samples.

Measurements using External Detectors

Measurements of internal contamination using external detectors are possible using laboratory based facilities, although the availability of suitable equipment is very limited. Contact HPA for details of where these measurements could be carried out.

Urine Measurements

Urine measurements can be used to quantify internal contamination. Instructions on how to provide a 24-hour urine sample are given in Appendix G. Information for laboratories who might conduct the urine sample analyses is given in Appendix H. The measured 24-hour urine activity should be compared with the action level values in Table 30. Select the column for the appropriate age group and read off the action level for the number of days between the incident and sample collection. If the measured activity is greater than or the same as this value then the person should be urgently referred for medical assessment.

It is unlikely that more than 20 samples per day could be analysed in the UK using adapted routine methods. This capacity could be maintained for many months and could be increased by sending samples to laboratories outside the UK.

[*] Other detector types which are suitable for alpha contamination monitoring can be used, see Burgess (2001).

A rapid method is available for the analysis of $^{237}Np/^{233}Pa$ in urine. For this method the time required for the analysis of an individual sample is approximately 30 hours from receipt of the sample at the laboratory, and the limit of detection is approximately 2 mBq/24-hour sample (Appendix H). The rapid method can be used to identify people of all ages who require medical assessment for samples taken up to at least 30 days after the incident.

Table 30 Action Levels for Neptunium-237/Protactinium-233 in urine

Time between incident and sample collection (days)	Action Level (mBq/24-hour sample)		
	Age up to 10 years	Ages 10 years to 19 years	Age 20 years and older
1	85	290	610
2	25	91	190
3	16	56	120
4	12	43	91
5-6	8.7	32	67
7-8	7.2	27	57
9-10	6.5	24	52
11-12	6.0	23	42
13-14	5.8	20	31
15-16	5.5	17	26
17-18	5.3	15	23
19-20	5.2	14	21
21-30	4.0	10	16

5.2.12 Plutonium-238 (^{238}Pu)

The hand-held radiation monitors described in this guidance cannot be used as their sensitivity to ^{238}Pu internal contamination is inadequate. The sensitivity is inadequate because this radionuclide produces weakly penetrating radiation which is absorbed before reaching the detector.

External Contamination Monitoring

If external contamination monitoring using hand-held instruments has been carried out then people found to be contaminated should be given a high priority for internal contamination measurements. People could be prioritised for internal contamination measurements based on the level of external contamination found. If activity is detected on the face then this could indicate intake by inhalation has occurred.

Face Wipe and Nose Blow Samples

For suspected intakes by inhalation, these samples can be used to give a qualitative indication of whether an intake has occurred providing samples are taken soon after the incident. Absence of measurable activity must not be taken to imply the absence of an intake. Samples may be measured using hand-held instruments (zinc sulphide scintillation detector or dual phosphor detector[*]) and kept for laboratory analysis or if available measured with portable sample (total alpha) counting equipment. Appendix E gives additional information on the collection and use of face wipe and nose blow samples.

Measurements using External Detectors

Measurements of internal contamination using external detectors are possible using laboratory based facilities, although the availability of suitable equipment is very limited. Contact HPA for details of where these measurements could be carried out.

Urine Measurements

Urine measurements can be used to quantify internal contamination. Instructions on how to provide a 24-hour urine sample are given in Appendix G. Information for laboratories who might conduct the urine sample analyses is given in Appendix H. The measured 24-hour urine activity should be compared with the action level values in Table 31. Select the column for the appropriate age group and read off the action level for the number of days since intake. If the measured activity is greater than or the same as this value then the person should be urgently referred for medical assessment.

It is unlikely that more than 60 samples per day could be analysed in the UK using adapted routine methods. This capacity could be maintained for many months and could be increased by sending samples to laboratories outside the UK.

For the analysis of ^{238}Pu in urine both a routine method and a more rapid method are available. For the rapid method the analysis time is approximately 12 hours from receipt of the sample at the laboratory and the limit of detection is 2 mBq/24-hour sample

[*] Other detector types which are suitable for alpha contamination monitoring can be used, see Burgess (2001).

(Appendix H). The rapid method can be used to identify people who require medical assessment when the following conditions are satisfied:

- People are aged 20 years and older
- People are aged from 10 years to 19 years and samples collected within 10 days of the incident
- People are aged up to 10 years and samples collected within 2 days of the incident

For samples collected outside these periods it is not possible to ensure everyone who requires medical assessment is identified if the rapid method is used. If more information becomes available on the properties of the contamination, it may be possible to increase the action levels so that the rapid method can be used to identify everyone who requires medical assessment for samples collected at up to at least 30 days after the incident.

For the routinely used method the analysis time for an individual sample is up to 10 days from receipt of the sample at the laboratory, and the limit of detection is approximately 0.2 mBq/24-hour sample. It may be possible to reduce this analysis time by up to 50% depending on number of samples, and by using a 24-hour shift pattern; however this could not to be maintained for long. The routine method can be used to identify people of all ages who require medical assessment for samples taken up to at least 30 days after the incident.

Table 31 Action Levels for Plutonium-238 in urine

Time between incident and sample collection (days)	Action Level (mBq/24-hour sample)		
	Age up to 10 years	Ages 10 years to 19 years	Age 20 years and older
1	4.7	11	16
2	2.8	7.1	10
3	1.8	4.8	6.8
4	1.4	3.7	5.3
5-6	0.95	2.7	3.9
7-8	0.76	2.3	3.3
9-10	0.66	2.0	3.0
11-12	0.61	1.9	2.8
13-14	0.58	1.9	2.7
15-16	0.56	1.8	2.6
17-18	0.54	1.8	2.6
19-20	0.53	1.8	2.6
21-30	0.49	1.7	2.5

5.2.13 Americium-241 (^{241}Am)

The hand-held radiation monitors described in this guidance cannot be used as their sensitivity to ^{241}Am internal contamination is inadequate. The sensitivity is inadequate because this radionuclide produces weakly penetrating radiation and a significant proportion is absorbed before reaching the detector.

External Contamination Monitoring

If external contamination monitoring using hand-held instruments has been carried out then people found to be contaminated should be given a high priority for internal contamination measurements. People could be prioritised for internal contamination measurements based on the level of external contamination found. If activity is detected on the face then this could indicate intake by inhalation has occurred.

Face Wipe and Nose Blow Samples

For suspected intakes by inhalation, these samples can be used to give a qualitative indication of whether an intake has occurred providing samples are taken soon after the incident. Absence of measurable activity must not be taken to imply the absence of an intake. Samples may be measured using hand-held instruments (sodium-iodide (NaI) based) and kept for laboratory analysis or if available measured with portable sample counting equipment sensitive to low energy gamma-rays. Appendix E gives additional information on the collection and use of face wipe and nose blow samples.

Measurements using External Detectors

Measurements of internal contamination using external detectors are possible using laboratory based facilities, although the availability of suitable equipment is very limited. Contact HPA for details of where these measurements could be carried out.

Urine Measurements

Urine measurements can be used to quantify internal contamination. Instructions on how to provide a 24-hour urine sample are given in Appendix G. Information for laboratories who might conduct the urine sample analyses is given in Appendix H. The measured 24-hour urine activity should be compared with the action level values in Table 32. Select the column for the appropriate age group and read off the action level for the number of days since intake. If the measured activity is greater than or the same as this value then the person should be urgently referred for medical assessment.

It is unlikely that more than 40 samples per day could be analysed in the UK using adapted routine methods. This capacity could be maintained for many months and could be increased by sending samples to laboratories outside the UK.

For the analysis of ^{241}Am in urine a more rapid method is available than standard methods. For the rapid method the time required for the analysis of an individual sample is up approximately to 24 hours from receipt of the sample at the laboratory, and the limit of detection is approximately 2 mBq/24-hour sample (Appendix H). The rapid method can be used to identify people of all ages who require medical assessment for samples taken up to at least 30 days after the incident.

Table 32 Action Levels for Americium-241 in urine

Time between incident and sample collection (days)	Action Level (mBq/24-hour sample)		
	Age up to 10 years	Ages 10 years to 19 years	Age 20 years and older
1	46	98	140
2	9.2	21	29
3	6.0	14	20
4	4.6	11	16
5-6	3.8	9.0	13
7-8	3.5	8.5	12
9-10	3.3	8.1	12
11-12	3.1	7.8	12
13-14	3.0	7.5	11
15-16	2.9	7.3	11
17-18	2.7	7.1	10
19-20	2.6	6.9	10
21-30	2.2	6.0	9.0

5.2.14 Californium-252 (^{252}Cf)

The hand-held radiation monitors described in this guidance cannot be used as their sensitivity to ^{252}Cf internal contamination is inadequate. The sensitivity is inadequate because this radionuclide produces weakly penetrating radiation which is absorbed before reaching the detector.

External Contamination Monitoring

If external contamination monitoring using hand-held instruments has been carried out then people found to be contaminated should be given a high priority for internal contamination measurements. People could be prioritised for internal contamination measurements based on the level of external contamination found. If activity is detected on the face then this could indicate intake by inhalation has occurred.

Face Wipe and Nose Blow Samples

For suspected intakes by inhalation, these samples can be used to give a qualitative indication of whether an intake has occurred providing samples are taken soon after the incident. Absence of measurable activity must not be taken to imply the absence of an intake. Samples may be measured using hand-held instruments (zinc sulphide scintillation detector or dual phosphor detector[*]) and kept for laboratory analysis or if available measured with portable sample (total alpha) counting equipment. Appendix E gives additional information on the collection and use of face wipe and nose blow samples.

Urine Measurements

Urine measurements can be used to quantify internal contamination. Instructions on how to provide a 24-hour urine sample are given in Appendix G. Information for laboratories who might conduct the urine sample analyses is given in Appendix H. The measured 24-hour urine activity should be compared with the action level values in Table 33. Select the column for the appropriate age group and read off the action level for the number of days since intake. If the measured activity is greater than or the same as this value then the person should be urgently referred for medical assessment.

It is unlikely that more than 40 samples per day could be analysed in the UK using adapted routine methods. This capacity could be maintained for many months and could be increased by sending samples to laboratories outside the UK.

For the analysis of ^{252}Cf in urine both a routine method and a more rapid method are available. For the rapid method the analysis time from receipt of the sample at the laboratory is approximately 24 hours and the limit of detection 2 mBq/24-hour sample (Appendix H). The rapid method can be used to identify people who require medical assessment when the following conditions are satisfied:

- People are aged 20 years and older and samples collected within 4 days of the incident

[*] Other detector types which are suitable for alpha contamination monitoring can be used, see Burgess (2001).

- People are aged from 10 years to 19 years and samples collected within 3 days of the incident
- People are aged up to 10 years and samples collected within 2 days of the incident

For samples collected outside these periods it is not possible to ensure everyone who requires medical assessment is identified if the rapid method is used. If more information becomes available on the properties of the contamination, it may be possible to increase the action levels so that the rapid method can be used to identify everyone who requires medical assessment for samples collected up to at least 30 days after the incident.

For the routinely used method the time required for the analysis of an individual sample is up to 10 days from receipt of the sample at the laboratory, and the limit of detection is approximately 0.2 mBq/24-hour sample. It may be possible to reduce this analysis time by up to 50% depending on number of samples, and by using a 24-hour shift pattern; however this could not to be maintained for long. The routine method can be used to identify people of all ages who require medical assessment for samples taken up to at least 30 days after the incident.

Table 33 Action Levels for Californium-252 in urine

Time between incident and sample collection (days)	Action Level (mBq/24-hour sample)		
	Age up to 10 years	Ages 10 years to 19 years	Age 20 years and older
1	26	61	94
2	4.5	12	18
3	1.6	4.4	7.0
4	0.57	1.6	2.4
5-6	0.33	0.89	1.4
7-8	0.33	0.89	1.4
9-10	0.33	0.89	1.4
11-12	0.33	0.88	1.3
13-14	0.33	0.88	1.3
15-16	0.33	0.88	1.3
17-18	0.33	0.88	1.3
19-20	0.33	0.87	1.3
21-30	0.32	0.86	1.3

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APPENDIX A **Radiation Monitors**

A1 THERMO MINI 900 WITH 44A PROBE

Type: Small sodium iodide detector

Operating Instructions

1. Remove cap
2. Turn rotary switch to first position ‘battery check’. If needle does not indicate in the green part of the display then replace battery and re-start procedure.
3. Turn rotary dial to extreme clockwise position. Wait for a few seconds and ensure the background count rate is approximately 5 counts per second.
4. Check response with a check-source if available (see Appendix B).
5. Instrument is now ready for measurements

The calibration factors in Table A1 are provided to allow experienced radiation monitoring staff to estimate activities of radionuclides in the body (see Appendix C1 for whole body measurements and Appendix C2 for measurements of ^{131}I in the thyroid).

Table A1 Calibration Factors (cps/kBq) for Thermo Mini 900 with 44A probe[1]

Age, years	Cobalt-60 (^{60}Co)	Selenium-75 (^{75}Se)	Caesium-137 (^{137}Cs)	Iridium-192 (^{192}Ir)	Iodine-131 (^{131}I)
20+	0.10	0.26	0.071	0.21	5.8
16	0.15	0.31	0.097	0.27	11
14	0.09	0.24	0.063	0.19	11
11	0.09	0.27	0.063	0.2	11
8	0.09	0.31	0.066	0.21	11
4	0.10	0.35	0.075	0.24	11
0.75	0.11	0.43	0.081	0.28	11
0.25	0.14	0.48	0.11	0.34	11

[1] Calibration factors are for calculation of whole body activity except for ^{131}I where it is for thyroid activity

A2 ROTEM RAM GENE-1

Type: GM detector

Operating Instructions

1. Turn instrument on. If instrument fails to switch on, change batteries and re-start procedure
2. Perform a function test as follows:
    a. Turn instrument on;
    b. Ensure that the audio sounds continuously for approximately 1 second;
    c. Ensure that the RATE LED illuminates continuously for approximately 1 second;
    d. Ensure that the liquid crystal display shows 8.8:8.8
3. Set the instrument to the contamination mode – CAP OFF
4. Ensure that the CONTAMINATION LED is illuminated continuously;

5. Observe for at least 10 seconds and ensure that the audio bleeps and the RATE LED illuminates intermittently;
6. Ensure that the background count rate (BCR) is between 0 and 1 count per second
7. Check response with a check-source if available (see Appendix B).
8. Instrument is now ready for measurements

Warning

This type of detector is very sensitive to beta activity and so if beta contamination is present on the skin or clothing then this may greatly increase the count rate measured for a contaminated person. So it is particularly important that external contamination is removed before the measurement is made.

The calibration factors in Table A2 are provided to allow experienced radiation monitoring staff to estimate activities of radionuclides in the body (see Appendix C1 for whole body measurements and Appendix C2 for measurements of ^{131}I in the thyroid).

Table A2 Calibration Factors (cps/kBq) for ROTEM RAM Gene-1[1]

Age, years	Cobalt-60 (^{60}Co)	Selenium-75 (^{75}Se)	Caesium-137 (^{137}Cs)	Iridium-192 (^{192}Ir)	Iodine-131 (^{131}I)
20+	0.012	0.0062	0.0042	0.0087	0.11
16	0.012	0.0071	0.0039	0.0085	0.21
14	0.011	0.0058	0.0036	0.0078	0.21
11	0.010	0.0065	0.0038	0.0079	0.21
8	0.014	0.007	0.0052	0.010	0.21
4	0.016	0.0097	0.0053	0.0099	0.21
0.75	0.020	0.01	0.0064	0.012	0.21
0.25	0.020	0.012	0.0066	0.013	0.21

[1] Calibration factors are for calculation of whole body activity except for ^{131}I where it is for thyroid activity

A3 RADOS RDS 200 WITH GMP-11 PROBE

Type: GM detector

Operating Instructions

1. Remove metal cover from connector at handle end and attach probe.
2. Remove probe cover.
3. Press the POWER button to switch on. Wait until instrument automatically enters cps mode.
4. Make sure that the battery low indicator is not shown. If it is replace the batteries.
5. Ensure that the background count rate (BCR) is approximately 1 count per second
6. Check response with a check-source if available (see Appendix B).
7. Instrument is now ready for measurements

Warning

This type of detector is very sensitive to beta activity and so if beta contamination is present on the skin or clothing then this may greatly increase the count rate measured for a contaminated person. So it is particularly important that external contamination is removed before the measurement is made.

The calibration factors in Table A3 are provided to allow experienced radiation monitoring staff to estimate activities of radionuclides in the body (see Appendix C1 for whole body measurements and Appendix C2 for measurements of ^{131}I in the thyroid).

Table A3 Calibration Factors (cps/kBq) for RADOS RDS 200 with GMP-11 probe[1]

Age, years	Cobalt-60 (^{60}Co)	Selenium-75 (^{75}Se)	Caesium-137 (^{137}Cs)	Iridium-192 (^{192}Ir)	Iodine-131 (^{131}I)
20+	0.012	0.0078	0.0050	0.009	0.063
16	0.011	-	0.0047	-	0.12
14	0.013	0.013	0.0044	0.010	0.12
11	-	0.0086	-	0.011	0.12
8	0.014	0.010	0.0051	0.013	0.12
4	0.015	0.012	0.0064	0.013	0.12
0.75	-	0.014	-	0.016	0.12
0.25	0.020	-	0.0088	-	0.12

[1]Calibration factors are for calculation of whole body activity except for ^{131}I where it is for thyroid activity

A4 APTEC-NRC ADM-300 WITH BSP-100 PROBE

Type: Thin plastic scintillator with thin window

Operating Instructions

1. Remove the probe cover.
2. Press and hold the POWER button until the instrument responds.
3. Press ↑ to change the mode to “c/min B+G”. Response is given in counts per minute. This instrument requires a lengthy (~ 30 second) stabilisation time when changing from a low to high (or vice versa) count rate.
4. Make sure that the battery low indicator is not shown. If it is replace the batteries.
5. Ensure that the background count rate (BCR) is approximately 180 counts per minute
6. Check response with a check-source if available (see Appendix B).

7. Instrument is now ready for measurements. The detector window should face the person for measurements.

8. Press and hold the POWER button to switch the instrument off.

Warning

This type of detector is very sensitive to beta activity and so if beta contamination is present on the skin or clothing then this may greatly increase the count rate measured for a contaminated person.

The calibration factors in Table A4 are provided to allow experienced radiation monitoring staff to estimate activities of radionuclides in the body (see Appendix C1 for whole body measurements)

Table A4 Calibration Factors (cpm/kBq) for APTEC-NRC ADM-300 with BSP-100 probe[1]

Age, years	Cobalt-60 (^{60}Co)	Selenium-75 (^{75}Se)	Caesium-137 (^{137}Cs)	Iridium-192 (^{192}Ir)	Iodine-131 (^{131}I)
20+	2.8	0.29	0.72	0.90	28
16	2.8	-	0.72	-	52
14	2.9	0.34	0.66	0.90	52
11	3.4	0.40	0.78	0.84	52
8	3.8	0.49	0.96	1.3	52
4	4.7	0.47	0.96	1.3	52
0.75	5.9	0.66	1.4	1.7	52
0.25	4.8	-	1.2	-	52

[1.] Calibration factors are for calculation of whole body activity except for ^{131}I where it is for thyroid activity

A5 SAIC EXPLORANIUM GR-135

Type: Sodium iodide based radionuclide identifier

Operating Instructions

1. Protective 'boot' should be in place
2. To switch the instrument on pull the joystick back and hold it until TESTING appears on the display. Use the joystick to navigate the menus: a quick movement of the joystick will move the cursor, but to select an option, 'enter', or 'return' pull the joystick back and hold briefly.
3. Select 'Search and Dose' from the main menu. The count rate in counts per second is displayed near the top of the display.
4. Make sure that the battery low indicator is not shown. If it is replace the batteries.
5. Ensure that the background count rate (BCR) is approximately 50 counts per second
6. Check response with a check-source if available (see Appendix B).
7. For measurements of people the display screen should be held horizontally so that the end of the detector faces the person.
8. Switch off by pushing the joystick forward and holding it until the countdown ends and the display is blank.

The calibration factors in Table A5 are provided to allow experienced radiation monitoring staff to estimate activities of radionuclides in the body (see Appendix C1 for whole body measurements).

Table A5 Calibration Factors (cps/kBq) for SAIC Exploranium GR-135[1]

Age, years	Cobalt-60 (^{60}Co)	Selenium-75 (^{75}Se)	Caesium-137 (^{137}Cs)	Iridium-192 (^{192}Ir)	Iodine-131 (^{131}I)
20+	0.73	0.78	0.43	1	18
16	0.69	0.69	0.42	0.91	27.8
14	0.68	0.76	0.41	0.95	27.8
11	0.73	0.85	0.44	1	27.8
8	0.80	0.95	0.48	1.2	27.8
4	0.90	1.1	0.55	1.3	27.8
0.75	1.10	1.3	0.65	1.6	27.8
0.25	1.10	1.2	0.64	1.5	27.8

[1] Calibration factors are for calculation of whole body activity except for ^{131}I where it is for thyroid activity

A6 TSA SYSTEMS PRM-470CS

Type: Large volume plastic scintillator

Operating Instructions

1. Press the POWER button to switch on.
2. Allow the instrument to finish the auto background count, then press the MODE button to enter search mode.
3. Response is given in counts per second.
4. Make sure that the battery low indicator is not shown. If it is replace the batteries.
5. Ensure that the background count rate (BCR) is approximately 70 counts per second
6. Check response with a check-source if available (see Appendix B).
7. For measurements of people the display screen should be held vertically so that the base of the detector faces the person.
8. Press the POWER button to switch off.

The calibration factors in Table A6 are provided to allow experienced radiation monitoring staff to estimate activities of radionuclides in the body (see Appendix C1 for whole body measurements).

Table A6 Calibration Factors (cps/kBq) for TSA systems PRM-470CS[1]

Age, years	Cobalt-60 (^{60}Co)	Selenium-75 (^{75}Se)	Caesium-137 (^{137}Cs)	Iridium-192 (^{192}Ir)	Iodine-131 (^{131}I)
20+	0.93	0.95	0.55	1.3	22
16	0.91	0.79	0.5	1.1	38
14	0.85	0.89	0.5	1.1	38
11	0.92	1	0.55	1.3	38
8	1.00	1.2	0.62	1.4	38
4	1.20	1.4	0.71	1.7	38
0.75	1.40	1.7	0.86	2.1	38
0.25	1.40	1.6	0.85	2	38

[1] Calibration factors are for calculation of whole body activity except for ^{131}I where it is for thyroid activity

APPENDIX B **Response of Hand-Held Radiation Monitors to a Point Source of Caesium-137**

The factors in Table B1 can be used if a calibrated point source of Cs-137 of known activity is available, to check that the radiation monitors are responding correctly.

Instructions

1. Ensure that the only source of radiation in the area is the Cs-137 point source
2. Remove any end cap from the detector
3. Position the source 10 cm from the detector
4. Set up the instrument as in the instructions in Appendix A
5. Observe the count rate for approximately 10 seconds.
6. Divide the observed count rate by the source activity in kilo Becquerels (kBq)
7. Compare the average count rate with the tabulated values below. If the individual instrument response is within 30% of the tabulated values then it can be considered to be responding acceptably. A correction for background count may be needed if the Cs-137 source is of particularly low activity.

Table B1 Typical instrument response factors to a point source of Cs-137

	Response Factors[1,2,3,4]	
Instrument	Counts per second/kBq	Counts per minute/kBq
APTEC-NRC ADM-300 with BSP-100 probe[5]	Not Applicable	260
RADOS RDS 200 with GMP-11 probe[5]	0.36	Not Applicable
ROTEM RAM Gene-1[5]	1.2	Not Applicable
Thermo Mini 900 with 44A probe	1.0	Not Applicable
TSA systems PRM-470CS	7.0	Not Applicable
SAIC Exploranium GR-135	3.7	Not Applicable

[1]Response factors are calculated assuming that protective covers have been removed.

[2]Care should be taken to set the source to probe distance to ± 2 mm of 100 mm

[3]Assumes background count rate can be neglected. If not the case then background should be subtracted before calculating the instrument response factor.

[4]Response factors within about 30% of tabulated values would be acceptable because of the high uncertainty of the activity of instrument test sources

[5]Response factors shown are for a rectangular Perspex source with a thickness of 2 mm, so that the maximum thickness of plastic is 1 mm. If the source construction varies significantly from this the response factors for these instruments will be significantly different because of attenuation of beta radiation.

APPENDIX C **Measurements of Internal Radionuclide Contamination in People**

C1 MEASUREMENTS OF COBALT-60, SELENIUM-75, CAESIUM-137 IRIDIUM-192 AND UNIDENTIFIED GAMMA-RAY EMITTING RADIONUCLIDES

To monitor people, hold the instrument about 30 cm from the centre of the chest (see Figures C1 and C2)

Figure C1 Monitoring of whole body activity with a hand-held radiation monitor

Figure C2 Monitoring of whole body activity with a hand-held radiation monitor

C2 MEASUREMENT OF IODINE-131

The thyroid gland lies in the front of the lower neck in a position just below the Adam's apple and above the line of the clavicles. It is made up of two lobes, each about the size of a plum cut in half, lying on either side of the trachea. The probe must be held so that the bottom edge is just above the line of the clavicles. The probe should be held as close as possible to the neck, but without touching skin or clothing (see Figures C3 and C4). The probe should be protected with plastic film which should be replaced if contamination of the probe is suspected.

Figure C3 Monitoring of the thyroid for I-131 with a hand-held radiation monitor

Figure C4 Monitoring of the thyroid for I-131 with a hand-held radiation monitor

APPENDIX D **Form for Recording Results of Screening with Hand-held Radiation Monitors**

Unique Person Code (or attach bar code):

Forename(s): _____ Sex: M F

Family Name: _____

Postcode: _____

D.O.B. _____

Age:

Date of exposure: _____/_____/_____ Time of exposure: _____

Person externally decontaminated: Yes / No

Date of measurement: _____/_____/_____ Time of measurement: _____

Results of measurement with hand-held radiation monitor

Instrument type: _____ Model: _____S/N _____

Total Count Rate, TCR (cps): _____

Background Count Rate, BCR (cps):_____

Net count rate), NCR (cps): _____

Activity (Bq): _____ (if calculated)

Measurement above Action Level ? Yes / No

Name of monitoring staff: _____

Organisation: _____

Date:

APPENDIX E **Additional Information on Monitoring**

E1 ADDITIONAL INFORMATION ON MONITORING WITH HAND-HELD RADIATION MONITORS

Monitoring Area

Monitoring must be carried out in an area of low background radiation. When a radiation monitor is used to measure gamma-rays near a potentially-contaminated person, the detector will respond to radiation coming from both the individual being surveyed and the surrounding environment (ground and air). It is therefore important that the measurements are made in an area where levels of natural background radiation are not unusually high, and where levels have not been significantly enhanced by contamination from the incident.

External Contamination on people

External contamination should be removed from people in order to reduce dose to the skin and prevent the possibility of inhalation or ingestion of some of the activity. Measurements using hand-held radiation monitors cannot readily distinguish between internal and external contamination and so the instrument response produced by the presence of external contamination can lead to an overestimate of internal contamination.

Persistent external contamination may be distinguished from internal contamination by surveying the entire body at a distance of a few centimetres. High readings on face, hands and feet compared to covered skin surfaces may indicate persistent external contamination and the need for further decontamination procedures. Large differences between measurements with the detector placed in front and behind the person could indicate skin or clothing contamination.

Detailed guidance on the detection and removal of external contamination is given in the TMT Handbook (Rojas-Palma et al., 2009) and HPA guidance (HPA, 2010).

Detector Saturation

If a monitor is subjected to a large number of interactions with radiation, there is a possibility that the maximum detector count rate will be exceeded. In that case, the radiation monitor will display erroneous readings and is said to be saturated. If this is suspected, move the detector towards and away from the person being measured and observe how the count rate changes. It should increase as the detector is held closer to the person and decrease as the detector is moved further away. If this does not happen then saturation is occurring and the person should be treated as having exceeded the action level.

Measurements using other external detectors

Other systems for measuring internal radiation contamination using external detectors will become available as the response to the incident progresses. Some of the systems are portable and can be deployed to the RMU (Youngman, 2002 and Youngman, 2008)

but there will be a delay before these become available. If small numbers of people are suspected to be internally contaminated at a significant level then these people can be taken to laboratory based monitoring facilities. These systems are more sensitive than hand-held radiation monitors and so can measure lower activities in people. In addition they are capable of spectrometry and so can simultaneously quantify the amounts of radionuclides in a mixture. These radiation monitors can also be used to identify positively the radionuclide(s) present if only gamma or beta/gamma emitters are present.

Estimating activity of radionuclides in people
Appendix A gives calibration factors for measurements of activity in people using hand-held radiation monitors. These can be used by suitably experienced staff to determine activity within people.

E2 ADDITIONAL INFORMATION ON MONITORING FOR RADIONUCLIDES WHERE HAND-HELD RADIATION MONITORS ARE UNSUITABLE

Many radionuclides cannot be measured in the body using the hand-held radiation monitors covered by this guidance. This is because these radionuclides emit weakly penetrating radiation which is mostly absorbed before reaching the sensitive region of the radiation monitor. For these radionuclides screening to find those people who have received intakes large enough to require medical assessment must be done in other ways.

E2.1 Monitoring soon after the incident

If monitoring is carried out on the day of the incident then the results of external contamination monitoring, face-wipe and nose blow samples could be used to identify people who are likely to be internally contaminated. In particular monitoring of the facial area with a suitable radiation monitor is important as activity deposited in this area could indicate inhalation of radioactive material. The face can be monitored directly or by taking a face-wipe sample which is then monitored. To take a face-wipe sample, a filter paper should be gently wiped over the bridge and sides of the nose, on the cheeks near to the nose and over the top lip. People can also be asked to provide a nose blow sample. Face-wipe samples and nose-blow samples can be monitored at the RMU with a sodium-iodide (NaI) or Geiger-Muller (GM) based detector for beta or gamma emitters or with a phosphor based detector for alpha emitters. A positive face-wipe or nose blow sample indicates an intake by inhalation has taken place. However the absence of activity can not rule out inhalation of radioactive material, because of the possibility of mouth breathing due to allergies, exercise or sinus congestion. Additionally if a subject sneezes or clears nasal passages before sampling then the count will not be representative of intake.

As an alternative to a nose blow sample a nasal swab can be taken. A typical nasal-swab procedure involves the use of a slightly moistened cotton tipped applicator which is gently rotated around the accessible surface of each nostril. This procedure should only be carried out by medically qualified personnel. A separate swab should be used

for each nostril. Swabs may also be measured directly with a contamination monitor, although swabs of alpha activity may need to be dried first.

Each face-wipe sample, nose blow sample or nasal-swab sample should be put in its own container and suitably labelled for possible subsequent laboratory analysis.

Wipes of the facial area and nose blow and nasal swab samples should preferably be taken before showering or washing, although decontamination should not be delayed to allow monitoring to take place. It is also important that nose blow samples and nasal wipes are taken as soon as possible after the incident as a few hours after the incident normal clearance may have already eliminated radioactive material from the nose.

In addition to the above, counting with external detectors may be possible (section E2.2). The collection and measurement or urine samples is also recommended (section E2.2).

E2.2 Monitoring at later times

If monitoring is carried out later than the day the incident occurred external contamination monitoring should still proceed and decontamination procedures should be followed as necessary. However it is unlikely that measurements of the face, nose blows or nasal swabs could be used to indicate internal contamination by inhalation.

Direct counting using external detectors may be possible but would need to be carried out in a laboratory and the UK capacity for these measurements is limited.

Collecting and measuring urine samples is a good way of quantifying internal contamination for all of the radionuclides covered by this guidance for which measurements with hand-held detectors are insufficiently sensitive. Collection of urine is reasonably straightforward and samples are easy to manage. Measurements of urine are also sensitive enough to identify all people who require medical assessment in all but a few cases. Exceptions to this are given in the sections for individual radionuclides. For large incidents it would be necessary to use triage methods to select for urine measurements only those people who are likely to be significantly contaminated (Section 3).

Instructions for individuals to allow them to collect 24-hour urine samples are given in Appendix G. This Appendix also has an example information sheet for those people asked to give a urine sample. A 24-hour urine sample is recommended as samples collected over shorter times do not provide a reliable estimate of internal contamination. Under certain conditions it may be necessary to collect a single voiding urine sample because there is a high probability that the individual has received a large dose, and a 24-hour delay is unacceptable. For these samples the bladder should be emptied as soon as possible after the incident and collection of the urine sample for analysis should ideally not commence before 4 hours after the incident to allow biokinetic processes to produce a representative sample. If a urine sample is provided earlier than 4 hours after the incident, then care is required in its interpretation as the measured activity will produce a less reliable estimate of intake. For spot urine samples the 24-hour urine excretion must be calculated to allow comparison with action levels. This is done by multiplying the measured activity per litre, in the spot sample, by the expected 24-hour

urine excretion volume. It is generally assumed that an adult male excretes 1.6 litres per 24-hours and an adult female 1.2 litres. However, these are average values and the volume of urine excreted by an individual may be very different from these values. After collection urine samples would need to be transported to appropriate laboratories. HPA has a formal responsibility to coordinate monitoring, and would coordinate this analysis.

E3 REFERENCES

Youngman MJ (2002). Transportable In Vivo Monitoring System for Accident Monitoring of Internal Contamination. NRPB - W12 www.hpa.org.uk/Publications/Radiation/NPRBArchive/NRPBWSeriesReports/2002nrpbw012/ last accessed December 2010.

Youngman MJ (2008). The Use of High-resolution Radionuclide Identifier as a Portable Whole Body Monitor. HPA-RPD-045 www.hpa.org.uk/Publications/Radiation/HPARPDSeriesReports/HPARPD045/ last accessed December 2010.

APPENDIX F **Modification of Guidance for Mixtures of Radionuclides**

F1 MIXTURES OF COBALT-60, SELENIUM-75, IODINE-131, CAESIUM-137 AND IRIDIUM-192 AND OTHER GAMMA-RAY EMITTING RADIONUCLIDES

If a mixture of ^{60}Co, ^{75}Se, ^{131}I, ^{137}Cs or ^{192}Ir are present in any combination or if another gamma-ray emitting radionuclide of energy greater than about 200 keV with yield greater than 10% is present, then the procedures for using hand-held instruments in section 5 must not be used to identify people who require medical assessment. The hand-held instruments used as described in this guidance are unable to distinguish between different gamma-ray emitting radionuclides and all can contribute to the count rate measured using a hand-held detector. In this situation the procedure in 5.2.1 should be used to identify the people who have the highest levels of internal contamination. These people can then be prioritised for measurements with systems capable of gamma-ray spectrometry which are able to quantify the individual gamma-emitting radionuclides in a mixture. HPA should be contacted for details of how these measurements could be made.

F2 MIXTURES OF ONE OF COBALT-60, SELENIUM-75, IODINE-131, CAESIUM-137 AND IRIDIUM-192 WITH ONE OF STRONTIUM-90/YTTRIUM-90, RADIUM-226, THORIUM-228, THORIUM-232, NEPTUNIUM-237/PROTACTINIUM-233, PLUTONIUM-238, AMERICIUM-241 AND CALIFORNIUM-252

If one of the radionuclides ^{60}Co, ^{75}Se, ^{131}I, ^{137}Cs or ^{192}Ir is present with either ^{90}Sr/^{90}Y, ^{226}Ra, ^{228}Th, ^{232}Th, ^{237}Np/^{233}Pa, ^{238}Pu, ^{241}Am or ^{252}Cf, then the procedures in this guidance can be used, but the results for the two radionuclides would need to be combined to identify people who require medical assessment.

The monitoring instructions for ^{60}Co, ^{75}Se, ^{131}I, ^{137}Cs or ^{192}Ir should be followed and the Net Count Rate (NCR) and the appropriate action level (AL) recorded. These can be given the subscript A (e.g. NCR_A, AL_A). The results of the 24-hour urine measurement for ^{90}Sr/^{90}Y, ^{226}Ra, ^{228}Th, ^{232}Th, ^{237}Np/^{233}Pa, ^{238}Pu, ^{241}Am or ^{252}Cf are then obtained (denoted UA_B) and the action level from the appropriate part of section 5 (denote AL_B).

If $$\left(\frac{NCR_A}{AL_A}\right)+\left(\frac{UA_B}{AL_B}\right) < 1$$

Then the person does not require medical assessment.

However, if $$\left(\frac{NCR_A}{AL_A}\right)+\left(\frac{UA_B}{AL_B}\right) \geq 1$$

Then the person requires medical assessment.

F3 MIXTURES OF STRONTIUM-90/YTTRIUM-90, RADIUM-226, THORIUM-228, THORIUM-232, NEPTUNIUM-237/PROTACTINIUM-233, PLUTONIUM-238, AMERICIUM-241 AND CALIFORNIUM-252

If a mixture of two radionuclides is present from ^{90}Sr/^{90}Y, ^{226}Ra, ^{228}Th, ^{232}Th, ^{237}Np/^{233}Pa, ^{238}Pu, ^{241}Am or ^{252}Cf, then the procedures in this guidance can be used, but the results for the two radionuclides would need to be combined to identify people who require medical assessment.

The results of the 24-hour urine measurement for both radionuclides should be obtained (UA_A UA_B) and the action levels from the appropriate parts of section 5 (AL_A and AL_B).

If $\left(\frac{UA_A}{AL_A}\right)+\left(\frac{UA_B}{AL_B}\right) < 1$

Then the person does not require medical assessment.

However, if $\left(\frac{UA_A}{AL_A}\right)+\left(\frac{UA_B}{AL_B}\right) \geq 1$

Then the person requires medical assessment. This procedure can be extended to mixtures of three or more radionuclides. If it is necessary to divide a 24-hour urine sample to analyse for different radionuclides then the sensitivity of the urine sample measurement will be reduced.

APPENDIX G Instructions to a Person Providing a Urine Sample

G1 INSTRUCTIONS FOR COLLECTION OF URINE SAMPLES

The aim is to collect all of your urine excreted during a 24 hour period. It does not matter what the volume of urine is.

1. Start the collection as soon as possible but before the first collection you must have a bath or shower and wash your hair.
2. Before the first collection, label the container with your name, date and time of the first collection and complete the first part of the sample record below.
3. Pass all urine excreted in the next 24 hours into the container provided. If necessary collect the urine in a clean, non metallic bowl or jug and then pour into the container using a funnel but do not rinse the funnel into the container.
4. 24 hours after the first collection empty your bladder into the container. Write the finish date and time on the container and sample record form.
5. The urine collection is now complete. Please check that the cap is firmly screwed onto the container.
6. In warm weather try and keep the urine cool
7. The person giving you these instructions will instruct you about the return of the sample and form.
8. If you have any questions about this sampling please contact _____

SAMPLE RECORD FORM

Container number _____(already marked on container)

Full name _____

Date of Birth

Full address _____

_____

_____

_____

_____

Contact Telephone number _____

Collection dates and times (day/month/year, Hour:minute)

Start date & time _____/_____/____, ____:_____

Finish date & time _____/_____/____, ____:_____

G2 INFORMATION FOR PEOPLE WHO ARE PROVIDING A 24 HOUR URINE SAMPLE

Background information

You have been asked to provide a urine sample because you may have come into contact with a radioactive material. It is unlikely you have received a radiation dose high enough to give rise to medical symptoms. Nevertheless, a monitoring programme has commenced, and this request for urine samples is part of that programme.

What is a 24 hour urine collection?

As the name implies, a 24 hour urine collection is all of your urine passed over a 24 hour period. The time you start the collection is not important, but it is very important that you complete the 24 hour collection and collect all urine passed during this time.

What information will be obtained from the sample ?

Measurements on your urine sample will enable us to determine how much radioactive material, if any, was taken into your body, and the radiation dose you will receive as a result.

Why do I have to take a bath or shower before providing the sample ?

We need to be sure there is no radioactive material on your skin or clothing which could be transferred to the sample. The amounts present in the sample arising from any intake could be very small, and so any possible contamination of the sample must be avoided. Bathing and showering are an effective way of removing external contamination.

How much urine should I provide ?

You must provide a sample containing all the urine that you produce in a 24 hour period.

What do I do after I have finished the sample ?

Fill in the sample form which accompanies this sheet and put it in a plastic bag with the container. You will be given further details about where to return the sample.

When will I receive the results ?

The tests take a number of days to perform, and we can only perform a limited number of tests per day. Do not expect results in less than a week, probably longer.

What do I do if I feel unwell ?

Any symptoms you have while waiting for the test results are unlikely to be caused by the radioactive material. If you are worried about your health, contact your GP.

APPENDIX H Assessment of Analytical Procedures for Determination of Radionuclides in Urine

H1 ASSESSMENT OF ANALYTICAL PROCEDURES FOR DETERMINATION OF RADIONUCLIDES IN URINE

H1.1 Introduction

This Appendix contains information for staff of radiochemical analysis laboratories who could be asked to analyse urine samples following an emergency. It gives advice on the methods to use which, in almost all situations, will detect intakes which correspond to levels of dose where people would require medical assessment. Where possible, information is given on where analysis times can be reduced, to produce what is known as a 'rapid method'. The radionuclides considered are all those in Table 1 where measurements with hand-held radiation monitors are not sufficiently sensitive.

H1.2 Analytical Methods for rapid urine analysis

For the purpose of discussion of radiochemical methods, the radionuclides can be grouped into beta-emitting radionuclides and alpha-emitting radionuclides. Methods that can be considered 'rapid' and which are able to determine activities at the required limits of detection are briefly reviewed and adaptation of routinely used methods to make them quicker to carry out is also discussed. A large number of methods were reviewed from the open literature; however, only a few were appropriate for the purposes of this guidance.

Pre-concentration of radionuclides in urine samples is required to analyse alpha and beta emitting radionuclides because the minimum detectable activity for alpha and beta counting equipment is not sufficiently low enough to reach the required limits of detection without using all or a large fraction of a 24 hour urine sample. For analysis of alpha emitters it is also necessary to carry out chemical separation to isolate the individual radionuclide of interest. This is because other alpha emitting radionuclides could be present and would interfere with the analysis of the radionuclide of interest.

Mass spectrometry offers an attractive alternative option for measuring radionuclides. A pre-concentration step would still be required to reach the necessary limits of detection, but further chemistry to isolate specific radionuclides is not required so the overall analysis times are reduced. The disadvantages of mass spectrometry are that the technique is not widely available in UK radiochemistry laboratories for measuring radionuclides, and there is very little published validation information for the radionuclides of interest.

Beta emitting radionuclides

Strontium-90 (^{90}Sr) and its short lived progeny yttrium-90 (^{90}Y) are the only pure beta emitters included in the list of radionuclides being considered. For the purpose of this guidance, ^{90}Sr and ^{90}Y are assumed to be in equilibrium. The source is also considered to be free from ^{89}Sr, which would not be the case if the source was from a nuclear power station release. Routine methods for determination of ^{90}Sr usually require the separation

of strontium and then, after its ingrowth, separation and counting of its yttrium progeny. The 2 week ingrowth time makes this method too long to be of use as a 'rapid method'. Any useful rapid methods therefore have to measure the parent radionuclide ^{90}Sr directly.

Most rapid methods documented in the open literature are used for measuring environmental samples following a release from nuclear power stations (Green, 1993) and not for measurement of bioassay samples. Activity concentrations in the environment will be higher than those subsequently found in people and excreta and so the limits of detection required for analysis of environmental samples are usually higher than those required for measuring bioassay samples. There are some rapid methods available for the determination of ^{90}Sr (Maxwell, 2007, Brun, 2001). The limits of detection achievable by these techniques suggest that they are developed for screening or environmental monitoring purposes and would not reach the limits of detection required in this guidance. However, the method employed in the Maxwell study would only require a pre-concentration step to make it suitable for reaching the required limits of detection. The Maxwell method makes use of extraction chromatography resins to sequentially remove isotopes of plutonium, americium, thorium, curium, uranium and strontium from urine. Pre-packed chromatography resin cartridges are used along with a vacuum box to maximise flow through the columns. If only a single radionuclide is being considered, the Maxwell scheme can be simplified by removing separation steps not relevant to the required radionuclide.

If only ^{90}Sr/^{90}Y was known to be present, then yield determination could be carried out by the addition of a ^{85}Sr tracer which is a gamma emitter. The addition of yield tracers is also discussed in the Maxwell study, with a gravimetric determination of yield for strontium using a calibrated strontium carrier. The final source is dried and weighed on a planchet and counted on a gas proportional counter. If, however, ^{85}Sr is used as the yield tracer the final source could be an aqueous solution and could be counted using a low level liquid scintillation counter in the presence of a scintillant. The counter would first need to be calibrated using a standard ^{90}Sr solution. Yield determination is calculated by comparing a known activity of ^{85}Sr in a standard with the ^{85}Sr in the sample using the same counting geometry. The advantages of using a liquid scintillation counter as opposed to a gas proportional counter are that liquid scintillation counters are used more widely in UK laboratories and the solution collected from the extraction chromatography column can be counted directly without the need for further source preparation. As part of this work, direct counting was evaluated in the laboratory to further validate this. Results are discussed in Section H1.4 and suggest that this method would be suitable for the rapid determination of ^{90}Sr/^{90}Y in urine. The use of pre-packed resin cartridges and a vacuum box may reduce the analysis time further.

The other rapid method considered for ^{90}Sr/^{90}Y was counting an aliquot of the urine sample directly using a liquid scintillation counter. The advantages of this method are that a yield tracer is not required and the analysis time is very short. However, the disadvantage is that, as only a small sample is taken, the achievable limit of detection is higher than that required. This method could have some practical use for screening purposes where higher limits of detection are acceptable.

Alpha emitting radionuclides

Plutonium and americium isotopes

Rapid methods for the determination of ^{238}Pu and ^{241}Am are described in the open literature (Maxwell, 2007, Green, 1993). They are usually existing methods that have been modified to reduce the analysis times. The methods can not be considered rapid (with typical analysis times of 1-3 days), but are quicker than routine methods. If the required limits of detection are higher than those normally needed for routine work, alpha spectrometry counting times can be reduced. Counting can be stopped as soon as results have been obtained with suitable uncertainties or the required limit of detection has been reached. As urine has a relatively low concentration of interfering stable elements such as iron, some chemical clean up steps are not required. A pre-concentration step will remove most of the impurities in the urine such as dissolved solids and leave an analytically clean solution. Ion exchange chromatography can then be used to separate plutonium and americium isotopes and if required the americium can be further purified by extraction. The plutonium and americium fractions are electrodeposited onto stainless steel discs and counted by alpha spectrometry. Yields are determined by the addition of ^{242}Pu or ^{243}Am tracers prior to the analysis.

Californium-252

The determination of ^{252}Cf is exactly the same as for ^{241}Am due to the similarity in their chemical properties (Butler and Hall, 1970). There is no suitable californium isotope available to use as a tracer, so yield would be determined using ^{243}Am which is sufficiently similar and acts as an analogue of californium. There is sufficient literature available to show the validity of using americium as a tracer.

Neptunium and protactinium isotopes

The determination of ^{237}Np and its short lived progeny ^{233}Pa is complex and time consuming (Hursthouse, 1991). There are no suitable rapid methods available for determinations in urine. The most common approach is to measure ^{237}Np by alpha spectrometry. A ^{239}Np yield tracer is required for this type of determination. Neptunium-239 is a beta emitter with a half life of 2.4 days and is a direct progeny of ^{243}Am, so it is either prepared from an ^{243}Am source prior to analysis or the equilibrium mixture of ^{243}Am / ^{239}Np is added directly to the sample prior to the analysis. Pre-concentration of the sample is required using a partial phosphate precipitation. Neptunium is isolated using anion exchange and is further purified using solvent extraction. The neptunium is electrodeposited onto a stainless steel disc. The radiochemical yield is then determined by counting the ^{239}Np in a beta counter before the ^{237}Np is counted using an alpha drawer counter. The activity concentration is then calculated using the alpha activity and chemical recovery determined by the ^{239}Np.

Radium-226

Radium-226 is usually determined using radon emanation. This requires a considerable time for the ingrowth of its ^{222}Rn progeny (typically 4-6 weeks), but can be reduced to 10 days. This process is too long to be of use as a ‘rapid method’. There is no information

on rapid determination of ^{226}Ra available in the open literature. The use of Empore™ Radium RAD Disks* may offer a possible solution to the rapid determination of ^{226}Ra, but, as yet, the only application is for ^{228}Ra. Further research would be required to validate this for broader application. Another possible method is one developed by Lozano (Lozano, 2010), which sequentially extracts lead and radium from high concentrations of nitrate solutions. The radium is separated from a sodium-DTPA solution as a sulphate and counted using an alpha spectrometer. This method offers some possibilities for the rapid determination of ^{226}Ra, but as this method is not in common use in UK laboratories, validation and training would be required before it could be used.

Thorium isotopes

Determinations of thorium isotopes using alpha spectrometry are routinely performed in many UK laboratories. There are no rapid methods available as such, but routine methods could be adapted to reduce analysis times. This is discussed further in Section H1.4. A pre-concentration step is required followed by anion exchange separation. The sample then undergoes electrodeposition onto a stainless steel disc followed by alpha spectrometry counting. A yield tracer of ^{229}Th is available and is in common use. One consequence of thorium analysis is that the detectors in the alpha-spectrometry counting equipment used will become contaminated with higher energy alpha progeny and may not be usable for other determinands.

H1.3 Required Limits of Detection

Table H1 gives the calculated activity in a 24 hr urine sample taken 2 days after an intake of each radionuclide that, if observed, would require medical assessment of the person. This information is summarised in Section 5. Table H2 gives the equivalent calculated activity in a 24 hr urine sample taken 30 days after an intake. These estimated activities in a 24 hr urine sample can be taken as the approximate required limits of detection that need to be achieved if any rapid analytical method is to be successful in identifying people who could need medical assessment. The use of the 2nd day and 30th day after intake has been chosen to span the range in the limits of detection that it is desirable to be able to achieve. It is unlikely that intakes would still need to be established 30 days after intakes have occurred but there could be cases where it is not known that exposures may have occurred for several weeks after an incident. The activity in a 24-hour urine sample at 30 days which if observed would require medical assessment of the person, can be taken as providing a lower limit of detection that needs to be achieved for the purposes of this guidance.

* Where trade marked products have been identified, other equivalent products may be available and the authors are not endorsing or recommending the use of a particular product.

Table H1 Activity (Bq) in 24 hr urine sample taken on the 2nd day after intake corresponding to doses where medical assessment is required

Age of person	3 months	1 year	10 years	20 years (Adult)
$^{90}Sr/^{90}Y$	9.20E+00	1.30E+01	2.20E+01	5.70E+01
^{226}Ra	3.50E-03	4.60E-03	9.50E-03	2.20E-02
^{228}Th	2.80E-03	1.10E-03	3.00E-03	7.10E-03
^{232}Th	1.80E-03	9.00E-04	2.20E-03	4.90E-03
^{238}Pu	2.80E-03	3.10E-03	7.10E-03	1.00E-02
$^{237}Np/^{233}Pa$	5.00E-02	2.50E-02	9.10E-02	1.90E-01
^{241}Am	1.80E-02	9.20E-03	2.10E-02	2.90E-02
^{252}Cf	1.10E-02	4.50E-03	1.20E-02	1.80E-02

Table H2 Activity (Bq) in 24 hr urine sample taken on the 30th day after intake corresponding to doses where medical assessment is required

Age of person	3 months	1 year	10 years	20 years (Adult)
$^{90}Sr/^{90}Y$	3.70E+00	4.40E+00	8.10E+00	1.50E+01
^{226}Ra	1.00E-03	8.20E-04	1.90E-03	3.10E-03
^{228}Th	4.20E-04	2.90E-04	8.90E-04	2.10E-03
^{232}Th	3.70E-04	2.40E-04	6.70E-04	1.50E-03
^{238}Pu	4.90E-04	6.30E-04	1.70E-03	2.50E-03
$^{237}Np/^{233}Pa$	6.30E-03	4.00E-03	1.00E-02	1.60E-02
^{241}Am	3.20E-03	2.20E-03	6.00E-03	9.00E-03
^{252}Cf	9.10E-04	3.20E-04	8.60E-04	1.30E-03

H1.4 Suggested adaptation of routine methods

The following guidance is to enable laboratories to make quick adjustments to regularly used routine methods that are similar to the suggested 'rapid methods' discussed in Sections H1.2 and H1.3. Some limited validation will be required for each laboratory before these methods are used. Laboratory standards could be used to validate any deviations from standard methods. Limits of detection and approximate analysis times are suggested for the various methods. Only one method has been suggested for each radionuclide based on available information on routine methods and the review of available rapid methods. Specific rapid methods can be used if they are validated and practised.

Strontium-90 and yttrium-90

As discussed in Section H1.2, pre-concentration of urine samples is required to achieve the required limits of detection in Tables H1 and H2. After the addition of a ^{85}Sr tracer, a phosphate precipitation is undertaken to isolate the Sr/Y and reduce the overall volume of the sample and remove impurities. The phosphate precipitate is removed and can be either destroyed by ashing and the residue dissolved using nitric acid or vigorously boiling the precipitate with nitric acid. The solution is diluted and is passed through Eichrom Sr resin™. This effectively separates the strontium parent nuclide from its progeny to enable direct counting. The strontium is eluted into a scintillation vial and liquid scintillant is added. The sample is counted using gamma spectrometry to determine the yield from the ^{85}Sr present by comparing against a standard containing a known amount of ^{85}Sr. The ^{90}Sr activity is determined by liquid scintillation counting.

This method has been evaluated experimentally in the laboratory as part of this work. The results obtained suggest that a limit of detection of 1Bq per sample is readily achievable with a 30 – 60 minute count using a liquid scintillation counter. Yields in the range of 80 – 90% were recorded. The approximate analysis time is 24 hours. Typical limits of detection that could be expected and approximate analysis times are given in Table H3.

Alpha emitting radionuclides except radium-226

Similarly to ^{90}Sr, pre-concentration of urine samples is required to achieve the required limits of detection. In routine methods, after the addition of a suitable yield tracer, a phosphate precipitation will isolate the radionuclides of interest. All of the radionuclides considered require separation using Dowex™ 1-X8 resins*. For plutonium, further purification is not required as little interference should be present. Neptunium is further purified by solvent extraction using 2-Thenoyltrifluoroacetone. Thorium requires further purification using 1-X8 resin as thorium alpha spectra can be subject to interference. Americium and californium are further purified using TRU and TEVA ™ resins. The final sources are prepared by electrodeposition onto stainless steel discs before alpha-spectrometry counting. A limit of detection of 2 mBq is achievable with a 2 – 3 hour counting time. The limit of detection could be reduced by an order of magnitude by counting overnight (12 – 14 hours). Approximate analysis times are given in Table H3.

Radium-226

There are no 'rapid methods' available for the determination of ^{226}Ra as discussed in section H1.2. The only routine method that is used in the UK that has a limit of detection close to what is required is measuring radium by radon emanation. A limit of detection of 5 mBq on a 24 hour urine sample can be achieved with an analysis time of at least 10 days. The limit of detection can be reduced to about 2 mBq, but the analysis time would be increased to 4 weeks. As previously mentioned, the Lozano method could be an option, but is not currently used in the UK.

H1.5 Guidance on Limits of Detection and analysis times that could be expected

Limits of detection and analysis times have been collated for selected recognised routine methods and for adapted routine methods. These are given in Table H3. The methods chosen are representative of the common techniques used by many laboratories in the UK and are either already being used or are very similar to widely used methods.

* There are several suppliers of various grades of Dowex 1-X8 resin e.g. BIO-Rad, Eichrom.

Table H3 Limits of detection that could be expected and analysis times

Radionuclide	Method	Analysis time[a]	Limit of detection, Bq/ 24 hr sample
$^{90}Sr/^{90}Y$	Direct liquid scintillation counting[b]	6 hr	50
$^{90}Sr/^{90}Y$	Extraction chromatography and liquid scintillation[c]	24 hr	1
^{226}Ra	Radon emanation[b]	10 days	5.00E-03
^{228Th}	Anion exchange[c]	24 hr	2.00E-03
^{232}Th	Anion exchange[c]	24 hr	2.00E-03
^{238}Pu	Anion exchange[c]	12 hr	2.00E-03
$^{237}Np/^{233}Pa$	Extraction chromatography[c]	30 hr	2.00E-03
^{241}Am	Extraction chromatography[c]	24 hr	2.00E-03
^{252}Cf	Extraction chromatography[c]	24 hr	2.00E-03

[a] Analysis time is from receipt of sample to production of a result
[b] Recognised routine method
[c] Adapted routine method

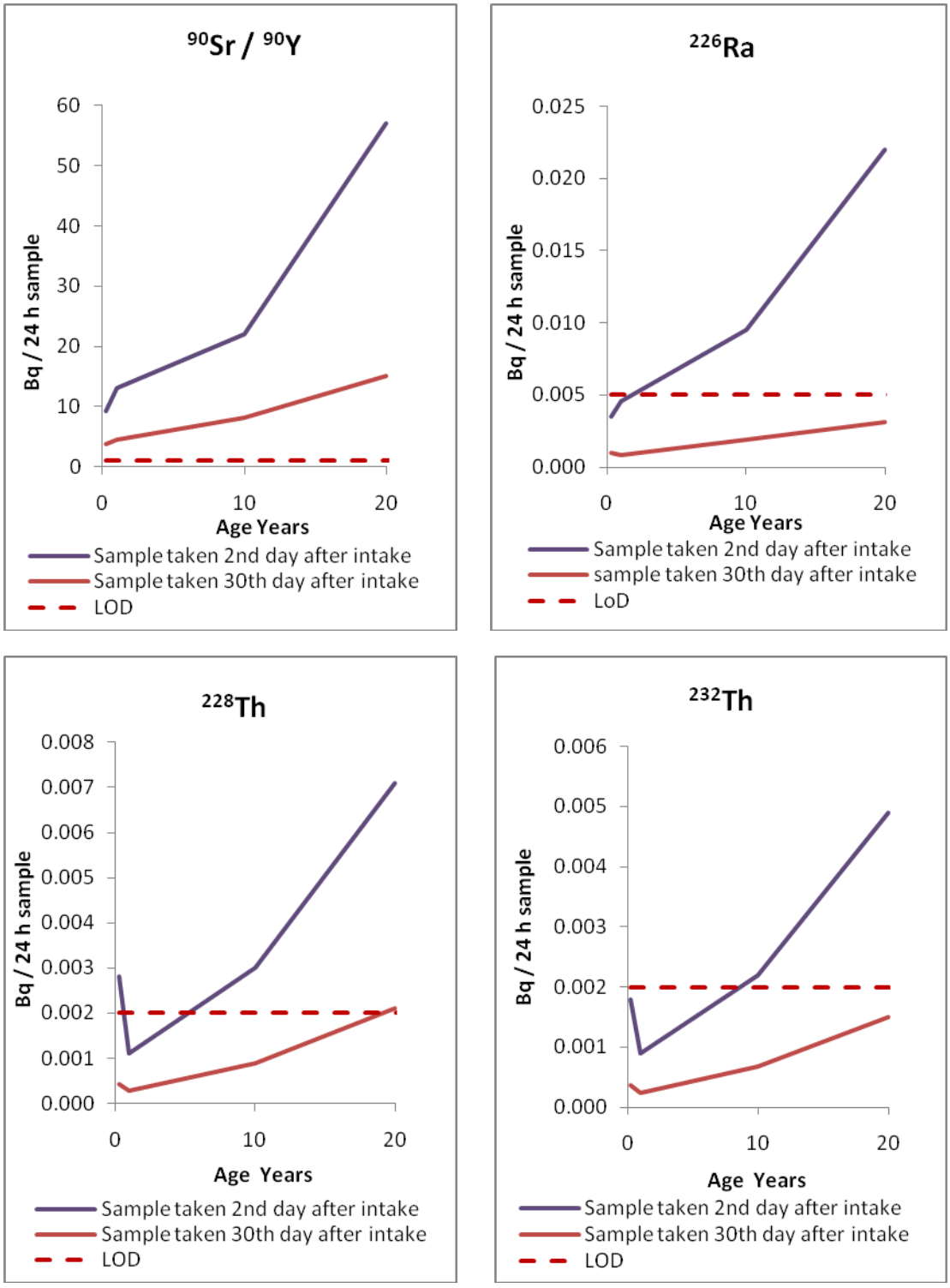

Figure H1a Comparison of limits of detection (LOD) for rapid analytical methods with the 24-hour urine activity action level

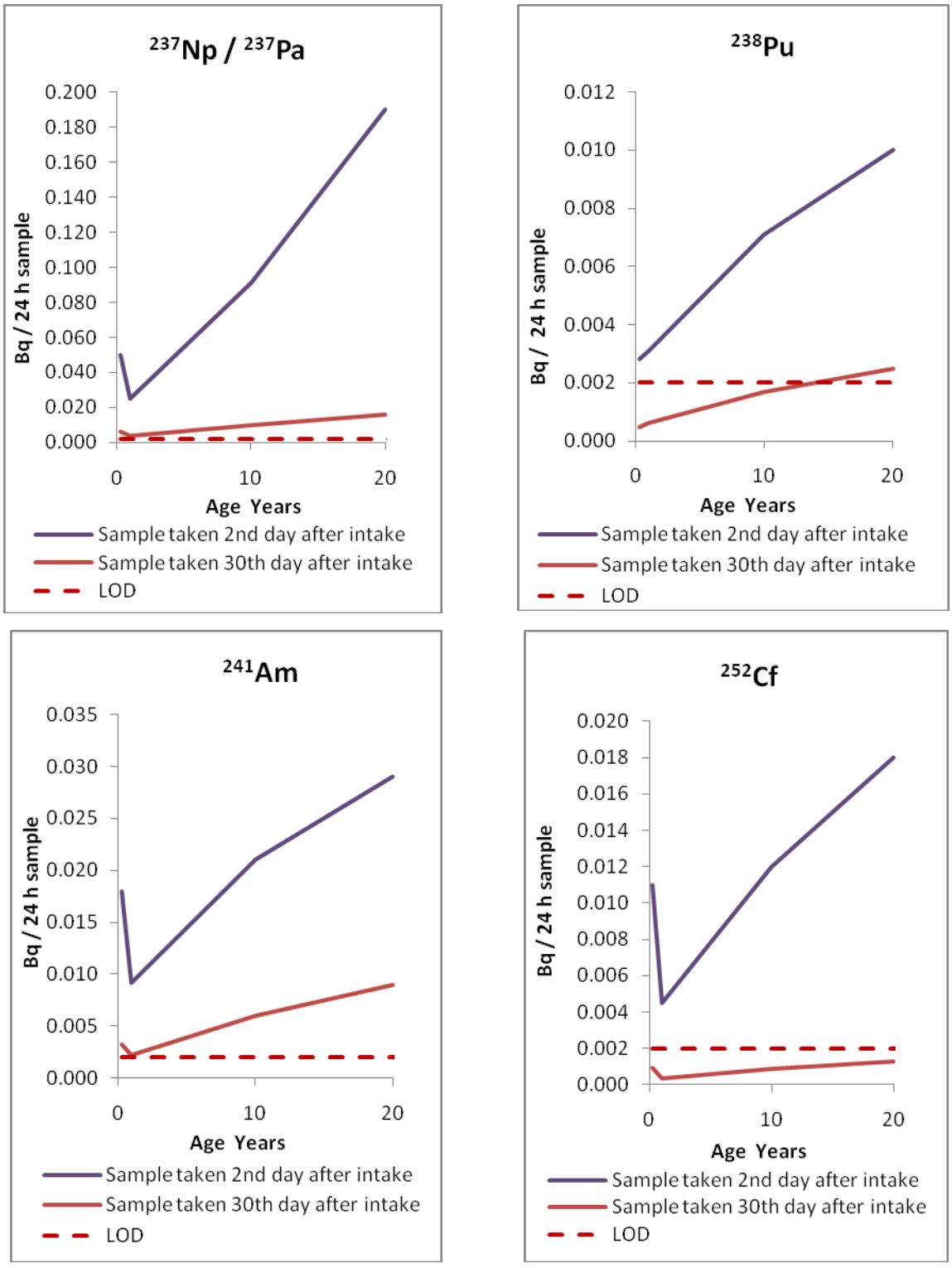

Figure H1b Comparison of limits of detection (LOD) for rapid analytical methods with the 24-hour urine activity action level

Figure H1a and H1b compares limit of detection for rapid analytical methods to the 24-hour urine activity which if observed or exceeded would require medical assessment of the person. The limit of detection shown for ^{226}Ra is for the time consuming radon emanation method as no rapid method is available. For samples collected 2 days after intake, only those limits of detection required for ^{90}Sr/^{90}Y, ^{237}Np/^{233}Pa, ^{238}Pu, ^{241}Am and ^{252}Cf can always be achieved (Figure H1). For samples collected 30 days after intake, limits of detection required can be reached for ^{90}Sr/^{90}Y, ^{237}Np/^{233}Pa, and ^{241}Am. For samples collected 30 days after intake, analysis of ^{226}Ra can not reach the required limits of detection for people of any age.

The limit of detection shown for ^{90}Sr/^{90}Y is for the modified method and not by direct measurement because direct counting is far too insensitive to reach the required limits of detection, the likely value being 50 Bq in a 24 hour urine sample.

For ^{238}Pu, the limit of detection can only be reached for individuals aged at least 15 years old. It is likely, however, that measurements on samples collected 30 days after an intake may not require analysis so quickly and more sensitive but longer routine methods may be acceptable for doing the analysis.

Routine methods would reach the limits of detection required for samples collected 2 days after intake for all of the radionuclides with the exception of ^{226}Ra where the limit of detection is reached for people older than 10 years.

It should be noted that the limits of detection quoted are cautious and a reduction of a factor of 2 could probably be achieved quite easily by increasing the counting times. So where limits of detection are close to those required, it is still possible that they can be reached but over a slightly longer timescale. When information on the route of intake and physical and chemical characteristics of the radionuclide are available it is probable that higher action levels can be used and methods with higher limits of detection can be adopted.

H1.6 Discussion

The required limits of detection for measured activity in a 24 hour urine sample required to meet the action levels are very low and mean that pre-concentration of the radionuclides is almost always needed. Further chemical separation is also required to reduce the effects of interference particularly for the alpha emitting radionuclides. This means that analysis in less than 1 day is very unlikely for most radionuclides, if the required limits of detection are to be achieved. There are methods which are quicker than those routinely used in laboratories in the UK that are available for the determination of all the radionuclides of interest except for ^{226}Ra, with typical analysis times of 1-2 days. The suggested ‘rapid methods’ are adaptations of methods used for routine analyses and reflect the common analytical approaches taken by many laboratories in the UK. This means that the general principles of these rapid methods will be familiar to many laboratories that carry out similar routine analyses. Familiarity with the general principles of the methods means that training requirements are minimised. Each laboratory would have to carry out its own validation, but as these are not entirely new methods, validation can also be minimised. It is unlikely that a

laboratory that is not familiar with the general principles of the methods outlined in this guidance would adopt the particular rapid methods suggested. Also they would be unlikely to have the necessary reagents or tracers available to do the methods.

Limits of detection and analysis times have been suggested for the identified rapid methods. This is only intended as a guide. Limits of detection can be reduced further by increasing counting times. Analysis times can be shortened by using pre-packed resin cartridges and vacuum systems to speed up column flows, although this does require further validation. The analysis times given are for a single sample analysis but increasing batch sizes would not increase analysis times significantly. For example, for alpha emitting radionuclides a batch size of 6 -12 is common. For beta emitters a batch size of 4 – 8 is typical, although as samples are counted sequentially when using liquid scintillation, overall analysis times would increase by the time taken to count each sample in the batch.

The rapid determination of ^{226}Ra is problematic. The most common routine method (Rn emanation) takes at least 4 weeks to complete but could be reduced to 10 days. This is an area where further research is required if ^{226}Ra is considered an important radionuclide for the scenario envisaged and if results are required quickly. Other methods of analysis are available such as by alpha spectrometry and mass spectrometry, but are not widely used in the UK and there is no information on the likely limits of detection achievable.

Mass spectrometry may be a solution to providing quicker methods of analysis, but availability and validation requirements means that this technique would not be widely implemented currently. Mass spectrometry may also offer a solution for the determination of ^{226}Ra.

The required limits of detection are based on 24 hr urine samples being analysed. Achievable limits of detection would be much higher if only a fraction of the sample was analysed. Collecting reliable 24 hr urine samples from young children is very difficult and this requires consideration.

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APPENDIX I Calculation of Action Levels

I1 CALCULATION OF ACTION LEVELS

This section describes how the action levels presented in section 5 have been calculated and discusses the dose reference levels which have been used in the calculation of these action levels.

The aim of this work is to detect people who could have internal contamination at levels where medical assessment and further evaluation is needed. Deliberately pessimistic assumptions have been made about the physical and chemical properties of the contaminating radioactive material so that people who require medical assessment are always identified. In the calculation of action levels it was necessary to consider both deterministic effects and long term risk of cancer. This requires the consideration of stochastic risk as judged by the calculated effective dose over 50 years for adults and up to 70 years of age for children, and the relative biological effectiveness (RBE) weighted absorbed organ doses to determine likelihood and severity of deterministic effects. The RBE weighted absorbed dose reference levels used in this guidance were taken from IAEA guidance (IAEA, 2005) and are reproduced in Table I1. The RBE weighting factors used are shown in Table I2.

TABLE I1 Reference Levels on RBE-weighted absorbed dose[1]

Organ	RBE-weighted absorbed dose (Gy-Eq)[2]
Red marrow (intakes of actinides)	0.2
Red marrow (intakes of other radionuclides)	2
Thyroid	2
Lung	30
Colon	20

[1]Adapted From IAEA EPR-Medical, 2005, Table F2.

[2]Integration period = 30 d.

TABLE I2 Relative Biological Effectiveness (RBE)[1]

Radiation	RBE
Gamma-radiation & X-radiation	1
Beta particles	1
Alpha particles irradiating lungs	7
Alpha particles irradiating red bone marrow	2
Alpha particles irradiating colon	0
Iodine-131 irradiating thyroid	0.2

[1] Adapted From IAEA EPR-Medical, 2005, Table F1.

To determine stochastic risk (and specifically, the risk of cancer) it is necessary to consider committed effective dose. The reference level used in this guidance corresponds to a committed effective dose of 200 mSv. This value has been proposed as the upper limit above which medical treatment to reduce dose should be considered

(Menetrier et al., 2005, Menetrier et al., 2007, Rojas-Palma et al., 2009). This dose represents approximately a 1% lifetime risk of fatal cancer attributable to the radiation dose.

Calculations of the activity in whole body corresponding to the dose reference levels were repeated for times after intake of between 1 and 30 days, and for each age group. In each case the smallest activity which corresponds to any of the absorbed dose reference levels or the effective dose reference level was selected. These values were then combined with the instrument calibration factors to give the action levels in the tables in section 5. The action levels in these tables are directly related to the dose reference levels but are specified in terms of measured quantities, i.e. the response of a particular hand-held monitor.

Age is an important factor in determining dose, so calculations of activity corresponding to the dose reference levels were made for four ages; 100 days, 1 year, 10 years and 20 years. The action levels tabulated in section 5 have been calculated for three age groups; up to 10 years, 10 to 19 years and 20 years and older. Calculations were made using the value of whole body activity calculated for the youngest age in the band, so that doses can not be underestimated.

Calculation of action levels were made for each radionuclide and for intakes by inhalation and ingestion. In an emergency, very little or no information would be available on solubility and aerosol size, so these parameters have been varied to cover all values which could be encountered. The smallest activity was then selected which could indicate a dose equal to the dose reference levels. For example, for ^{192}Ir at times up to 5 days after intake, the activity which corresponds to a dose of 200 mSv is smallest when the particle diameter is 0.01 micrometres (µm) and at later times when the diameter is 100 µm.

The particle diameter range which was considered was from 0.01 to 100 µm. Generally all default solubility types were considered but for some radionuclides there is no published evidence for the existence of certain solubility types. Therefore the following types were excluded from consideration; Neptunium Type F, Plutonium Type F, Iodine Type S and Selenium Types M and S. For some radionuclides there are very few published studies designed to assign compounds to default solubility types. This is the case for iridium and californium, and so all solubility types have been considered for these elements. Another parameter which is needed to calculate doses is the gut uptake factor. ICRP default values for each solubility type were used for this guidance. Where solubility types for some elements have not been identified then no gut uptake factor is published by ICRP. For these situations the procedure detailed in ICRP Publication 72, paragraph 8 was adopted (ICRP,1996).

For radionuclides where measurements of internal activity with external detectors are unlikely to be sufficiently sensitive, calculations were also made of activity excreted in a 24 hour urine sample. This was done using a very similar procedure as detailed above for whole body activity.

It was found that the effective dose reference levels were more restrictive than any of the absorbed dose criteria. Thus identifying people who may receive a committed

effective dose of 200 mSv will automatically also identify people whose organ dose could exceed the absorbed dose reference levels.

It should be emphasised that a large proportion of people who exceed the action levels will be found after further investigation to have received doses which are much less than any of the dose reference levels. This is because the action levels have been calculated using the most pessimistic combination of intake route, particle size and solubility type. As the response to the incident develops, information should become available on these parameters so that more realistic incident-specific doses can be calculated.

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