

Clearance and Exemption  
Principles, Processes and Practices  
for Use by the  
Nuclear Industry

A Nuclear Industry Code of Practice



This Issue of the Nuclear Industry Code of Practice on Clearance and Exemption Principles, Processes and Practices was published on behalf of the Nuclear Industry Safety Directors Forum in July 2005

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This Code of Practice details the principles, processes and practices that should be used when determining whether an article or material may be released from any further controls on the basis of radiological protection considerations. Historically, this concept has been termed 'free release' but, because the management of such releases are subject to stringent controls, they are better termed controlled clearances.

All such clearances do, of course, have to meet the requirements of relevant legislation and, ultimately, it is compliance with relevant legislation, rather than this Code of Practice that would be tested. However, it is intended that if the methods described in this document are properly applied, and the criteria met, then relevant legislation will be satisfied, and the article or material in question can be released for disposal or re-use without further control.

Notwithstanding the contents of this Code of Practice and adoption thereof, individual organisations may, on the basis of corporate risk considerations, decide that such items should still be treated as radioactive, or potentially radioactive material, and re-used or disposed accordingly.

This Code of Practice is not, in itself, a working level procedures document. It is aimed at those responsible for formulating organisational policy and developing working level procedures.

Initial issues of this Code of Practice cannot practicably identify every type of controlled clearance that takes place, although every effort has been made to cater for all generically applicable situations. It is inevitable that specific situations will arise which are not completely covered by the principles, processes and practices given. Where such situations do arise, users are asked either to refer them for determination and agreement of good practice, or communicate the means used to address the situation, to the Clearance and Exemption Working Group at the address on the previous page.

Finally, this issue represents the nuclear industry understanding of the most robust way of undertaking controlled clearance at the current time. We recognise, however, that the approach to, and view of, any activity in life is in a constant state of change and this area is no different.

## REVISIONS SHEET

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<b>Issue Number</b>	<b>Date</b>	<b>Comments</b>
Interim Issue	May 2003	Incorporating comments from consultation Jan - March 2003
Issue 1	June 2005	Incorporating: <ul style="list-style-type: none"><li>• Statistics Chapter;</li><li>• Monitoring Chapter;</li><li>• Revised Transport Section (as new Chapter);</li><li>• Changes arising from comments made by interested parties; and</li><li>• Modifications as a result of consideration of practical issues raised by users.</li></ul>
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## Definitions

**ALARP:** As low as reasonably practicable. In this Document, where public doses are addressed, **ALARA** (as low as reasonably achievable) is implied by the use of **ALARP**.

**Article:** Something solid which has been manufactured (everything is either an *article* or a *substance*).

**Assessment:** Use of all existing information about the nature, *history* of, and *measurements* associated with, an *article*, *substance* or *waste* to permit further decisions to be made (including *sentencing* decisions).

**Bulk material or bulk waste:** A significant quantity of a *substance* or mixture of *substances* which has some degree of uniformity and usually originates from a common source.

**Clean:** An article or substance that has never been contaminated or activated. This is usually declared on the basis of provenance alone. An article or substance for which there is inadequate provenance to justify an immediate declaration as clean may still be declared clean if suitable measurements confirm the absence of activity above normal background for the article or substance in question.

**Clearance:** The entirety of the process to confirm that an *article* or *substance* is *clean*, or *excluded* or *exempt* from further control under all relevant legislation on the basis of its radioactivity.

**Excluded:** An *article* or *substance* that is not radioactive under the Radioactive Substances Act 1993 (RSA 93) (and not subject to any control under the Act). An *excluded article* or *substance* is unlikely to be subject to control as radioactive under other legislation (see Chapter 3).

**Exempt:** An *article* or *substance* that is radioactive or contaminated under the Radioactive Substances Act 1993 (RSA 93) because it contains levels of specified radioelements above RSA 93 Schedule 1 exclusion limits or because it contains other radioelements wholly or partly attributable to either an artificial process or as a result of the disposal of radioactive waste, but in both cases at levels below relevant limits in Exemption Orders under the Act. These exemptions are from the requirements of registration or authorisation under RSA 93 (see Sections 2.1 - 2.7). An (RSA) *exempt article* or *substance* may be subject to control as radioactive under other legislation (mostly due to the presence of *exempt* levels of RSA 93 Schedule 1 radioelements) (see Chapter 3).

**History:** see provenance.

**Item:** An *article* (which may or may not be *waste*).

**Justify:** To possess or provide adequate evidence to support an action or conclusion.

**Material:** A gas, liquid or solid, which may include *articles* and *items*. It may or may not be a *waste*.

**Measurement:** The processes of *monitoring* and/or *sampling* (including *wiping*) as appropriate to the circumstances and including the results obtained.

**Monitoring:** A direct *measurement* procedure for detecting radioactivity using an instrument which detects radiation.

**Normal background:** The appropriate background level of radioactivity in an *article* or *substance* to be taken into account during *clearance* and *sentencing* according to circumstances (see Section 2.6).

**Provenance:** A knowledge of the use (including location) and controls which have been applied to an *article* or *substance* to determine its potential to have become activated and/or contaminated by radioactivity, and the nature of any potential activation or contamination (sometimes termed ‘history’).

**Quality plan:** A plan which specifies the activities and sequence of activities to be carried out, the procedures and instructions to be used, the inspection activities, the hold points, and the decision criteria, and identifies relevant individual responsibilities and record keeping requirements (see Section 5.4 paragraph 5.4.5).

**Radioactive article, substance or waste:** In this document, this is an *article, substance* or *waste* which is not *clean, excluded* or *exempt*. (It should be noted that *exempt articles, substances* or *wastes* are strictly *exempt but still radioactive* under the Radioactive Substances Act 1993 – see definitions of *excluded* and *exempt*).

**Reasonably practicable:** A proven or achievable action or standard of operation for which it may be reasoned that the overall cost of implementation, in terms of time, trouble or money, is not grossly disproportionate to the actual or expected benefit.

**Sampling:** An indirect *measurement* procedure which includes taking a sample for preparation and assay/counting in another location.

**Schedule 1 elements/radioelements:** Those elements specified in Schedule 1 of the Radioactive Substances Act 1993 (RSA 93) (see Section 2.2, Table 1 of this Document).

**Sentence/Sentencing:** That step of the *clearance* process at which the decision is made that an *article* or *substance* is *clean, excluded, exempt* or radioactive.

**Sentencing volume:** The volume of an *article* or *substance* over which an individual *sentencing* decision is taken.

**Smearing:** See *wiping*.

**Specified elements/radioelements:** Same as *Schedule 1 radioelements*.

**Substance:** A liquid or gas, or a solid which is not an *article*. It may or may not be *waste*.

**Substantially insoluble solid:** A solid (including suspensions of particulates) where the solubility is sufficiently small that the disposal impact is dominated by the solid form, rather than from any *material* that may dissolve and escape (see [ref. 1] and also this document (Section 2.7)) (Note this is a working definition; legal definition would be strictly a matter for the courts).

**Surface contaminated item:** An impervious *article* or *item* (or exceptionally a *substance*) with accessible surfaces, which has the potential to be contaminated by radioactivity only on or at its surfaces, and has not been activated. Such radioactivity must be detectable by external measurements (*monitoring* and/or *wiping*) (see Section 6.3) (A *surface contaminated item* is not necessarily the same as a surface contaminated object (SCO) under the Transport Regulations (see Chapter 3)).

**Swabbing:** See *wiping*.

**Wiping:** A procedure which is intended to remove a sample of surface radioactivity, if present, by wiping (or *swabbing* or *smearing*), in order to estimate the level of loose surface contamination present. The wiping procedure may use a wet wipe or dry wipe, and the wipe is processed and assessed in another location, usually by *monitoring*.

## Executive Summary

This Code of Practice has been produced to identify and facilitate consistent application of good practice within the nuclear industry regarding the clearance (including sentencing) of articles, substances and wastes which may be clean, or radioactive at levels below the thresholds of regulatory control. It includes:

- (i) Clarification of the nuclear industry's interpretation of legislation associated with the clearance and sentencing of articles, substances and wastes which are or have the potential to have been contaminated by radioactivity or activated by nuclear radiations;
- (ii) Where legislation is imprecise or unclear, an agreement on what is considered to be the industry standard of good practice;
- (iii) A standard management framework to be adopted by all organisations within the nuclear industry to justify safe and efficient clearance of potentially radioactive articles, substances and wastes; and
- (iv) Agreed guidance on the principles, processes and practices which should be followed for clearances and sentencing.

This Code of Practice is believed to be consistent with all legislation and guidance listed in the References (Chapter 9) and Bibliography (Chapter 10), and has so far been endorsed by the following organisations:

- AWE plc;
- British Nuclear Fuels plc;
- British Energy;
- Devonport Royal Dockyard Ltd. (DRDL);
- GE Healthcare Ltd;
- UKAEA;
- Ministry Of Defence;
- Rolls-Royce;
- National Physical Laboratory

The Radioactive Substances Act 1993 [ref. 2], relates to the use of radioactive material on premises and the disposal of radioactive articles and substances. It requires any disposal of a radioactive waste to be carried out only under an authorisation issued by the Environment Agency (EA) or Scottish Environment Protection Agency (SEPA) unless they are excluded by the Act itself or exempted by one of its Exemption Orders (for application to the Ministry of Defence, see Appendix ES1). These exclusions or exemptions mostly require the radioactivity concentration, or specific activity, of the article or substance to be below specified values, although there may also be other requirements which must also be satisfied. Excluded or exempted articles or substances are said to have been *cleared* and are termed *excluded* or *exempt* as appropriate. This Code of Practice sets the nuclear industry standard

by which the processes of *clearance* process (including *sentencing* as radioactive) are undertaken.

The clearance process is applicable to articles and substances which are to be transferred either physically or in the management sense outside the scope of continuous control (such as that maintained within a controlled contamination area) because they have no or only very low levels of radioactivity. However, it is not applicable to the transfer of articles or substances from one controlled area or regime to another within a single site where this is achieved by containment during transfer, nor is it applicable to the delicensing of land on nuclear licensed sites which is regulated by the Nuclear Installations Inspectorate (NII).

The Code of Practice mandates a system that allows articles and substances to be released from further control, where this is appropriate, using robust radiological protection principles. The need to avoid sentencing of clean materials as radioactive waste where this is not appropriate, the primacy of bulk, rather than surface radioactivity clearance criteria, and the need to disallow such clearances until all relevant legislation (not just the Radioactive Substances Act and its Exemption Orders) has been satisfied, are all clear principles.

The Document has been produced by the Clearances and Exemptions Working Group (CEWG) whose membership is given in Appendix ES2. However, it would not have been possible without the help of many other interested parties and the members of the CEWG take this opportunity to formally record their appreciation and thanks to all of those who have contributed.

## 1. Introduction

### 1.1 The 1992 HASPEM Report on Radioactive Clearance Monitoring

In 1992, through the Health and Safety Policy Exchange Meeting (“HASPEM”), a working group was set up to develop and define a common framework for radioactive clearance monitoring for use within the nuclear industry. Principles were recorded in a summary document entitled the “Health and Safety Policy Exchange Meeting (HASPEM) Document - Report on Radioactive Clearance Monitoring” [ref.3]. That document described a common basis for radioactive clearance monitoring and the surface clearance levels to be used as these were not specified explicitly in legislation. It also recommended that the status of clearance levels and industry activities in this field should remain under periodic review.

The Document specified industry agreed values for the clearance of surface contaminated materials that were based on Derived Working Levels (DWLs) rounded into SI units. These were:

- (i) 40 Bq/cm<sup>2</sup> for low toxicity beta emitters (<sup>3</sup>H, <sup>14</sup>C and <sup>35</sup>S);
- (ii) 4.0 Bq/cm<sup>2</sup> for beta, low toxicity alpha emitters and Uranium (except <sup>230</sup>U/<sup>232</sup>U); and
- (iii) 0.4 Bq/cm<sup>2</sup> for alpha emitters including <sup>230</sup>U/<sup>232</sup>U (but excluding other Uranium isotopes)

There were also a few additional restrictions agreed for certain unusual radionuclides. All these values were based upon risk assessments undertaken by radiological protection expert groups in the 1950’s and 1960’s. The industry also recognised that the NRPB had given recommended values [ref.4], and the Ionising Radiations Regulations 1985 [ref.5] (then extant), in Schedule 2, gave surface contamination values (for areas which had to be formally controlled under those regulations), which were higher than those in the HASPEM Document. Finally, a screening surface dose-rate for beta-gamma radiation, which should be as low as reasonably practicable (ALARP) with an upper limit of 1 microSv/h, was recommended, as the surface contamination limits were seen to be inadequate for some beta and gamma emitters.

The Document also took cognisance of the legal Exclusion and Exemption Limits defined in:

- (i) The third Schedule of the Radioactive Substances Act 1960 [ref.6] (then extant) for some naturally occurring radioelements; and
- (ii) The suite of Exemption Orders, primarily the Substances of Low Activity Exemption Order 1986 [ref.7], which included an exemption limit of 0.4 Bq/g for all radioelements

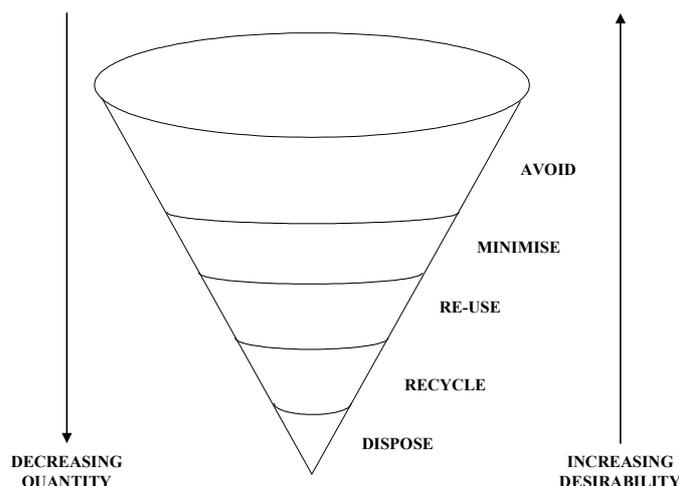
Finally, the Document recommended that materials which passed out of regulatory control should be designated using the words: “*For all regulatory and control purposes this material is not radioactive*”.

## 1.2 Background to this Code of Practice

In 2001, the Safety Directors' Forum (SDF), the successor to HASPEM, requested a detailed review and revision of the HASPEM Document, with increased emphasis on development of a common means of clearing materials which could be activated or could contain radioactive contamination within their bulk as well as on their surfaces. Revision of the HASPEM Document began with a workshop organised jointly by the Clearance and Exemption Working Group (C&EWG) and Health Physics Operational Liaison Meeting (HPOLM) on 1<sup>st</sup>/2<sup>nd</sup> November 2001 at BNFL Berkeley. The objective of the workshop was to identify relevant clearance issues associated with interpretation and application of the Radioactive Substances Act 1993 [ref. 2] and its Exemption Orders (listed in Appendix 1), and the extent of agreement within the industry on these issues. All larger nuclear organisations were represented. NRPB and representatives of relevant government departments and regulators (EA, SEPA, NII and DEFRA) also attended part of the workshop as observers.

It was noted at the workshop that, while RSA 60 [ref.6] had been repealed by RSA 93 [ref.2], there had been few changes in the new Act, and none of significance to the associated Exemption Orders. However, the new European Basic Safety Standards Directive [ref. 8], the new Ionising Radiations Regulations 1999 [ref.9], the Environmental Protection Act 1990 [ref. 10] and the Government's Waste Strategy 2000 [ref.11] all had impacts on the management and control of materials and options when they were to be cleared or sent for disposal. In the previous decade materials would often have been sent for disposal as radioactive for convenience when they were, in fact, likely to have been *exempt*, *excluded* or even *clean*. There has since been a shift of emphasis towards clearance of materials as *exempt*, *excluded* or *clean* whenever practicable, to permit re-use, recycling or disposal at ordinary licensed waste sites, instead of inappropriate disposal as radioactive waste.

The workshop concluded that there were a significant number of issues to be addressed. It was recognised that the Exemption Order limits in legislation had been further justified by newer risk assessments [ref. 12], and the consensus was that the continued use of self-imposed surface clearance levels was also reasonable. In addition, the preferred hierarchy for wastes (avoid, minimise, re-use, recycle, dispose), now stated as Government Policy [ref. 11], and presented diagrammatically in Fig 1, should be the principal objective for the management of all materials and wastes, including those containing radioactivity.



**Figure 1 Waste Management Hierarchy**

Measurements required for sentencing at very low levels (such as those given in the SoLA Exemption Order [ref.7]) to prove minimally radioactive material or waste is *excluded or exempt* are difficult and very resource intensive. Therefore, clearance should primarily be treated as a management process. Management arrangements should give high priority to minimising the potential for all materials to become contaminated by radioactivity or activated during their useful lifetime, and should record their provenance to provide documented confirmation. Detailed knowledge of the provenance of such materials may justify reduction of the number of measurements to be taken during eventual clearance. However, although the preferred waste hierarchy can and should be applied where practicable to all materials (*clean, excluded, exempted* and radioactive), re-use and recycle choices may not often be practicable options for radioactive materials. For these, particular emphasis should be placed on avoiding production and minimisation as far as reasonably practicable, because they often can only be disposed of as radioactive wastes.

This Code of Practice was originally issued in an interim form pending further consultation and completion of Chapters 7 and 8 in 2003. That interim issue replaced the HASPEM report [ref.3], and was based upon outputs from the workshop, developed in parallel discussions with stakeholders including the Environment Agency (EA), the Scottish Environment Protection Agency (SEPA) and the Nuclear Installations Inspectorate (NII). This first complete issue builds on that interim issue, although the regulators have advised us that ultimately their interests will be whether legal requirements have been complied with in individual cases, rather than compliance with this Document.

By agreement within the industry, it is designated as a Nuclear Industry Code of Practice. It is intended to be applied across the nuclear industry, and includes principles, processes and practices representing good practice for the management of *clean*, potentially radioactive and radioactive materials prior to, and for the purposes of, clearance and sentencing. It also provides a framework within which increasing priorities to achieve sustainable development in industrial operations associated with materials are addressed, *clean*, *excluded* and *exempt* releases are responsibly maximised, and erroneous sentencing is minimised.

It is intended that the principles and processes in this Document will be robust against further changes in the approach to surface clearance levels or Exemption Order limits; it will in any case be kept under review, and revised when necessary. The continued use of a standard industry Code of Practice is intended to provide assurance to regulators (EA, SEPA, NII), government and other stakeholders that effective and safe systems are in place to control the release of potentially radioactive materials.

## 2. Regulatory Background

### 2.1 Summary of Relevant Legislation and Regulatory Guidance

The Radioactive Substances Act 1993 [ref.2] and its associated Exemption Orders are the principal statutory legislation relating to radiological clearance of articles and materials for re-use, recycling, or for disposal. The extant Exemption Orders are listed in Appendix 1.1. The two most widely used for clearance purposes are:

- The Radioactive Substances (Substances of Low Activity) Exemption Order 1986 (as amended 1992) [ref. 7]; and
- The Radioactive Substances (Phosphatic Substances, Rare Earths etc) Exemption Order 1962 [ref.13].

These two exemption orders provide for clearances of a wide range of items and materials under specified circumstances.

Section 4 of “*Guidance on the Characterisation and Remediation of Radioactively Contaminated Land*” (Environment Agency, May 2002) [ref. 1]), produced by the Environment Agency for contaminated land associated with non-nuclear licensed sites, provides a comprehensive description of the Radioactive Substances Act 1993 and associated Exemption Orders as they apply to contaminated land in England and Wales, and guidance on interpretation of Exemption Order limits. Much of this guidance is also relevant and directly applicable to radiological clearance of items and materials other than contaminated land. The regulatory framework and interpretation of legislation given in this Code of Practice are consistent with that given in this EA Guidance.

Authorisations issued by the EA and SEPA, which contain clauses requiring best practicable means (BPM) to be used in radioactive waste management to minimise arisings, discharges and disposals, are also relevant. However, account must be taken of IRR 99 [ref. 9], which requires that, in the use and handling of radioactive materials, employees and other persons only receive radiation doses and risks which are justified, optimised and within legal limits. Government policy [ref. 14], which states that the best practicable environmental option (BPEO) should be sought for discharges and disposals, also needs to be considered.

The Transport Regulations [refs. 15 and 16] contain specific and relevant requirements concerning *excluded* and *exempt* items and materials, and some *clean*, *excluded* and *exempt* wastes may be subject to controls under EPA 90 [ref. 10] or Special/Hazardous Waste Regulations [ref. 17]. Finally, delicensing of land on nuclear licensed sites is subject to regulation by the NII under the Nuclear Installations Act 1965 (NIA 65) [ref. 18], although this is not within the scope of this Code of Practice.

## 2.2 The Radioactive Substances Act 1993 (RSA 93)

For general industry, the Radioactive Substances Act 1993 (RSA 93) [ref.2] is the principal legislation governing the keeping, use and disposal of radioactive materials (in Section 7 of the Act), and the accumulation and disposal of radioactive waste (in Sections 14 and 13 respectively). On nuclear licensed sites the keeping and use of radioactive material and the accumulation of radioactive waste are regulated by the NII under NIA 65 [ref. 18], but disposals are always regulated by the EA or SEPA regardless of whether or not a site is subject to nuclear site licence conditions.

Section 1 of RSA 93 specifies that a material is radioactive for regulatory purposes under the Act if it contains:

- (a) an element specified in Schedule 1 of Section 1 of RSA 93, which is present at specific activity levels greater than those given in the adjoining columns of that Schedule (reproduced as Table 1, below). If this element is present at lower activity levels than those given in Schedule 1, then the substance is not classed as radioactive (i.e. it is *excluded*);
- (b) any substances whose radioactivity is wholly or partly due to nuclear fission, neutron or ionising radiation or as a consequence of the disposal of radioactive waste, or by contamination as a consequence of the application of a process to some other substance. Thus any substance containing man-made radionuclides will be classified as radioactive, irrespective of its specific activity, and will be subject to some or all of the provisions of RSA 93, depending upon whether one of the exemptions under the Act applies.

Section 2 of RSA 93 specifies that “radioactive waste” means waste which consists wholly or partly of:

- (a) a substance or article which, if it were not waste, would be radioactive material;
- (b) a substance or article which has been contaminated in the course of the production, keeping or use of radioactive material, or by contact with or proximity to other waste falling within paragraph (a) of Section 2 (above), or this paragraph.

**Table 1**      **Schedule 1 from RSA 93 - The specified elements and their limiting specific activities**

Element	Bq/g		
	Solid	Liquid	Gas or vapour
Actinium	0.37	$7.4 \times 10^{-2}$	$2.59 \times 10^{-6}$
Lead	0.74	$3.70 \times 10^{-3}$	$1.11 \times 10^{-4}$
Polonium	0.37	$2.59 \times 10^{-2}$	$2.22 \times 10^{-4}$
Protactinium	0.37	$3.33 \times 10^{-2}$	$1.11 \times 10^{-6}$
Radium	0.37	$3.70 \times 10^{-4}$	$3.70 \times 10^{-5}$
Radon	-	-	$3.70 \times 10^{-2}$
Thorium	2.59	$3.70 \times 10^{-2}$	$2.22 \times 10^{-5}$
Uranium	11.1	0.74	$7.40 \times 10^{-5}$

Section 47 of RSA 93 defines “waste” and “disposal” as follows:

“‘waste’ includes any substance which constitutes scrap material or an effluent or other unwanted surplus substance arising from the application of any process, and also includes any substance or article which requires to be disposed of as being broken, worn out, contaminated or otherwise spoilt”

“‘disposal’, in relation to waste, includes its removal, deposit, destruction, discharge (whether into water or into the air or into a sewer or drain or otherwise) or burial (whether underground or otherwise) and ‘dispose of’ shall be construed accordingly”

### 2.3 Exemption Orders

Two Exemption Orders in particular specify the conditions under which a very wide range of materials or wastes defined as radioactive under RSA 93 are *exempt* from some or all of its provisions. These are:

- The Radioactive Substances (Substances of Low Activity) Exemption Order, SI No. 1002, 1986 and amendment SI No. 647, 1992 [ref.7] (the “SoLA Exemption Order”); and
- The Radioactive Substances (Phosphatic Substances, Rare Earths, etc) Exemption Order, SI No. 2648, 1962 [ref. 13] (the “PSRE Exemption Order”)

The SoLA Exemption Order specifies that solid radioactive material is *exempt* from the regulatory requirements for keeping and use, and waste is *exempt* from the regulatory requirements for disposal under RSA 93, provided that it is substantially insoluble in water and has an activity that does not exceed 0.4 Bq/g. (It also re-iterates the exclusions for solids under RSA 93 Schedule 1, which up to specified limits do not contribute to the total (see Table 1, above).) The SoLA Exemption Order also exempts organic liquid waste containing only  $^{14}\text{C}$  or  $^3\text{H}$  from regulatory requirements for disposal under RSA 93, provided it has an activity which does not exceed 4 Bq/ml, and gaseous wastes which contain no radionuclides or their decay products having a half life greater than 100 seconds. Disposals of any of these wastes do not require authorisations from the regulator (EA in England and Wales or SEPA in Scotland). The SoLA Exemption Order is important for wastes that contain any man-made radionuclides.

The PSRE Exemption Order states that a solid material which is radioactive solely because of the presence of one or more of the Schedule 1 elements (see Table 1, above), and is substantially insoluble in water, is unconditionally exempted from the provisions of RSA 93 provided that the specific activity of *each* of the Schedule 1 elements present does not exceed 14.8 Bq/g. (The same limits apply to Schedule 1 elements in liquids during their useful life, but not when a liquid becomes a waste.) This Order is particularly relevant to solid wastes arising from operations involving naturally occurring radionuclides.

#### **2.4 Interpretation of Limits for (naturally occurring) Radioelements Specified in Schedule 1 of RSA 93**

Interpretation of the limits given in RSA 93 and the SoLA Exemption Order were addressed in a DETR (now DEFRA) report “*An interpretation of Schedule 1 of the Radioactive Substances Act 1993 and related issues*” [ref. 19], and supplemented and extended to the PSRE Exemption Order in EA Guidance [ref. 1]. The following principles (in Sections 2.4 and 2.5) are consistent with guidance in these two documents, and their application to a substantially insoluble solid is illustrated schematically in Flowchart 2.1, and to a simple liquid waste (one not containing visible amounts of any solids) in Flowchart 2.2.

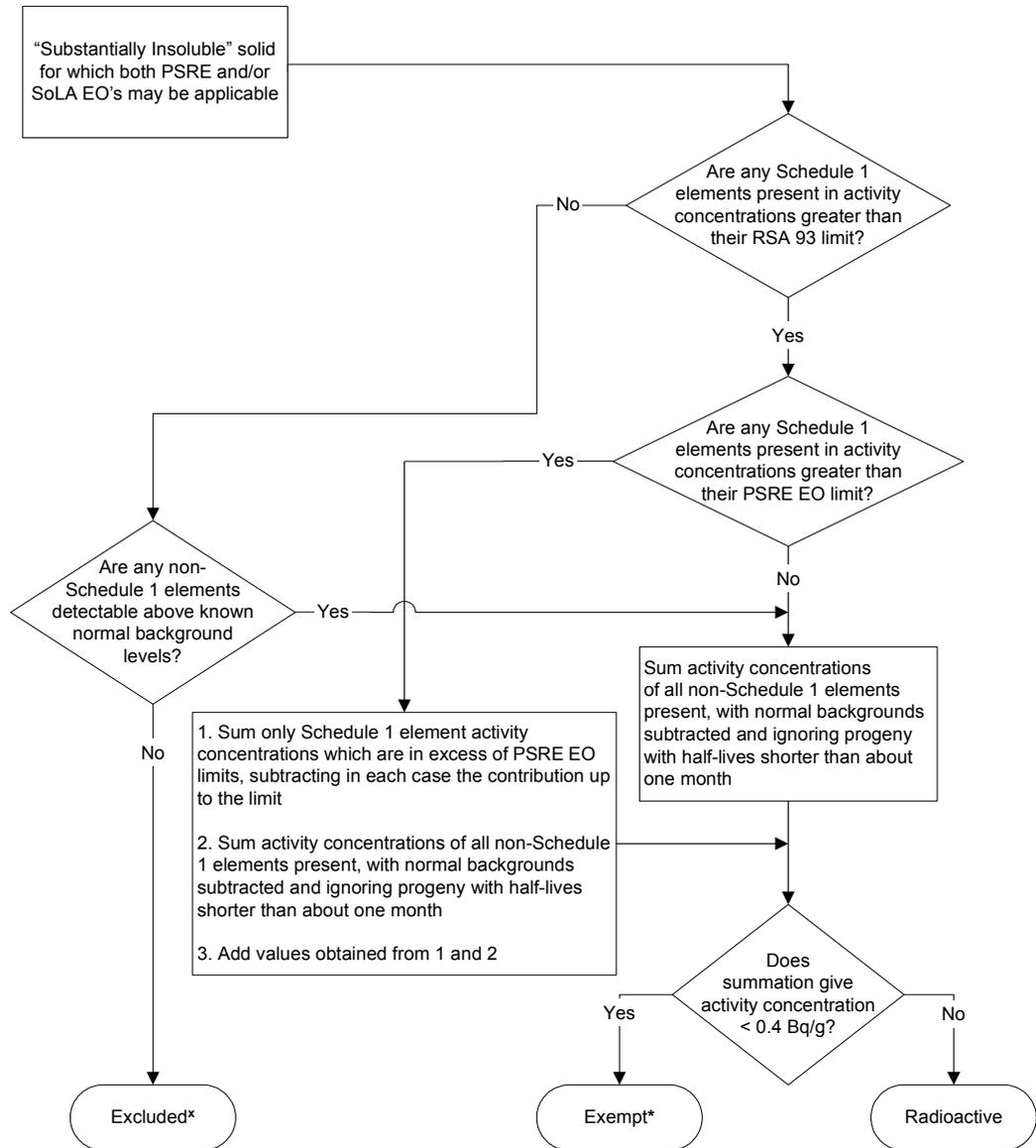
- 2.4.1 PSRE Exemption Order activity concentration limits for specified radioelements and the SoLA Exemption Order limit of 0.4 Bq/g may both be used simultaneously if both PSRE and SoLA Exemption Orders are applicable
- 2.4.2 RSA 93 Schedule 1 values and the PSRE Exemption Order activity concentration limits for specified radioelements, are absolute values which apply regardless of whether the origin of the radioactivity is natural or artificial. They therefore include normal and natural background levels (hence naturally occurring radioelements which are concentrated by some means or another, can become subject to regulatory control under RSA 93) (see Section 2.6)

- 2.4.3 Specified radioelements in Schedule 1 of RSA 93 (see also Table 1 above) are each independently excluded up to the radioactivity concentration values specified in RSA 93, and exempted up to the radioactivity concentration values specified in the PSRE Exemption Order, where applicable. Amounts in excess of each limiting value (either in RSA 93 Schedule 1 or in the PSRE Exemption Order, as appropriate) contribute to the additional 0.4 Bq/g limit under the SoLA Exemption Order for a material or waste which is a substantially insoluble solid, where this is applicable
- 2.4.4 In the absence of other guidance, and following the recommendation given in reference 19, it is only necessary to include the activities of longer-lived isotopes of radioelements specified under RSA 93 and the SoLA Exemption Order when comparing their activities with their Exemption Order limits. All short-lived progeny of specified radioelements having half-lives of less than about one month (such as Pa-234m,  $^{231}\text{Th}$  and  $^{234}\text{Th}$  arising in uranium decay) can be omitted even where secular equilibrium is assumed. (The exclusion of short-lived progeny does *not* apply to the PSRE Exemption Order (see 2.4.5 below))
- 2.4.5 PSRE Exemption Order activity concentration limits refer to the sum of radioactivity concentrations of all the radionuclides for each radioelement specified, and secular equilibrium is assumed unless evidence justifies otherwise. ( $^{226}\text{Ra}$  (in the absence of other Ra radioisotopes) is therefore limited by its Po daughters to 4.9 Bq/g, and  $^{232}\text{Th}$  (in the absence of other Th radioisotopes) is limited by its Ra daughters to 7.4 Bq/g, unless adequate justification can be made these daughters are not present at equilibrium levels (see ref.1).) (The short-lived progeny exclusions rule in para 2.4.4 does *not* apply to PSRE Exemption Order limits)

## **2.5 Interpretation of Limits for (all artificial and some naturally occurring) Radioelements not Specified in RSA 93**

- 2.5.1 All such radionuclides must be considered in establishing compliance with legislation, regardless of radiotoxicity. Due account must be taken of low-radiotoxicity nuclides such as  $^{241}\text{Pu}$  or  $^{14}\text{C}$  which may be difficult to detect
- 2.5.2 Only enhanced concentrations above normal background of radionuclides which are not specified under RSA 93 or the SoLA or PSRE Exemption Orders, are required to be included in the summation under the relevant SoLA Exemption Order limit of 0.4 Bq/g, after the normal background concentrations of each has been subtracted (see Section 2.6)
- 2.5.3 In the absence of other guidance, and following the recommendation given in [ref.19] which justifies para 2.4.4 (for the specified radioelements), it is acceptable practice to exclude from the relevant summation under the relevant SoLA Exemption Order limit of 0.4 Bq/g, those short-lived or metastable progeny (having half-lives of less than about one month) of radioelements which are not specified in Schedule 1 of RSA 93 and the SoLA Exemption Order (such as Ba-137m arising in  $^{137}\text{Cs}$  decay).

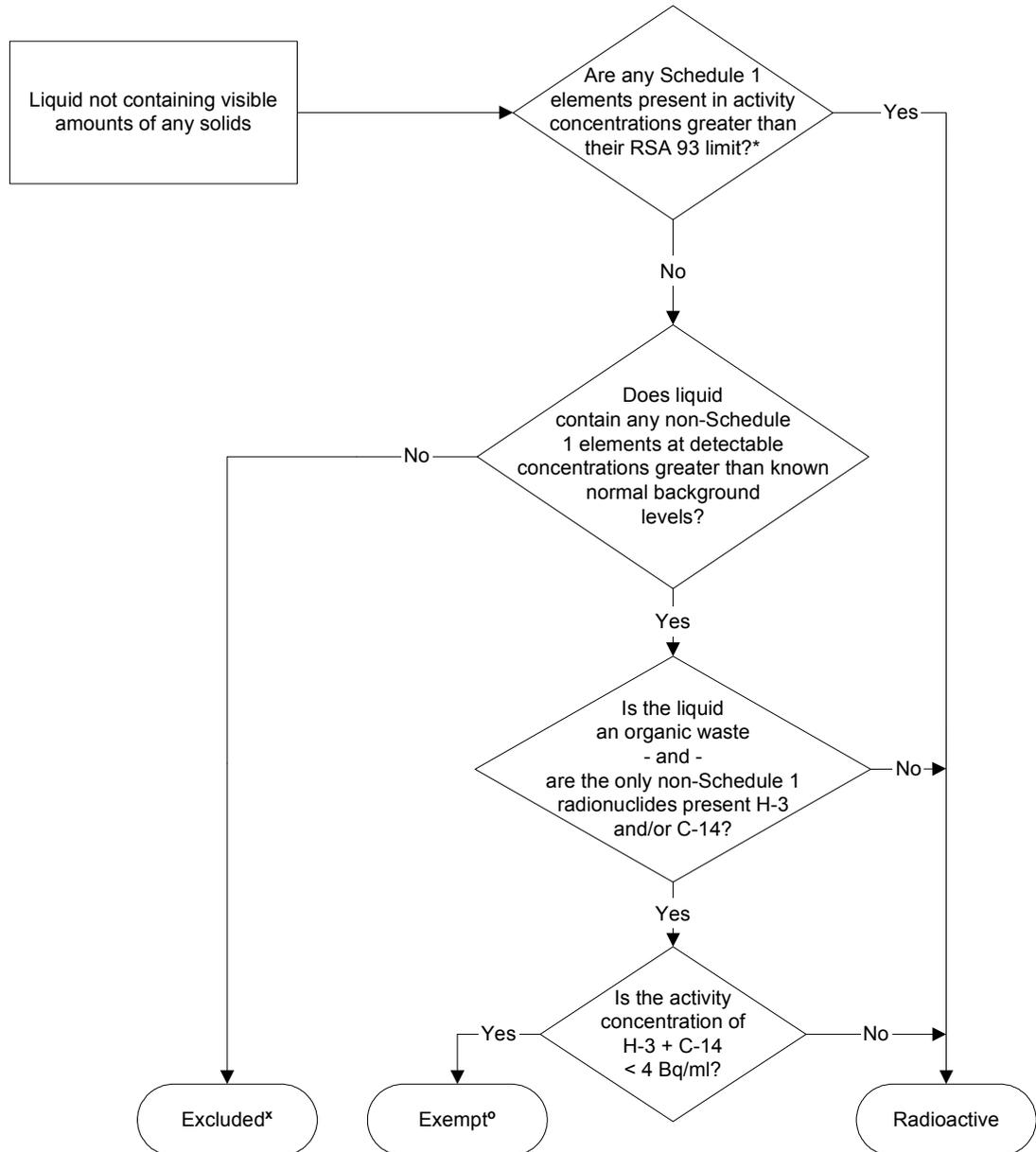
**Flowchart 2.1 - Application of Exemption Order Limits to a Substantially Insoluble Solid Item, Material or Waste for which both the Phosphatic Substances, Rare Earths, etc Exemption Order (SI 2648 1962) and Substances of Low Activity Exemption Order (SI 1002 1986) are Applicable**



\*Excluded from regulation under RSA 93

\*Exempt from the requirements of RSA 93 for registration as a material or exempt from authorisation for accumulation or disposal as a waste

**Flowchart 2.2 - Application of RSA 93 and Substances of Low Activity Exemption Order (SI 1002 1986 and SI 647 1992) Limits to a Liquid not Containing Visible Amounts of any Solids**



\*Excluded from regulation under RSA 93

\*The higher Phosphatic Substances, Rare Earths, etc Exemption Order (SI 2648 1962) limits (instead of RSA 93 limits) can be applied here to liquid materials, but not to liquid wastes (in the absence of non-Schedule 1 elements this will be exempt, not excluded)

°Exempt from the requirements of RSA 93 for registration as a material or exempt from authorisation for accumulation or disposal as a waste

## 2.6 Interpretation of Background

Natural background can be discussed in terms of both radiation levels i.e. dose rates, and activity concentrations. For the purposes of compliance with RSA 93 and its associated Exemption Orders, only radioactivity, or, more precisely, radioactivity concentrations are relevant. In assessing the compliance of radioactivity concentrations with relevant limits, *normal backgrounds* of non-specified radioelements can be subtracted (see para. 2.5.2). However, for specified radioelements, subtraction of natural background or normal background concentrations is not permitted, although concentrations up to certain limits are excluded under the Act and exempted under Exemption Orders (see paras 2.4.2 and 2.4.3).

The following principles associated with the definition of *normal background* apply to all naturally occurring radionuclides (such as  $^{40}\text{K}$ ), artificial radionuclides (such as  $^{137}\text{Cs}$ ), and also those which may occur both naturally and artificially (such as  $^3\text{H}$  and  $^{14}\text{C}$ ). They are consistent with EA and DETR (now DEFRA) Guidance [refs. 1 and 19]), where this is given:

- 2.6.1 Normal background includes naturally occurring concentrations of radioactivity. These may be local environmental values where local materials (soils, sediments) are under assessment, or values specific to the constituents of the material or waste itself (bricks, concrete).
- 2.6.2 Normal background includes widespread environmental fallout due to activities such as atmospheric weapons testing and nuclear accidents such as Chernobyl.
- 2.6.3 Outside the site boundary, and not on sites that have been designated by the Nuclear Decommissioning Authority as “contaminated”, normal background includes enhanced values due to legitimate past discharges which were authorised by the relevant regulator (EA, SEPA or their predecessors) (see also para 3.2.1), but not contributions due to those discharges or escapes which were not authorised or were accidental. It is not, however, permissible to use as a measure of natural background a region having obvious elevated activity that is a result of such discharges.
- 2.6.4 Values used for normal backgrounds should be assessed, recorded, and justified.

## 2.7 Insolubility Criteria in SoLA and PSRE Exemption Orders

The SoLA and PSRE Exemption Orders are limited to solids which are “substantially insoluble” in water. This term is not defined in the Exemption Orders. The following principles are consistent with EA Guidance [ref. 1].

- 2.7.1 For chemical forms of some radionuclides normally considered to be soluble in water, it would be necessary to demonstrate that their ability to leach out of an item or material is sufficiently small that the disposal impact will be dominated by the solid form of the item or material, rather than from any radioactive material that may dissolve and escape
- 2.7.2 Insoluble suspensions (including sludges) in liquids may be considered as a substantially insoluble solid, plus a liquid, under SoLA and PSRE Exemption Orders

in the clearance process for such mixtures, either for their clearance without separation or where the separation of liquid and solid phases is practicable and is advantageous for waste management or disposal purposes. (This is described in Section 6.11 and illustrated in Flowchart 6.11).

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### 3. Interactions with Other Legislation

It is important to recognise that the definition of what constitutes a radioactive material or waste for regulatory control may be different under other regulations (and in some cases impose further requirements relevant to the clearance of materials). The most important of these, for the purpose of clearance and exemption, are the Transport Regulations.

#### 3.1. The Transport Regulations (RamRoad 2002 and RamRail 2002)

Internationally, the regulations for the transport of radioactive material have been developed in close co-operation with the IAEA and are based on the 1996 Edition of the IAEA Regulations for the Safe Transport of Radioactive Material (ST-1 Revised as TS-R-1). The content of these regulations has been re-formatted so as to be integrated in the regulations for each transport mode, as follows:

- The European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR)(2005 Edition)
- Convention concerning International Carriage by Rail (COTIF) 9.5.80. Appendix 'B' Uniform Rules concerning the contract for International Carriage of Goods by Rail (CIM) Annex 1.
- Regulations concerning the International Carriage of Dangerous Goods by Rail (RID) (Class 7), 2003 Edition.
- International Maritime Organisation (IMO) International Maritime Dangerous Goods Code (IMDG Code)2002 Edition (including amendment 31-02). IMDG Code supplement-2002 Edition (including amendment 30-00).
- International Civil Aviation Organisation's Technical Instructions for the Safe Transport of Dangerous Goods by Air (Class 7) Edition.
- International Air Transport Association (IATA) Dangerous goods regulations. 45<sup>th</sup> Edition Effective 1 January 2004.

In the United Kingdom the following Statutory Instruments regulate the transport of radioactive material by road and by rail:

- The Radioactive Material (Road Transport) (Definition of Radioactive Material) Order 2002 (SI 2002/1092)
- The Radioactive Material (Road Transport) Regulations 2002 (colloquially known as RAMroad (SI 2002/1093)
- The Radioactive Material (Road Transport) (Amendment) Regulations 2003 (SI 2003/1867)
- The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2004' (SI 2004/568)(*these regulations invoke the requirements of RID*).

For the purposes of this document, the UK specific regulations above are collectively called the 'Transport Regulations', and apply when transport is off the licensed site.

The requirements of the Transport Regulations must always be considered BEFORE the transport of material. Where the Transport Regulations consider the material radioactive (and

hence place particular requirements), the material cannot be considered a candidate for controlled clearance for unconditional re-use or disposal.

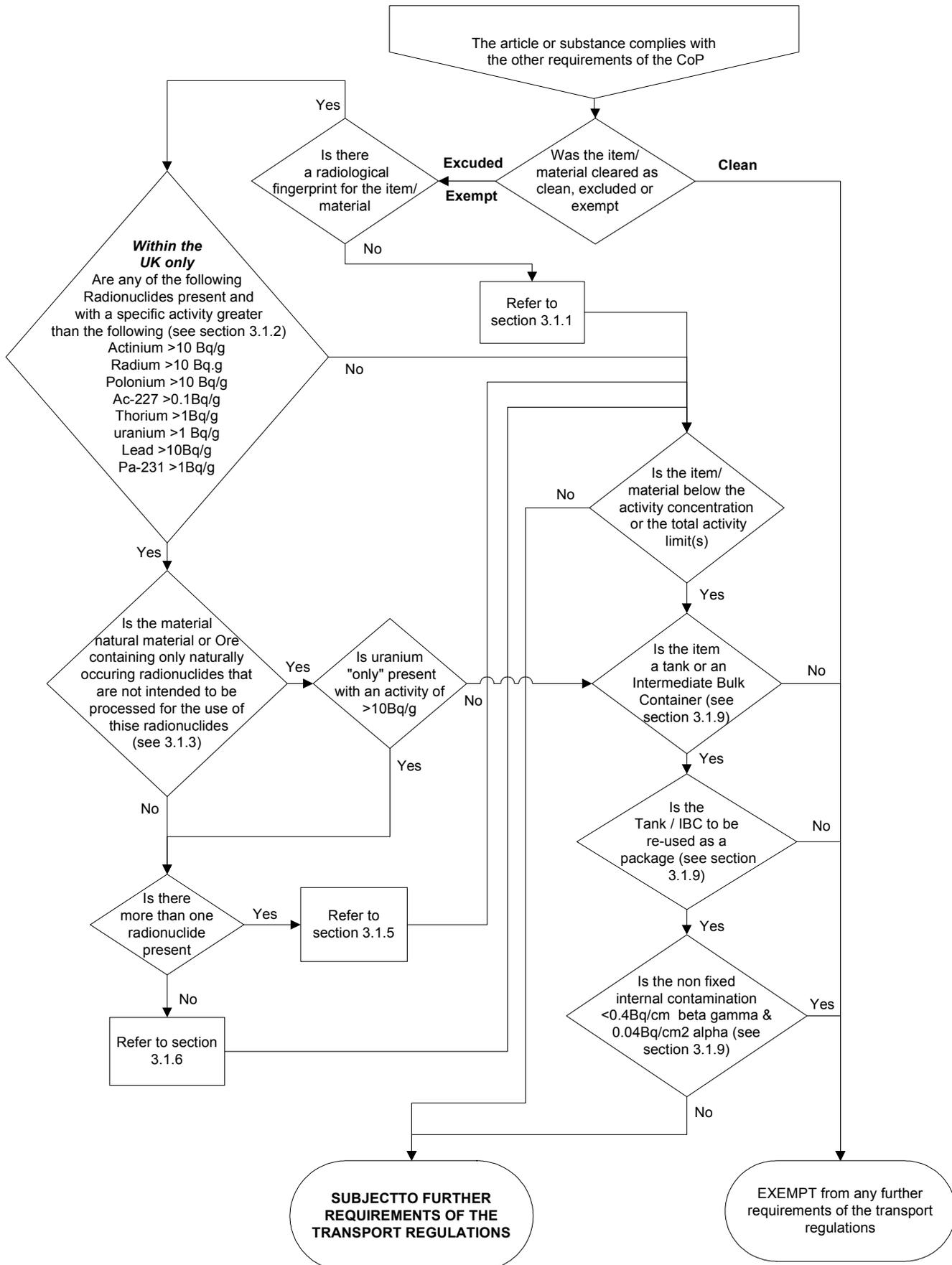
If there is no reasonable belief that the article or substance presented for sentencing could have become activated or contaminated (i.e. it is deemed clean), then the requirements of the Transport Regulations do not apply, and further consideration is not necessary.

The Transport Regulations apply both an individual radionuclide activity concentration limit and an individual radionuclide total activity limit per consignment (i.e. the total material or object on a conveyance prepared for transport), whereas RSA/SoLA only refers to activity concentration. However, many of the activity concentration limits in the transport regulations are above the RSA Schedule 1/SoLA Exemption limits, and so it is only for a limited number of radionuclides that material exempt under SoLA will be subject to the Transport Regulations. These radionuclides are identified in Flowchart 3.3

Although the Transport Regulations contain limits for both activity concentration and total activity, **both** of these have to be exceeded for the object or material in question to fall within the remit of the Transport Regulations. Hence, apart from those few specific radionuclides covered in flowchart 3.1, if the material or object is exempt from RSA/SoLA, then it will be exempt from the requirements of the Transport Regulations irrespective of the total activity.

Flowchart 3.1 summarises the process to be used to determine whether the Transport Regulations apply.

**Flow Chart 3.1 Application of the Transport Regulations**



3.1.1 If only gross measurement data exists, no relevant data exists or there are unusual radionuclides present in the material (i.e. not listed Table 1 of RAMroad, RID 2.2.7.7.2.1 to 2.2.7.7.2.6.), transport regulations impose default concentration values/default consignment values that must be used:

- Where only beta and gamma emitting nuclides are known to be present, a 10 Bq/g activity concentration and  $1 \times 10^4$  Bq consignment limit apply;
- Where alpha emitting nuclides are known to be present (either with beta/gamma nuclides or on their own), or no relevant data is available, a 0.1 Bq/g activity concentration value and  $1 \times 10^3$  Bq activity consignment apply.

Unless **both** limits (activity concentration limit **and** activity consignment limit) are exceeded the material is exempt from any further requirements of the regulation's for transport of radioactive material by road and rail

3.1.2 These specific radionuclides are listed because the limits contained within the Transport Regulations are lower than those if only RSA/SoLA are taken into account. Hence, if these nuclides are present at activities greater than those shown, the Transport Regulations would apply even if the material or object could be considered exempt under RSA/SoLA (and it could not, therefore, be considered for unconditional disposal or re-use).

3.1.3 These regulations include a provision for natural material and ores, providing they contain only naturally occurring radionuclides that are not intended to be processed for use of those radionuclides (including man made radionuclides in natural background). Such provision permits the activity concentration values for exemption to be raised by one order of magnitude.

3.1.4 When the factor of 10 for the nuclides referred to in 2.9.3 is taken into account, all but the limit for uranium become higher than that in RSA/SoLA. Hence, providing the material has been confirmed exempt under RSA/SoLA, then the Transport Regulations will also not apply unless uranium is present at an activity concentration greater than 10 Bq/g.

- 3.1.5 For objects or materials where one or more of the limits in the Transport Regulations are exceeded, and which contain more than one radionuclide (a mixture) then a weighted average must be calculated using the following formula to determine if the exemption limits have been exceeded. NOTE: In this situation, the activity of **all** radionuclides present must be taken into account even if, in themselves, their activity is less than the limit.

$$X_m = \frac{1}{\sum_i f(i)/X(i)}$$

Where:

f(i) is the fraction of activity or activity concentration of radionuclide i (as appropriate) in the mixture:

X(i) is the appropriate total activity or activity concentration limit (as appropriate) given in RAMroad Table 1 in Schedule 1, RID 2.2.7.7.2.1 to 2.2.7.7.2.6.; and

X<sub>m</sub> is the derived value of the activity concentration for exempt material or the activity limit for an exempt consignment in the case of a mixture.

Unless **both** limits (activity concentration limit **and** activity consignment limit) are exceeded the material is exempt from any further requirements of the regulations the transport of radioactive material by road and rail.

- 3.1.6 For material containing only one radionuclide the values referred to in flowchart 3.1 and paragraph 3.1.2 must be referred to together with the total activity value for the radionuclide concerned (RAMroad Table 1 in Schedule 1, RID 2.2.7.7.2.1 to 2.2.7.7.2.6) to determine whether the activity concentration limit or the activity consignment limit has been exceeded. Unless **both** limits (activity concentration limit **and** activity consignment limit) are exceeded the material is exempt from any further requirements of the Transport Regulations.
- 3.1.7 The definition of loose contamination in the transport regulations is defined as one order of magnitude less than the levels stated in section 3,9 SC2. These lower limits are used within the regulatory text for the internal non-fixed contamination of Intermediate Bulk Container's' (IBC) and Tank Containers (see 2.9.9 & flow chart 2.3). However it can be inferred from the transport regulations that an acceptable level of non-fixed contamination for material/items entering the public domain is 4 Bq/cm<sup>2</sup> beta/gamma/low toxicity alpha emitters & 0.4 Bq/cm<sup>2</sup> alpha. Such information is stated in the regulatory text regarding non-fixed contamination limits on conveyances or equipment that have been used in connection with the transport of radioactive material/equipment.

The regulatory limits for the transport by road and rail of Surface Contaminated Objects (SCO-I) relate to the **fixed** contamination on the surface(s) averaged over 300cm<sup>2</sup> (or the area of the surface if smaller than 300cm<sup>2</sup>). The limits are up to 4 x 10<sup>4</sup> Bq/cm<sup>2</sup> for beta and gamma emitters *and low toxicity alpha emitters*; or 4 x 10<sup>3</sup> Bq/cm<sup>2</sup> for all other alpha emitters.

3.1.8 The Transport Regulations do not, in themselves, require controls on the transport of objects or materials sentenced as **exempt** (on the basis of activity concentration or total activity considerations) and which have a radiation level at the surface greater than 5 µSv/hr. However;

- They do put specific requirements and controls on packages that contain or have contained radioactive material which show surface radiation levels greater than 5µSv/hr, and
- Put specific requirements on conveyances and equipment (or part thereof) used in connection with transporting radioactive material in the public domain, which have surface radiation levels greater than 5µSv/hr.

**Hence it is not appropriate for material that is being released for uncontrolled disposal or re-use to have surface radiation levels exceeding 5µSv/hr.**

3.1.9 For transport regulation purposes the definition of an Intermediate Bulk Container and a Tank Container is defined as follows;

- A Tank Container is an article of equipment meeting the definition of a container, and comprising a shell and items of equipment, including the equipment to facilitate its movement. They are used for the carriage of gases, liquids, powdery or granular substances and having a capacity of more than 450 litres.

*The term "Container" is defined in the transport regulations as an article of transport equipment specially designed to facilitate the carriage of goods, by one or more means of transport, without breakage of load. But fitted with devices permitting its ready stowage and handling, and so designed as to be easy filled and emptied.*

- An Intermediate Bulk Container (IBC) is defined as a rigid or flexible portable packaging that has a capacity up to 3m<sup>3</sup> that has been designed to conform with the standards listed in the United Nations Recommendations on the transport of Dangerous Goods [twelfth edition]
- In the special case of tanks or Intermediate Bulk Containers that are to be designated for unrestricted reuse, the loose internal surface contamination must not exceed 0.4 Bq/cm<sup>2</sup> beta/gamma/low toxicity alpha emitters & 0.04 Bq/cm<sup>2</sup> alpha.

### 3.2 The Ionising Radiations Regulations 1999 (IRR 99) and associated guidance.

The Ionising Radiations Regulations 1999 (IRR 99) and associated guidance [ref. 9] impose duties on employers to protect employees and other persons against ionising radiation arising from work with radioactive materials, and also impose certain duties on employees. They address specifically employee and public protection when working with radiation and radioactive materials and the need to minimise, contain and control radioactivity and surface contamination. (The latter impacts the creation and minimisation of radioactive waste which is discussed in Chapter 5.)

Under IRR 99, a “radioactive substance” is defined as “any substance which contains one or more radionuclides whose activity cannot be disregarded for the purposes of radiation protection”. More explicitly, Schedule 8 Part 1 of the regulations lists radionuclide-specific bulk radioactivity concentrations which may require “notification of specified work” to the regulator under regulation 6. This regulation is not applicable on nuclear licensed sites, but will be applicable to work undertaken by a licensed operator outside his licensed site. The threshold radioactivity concentrations for regulation under IRR 99 for some isotopes of the specified radioelements (in Schedule 1 of RSA 93) are slightly lower than those permitted under RSA 93, and most are considerably lower than the PSRE Exemption Order limit of 14.8 Bq/g. For non-specified radioelements, only <sup>250</sup>Cm is lower than the 0.4 Bq/g SoLA Exemption Order limit.

This implies that under some unusual circumstances, almost entirely associated with specified radioelements, substances *excluded* or *exempt* from regulatory control under RSA 93 may remain subject to regulation 6 and other regulations of IRR 99. Schedules 1 and 8 and regulation 6 of IRR 99 must be consulted to ensure compliance. Discussion of these requirements will be covered in a future issue of this document.

### 3.3 The Environmental Protection Act 1990 (EPA 90) and Special/Hazardous Waste Regulations

A material which is *clean* or *excluded* or *exempt* under RSA 93, may be subject to the Environmental Protection Act 1990 (EPA 90) [ref. 10] as a controlled waste or the Special/Hazardous Waste Regulations [ref. 17] as a special/hazardous waste. EPA 90 defines and contains provisions for controls on controlled waste under Part II, notably s.33 (prohibition of unauthorised treatment or disposal) and s.34 (duty of care). The Special/Hazardous Waste Regulations place additional controls on those controlled wastes with specific hazardous properties (known as special/hazardous wastes). The following principles are consistent with this legislation:

- 3.3.1 Waste which is *clean* (because it contains no radioactivity above normal background) may be subject to control as a controlled or special waste according to its non-radioactive properties

- 3.3.2 Waste which is *excluded* (because it contains specified radioelements at activity concentrations below Schedule 1 limits in RSA 93, and contains no other radioactivity above normal background) is not radioactive within the meaning of RSA 93, and is therefore subject to control as a controlled or special waste in the same way as *clean* waste
- 3.3.3 Waste which is *exempt* under any of the Exemption Orders (but is not *excluded* by Schedule 1 of RSA 93) remains radioactive under RSA 93, and is therefore not subject to control as a controlled waste under EPA 90. However, if its properties (other than *exempt* levels of radioactivity) make it a special waste, then it is subject to regulation under the Special/Hazardous Waste Regulations.
- 3.3.4 It is good industry practice to treat *exempt* waste which is not special/hazardous waste as if it were controlled waste, although this is not mandatory under legislation.

## 4. Industry Practices not Specified by Regulations or Regulatory Guidance

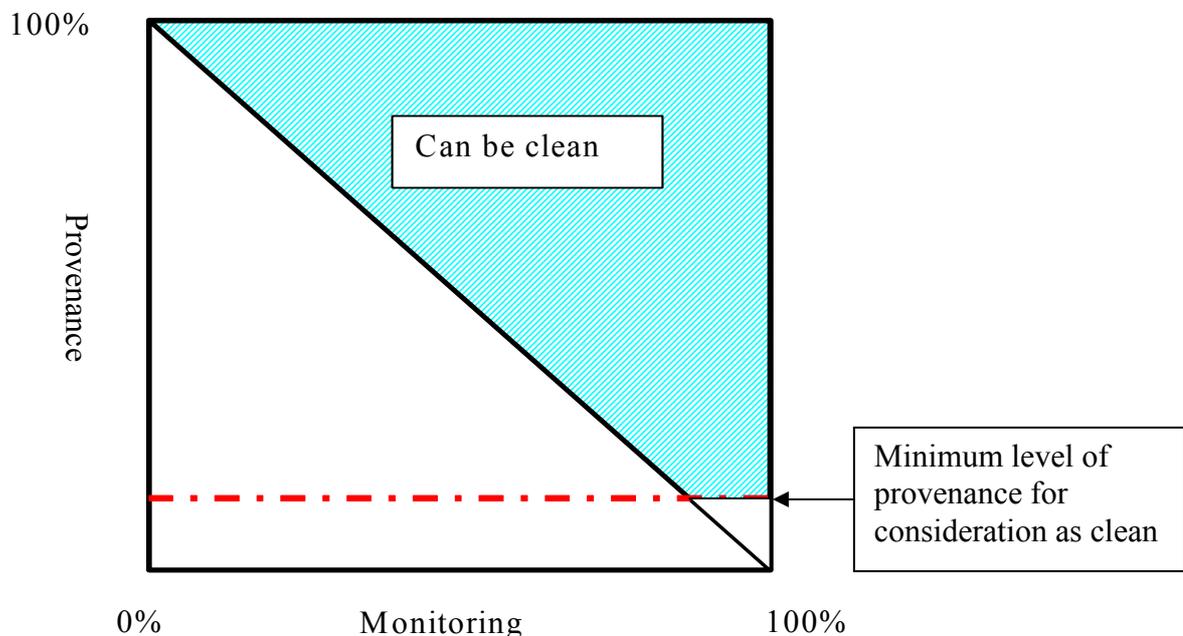
This chapter specifies the policies and practices to be adopted by the nuclear industry where legislation or regulatory guidance are currently considered imprecise or unclear.

### 4.1 The Concept of a Clean Article or Substance

- 4.1.1 The majority of articles or substances used on a nuclear site will not be contaminated or activated during use and will therefore be, in radiological terms, the same as similar articles or substances used in any work environment. It is therefore unsustainable and unreasonable to treat such articles or substances as radioactive in any way, because this would unnecessarily prevent their re-use or recycling, or would be an inappropriate use of any disposal facility for radioactive materials.
- 4.1.2 An article or substance that has never been contaminated or activated is therefore, for the purposes of this Code of Practice, termed 'clean'.
- 4.1.3 All articles or substances contain some naturally occurring radioactivity, and clean articles or substances are no different. This will, however, be no different to that in any similar article or substance used in a non-nuclear environment (in either activity concentration or constituent radionuclide terms – see also the definition of normal background).
- 4.1.4 There are two ways in which an item can be considered clean both of which, to one degree or other, rely on some knowledge of the provenance of the article or substance:
- Knowledge of the provenance alone may be sufficient to show that the article or substance is clean. For example, it may have been used in an area where there was no potential for activation or contamination:
  - Alternatively, the article or substance may have been used in an area where there is a *potential* for articles or substances to become contaminated. However, the provenance of the article or substance in question gives strong confidence that there has been no potential for contamination or activation.
- 4.1.5 It is important to remember that, in both of these cases, **the article or substance in question will never have been contaminated or activated**. Given an *a priori* belief that an article lies in one or other of the two cases given in 4.1.4, **the only difference lies in the level of monitoring required to confirm that the article or substance in question is clean**. In the former case, only *reassurance* monitoring to confirm that belief will be necessary (and, in some cases, no monitoring at all). In the latter case, there will be a need for an appropriate depth of monitoring to confirm the belief.

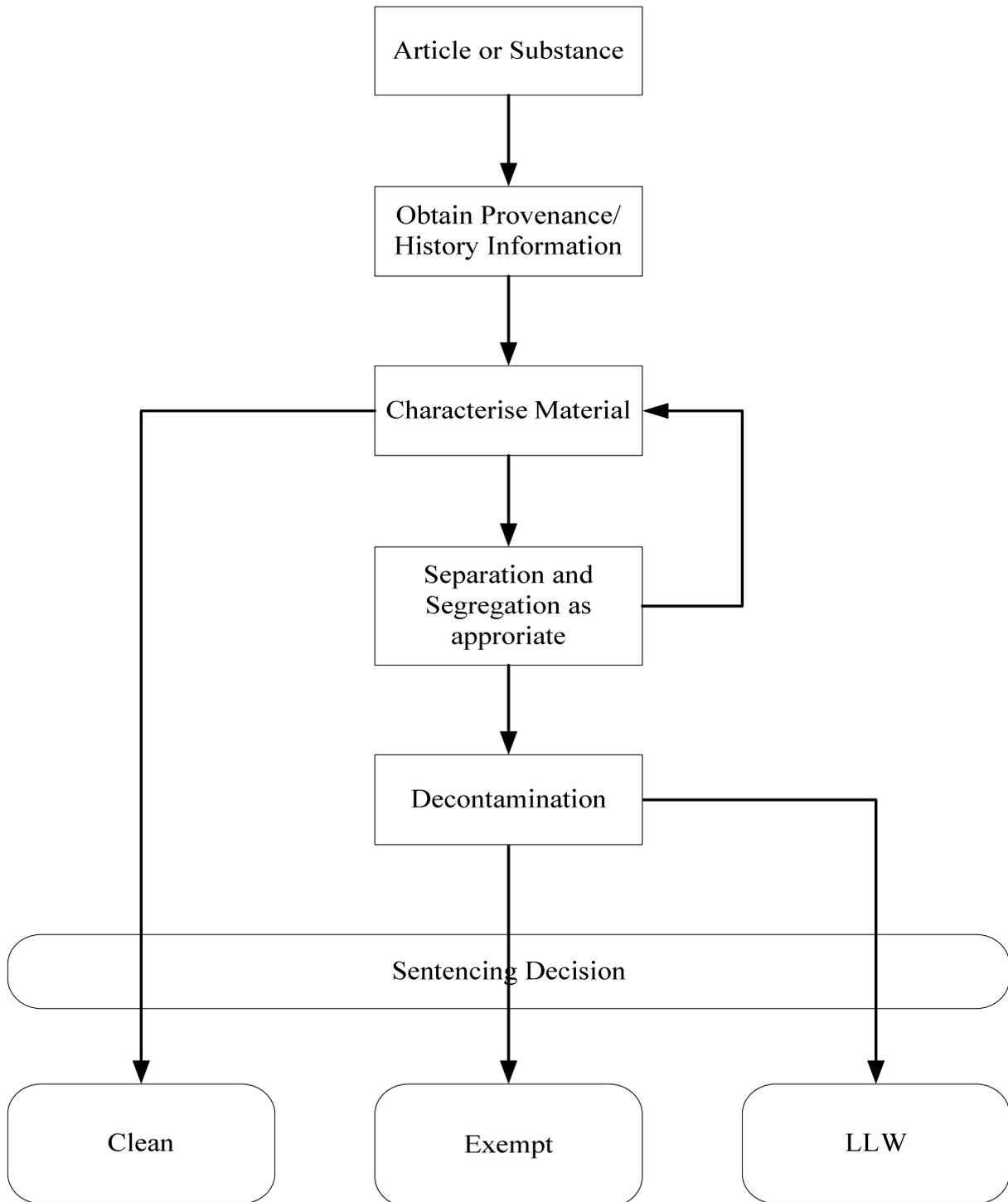
- 4.1.6 In respect of clean items, the use of an appropriate level of monitoring for reassurance does not imply a belief that the article or substance is radioactive, but is simply being used to confirm a belief that it is clean.
- 4.1.7 The relationship between provenance and the use of monitoring in confirming an item to be clean is shown diagrammatically in figure 4.1. In essence, if there is 100% certainty of the history then little or no monitoring is necessary (and any done would be purely for reassurance purposes). If there is reduced certainty about the provenance, but still a belief that the article or substance is clean, a greater degree of monitoring will be necessary. Note that there must be *some* knowledge of the history of the article or substance in question – sentencing as clean cannot be based on monitoring alone.

**Figure 4.1 – Relationship between certainty of provenance and the amount of monitoring required**



- 4.1.8 It is acceptable practice to physically separate and segregate articles or substances so that clean constituents are treated appropriately. This is summarised in flowchart 4.1. **Note, however, that materials themselves cannot be decontaminated and then declared clean.** For example, painted steel can be segregated into the paint layer and the steel itself. If the treatment is such that the separation process is partly used to remove potentially contaminated sections of the steel – areas of rust, perhaps, then neither constituent can be considered clean. However, if the steel were totally contained in an impermeable layer that has not been breached, then there *may* be justification for sentencing it as clean.

**Flowchart 4.1**      **Summary of the Overall Approach to Separation and Segregation of Materials**



## **4.2 Applicability of the Clearance Process in this Code of Practice**

- 4.2.1 The preceding section (4.1) notes that it is inappropriate to dispose of articles and substances as radioactive, or devote inappropriate resources to their assessment, where there has been no activation or contamination. Therefore, without prejudice to the sections that specifically discuss how to approach clean items, the detailed requirements of this Code of Practice which relate to the application of legislation covering radioactive materials must only be applied to articles or substances which have, or may potentially have, been activated or contaminated.
- 4.1.2 Where provenance alone is sufficient to justify sentencing as clean, the article or substance may be monitored in an appropriate manner to confirm the belief that it is *clean*. It must be clearly understood that such monitoring (which could involve use of hand held monitors or gatepost monitors, for example) does not imply any belief that the article or substance either is, or may be, contaminated or activated.
- 4.2.3 This Code of Practice is not intended to be used for the transfer of articles or substances from one controlled area or regime to another within a single site where this is achieved by management control and containment during transfer.
- 4.2.4 This Code of Practice is not applicable to the delicensing of land on nuclear licensed sites, which is regulated by the Nuclear Installations Inspectorate.

## **4.3 General Applicability of RSA 93 and the Exemption Orders**

- 4.3.1 Articles and substances beyond the site boundary which are contaminated from previously authorised discharges are not subject to regulation as radioactive under RSA 93 (see also Chapter 2, section 2.6, para 2.6.3).
- 4.3.2 It is good practice for articles and substances in which the radioactivity can be demonstrated to have decayed to below Exemption Order limits at the point at which they are identified as waste or a candidate for re-use or recycling, to be sentenced as *exempt*.
- 4.3.3 People and animals are not subject to control under RSA 93, although personal risk considerations and IRR 99 require them to be monitored and decontaminated where possible

## **4.4 Limitations on the Dilution of Radioactivity in Solid Materials**

- 4.4.1 Deliberate dilution by mixing of different arisings to achieve clearance is not an acceptable practice

4.4.2 Unavoidable dilution may occur, and is acceptable, where the extent of separation or segregation is determined by the technique employed, and the technique is designed to ensure complete removal (such as the use of an excavator to dig out a volume of contamination). Alternatively acceptable dilution may occur as a result of the nature of the material (for example, where brickwork is contaminated only close to the surface on one side but segregation or separation is not practicable), subject to consideration of section 4.5. In such cases, care must be taken to ensure that any subsequent sampling or monitoring is suitably representative.

#### **4.5 Limitations on the Inhomogeneous Distribution of Radioactivity in Solid Materials**

4.5.1 The following principles should be used when analysing results from sampling of bulk material where inhomogeneity is known or suspected and/or where a material to be cleared is made of two or more layers (intimately bound materials or otherwise, e.g. laminates or blocks and paint). A summary of outcomes compliant with this Code of Practice for the inhomogeneity criteria described below is given in Table 4.1, and a proposed process is presented in Flowchart 4.2. Note however, that this general approach is additional to the overall need to properly demonstrate compliance with relevant criteria as discussed in Chapter 7.

4.5.2 If initial radioactivity samples are taken in bulk material and results are:

- found to vary by more than an order of magnitude (excluding nil results), and the average is greater than three-quarters of the relevant Exemption Order limit (including nil results); or
- any measurement is more than five times the relevant limit;

then averaging over the whole material volume (as a single sentencing volume) is unlikely to be acceptable without proper (documented) consideration of:

- (i) The practicability of segregation and separation;
- (ii) Suitable revision of monitoring and numbers of samples (See chapter 7);
- (iii) Suitable reduction in the size of each sentencing volume;
- (iv) Whether it is practicable to make further measurements to identify each area or volume containing significant concentrations of radioactivity;
- (v) Whether it is practicable to remove or segregate small areas or volumes containing significant concentrations of radioactivity (hot spots);
- (vi) The potential radiological significance of inhomogeneity.

4.5.3 Practicability should take into account:

- the costs in terms of effort, time and resources involved in undertaking separation and segregation;
- the hazards and risks to the workforce undertaking the separation and segregation;
- the impacts against these parameters of disposal of the material as radioactive waste (LLW, VLLW where available or authorisation) or as exempt waste must be considered.

4.5.4 In considering suitable scenarios against which to determine the radiological detriment a proportionate approach akin to that employed in the use of Generalised Derived Limits may be employed. viz.,

1) Very cautious simplistic "All-in-a-Coffee Cup" model - assuming a most sensitive member of the public is exposed to the full inventory of the project. If the dose is  $<10\mu\text{Sv}/\text{yr}$  then no further consideration of separation and segregation is necessary.

2) Scenario for recycling or re-use - Where the material is not expected to fallout of the chain of utility a conservative model should be used.

3) Scenario for landfill disposal: recognising that disposal to landfill/burial may result in lower public exposure than unrestricted exempt release a suitable model should be employed against which to justify the radiological impact.

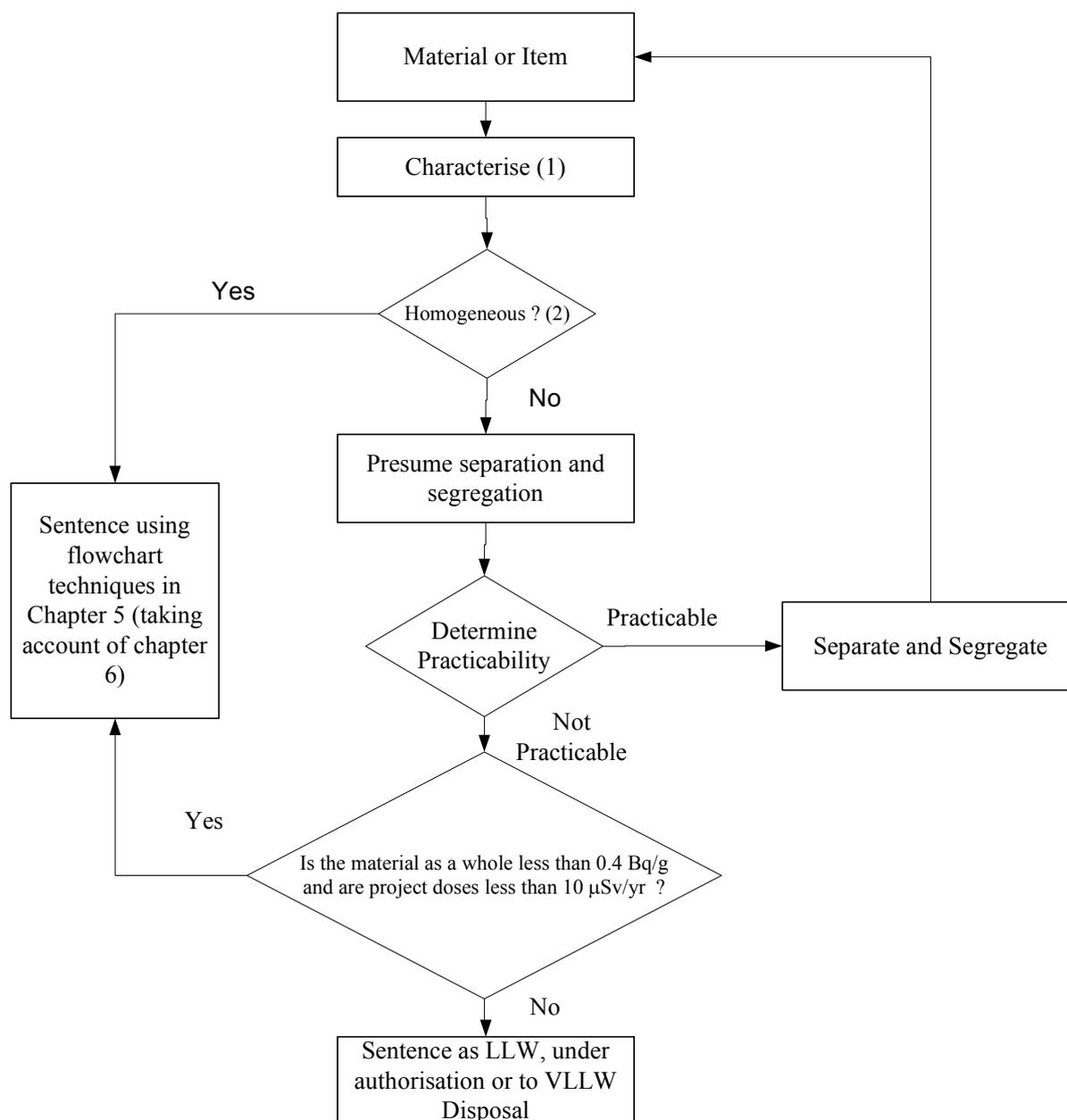
4.5.5 In cases where the potential radiological significance of exempting of the material would exceed  $10\mu\text{Sv}/\text{yr}$ , clearance is NOT permissible and the material must either be segregated or disposed in total as LLW/VLLW (where available) or under authorisation.

4.5.6 In some cases it may not be practicable to remove areas of relatively higher activity/hot spots, but the overall radiological significance is negligible. In these cases, however, it may still be appropriate to sentence the item or material conservatively as radioactive, if the stakeholder significance is not negligible (for example if the radioactivity could be easily detected with readily available instruments).

**Table 4.1: Indication of potential outcomes**

Surface Layer (e.g. Paint, Laminate, or region of increased radionuclide concentration)	Bulk layer (e.g. Brick, blockwork, metal structure components)	Overall Average	Code Compliant Outcome
Average < relevant EO Limit	Average < relevant EO Limit	< EO Limit	No Radiological requirement to undertake Separation and Segregation, prior to sentencing as exempt waste, although commercial considerations (e.g. recycling or re-use options) should be considered.
Average > relevant EO Limit	Average < relevant EO Limit	<EO Limit	Presumption of Separation and Segregation unless a justification can be made that removal is not reasonably practicable, the expenditure (whether in time, trouble or money) is grossly disproportionate to the safety and environmental benefits gained, and the overall impact of disposal is less than 10 $\mu$ Sv/yr.
Average < relevant EO Limit	Average > relevant EO Limit	> EO Limit	Unless commercial considerations (e.g. recycling or re-use options) for the exempt surface layer are sufficient to justify the safety and environmental impacts of separation and segregation it would be expected that material in this configuration would be sentenced as LLW en masse.
Average > relevant EO Limit	Average > relevant EO Limit	> EO Limit	Sentence as LLW.

**Flowchart 4.2 Determination of Requirement to Separate and Segregate**



1. Characterisation means, in this case, the acquiring of knowledge about the material. This knowledge might simply be obvious (in the case of paint layers, for example, or might result from a preliminary or comprehensive sampling program.

2. A material is not homogeneous if:

- There is a distinct layer (e.g. paint or activity) or
- Any non-homogeneities could foreseeably result in dissociation post disposal, or
- section 4.5 applies

#### **4.6 Confidence Levels for the Sentencing of Solid Items and Materials**

- 4.6.1 Nothing in the following paragraphs should be applied in isolation from the detailed requirements for statistical analysis in Chapter 7.
- 4.6.2 Decisions should be taken so that the probability level that a radioactive item or material is incorrectly cleared as *excluded* or *exempt* is very low (i.e. a “false negative”), and will generally be lower than the probability of an *excluded* or *exempt* item or material being sentenced incorrectly as radioactive (i.e. a “false positive”)
- 4.6.3 In the absence of other guidance, the confidence levels sought typically should be:  
(i) there is < 5% probability that a radioactive sentencing volume or item has been incorrectly sentenced as *excluded* or *exempt* (false negative)  
(ii) there is < 20% probability that an *excluded* or *exempt* sentencing volume or item has been incorrectly sentenced as radioactive (false positive)
- 4.6.4 Even if the required statistical confidence level is achieved, paras 4.5.1 and 4.5.2 should be considered

#### **4.7 Sentencing and Compliance Volumes for Solid Materials**

- 4.7.1 The *sentencing volume* of an article or substance is the volume (or part of an article) over which an individual sentencing decision is taken
- 4.7.2 Determination of the number of samples necessary is discussed in Chapter 7.
- 4.7.3 The sentencing volume should be chosen or adjusted to satisfy inhomogeneity limitations and confidence level requirements (Sections 4.5 and 4.6 (above))
- 4.7.4 Subject to para 4.7.3 above, the sentencing volume over which the radioactivity concentration is averaged and the RSA 93 or Exemption Order limits must be satisfied is often set by practical considerations such as the unit of volume in which it will be transported. It will usually be from a single arising or arisings of a very similar nature, and for bulk material is likely to be in the range 0.1 – 10 m<sup>3</sup> or tonnes. In general, larger sentencing volumes are acceptable for major arisings where contamination is reasonably uniform, and smaller sentencing volumes where inhomogeneity is significant

4.7.5 In some instances, because of measurement limitations at very low levels, a number of similar sentencing volumes may be cleared as *excluded* or *exempt*, but the confidence level that some are not *false negatives* is not as high as the requirement. Under such circumstances, it is acceptable practice to bulk such sentencing volumes following sentencing to produce a larger *compliance volume*, which does satisfy the overall confidence level. (This is *not* dilution as it is undertaken after sentencing)

#### **4.8 Surface Contaminated Items and High Surface Area to Volume Items (and Materials)**

Some solid items and materials are impervious with accessible surfaces, and therefore have the potential to be contaminated by radioactivity only on or at their surfaces, with no potential for contamination within. Such radioactive contamination is detectable by external measurements (monitoring and/or wiping), and such items and materials are called potentially *surface contaminated items*.

Some items, which will often be *surface contaminated items*, have a large ratio of surface area to volume and these are termed *high surface area to volume items*. There is no rigid delineation of this grouping, neither is one necessary, but paper, card, plastic sheeting and clothing are within this group and glass and thin metal sheeting of low to moderate density may be included.

Solid items and materials which satisfy the physical criteria of *surface contaminated items*, or *high surface area to volume items*, but are potentially activated or contaminated by tritium (which migrates into surfaces and is difficult or impossible to measure by surface monitoring) cannot be considered to be *surface contaminated items* or *high surface area to volume items*, and should be considered as potentially activated solids (see Section 6.5) or potentially tritiated solids (see Section 6.6), as appropriate. Items and materials potentially contaminated by other radionuclides capable of diffusing into them (for example caesium), should also not be considered under these circumstances to be *surface contaminated items* or *high surface area to volume items* if their total radioactivity cannot be quantified by external measurements alone (see further discussion in Sections 6.3 and 6.4).

The importance of identifying *surface contaminated items* and *high surface area to volume items* is that they are often cleared and sentenced by external monitoring and wiping only; bulk sampling is not necessary. However, this is a simplification which can lead to an emphasis on surface radioactivity and inadvertent non-compliance with RSA 93 or the Exemption Orders, so both surface and consequential average bulk contamination assessment of these particular items must be considered carefully, as explained in Section 4.9.

#### 4.9 The Requirement for Surface Clearance Levels

For the purposes of clearance of items and materials from regulatory control under RSA 93 [ref. 2], compliance with RSA 93 Schedule 1 values or Exemption Order (bulk) activity concentration limits is **always** necessary and is the prime requirement. This is not, however, considered to be sufficient because there are additional concerns regarding handling safety and the potential to spread contamination. These concerns are primarily for *surface contaminated items* and *high surface area to volume items* (as defined in Section 4.8) because all their radioactivity is located on surfaces and may be loose and removable. In general, surface contamination is regulated by IRR 99 [ref. 9], although, unlike IRR 85 [ref. 5], IRR 99 has no quantitative limits for acceptable levels of surface contamination, and even in IRR 85 these are only given as values for the designation of controlled areas under the regulations, and are therefore not directly relevant to the clearance of items or materials.

For many years the nuclear industry has specified self-imposed surface clearance levels and criteria which are additional mandatory constraints on all *excluded* and *exempt* items and materials cleared under RSA 93 Schedule 1 and Exemption Order limits specified in legislation. These surface clearance levels were reviewed in the earlier HASPEM Document in 1992 [ref. 3] and have been reviewed again for this Code of Practice. The updated surface clearance levels and criteria are called *reference surface clearance levels* and are given in Section 4.10 of this Document. They are similar (but not identical) to those given in the HASPEM Document, and are now also consistent with threshold levels for surface contaminated objects (SCO1) in the new Transport Regulations [refs. 15 and 16].

It is necessary to ensure that the activity of an item or material does not exceed the relevant RSA 93 or Exemption Order (bulk) limits. For some *surface contaminated items* and most *high surface area to volume items* (principally paper and plastic sheeting and personal clothing), *reference surface clearance levels*, which are set for safety and to prevent the spread of contamination, are not low enough under many circumstances to also ensure compliance with the regulatory (bulk) limits. Thus clearance must not be given on the basis of compliance with these *reference surface clearance levels* alone. Table 4.9.2 gives some illustrative values of minimum thicknesses of “items” implied by the surface contamination values in SC3 of the *reference surface clearance levels* (see Section 4.10) for simultaneously providing compliance at the upper limits with the 0.4 Bq/g value in the SoLA Exemption Order, for several common materials, in simple geometry.

**Table 4.9.2 Illustrative minimum thicknesses of items for application of *reference surface clearance levels* alone to ensure simultaneous compliance with the SoLA Exemption Order limit when surface contamination exists on one side only at SC3 limiting levels**

Material	Typical density g/cm <sup>3</sup>	Minimum average thickness of surface contaminated material (cm) for simultaneous compliance with the SoLA Exemption Order limit of 0.4 Bq/g		
		0.4 Bq/cm <sup>2</sup> α activity	4.0 Bq/cm <sup>2</sup> βγ activity	40 Bq/cm <sup>2</sup> low toxicity radionuclides
Wood	0.75	1.3	13	130
Glass	2.2	0.45	4.5	45
Steel	8	0.12	1.2	12

To prevent non-compliance with regulatory (bulk) activity limits, *high surface area to volume items*, should be cleared where practicable (and where self absorption can be taken into account, if necessary) using specialised bulk monitoring equipment capable of measuring down to bulk limits directly rather than by use of surface monitoring instruments. Because of the difficulty of confirming compliance with bulk limits by measurement, additional care should be taken with *high surface area to volume items* to minimise, or if possible eliminate, their potential for becoming contaminated, or clearance may not be permissible (see para 4.3.8).

#### 4.10 Reference Surface Clearance Levels

The principles outlined above are summarised as “*reference surface clearance levels*”, which are applicable to all clearances but are of particular relevance to *surface contaminated items* and *high surface area to volume items* and are given in SC1 – SC6 below:

- SC1 The systems for management and clearance of all items and materials shall ensure compliance with RSA 93 and Exemption Order (bulk) activity concentration limits. (This principle takes precedence over SC2 – SC6.)
- SC2 Loose surface contamination shall not exceed 0.4 Bq/cm<sup>2</sup> α and 4.0 Bq/cm<sup>2</sup> βγ activity, and shall be reduced as far as reasonably practicable below these values. In many circumstances reduction below 0.04 Bq/cm<sup>2</sup> α and 0.4 Bq/cm<sup>2</sup> βγ activity may not be justifiable. (Consideration of the Transport Regulations (Chapter 3) is required prior to transportation.)

SC3 The total (loose + fixed) surface contamination and the dose-rates at the surface of any item or material to be cleared shall be as low as reasonably practicable and shall not exceed the following:

- (i) 40 Bq/cm<sup>2</sup> activity for low toxicity  $\beta$  and electron capture radionuclides (<sup>3</sup>H, <sup>14</sup>C, <sup>35</sup>S and <sup>55</sup>Fe); and
- (ii) 4.0 Bq/cm<sup>2</sup>  $\beta\gamma$  activity; and
- (iii) 0.4 Bq/cm<sup>2</sup>  $\alpha$  activity; and
- (iv) 5 microSv/h surface  $\beta\gamma$  dose-rate as indicated by a surface dose-rate monitor; and
- (v) 1 microSv/h penetrating  $\gamma$  dose-rate measured by an area monitor at 20 cm from any surface

*(For some radionuclides, and some mixtures, dose-rate limitations will be stronger constraints than surface radioactivity values)*

SC4 For *high surface area to volume items* (in particular sheets of paper, plastic sheeting and personal clothing), specialised bulk monitoring equipment (such as a bag monitor) should be used where practicable to measure compliance directly with legislative (bulk) limits (SC1). (Additional surface monitoring and wiping to confirm compliance with SC2 and SC3 may also be necessary in some circumstances)

SC5 Where SC4 is not practicable for *high surface area to volume items*, measurements should be made using suitable surface and dose-rate monitors, and wipes where necessary, and either these measurements must be able to confirm that legislative bulk limits (SC1), and SC2 & SC3 surface levels are not exceeded, or clearance must be on the basis of “no detectable radioactivity above normal background” (NDA) using monitors capable of measurement down to 25% of SC3 levels or lower

SC6 The surface contamination values in SC2 and SC3 shall be averaged over areas appropriate to circumstances. The default values are any:

- 100 cm<sup>2</sup> for clothing and small items;
- 300 cm<sup>2</sup> for larger items; and
- any 1000 cm<sup>2</sup> for floors, walls and large containers

The application of these *reference surface clearance levels* is described further in relevant parts of Chapter 6.

## 5. Management Principles and Arrangements

The aim of government policy for the management of items, materials and wastes is to achieve *sustainable development*. In response to this aim, the waste management objectives are identified as:

- (i) To avoid where possible and otherwise minimise the creation of radioactive items and materials;
- (ii) To avoid where possible and otherwise minimise the creation of all wastes, including *excluded* and *exempt* wastes, but to maximise the quantities of potentially radioactive items and materials that may be correctly cleared as *excluded* or *exempt*;
- (iii) To maximise re-use and recycle options and minimise the need for disposals;
- (iv) To achieve a high level of safety in all disposals;
- (v) To have a high level of confidence that sentencing is technically correct and is demonstrably safe;
- (vi) To undertake these activities in compliance with legislation; and
- (vii) To achieve (i)-(vi) effectively and efficiently.

These objectives are achieved in part by preventing and controlling surface contamination, which is legislated and regulated by the Health and Safety Executive (HSE) and Nuclear Installations Inspectorate (NII) under the Ionising Radiations Regulations 1999 and its associated Guidance [ref. 9], and by licence conditions in nuclear site licences. These regulations therefore have relevance to the minimisation of radioactive wastes and are also the origin of the requirement to justify exposures and keep radiation doses and risks as low as reasonably practicable (ALARP). In addition, authorisations for discharges, disposals and transfers granted by the environmental regulators (EA and SEPA) under RSA 93 always contain a mandatory requirement to apply best practicable means (BPM) to the management and minimisation of waste. These authorisations will have considered the best practicable environmental options (BPEO) at the time of their issue, but, where individual decisions on treatments, discharge and disposal routes have to be taken, account has to be taken of the overarching BPEO [ref. 14] in justifying them.

It follows that these waste management objectives are to be achieved using *best practicable means* (BPM), with radiation doses and risks to workers and the public being *justified* and kept *as low as reasonably practicable* (ALARP), and the *best practicable environmental option* (BPEO) must also be considered either implicitly or explicitly.

In support of these objectives, the management principles and arrangements described in the remainder of this Chapter are to be adopted.

## 5.1 Safety and Environmental Principles

- 5.1.1 Best practicable means (BPM) should be used to minimise potentially radioactive arisings and in all significant treatment, clearance and sentencing activities, while radiation doses and risks should be kept as low as reasonably practicable (ALARP)
- 5.1.2 Best practicable means (BPM) should be used to reduce or remove contamination on or within items and materials to be cleared as *exempt or excluded*, subject to the principle that radiation exposures are kept as low as reasonably practicable (ALARP)
- 5.1.3 The holistic approach should be used in waste management. If significantly more waste, or an intractable waste, will be created by decontamination, or if an item or material cannot be economically decontaminated, it may be best practice not to decontaminate it but to sentence it as radioactive waste
- 5.1.4 Where practicable, “concentrate and contain” is preferable to “dilute and disperse”
- 5.1.5 Where it is demonstrably safe to do so, all waste management arrangements should seek to minimise the need for all disposals (especially of radioactive wastes) and maximise the use of processes that encourage the re-use and recycling of materials
- 5.1.6 To the best belief of the operator, the release of items or materials from regulatory control should have no significant impact on human health or the environment. The operator must recognise that sentencing as *clean, excluded* or *exempt* is unconditional, and that the operator at all times retains other duties under regulations, notably a duty of care until re-use, recycling or final disposal has taken place
- 5.1.7 No item or material should be released from control unless there is adequate recorded evidence that it has been correctly sentenced. Sentencing decisions should always be made conservatively

## 5.2 Principles for Plant Operation

- 5.2.1 Plant should be designed, and operations involving radioactivity and radioactive materials should be carried out, if possible to prevent, and otherwise to minimise, the activation or contamination of the items and materials used (and the plant itself)
- 5.2.2 Plant, items and materials should as far as practicable be designed and used in ways to facilitate their subsequent decontamination, if this becomes necessary
- 5.2.3 Plant, items and materials likely to become activated or contaminated should be managed and controlled throughout their life, and their history accurately recorded to support and simplify eventual clearance or sentencing processes
- 5.2.4 All such items and materials should be identifiable throughout their life and they should remain segregated or separable where practicable if this will simplify later treatment and sentencing

- 5.2.5 The spread of radioactive contamination in general should be prevented by delineating and controlling all access and egress to areas which have the potential to become, or are, contaminated by radioactivity. These areas will usually be static locations (whether temporary or permanent), but could for example be the inside of a containment which is transportable
- 5.2.6 Such areas should themselves be monitored regularly so the actual extent and nature of any contamination present is known. They should always be kept as clean as reasonably practicable as the principal defence against spread of radioactivity and contamination to items and materials
- 5.2.7 Items and materials should only be introduced into such areas if this is essential to operations and they must then be controlled until formally cleared or sentenced.
- 5.2.8 Additional care should be taken where practicable to avoid contamination of high surface area to volume items and materials (principally paper, plastic sheeting and personal clothing), which may have to be cleared on the basis of lower operational values than SC3 (sometimes NDA (see SC5 (Section 4.10) and also Section 6.4)), in order to demonstrate their compliance with Exemption Order limits.
- 5.2.9 The management principles outlined above should be the first lines of defence, and an appropriate monitoring regime (usually monitoring and wiping) during clearance of potentially *surface contaminated items* from the area should be for reassurance as the last line of defence to confirm that management arrangements have been adequate.

### **5.3 Quality Assurance Arrangements**

- 5.3.1 Quality systems should require personnel to be trained as appropriate in the procedures to be followed, and in the use, calibration and maintenance of monitoring equipment
- 5.3.2 Quality systems should be subject to company audit programmes and procedures and records should be open to scrutiny by regulators
- 5.3.3 Quality systems should address in particular the requirements in the following paragraphs (5.3.4 – 5.3.12)
- 5.3.4 Items and materials with the potential to become radioactive should be identifiable and should have an owner at all times, with responsibilities for its overall control, maintaining segregation and separability when this will be advantageous for later clearance, and for recording and keeping documentation on its history of use
- 5.3.5 Systems should require records to be kept where necessary. These should include:
- (i) Clearance certificates (see paras 5.3.8 and 5.3.9);
  - (ii) Other records which demonstrate and justify the clearance and sentencing decisions for items and materials and conformance to the principles and practices given within this Code of Practice; and

- (iii) Records of quantities and types of material or waste cleared.
- 5.3.6 Clearance systems should place clear responsibilities on individuals, especially for decision taking
- 5.3.7 Relevant decision criteria employed in sentencing should be specified and traceable to this Code of Practice
- 5.3.8 In general, clearance certificates should be issued for offsite re-use, recycling and disposal and under all other circumstances deemed necessary. Company procedures should identify these circumstances
- 5.3.9 Where clearance certificates are issued with items or materials, they should include the following features:
- (i) Unique identification (as far as practicable) of the item or material cleared;
  - (ii) Identification of the documentation which supports the certificate;
  - (iii) Identification of the legislation with which it is compliant (e.g. IRR 99, RSA 93, RamRoad etc)
  - (iv) A statement of caveats where applicable (e.g. radioactivity not detectable by the measurement systems used; presence of other toxic substances etc);
  - (v) A statement of recommendations by and signature of a nominated suitably qualified and experienced person (SQEP) concerning compliance with legislation and future use or disposal;
  - (vi) Authorisation by and signature of the owner of the item or material;
  - (vii) A date of issue and period of validity of the certificate;
  - (viii) A statement of responsibilities for keeping the documentation and certificate
  - (ix) A signed confirmation of release and date;
  - (x) The statement “For all regulatory and control purposes, this material is not radioactive”.
- 5.3.10 The condition of items and materials for which clearance certificates have been issued, and the validity of the certificates, must be preserved until they are released from control
- 5.3.11 Operators should have arrangements to ensure consistency of application of this Code of Practice, in particular across large or complex sites
- 5.3.12 Systems and procedures must be practicable and proportionate

#### **5.4 Clearance and Sentencing Arrangements for Items and Materials**

- 5.4.1 Clearance processes should follow the relevant Flowcharts and guidance in Chapters 6-8 of this Code of Practice.
- 5.4.2 All sentencing and clearances must comply with both RSA 93 and Exemption Order limits and industry *reference surface clearance levels*

- 5.4.3 In considering clearance under RSA 93, the requirements for exclusion from regulatory control under the Ionising Radiations Regulations [ref. 9] (see Section 3.8), and the Road Transport Regulations [ref.15] and the Carriage by Rail Regulations [ref. 16] (see Chapter 3) must also be satisfied for full uncontrolled release of the item or material to be permitted
- 5.4.4 A generic or individual quality plan is required for each significant waste treatment, clearance and sentencing operation (unless it can be shown that one is unnecessary). The requirements are outlined in para 454.5 and Sections 6.2 – 6.13
- 5.4.5 Quality plans drawn up in accordance with the quality management system should include the following:
- (i) The activities (treatments, measurements, assessments & sentencing), and the sequence of activities, to be carried out;
  - (ii) The procedures and instructions to be followed for the activities;
  - (iii) The inspection activities hold and decision points;
  - (iv) Relevant responsibilities for all activities, inspections, decisions and authorisations, and
  - (v) The documentary and record keeping requirements and responsibilities.
- 5.4.6 Simpler procedures may be adopted for the sentencing of items and materials that are *clean* (where they have not been contaminated or activated) compared to those procedures for sentencing items and materials that are potentially radioactive. When doubt exists, items and materials must not be assumed to be *clean* (see Section 6.2).

## 6. Clearance and Sentencing Processes

### 6.1 Overview of Radioactive Material Sentencing

Flowchart 6.1 is an illustrative overview of the clearance and sentencing routes for all types of potentially radioactive materials (solids, liquids and gases). It identifies the Flowcharts to be followed for any item or material, the secondary or changed form arisings which could be produced from its treatment, and the final sentencing decisions which can result.

Sentencing of solids is much more complex than sentencing of liquids or gases because of the variety of types of solids, the greater potential for solids to conceal radioactivity (including both small and large particles), the greater potential to contain a high degree of non-uniformity, the larger number of options for monitoring and sampling, the greater complexity of, and potential for, treatment, and the greater range of Exemption Order limits and constraints. Sentencing of solids therefore follows a number of possible routes.

In every case, the sentencing route for solids starts in Section/Flowchart 6.2, which contains the initial sequence for identifying items or materials whose provenance alone provides sufficient justification that the solid is *clean* (has never been contaminated or activated). Under these circumstances, measurements are undertaken for reassurance only. Articles or substances not unambiguously sentenced as *clean* follows the first of the succeeding Sections/Flowcharts 6.3 – 6.10 which is applicable, (even if more than one is applicable), according to the type of solid or nature of the potential radioactivity associated with it. (Each of the sections indicates further sections which may need to be followed). **Note that, as discussed in Chapter 4, that there may be situations where articles or substances are believed clean, but that their provenance alone is not considered sufficient to justify this. In this case, a conservative approach is followed and the relevant flowchart used, although this does not indicate a belief that the article or substance in question has either the potential to be, or is, contaminated or activated.**

It should be noted that, although not considered explicitly in this Document, there may be circumstances where a solid is not substantially insoluble but it may be practicable and advantageous to convert it chemically to either a stable soluble or (substantially) insoluble form. The latter is usually preferable as a wider range of Exemption Orders is applicable for solids than for liquids.

For nearly all solids, the possibility that surface coatings (paint or otherwise) may cover radioactive contamination which cannot be detected through them must be considered. Surface scrapings may be necessary to determine whether this has occurred and whether surface stripping is desirable or practicable. Such contamination must be quantified as part of the assessment. This is not considered explicitly in the Flowcharts.

It may be justifiable to crush some solids to facilitate measurements.

For liquids, complexities occur when the liquid is a mixture of immiscible liquids and/or is associated with significant (visible) amounts of insoluble solids, including sludges and/or suspensions of fine particulate. Such liquids are analysed by initially following

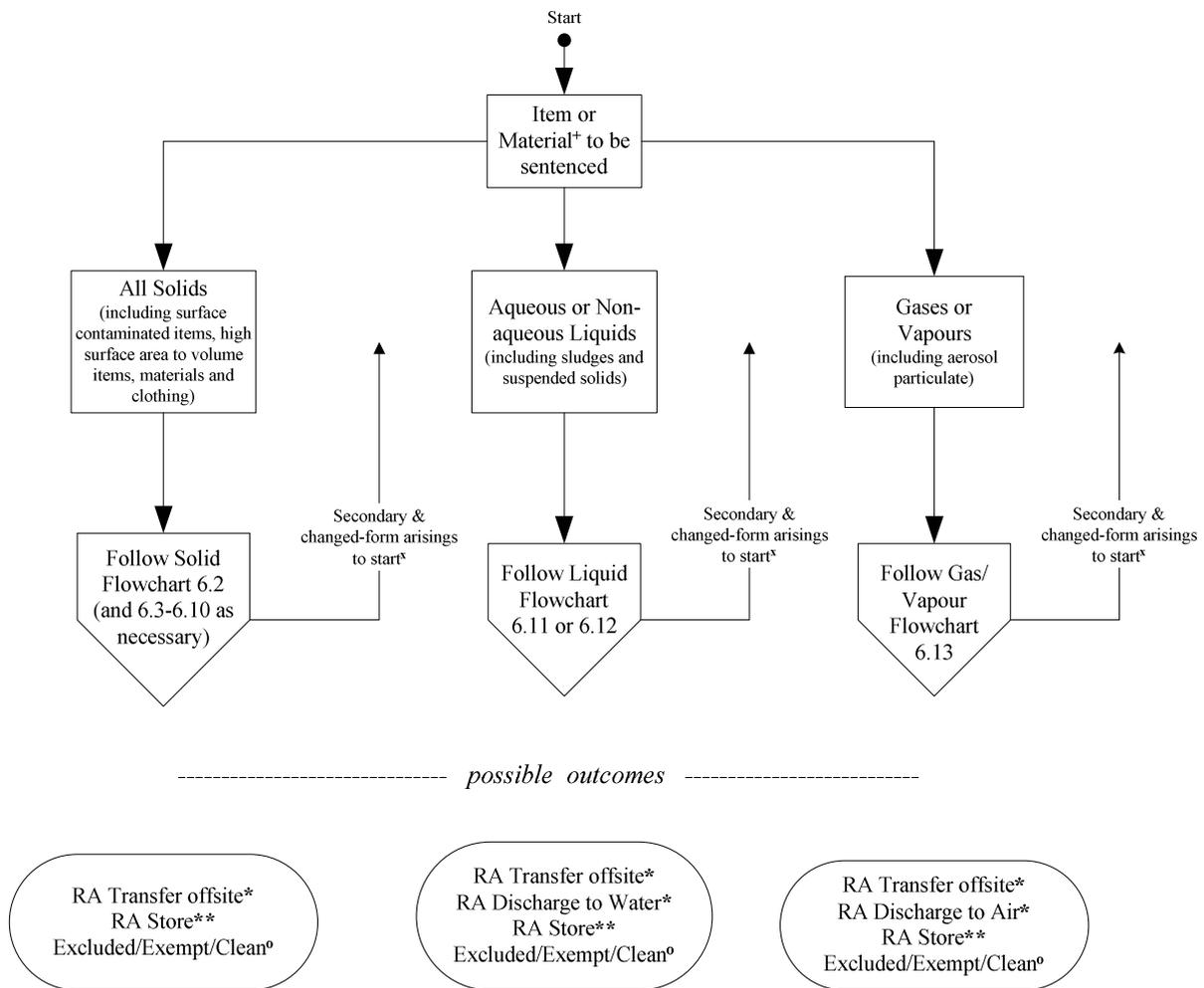
Section/Flowchart 6.11. Where it is found that the radioactivity resides solely in one phase (liquid or solid), and if each phase separately meets the clearance criteria, then it is not necessary to segregate the item for the purpose of sentencing.

Also, if one or more of the phases is radioactive, and their separation by physical or chemical means would be practicable, it is necessary to know where the radioactivity resides to identify the best practice for subsequent treatment. Where the liquid has no visible solids, (or following separation from solid material using Section/Flowchart 6.11), Section/Flowchart 6.12 should be followed.

Section/Flowchart 6.13 is applicable where a gas is held for clearance and sentencing purposes. Continuous discharge processes are not within the scope of this Code of Practice.

As stated in the following individual sections, statistical analysis should use the guidance given in Chapter 7, and in all cases measurements made should use the guidance given in Chapter 8.

**Flowchart 6.1 - Overview of Radioactive Material Sentencing**



+Includes items, articles, substances and materials intended to be cleared for reuse, recycling or recovery as well as those to be sentenced for transfer, discharge or disposal

^Secondary arisings of the same or different form and changed-form primary arisings can be produced from onsite physical and chemical treatments (for example: segregation, washing, scrubbing, solidification, incineration)

\*Transfer or discharge of these radioactive (RA) wastes is only under RSA 93 authorisation given by EA or SEPA. Transfer may be to another site for further processing for recovery or prior to, or for, disposal. Authorised solid radioactive waste disposal onsite is not usually permitted

\*\*If no disposal route is available, storage may be the only option

^Excluded/exempt/clean materials or wastes do not require authorisation under RSA 93 for transfer, discharge or disposal, but follow the preferred hierarchy of reuse, recycling or recovery, onsite or offsite, or transfer, discharge or disposal under the relevant waste legislation for non-RA wastes. Regulators may permit excluded or exempt demolition and other high volume wastes to be left onsite

## 6.2 Sentencing of Solid Items and Materials Believed to be Clean

Section/Flowchart 6.2 is followed initially for all types of solid items and materials, including potentially surface contaminated items and high surface area to volume items, materials and clothing, to establish whether they are *unambiguously* clean. This is a process which may be undertaken under a generic quality plan, often at a boundary (usually a barrier associated with a controlled or supervised area under IRR 99).

If provenance alone is enough to provide strong justification that an item or material has not been activated or contaminated, measurements are only taken for reassurance. It is not necessary in this case to follow statistical guidance in Chapter 7, although professional judgement is required to decide the extent of and locations where measurements should be made.

If the provenance of the item or material is adequately known, it may provide sufficient justification that there have been no circumstances which could have led to activation or contamination. However, if the provenance alone is not considered sufficient to justify sentencing as clean (but there is still a belief that the article or substance is clean), then the article or substance can be considered under one of the later Sections/Flowcharts (i.e. after suitably rigorous monitoring under one of them, sufficient further information might be gained to justify the belief that the article or substance is clean).

To become radioactive, an item or material must be either activated or contaminated. To become activated, an item or material must have been irradiated by neutrons. (More rarely, activation can also be caused by high energy gamma radiation.)

Any item or material must be considered to be potentially contaminated if it:

- (i) has been in contact with a radioactive material which was not completely sealed; or
- (ii) has been in contact with a radioactive liquid or gas; or
- (iii) has been in a contamination area and has not been adequately protected from contamination; or
- (iv) has taken from a ground or structural location where radioactive contamination is known or suspected.

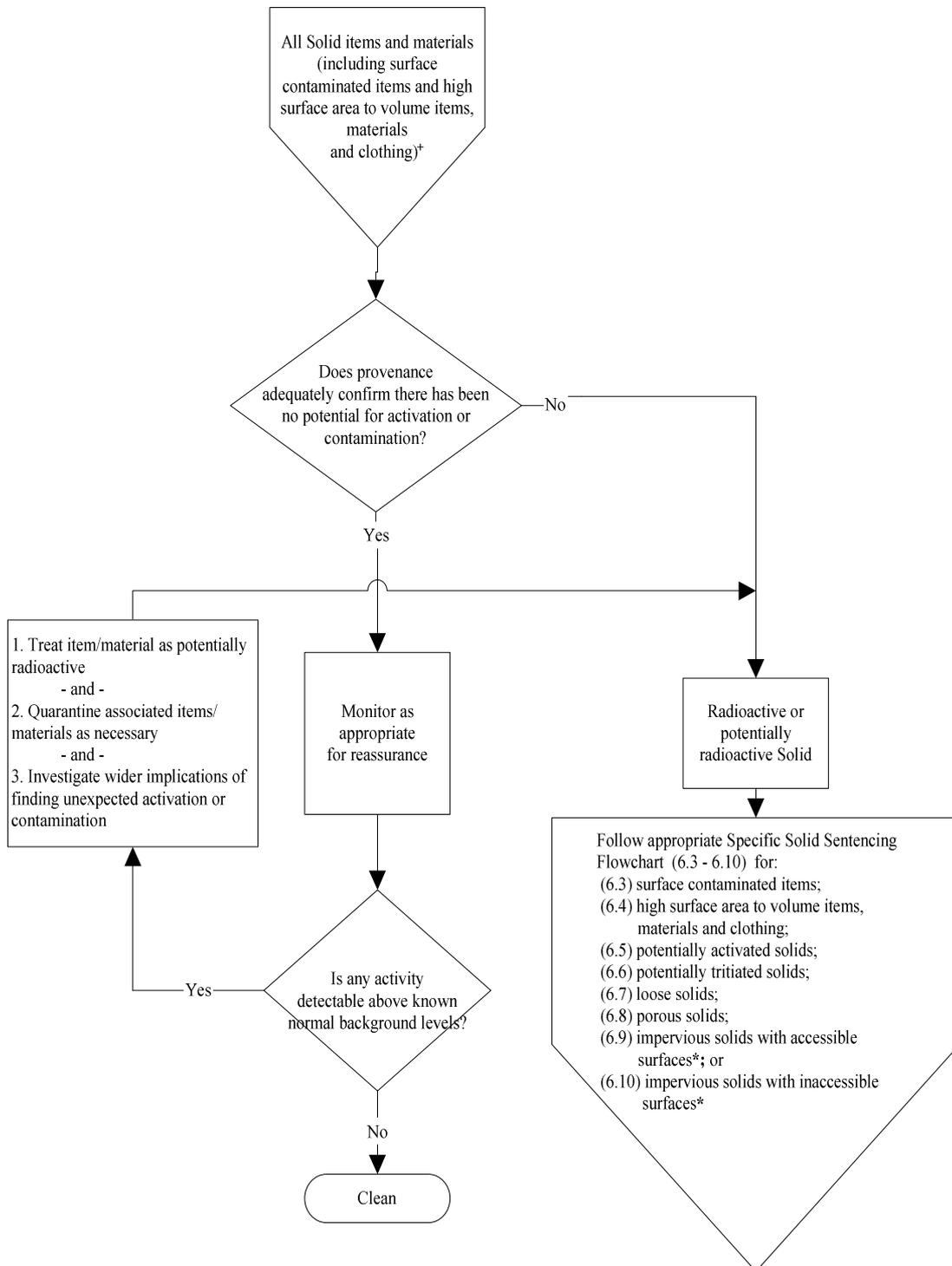
Measurement methods are selected according to potential activation products (which are dependent on the elemental composition of the item or material itself and whether activation would have been caused by neutrons or photons), and/or credible contamination fingerprints, usually requiring monitoring and sometimes wiping. Where necessary, samples may also be taken and analysed from the parts of a material where activation or contamination is most credible. Measurement practices should follow relevant guidance in Chapter 8.

However, if, as expected, the item or material shows no radioactivity above known normal background levels, it is sentenced as *clean*, and this completes the clearance process. *Clean* items and materials should subsequently follow the hierarchy of re-use, recycling, recovery in preference to disposal by discharge or transfer.

If any radioactivity is detected above known normal background radioactivity levels appropriate for the item or material, this must be investigated, not only because the item or material is not *clean*, but also because it implies a breakdown in its management control or the control of its environment. This control failure must be identified and corrective actions taken to prevent further occurrences. The item or material itself must be treated as potentially radioactive, and any associated items or materials may require quarantining until it is established whether they also need to be treated as potentially radioactive.

Any item or material found to be radioactive or potentially radioactive must be considered under the first of the following Sections/Flowcharts (6.3 – 6.10) which is relevant, according to the nature of the radioactivity or the type of solid.

**Flowchart 6.2 - Clearance of Solid Items and Materials Believed to be Clean**



\*Includes items, articles, substances and materials intended to be cleared for reuse, recycling or recovery as well as those to be sentenced for transfer or disposal

### 6.3 Sentencing of Potentially Surface Contaminated Items

Sentencing of all solid items (and materials) should initially follow the Section/Flowchart 6.2. Where an item cannot be considered *clean* when Flowchart 6.2 is followed, it is a radioactive or potentially radioactive solid, and is required to follow the first of the Sections 6.3 – 6.10 which is applicable.

Where a radioactive or potentially radioactive solid is an item which is impervious with accessible surfaces, it is provisionally identified as a potentially surface contaminated item (SCI), which is sentenced using this Section/Flowchart (6.3), unless the following two paragraphs require sentencing under another Section/Flowchart.

If the item is a high surface area to volume item or material (which may or may not be strictly impervious and includes personal clothing (see 4.7)), it should be sentenced by following Section/Flowchart 6.4.

If the item is physically a surface contaminated item, but is potentially activated, or has had potential for contact with tritium, it cannot be sentenced as a surface contaminated item, but is sentenced using Section/Flowchart 6.5 or 6.6 as appropriate. If it has had the potential to have been contaminated by a diffusive radioelement such as caesium, which, like tritium, could have permeated the surface, consideration has to be given to whether the radionuclide(s) can be detected and quantified, and the item sentenced, by surface measurement only. In cases where this is uncertain, Section/Flowchart 6.8 (for a porous solid) should be used. Where the item is complex, or has inaccessible surfaces, Section/Flowchart 6.9 or 6.10 should be followed.

If the item satisfies all the criteria above for a potentially surface contaminated item, surface measurements and reference surface clearance levels SC1 – SC3 and SC6 are the criteria for clearance. This Section/Flowchart (6.3) describes the sentencing process, which may be undertaken under a generic quality plan, often at a boundary (usually a barrier associated with a controlled or supervised area under IRR 99).

Where practicable, surface monitoring is undertaken of 100% of surfaces, but, where it is not, professional judgement should be used to decide adequacy and vulnerable areas for monitoring. In cases which are uncertain or complex, Section/Flowchart 6.9 should be used. Guidance on statistics in Chapter 7 and measurement practices in Chapter 8 should be followed.

If no radioactivity is detectable above known normal background levels and there is adequate justification that none remains undetected, the item is sentenced as *clean*.

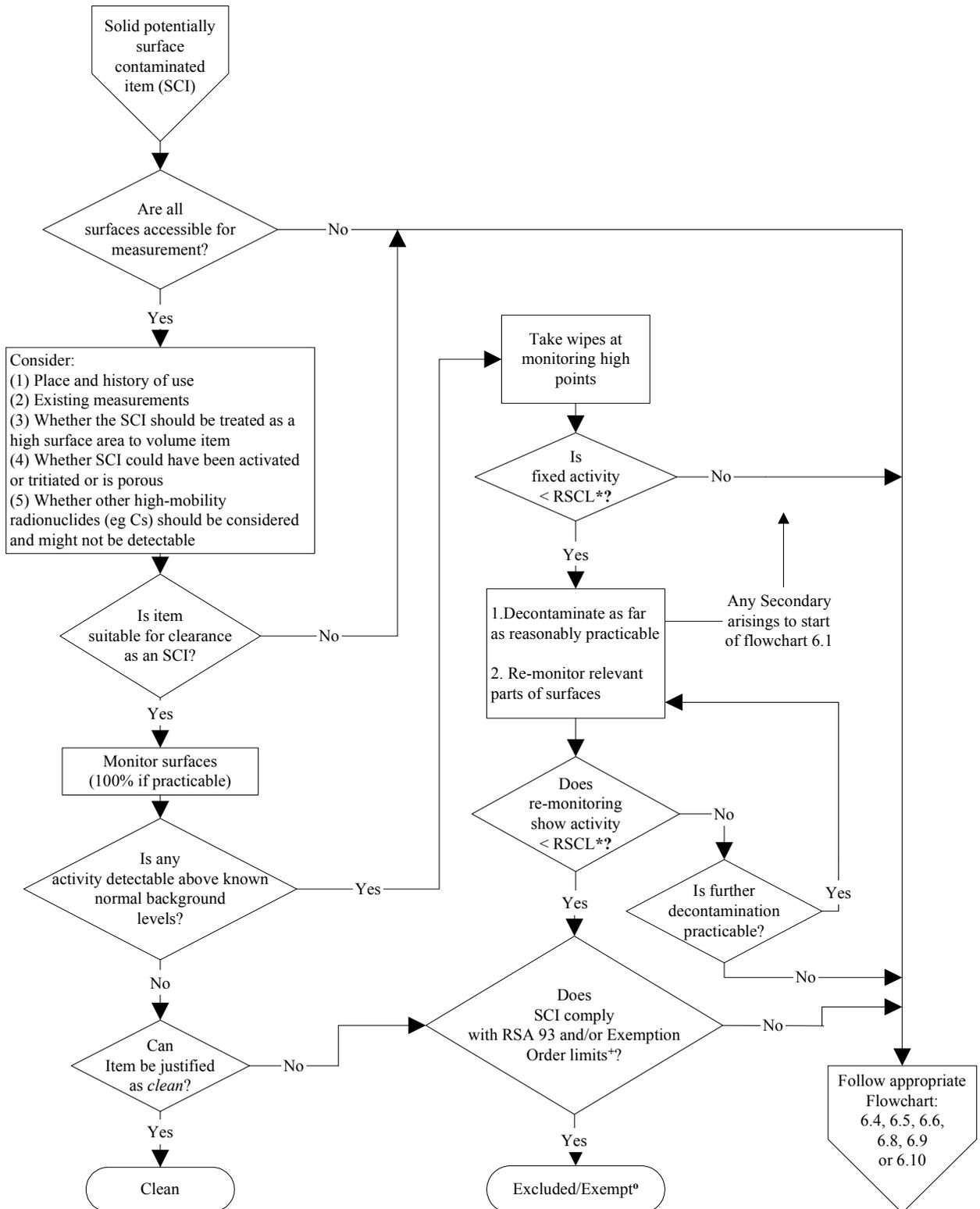
If contamination is found by monitoring, wipes should be taken at all locations where significant levels are found to determine whether the radioactivity is likely to be easily removable, and what fraction is fixed. If the fixed radioactivity exceeds the reference surface clearance levels (SC3) the item cannot be sentenced as clean by this process, and must be considered under Section/Flowchart 6.8 or 6.9, according to circumstances.

If the fixed radioactivity is less than the reference surface clearance levels, the item should be decontaminated, and loose contamination removed as far as reasonably practicable. Following decontamination, surface monitoring should be undertaken again, especially on the previously contaminated areas. To confirm that any remaining contamination is not removable, wiping should be repeated. Further decontamination should be undertaken if necessary and if practicable.

If the contamination is below the reference surface clearance levels, and wipes (which measure loose contamination only) show no detectable radioactivity above known normal background, then the criteria SC2 & SC3 are satisfied.

Finally, in compliance with SC1, the item is *excluded* or *exempt* if the calculated or measured total radioactivity on the surfaces above known normal background, compared with the weight of the item, does not exceed RSA 93 Schedule 1 limits or Exemption Order limits, respectively. Under all other circumstances, sentencing transfers to Flowchart 6.9, which leads to other treatments being considered, or sentencing as radioactive.

**Flowchart 6.3 - Clearance of Potentially Surface Contaminated Items**



\*RSCL = Reference Surface Clearance Levels (see Section 3.9)

\*Use Flowchart 2.1 to determine whether activity is below RSA 93 or EO (bulk) activity concentration limits

\*Excluded from regulation under RSA 93 or exempt from the requirements of RSA 93 for registration as a material or from authorisation for accumulation or disposal as a waste (see Definitions)

#### **6.4 Sentencing of High Surface Area to Volume Items, Materials and Clothing**

Sentencing of high surface area to volume items and materials and clothing (in particular, sheets of paper or plastic sheeting, and also personal clothing (see Section 4.8)) should initially follow Section/Flowchart 6.2. As stated in para 5.2.8, particular care should be taken to avoid contamination (or activation) of such items while they are in the contamination (or activation) area if clearance will subsequently be required. If this principle has been applied, such items and materials can usually be sentenced under Section 6.2.

Where it cannot reasonably be demonstrated that contamination or activation has been avoided, high surface area to volume items and materials must be sentenced under this Section (6.4) and Flowchart 6.4.1, 6.4.2 or 6.4.3 according to the equipment used for measurements. This process may be undertaken under a generic quality plan, often at a boundary (usually a barrier associated with a controlled or supervised area under IRR 99).

If the item is physically a high surface area to volume item, but is potentially activated, or has had potential for contact with tritium, it cannot be cleared as a surface contaminated item, but is sentenced using Section/Flowchart 6.5 or 6.6 as appropriate. If it has had the potential to have been contaminated by a diffusive radioelement such as caesium, which, like tritium, could have permeated the surface, consideration has to be given to whether the radionuclide(s) can be detected and quantified, and the item cleared, by surface measurement only. In cases where this is uncertain, Section/Flowchart 6.8 (for a porous solid) should be used. Where the item is complex, or has inaccessible surfaces, Section/Flowchart 6.9 or 6.10 should be followed.

For high surface area to volume items, materials and clothing, the reference surface clearance level criteria SC4 and SC5 are applied using Flowcharts 6.4.1, 6.4.2 or 6.4.3 according to the type of monitoring used.

SC4 states that specialised bulk monitoring equipment (such as bag monitors) should be used, where practicable, to directly measure compliance with SC1. Flowchart 6.4.1 is followed. Surface monitoring and wiping are used to confirm that any enhanced areas and loose contamination comply with the levels in SC2 and SC3. If surface monitoring is not practicable under these circumstances, section 6.4.2 should be used, to judge whether sentencing as clean or as radioactive is appropriate.

Specialised bulk monitoring equipment which is not sensitive enough to be able to confirm compliance with SC1 may be used if it has a limit of detection which is at least as low as suitable surface and dose-rate monitors. Flowchart 6.4.3 should be followed for sentencing.

SC5 states that, where measurements have to be made by suitable surface and dose-rate monitors, such instruments will either:

- (i) be able to confirm compliance with SC1 for the item or material being sentenced (by calculating total surface activity from measurements) - Flowchart 6.4.2 is followed; or
- (ii) be unable to confirm compliance with SC1 (because limits of detection are not low enough, although they should be capable of measuring at least down to 25% of SC3 levels), and sentencing must be based on “no detectable radioactivity or dose-rate above normal background” (NDA) - Flowchart 6.4.3 is followed.

Where surface monitoring is undertaken under SC4 or SC5, the entire surface should be monitored on both sides if practicable and necessary. (As examples: clothes would normally only require monitoring on the outer surfaces of outer garments; and some radioactivity on both sides of a thin item or material can be detected by monitoring one side only). Where 100% surface monitoring is not undertaken, professional judgement should be used to include those areas most vulnerable to activation or contamination. Statistical guidance in Chapter 7 and monitoring guidance in Chapter 8 should be followed.

Whether sentencing is by SC4 or SC5, when equipment capable of measuring compliance with SC1 directly is used, and if radioactivity is detected, wiping is required to determine whether it is removable. If decontamination is practicable, it should be undertaken as necessary, with subsequent re-monitoring of previously contaminated surfaces.

Where specialised bulk monitoring equipment capable of measuring compliance with SC1 is used with Flowchart 6.4.1 and SC4:

- (i) if no radioactivity is detectable above known normal background levels and there is adequate justification that none remains undetected, the item or material is sentenced as *clean*
- (ii) if radioactivity is detected, the item or material is sentenced as *excluded*, *exempt* or sentenced as radioactive according to Flowchart 6.4.1

Where suitable surface monitoring equipment which is capable of measuring compliance with SC1 for the item or material is used with Flowchart 6.4.2 and SC5:

- (i) if no radioactivity is detectable above known normal background levels and there is adequate justification that none remains undetected, the item or material is sentenced as *clean* ;
- (ii) if radioactivity is detected, the item or material is sentenced as *excluded*, *exempt* or sentenced as radioactive, according to Flowchart 6.4.2

Where specialised bulk monitoring equipment or suitable surface monitoring equipment are used which are not capable of measuring compliance with SC1 for the item or material, Flowchart 6.4.3 is followed:

- (i) if no radioactivity is detectable above known normal background levels and (within the limitations of the equipment) there is adequate justification that none remains undetected,

the item or material is sentenced as *exempt* (it may be *clean or excluded*, but the limits of detection are incapable of confirming this)

(ii) if radioactivity is detected, the item or material is sentenced as radioactive

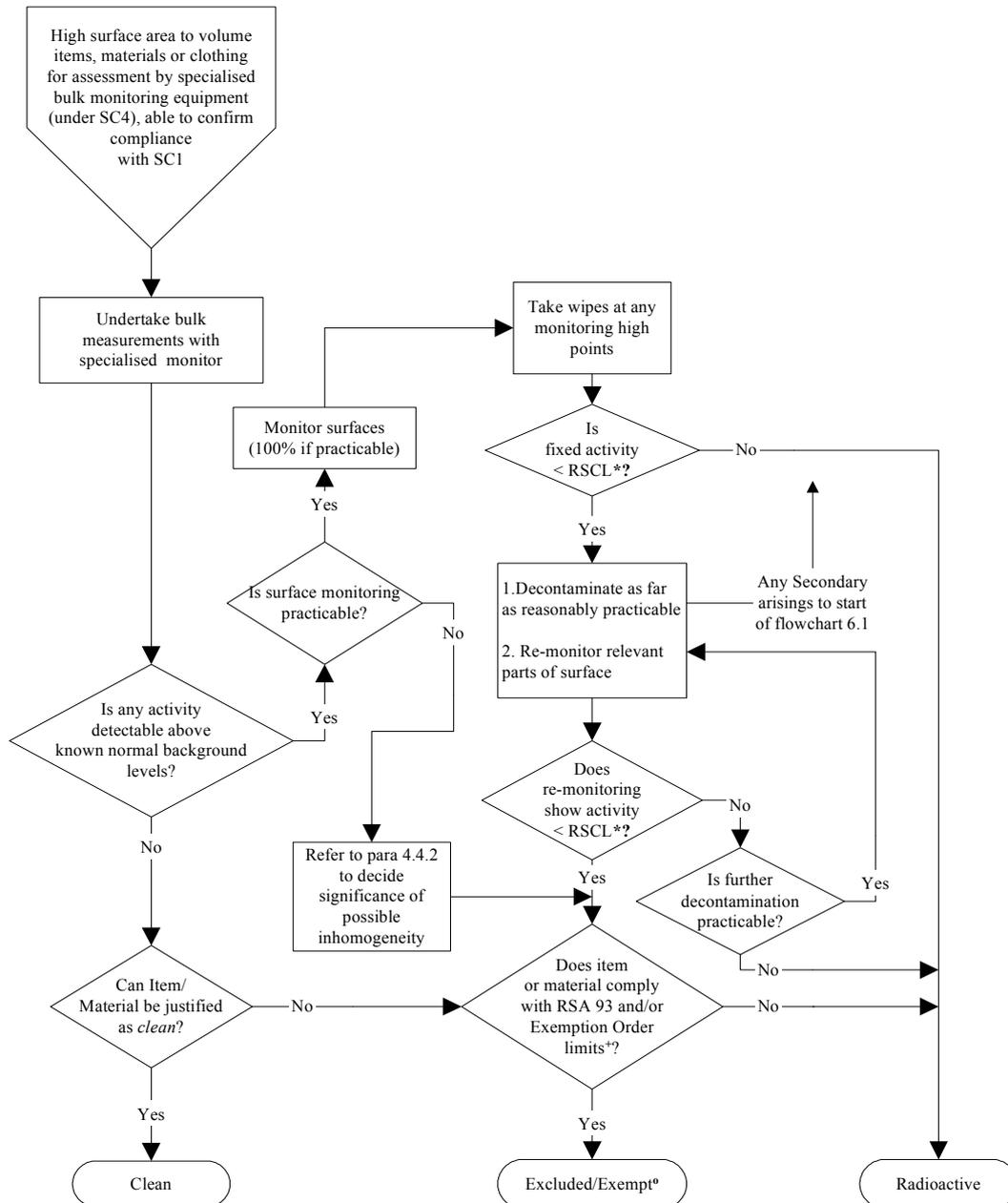
It should be noted that:

(i) A notebook consisting of typically 50-100 sheets which could not be sentenced under Section/Flowchart 6.2, can usually be sentenced as a *surface contaminated item* using Section/Flowchart 6.3 (with limits as SC1, SC2 and SC3) so long as any potential contamination could only reside on its outer covers

(ii) Plastic sheeting which is used as temporary containment will not itself have been protected against contamination, and decontamination is unlikely to be practicable, so it will usually be sentenced as radioactive

(iii) Working coveralls are generally not able to be adequately protected against contamination. They are often difficult to monitor or wipe and are particularly difficult to measure if the potential contamination is by alpha or low-energy beta emitters. Usually they are monitored primarily for personnel safety surveillance, as indicators of personal and/or area contamination, but not for clearance purposes, as they remain in the area for further use. Clearance for laundering or disposal is likely to require specialised and detailed justification associated with history and properties of the area and the ways in which the coveralls are used. Clearance of coveralls is outside the scope of this Code of Practice (although they may be transported and laundered as radioactive)

**Flowchart 6.4.1 - Clearance of High Surface Area to Volume Items, Materials and Clothing: Assessment Using Specialised Bulk Monitoring Equipment able to Confirm Compliance with SC1 (RSA 93 Schedule 1 or Exemption Order Limits)**

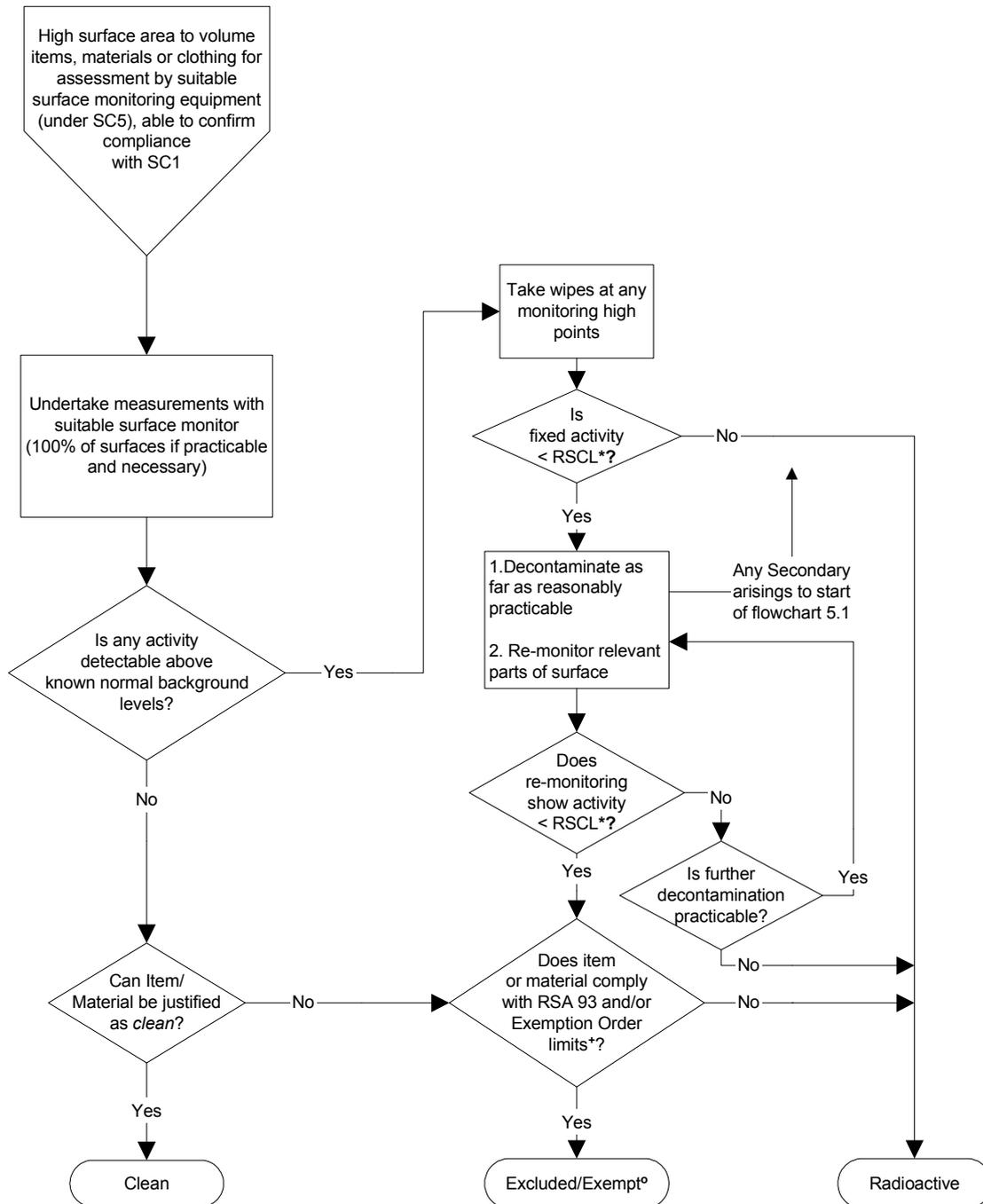


\*RSCL = Reference Surface Clearance Levels (see Section 4.10)

\*Use Flowchart 2.1 to determine whether activity is below RSA 93 or EO (bulk) activity concentration limits

\*Excluded from regulation under RSA 93 or exempt from the requirements of RSA 93 for registration as a material or from authorisation for accumulation or disposal as a waste (see Definitions)

**Flowchart 6.4.2 - Clearance of High Surface Area to Volume Items, Materials and Clothing: Assessment Using Suitable Surface Monitoring Equipment able to Confirm Compliance with SC1 (RSA 93 Schedule 1 or Exemption Order Limits)**

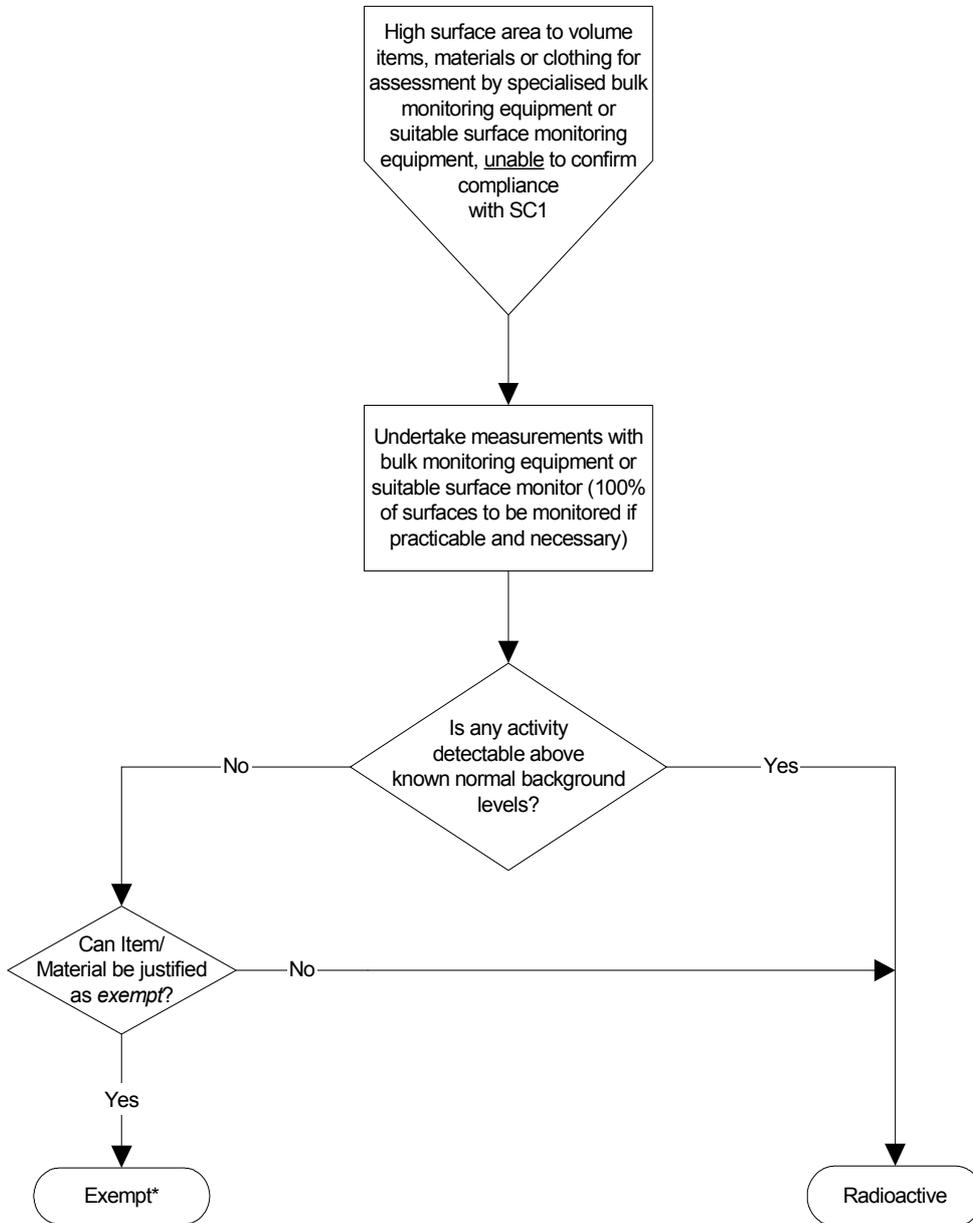


\*RSCL = Reference Surface Clearance Levels (see Section 3.9)

\*Use Flowchart 2.1 (p.21) to determine whether activity is below RSA 93 or EO (bulk) activity concentration limits

°Excluded from regulation under RSA 93 or exempt from the requirements of RSA 93 for registration as a material or from authorisation for accumulation or disposal as a waste (see Definitions p.7)

**Flowchart 6.4.3 - Clearance of High Surface Area to Volume Items, Materials and Clothing: Assessment Using Specialised Bulk Monitoring Equipment or Suitable Surface Monitoring Equipment unable to Confirm Compliance with SC1 (RSA 93 Schedule 1 or Exemption Order Limits)**



\*Exempt from the requirements of RSA 93 for registration as a material or from authorisation for accumulation or disposal as a waste (see Definitions).

## 6.5 Sentencing of Potentially Activated Solids

Activated or potentially activated solids are identified initially by following Section/Flowchart 6.2. Such solids have a history of irradiation (or the potential to have been irradiated) by neutrons or high energy gamma radiation, and must be sentenced using this Section/Flowchart (6.5).

Any solids which are both potentially activated and tritiated should be considered individually, by combining relevant parts of Sections/Flowcharts 6.5 and 6.6. In such cases the overall complexity of measurements required to justify clearance may not be cost-effective, and sentencing as radioactive might be the most appropriate option. Any solids also potentially contaminated by other radionuclides must be considered using relevant parts of Sections/Flowcharts 6.7 – 6.10 as well as this Section/Flowchart (6.5).

Activation occurs in the bulk of the solid where neutrons have penetrated, and is strongly influenced by its elemental composition. It can be highly variable in type, can be concentrated in certain parts of the solid and can be greater within the solid than close to its surface. If all the relevant irradiation and material parameters are known (neutron fluence, neutron distribution (beams or otherwise), neutron spectrum, elemental composition of the solid, activation cross-sections and decay parameters for the activation products and daughters) the radioactivity can and should be calculated or at least estimated. Most activation products are  $\beta\gamma$  emitters, although these are not always penetrating radiations, so the capability of surface monitoring to measure them must be considered, and sampling within or coring into the solid may be necessary. (In unusual circumstances where fissile contamination exists or has existed, fission products could also be present as well as activation products. These are assessed in the same way, although their physical distribution will be similar to that of the fissile parent.)

From available data on irradiation history and existing or new screening monitoring, it will usually be practicable to determine whether activation is likely to be close to or exceed Exemption Order limits (for activation, RSA 93 Schedule 1 elements are not relevant). At the same time the potential for the presence of surface contamination as well as activation should be considered (unless the solid is a loose material); this will require measurement by a monitor which discriminates against radioactivity due to activation, or by surface wiping where appropriate, and the levels must be compared with reference surface clearance levels. If either activation or contamination is estimated to be close to or greater than the limits, the cost and practicability of further measurement or treatment has to be considered, and a decision taken whether it should be sentenced as radioactive with minimal further measurement.

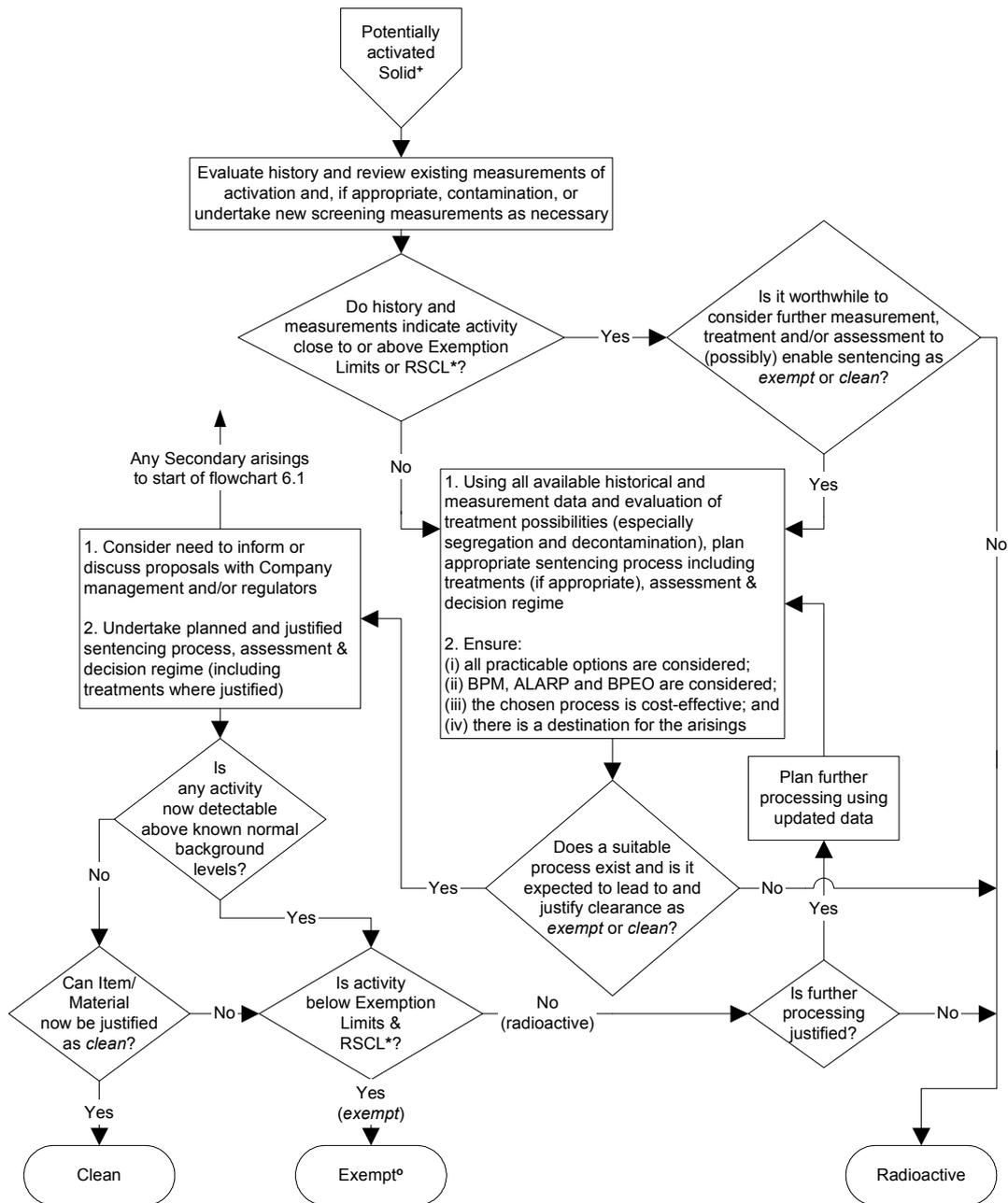
If activation and contamination are small, or efficient and effective treatment possibilities exist (these may include separation or segregation), a quality plan should be produced, which may be simple or very complex according to circumstances. The plan should define the chosen outcome of using all available information to consider all practicable treatment options, whether they satisfy BPM, ALARP and BPEO, their cost-effectiveness and the availability of destinations for the arisings. The plan should include the measurements required, how they will be assessed, and decision regimes. Guidance on the statistical basis for measurement in Chapter 7 and on measurement practices in Chapter 8 should be used.

If no suitable process can be identified which is likely to result in clearance of substantial arisings as *exempt* or *clean*, it may be best practice to sentence the solid as radioactive. However, many activation products have relatively short half-lives and consideration should be given to whether the solid may decay to below Exemption Order limits before it is sentenced.

If a suitable process is identified, this is described in detail in the quality plan, and the proposals should be submitted to Company management and/or the regulators informed of them as necessary prior to undertaking it.

Arisings (which may include several or many sentencing volumes or segregated parts) are (individually) sentenced as *clean* if no radioactivity is detectable above known normal background levels, and there is adequate justification that none remains undetected. If radioactivity is detected, but is below Exemption Order limits and reference surface clearance levels (if relevant), they are sentenced as *exempt*. Further processing may be planned, approved and carried out for any arisings which are not sentenced as *clean* or *exempt*, or, if this is not cost effective or is unlikely to be successful, these arisings should be sentenced as radioactive.

**Flowchart 6.6 - Sentencing of Potentially Activated Solids**



\*Includes items, articles, substances and materials intended to be cleared for reuse, recycling or recovery as well as those to be sentenced for transfer or disposal

\*Use Flowchart 2.1 to determine whether activity is below EO (bulk) activity concentration limits. RSCL = Reference Surface Clearance Levels (see Section 4.10); if the solid is a loose material, RSCLs are not applicable

°Exempt from the requirements of RSA 93 for registration as a material or exempt from authorisation for accumulation or disposal as a waste (Exclusion does not generally apply as activation products are not RSA 93 Schedule 1 radioelements)

## 6.6 Sentencing of Potentially Tritiated Solids

Tritiated or potentially tritiated solids are identified initially by following Section/Flowchart 6.2. Such solids have a history of potential or actual exposure to tritium, and must be sentenced using this Section/Flowchart (6.6).

Any solids which are both potentially activated and tritiated should be considered individually, by combining relevant parts of Sections/Flowcharts 6.5 and 6.6. In such cases the overall complexity of measurements required to justify clearance may not be cost-effective, and sentencing as radioactive might be the most appropriate option. Any solids also potentially contaminated by other radionuclides must be considered using relevant parts of Sections/Flowcharts 6.7 – 6.10 as well as this Section/Flowchart (6.6).

Tritium is a highly mobile radioelement, and, in evaluating the history of any solid potentially exposed to it, the following should be noted:

- (i) The form of the tritium at the time when exposure could have occurred is important;
- (ii) Surface contamination wipes may not be sufficient as tritium may have permeated into the bulk volume and through seals and/or containment barriers;
- (iii) Absorption of tritium into the material will depend on a number of factors, such as the concentration, the form of tritium (elemental, oxide, particulate, liquid), the exposure period, humidity, pressure and temperature, as well as the form of the material;
- (iv) For similar exposure histories, porous materials and items with a large moisture content, or hydrocarbon-based structure, for example: plastics, rubber, oils and greases, will have the highest absorption. Metals also absorb tritium to some extent, with the higher levels typically just below the surface;
- (v) When surface contamination surveys are or have been undertaken, wipes taken immediately after cleaning of the surface can underestimate later contamination due to subsequent re-growth. Sufficient time between cleaning and surveys should be allowed; and
- (vi) Removable surface contamination does not necessarily correlate with volume absorption. Absence of surface contamination should not be taken to mean absence of bulk absorption; it may be necessary to take samples from within the solid.

Guidance on tritium measurement is given in Chapter 8. Assessing tritium contamination from both history and measurement is highly specialised. However, tritium is very mobile and localised high levels within a material are not likely to be present, although high levels may be found within particular constituent materials with which tritium has particular affinity.

If tritium levels are estimated to be close to or greater than the limits, the cost and practicability of further measurement or treatment has to be considered, and a decision taken whether it should be sentenced as radioactive with minimal further measurement.

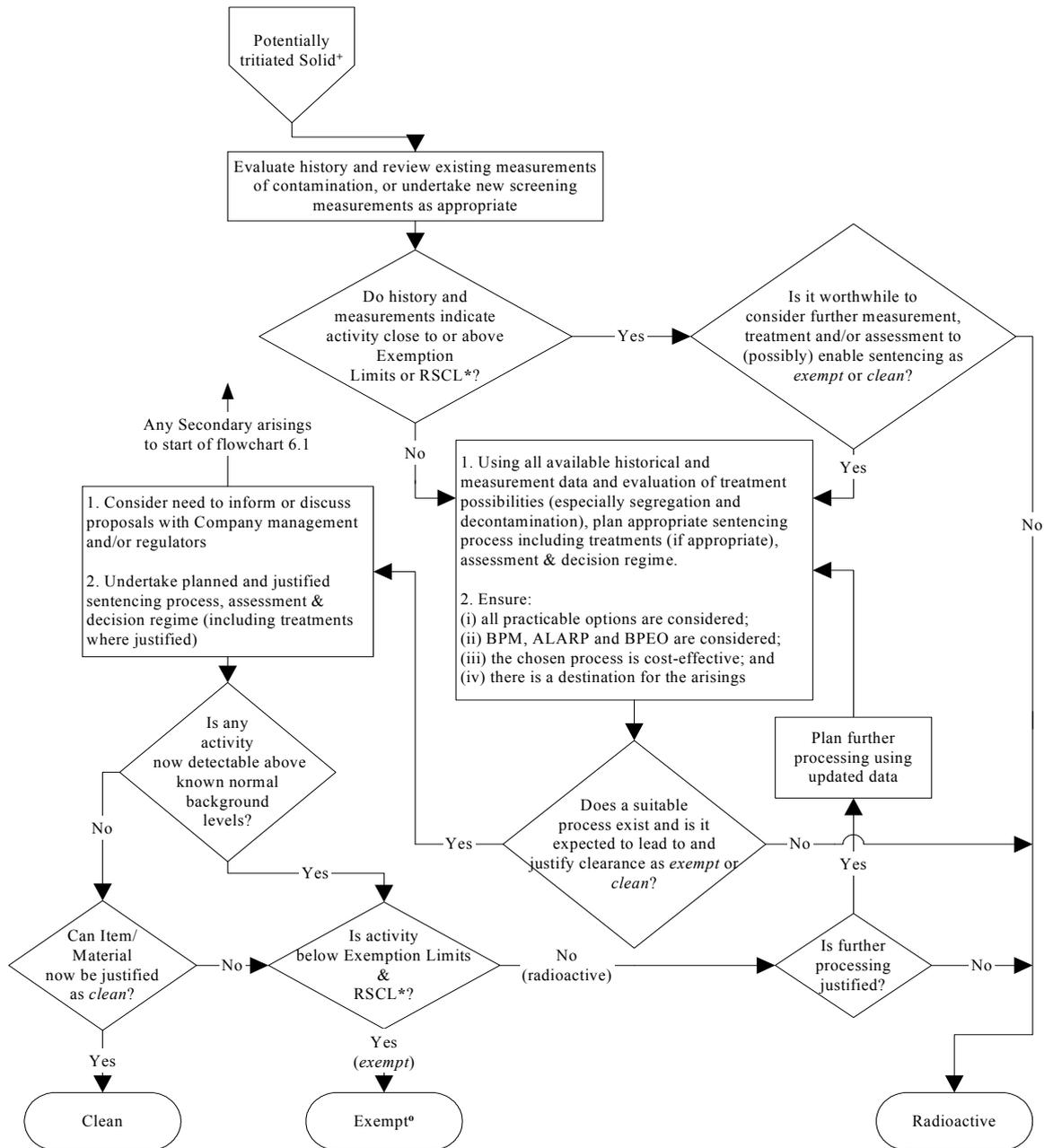
If tritium levels are low, or efficient and effective treatment possibilities exist (these may include separation or segregation), a quality plan should be produced, which may be simple or very complex according to circumstances. The plan should define the chosen outcome of using all available information to consider all practicable treatment options, whether they satisfy BPM, ALARP and BPEO, their cost-effectiveness and the availability of destinations for the arisings. The plan should include the measurements required, how they will be assessed, and decision regimes. Guidance on the statistical basis for measurement in Chapter 7 and on measurement practices in Chapter 8 should be used.

If no suitable process can be identified which is likely to result in sentencing as *exempt* or *clean*, it may be best practice to sentence the solid as radioactive.

If a suitable process is identified, this is described in detail in the quality plan, and the proposals should be submitted to Company management and/or the regulators informed of them as necessary prior to undertaking it.

Arisings (which may include several or many sentencing volumes or segregated parts) are sentenced (individually) as *clean* if no radioactivity is detectable above known normal background levels, and there is adequate justification that none remains undetected. If radioactivity is detected, but is below Exemption Order limits and reference surface clearance levels, they are sentenced as *exempt*. Further processing may be planned, approved and carried out for any arisings which are not sentenced as *clean* or *exempt*, or if this is not cost effective or unlikely to be successful, these arisings should be sentenced as radioactive.

**Flowchart 6.6 - Sentencing of Potentially Tritiated Solids**



+Includes items, articles, substances and materials intended to be cleared for reuse, recycling or recovery as well as those to be sentenced for transfer or disposal

\*Use Flowchart 2.1 to determine whether activity is below EO (bulk) activity concentration limits. RSCL = Reference Surface Clearance Levels (see Section 4.10)

°Exempt from the requirements of RSA 93 for registration as a material or exempt from authorisation for accumulation or disposal as a waste (Exclusion does not apply to tritium)

## 6.7 Sentencing of Potentially Contaminated Loose Solids

Contaminated or potentially contaminated loose solids (such as soils, sediments and sludges) are identified initially by following Section/Flowchart 6.2. Such solids must be sentenced using this Section/Flowchart (6.7), unless potentially activated or tritiated, in which case they are sentenced using Section/Flowchart 6.5 or 6.6 as appropriate.

For loose materials, only compliance with RSA 93 Schedule 1 and Exemption Order limits are relevant, and reference surface clearance levels have no significance. Knowledge of the history of the solid and how it could have become contaminated are very important to understanding the likely distribution profile of any radioactivity, whether it is in particulate form, and how large those particles might be. Screening using a suitable instrument capable of measuring hot-spots from the surface is often very useful (even if it is not capable of measuring down to uniform contamination at RSA 93 Schedule 1 or Exemption Order limits), and such screening also indicates where some samples should be taken.

If contamination levels are estimated to be close to or above the limits, the cost and practicability of further measurement or treatment has to be considered, and a decision taken whether the solid should be sentenced as radioactive with minimal further measurement. In some cases, sentencing as radioactive may be the best practicable option if significant contaminated volumes are widespread and/or difficult to locate or segregate, but, if quantities are large, considerable effort to justify sentencing as clean or exempt may be appropriate.

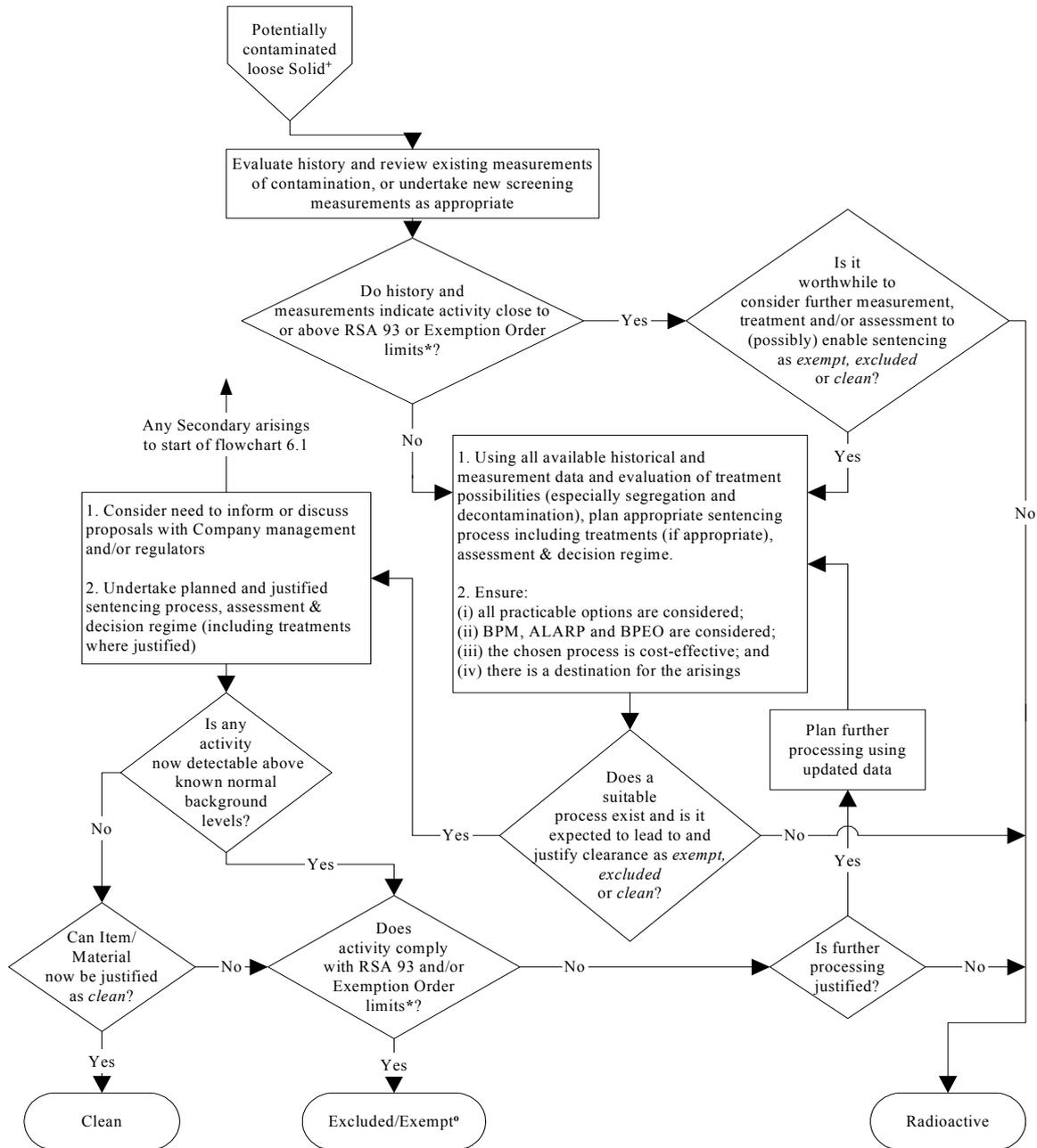
If contamination levels are mostly low, or efficient and effective treatment possibilities exist (these may include separation or segregation), a quality plan should be produced, which may be simple or very complex according to circumstances. The plan should define the chosen outcome of using all available information to consider all practicable treatment options, whether they satisfy BPM, ALARP and BPEO, their cost-effectiveness and the availability of destinations for the arisings. The plan should include the measurements required, how they will be assessed, and decision regimes.

Measurement methodologies must be very carefully chosen. Although screening by surface measurement may be very useful, and passing material under monitors on a conveyor may be sufficient for sentencing (depending on the penetrating properties of the radiation emitted by the contamination), sampling will often be required, and may be the only satisfactory measurement method for contamination by most alpha emitters. Samples should always be taken in locations where screening monitoring has indicated elevated levels as well as in locations indicated by statistical considerations. It is important that guidance in Chapter 7 on the statistical basis of sampling and assessment of sample results should be followed, together with guidance on measurement practices in Chapter 8.

If no suitable process can be identified which is likely to result in sentencing as *exempt*, *excluded* or *clean*, it may be best practice to sentence the solid as radioactive. If a suitable process is identified, this is described in detail in the quality plan, and proposals should be submitted to Company management and/or the regulators informed of them as necessary prior to undertaking it.

Arisings (which may include several or many sentencing volumes defined in conformance with Section 4.7) are sentenced (individually) as *clean* if no radioactivity is detectable above known normal background levels, and there is adequate justification that none remains undetected. If radioactivity is detected, but is below RSA 93 Schedule 1 or Exemption Order limits, they are sentenced as *excluded* or *exempt*, respectively. Further processing may be planned, approved and carried out for any arisings which are not sentenced as *clean*, *excluded* or *exempt*, or if this is not cost effective or unlikely to be successful, these arisings should be sentenced as radioactive.

**Flowchart 6.7 - Sentencing of Potentially Contaminated Loose Solids**



\*Includes items, articles, substances and materials intended to be cleared for reuse, recycling or recovery as well as those to be sentenced for transfer or disposal

<sup>o</sup>Use Flowchart 2.1 to determine whether activity is below RSA 93 or EO (bulk) activity concentration limits

<sup>o</sup>Excluded from regulation under RSA 93 or exempt from the requirements of RSA 93 for registration as a material or from authorisation for accumulation or disposal as a waste (see Definitions).

## **6.8 Sentencing of Potentially Contaminated Porous Solids**

Contaminated or potentially contaminated porous solids (such as concrete and bricks) are identified initially by following Section/Flowchart 6.2. Such solids must be sentenced using this Section/Flowchart (6.8), unless potentially activated or tritiated, in which case they are sentenced using Section/Flowchart 6.5 or 6.6 as appropriate. Surface contaminated items with significant fixed radioactivity or contaminated by diffusive radionuclides should also be sentenced through this Section/Flowchart (as indicated in Section/Flowchart 6.3).

For porous materials, compliance with both RSA 93 Schedule 1 and Exemption Order limits and reference surface clearance levels is relevant. Knowledge of the history of the material and how it could have become contaminated are very important to understanding the likely distribution and nature of any radioactivity, whether it would have penetrated in liquid form, or was in particulate form, and how large those particles might be. Screening using a suitable instrument capable of measuring enhanced radioactivity close to the surface (even if it is not capable of measuring bulk radioactivity within the solid) is likely to be useful, and also indicates where some samples should be taken.

If contamination levels are estimated to be close to or above the limits, the cost and practicability of further measurement or treatment has to be considered, and a decision taken whether the solid should be sentenced as radioactive with minimal further measurement. In some cases, sentencing as radioactive may be the best practicable option if significant contaminated areas are widespread and/or difficult to locate or segregate, but, if quantities are large, considerable effort to justify sentencing as clean or exempt may be appropriate.

If contamination levels are mostly low, or efficient and effective treatment possibilities exist (these may include separation or segregation), a quality plan should be produced, which may be simple or very complex according to circumstances. The plan should define the chosen outcome of using all available information to consider all practicable treatment options, whether they satisfy BPM, ALARP and BPEO, their cost-effectiveness and the availability of destinations for the arisings. It should include the measurements required, how they will be assessed, and decision regimes.

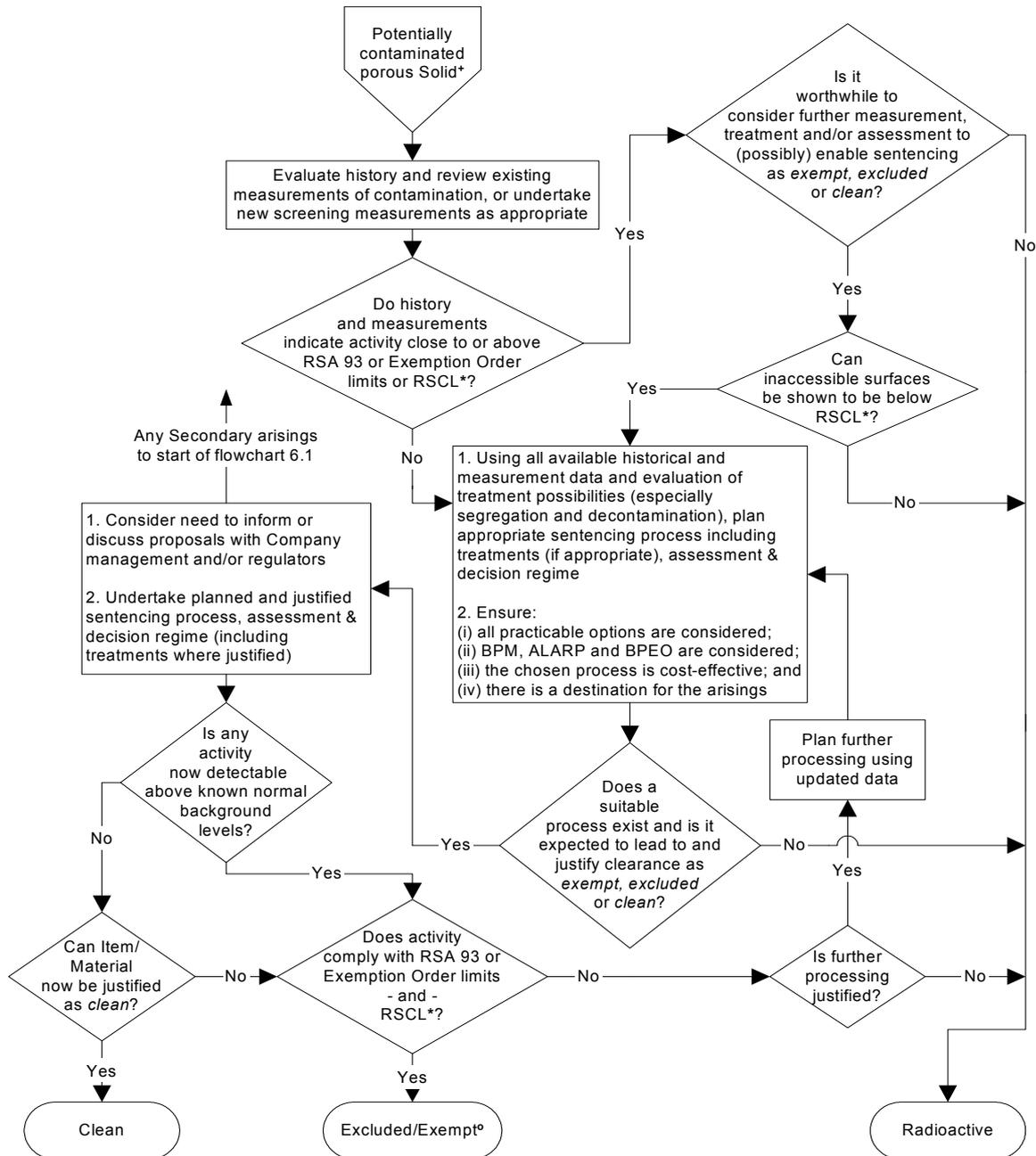
Measurement methodologies must be very carefully chosen. Screening by surface measurement may be very useful and necessary for confirming compliance with reference surface clearance levels, as well as indicating where some samples at depth, or cores, should be taken. Samples should always be taken in locations where screening monitoring has indicated elevated levels as well as in locations indicated by statistical considerations. Guidance in Chapter 7 on the statistical basis of sampling and assessment of sample results should be followed, together with guidance on measurement practices in Chapter 8.

Core sampling is likely to be the only satisfactory measurement method for contamination by most alpha emitters, although under other circumstances, depending on the penetrating properties of the radiation emitted by the contamination, crushing (if acceptable), and passing crushed material under monitors on a conveyor, may be an efficient and effective method of measurement, eliminating the need for coring.

If no suitable process can be identified which is likely to result in sentencing as *exempt*, *excluded* or *clean*, it may be best practice to sentence the solid as radioactive. If a suitable process is identified, this is described in detail in the quality plan, and proposals should be submitted to Company management and/or the regulators informed of them as necessary prior to undertaking it.

Arisings (which may include several or many sentencing volumes defined in conformance with Section 4.7) are sentenced (individually) as *clean* if no radioactivity is detectable above known normal background levels, and there is adequate justification that none remains undetected. If radioactivity is detected, but is below RSA 93 Schedule 1 or Exemption Order limits and reference surface clearance levels (these may not be relevant for crushed material), they are sentenced as *excluded* or *exempt*, respectively. Further processing may be planned, approved and carried out for any arisings which are not sentenced as *clean*, *excluded* or *exempt*, or, if this is not cost effective or unlikely to be successful, these arisings should be sentenced as radioactive.

**Flowchart 6.8 - Sentencing of Potentially Contaminated Porous Solids**



\*Includes items, articles, substances and materials intended to be cleared for reuse, recycling or recovery as well as those to be sentenced for transfer or disposal

\*Use Flowchart 2.1 to determine whether activity is below RSA 93 or EO (bulk) activity concentration limits. RSCL = Reference Surface Clearance Levels (see Section 4.10)

°Excluded from regulation under RSA 93 or exempt from the requirements of RSA 93 for registration as a material or from authorisation for accumulation or disposal as a waste (see Definitions).

## **6.9 Sentencing of Potentially Contaminated Impervious Solids with Accessible Surfaces**

Contaminated or potentially contaminated impervious solids with accessible surfaces (which may also include large or complex surface contaminated items such as metal transport flasks) are identified initially by following Section/Flowchart 6.2 or 6.3. Such solids must be sentenced using this Section/Flowchart (6.9), unless potentially activated or tritiated, in which case they are sentenced using Section/Flowchart 6.5 or 6.6 as appropriate.

For impervious solids with accessible surfaces, compliance with reference surface clearance levels SC2 and SC3 are the principal practical criteria, but it will need to be demonstrated that compliance with these levels will ensure compliance with RSA 93 Schedule 1 or Exemption Order (bulk) limits (SC1). Knowledge of the history and use of the item (or material), and how it could have become contaminated, are very important to understanding the likely distribution of contamination on it and nature of any radioactivity. If it has had the potential to have been contaminated by a diffusive radionuclide such as caesium, which, like tritium, could have penetrated the surface, consideration has to be given to whether the radionuclide can be detected and the solid sentenced by surface measurement only; if not, Section/Flowchart 6.8 (for porous solids) should be followed.

If history and/or screening monitoring shows contamination levels estimated to be close to or above the limits, the cost and practicability of further measurement or treatment has to be considered, and a decision taken whether the solid should be sentenced as radioactive without decontamination and with only minimal further measurement. However, for impervious solids with accessible surfaces, decontamination will usually be practicable, although keeping worker doses ALARP and the contaminated secondary arisings likely to be created may both be important considerations.

If contamination levels are mostly low, or efficient and effective treatment possibilities exist (these could include separation or segregation of parts), a quality plan should be produced, which may be simple or very complex according to circumstances. It is unlikely to be a completely generic plan, although for surface decontamination parts of it may be generic. The plan should define the chosen outcome of using all available information to consider all practicable treatment options, whether they satisfy BPM, ALARP and BPEO, their cost-effectiveness and the availability of destinations for the arisings. It should include the measurements required, how they will be assessed, and decision regimes. The processes, including contingencies on finding elevated levels and decision criteria for consequential actions (if relevant), should be described in detail.

Surface monitoring is largely generic and the quality plan may incorporate a generic plan for it: monitoring should be undertaken of all locations (corners and crevices, and/or parts most likely to have been in contact with radioactivity) where contamination is most likely to be concentrated, and a sufficient fraction of the remaining surfaces, using the statistical guidance in Chapter 7. Additional methods of measurement, which may be very useful in some circumstances, may include sampling of dirt in corners and crevices to determine whether it is contaminated. Guidance on measurement practices in Chapter 8 should be followed.

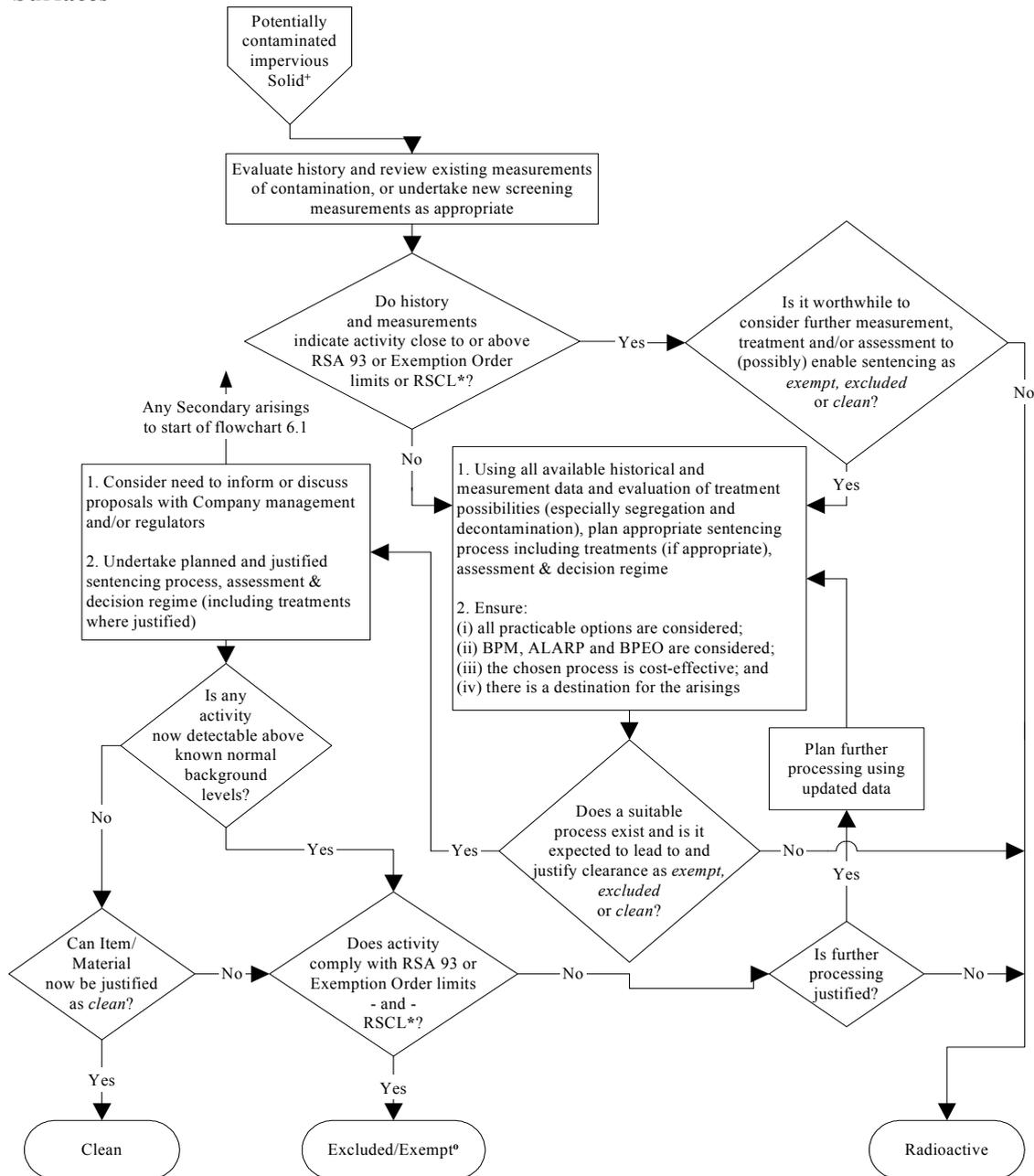
The plan should indicate the process to be followed if contamination is found by monitoring; usually wipes should be taken at all locations where significant levels are found to determine whether the radioactivity is likely to be removable, and what fraction is fixed. If the fixed radioactivity is less than the reference surface clearance levels, decontamination should take place, and loose contamination must be removed as far as reasonably practicable (see SC2). Following decontamination, surface monitoring should be undertaken again, especially on the previously contaminated areas. To confirm that any remaining contamination is not removable, wiping should be repeated. Further (more aggressive) decontamination should be undertaken if necessary and if practicable. At some stage in these operations, contingencies for disassembly for sentencing or cleaning may be relevant.

Proposals within the plan should be submitted to Company management and/or the regulators informed of them as necessary prior to undertaking it.

If monitoring of any segregated part (if necessary) shows no detectable radioactivity above known normal background levels, and there is sufficient confidence that none could have been missed, then the item or part is *clean*.

If the contamination is below the reference surface clearance levels, and wipes (which measure loose contamination only) show no detectable radioactivity above known normal background levels, then the criteria SC2 & SC3 are satisfied. Additionally, in compliance with SC1, the item or segregated parts are each *excluded* or *exempt* if the calculated or measured total radioactivity on the surfaces for the relevant item or part, compared with the weight of the item, does not exceed RSA 93 Schedule 1 or Exemption Order limits, respectively.

**Flowchart 6.9 - Sentencing of Potentially Contaminated Impervious Solids with Accessible Surfaces**



\*Includes items, articles, substances and materials intended to be cleared for reuse, recycling or recovery as well as those to be sentenced for transfer or disposal

\*Use Flowchart 2.1 to determine whether activity is below RSA 93 or EO (bulk) activity concentration limits. RSCL = Reference Surface Clearance Levels (see Section 4.10)

\*Excluded from regulation under RSA 93 or exempt from the requirements of RSA 93 for registration as a material or from authorisation for accumulation or disposal as a waste (see Definitions).

## **6.10 Sentencing of Potentially Contaminated Impervious Solids with Inaccessible Surfaces**

Contaminated or potentially contaminated impervious solids with inaccessible surfaces (which may also include large or complex surface contaminated items such as digging machines) are identified initially by following Section/Flowchart 6.2 or 6.3. Such solids must be sentenced using this Section/Flowchart (6.10), unless potentially activated or tritiated, in which case they are sentenced using Section/Flowchart 6.5 or 6.6 as appropriate.

For impervious solids with inaccessible surfaces, compliance with reference surface clearance levels SC2 and SC3 are the principal practical criteria, but it will need to be demonstrated that compliance with these levels will ensure compliance with RSA 93 Schedule 1 or Exemption Order (bulk) limits (SC1). Knowledge of the history and use of the item (or material), and how it could have become contaminated, are very important to understanding the likely distribution of contamination on it and nature of any radioactivity. If it has had the potential to have been contaminated by a diffusive radionuclide such as caesium, which, like tritium, could have penetrated the surface, consideration has to be given to whether the radionuclide can be detected and the solid sentenced as clean or exempt by surface measurement only; if not, Section/Flowchart 6.8 (for porous solids) should be followed.

If history and/or screening monitoring shows contamination levels are estimated to be close to or above the limits, the cost and practicability of further measurement or treatment has to be considered, and a decision taken whether the solid should be sentenced as radioactive without decontamination and with only minimal further measurement. Because of the presence of inaccessible surfaces, further measurements may present considerable difficulties, and dismantling of parts may be necessary. However, if no significant levels of radioactivity are detected on exposed surfaces it may be possible to justify that the same will be true for inaccessible surfaces. This would not be true for an air intake or filter, for example, and in this case dismantling and segregation of the relevant component parts would be necessary. Under other circumstances, pipework potentially contaminated on inner surfaces may be cut into short lengths for monitoring and/or decontamination. In all cases, keeping worker doses ALARP and any contaminated secondary arisings likely to be created are important considerations, and it is important not to remobilise radioactive contamination. Professional judgement is particularly important in these decisions.

If contamination levels are mostly low, or efficient and effective treatment possibilities exist (these could include separation or segregation of parts), a quality plan should be produced, which may be simple or very complex according to circumstances. It is unlikely to be a completely generic plan, although for surface decontamination parts of it may be generic. The plan should define the chosen outcome of using all available information to consider all practicable treatment options, whether they satisfy BPM, ALARP and BPEO, their cost-effectiveness and the availability of destinations for the arisings. It should include the measurements required, how they will be assessed and decision regimes. The processes, including contingencies on finding elevated levels and decision criteria for consequential actions (if relevant), should be described in detail.

Surface monitoring is largely generic and the quality plan could incorporate a generic plan for it: monitoring should be undertaken of all locations (corners and crevices, and/or parts most likely to have been in contact with radioactivity) where contamination is most likely to be concentrated, and a sufficient fraction of the remaining surfaces, using the statistical guidance in Chapter 7. Additional methods of measurement, which may be very useful in some circumstances, may include sampling of dirt in corners and crevices to determine whether they are contaminated. Guidance on measurement practices in Chapter 8 should be followed.

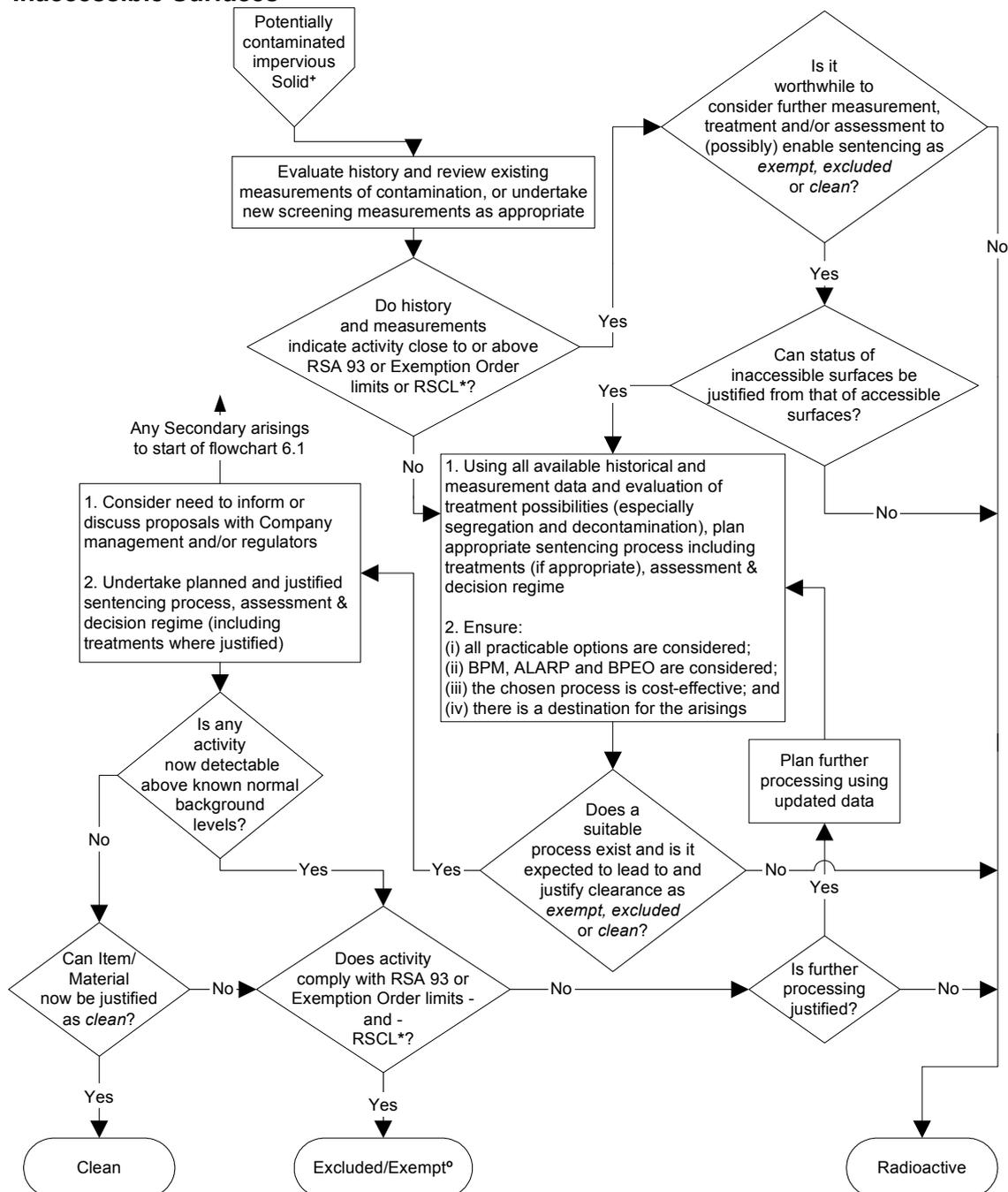
The plan should indicate the process to be followed if contamination is found by monitoring; usually wipes should be taken at all locations where significant levels are found to determine whether the radioactivity is likely to be removable, and what fraction is fixed. If the fixed radioactivity is less than the reference surface clearance levels, decontamination should take place, and loose contamination must be removed as far as reasonably practicable (see SC2). Following decontamination, surface monitoring should be undertaken again, especially on the previously contaminated areas. To confirm that any remaining contamination is not removable, wiping should be repeated. Further (more aggressive) decontamination should be undertaken if necessary and if practicable. At some stage in these operations, contingencies for disassembly for sentencing or cleaning may be relevant.

Proposals within the plan should be submitted to Company management and/or the regulators informed of them as necessary prior to undertaking it.

If monitoring following of any segregated part (if necessary) shows no detectable radioactivity above known normal background levels, there is sufficient confidence that none could have been missed, and the status of inaccessible surfaces can be justified to be the same, then the item or part is *clean*.

If the contamination is below the reference surface clearance levels, and wipes (which measure loose contamination only) show no detectable radioactivity above known normal background levels, and the status of inaccessible surfaces can be justified to be the same, then the criteria SC2 & SC3 are satisfied. Additionally, in compliance with SC1, the item or segregated parts are each *excluded* or *exempt* if the calculated or measured total radioactivity on the surfaces for the relevant item or part, compared with the weight of the item, does not exceed RSA 93 Schedule 1 or Exemption Order limits, respectively.

**Flowchart 6.10 - Sentencing of Potentially Contaminated Impervious Solids with Inaccessible Surfaces**



\*Includes items, articles, substances and materials intended to be cleared for reuse, recycling or recovery as well as those to be sentenced for transfer or disposal

\*Use Flowchart 2.1 to determine whether activity is below RSA 93 or EO (bulk) activity concentration limits. RSCL = Reference Surface Clearance Levels (see Section 4.10)

°Excluded from regulation under RSA 93 or exempt from the requirements of RSA 93 for registration as a material or from authorisation for accumulation or disposal as a waste (see Definitions)

## 6.11 Sentencing of Potentially Contaminated Aqueous or Non-aqueous Liquids Containing Sludges and/or Suspensions

Aqueous and non-aqueous liquids containing sludges and/or suspensions of solids which are substantially insoluble in water (as well as in the liquid, if it is non-aqueous) are analysed, and may be sentenced as a mixture, using this Section/Flowchart (6.11). If any solids are not substantially insoluble, it may be advantageous to consider either chemical dissolution into a stable solution (and sentencing using Section Flowchart 6.12), or (more likely) chemical precipitation into a stable and substantially insoluble form prior to following this Section/Flowchart (6.11). (These preliminary treatments are not considered in the Flowcharts.)

This Section/Flowchart (6.11) should be used primarily to decide whether separation of the phases (or constituents) into liquids and solids would be worthwhile for waste management, re-use, recycling, recovery or disposal. The process assumes multiple constituents (immiscible liquids and sludges as well as suspended solids) although there will often be only one liquid and one solid phase.

Before disturbing any liquid of this nature, any additional risks it may pose should be considered (including criticality), and any relevant clearances or authorisations to proceed must be obtained.

If the liquid mixture is believed to be radiologically *clean*, it is economic, if practicable, to take a representative (homogeneous) sample and to determine whether this contains any radioactivity above known normal background levels. For liquid mixtures, it should usually be possible to stir quantities of up to about ten litres to achieve the uniformity required before taking a sample. For larger quantities, or if homogenisation is not practicable, samples should be taken in each undisturbed layer of liquid (if there are two or more immiscible liquid layers), and in the sludge. Guidance in Chapter 8 should be followed.

Sampling of liquids should be consistent with sentencing volumes and, in the case of a sludge, several samples should be taken if inhomogeneity is suspected. In general, for liquids, bulking of similar liquids from similar sources likely to have similar radioactive contents is permissible, and sentencing volumes are usually the same as storage volumes. However, the sizes of bulked quantities are often limited to relatively small amounts by handling practicalities.

Liquid samples are filtered, if necessary, and both the liquid and dried filtered solids (suspensions) measured for radioactivity. Sludges should also be dried and measured for radioactivity. If any method used drives off volatile substances which may be radioactive, these should be captured and also assessed (this possibility is unusual, and is not covered in the Flowchart). Determinations of whether the filtered liquid sample(s) (which could contain dissolved solids) would be radioactive, *exempt*, *excluded* or *clean* are made using Flowchart 2.2, and whether the dried sample(s) of suspensions and sludges would be radioactive, *exempt*, *excluded* or *clean* are made using Flowchart 2.1.

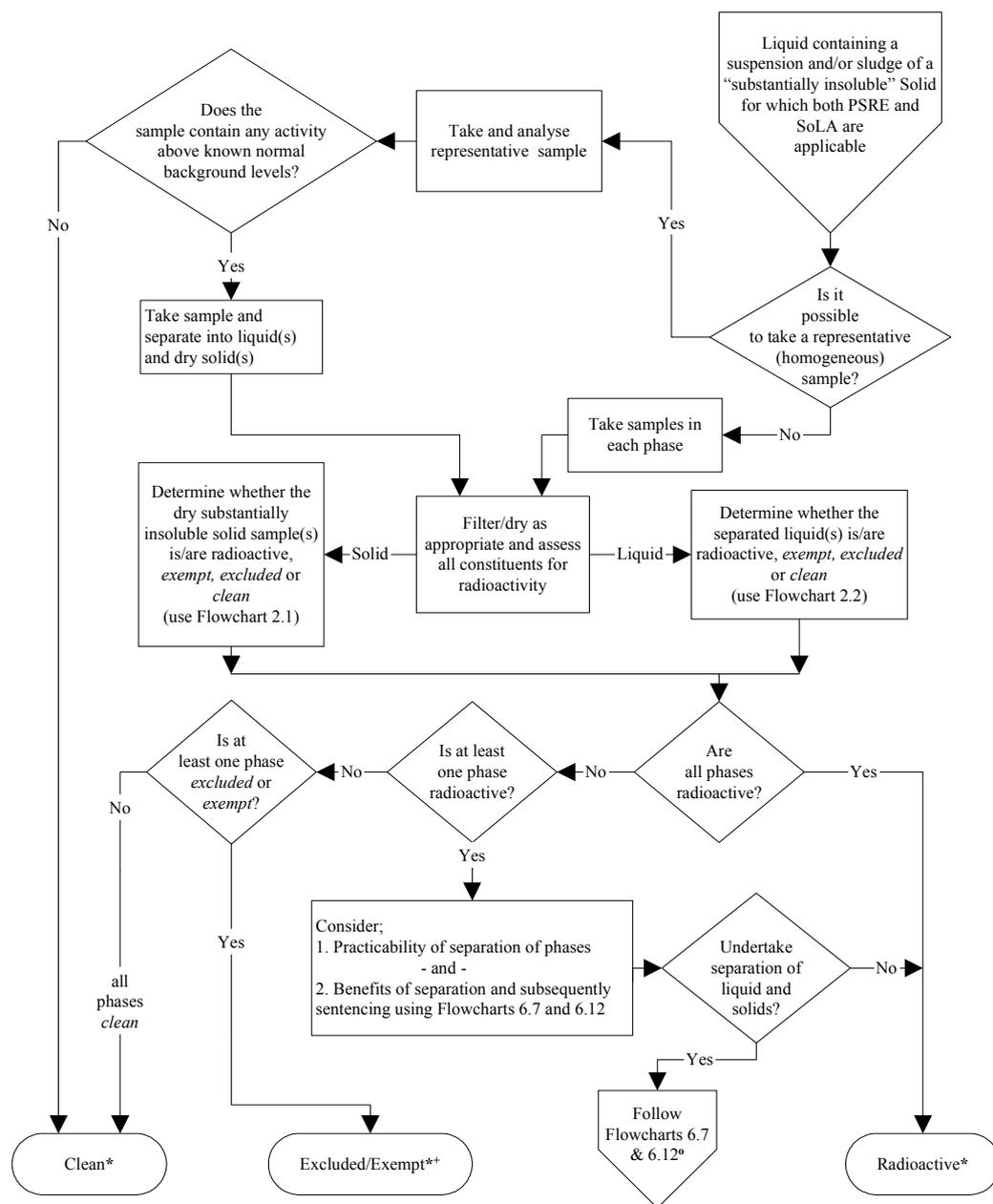
A liquid is *clean* if no radioactivity is positively detectable above known normal background levels. It is *excluded* if only RSA 93 Schedule 1 radioelements are present at below the

specified limits, and *exempt* if it is an organic liquid containing  $^3\text{H}$  and/or  $^{14}\text{C}$  which is positively detectable above known normal background, with a total activity concentration below the SoLA Exemption Order limit of 4 Bq/ml above known normal background levels (see Flowchart 2.2). (Note *exempt* organic liquids can also contain Schedule 1 radioelements at below the specified limits). For radioactivity to be “not positively detectable”, operationally practicable laboratory measurement techniques should be used and their detection limits should be assessed and their adequacy justified as necessary.

If all phases are radioactive, there is likely to be no benefit in separating them unless this is necessary for disposal as radioactive wastes. If only some are radioactive, the practicability of separating some or all of them, and the benefits of sentencing the solid(s) using Section/Flowchart 6.7 and the liquid(s) using Section/Flowchart 6.12, should be considered. Decisions are likely to be based upon the availability of re-use, recycling, recovery or disposal routes for various mixtures and/or for their constituent phases. If all phases are *exempt*, *excluded* or *clean* (or a mixture of some or all of *exempt*, *excluded* and *clean*), separating them is less likely to be advantageous.

It should be noted that liquid radioactive discharges to sewers or controlled waters are only permitted in compliance with authorisations issued under RSA 93 [ref. 2], and their non-radioactive properties are limited by consents issued by Water Undertakings under the Water Industry Act [ref. 21] (for sewers) or consents issued by EA or SEPA under the Water Resources Act [ref. 22] (for controlled waters). These consents apply whether or not the liquid is radioactive, and not only constrain or prohibit the discharge of non-aqueous liquids, but also the extent to which suspensions and sludges may accompany discharged liquids. Offsite disposal by specialist incineration is likely to be best practice for many non-aqueous liquids where this is permitted.

**Flowchart 6.11 - Sentencing of Potentially Contaminated Aqueous or Non-aqueous Liquids Containing Sludges and/or Suspensions**



\*Boxes refer to the sentencing result applied to the original liquid containing the suspended solid or sludge

+Excluded from regulation under RSA 93 or exempt from the requirements of RSA 93 for registration as a material or from authorisation for accumulation or disposal as a waste (see Definitions) (Separation may still be desirable for re-use or recycling, or disposal purposes)

°Follow Flowchart 6.7 for the separated solids or sludges and Flowchart 6.12 for the separated liquids

*Secondary arisings may occur in some of these processes, and these return to the start of flowchart 5.1*

## 6.12 Sentencing of Potentially Contaminated Aqueous or Non-aqueous Liquids not Containing Visible Amounts of any Insoluble Solids

Aqueous and non-aqueous liquids which do not contain visible amounts of any insoluble solids are sentenced using this Section/Flowchart (6.12). Such liquids can arise from separation from sludges and/or suspensions when following Section/Flowchart 6.11. Where solids are dissolved, it may be advantageous to precipitate them chemically (or evaporate a sample to dryness) and follow Section/Flowchart 6.11 to determine where any radioactivity resides. Alternatively, the liquid can be sentenced without separation from dissolved solids using this Section/Flowchart (6.12). However, in the case of dissolved solids in a non-aqueous liquid, the possibility that they may be precipitated in water may need to be considered.

While history and existing measurements may give a good indication of whether the liquid is radiologically *clean*, a representative sample should always be taken and analysed. Small volumes should be stirred to ensure uniformity and a single sample taken; for larger volumes where stirring is not practicable, samples should be taken close to the top, middle and bottom, to detect unexpected non-uniformity. Guidance in Chapter 8 should be followed. Sampling should also be consistent with sentencing volumes. Bulking of similar liquids from similar sources likely to have similar radioactive contents is permissible, and sentencing volumes are usually the same as their storage volumes.

Liquid samples should be measured without filtration or evaporation to ensure all radioactivity present is detected (liquid scintillation counting is likely to be most appropriate).

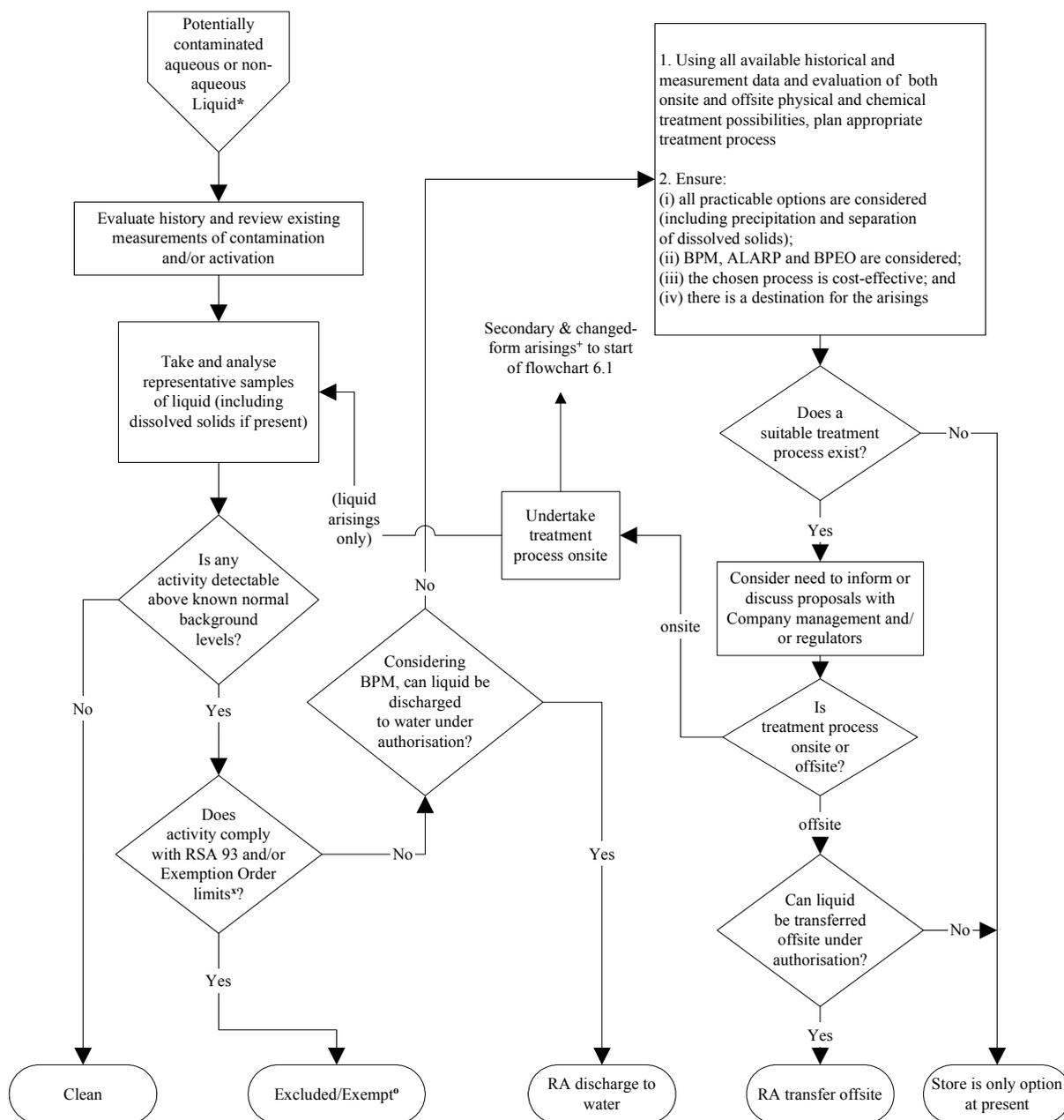
It is *clean* if no radioactivity is positively detectable above known normal background levels. It is *excluded* if only RSA 93 Schedule 1 radioelements are present at below the specified limits, and *exempt* if it is an organic liquid containing  $^3\text{H}$  and/or  $^{14}\text{C}$  which is positively detectable above known normal background, with a total activity concentration below the SoLA Exemption Order limit of 4 Bq/ml above known normal background levels (see Flowchart 2.2). (Note *exempt* organic liquids can also contain Schedule 1 radioelements at below the specified limits). For radioactivity to be “not positively detectable”, operationally practicable laboratory measurement techniques should be used and their detection limits should be assessed and their adequacy justified as necessary.

If the liquid is radioactive, it can only be discharged to water (sewers or controlled waters) if BPM has been applied to its treatment and if it is compliant with authorisations issued under RSA 93 [ref.2] and non-radioactive properties specified by consents issued by Water Undertakings under the Water Industry Act [ref. 21] (for sewers) or consents issued by EA or SEPA under the Water Resources Act [ref. 22] (for controlled waters). These consents apply whether or not the liquid is radioactive, and constrain or prohibit the discharge of non-aqueous liquids.

If discharge is not permitted, further treatment should be considered. This will require a quality plan to be produced, which may be simple or complex according to circumstances. The plan should define the chosen outcome of using all available information to consider all practicable treatment options (including precipitation of dissolved radioactive solids, if applicable, and both onsite and offsite treatments), whether they satisfy BPM, ALARP and BPEO, their cost-effectiveness and the availability of destinations for the arisings. If treatment onsite is the best option, the plan should include the measurements required, how they will be assessed, and decision regimes. Measurement practices should use guidance in Chapter 8. If treatment is to be undertaken offsite, much less detail may be necessary in the quality plan. If no suitable treatment can be identified which is likely to result in a route for disposal for arisings, it may be necessary to store them until one is available.

If a suitable treatment is identified, this is described in the quality plan, and proposals should be submitted to Company management and/or the regulators informed of them as necessary prior to undertaking it. For treatments undertaken onsite, liquid arisings are re-measured after treatment against the same criteria as before; radioactive solid arisings (following cementation for example) will follow appropriate disposal procedures. For treatments to be undertaken offsite, authorised transfer is required. If this is not available, the liquid will have to be stored onsite until an authorisation is obtained.

**Flowchart 6.12 - Sentencing of Potentially Contaminated Aqueous or Non-aqueous Liquids not Containing Visible Amounts of any Insoluble Solids**



\*Includes liquids which may contain very small amounts of solids and may be intended to be cleared for reuse, recycling or recovery as well as those to be sentenced for transfer or discharge

<sup>u</sup>Use Flowchart 2.2 to determine whether activity is below RSA 93 or EO activity concentration limits

<sup>i</sup>Incineration or solidification of liquids leads to changed form

<sup>o</sup>Excluded from regulation under RSA 93 or exempt from the requirements of RSA 93 for registration as a material or from authorisation for accumulation or disposal as a waste (see Definitions).

### 6.13 Sentencing of Potentially Contaminated Gases or Vapours (Including Aerosols if Present)

Most gaseous discharges are associated with continuous ventilation of buildings, and consist of air potentially containing radioactive gases and aerosol particulates. Air is continuously discharged, often through filtration plant with online sampling and/or monitoring. Continuous discharge processes of this type are not within the scope of this Code of Practice.

Where a gas is a contained volume (or batch) held for sentencing, the exclusion limits for specified radioelements in Schedule 1 of RSA 93 are relevant; there are no Exemption Order limits, as the exemption of radionuclides having half-lives of less than 100 seconds (and whose decay products also have half-lives less than 100 seconds) under the SoLA Exemption Order [ref. 7] are not relevant.

History and existing measurements provide information on the potential activation or contamination levels. Measurement by external (gamma) monitoring or internal monitoring (passing the gas or vapour itself through an ionisation or proportional counter) may be applicable. In some cases physical or chemical entrapment of the radioactivity from a sample of the gas (such as filtration of air containing potentially radioactive aerosol particulate, or capture of tritiated water in a bubbler) may be appropriate. Guidance in Chapter 8 should be followed.

The gas or vapour is *clean* if no radioactivity is positively detectable above known normal background levels, and *excluded* if no radioactivity other than that up to the limits permitted in RSA 93 Schedule 1 for specified radioelements, or relevant exemption orders. For radioactivity to be “not positively detectable”, operationally practicable laboratory measurement techniques should be used and their detection limits should be assessed and their adequacy justified as necessary.

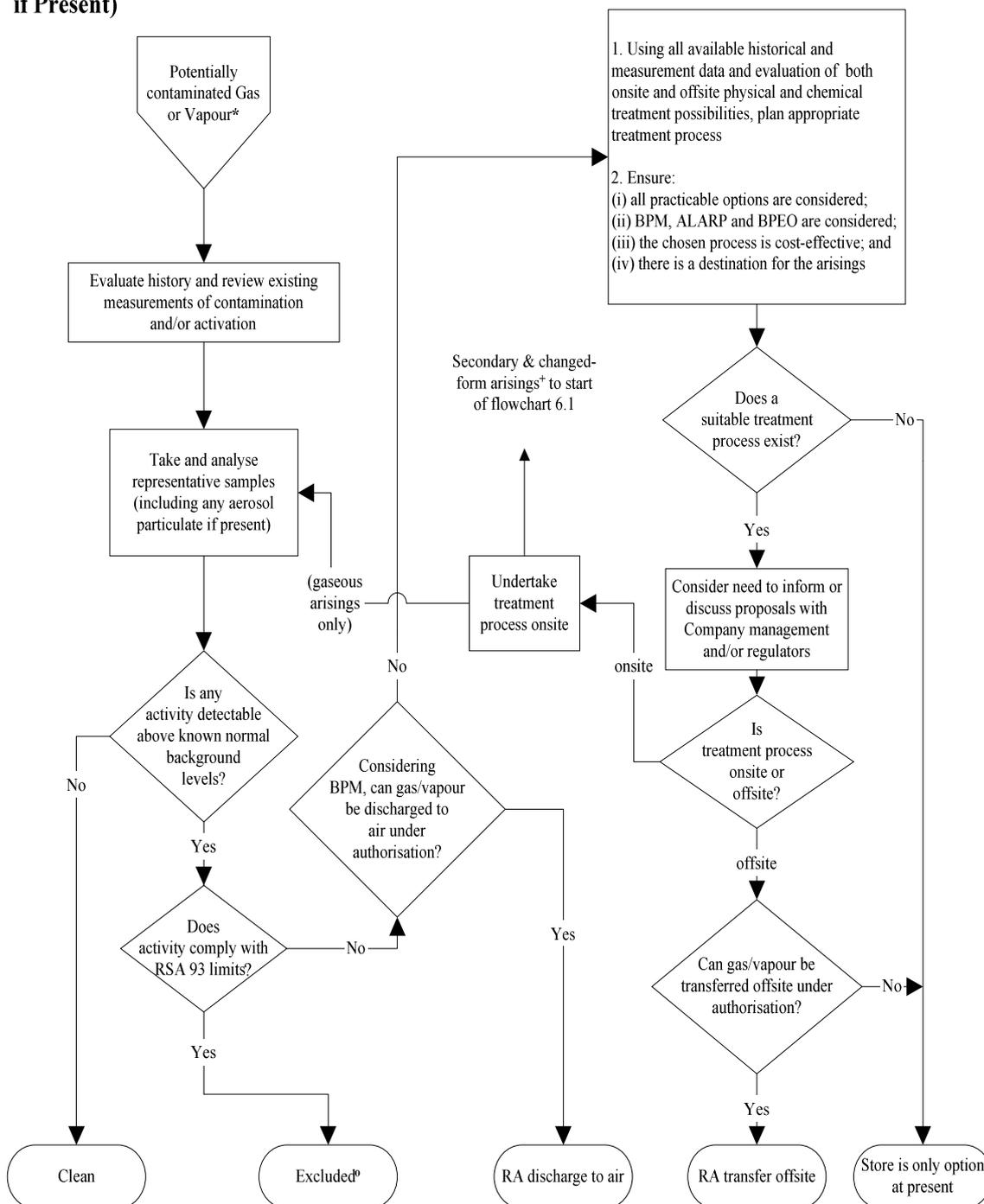
If the gas or vapour is radioactive, it can only be discharged to air if BPM has been applied to its treatment (this will often require filtration where radioactive particulate may be present), and if it is compliant with authorisations issued under RSA 93 [ref. 2] and other regulatory constraints on the physical and chemical properties associated with discharges to air. These constraints apply whether or not the gas or vapour is radioactive, and are associated with permits issued by EA or SEPA.

If discharge is not permitted, further treatment should be considered. This will require a quality plan to be produced, which may be simple or complex according to circumstances. The plan should define the chosen outcome of using all available information to consider all practicable treatment options (including both onsite and offsite treatments), whether they satisfy BPM, ALARP and BPEO, their cost-effectiveness and the availability of destinations for the arisings.

If treatment onsite is the best option, the plan should include the measurements required, how they will be assessed, and decision regimes. Measurement practices should use guidance in Chapter 8. If treatment is to be undertaken offsite, much less detail may be necessary in the quality plan. If no suitable treatment can be identified which is likely to result in a route for disposal for arisings, it may be necessary to store them until one is available.

If a suitable treatment is identified, this is described in the quality plan, and proposals should be submitted to Company management and/or the regulators informed of them as necessary prior to undertaking it. For treatments undertaken onsite, gaseous arisings are re-measured after treatment against the same criteria as before; radioactive solid arisings (following chemical fixing for example) will follow appropriate disposal procedures. For treatments to be undertaken offsite, authorised transfer is required. If this is not available, the arisings will have to be stored onsite until an authorisation is obtained.

**Flowchart 6.13 - Sentencing of Potentially Contaminated Gases or Vapours (Including Aerosols if Present)**



\*Includes gases and vapours which may contain aerosol particulate and may be intended to be cleared for reuse, recycling or recovery as well as those to be sentenced for transfer or discharge

+Adsorption or chemical fixing leads to changed form

°Excluded from regulation under RSA 93 (Exemption is only permitted for gases and their decay products having half-lives shorter than 100 seconds and is not relevant for gases held for sentencing) (see Definitions).

## 7. Statistical Basis for Sentencing

### 7.1 The Statistical Approach

There is a substantial challenge in providing guidance on the collection and analysis of data for radiological sentencing (meaning, in the context of this chapter, the decision-making process on whether appropriate limits or constraints have been met). This is because of the very wide range of materials likely to be encountered which include, for example (but are in no way limited to):

- equipment and clothing;
- skips of mixed waste, and
- areas of land.

Nevertheless, a consistent approach to dealing with such a varied range of materials and circumstances is very important, because it forms the basis for complying with legislation. One approach to sentencing relies upon the use of instrumentation to produce real-time data over 100% of the material, although in practice even 100% monitoring is based on discrete but closely spaced readings that cover the entire area or mass of material. Such monitoring is also only possible where the radionuclides are detectable by suitable instruments and the mass or area of the material is reasonably accessible to the instrumentation in use. There are often situations, however, where full monitoring is not achievable or practicable. These are materials or items:

- that have a complex and extensive shape, or comprises a mass of heterogeneous material where activity within the body of the mass is not detectable at the surface; or
- where the radioactivity is not detectable by surface monitoring equipment, for example alpha emitters beneath paint.

Where either of these situations exist, two alternative approaches may be followed:

- if access to, or the amount of, the material is the problem, monitoring may be focused on a specific number of locations in or on the material, which give a finite number of data points ); or
- if detectability of the radionuclides is the problem, a discrete number of samples may be taken to a laboratory for analysis).

This chapter provides guidance on how to make decisions about sentencing when 100% monitoring is not possible, and a restricted number of data points must be relied upon. This situation arises routinely, but poses some considerable technical challenges. It is necessary, for example, to make judgements about the number of locations to be sampled and the approach to the interpretation of the sample analyses. The approach used to make these judgements must provide, for all stakeholders, an appropriate level of confidence that the material will be characterised correctly and sentenced correctly.

The approach is wrapped up in a process referred to as hypothesis testing. The aim of hypothesis testing is to provide a mechanism for making a choice between two hypotheses (e.g. the population mean exceeds or is equal to a threshold versus the alternative that the population mean is less than the threshold.). Hypothesis testing assumes that one hypothesis is more important than the other by proposing that it should only be rejected in favour of the alternative if there is strong evidence for the alternative. The more important hypothesis is referred to as the null hypothesis and the opposing hypothesis is referred to as the alternative hypothesis. The null and alternative hypotheses must together include all possible outcomes. ‘Most important’ can be loosely translated here as ‘carries the most danger if it is true’. This favouritism for one event effectively replicates the risk estimation process previously described.

The method of stating the hypothesis test is as follows:

Null hypothesis, $H_0$	$\mu \geq Z_T$ [ $Z_T$ = threshold activity]
Alternative hypothesis, $H_A$	$\mu < Z_T$
Significance level	X%

The significance level is the maximum probability that the null hypothesis will be true but will be rejected in favour of the alternative hypothesis. Typical significance levels are 5%. This can be stated as there must be at least a (100-X)% chance that the alternative hypothesis is true before the alternative will be accepted as correct. Roughly speaking we have to be 95% or more certain that the alternative is true before we will accept it but only 5% or more certain that the null hypothesis is true before we will accept it. The favouritism is now obvious.

The requirements of hypothesis testing are that the probability distribution for  $\mu$  can be defined from the sample data and that a sensible value for the significance level can be defined *a priori*.

**PRINCIPLE: The information gathered, any analysis that is done, and the reasoning behind the decisions taken at each step, must all be properly recorded for collation into an overall justification for the final sentencing decision made.**

Statistical methods need to be applied to both the approach to defining the data collection strategy **and** to the interpretation of data flowing from the subsequent analysis of the data. This chapter defines how a reasonable approach to data collection and assessment may be taken, depending on the particular circumstances of the source of contamination and the materials to be sentenced.

The approach given in this chapter relates primarily to solids. Sampling of liquids and gases does not normally need a statistical approach to be taken because, provided that the material has been appropriately zoned where necessary, a single sample should be representative of the volume as a whole.

For the purposes of this chapter and as noted in the glossary, the term “monitoring” refers to the collection of data by instrumentation on a continuous basis. “Sampling” refers to collection of data either by taking a discrete number of data points from material using monitoring equipment, or by taking samples of material for laboratory analysis and subsequent generation of results.

This chapter also considers the uncertainty associated with the sampling. However, it must be recognised that other uncertainties exist in relation to other aspects of the overall sentencing process including:

1. Physical material sampling methods;
2. Field equipment; and
3. Laboratory analysis methods.

Uncertainties introduced by the way in which material samples are taken (1) can be minimised by following a set protocol. Localised heterogeneity in the material will also be reflected in the sample results, but use of the approach described in this chapter should result in any such heterogeneities being minimised.

Uncertainties in both field measurements (2) and laboratory analyses (3) should also be considered when making judgements about the overall sentencing process. Chapter 7 provides further information on methods of field measurement and their limitations. Information on laboratory analysis uncertainties should be obtained from the laboratories that carry out the work (data on precision, accuracy and bias should be provided as part of their service). The uncertainties in the laboratory analysis are normally much smaller than those which may arise from, for example, field monitoring and sampling.

**PRINCIPLE: The sampling process itself must be carefully designed because this is the source of the greatest uncertainties.**

This chapter details the steps necessary to obtain a statistically robust and defensible analysis of the overall activity concentration in material, which can then be compared with the relevant limit or constraint. There is no need for a detailed knowledge of statistics to be able to apply the methods given. However, detailed summaries of the statistical methods used are included in the following appendices to the Code of Practice for those who wish to read them.

<b>Appendix Number</b>	<b>Description</b>
7.1	Contains the justification for setting the acceptable confidence level at 95%.
7.2	Contains examples of everyday materials and the distribution class they are assigned to.
7.3	Discusses approaches to unbiased sampling methods.
7.4	Gives further details about variograms.
7.5	Gives further details about post plots.
7.6	Gives further details about contour plots.
7.7	How to perform the Wilcoxon Signed Rank test.
7.8	How to perform the Students t test.
7.9	How to do a Bootstrap analysis.
7.10	How to do a Lands (1975) test.
7.11	Discussion of Histograms.
7.12	How to do the Wilks-Shapiro test.
7.13	How to do tests for outliers.
7.14	Lists and compares the merits of a number of packages containing statistical tools that may be found useful.

Finally, the basic concepts relevant to statistical sampling and statistical analysis and the specific procedures and methods used to develop the approach given in this Chapter are separately available as two supporting papers.

## 7.2 Sampling Strategy

### 7.2.1 Objectives

Chapter 5 sets out the management principles and arrangements that support a sustainable approach to radioactive waste management in the nuclear industry. A subset of these overall objectives (the sampling principles), can be defined as follows:

- Generation of a sampling plan that will provide demonstrable compliance with the regulatory requirements for clearance of materials; and
- Ensuring that the sampling and assessment process is robust and defensible.

### 7.2.2 Generic Sampling Strategy

Based on knowledge of the provenance of the article or substance in question:

**PRINCIPLE: Where there is a high level of confidence that the material is clean, then monitoring is undertaken for reassurance purposes only and there is no need to apply statistical methods to the outcome.**

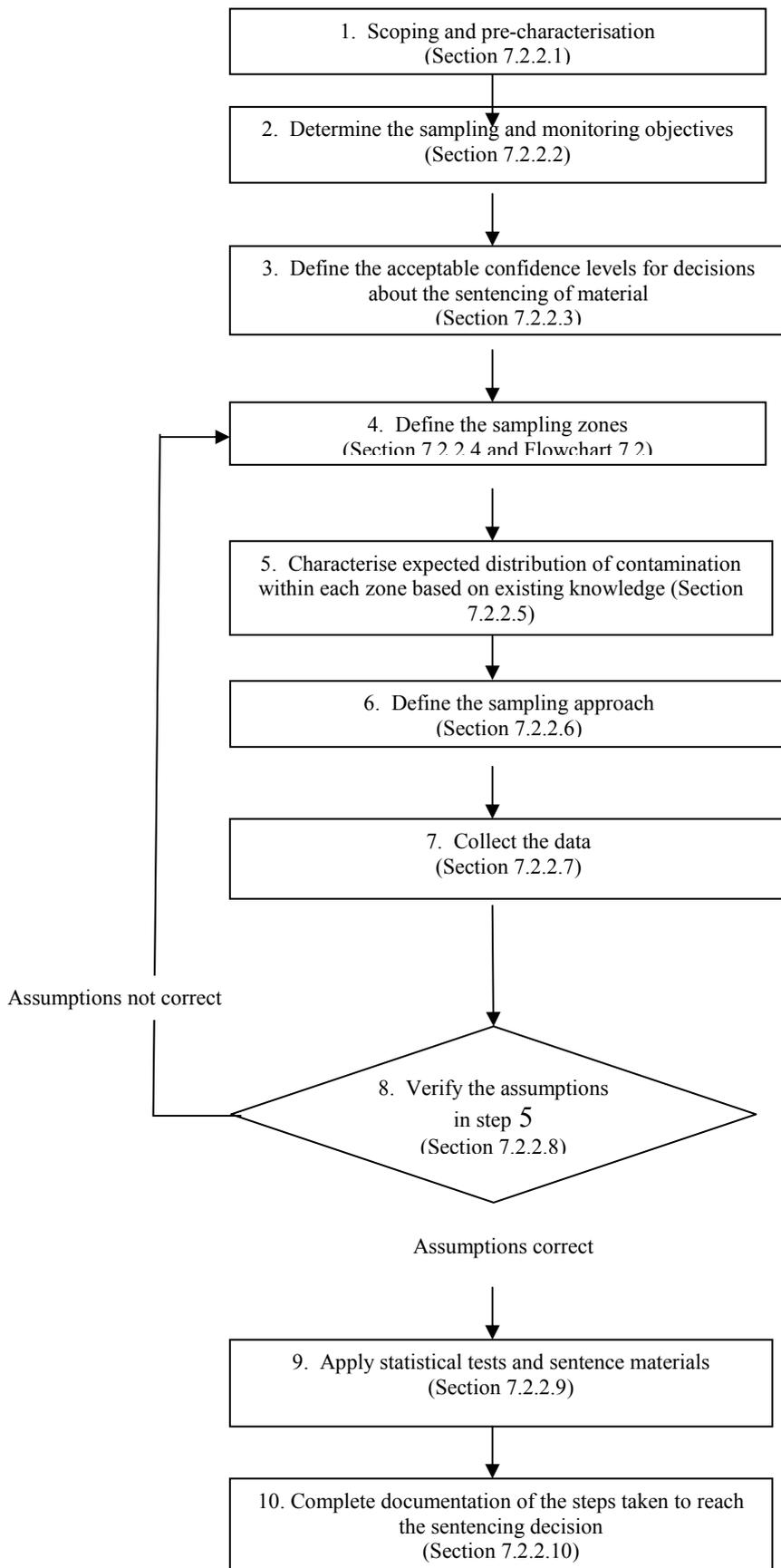
An example of this situation might be monitoring of people as they leave a controlled area. The normal precautions to control contamination risk are considered sufficient to allow people to leave the area without going through the formal sentencing process.

**PRINCIPLE: Where there is any reasonable doubt about the history of the material and the potential for it to have been contaminated or activated, then it should be assumed to be potentially radioactive and subject to the appropriate sentencing process from Chapter 6.**

The approach summarised in this chapter will then be necessary where 100% monitoring is not practicable and a series of discrete samples needs to be collected.

Flowchart 7.1 summarises the steps that should be followed in order to construct a robust statistical approach, and it is the starting point for development of the detailed sampling strategy to be adopted.

**Flowchart 7.1 Sequence of activities for any statistical sampling procedure**



### 7.2.2.1 Step 1 – Scoping and Pre-characterisation

*Review all existing knowledge of the article or substance to be sampled.*

Of particular interest are the results of any previous sampling or monitoring of the material that can be used to determine if any additional pre-characterisation samples would be of benefit.

Where there is no prior information on the activity concentration, some preliminary sampling will need to be undertaken to provide data on which to base the process. Generally, this would mean a few samples taken randomly from the article or substance.

### 7.2.2.2 Step 2 – Identifying the Sampling Objectives

*Set any specific sampling objectives.*

In addition to the generic sampling principles given in section 7.2.1, other specific objectives may be needed taking into account the provenance of the materials. These may include, but are not necessarily limited to:

- consideration and setting of sentencing and compliance volumes (for example, in the case of a significant amount of soil, it may be necessary to consider it in batches).
- technical considerations such as the composition of materials and the potential for early segregation or zoning (these will affect the assessment methods and costs);
- logistical considerations, such as storage constraints pending the outcome of testing (once sentenced, any possibility of further contamination or activation must be prevented) ;
- the desired time scales for completion of the sentencing process (these may dictate the sampling methods available) ;
- optimisation of the costs of sampling, measurement and disposal of materials.

For example, constraints on time may affect decisions about whether or not to adopt a phased sampling analysis approach. A single round of analysis may be quicker than a multi-stage analysis, but is not necessarily the most cost-effective way to sentence materials. It is therefore important to remember that all of these objectives may interact with each other, and have a significant effect on the approach used, which is why it is necessary to define the objectives.

### 7.2.2.3 Step 3 – Set the Acceptable Confidence Level

*Define the acceptable confidence level that materials will be correctly sentenced.*

The **recommended** confidence level for materials to be sentenced as exempt is **95%**. Justification for this value is given in Appendix 7.1.

#### 7.2.2.4 Step 4 – Defining the Sampling Zones

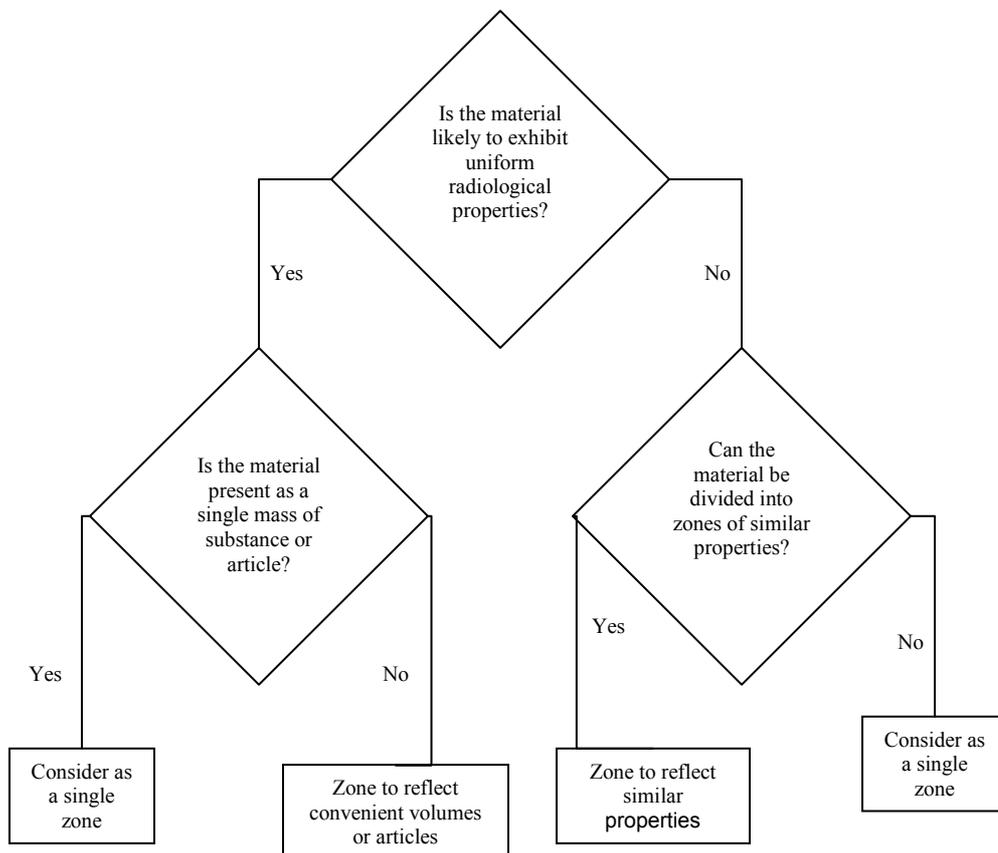
*Consider zoning the article or substance to facilitate the statistical assessment of its properties and the nature and type of contamination.*

**PRINCIPLE: Zoning should be used wherever it is reasonable to do so.**

Different zones will be independently sampled and sentenced in a way that reflects the nature of the material and/or the perceived level, nature and type of contamination of the zone in question, and hence the sentencing decision. Redefinition of zones may occur at other stages in the overall process, or between stages, as more information leads to a better understanding of the article or substance under consideration. Note that there will always be at least one zone.

Flowchart 7.2 sets out the method of deciding whether zoning is appropriate.

#### Flowchart 7.2 Deciding Whether Zoning is Appropriate



### 7.2.2.5 Step 5 - Characterise the Expected Distribution of the Contamination

*Use the prior knowledge referred to in step 1 to make a judgement about the possible distribution of contamination within each zone.*

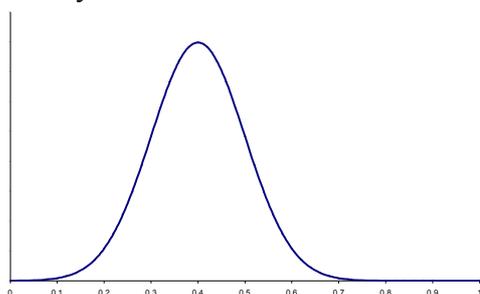
**IMPORTANT:** The distribution is necessary to determine which statistical test and sampling approach is initially used.

The statistical test and sampling approach used is dependent on the distribution of activity. At this point, an initial assumption as to the distribution is made which will be reviewed later at step 8.

The approach used in this Code of Practice is based on two classes of heterogeneity which are given and described below. Appendix 7.2 gives everyday examples of materials and the class in which they are likely to belong.

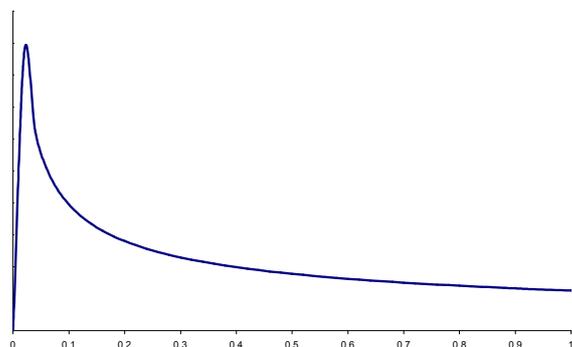
**Class 1:** The activity exhibits a symmetric distribution of sample values. This could have arisen from a diffuse source of contamination that has impacted the whole zone, for example a contaminated suspension.

The following histogram illustrates a situation where there is a symmetric distribution of activity:



**Class 2:** The activity exhibits a skewed distribution of sample values. This could have arisen from a diffuse source of contamination that has impacted only a proportion of the mass or area of material, for example walls in buildings where tritium is processed.

The following histogram shows an asymmetric or skewed distribution:



### 7.2.2.6 Step 6 –Define the sampling requirements.

*Determine the number of samples to be taken from each zone and the sampling patterns.*

**The number of samples to be taken depends on which distribution the material has been found to belong to by application of the previous step (step 5)**

#### **If the material is in Class 1 (symmetric distribution):**

(a) Using the available data, estimate the standard deviation ( $\sigma$ ) of the activity in the material using the following formula:

$$\sigma = \sqrt{\frac{\sum_{i=1}^N (\bar{n} - n)^2}{(N-1)}}$$

Where  $N$  is the total number of samples,  $\bar{n}$  is the mean of the sample values and  $n$  represents each value.

(b) Calculate the number of samples ( $N_V$ ) required using the following formula:

$$N_V = \text{Integer}[(\sigma^2 / (0.1 * Z_T))] + 1$$

where ( $Z_T$ ) is the threshold value for the activity (e.g. 0.4 Bq/g)

For bulk monitoring of solid materials, if the calculated number of samples is less than four, use at least four samples. If the calculated number is greater than four, use the calculated number of samples.

#### **If the material or item is in class 2 (asymmetric or skewed distribution):**

(a) Estimate the standard deviation ( $\sigma$ ) of the natural logarithm of the sample values by assuming that  $\mu = \sigma$ .

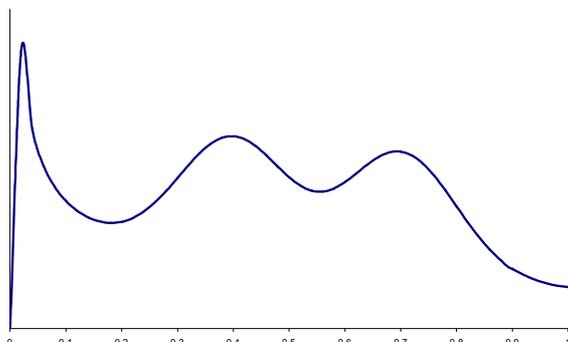
(b) Calculate the number of samples required to give a variance of the sample mean of 10% of the maximum value of the activity ( $Z_T$ ) allowed for exemption using the following formula.

$$N_V = \text{Integer}\left(e^{2\mu} \left(e^{2\sigma^2} - e^{\sigma^2}\right) / (0.1 * Z_T)\right) + 1$$

For solid materials, if the result is less than four, then adopt a sample number of at least four. Otherwise adopt the calculated number and exit this process.

In some special circumstance, there may be situations where the contamination of the article or substance in question does not immediately fall into one or other of the distributions given above. A simple example might be where an area of land with a broadly low level of activity present, but with a number of areas having higher activities. Such a distribution would be multi-modal, and this is shown below:

The following histogram shows a multi-modal distribution



There are also other types of distribution, for example Poisson, Weibull and so on. However, where such distributions are encountered, then it will almost always be possible either to zone the material in question further, or to ‘mechanically’ divide the material (for example by stripping off layers of vegetation that might have enhanced levels of activity, or by use of decontamination techniques) so that the activity in the rezoned or mechanically separated materials follows either of the two basic distributions identified above.

Use of alternative distributions is, therefore, discouraged (especially given that it may be considered to be a form of dilution if such a material was treated as a single zone). Nevertheless, if an alternative is considered appropriate, ***and proper justification can be made for departing from the requirements of this Code of Practice***, then similar steps can be invoked for the alternative distribution with replacement of the equation elements for the variance by appropriate elements for the chosen distribution. Professional statistical help would normally need to be sought to do this.

#### 7.2.2.7 Step 7 – Collect the data

*Take the samples.*

**When physically taking samples, a fundamental requirement of the application of statistical tests is that the data should be unbiased, i.e. the sampling pattern must be truly random.**

If bias is introduced into sampling (for example by taking samples only from those locations where direct measurement shows elevated activity) then the outcome of a statistical test will be compromised.

Square grid patterns or herringbone patterns are both permissible approaches to taking samples. Where contamination is not elongate in shape and aligned in the direction of the grid, square grid sampling is sufficient to meet most sampling requirements, and is relatively simple to set out. In other situations, herringbone pattern approaches should be used.

**PRINCIPLE: Whatever sampling pattern is finally selected, an unbiased (random) starting point located anywhere within the area MUST be used.**

In cases where a large volume of material is to be sampled, it is permissible to consider this as a stack of layers, each of which can be divided up into a grid and sampled accordingly. Note, however, that if this approach is taken, then each layer must be considered as a separate zone.

Other measurements (or making reference to the previously determined nuclide fingerprint) may be used to support the analysis of the material, provided that sufficient data are available from which to estimate the association between the surrogate measurement and the activity of the sample. Chapter 8 gives relevant information on this topic.

Note that, if good quality data from which the activity levels can be derived already exists, this can be used provided that use of the data can be properly justified, and that the justification is recorded as part of the documentation.

A fuller discussion of the approach to collection of samples in an unbiased manner is included in Appendix 7.3.

#### **7.2.2.8 Step 8 –Verify assumptions**

*Verify that the decision made in step 5 about the relevant distribution was correct.*

The data gained in the previous step (step 7) should be plotted as a histogram, and the shape compared to the examples given in step 5 (further discussion about the construction of a histogram can be found in Appendix 6.11). If the shape confirms the initial judgement, then the most appropriate statistical test can be chosen as described in the next step (step 9).

If it is not certain that the initial assumption was correct, then consideration must be given as to whether further data is necessary. If either extra data or the histogram show the original judgement of heterogeneity class to be incorrect, there should be further consideration as to whether the numbers of sample taken were sufficient by repeating the process from step 6 before going on to step 9.

Tests of spatial distribution and correlation (Appendix 6.4) should also be carried out at this point as well as tests for outliers (Appendix 6.13) that might reduce the effectiveness of the statistical tests. If outliers have been identified, the reason for this should be established. If the outlier has resulted from analytical or measurement error, then the result may reasonably be ignored. If the outlier is genuine, then the material may need further zoning to home in on specific hotspot(s) represented by the outlier(s). More detail on these tests is included in the appendices.

It is important to recognise that some of the techniques for visualisation of data can be misleading. The selection of bin sizes when constructing histograms should be undertaken with care to avoid masking trends in data. General guidance would be to set the bin size as 10% of the appropriate limit.

Where analysis of the final data has shown that further samples are necessary, or that a change of heterogeneity class is appropriate, the process described above must be iterated until it is certain that the appropriate class has been identified and sufficient samples have been taken.

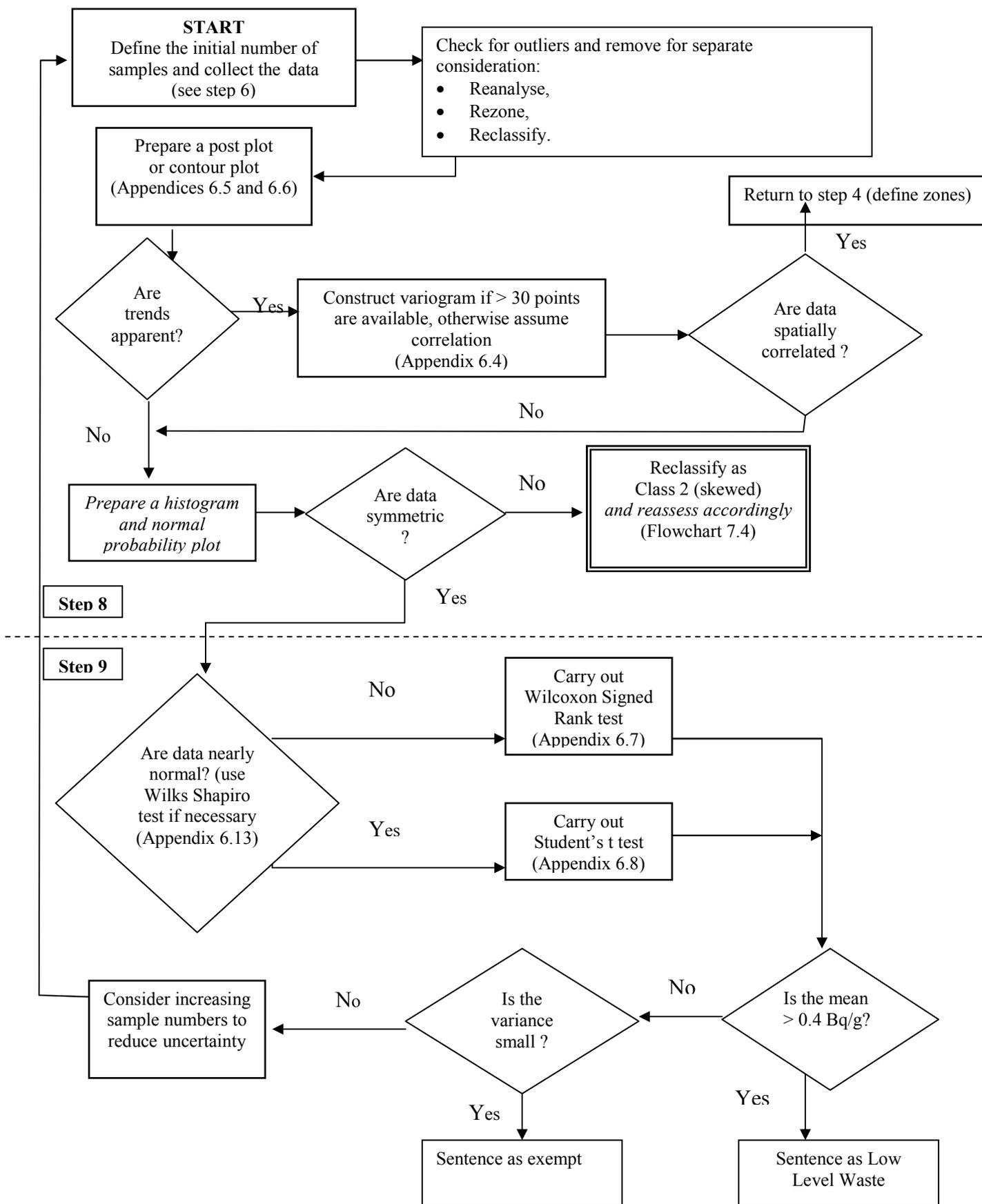
#### **7.2.2.9 Step 9 – Apply statistical tests and sentence materials**

*Complete the statistical analysis, and make a decision about the sentencing of the material.*

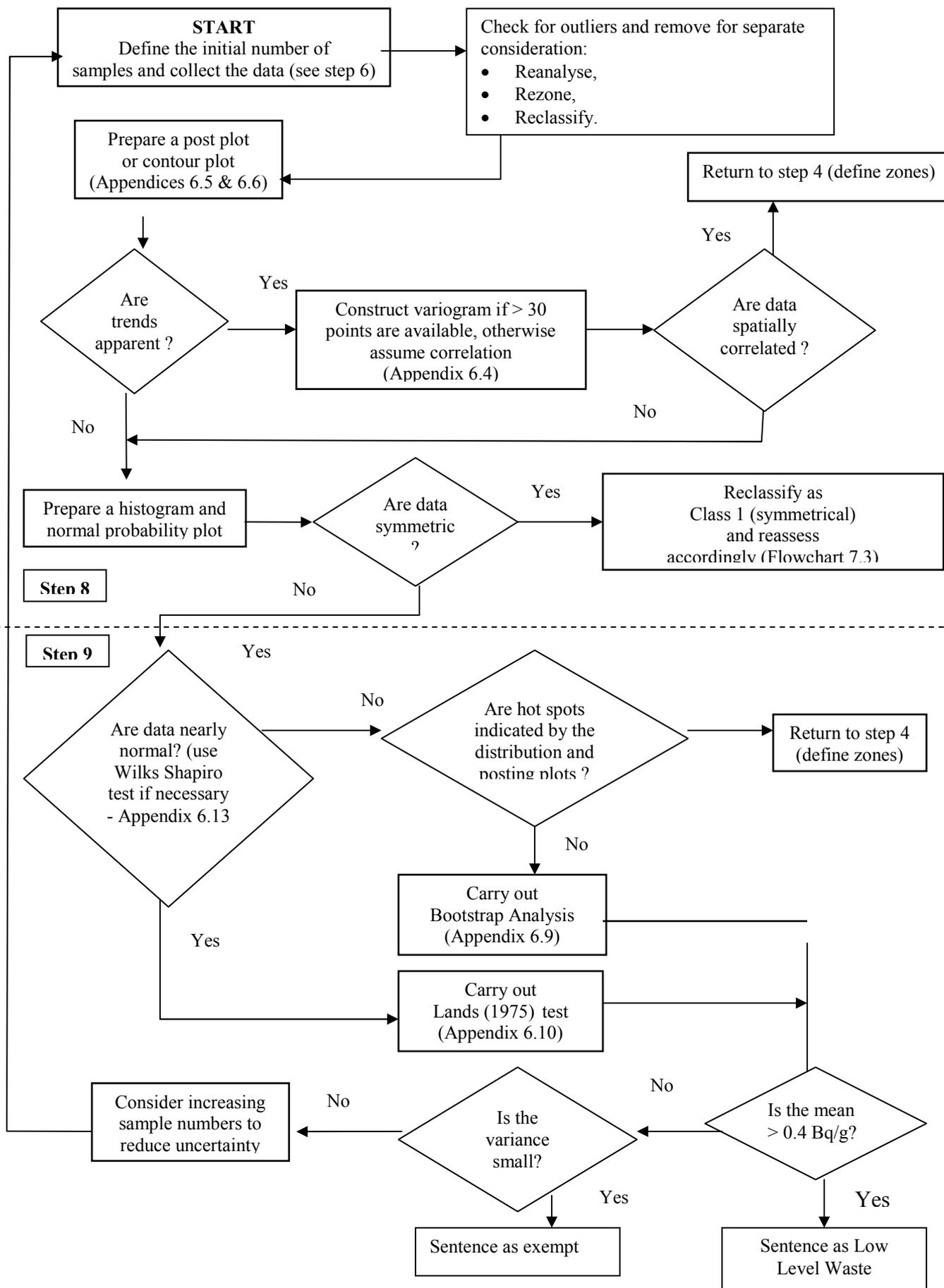
For materials confirmed to be Class 1 (symmetric) materials, follow Flowchart 7.3. For materials confirmed to be Class 2 (skewed) materials, follow Flowchart 7.4.

It is strongly recommended that the user has access to a suitable statistical software package to perform the graphical manipulations and statistical tests in this section. A very useful web based resource and freely available software (DATAPLOT) can be found at <http://www.itl.nist.gov/div898/handbook/prc/section2/prc213.htm>. Alternatively, some of these tests can be performed through Excel spreadsheets and graphs.

**Flowchart 7.3 Application of Statistical tests for Class 1 (symmetrical) Materials**



**Flowchart 7.4 Application of Statistical Tests for Class 2 (skewed) Materials**



#### **7.2.2.10 Step 10 – Document process**

Recording of:

- all of the data gathered and used;
- the reasons for the decisions made at each stage; and
- the outcome of the analysis

must have been undertaken throughout the process. All of these records should now be collated and stored appropriately in accordance with the other requirements in this Code of Practice.

## 8. Measurement Practices

### 8.1 Principles of Monitoring

This Chapter provides information on the basic processes and techniques of monitoring. Flowcharts 8.1 and 8.2 summarise the process to be used when considering the monitoring approach techniques that are appropriate.

The purpose of monitoring and sampling is to produce a numerical estimate of surface or bulk activity levels which can be compared with criteria described elsewhere in this document. Often, because of the uncertainties in the process and the fact that many of the materials monitored may be genuinely clean, the results will demonstrate that the materials under investigation are below the minimum reliably detectable activity.

The methods used for this and the equipment employed will depend on:

- the physical form of the materials to be monitored,
- the relevant averaging areas and masses,
- the natural background levels in the materials,
- the fingerprint, i.e. the expected contaminating radionuclide mix,
- the desired maximum missable activity,
- the environment in which the monitoring is to take place,
- the type of person who is going to perform the measurements,
- when the monitoring is to take place and
- the balance between manual and automatic monitoring

These points will be expanded on later in this chapter. Frequently, deciding on exactly the method of monitoring will be an iterative process, where a variety of techniques and equipment is considered, the pros and cons weighed and a judgement made on what is the best approach for the particular circumstances.

#### 8.1.1 The physical form of the materials to be monitored

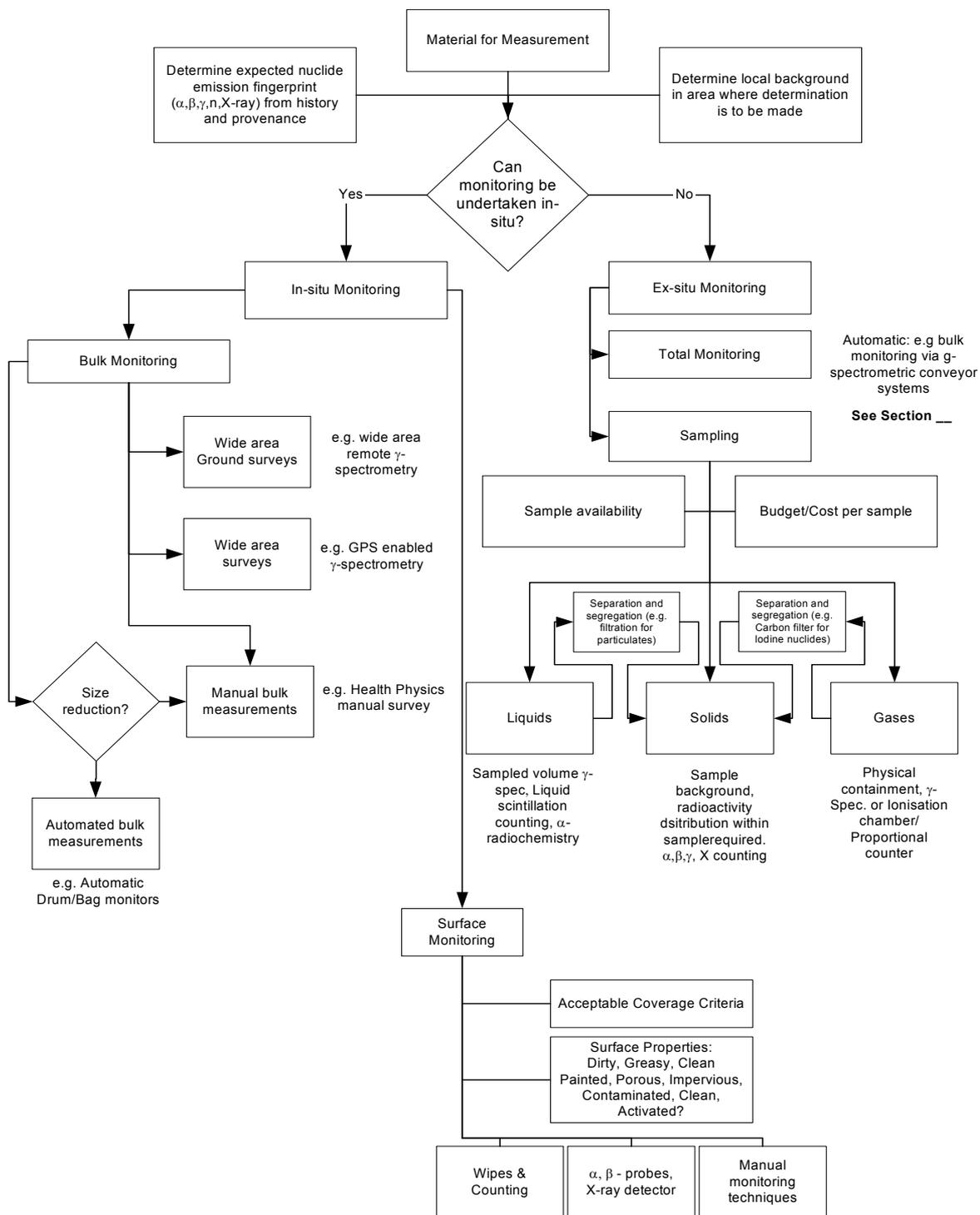
Chapter 5 comprises a set of flow charts which are to be used in the assessment of bulk and surface activity and which are based on the physical form of the material to be cleared. The influence of the physical form of the materials to be monitored is considerable. Intact solids such as steel plate and bricks demand sampling methods which are aggressive for bulk samples, but are easy to monitor directly for surface contamination. Materials such as wire, piping and cable can be cut up into convenient sized pieces for bulk activity assessment. However, direct contamination monitoring is difficult and wiping may be unacceptable for many materials because of safety considerations.

For contamination monitoring, surface condition can also be important. Direct monitoring of low range emissions such as soft betas and all alphas can only take place on surfaces which are essentially clean in terms of dust, grime and grease and are free of condensation. If activity could be buried beneath a layer of grease or paint then that surface is unmonitorable. In addition, for low range emissions, surfaces need to be relatively flat so that the distance between detector and surface does not vary by more than a few mm over the area of the detector window. Direct counting of wipes from a greasy surface is also impossible, as any grease will greatly reduce the counting efficiency of any detector. Such wipes will require counting by liquid scintillation or will require radiochemical treatment to produce a countable sample. In effect, only surfaces which are clean and dry and where there is no chance of significant activity under paint are acceptable for direct monitoring for low range radiations. This means that many surfaces which may have been contaminated at some time will have to be cleaned down to the earliest surface before monitoring.

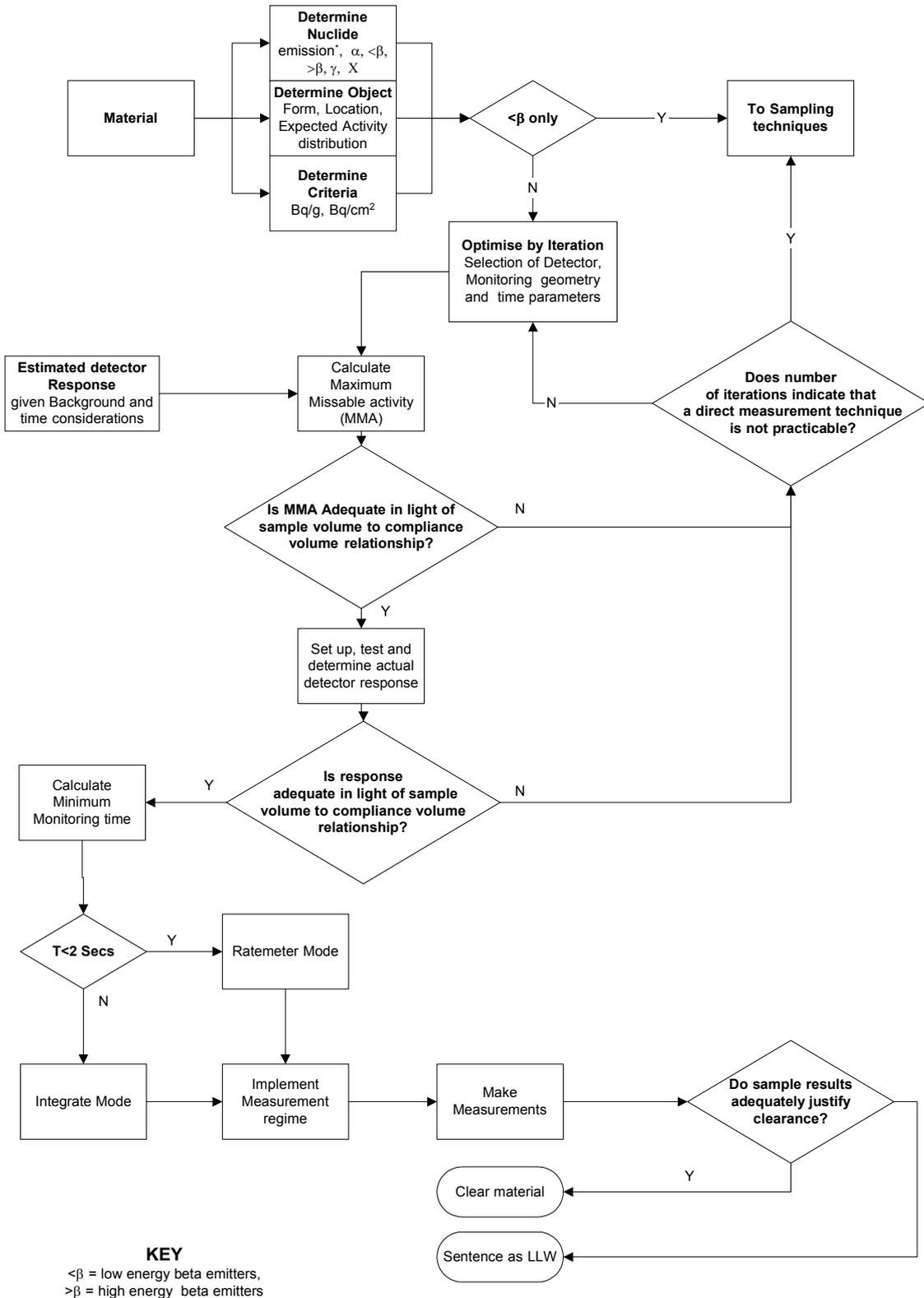
*For each material anticipated, a careful assessment of the physical form will be essential to allow selection of the most appropriate general method, monitoring device type and monitor size.*

Detailed description of the monitoring techniques is given in Appendix 8.

**Flowchart 8.1 Overall Process for use when Considering the Approach to Monitoring (Part 1)**



**Flowchart 8.1 Overall Process for use when Considering the Approach to Monitoring (Part 2)**



### **8.1.2 Permitted Averaging Areas and Masses**

Averaging areas for contamination assessment are given in section 4.10, SC6, and averaging volumes in section 4.6.4.

The form of the material may define the maximum effective area of the monitoring device, particularly for direct surface contamination monitoring. As an example, the choice of equipment available for monitoring for beta activity inside a pipe is likely to be limited. However, for bulk activity assessment, the user is likely to be able to obtain equipment in a range of sizes.

For direct surface contamination monitoring, the time taken to monitor a particular area to a particular level of confidence is inversely dependent on approximately the square of the detector size. Hence, doubling the detector size will tend to reduce the time taken to monitor a particular area by a factor approaching 4. There are 2 influences. One is obvious, in that the number of measurement points or detector repositionings required is inversely proportional to the detector size. The other, less obvious, one is that the length of time required to accumulate a statistically acceptable number of counts is generally also approaching the inverse of the detector size. The same general effect occurs for volume sources and bulk activity assessment.

*Hence, it is advantageous to make use of the maximum practicable and permitted areas or volumes when designing the monitoring regime.*

### 8.1.3 Natural Background Levels

All practical materials have some natural radioactive content and in many the radioactive content approaches or exceeds 1 Bq/g. This natural level makes the detection and measurement of any possible added activity more difficult to perform. One very common example is a high level of potassium in some types of high quality brick. All potassium contains the isotope  $^{40}\text{K}$ , which emits energetic gamma radiation (1.46 MeV). If the potential contaminant is  $^{137}\text{Cs}$  (0.662 MeV gamma) then there will always be some interference by the  $^{40}\text{K}$  with the  $^{137}\text{Cs}$  measurement, because Compton scatter within the bulk material will generate a number of 0.662 MeV gammas. The same problem affects tiles and glazed sanitary ware. Plasterboard can sometimes contain significant levels of  $^{226}\text{Ra}$  which will be in equilibrium with its decay chain down to  $^{214}\text{Po}$ . This decay chain generates a complicated mixture of alpha, beta and gamma radiation.

The influence of the natural activity can be minimised by using energy selective monitoring, discussed later in detail for gamma radiation but also applicable to beta radiation. In cases where the natural level is constant, the main effect is that the background count rate from any monitoring equipment is increased, which increases the statistical uncertainty in any measurement of net activity. A more significant problem is where it is variable, as might be the case when demolishing a building which uses 2 types of brick. The background in that case could well depend on the mix of the two types in any load. This will further increase the uncertainty. This may best be managed by ensuring that loads are segregated so that the problem does not occur. A further similar complication can arise with tiled areas in buildings. Tiles can have very high levels of bulk activity and are difficult to separate from walls.

*Hence it is vital that the natural nuclides present in any material are identified and measured before choosing monitoring techniques and equipment and before planning the demolition sequence.*

### 8.1.4 The Fingerprint

In the same way that it is essential to understand the natural activity in a material then it is essential to understand the expected contaminating nuclide mix, i.e. the fingerprint. **The aim should be to subdivide any task into a series of areas where it is possible to be confident that the nuclides present are in relatively fixed proportions.** This concept is fundamental to the application of zoning, as discussed in the previous chapter. The fingerprint can sometimes be easy to decide. If an area has only processed one nuclide which has a long half life and no significant progeny then the fingerprint is that nuclide. However, if there is the potential for a complicated mix of nuclides to be present then deciding on the fingerprint can be much more difficult. **It is essential that sufficient time, thought and money are devoted to producing each fingerprint as mistakes can lead to delay, expense and loss of credibility later.** One problem that can arise is where there is a potential mix of fuel, fission products and activation products. Within that mix, there are gamma emitters, alpha emitters, relatively easy to monitor beta emitters, low energy beta emitters, low energy X-ray emitters and tritium. Tritium has been identified separately because its chemical and physical properties are very different to most other nuclides, particularly its high mobility.

Fingerprinting will normally demand sampling which should be guided by an understanding of the process that took place and by direct measurement. For example, for soil contaminated by fission products,  $^{137}\text{Cs}$  is likely to be present. The highest activity concentrations can be identified using a large sodium iodide scintillation detector. Samples can be taken and counted by gamma spectrometry to assess the activity of the  $^{137}\text{Cs}$  and other gamma emitters. This should then be followed by radiochemistry to assess the activity of the other nuclides likely to be present, such as  $^{90}\text{Sr} + ^{90}\text{Y}$ , which are difficult to monitor directly. Similarly, where the material under consideration is steel which has potentially been activated, there are several computing codes that can be used to predict nuclide levels based on knowledge of the alloy and the neutron spectrum and intensity. These levels should then be corrected for radioactive decay to give a current predicted nuclide mix.

For direct monitoring to be possible there must be at least one directly monitorable nuclide present in relatively fixed proportions to the others. Activity estimation can then go ahead on the basis of monitoring for that nuclide and deriving a maximum acceptable count rate, for example, which takes account of the fraction of the fingerprint which is detectable and the limiting activity level. Direct monitoring per square meter of surface typically costs less than 1% of the cost of analysing a single sample.

Even if apparently stable fingerprints are found it is important to repeat the process as clearance takes place. Physical and chemical effects can change the nuclide ratios in soil, for example, where  $^{137}\text{Cs}$ ,  $^{90}\text{Sr}$  and  $^{90}\text{Y}$  can have different mobilities. There may be direct ways of checking this, such as the gross beta to  $^{137}\text{Cs}$  ratio, which are either not too expensive or can be performed in situ, but it may also be necessary to repeat the full radiochemical investigation from time to time.

This process will allow selection of the best monitoring method and equipment and the calculation of responses per  $\text{Bq}\cdot\text{cm}^{-2}$  or  $\text{Bq}\cdot\text{g}^{-1}$  as appropriate, using information from type test data. It may also influence other aspects of the clearance process, such as the segregation of different materials.

### **8.1.5 The Environment in which the Monitoring is to take Place**

The environment in which the monitoring is to take place is very important. The better the environment for equipment and staff, the better will be the quality of the result and the higher the throughput. The most difficult environment is the one that is changing. Generally, monitoring in buildings which are being stripped is difficult. Lighting, ventilation and cleanliness can all be less than satisfactory. The possibility of contamination of cleared materials has to be avoided. Any materials which are found to exceed a limit should be segregated away from cleared materials. Normally, it should be very rare to find activity significantly over the set limit during the clearance process as all such items should have been identified and either cleaned or removed earlier.

For surface contamination monitoring, complete access to the surfaces of interest is essential (see flowchart 6.10). Sometimes it is unlikely that activity is present inside gas cylinders, for example, and only the outside would require monitoring. This would apply to cylinders of counting gas for hand and foot monitors, for example. Conversely, cylinders used as part of an active gas process could well be internally contaminated and would require the assessment of internal and external activity.

It is important that a person performing monitoring is comfortable. Equipment should be designed or adapted to ensure this. For small objects, a well-lit stainless steel surfaced sorting table is ideal. For larger objects and for in situ monitoring of equipment floor monitors are often ideal. These have wheels which can be used to keep a fixed surface to detector sensitive volume distance. This is particularly important where the emissions are alpha and soft betas and the count rate is very dependent on distance. Environmental background stability is also paramount. There is no point trying to perform monitoring at release levels for bulk gamma emitters, for example, where site operations such as the movement of waste packages in an adjacent building is taking place. Similarly, where the material to be monitored for release is moveable, the pros and cons of moving it to a central monitoring station in a low background building (rather than working in a normal or variable background building) should be assessed.

#### **8.1.6 Who Performs the Measurements?**

Clearance monitoring is very different from routine radiation protection monitoring, mainly because acceptable residual levels are generally less than normal operating limits and are often close to the minimum reliably detectable level. It may be better to train new staff to perform clearance monitoring than to use established radiation protection monitoring staff. The new people come with a fresh mind, whereas established staff sometimes find it difficult to appreciate the importance of complying with clearance levels. Against this, established staff can bring knowledge of the likely areas of maximum contamination in equipment and materials removed from an area in which they had worked.

There is a very clear trade-off between staff skill level and equipment capability. The less the staff skill, the greater the ability required of the equipment. Clear thought on these points will help the development of a robust monitoring programme greatly.

#### **8.1.7 When to Perform the Monitoring**

**The timing of monitoring is not a trivial consideration.** Monitoring early in any demolition process or strip out runs the risk of the material being contaminated by dust from other parts of the site. Monitoring after removal means that the object will have been handled and any activity may have been transferred on to workers and cutting equipment. Monitoring after demolition means that surfaces have been broken up and aren't accessible and volumes of significant activity may have been buried under relatively clean material or may have been mixed in with clean material, greatly increasing the volume of active waste.

Generally, the best approach is to have a good understanding of the problems, supported by in situ monitoring information, and then plan the clearance process to ensure that potential cross contamination is minimised. Where equipment, such as benches, is to be left, then the last step should be monitoring to confirm that the article meets the set criteria. Similarly, for a building, the contents should be removed and then the building monitored before demolition.

### **8.1.8 The Balance between Automatic and Manual Monitoring**

An automatic process is far better for clearance operations which require a large number of repetitive measurements. It is auditable and its performance is easier to predict. A machine does not get bored. Clearance monitoring is generally a rather dull process where virtually all the results are so close to background as to be indistinguishable. The end result can be that the quality of monitoring declines catastrophically and, eventually, a significantly contaminated item slips through the net.

**Automatic monitoring is preferable where both technically possible and financially viable.**

### **8.1.9 The Desired Maximum Missable Activity**

**The desired maximum missable activity is fundamental to the selection of monitoring technique and equipment.**

It is important that the final technique should be capable of identifying a sample at exactly the sentencing limit on 95% of occasions as being potentially at, or in excess of, the limit. It is also important that the technique does not yield an excessive number of false positives, which is when it rejects material which is in fact significantly below the sentencing limit. For many circumstances, selection of the technique should be an iterative process, where the total costs (time, equipment, services, and staff costs) are balanced against the technical quality of the process. The final selection is a technique that will produce a result of the desired quality but at the lowest cost.

### **8.1.10 Reaction to Unexpected Results and Management Control**

By the time monitoring for release begins, the operator should have a sufficient knowledge of the area, processes and plant to have removed anything that is not expected to meet the release criteria. Even when material has been sentenced, it often makes sense to pass some types of waste, such as scrap steel, through a gate monitor designed for scrap monitoring. This will pick up radioactive objects in the scrap which have got there either by error on the part of staff or because of an unexpected change in circumstances.

If anything unexpected does happen, it is essential that the management investigate the circumstances in sufficient detail to identify why it happened and to develop procedures to reduce greatly the chance of it happening again. This could involve reviewing the zoning of areas, for example, or developing a deeper understanding of the work that took place in the area which is being stripped.

## 8.2 Monitoring Equipment

Typical monitoring equipment is described in detail in the appendices. It can be subdivided into 2 broad categories, bulk and surface monitoring. In the first category, the measurement quantity of interest is generally activity per unit mass (Bq/g) whereas in the second it is activity per unit area (Bq/cm<sup>2</sup>). Activity per unit mass is the quantity of interest when demonstrating compliance with release criteria. Activity per unit area can be used to calculate activity per unit mass for surface contaminated objects and to demonstrate compliance with transport limits.

Surface contamination monitoring is generally concerned with the estimation of alpha and beta activity, but there can be circumstances where the main contaminant is an X-ray emitter such as <sup>55</sup>Fe. Generally, direct monitoring for high energy gamma emitters for surface contamination assessment is best avoided. Normally such nuclides, e.g. <sup>137</sup>Cs and <sup>60</sup>Co, have associated beta emissions. Beta detectors have a much lower background per unit area. As an example, for <sup>137</sup>Cs contamination, a 50 mm diameter, 50 mm thick sodium iodide scintillation detector will have a similar response, in terms of counts per second per Bq/cm<sup>2</sup>, as a 50 mm diameter thin end window pancake GM detector. The background count rate from the sodium iodide detector will typically be 50 to 100 per second whereas the count rate from the GM detector will be around 1 per second. The signal from a beta detector is also much more dominated by the activity directly below the detector window. Background correction is also easy for a beta detector. Interposing a 4 mm aluminium plate between surface and detector will stop virtually all beta particles while leaving the gammas almost unaffected. This can allow a skilled user to assess beta surface activity even on a material with significant natural gamma activity. The same process does not work for gamma measurements.

The following measurement techniques are described, along with the relevant equipment.

- Bulk alpha monitoring
- Bulk beta monitoring
- Bulk gamma monitoring
- Direct alpha surface monitoring
- Direct hand-held surface beta monitoring
- Direct surface X and low energy gamma monitoring
- Tritium surface activity monitoring
- Surface monitoring by wipe (excluding tritium)

### 8.3 Activity Assessment using Sampling followed by Radiochemistry

In many circumstances, assessment of activity may not be possible without sampling followed by radiochemical treatment and analysis. This section addresses the procedures to be followed.

*Note that analytical laboratories will normally quote results in Bq/kg whereas regulatory limits are generally in Bq/g.*

#### 8.3.1 Sample Collection and Preparation

*The validity of the analytical programme will, in most cases, be reliant on appropriate sample collection and storage procedures.*

***Samples must be collected, preserved and stored in such a way as to prevent any significant change in the concentration and form of the radionuclides present.*** Such changes can include

1. Loss of volatile radionuclides e.g. evaporation of tritiated water or loss of radon gas;
2. Loss of radionuclides such as  $^3\text{H}$  and  $^{14}\text{C}$  via biological degradation of organic compounds;
3. Changes in the physical and chemical form of the radionuclide;
4. Adsorption of the radionuclide onto the walls of the container;
5. Cross-contamination.

The procedures used for collecting the sample must be carefully chosen such that the integrity of the sample and the activity concentrations of the radionuclides being analysed are not affected. This is particularly important when collecting samples for tritium analysis. If drilling is used to collect core samples, care must be taken during the sub-sampling stages to avoid material from the cut surfaces where loss of tritium (and other volatile radionuclides) may have occurred.

For certain analyses, the choice of storage bottle is important. Water samples collected for radon analysis must be collected in air-tight containers, using a set procedure to prevent loss of the radon gas. Samples collected for tritium analysis must be stored in air-tight containers or bags. Where possible, solid samples containing tritium should be wrapped in aluminium foil before being transferred to the storage container.

If samples are to be stored for a period prior to dispatch to the analytical laboratory, some form of preservation may be required. Freezing the sample will help to prevent the loss of radionuclides via evaporation or bacterial degradation, whilst acidification of the sample may help prevent adsorption of actinides, for example, onto the container walls. However, acidification may result in the loss of radionuclides such as  $^{129}\text{I}$ ,  $^{131}\text{I}$  etc. In some instances, particularly for aqueous samples, the analytical laboratory may recommend that a carrier is added to the sample prior to storage. For example, when measuring  $^{90}\text{Sr}$ , it is advisable to add a small quantity of stable strontium as a carrier. Again, such approaches should be discussed with the analytical laboratory.

It should be noted that a preservation procedure may affect any subsequent chemical separation procedures and it is therefore vital that any sample storage or preservation regimes are agreed with the laboratory prior to sample collection. In all cases, a record of any preservation undertaken must be accurately recorded and details supplied to the laboratory.

**Table 8.1: Recommended sample preservation procedures**

Analyte	Storage bottle type	Preservation	Storage times		Other information
			+4°C	-20°C	
<b>Solids (non-biodegradable)</b>					
<b>Tritium &amp; iodine</b>	Polythene	Wrap in aluminium foil & double bag	30 days	6 months	Store in dark
<b>Other nuclides</b>	Polythene	None	4 months	> 1 year	Store in dark
<b>Solids (biodegradable)</b>					
<b>Tritium</b>	Polythene	Wrap in aluminium foil & double bag	NR	6 months	Store in dark
<b>Other nuclides</b>	Polythene	None	7 days	1 year	Store in dark
<b>Aqueous samples</b>					
<b>Gross alpha/beta</b>	Polythene	None	1 month	NR	
<b>Gamma spec.</b>	Polythene	None	2 days	NR	
<b>Tritium</b>	Polythene	none	2 months	NR	
<b>Radon</b>	Glass vial fitted with Viton seal	10ml mineral cocktail	1 day	NR	Return to laboratory as quickly as possible
<b><sup>14</sup>C, <sup>106</sup>Ru</b>	Glass	4g/1000ml NaOH			

Analyte	Storage bottle type	Preservation	Storage times		Other information
			+4 <sup>0</sup> C	-20 <sup>0</sup> C	
<b>Iodine isotopes</b>	Glass	2ml sodium hypochlorite (10% w/v) / 1000ml	2 days	NR	
	Glass	Sodium thiosulphate	2 days	NR	
<sup>134</sup> Cs & <sup>137</sup> Cs	Polythene	pH < 2 with HCl	6 months	NR	
<b>Plutonium</b>	Polythene	12.5ml c. HNO <sub>3</sub> /1000ml	6 months	NR	1 month maximum storage recommended in BS6068-6.3:2003
<b>Actinides (e.g. Th, U, Np, Pu &amp; Am)</b>	Polythene (acid washed)	pH < 2 with HNO <sub>3</sub>	6 months	NR	1 month maximum storage recommended in BS6068-6.3:2003

NR – not recommended

### 8.3.2 Sample Sizes

The quantity of sample required for analysis will depend on

- the analyses required
- the limits of detection required
- the heterogeneity of the item being sampled
- specific requirements for sample archiving

The quantity of sample required for multiple radionuclide determinations can often be reduced by performing simultaneous separations on one sub-sample. However, this will depend on the analyses required and the procedures available to the laboratory. A summary guide to the quantity of sample required for various analyses is given below (although this will vary between laboratories).

#### 8.3.2.1 Summary of sample masses and corresponding limits of detection

Tables 8.2 and 8.3 give the minimum mass required to achieve the specified limits of detection for each nuclide group. In many instances, lower limits of detection are achievable if desirable although larger sample sizes may be required.

Smaller sample masses may also be analysed although the limit of detection will increase proportionally.

**Table 8.1 Minimum Masses for Solid Samples**

Group	1	2	3	4	5	6	7	8	9	10	11
<b>Nuclides</b>	Gamma emitting nuclides	Gross alpha Gross beta	<sup>3</sup> H and <sup>14</sup> C	<sup>129</sup> I	<sup>55</sup> Fe, <sup>63</sup> Ni, <sup>99</sup> Tc	<sup>90</sup> Sr	<sup>210</sup> Po	<sup>241</sup> Pu, <sup>239</sup> Pu, <sup>240</sup> Pu, <sup>238</sup> Pu, <sup>232</sup> Th, <sup>230</sup> Th, <sup>241</sup> Am	<sup>238</sup> U, <sup>236</sup> U, <sup>235</sup> U, <sup>234</sup> U, <sup>242</sup> Pu	<sup>237</sup> Np	<sup>226</sup> Ra
<b>Mass to achieve LOD (g)</b>	30g	5g	10g	50g (can include the 30g from gamma spec)	5g	5g	10g	5g	5g	5g	5g
<b>LOD Bq/g</b>	0.001 typically	0.1	0.01	0.05	0.005 to 0.01	0.01	0.0002	0.0002 ( <sup>241</sup> Pu - 0.01)	0.0002	0.001	0.001

**Table 8.2 Minimum Masses for Aqueous Samples**

Group	1	2	3	4	5	6	7	8	9	10	11
Nuclides	Gamma emitting nuclides	Gross alpha Gross beta	$^3\text{H}$ and $^{14}\text{C}$	$^{129}\text{I}$	$^{55}\text{Fe}$ , $^{63}\text{Ni}$ , $^{99}\text{Tc}$	$^{90}\text{Sr}$	$^{210}\text{Po}$	$^{241}\text{Pu}$ , $^{239}\text{Pu}$ , $^{240}\text{Pu}$ , $^{238}\text{Pu}$ , $^{232}\text{Th}$ , $^{230}\text{Th}$ , $^{241}\text{Am}$	$^{238}\text{U}$ , $^{236}\text{U}$ , $^{235}\text{U}$ , $^{234}\text{U}$ , $^{242}\text{Pu}$	$^{237}\text{Np}$	$^{226}\text{Ra}$
Mass to achieve LOD (g)	500g	500g	50g	50g	100g	5g	200g	200g	200g	200g	100g
LOD Bq/kg	0.05 typically	0.1	5 to 10	50	1	1	0.005	0.005 ( $^{241}\text{Pu}$ - 0.05)	0.005	0.005	0.001

**Notes**

The quoted ‘minimum mass required’ is the mass of sample required for the analysis of any/all the nuclides listed in that group.

**To determine the total mass of sample required, identify the groups containing the nuclides required for analysis and sum the masses for each group. For example, if gamma spectrometry and tritium analysis is requested in a solid sample, the total sample mass required will be the minimum mass for groups 1 and 2 i.e. 30g + 5g = 35g. If  $^{14}\text{C}$  is also required additional sample is needed.**

### **8.3.3 Sample matrices**

Radioanalytical laboratories will have validated methodologies for the analysis of a wide range of common sample types. However, more unusual materials which often arise during decommissioning operations may be more difficult to analyse and pose particular technical problems. For non-standard sample types, always check that the analytical laboratory possesses validated procedures that are suitable for the matrix, or discuss any additional validation or testing studies that may be required prior to analysis of the sample.

Certain sample matrices pose a hazard to analytical personnel and specific precautions must be taken to overcome these hazards. Any samples containing a chemical (e.g. mercury, beryllium or asbestos), biological (sewage sludge) or radiological hazard must not be dispatched to the analytical laboratory without first notifying the laboratory and gaining permission to consign such materials. Appropriate warnings must be displayed on the sample containers and details of the hazard included in the accompanying paperwork.

### **8.3.4 Sample Transfer and Chain of Custody**

The analytical laboratory must be notified prior to dispatch of samples. In particular, arrangements for receipt of radioactive materials (where appropriate) must be confirmed and all necessary paperwork completed. Details of the numbers of samples, physical form, estimated activity levels, potential hazards and analytical requirements should be forwarded to the laboratory ahead of the samples. Samples should be accompanied by a chain of custody form confirming the following details

1. The sample identification numbers (unique codes for each sample)
2. The date of sampling / reference date
3. Details of any specific hazards (these should be discussed with the analytical laboratory prior to dispatch of the samples).
4. The analytical requirements
5. Details of any preservation or initial preparation procedures that have been performed on the sample.

The analytical laboratory should confirm receipt of the samples and provide details of any discrepancies between the reported and actual content of the consignment.

### **8.3.5 Sample Preparation**

In most instances, some form of sample preparation is required before any analytical procedure is attempted. In some cases, the preparation procedures adopted could impact on the final results and the approaches used should be discussed with the laboratory.

Water samples often contain suspended particulate matter, which may hold many of the radionuclides of interest. It must be decided whether to filter the sample and analyse each component separately or to homogenise the sample and analyse the total.

This should be decided at the outset as quite different results can be obtained depending on the approach chosen.

For soil samples, the sample is often coarsely sieved to remove flints and any large debris. The mass of any material removed should be recorded and reported. However, if required, it is possible to grind and homogenise the total sample as received.

### **8.3.6 Homogenisation and sub-sampling**

Once a fraction has been obtained for analysis, it must be homogenised. This may be performed either before or after further sample pre treatment such as drying or ashing and this choice will depend on the analyses required. It is vital that the sample is homogenised prior to sub sampling to ensure that the measured aliquot is representative of the bulk sample.

In some instances (e.g. for mixed soft wastes) thorough homogenisation of the sample is impractical or impossible. In these cases it is advisable to take the entire sample for analysis. Where chemically similar alpha and beta emitting radionuclides are being analysed, it is often possible to leach the entire sample and produce a stock leachate which can be further sub sampled for individual alpha and beta radionuclide determinations. However, if chemically different alpha and beta emitting radionuclides are to be measured where different pre-treatment and or dissolution techniques are required for each analysis, it will not be possible to employ a universally acceptable leaching procedure. In this case, the entire sample is taken for gamma spectrometry to determine the total inventory of gamma emitting radionuclides. Sub samples are then taken for each analysis and each one is measured by gamma spectrometry to determine the proportion of the total gamma inventory present in the sub sample. All subsequent analytical results relating to the individual sub sample are then corrected back to the total sample using the gamma radionuclide data. This assumes that the fingerprint is essentially stable and that only the overall contamination level is varying and will introduce uncertainties where the activity could have undergone radiochemical separation to any degree.

### **8.3.7 Sample Drying and Ashing**

Samples are often dried to a constant weight before analysis to overcome effects from variable water content. Drying also produces a sample that is more stable during storage. Both freeze-drying and oven drying may be used, although freeze-drying avoids thermal decomposition of the sample. However, sample drying will lead to the loss of tritiated water along with certain other volatile radionuclides; the magnitude of the loss will depend on the approach used.

In addition many techniques require that organic matter is removed by ignition. Again volatile radionuclides may be lost during ignition depending on the ignition temperatures used. Typical radionuclides that may be lost during ignition are  $^3\text{H}$ ,  $^{14}\text{C}$ ,  $^{35}\text{S}$ ,  $^{99}\text{Tc}$ ,  $^{103}\text{Ru}$ ,  $^{106}\text{Ru}$ ,  $^{137}\text{Cs}$  and  $^{210}\text{Po}$ .

### 8.3.8 Sample Dissolution

Most radioanalytical techniques for the measurement of alpha or beta emitting radionuclides begin with a sample dissolution stage. Often this simply involves leaching the sample with a suitable acid such as nitric acid, hydrochloric acid or *aqua regia*. However, some forms of plutonium and mineral-bound uranium and thorium will not be effectively solubilised in this way and a more aggressive dissolution procedure is required. Total sample solubilisation, often employing hydrofluoric and/or perchloric acids, is widely used. Alternatively, the sample may be mixed with a flux such as lithium borate or potassium hydrogen fluoride and the mixture fused at high temperatures to produce a melt. The specific approach chosen will depend on the sample type and the radionuclides analysed and in some instances can significantly affect the final result.

### 8.3.9 Gamma Spectrometry

Gamma spectrometry is used to measure a wide range of gamma emitting radionuclides including:

**Activation products:**  $^{51}\text{Cr}$ ,  $^{54}\text{Mn}$ ,  $^{55}\text{Fe}$  (via X-ray using low energy gamma spectrometry),  $^{59}\text{Fe}$ ,  $^{60}\text{Co}$ ,  $^{65}\text{Zn}$ ,  $^{134}\text{Cs}$

**Fission products:**  $^{131}\text{I}$ ,  $^{137}\text{Cs}$

**Actinides:**  $^{241}\text{Am}$ , natural uranium and thorium decay chains

Gamma spectrometry requires minimal sample preparation and no separation chemistry. The sample (usually dried or freeze-dried although fresh samples can be analysed) is packed into a container and placed onto the gamma spectrometry system. Typically high purity germanium detectors (hpGe) are used, which require cooling with liquid nitrogen. Sodium iodide (NaI) crystals are also used as they do not require cooling with liquid nitrogen and have higher detection efficiencies compared with hpGe detectors. However, the energy resolution of these systems is not as good, making all but the simplest spectrometry impossible. Typically, gamma spectrometry systems can detect photons down to *ca.* 40 keV although lower photon energies associated with e.g.  $^{55}\text{Fe}$  or  $^{129}\text{I}$  can be measured if a special window is fitted.

Data acquisition and spectrum analysis is often performed automatically with manual checking of the data. The response of the detector and hence the efficiency calibration will depend on the following

- the energy of the gamma photon
- the size of the crystal
- geometry of the sample
- sample density (particularly a problem for low energy gamma emitters such as  $^{210}\text{Pb}$  and  $^{241}\text{Am}$ )

Counting efficiencies over the energy range for a given geometry and sample density are usually determined by preparing matrix-matched standards containing a range of radionuclides.  $^{241}\text{Am}$  is often included to provide a low energy calibration point and a

new standard solution containing a wider range of radionuclides has recently become available. Some laboratories still use a  $^{152}\text{Eu}$  calibration source, which has a number of gamma emissions covering wide energy range. However, this standard is particularly prone to coincidence summing (see next section).

In addition, spuriously low activities can be obtained for gamma emitters with more than one gamma emission. In certain instances the two emissions are not distinguished by the detector and are recorded as one event with energy equal to the sum of the two individual gamma photon energies. This is known as *coincidence* or *cascade summing* and is a particular problem for  $^{134}\text{Cs}$  and some rare earth radionuclides.

Gamma spectrometry is often used for the measurement of natural radionuclides of the uranium and thorium decay chain. Usually, gamma emissions from daughter radionuclides are used to infer activities of the uranium and thorium parents. However, it is important to remember that any loss of radon from the sample may result in a decay chain that is not in secular equilibrium and measurement of e.g.  $^{214}\text{Pb}$  at the end of the chain may not give an accurate representation of uranium content of the sample. In addition, the presence of purified uranium may not be detected through the gamma spectrometric measurement of daughter radionuclides that have had insufficient time to attain equilibrium with the parent. It should also be noted that  $^{226}\text{Ra}$  has a similar gamma emission energy to  $^{235}\text{U}$  and, unless significant quantities of  $^{235}\text{U}$  are present, it can be difficult to deconvolute the two radionuclides.

### 8.3.10 Alpha Emitters

The following radionuclides are routinely measured using alpha counting

$^{224}\text{Ra}$ ,  $^{226}\text{Ra}$ ,  $^{230}\text{Th}$ ,  $^{232}\text{Th}$ ,  $^{234}\text{U}$ , ( $^{235}\text{U}$ ,  $^{236}\text{U}$ ),  $^{238}\text{U}$ ,  $^{237}\text{Np}$ ,  $^{239}\text{Pu}$ ,  $^{240}\text{Pu}$ ,  $^{238}\text{Pu}$ ,  $^{241}\text{Am}$ ,  $^{242}\text{Cm}$ ,  $^{244}\text{Cm}$ ,  $^{252}\text{Cf}$

Although alpha spectrometry is possible, the energy of the alpha particle is significantly attenuated through interaction with surrounding matter resulting in severely degraded spectra. It is therefore necessary to separate the alpha emitter of interest from the bulk of the sample and produce a thin source suitable for alpha counting.

In some cases there are spectral overlaps between alpha emitters of different elements, which can only be overcome through chemical separation of these elements. However, for energy overlaps between different radioisotopes of the same element deconvolution is not routinely possible (e.g.  $^{239}\text{Pu}$  and  $^{240}\text{Pu}$  or  $^{235}\text{U}$  and  $^{236}\text{U}$  cannot be readily resolved by alpha spectrometry). *Yield monitors* are added prior to any chemical separation to determine the loss of the analyte during the separation. Usually the yield monitor is an isotope of the element being analysed that would not be expected at significant activities in the sample. In the case of curium isotopes, the chemistry of curium and americium are sufficiently similar that  $^{243}\text{Am}$  can be used as the yield monitor. Where possible, an alpha emitter is chosen to permit simultaneous measurement of the yield monitor with the unknown radionuclide.

This is not the case for  $^{237}\text{Np}$  where the beta emitting  $^{239}\text{Np}$  is often used as a yield monitor and separate measurements of the two radionuclides is required

Chemical separation usually employs a number of separation stages designed to isolate the radionuclide of interest from the bulk of the sample. Precipitation, solvent extraction, ion exchange and extraction chromatography are all routinely used to achieve such a separation. Final **source preparation** is achieved in one of two ways. The alpha emitter may be electrodeposited onto a disc or may be co-precipitated with a rare earth fluoride to produce a fine source suitable for alpha counting. Electrodeposition produces a robust source that may be readily archived. However, the approach is relatively time-consuming. Fluoride precipitation is much more rapid but the source is not as robust.

Measurement of the final source is usually achieved using **alpha spectrometry** and employing ion-implanted detectors in a vacuum. The system is capable of very low limits of detection and provides spectral information. Alternatively gross alpha measurements can be made using either **gas flow proportional counters** or **zinc sulphide screen scintillation** detectors. More recently alpha / beta discriminating **liquid scintillation** counting has been used for the measurement of alpha emitters and has been successfully applied to radium and radon analysis and to assessment of total alpha activity in aqueous samples.

### 8.3.11 Beta Emitters (and certain electron capture radionuclides)

**Activation products:**  $^3\text{H}$ ,  $^{14}\text{C}$ ,  $^{35}\text{S}$ ,  $^{41}\text{Ca}$ ,  $^{45}\text{Ca}$ ,  $^{55}\text{Fe}$ ,  $^{63}\text{Ni}$

**Fission products:**  $^{89}\text{Sr}$ ,  $^{90}\text{Sr}$ ,  $^{99}\text{Tc}$ ,  $^{129}\text{I}$ ,  $^{147}\text{Pm}$

**Actinides:**  $^{241}\text{Pu}$

The energy of the beta decay is split between the beta particle and the anti-neutrino, producing a wide band of possible beta particle energies from essentially zero up to the maximum decay energy. This is more difficult to analyse by spectrometry when compared to the discrete energies encountered for gamma and alpha decays. Analysis of beta emitters therefore relies on the chemical separation of the specific element followed by a beta measurement of the purified fraction. Limited spectral deconvolution is possible if the energy of the beta decay events is significantly different allowing the quantification of e.g.  $^{89}\text{Sr}$  and  $^{90}\text{Sr}$  in the same source. As with alpha spectrometry, a yield monitor is often added to correct for any losses of the analyte during chemical separation, although in many case the yield monitor is normally the stable element analogue of the radionuclide being analysed. For some determinations, a gamma emitting radioisotope of the element can be used where the gamma emission has a negligible effect on the beta measurement (e.g.  $^{85}\text{Sr}$  for  $^{90}\text{Sr}$  determinations) or where the gamma emitting radioisotope has a sufficiently short half life that it may be left to decay before the beta measurement is performed (e.g.  $^{99\text{m}}\text{Tc}$  for  $^{99}\text{Tc}$  measurements).

Again chemical separation is often a combination of precipitation, solvent extraction, ion exchange chromatography and / or extraction chromatography.

Final measurement of beta activity is often performed using a gross beta counting technique such as *gas flow proportional* counting, *anthracene-screen scintillation* counting or *Geiger-Müller* tube. Alternatively *liquid scintillation counting* is widely used giving high counting efficiencies and sensitivity to low energy beta emitters.

Measurements of low-energy beta emitters, such as  $^3\text{H}$ ,  $^{14}\text{C}$ ,  $^{63}\text{Ni}$  etc and for very low energy X-ray emitters such as  $^{55}\text{Fe}$ , are best performed using liquid scintillation counting although interference from chemiluminescence may give erroneous results if not carefully corrected for. For high-energy beta emitters such as  $^{90}\text{Sr}$  (or more accurately the  $^{90}\text{Y}$  daughter), Cerenkov counting can be used, resulting in lower backgrounds and greater measurement sensitivity.

### 8.3.12 Analysis of Tritium

Analysis of tritium in samples is particularly complex. The choice of analytical technique will depend on the chemical form of the tritium and the sample matrix. For aqueous samples, distillation is often used to purify a fraction of water prior to tritium analysis. The water may be made alkaline prior to distillation to prevent volatile radionuclides from distilling over. However, tritium bound to organic molecules may not distil over and may be missed. For solid samples a number of approaches have been used. The sample can be soaked in water and the amount of tritium leached into the water measured. This works reasonably well for samples that are surface contaminated with tritiated water. However, if the contamination is not as tritiated water or the contamination is associated with the matrix of the sample a total sample decomposition procedure is preferable. This usually involves decomposing the sample either chemically or thermally in a combustion furnace, and converting all liberated tritium species to tritiated water that is subsequently trapped and measured.

The choice of method will largely depend on the most likely form of the contamination and the analytical budget.

### 8.3.13 Gross Alpha and Beta Measurements

*Gross alpha and beta measurements are crude assessment of the alpha and beta activity of the sample.*

The measurement is usually performed on a sample following minimal sample pre-treatment. Normally gas flow proportional counting is used to determine the alpha/beta activity although alpha/beta discriminating liquid scintillation counting is also used particularly for screening water samples. The instrument is calibrated against one alpha emitting (U, plutonium or  $^{241}\text{Am}$ ) and one beta emitting radionuclide ( $^{40}\text{K}$  or  $^{137}\text{Cs}$ ) and the response of the instrument will vary depending on the calibration radionuclide chosen.

The technique does not take into account any difference in instrument response with energy and is totally insensitive to low-energy beta emitters such as  $^3\text{H}$ ,  $^{14}\text{C}$ ,  $^{63}\text{Ni}$  etc. Sample composition and particle size may also affect the instrument response.

*The technique should only be treated as a screening procedure and should be followed by individual radionuclide analysis if elevated activities are detected.*

Widely varying gross alpha and beta results have been observed for soils which are attributable to variations in the natural radionuclide content of the soils. In many cases, this wide variability is linked to the variation in clay content where a significant proportion of natural uranium and thorium can reside. To subtract this effect from any enhancement in alpha and beta activity associated with operational deposition, it is possible to derive a correlation between the natural gross alpha and beta activity and certain elements that are indicative of clay content (e.g. rubidium). Such a correlation must be assessed for each site. X-ray fluorescence analysis is particularly effective for this purpose.

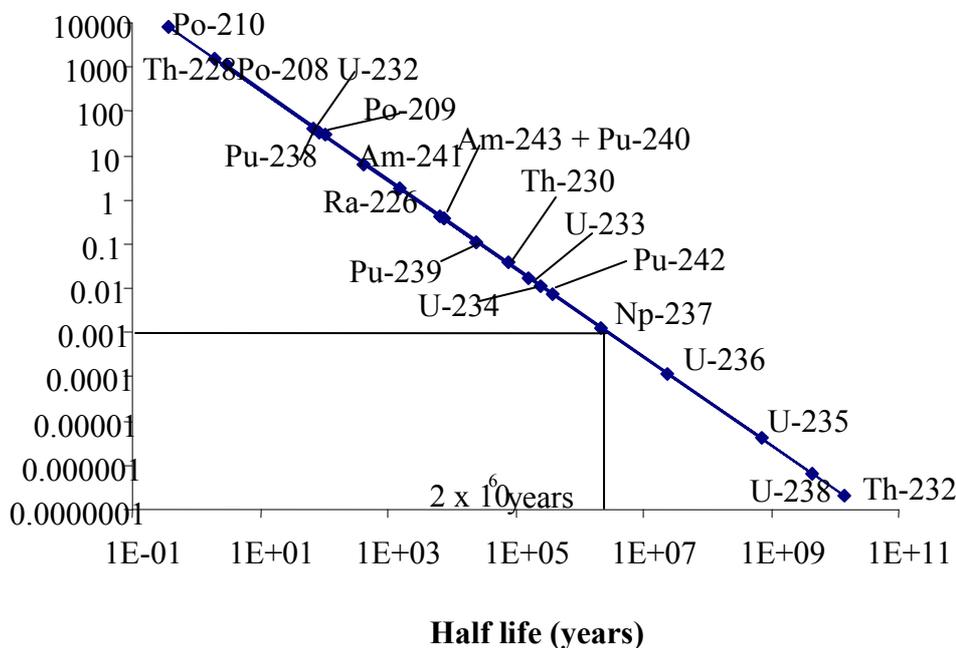
#### **8.3.14 Non-Radiometric Techniques**

Non-radiometric techniques have been widely used for the quantification of radionuclides. The techniques are usually most effective for the measurement of long-lived radionuclides such as  $^{99}\text{Tc}$ ,  $^{129}\text{I}$ , U, Thorium,  $^{237}\text{Np}$  and plutonium. In addition, mass spectrometric techniques often permit the more precise determination of isotope ratios (e.g.  $^{238}\text{U}$ : $^{235}\text{U}$  or  $^{232}\text{Th}$ : $^{230}\text{Th}$  ratios) and, unlike alpha spectrometry, can distinguish between  $^{239}\text{Pu}$  and  $^{240}\text{Pu}$ . Non radiometric techniques include fluorimetry, inductively coupled plasma mass spectrometry (ICP-MS, high resolution ICPMS and multi collector ICPMS), thermal ionisation mass spectrometry (TIMS), secondary ion mass spectrometry (SIMS), resonance ionisation mass spectrometry (RIMS) and accelerator mass spectrometry (AMS).

The technique operates by detecting atoms, not emissions. As a simple rule, the minimum detectable activity (Bq) is approximately equal to 2500 divided by the half-life in years. This is shown in figure 1 (below).

**Figure 1 : ICPMS minimum detectable activity versus half life.**

**Minimum activity (Bq)**



ICPMS is more sensitive than alpha spectrometry for nuclides with half lives greater than approximately 2 million years. This is indicated on the figure above.

In many cases, results from non-radiometric analyses are reported in terms of concentration rather than activity. The following equation can be used to convert from mass concentration to activity concentration

$$\text{Activity (Bq/kg)} = (\text{Mass fraction (ppm)} \times 4.17 \times 10^{20}) / (A \times t)$$

Where A is the atomic weight of the radionuclide and t is the half life of the radionuclide in seconds

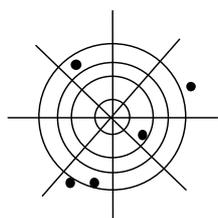
### 8.3.12 The Performance of a Method

#### Sensitivity:

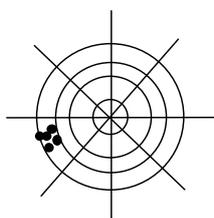
A measure of the resolving power of a method. Sensitivity is dependent on the instrument efficiency, typical chemical recovery and the amount of sample taken for analysis.

Accuracy and Precision:

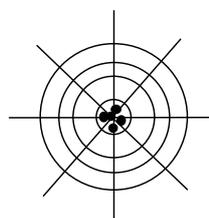
Accuracy is a measure of how close the measured value is to the 'true' result, whilst precision is a measure of the scatter of results for repeated analyses.



Poor accuracy  
Poor precision



Poor accuracy  
Good precision



Good accuracy  
Good precision

Uncertainties:

An analytical result is normally quoted along with an uncertainty at a given confidence level (quoted as either a percentage or a number of standard deviations). For example, a result of  $10 \pm 1$  Bq/kg at the 95% confidence level indicates that we are confident at this quoted level that the true result is somewhere between 9 and 11 Bq/kg. Uncertainties are often only quoted based on counting statistics and refer only to the measurement. However, uncertainties arise at all stages of the analytical procedure and a more meaningful calculation of uncertainty includes all these method uncertainties. Typically, method uncertainties are around 5 – 10% of the measured value.

Limits of detection:

The **limit of detection** is defined for a given measurement process as the smallest true net count rate that is 'certain' to be detected with a specified degree of confidence, i.e. effectively, in many cases, the maximum missable activity.

The **minimum detectable concentration** (MDC) is the detection limit corrected to units of Bq per unit volume or mass of sample.

A number of factors affect the limit of detection:

- Method used for calculation!
- Instrument background
- Counting efficiency
- Amount of sample analysed
- Length of count time

In general, lower limits of detection result in higher analytical costs.

### **8.3.15 Quality Control**

It is normal to monitor the performance of an analytical procedure through the analysis of some or all of the following:

- method blanks
- spiked sample controls
- in-house reference materials
- certified reference materials

It is important to agree how frequently these controls will be run at the beginning of the analytical programme.

### **8.3.16 Sample Archiving and Disposal**

In many cases a sub-sample is taken for analysis and it is therefore important that the customer agrees with the laboratory how the remaining sample will be stored. When reviewing sample archiving requirements it is important to consider what additional analyses may be required and any implications to the storage procedure adopted.

### **8.3.17 Summary of Issues Relating to the Development of an Analytical Approach**

There is a wide range of analytical techniques available for radionuclide analysis. To ensure that the data is 'fit for purpose' it is vital that the most appropriate technique is used. To ensure this, the analytical laboratory must be involved at the initial stages of project development.

**Agree on the following aspects of the analytical programme:**

- Any specific sampling and preservation procedures that may be required prior to dispatch to the analytical laboratory
- The appropriate containers to store the samples
- The method for sample transport to the analytical laboratory and implementation of chain of custody forms
- The most appropriate analytical technique for the nuclides being investigated
- Specific sampling and storage requirements and the amount of sample required
- Sub-sampling, preparation and dissolution procedures
- Specific procedures that may be necessary to overcome heterogeneity issues
- Potential interferences
- The required sensitivity, precision and detection limits
- Methods for calculating uncertainties and detection limits
- Quality control
- Timescales / deadlines
- The method used to report the results (e.g. interim results reported electronically followed by a signed report)

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## 9. References

1. Guidance on the Characterisation and Remediation of Radioactively Contaminated Land Environment Agency, May 2002
2. The Radioactive Substances Act 1993
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6. The Radioactive Substances Act 1960 (repealed by Ref. 2)
7. The Radioactive Substances (Substances of Low Activity) Exemption Order, SI No. 1002, 1986 and amendment SI No. 647, 1992
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18. The Nuclear Installations Act 1965 (as amended 1969)
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4. Pacific Northwest National Laboratory, USA. Sept 2002. *Visual Sampling Plan Version 2.0 User's Guide* Report PNNL-14002 (this user's guide, Visual Sampling Plan software and updates, and other related information, can be downloaded from <http://dgo.pnl.gov>)

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## Appendix ES1

### Membership of the Clearance and Exemptions Working Group (C&EWG)

David Owen	BNFL	(Chairman)
Natalie Buckley	AWE	(Secretary)

Alan Simpson	British Energy
Bob Anderson	British Nuclear Group Sellafield Ltd
Chris Fayers	Magnox Electric Ltd
Colin Hunt	AWE
Mike Gaunt	Rolls-Royce
Paul McClelland	UKAEA
Paul Mountford-Lister	UKAEA
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Iain Devine	Magnox Electric Ltd
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Marc Flynn	BNFL
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Phil Walker	BNFL
Phil Warwick	University of Southampton
Rae Mackay	University of Birmingham
Reg Green	BNFL
Simon Jerome	NPL

## **Appendix ES2**

### **Application of the Radioactive Substances Act 93 to the Ministry of Defence**

The Radioactive Substances Act 93 (RSA93) does not apply to premises occupied by the Crown for naval, military or air force purposes. However, the Ministry of Defence (MOD) operates a policy of voluntary compliance through administrative arrangements with the appropriate regulatory agencies. The agencies issue “Letters of Agreement” in lieu of authorisations under Section 13 RSA93 (Disposal of radioactive waste) and Section 14 RSA93 (Accumulation of radioactive waste) for the accumulation, discharge and disposal of radioactive waste.

Similarly, the agencies issue “Noting Letters” in lieu of registrations under Section 7 RSA93 (Registration of users of radioactive material) and Section 10 RSA93 (Registration of mobile radioactive apparatus) that cover the MOD’s holdings of radioactive substances.

Although these letters have no status under the RSA93 they are treated by MOD as if the Act applied, and the arrangements provide a mechanism for control as rigorous as the civil regime.

## Appendix 1

### Exemption Orders under the Radioactive Substances Act 1993

<b>Statutory Instrument Number</b>	<b>Exemption Order Title</b>
SI 1962 No. 2645	The Radioactive Substances (Exhibitions) Exemption Order 1962
SI 1962 No. 2646	The Radioactive Substances (Storage in Transit) Exemption Order 1962
SI 1962 No. 2648	The Radioactive Substances (Phosphatic Substances, Rare Earths etc.) Exemption Order 1962
SI 1962 No. 2649	The Radioactive Substances (Lead) Exemption Order 1962
SI 1962 No. 2710	The Radioactive Substances (Uranium and Thorium) Exemption Order 1962
SI 1962 No. 2711	The Radioactive Substances (Prepared Uranium & Thorium Compounds) Exemption Order 1962
SI 1962 No. 2712	The Radioactive Substances (Geological Specimens) Exemption Order 1962
SI 1963 No. 1831	The Radioactive Substances (Waste Closed Sources) Exemption Order 1963
SI 1963 No. 1832	The Radioactive Substances (Schools etc) Exemption Order 1963
SI 1963 No. 1836	The Radioactive Substances (Precipitated Phosphate) Exemption Order 1963
SI 1967 No. 1797	The Radioactive Substances (Electronic Valves) Exemption Order 1967
SI 1980 No. 953 and SI 1991 No. 477	The Radioactive Substances (Smoke Detectors) Exemption Order 1980 The Radioactive Substances (Smoke Detectors) Exemption (Amendment) Order 1991
SI 1985 No. 1047	The Radioactive Substances (Gaseous Tritium Light Devices) Exemption Order 1985
SI 1985 No. 1048	The Radioactive Substances (Luminous Articles) Exemption Order 1985
SI 1985 No. 1049	The Radioactive Substances (Testing Instruments) Exemption Order 1985

SI 1986 No. 1002 and SI 1992 No. 647	The Radioactive Substances (Substances of Low Activity) Exemption Order 1986 The Radioactive Substances (Substances of Low Activity) Exemption (Amendment) Order 1992
SI 1990 No. 2512 and SI 1995 No. 2395	The Radioactive Substances (Hospitals) Exemption Order 1990 The Radioactive Substances (Hospitals) Exemption (Amendment) Order 1995
SI2002 No.1177	The Radioactive Substances (Natural Gas) Exemption Order 2002

NB.

- a) Further details may be found at the HMSO website:

[www.legislation.hmso.gov.uk](http://www.legislation.hmso.gov.uk)

- b) In some cases there may be a separate, but similar, SI for Scotland or Wales. These can be found at the relevant HMSO websites:

[www.scotland-legislation.hmso.gov.uk](http://www.scotland-legislation.hmso.gov.uk) or [www.wales-legislation.hmso.gov.uk](http://www.wales-legislation.hmso.gov.uk)

## Appendix 7.1 – Default Value for Confidence Level

This is a value judgement based upon guidance given by Defra and the Environment Agency in Section 3.63 Contaminated Land Report CLR 10. As noted in CLR 10, a balance must be struck between taking worst-case circumstances that perhaps lead to implausible outcomes, and undue optimism that erodes protection of sensitive receptors. The application of a statistical test to data from a particular sentencing mass or area of material will only exempt the material if there is at least a 95% confidence level that the material is below the activity threshold for clearance. In many instances, the sampled activity will fall well below the clearance level and the confidence level will be much higher than 95% for these cases.

The adoption of a 95% confidence level for individual sentencing areas or masses does not imply that on average one will be incorrectly sentenced for every 20 units of material that are assessed and sentenced. This would be statistically true if all exempted areas or masses had exactly a 5% chance of being radioactive, but as noted above this is a limiting case and the majority sentenced as exempt will have a much lower likelihood of containing levels of radioactivity above the threshold. In practice it is likely that the average risk of incorrectly exempting a mass or area which exhibits activity in excess of the limit specified in the relevant Exemption Order (EO) will be less than 1%, and likely to be lower still for material being significantly above the EO limit.

The justification for choosing the 95% confidence level is based on a reasonable worst case situation. This balances using Best Practical Means to minimise radioactive waste arisings with keeping exposure as low as reasonably practicable - the ALARP principle - and introduces an implied cost-benefit test. This level of confidence is already in use as the default level for assessment of chronic risks to human health from exposure to chemicals in the ground [ref. 1].

It should also be remembered that conservative assumptions are built into the clearance process when setting clearance thresholds and these will be based on judgements about confidence levels for other criteria than just the sampling process. Ultimately the total risk arising from the judgements made about each component of the analysis, when combined, should be very low.

**A complementary reason for setting confidence at the proposed reasonable worst case level relates to the over-arching objectives for waste management set out in Chapter 4. These promote the principles of waste minimisation and the avoidance of unnecessary creation of radioactive waste. If the confidence level is set too high, a substantial amount of material will be sentenced as low level waste that should in practice be designated exempt. Furthermore, if sentencing regimes are made too onerous, sampling times and costs will escalate. In this case, decisions will be made to allocate materials which should be exempt into low level waste categories as a pragmatic alternative to spending time and money on better informed sentencing.**

## Appendix 7.2 – Examples of Everyday Materials and their Heterogeneity Class

Description	Chapter 5 Section	General Examples of Materials	Heterogeneity class	Specific Example of Materials
Surface contaminated items with impervious surfaces which may have been contaminated, but not activated or tritiated	5.3	Ceramic filter media Bench tops Glove box screens Wall/floor tiles Plant items	1 (symmetric)	PWR PC CRUD
			2 (skewed)	Uncontained process residue
High surface area to volume items which may have been contaminated, but not activated or Tritiated	5.4	Clothing, paper, sheets of metal, polythene sheeting	1 (symmetric)	Single simple items
			2 (skewed)	Mixture of simple items
Solid items and materials which have a history of irradiation and activation occurs in the bulk of the solids	5.5	PWR Reactor plant structure	1 (symmetric)	Simple individual plant components
			2 (skewed)	Mixtures of plant components
Solid items and materials which have a history of exposure to tritium and tritiation has occurred in the bulk of the solids	5.6	Flooring, sewage bed sludge	1 (symmetric)	Tritiated alcohol
			2 (skewed)	GTLS workshops
Loose solids	5.7	Soils, sediments, sludges, vacuum dust, swarf	1 (symmetric)	Pile of soil / spoil
			2 (skewed)	Boiler house ash and clinker
Porous solids	5.8	Concrete, bricks, plaster	1 (symmetric)	A small concrete slab
			2 (skewed)	Pile of bricks
Impervious solids with accessible surfaces	5.9	Metal transport flask or ISO container, large section ducting	1 (symmetric)	A length of pipe
			2 (skewed)	A complex of connected pipework
Impervious solids with inaccessible surfaces	5.10	Mechanical equipment such as an excavator or pump or pipework	1 (symmetric)	Small simple items
			2 (skewed)	Mixture of small simple items

## Appendix 7.3 – Approaches to unbiased sampling

Generally, sampling strategies fall into two basic approaches:

- *judgmental* or *random* sampling, typically used to efficiently confirm the presence and nature of contaminants based on prior knowledge or as part of the initial characterisation; and
- *Probabilistic* or *systematic* sampling, used to obtain representative data on a specified area (or volume) of material without any form of bias.

**Judgmental sampling introduces bias into the choice of material to sample, and if such sample data were used in statistical tests, then the results would automatically fail the basic assumption of unbiased data which underpins the use of the tests.**

Systematic sampling is therefore a necessary pre-requisite of the application of tests given.

Efficient systematic sampling designs may:

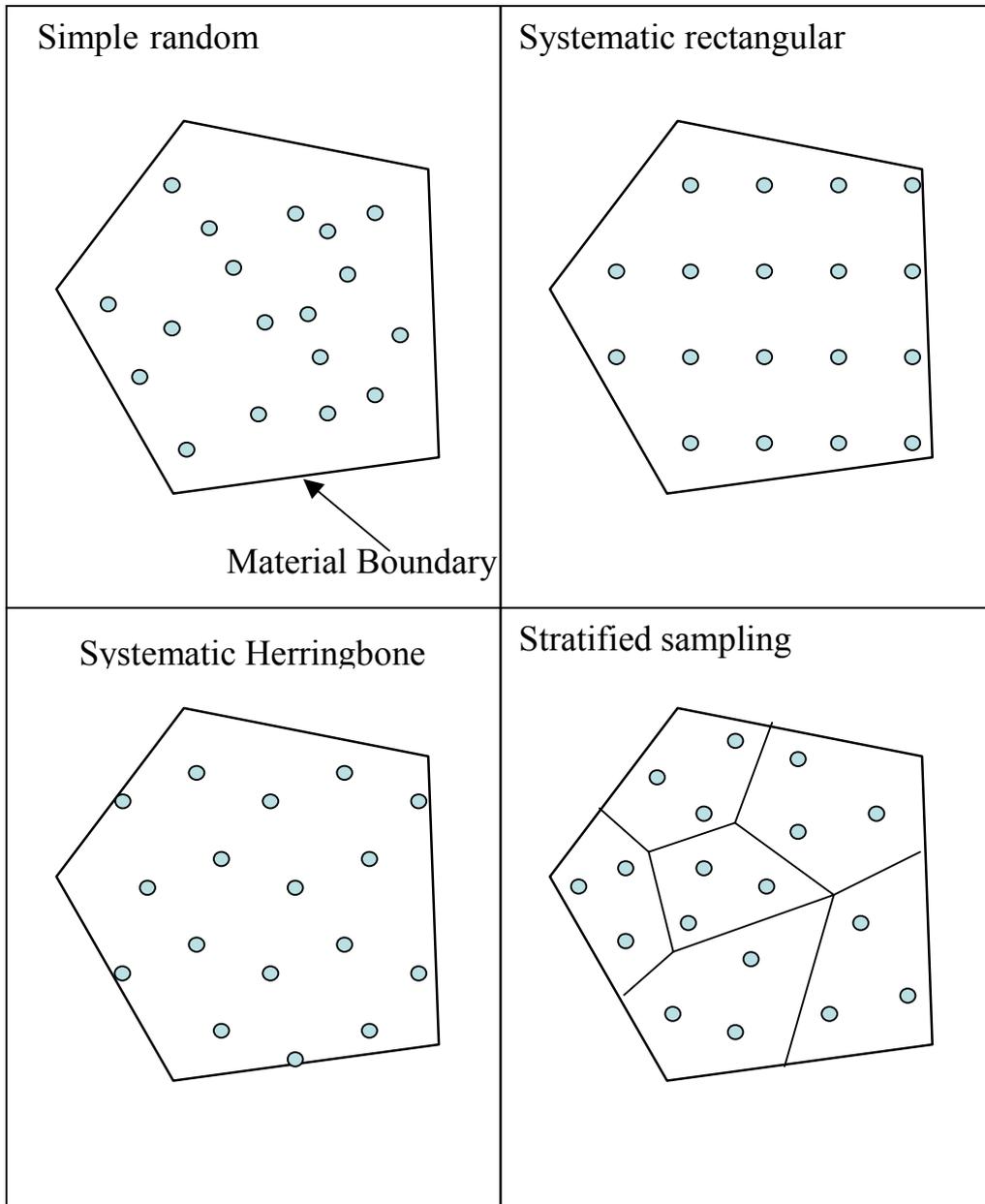
- Be stratified (i.e. each zone to be sampled should be divided into regular sub-zones).
- Carry the same number of sampling points for each sub-zone.

Entirely random sampling patterns can be perceived as being problematic, as they can result in very uneven sampling densities, which means that some parts of the material may receive a number of sampling points and others none at all. Whilst these methods are statistically valid, it is possible that relatively large areas of contamination could be missed altogether, although this is unlikely in real life. For this reason, random sampling patterns are not recommended.

**However, whatever sampling pattern is finally selected, it is important to use an unbiased (random) starting point located anywhere within the area.**

**Figure 1 gives an indication of the different sampling patterns possible.**

**Figure 1 – Sampling Patterns**



## Appendix 7.4 – Variograms

An experimental variogram characterises the spatial correlation between data in space for different spatial separations. Data that are uncorrelated will produce a variogram that can be fitted by a horizontal line with intercept on the Y axis equal to zero. The correlation may be isotropic (independent of direction) or anisotropic (dependent on direction). Correlated data will show a marked trend in the magnitude of the variogram with increasing spatial separation. At least 30 sample points are required to produce a meaningful plot.

Spatial correlation is commonly described using the Variogram, as correlation is normally a function of the separation distance between observations. As a general rule, the larger the separation the lower will be the correlation.

The equation for the variogram is as follows:

$$\gamma(\underline{h}) = 0.5E[(Z(\underline{x}) - Z(\underline{x} + \underline{h}))^2]$$

where  $E[\ ]$  denotes the expected value

$\underline{x}$  is spatial location in the material

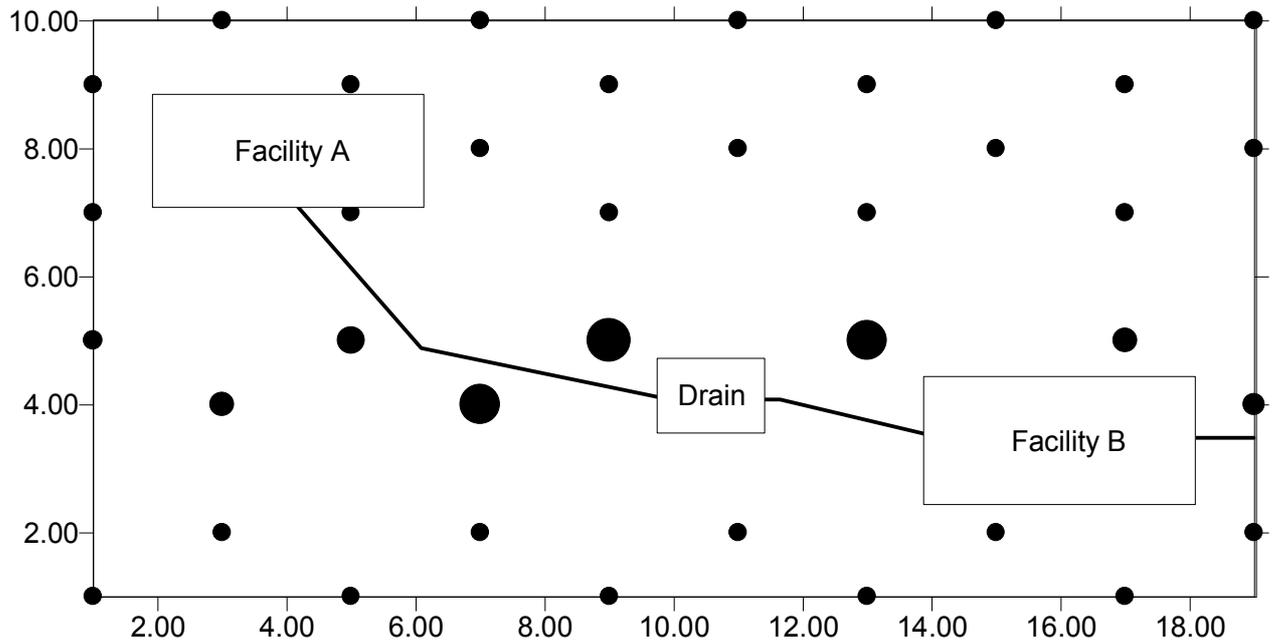
and  $\underline{h}$  is the separation distance between samples.

For the statistical testing in this code of practice it will be assumed that correlation can be ignored, although tests for its occurrence using the variogram and visual inspection will be employed to demonstrate its existence or absence.

## Appendix 7.5 – Post plots

This plot shows the location of the samples in space and the values observed at each location. It allows the trends in the data to be observed and if maps or other spatial data are overlaid on the post plot, possible associations with features in the material can be identified.

The post-plot shows the location of samples and can indicate the magnitude of the sample results: as shown in the figure for a fictional facility. A random start herringbone grid has been employed.

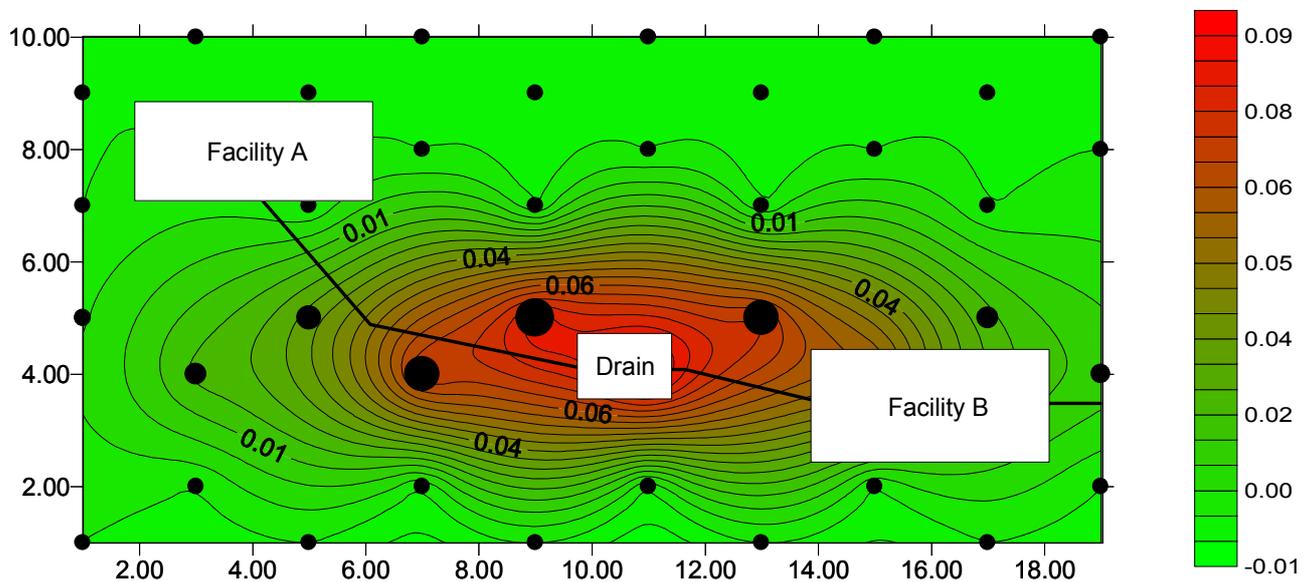


## Appendix 7.6 – Contour plots

Contouring can reinforce the visualisation of spatial trends in the data.

*Note: Care should be taken if automated contouring packages are used to ensure that the contouring method is not introducing undesirable artefacts – spurious trends, for example.*

Interpolation of values between data points using software such as Surfer ([www.golden.com](http://www.golden.com)) or a geographical information package such as Arc View ([www.esri.com](http://www.esri.com)) or MapInfo ([www.mapinfo.com](http://www.mapinfo.com)) or free software (<http://freegis.org>) can be used to produce estimated contaminant contours. Whilst great care must be taken in the use and interpretation of the visualisations produced, such packages are invaluable in developing an understanding of the sampling data.



## Appendix 7.7 – Wilcoxon Signed Rank test

Stage 1: Assign values to any observations below the detection limit. If this is not possible, assign a value of 'detection limit/2' to these observations.

Stage 2: Subtract each sample value  $Z_i$  from  $Z_t$  to obtain the set of sample deviations  $d_i$ . If any of the deviations are zero they should be deleted from the list and the sample size  $N$  reduced accordingly.

Stage 3: Order the absolute deviations  $|d_i|$  from smallest to largest. Rank the list. Rank 1 is assigned to the smallest value, then rank 2 to the second smallest value, etc. If two or more of the absolute deviations have an equal value, assign the average of the ranks which would have been assigned to them.

Stage 4: Construct the signed rank by assigning the sign of each deviation to its rank in the list. The sign is positive if the deviation  $d_i$  is positive ( $d_i > 0$ ).

Stage 5: Calculate the sum of the ranks with a positive sign,  $w$ .

Stage 6: Test the hypothesis by comparing  $w$  with the critical value  $w$

If the number of samples is less than or equal to 20 then:

Use Table 1 to find the critical value  $w_{crit}$  for the chosen significance level .  
If  $w < n(n+1)/2 - w_{crit}$  , the null hypothesis may be rejected (the material is exempt). Otherwise, there is not enough evidence to reject the null hypothesis

Else if the number of samples is greater than 20 then:

Calculate  $w_{crit}$  using the equation below.

$$w_{crit} = \frac{N(N+1)}{4} + z_{\alpha} \sqrt{N(N+1)(2N+1)/24}$$

where  $z_{\alpha}$  = the  $\alpha$  percentile of the standard normal distribution (Table *t test*)

If  $w < w_{crit}$  , the null hypothesis may be rejected (the material is exempt).  
Otherwise, there is not enough evidence to reject the null hypothesis

Report the values of  $N$ ,  $w$ ,  $w_{crit}$  and the result

Table 1

n	w <sub>.01</sub>	w <sub>.05</sub>	w <sub>.10</sub>	w <sub>.20</sub>
4	0	0	1	3
5	0	1	3	4
6	0	3	4	6
7	1	4	6	9
8	2	6	9	12
9	4	9	11	15
10	6	11	15	19
11	8	14	18	23
12	10	18	22	28
13	13	22	27	33
14	16	26	32	39
15	20	31	37	45
16	24	36	43	51
17	28	42	49	58
18	33	48	56	66
19	38	54	63	74
20	44	61	70	82

## Appendix 7.8 – Students t test

Stage 1: Calculate the mean of the sample ( $\bar{Z}$ )

Stage 2: Calculate the standard deviation of the sample(s)

Stage 3: Obtain the critical value,  $t_{crit}$ , from Table 1 for the chosen significance level  $100(1-\alpha)\%$  and the number of degrees of freedom (N-1).

Stage 4: Compute the test statistic, t, using

$$t = \frac{(Z_t - \bar{Z})}{(s / \sqrt{N})}$$

Stage 5: If  $t < t_{crit}$  reject the null hypothesis (the material is exempt). Otherwise accept the null hypothesis (the material is radioactive).

Report the values of  $\bar{Z}$ ,  $Z_T$ , N,  $t_{crit}$ , t and the result.

Table 1

Degrees of Freedom	1 - $\alpha$								
	.70	.75	.80	.85	.90	.95	.975	.99	.995
1	0.727	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657
2	0.617	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925
3	0.584	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841
4	0.569	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604
5	0.559	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032
6	0.553	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707
7	0.549	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499
8	0.546	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355
9	0.543	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250
10	0.542	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169
11	0.540	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106
12	0.539	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055
13	0.538	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012
14	0.537	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977
15	0.536	0.691	0.866	1.074	1.34	1.753	2.131	2.602	2.947
16	0.535	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921
17	0.534	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898
18	0.534	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878
19	0.533	0.6880	0.861	1.066	1.328	1.729	2.093	2.539	2.861
20	0.533	.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845
21	0.532	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831
22	0.532	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819
23	0.532	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807
24	0.531	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797
25	0.531	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787
26	0.531	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779
27	0.531	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771
28	0.530	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763
29	0.530	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756
30	0.530	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750
40	0.529	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704
60	0.527	0.679	0.848	1.046	1.296	1.671	2.000	2.390	2.660
120	0.526	0.677	0.845	1.041	1.289	1.658	1.980	2.358	2.617
	0.524	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576

Note: The last row of the table ( degrees of freedom) gives the critical values for a standard normal distribution (z), e.g.,  $t_{.095} = z_{.095} = 1.645$ .

## Appendix 7.9 – Bootstrap analysis

Bootstrapping techniques need sufficient data (>20 samples) to be applied.

Bootstrapping assumes that the distribution in the data reflects the distribution in the whole population. Of course this is likely to be wrong but since the population cannot be inferred readily from the data we are no worse off making this assumption than we are fitting an incorrect parametric model.

The bootstrapping method is implemented on a computer as follows (most statistical packages provide software to perform the calculations):

Stage 1: N data values are randomly selected from the set of sample values, with replacement. Replacement simply means that any sample value may be selected more than once (up to N times in the extreme case).

Stage 2: The mean of the N values is calculated and recorded.  
[Stages 1 and 2 are repeated a large number of times (usually more than 1000)]

Stage 3: The recorded means are ordered and the value of the  $100_{(1-\alpha)}$  percentile,  $US_{(1-\alpha)}$  found. This method can underestimate the percentiles of the underlying distribution and to be conservative the 97<sup>th</sup> percentile may be considered safer.

Stage 4: The value  $US_{(1-\alpha)}$  is then compared to the threshold,  $Z_t$ . If the value is greater than  $Z_t$  the null hypothesis is rejected (the material is exempt). Otherwise accept the null hypothesis (the material is radioactive).

Report the values of  $\bar{Z}$ ,  $Z_T$ , N,  $US_{(1-\alpha)}$ , and the result.

## Appendix 7.10 – Lands (1975) test

Stage 1: Calculate the mean of the sample ( $\bar{Z}$ ) using the following equation:

$$\bar{Z} = \exp\left(\bar{y} + \frac{s_y^2}{2}\right)$$

where  $\bar{y}$  and  $s_y$  are the sample mean and standard deviation of the logarithms of the data values  $\{Y_i = \ln(Z_i)\}$

Stage 2: Obtain from Table 1 the value of  $H_{(1-\alpha)}$ , where  $\alpha$  is the significance level.

$H_{(1-\alpha)}$  depends on  $s_y$ , and  $N$ .

Stage 3: Calculate the upper confidence limit,  $US_{(1-\alpha)}$  using the following equation:

$$US_{(1-\alpha)} = \exp\left(\bar{y} + 0.5s_y^2 + \frac{s_y H_{(1-\alpha)}}{\sqrt{N-1}}\right)$$

Stage 5: If  $US_{(1-\alpha)} < Z_t$  reject the null hypothesis (the material is exempt). Otherwise accept the null hypothesis (the material is radioactive).

Report the values of  $\bar{Z}$ ,  $Z_T$ ,  $N$ ,  $US_{(1-\alpha)}$ , and the result.

In practice it is not strictly necessary to calculate  $\bar{Z}$  but it gives a clear indication of the uncertainty range in the mean and allows some consideration to be given to the value of collecting additional data.

Table 1 – Critical Parameters for H=0.95

$s_y$	n									
	3	5	7	10	12	15	21	31	51	101
0.10	2.750	2.035	1.886	1.802	1.775	1.749	1.722	1.701	1.684	1.670
0.20	3.295	2.198	1.992	1.881	1.843	1.809	1.771	1.742	1.718	1.697
0.30	4.109	2.402	2.125	1.977	1.927	1.882	1.833	1.793	1.761	1.733
0.40	5.220	2.651	2.282	2.089	2.026	1.968	1.905	1.856	1.813	1.777
0.50	6.495	2.947	2.465	2.220	2.141	2.068	1.989	1.928	1.876	1.830
0.60	7.807	3.287	2.673	2.368	2.271	2.181	2.085	2.010	1.946	1.891
0.70	9.120	3.662	2.904	2.532	2.414	2.306	2.191	2.102	2.025	1.960
0.80	10.43	4.062	3.155	2.710	2.570	2.443	2.307	2.202	2.112	2.035
0.90	11.74	4.478	3.420	2.902	2.738	2.589	2.432	2.310	2.206	2.117
1.00	13.05	4.905	3.698	3.103	2.915	2.744	2.564	2.423	2.306	2.205
1.25	16.33	6.001	4.426	3.639	3.389	3.163	2.923	2.737	2.580	2.447
1.50	19.60	7.120	5.184	4.207	3.896	3.612	3.311	3.077	2.881	2.713
1.75	22.87	8.250	5.960	4.795	4.422	4.081	3.719	3.437	3.200	2.997
2.00	26.14	9.387	6.747	5.396	4.962	4.564	4.141	3.812	3.533	3.295
2.50	32.69	11.67	8.339	6.621	6.067	5.557	5.013	4.588	4.228	3.920
3.00	39.23	13.97	9.945	7.864	7.191	6.570	5.907	5.388	4.947	4.569
3.50	45.77	16.27	11.56	9.118	8.326	7.596	6.815	6.201	5.681	5.233
4.00	52.31	18.58	13.18	10.38	9.469	8.630	7.731	7.024	6.424	5.908
4.50	58.85	20.88	14.80	11.64	10.62	9.669	8.652	7.854	7.174	6.590
5.00	65.39	23.19	16.43	12.91	11.77	10.71	9.579	8.688	7.929	7.277
6.00	78.47	27.81	19.68	15.45	14.08	12.81	11.44	10.36	9.449	8.661
7.00	91.55	32.43	22.94	18.00	16.39	14.90	13.31	12.05	10.98	10.05
8.00	104.6	37.06	26.20	20.55	18.71	17.01	15.18	13.74	12.51	11.45
9.00	117.7	41.68	29.46	23.10	21.03	19.11	17.05	15.43	14.05	12.85
10.00	130.8	46.31	32.73	25.66	23.35	21.22	18.93	17.13	15.59	14.26

Source: After Land, 1975.

## **Appendix 7.11 – Histograms**

This provides a simple representation of the distribution of the values of the data. The data are binned into ranges and the numbers of each data (scaled by the total number of data values for the frequency plot) are plotted as vertical bars against the ranges. The shape of the data distribution is made apparent by these plots.

As a rule of thumb bin sizes should be around 10% of the axis range.

## Appendix 7.12 – The Wilks-Shapiro Test

The Wilks Shapiro test statistic is defined as:

$$W = \frac{\left( \sum_{i=1}^N w_i Z'_i \right)^2}{\sum_{i=1}^N (Z_i - \bar{Z})^2}$$

The  $Z_i$  are the original data, and the  $Z'$  are the ordered data. The values  $w_i$  are obtained from manipulation of the covariance matrix.  $W$  is a measure of the straightness of the normal probability plot, and small values indicate departures from normality.

This test statistic cannot be calculated readily by hand and use of statistical software is suggested. Most packages will report the results for a range of significance levels (usually the 90<sup>th</sup>, 95<sup>th</sup> and 99<sup>th</sup> percentiles).

## Appendix 7.13 – Tests for Outliers

Two methods are described here for testing for outliers from data that are otherwise normally distributed. The methods are therefore useful for exploring Normal or Log Normal distributed data. For the log-normal case the logarithms of the data are examined. The first method (the Extreme value test) is useful for small numbers of data and when only one or two measurements are considered to be likely to be outliers. The second method (Rosner's test) is useful for larger numbers of data (>25) and can detect numerous outliers.

The identification of outliers cannot determine the cause of the differences between the main body of the data and the outliers. Judgement must be used to determine whether the outliers should be treated as real values (perhaps indicating hot spots) or inaccurate data (perhaps indicating transcription or analytical errors).

### *The Extreme Value Test*

The Extreme value test (also known as Dixon's test) provides an appropriate method for examining whether an observation is an outlier. The test is relatively simple to use. If more than one outlier is considered to be possible (from visual inspection of the data using frequency and/or normal probability plots) then the presumed outliers must be tested in sequence from the least severe to the most severe. This will avoid the possibility of one data value masking the other.

Before the test can proceed a test of normality on the data not suspected of being outliers must be performed. Normality of the main data is required for the application of the method.

Step 1: Order the data from smallest to largest. ( $Z'_i$  are the ordered data for the sample values  $Z_i$ )

Step 2: If  $Z'_1$  is a potential outlier, compute the test statistic – D from one of the following equations depending on the sample size:

$$D = \frac{Z'_2 - Z'_1}{Z'_N - Z'_1} \quad 3 \leq N \leq 7$$
$$D = \frac{Z'_2 - Z'_1}{Z'_{N-1} - Z'_1} \quad 8 \leq N \leq 10$$
$$D = \frac{Z'_3 - Z'_1}{Z'_{N-1} - Z'_1} \quad 11 \leq N \leq 13$$
$$D = \frac{Z'_3 - Z'_1}{Z'_{N-2} - Z'_1} \quad 14 \leq N \leq 25$$

Step 3: Determine the critical value,  $D_{crit}$ , from Table D2.5 (for significance level  $\alpha$ ). If  $D > D_{crit}$  then  $Z'_1$  can be considered to be an outlier and should be further investigated.

Step 4: If  $Z'_N$  is a potential outlier, compute the test statistic – D from one of the following equations depending on the sample size:

$$D = \frac{Z'_N - Z'_{N-1}}{Z'_N - Z'_1} \quad 3 \leq N \leq 7$$

$$D = \frac{Z'_N - Z'_{N-1}}{Z'_{N-1} - Z'_1} \quad 8 \leq N \leq 10$$

$$D = \frac{Z'_N - Z'_{N-2}}{Z'_{N-1} - Z'_1} \quad 11 \leq N \leq 13$$

$$D = \frac{Z'_N - Z'_{N-2}}{Z'_{N-2} - Z'_1} \quad 14 \leq N \leq 25$$

Step 5: Determine the critical value,  $D_{crit}$ , from Table D2.5 (for significance level  $\alpha$ ). If  $D > D_{crit}$  then  $Z'_1$  can be considered to be an outlier and should be further investigated. *Note: If 2 outliers are suspected on one tail remove the more severe value and reduce N by 1. If the least severe value is considered an outlier then the more severe must also be assumed to be an outlier. However, if the least severe value is rejected as an outlier then the test should be repeated for the outer value.*

### **Rosner's Test**

This test for outliers cannot be used for sample size less than  $N = 25$ .

Step 1: Order the data from smallest to largest. ( $Z'_i$  are the ordered data for the sample values  $Z_i$ )

Step 2: Determine by inspection of the data the maximum number of outliers that might be present,  $K$ .

Step 3: Iteratively ( $k = 0$  to  $K$ ) compute the mean  $\bar{Z}_k$  and standard deviation  $s_k$  of the remaining data after the  $k$  most extreme observations have been removed. The most extreme observation  $Z^k$  at each iteration is the observation furthest from the mean of the previous iteration.

$$\bar{Z}_k = \frac{1}{N-k} \sum_{i=1}^{N-k} Z_i$$

$$s_k = \left( \frac{1}{N-k} \sum_{i=1}^{N-k} (Z_i - \bar{Z}_k)^2 \right)^{1/2}$$

Step 4: Obtain the critical value,  $R_{crit,k}$  for each iteration from Table D2.6

Step 5: Iteratively ( $k = K, I$ ) compute the test statistic  $R_k$  and test against the critical value.

$$R_k = \frac{|Z^k - \bar{Z}_k|}{s_k}$$

If  $R_k > R_{crit, k}$  then the  $k$  extreme values,  $Z^k$ , are identified as outliers and the process is terminated.

**Table D2.5 Critical Values for the Extreme Values Test (Dixon's test)**

$n$	Level of Significance $\alpha$		
	0.10	0.05	0.01
3	0.886	0.941	0.988
4	0.679	0.765	0.889
5	0.557	0.642	0.780
6	0.482	0.560	0.698
7	0.434	0.507	0.637
8	0.479	0.554	0.683
9	0.441	0.512	0.635
10	0.409	0.477	0.597
11	0.517	0.576	0.679
12	0.490	0.546	0.642
13	0.467	0.521	0.615
14	0.492	0.546	0.641
15	0.472	0.525	0.616
16	0.454	0.507	0.595
17	0.438	0.490	0.577
18	0.424	0.475	0.561
19	0.412	0.462	0.547
20	0.401	0.450	0.535
21	0.391	0.440	0.524
22	0.382	0.430	0.514
23	0.374	0.421	0.505
24	0.367	0.413	0.497
25	0.360	0.406	0.489

**Table D2.6(a) Critical Values of R for Rosner's test**

n	r	$\alpha$	
		0.05	0.01
25	1	2.82	3.14
	2	2.80	3.11
	3	2.78	3.09
	4	2.76	3.06
	5	2.73	3.03
	10	2.59	2.85
26	1	2.84	3.16
	2	2.82	3.14
	3	2.80	3.11
	4	2.78	3.09
	5	2.76	3.06
	10	2.62	2.89
27	1	2.86	3.18
	2	2.84	3.16
	3	2.82	3.14
	4	2.80	3.11
	5	2.78	3.09
	10	2.65	2.93
28	1	2.88	3.20
	2	2.86	3.18
	3	2.84	3.16
	4	2.82	3.14
	5	2.80	3.11
	10	2.68	2.97
29	1	2.89	3.22
	2	2.88	3.20
	3	2.86	3.18
	4	2.84	3.16
	5	2.82	3.14
	10	2.71	3.00
30	1	2.91	3.24
	2	2.89	3.22
	3	2.88	3.20
	4	2.86	3.18
	5	2.84	3.16
	10	2.73	3.03
31	1	2.92	3.25
	2	2.91	3.24
	3	2.89	3.22
	4	2.88	3.20
	5	2.86	3.18
	10	2.76	3.06

n	r	$\alpha$	
		0.05	0.01
32	1	2.94	3.27
	2	2.92	3.25
	3	2.91	3.24
	4	2.89	3.22
	5	2.88	3.20
	10	2.78	3.09
33	1	2.95	3.29
	2	2.94	3.27
	3	2.92	3.25
	4	2.91	3.24
	5	2.89	3.22
	10	2.80	3.11
34	1	2.97	3.30
	2	2.95	3.29
	3	2.94	3.27
	4	2.92	3.25
	5	2.91	3.24
	10	2.82	3.14
35	1	2.98	3.32
	2	2.97	3.30
	3	2.95	3.29
	4	2.94	3.27
	5	2.92	3.25
	10	2.84	3.16
36	1	2.99	3.33
	2	2.98	3.32
	3	2.97	3.30
	4	2.95	3.29
	5	2.94	3.27
	10	2.86	3.18
37	1	3.00	3.34
	2	2.99	3.33
	3	2.98	3.32
	4	2.97	3.30
	5	2.95	3.29
	10	2.88	3.20
38	1	3.01	3.36
	2	3.00	3.34
	3	2.99	3.33
	4	2.98	3.32
	5	2.97	3.30
	10	2.91	3.22

n	r	$\alpha$	
		0.05	0.01
39	1	3.03	3.37
	2	3.01	3.36
	3	3.00	3.34
	4	2.99	3.33
	5	2.98	3.32
	10	2.91	3.24
40	1	3.04	3.38
	2	3.03	3.37
	3	3.01	3.36
	4	3.00	3.34
	5	2.99	3.33
	10	2.92	3.25
41	1	3.05	3.39
	2	3.04	3.38
	3	3.03	3.37
	4	3.01	3.36
	5	3.00	3.34
	10	2.94	3.27
42	1	3.06	3.40
	2	3.05	3.39
	3	3.04	3.38
	4	3.03	3.37
	5	3.01	3.36
	10	2.95	3.29
43	1	3.07	3.41
	2	3.06	3.40
	3	3.05	3.39
	4	3.04	3.38
	5	3.03	3.37
	10	2.97	3.30
44	1	3.08	3.43
	2	3.07	3.41
	3	3.06	3.40
	4	3.05	3.39
	5	3.04	3.38
	10	2.98	3.32
45	1	3.09	3.44
	2	3.08	3.43
	3	3.07	3.41
	4	3.06	3.40
	5	3.05	3.39
	10	2.99	3.33

**Table D2.6(b) Critical Values of R for Rosner's test**

n	r	$\alpha$	
		0.05	0.01
46	1	3.09	3.45
	2	3.09	3.44
	3	3.08	3.43
	4	3.07	3.41
	5	3.06	3.40
	10	3.00	3.34
47	1	3.10	3.46
	2	3.09	3.45
	3	3.09	3.44
	4	3.08	3.43
	5	3.07	3.41
	10	3.01	3.36
48	1	3.11	3.46
	2	3.10	3.46
	3	3.09	3.45
	4	3.09	3.44
	5	3.08	3.43
	10	3.03	3.37
49	1	3.12	3.47
	2	3.11	3.46
	3	3.10	3.46
	4	3.09	3.45
	5	3.09	3.44
	10	3.04	3.38
50	1	3.13	3.48
	2	3.12	3.47
	3	3.11	3.46
	4	3.10	3.46
	5	3.09	3.45
	10	3.05	3.39
60	1	3.20	3.56
	2	3.19	3.55
	3	3.19	3.55
	4	3.18	3.54
	5	3.17	3.53
	10	3.14	3.49

n	r	$\alpha$	
		0.05	0.01
70	1	3.26	3.62
	2	3.25	3.62
	3	3.25	3.61
	4	3.24	3.60
	5	3.24	3.60
	10	3.21	3.57
80	1	3.31	3.67
	2	3.30	3.67
	3	3.30	3.66
	4	3.29	3.66
	5	3.29	3.65
	10	3.26	3.63
90	1	3.35	3.72
	2	3.34	3.71
	3	3.34	3.71
	4	3.34	3.70
	5	3.33	3.70
	10	3.31	3.68
100	1	3.38	3.75
	2	3.38	3.75
	3	3.38	3.75
	4	3.37	3.74
	5	3.37	3.74
	10	3.35	3.72
150	1	3.52	3.89
	2	3.51	3.89
	3	3.51	3.89
	4	3.51	3.88
	5	3.51	3.88
	10	3.50	3.87
200	1	3.61	3.98
	2	3.60	3.98
	3	3.60	3.97
	4	3.60	3.97
	5	3.60	3.97
	10	3.59	3.96

n	r	$\alpha$	
		0.05	0.01
250	1	3.67	4.04
	5	3.67	4.04
	10	3.66	4.03
300	1	3.72	4.09
	5	3.72	4.09
	10	3.71	4.09
350	1	3.77	4.14
	5	3.76	4.13
	10	3.76	4.13
400	1	3.80	4.17
	5	3.80	4.17
	10	3.80	4.16
450	1	3.84	4.20
	5	3.83	4.20
	10	3.83	4.20
500	1	3.86	4.23
	5	3.86	4.23
	10	3.86	4.22

## **Appendix 7.14 - Review of Comparable Approaches**

### **Introduction**

In this Appendix a brief assessment is presented of the similarities and differences between the approach given in Chapter 7 and other approaches that have been developed for the determination of sampling patterns, sampling numbers and the analysis of sample data for sentencing material. The Appendix is divided into three parts:

- The first part considers the different approaches that may be used to test the adequacy of the number of samples chosen for the assessment of a particular mass or area.
- The second part is concerned with an examination of the range of techniques that are applied for the analysis of a data set obtained from point sampling. This part considers the different techniques that are applied to sampling design and sample data analysis. The approaches presented in BS10175 (2001) and DETR CLR4 (1994) as well as the approach presented in EPA/QA-G9 (2000) are summarised in tabular form.
- The third part considers a software tool that has been developed for statistical sampling design and analysis and which is freely available (June 2004) for download from the internet: Visual Sample Plan (VSP). This tool has been created with American Government Funding and represents 'state of the art' tools for statistical analysis. Visual Sample Plan (<http://dgo.pnl.gov/vsp/>) is specifically designed to calculate sample designs for any two dimensional area and as such is not directly applicable to the full range of materials envisaged in this Code of Practice. Nevertheless, this tool does provide solutions to a very broad range of conditions and has some very useful characteristics. Alternative statistical packages are also indicated that are appropriate to the methods proposed in Chapter 6.

### **Determining Sample Numbers**

There are only a limited number of approaches that can be used to determine the number of samples to be taken from a particular mass or area. These can be identified as: a) rule of thumb, b) informed (conceptually based) opinion, c) guess, d) budget limited, e) statistical.

a) Rules of Thumb

Rules of thumb were traditionally employed in the early contaminated land assessment guidance and traces of their use are still visible in the recent standards and guidance (BS 10175, 2001; CIRIA, 1995). For example, in the latest guidance on contaminated land assessment for the UK (BS10175, 2001) the exploratory and investigation phase densities for sampling suggest spacings of 50-100m for exploration and 25-50m for investigation. A smaller spacing of 10m is suggested for sensitive locations such as housing developments. These types of rule of thumb are derived for a specific class of potentially contaminated sites and are embedded within text that provides strong caveats covering such issues as zoning of the site area, the presumed contamination conditions and the characteristics of the site. Such rules are a pragmatic approach to encourage sensible numbers of samples to be collected initially but are only meaningful in a site assessment when iterative sampling is proposed. These methods are discouraged in this present code of practice since the range of materials and environments covered by the code do not admit the possibility of universal rules that can be applied unambiguously.

b) Informed or judgemental methods

In all the codes of practice, judgemental methods are employed at some stage in the development of the sampling strategy. Essentially, judgemental methods are employed in three areas of investigation. In all cases they rely on an identified conceptual model of the site development and history. The first concerns the zoning of the site/material according to the anticipated pattern of contamination. The second concerns the estimation of the heterogeneity of the contamination within the zones. The third concerns the choice of sampling locations. The method proposed in the present code and which is also endorsed by the Data Quality Objectives (DQO) approach of the United States EPA EPA/QA-G9 (US EPA, 2000a) acknowledges the value of judgement in splitting the site/material into zones and in the determination of the heterogeneity of the contamination within zones but stops short of recommending judgemental methods for the identification of sample locations. The avoidance of location identification by judgemental methods prevents the introduction of bias and correlation into the analysis of the sample data that may lead to errors in the statistical analysis of the data gathered. In BS10175 (2001) judgemental methods of locating samples are supported but little consideration is given in this document to the precise methods to be used to evaluate the data that are gathered. Application of the statistical methods proposed in DETR (1994) is suggested as an approach to the assessment of the data gathered using BS10175 (2001) but since the methods in DETR (1994) assume statistical independence of the data, an inconsistency emerges between these two documents that is not satisfactorily addressed in either document.

All of the codes of practice adopt very similar methods for dealing with hot-spots. Judgement is needed to specify the size of hot-spot that must be located with an acceptable level of assurance. Without specifying the smallest size of hot-spot to be located, there can be no method for sensibly defining the intensity of sampling needed to locate such a hot-spot. The geometric sampling grids used in all codes of practice are identical and a considerable amount of research has been presented to back up the sizing of the grid spacing for different hot-spot shapes (Smith, 2004 among others). Some of the early work prepared by Ferguson (1992) has been used in the UK codes of practice and guidance manuals (CIRIA, 1995), and this work implies that a herringbone design for sample layout is optimal for locating a hot spot. However, Smith, 2004 has demonstrated that this is not the case and the better layouts are triangular and rectangular for all cases of practical interest.

c) Guess

The adoption of a guess implies that effectively no knowledge exists about the potential conditions in the site/material. Where this is truly the case, then a guess is all that can be made. However, the guess should only be introduced to provide a first pass sampling intensity to provide some data on which to make a more informed opinion and to guide a further round of sampling. All codes of practice provide some form of 'guess' starting point as an option for a site/material of unknown condition. The rules of thumb in BS10175 (2001) can be considered to be, essentially, a good starting point as a guess. In Chapter 7 (this code of practice) a proposal is made to start with a statistically useful number of samples (10 -20) to allow some interpretation of the potential range of contamination in a zone.

d) Budget limited

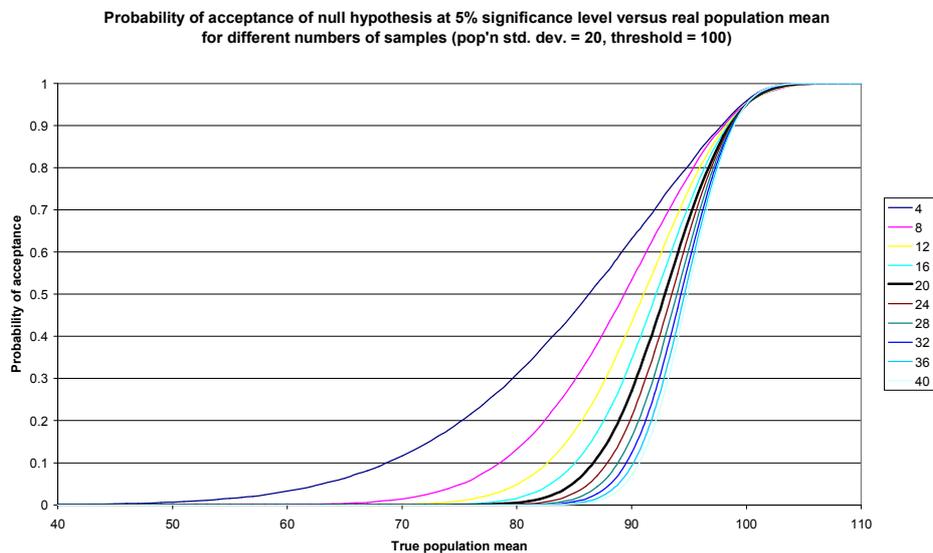
The costs of sampling and analysis can be high and there is a clear trade-off between the costs of sampling and the costs of sentencing the material as radioactive. One option for determining the number of samples is to establish the maximum number of samples and analyses that can be performed within a specified budget and to use the sample numbers so derived. The budget should be defined on the basis of a financial risk assessment that interrogates the likelihood of sentencing the material as clean (with the associated reduction in costs) against the costs of sampling. Such an assessment is only possible if information about the contaminant heterogeneity is already known. Therefore, budget sampling should fall into the statistical methods category. In the US EPA methodology for site investigation, the opportunity to control the sample numbers according to a budget is included as an option. In Chapter 7 (this code of practice) such an option is not included. It is assumed that if costs are an overriding factor in the determination of the number of samples then either the material will be automatically sentenced as radioactive (where insufficient samples can be taken to assess the material) or it will be sentenced on the basis of the statistical analysis of limited data (giving greater uncertainty) and the concurrent increased likelihood of sentencing clean material as radioactive.

e) Statistical

The number of samples to be taken to characterise the mean activity of a zone depends on the variance of the population distribution that defines, in a statistical sense, the variation of activity over the zone. The higher the variance of the population distribution, the greater the variability in the value of the sample mean, estimated from a given number of samples. Thus, more samples are needed to reduce the risk of errors in the assessment. Where the population distribution is extreme, as is the case with hot spots then special methods are needed that are based on the size of the hot spot to be located as described under judgemental methods above. The form of the population distribution is therefore also important when estimating sample numbers.

It is worth looking at the calculation of sample numbers when the population distribution can be approximately described by a Normal distribution. In this case, the variance of the distribution controls the identification of sample size. However, the control does not arise due to a possibility of an increased risk of accepting the material as exempt, when it is not. The statistical methods used to test the null hypothesis ensure that this risk is not increased. However, for small number of samples, the probability increases significantly of a material failing to meet exemption criteria when its actual mean activity is much lower than the threshold (See Figure A7.14.1). The choice of the number of samples is therefore defined in order to reduce the risk of condemning clean material unnecessarily. Two methods are currently employed to do this.

**Figure A7.14.1**



The first method sets a specified variance for the sample mean that ensures that the range of mean activity levels below the threshold where the risk of sentencing as radioactive essentially clean material is high, is kept to a minimum. The second method defines a lower bound to a 'grey' region (spelt 'gray' in the USA) below the threshold. The function of the grey area is the same as for method one but in this case the method also requires the maximum allowable risk to be specified that the material will be condemned when the actual mean activity is below the lower bound.

The maximum allowable risk is defined in terms of the probability that material with a mean activity equal to or less than the lower bound will be sentenced as radioactive.

**Figure A7.14.2 The Grey region**

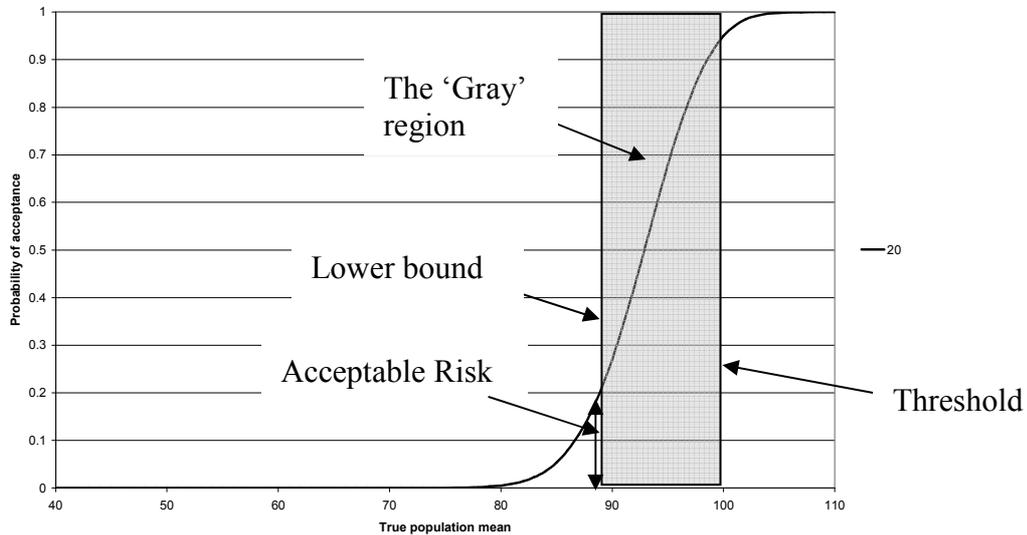


Figure A7.14.2 illustrates these two methods for the condition that both produce the same risk of condemning clean material. In this plot the probability of condemning material given a threshold level of 100 is presented for different 'true' values of activity and for different sample numbers. The threshold and a lower bound are shown corresponding to the second method. The probability distribution for 20 samples corresponds to that applicable to this problem when using the method proposed in this code of practice.

Both methods require an estimate of the variance of the underlying population distribution based on previous knowledge of similar situations.

#### Method 1: Specified variance

For this method a single data value is required, which is the factor defining the size of the sample variance given the threshold and the population variance. For the present code, this factor is fixed as 0.1. The method is conceptually simple to operate. The assessment of the sample variance against the initially assumed population variance can be used to determine whether further sampling is needed. If the sample variance is significantly higher than originally assumed further sampling may be adopted to reduce the sample variance and thereby restrict the likelihood of sentencing clean material. The factor of 0.1 is fairly stringent and is based on the judgement that the UK Nuclear industry should be minimising the amount of material being sentenced as radioactive and therefore requiring disposal.

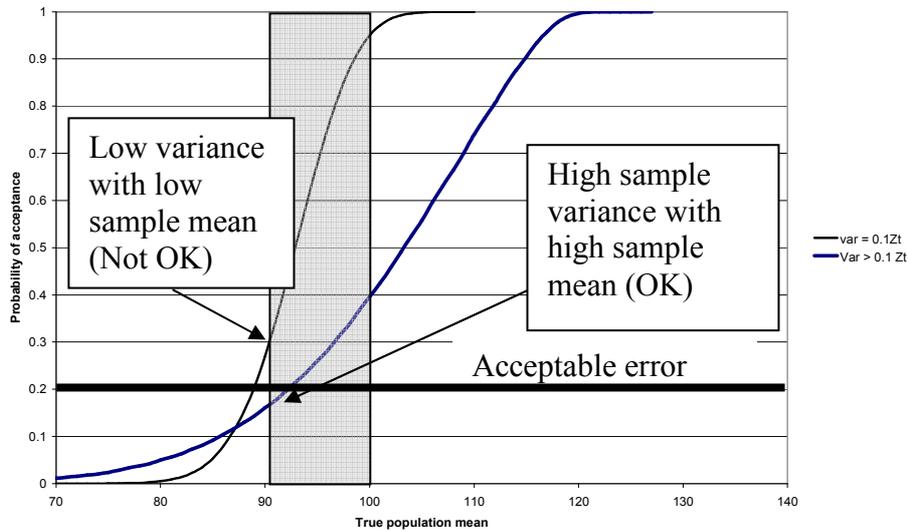
This should provide a clear message that the industry is complying with current government objectives of minimising unnecessary waste creation. The approach does not compromise the need to ensure that appropriate classification of materials occurs.

## Method 2: Specified grey region

Two data values are required to specify the number of samples for this method. The first is the position of the lower bound and the second is the acceptable risk of material with values lower than the bound being sentenced as radioactive. The choice of these two values is usually left to the analyst. There is no easy solution to determining appropriate values. Indeed, the solutions proposed in the codes of practice that adopt this method (e.g. US EPA, 2000a) are concerned with assessing the financial implications of condemning more material than is necessary versus the cost of the additional samples. It is relatively straightforward to do a probabilistic comparison of expected expenditure versus expected savings for a range of options. However it is only useful if robust estimates of the population distribution are available in advance of sampling or significant uncertainty is introduced into the cost benefit analysis.

The advantage of method two lies not in the initial estimation of the bounds but in the application of the method to the determination of the need for additional sampling once a first round of sampling and analysis has been completed. The decision is mechanical since the decision variables (size of gray region and associated risk) should be defined at the outset of the investigation. The decision in this case is based on the observed sample population parameters. If the variance is high and the sample mean high, then the probability of condemning clean material may be low without the need for further sampling. Whereas if the variance is high and the sample mean low then the need for further sampling will be established directly by this method. These points are illustrated in Figure A7.14.3.

**Figure A7.14.3 Illustrating how the Grey region can be used to assess the need automatically for further sampling (when the grey region remains unchanged)**



### Comparison of the available Statistical Methods

To illustrate the differences in the range of statistical methods that are employed in the different approaches, Table A7.14.1 has been produced. In this table the statistical methods are grouped in an attempt to make clearer the similarities and differences between the various approaches.

The major point being made in this Table is that the methods proposed in Chapter 7 exceed those offered for UK contaminated land investigation but are a subset of those presented in the US EPA guidance on data quality objectives (US EPA, 2000a). The major deviations arise in the range of sampling patterns proposed. While the EPA guidance offers a broad range of alternatives, many of the alternatives are not considered to be advantageous for most, if not all, cases of interest. For this reason the current code (Chapter 7) recommends that sampling patterns are limited to a small range of systematic (grid) layouts for all cases of interest.

The advice for determining the choice of the null hypothesis given in the EPA data quality objectives documentation (US EPA, 2000a) is appropriate to the problems of providing generic guidelines for a wide range of problem types but is unnecessary for sentencing potentially radioactive material. The null hypothesis that the material is radioactive is the only plausible choice for sentencing radioactive material.

**Table A7.14.1: Statistical Tests in use through different codes of practice**

Test	DQO <sup>*1</sup>	CLR4 <sup>*2</sup>	Ch 6 <sup>*3</sup>	Notes
<i>Sample Numbers</i>				
Judgmental sampling		*		All codes use judgement in the identification of zones and prior characterisation of zones.
Simple Random sampling	*	*		
Stratified sampling	*	*		
Systematic and Grid Sampling	*	*	*	Systematic sampling tends to outperform all other methods where the statistical properties of the zone being sampled are likely to be homogeneous at any magnitude of heterogeneity
Cluster sampling	*			
Composite sampling	*			Can be considered as a subset of the sampling problem and to introduce uncertainties in the point values derived during the compositing of the material
<i>Tests for the mean (one sample)</i>				
Student's t – test	*	*	*	For normal or near normal data. Can be extended to Log normal distributions using Land's equations (Land,1975) [see Ch. 6]
Wilcoxon signed rank test	*		*	For non-normally distributed data
Chen Test	*			Good for right skewed distributions. An extension of the t-test.
Bootstrap			*	No assumptions required about the distribution. Lower power than the 3 tests above.
<i>Tests of distribution</i>				
Wilks-Shapiro test	*	*	*	Valid for detecting deviation from a normal distribution
Goodness of Fit tests	*			

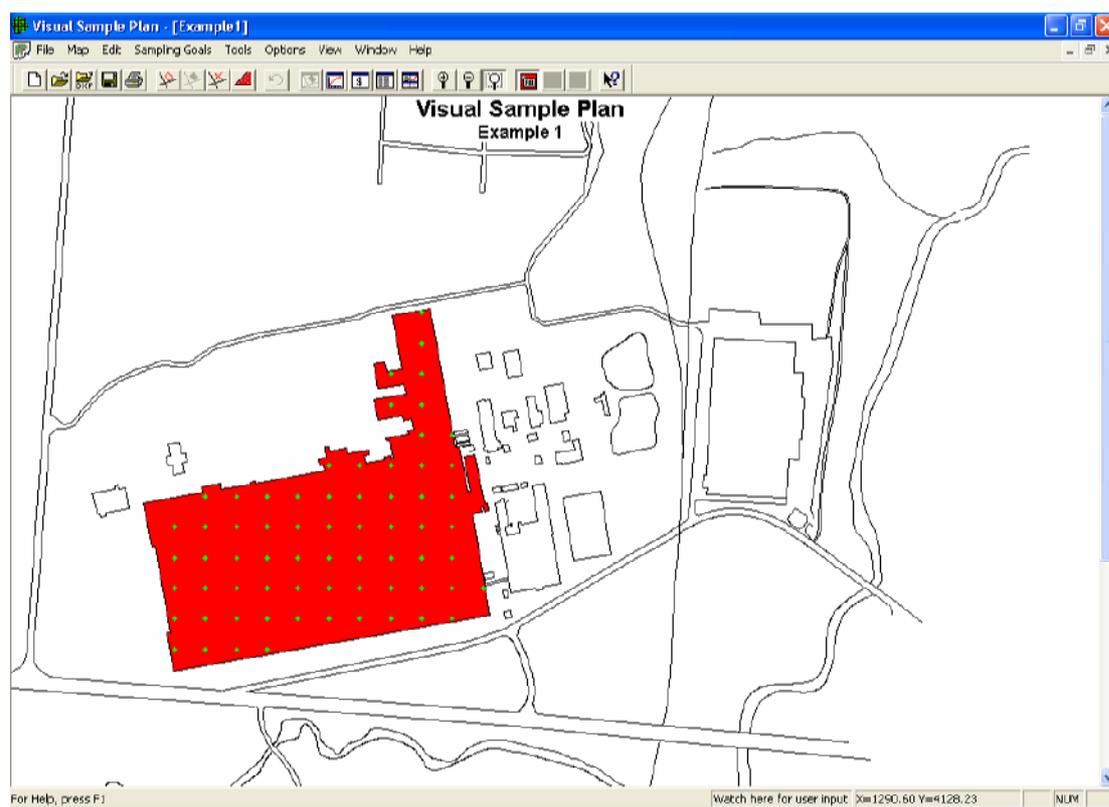
Table A7.14.1: Statistical Tests in use through different codes of practice (cont'd)

<i>Tests for outliers</i>				Both the Extreme Value and Rosner's test assume normality of the data. Therefore, the data need to be transformed prior to testing (e.g. application of a Log Normal transformation)
Extreme Value test	*	*	*	
Rosner's test	*		*	
<i>Tests for Trends</i>				All codes use these, but CLR4 is not explicit in presenting options.
Regression methods	*		*	
Autocorrelation methods	*		*	
Graphical methods	*		*	

## Visual Sampling Plan (VSP)

VSP has been designed to support the implementation of sampling design in accordance with the guidelines provided by the US EPA's data quality objectives. It is an exceptionally easy to use tool that works within a standard Windows environment to interactively define the area to be sampled, to mark the individual zones within the sampling area and to calculate the number and position of samples to achieve the desired sampling objective. Data required to support the calculations are requested through context driven forms. Most importantly, a report is automatically created defining the complete basis for the sampling design and the testing that will be required in order to confirm that the basis for the design is met by the actual conditions found. The report is written in a format that is easy to read and covers all the major points needed for quality assurance, rather than as a terse summary of the inputs that characterise most software output functions. To support the quality assurance full details of the supporting models and the testing of the models are provided (Gilbert *et al*, 2002). The system therefore provides a very effective quality assurance framework within which the sampling design and from which the subsequent sampling analysis is developed.

Figure A7.14.4 VSP window showing a site area with a rectangular systematic sample plan.



The system permits sensitivity analyses to be performed on the major input parameters. This is a very useful contribution as it yields the likely range of samples that could be needed to properly investigate the zone under investigation.

The only perceived drawbacks to the VSP software are that it is limited to two dimensional sampling problems and it requires the definition of the grey region.

The latter problem can be overcome by forcing the parameter values of the grey region to yield the equivalent probability function for acceptance of the null hypothesis assumed by applying the 0.1 factor for quantifying the sampling variance under Chapter 7 and Figure A7.14.2.

The former is a limitation but there will be many occasions when the software is directly applicable and it would be hard to justify not using it for some situations purely because it is not universally applicable to the full range of conditions envisaged by the present code of practice.

### **Statistical Analysis Software**

There are many software packages available that are able to provide the majority, but generally not all, the desired functionality required to perform the statistical analyses presented in Chapter 7. However, since the withdrawal of the DataQuest software by the US EPA there appears to be no specially designed package that works directly on the problem of environmental data analysis in exactly the right form for sentencing nuclear material. Commercially available software such as that provided by SAS ([www.sas.com](http://www.sas.com)) is used by the US EPA and will deliver the required functionality as well as providing significant additional functionality. Alternatives that would be worthy of consideration are ChemStat (a useful overview is provided through <http://www.rockware.com/catalog/pages/chemstat.html>) and Dataplot (<http://www.itl.nist.gov/div898/software/dataplot/>). Chemstat is the most directly applicable software to material sampling but has been designed around the problem of borehole water quality data analysis. Having said this, it is easy to use and can be tailored to the analysis of Nuclear material relatively easily. Dataplot can perform a broad range of testing but excludes easy application of 2D and 3D trend analysis to interrogate data for complex spatial correlations.

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## **Appendix 8      Monitoring Equipment and Measurement Techniques**

### **A8.2.1 Bulk Alpha Monitoring**

Bulk alpha monitoring is difficult without using radiochemistry. The explanation is simple. The maximum range of an alpha particle is very short, only a few microns in dense solids. For low natural activity materials, it is sometimes possible to remove a sample from a bulk material, such as soil or concrete. This is then homogenised and either counted as a very thin layer (a few microns) or as an infinitely thick layer. The first approach has the advantage of a relatively efficient sample, i.e. one in which a significant proportion of any alphas generated leaves the surface of the source. The response of an alpha detector placed directly above, and in virtual contact with, the sample can be estimated reasonably well. The disadvantage is that the mass of the very thin sample is extremely low, normally less than 0.1 g, and the maximum count rate at a limiting level of 0.4 Bq/g will be less than 1 count in 100 seconds. Counting times to get any sort of statistically credible number will be very long and significant corrections for even the very low background count rate of a well designed and clean alpha counter will be significant. Any level of inhomogeneity will also cause major uncertainties and the mass present will have to be measured very carefully.

The same detectors can also be used for a much thicker sample which removes the uncertainty associated with the mass as the thickness is in excess of the maximum range of an alpha particle, i.e. it is effectively infinitely thick. The count rate will be slightly higher but the response is more difficult to predict. The need for homogeneity is slightly reduced, but is still important. The technique can be used, for example, on a concrete surface or on a tray of soil which has been riddled to remove twigs and pebbles and then flattened.

The only reliable way of calibrating such equipment is to take a well mixed sample of the material of interest, determine the net (background corrected) count rate using the equipment described above and then determine the alpha activity of the nuclides of interest by radiochemistry. This basically involves extracting the alpha emitting nuclides from a bulk sample, concentrating them and then manufacturing an efficient source which can be counted in much the same way as described above. The net count rate from the direct counting process can then be compared with the activity of the nuclides of interest to produce a response factor. This process is described in more detail in the section on radiochemistry.

The main uses of direct bulk alpha measurement are to make regular checks on the fingerprint of materials with a significant alpha fingerprint fraction to confirm the stability of the fingerprint and to confirm the relative homogeneity of materials which only contain alpha emitters, thus limiting the number of samples required per unit mass cleared. It will not work at all well where the materials have high natural alpha activity levels, such as some soils and concrete. The detectors employed are basically the same as those used for direct surface monitoring.

*Note that many alpha emitters also emit X radiation and it may be better to employ X-ray monitoring techniques.*

### **A8.2.2 Bulk Beta Monitoring**

Direct bulk monitoring for  $^3\text{H}$  and  $^{63}\text{Ni}$  is impossible, and reliance must be placed on sampling. For other beta emitters, broadly the same restrictions apply to direct beta monitoring as for direct alpha monitoring. For low energy emitters, such as  $^{14}\text{C}$ , the range is similar to an alpha particle but for high energy emitters, such as Pa-234m, which is part of the  $^{238}\text{U}$  decay chain, the range is up to 6 mm in soil or concrete. It is for these higher energy emitters that direct monitoring is possible, either in situ, on concrete surfaces or soil, or following sampling and a very limited preparation, such as riddling soil and flattening.

The detectors employed are basically the same as those used for direct surface beta monitoring. The difference from alpha monitoring is that there will always be a significant background count rate, either from environmental background gamma radiation or from gamma emitters within the sample. This is why the technique only works for more energetic emitters, where the count rate per Bq per gram can be 100 times higher than the corresponding value for alpha or low energy beta emitters.

It is possible to make a reasonable estimate of a detector's response but again the best approach is to use analytical methods to determine the true activity of the contaminant and compare this value with the apparent net activity. Similarly, the main usefulness of the technique is as a part of a check on consistency of fingerprint or of the relative homogeneity of activity in identified materials.

### **A8.2.3 Bulk Gamma Monitoring**

Bulk gamma monitoring forms the basis of many clearance exercises. It can be a relatively accurate technique compared to many. The main uncertainty comes from the homogeneity (or lack thereof) of the material being assessed. Either the selected monitoring volume (drum, 1 m<sup>3</sup> builder's bag, loader bucket, in situ area) can be assessed directly or the volume can be sub-sampled. For full volume monitoring, good results can be produced for material such as:

- Brick and concrete rubble;
- Soil;
- Shredded low density metal; and
- Low atomic number, low density, materials generally.

An important point is that it is generally necessary to have a volume of known clean material to act as a background. One reason is because natural activity in the material will produce a signal from the detector. Another reason, when monitoring is performed with the material in bags or drums, is that a clean sample will provide at least partial shielding for the detector. Failure to take this point into account can lead to a clean sample apparently having negative artificial activity. For sub-sample monitoring, the accuracy is less dependent on the material and density but is much more dependent on homogeneity (or the lack thereof). The various measurement techniques are described below. In all cases, it is worth bearing in mind that doubling the detector linear dimensions will tend to reduce the time taken to monitor a particular volume of material by a factor of at least 4.

#### **(a) Monitoring using a relatively small hand-held detector and gross gamma detection**

This approach generally uses a fairly simple ratemeter connected to a probe by a cable about 1 metre in length.

##### Detector types:

Sodium iodide scintillation detectors, plastic scintillation detectors

##### Essential attributes:

The detector should have a reasonably large area and a significant probability of detecting any gamma photon that strikes it. Most popular is the 2 inch diameter, 2 inch thick, sodium iodide scintillator. Increasing the diameter reduces the maximum missable activity effectively but there is little point in increasing the thickness. Large plastic scintillators are also useful and have the advantage that for the same weight they have a larger area which will even out fluctuations due to activity inhomogeneity.

Generally, they are set up with an energy threshold of less than 60 keV. This is as much for the convenience of testing and calibration as for operational use as <sup>241</sup>Am is the most convenient and widely available low energy (60 keV gamma) source.

The mode of operation is to hold the detector in virtual contact with the volume to be monitored and to note the count rate. **The background count rate, derived, for preference, from a known clean volume of the same material is then subtracted** and the net count rate divided by the detector response in counts per second per becquerel per gram.

Calibration is best achieved using a representative load which is contaminated to several times the acceptance limit with the appropriate nuclide mix. This is only rarely possible but can be found, for example, when decommissioning fuel cooling ponds where the surface is likely to be much more contaminated than the bulk. The average activity in a well mixed volume can be established by gamma spectrometry and radiochemistry. This value can then be used to divide the net count rate from the normal monitor to derive a response in counts per second per Bq per gram which can, in turn, be used to calculate the acceptance limit.

Alternatively, and generally more practically, the net count rate can be calculated using a deterministic or Monte Carlo based code designed to model interactions both within the load and the detector. The accuracy of the programme can generally be checked by calculating the response to a source buried in a defined position within a load. This can then be checked by reproducing the situation with a real source and measuring the real count rate. Agreement between the calculated and experimental source will give confidence in the bulk load prediction.

A very simple method of predicting the response is to treat the source as semi-infinite and to calculate the surface dose rate. This can then be combined with the measured dose rate based on the energy response of the detector to the major gamma line to give a corresponding count rate. Generally that will give a result which is lower than the true value.

Setting a limit for monitoring on that basis will mean that monitoring is conservative. This is not a problem where the material to be processed has a low natural gamma activity level and where the vast bulk is expected to be genuinely clean.

The equipment is easy to use and much tougher than surface contamination monitoring equipment. Any measurement is also derived from a significant mass of material, given the penetrating nature of gamma radiation.

#### Potential problems:

Lack of homogeneity can be addressed by making several measurements round the volume of interest, for example one on each side of a builder's bag and one on top, and averaging the answer. Monitoring of material in an excavator bucket can use the same approach except that measurements made through the side of the bucket will have to be corrected for the attenuation in the bucket walls, which can be up to 15 mm thick steel.

Measurements cannot be made close to edges of the load but must be made in positions where the load fills the view forward from the detector. The measurement is also potentially susceptible to either missing hot spots or overestimating the bulk activity if activity might be present in discrete pieces, such as fuel particles or radium luminised dials. In this case, it is almost always worth searching for such objects before final monitoring. The simple way to do this is to spread excavated material in a thin layer on a floor and walk over it with a sensitive gamma monitor. A better way is to pass the material in a thin layer down a conveyor belt under similar detectors fitted with an alarm. Any hot spots can then be picked out before final checking for average bulk activity. Alternatively, where multiple position measurements are made, two criteria can be set; one is that the mean count rate should be below a defined value and the other is that the maximum should be below a higher defined value. This latter approach will check that there are no hotspots in the outer layer of a bagged load but, ultimately, in any significant weight or dimension of material, there is a fraction of the material in the centre of the load which is effectively not monitored. Hence, bulk monitoring without an initial thin layer search is best applied to material which is unlikely to contain significant hotspots. See section 4.4.2 for guidance.

The technique is also best employed where the material to be monitored has a low natural activity or, at minimum, has a low and consistent natural activity. Problems can arise with building rubble where the natural activity per gram can vary from less than 0.1 Bq/g in flint concrete to several Bq/g in granite, tiles and glazed sanitary ware. It is important to ensure that mixed activities are not present in one bag and that the limit is adjusted for each material type to allow for the changes in background activity. For clearance where the gamma component of the fingerprint is low, it will not be possible to employ simple gross gamma monitoring techniques for materials other than those with negligible natural activity.

#### Signal processing:

Measurements can often be made in ratemeter mode where the fingerprint is dominated by energetic gamma emitters and the natural activity levels are low. In this case, the background count rate will be low and the limiting count rate will be much higher. The normal approach is to calculate the net count rate corresponding to the limiting activity and add the background count rate. This then becomes the technical acceptance limit. Most programmes introduce a note of caution here and give the operator two other limits; one is significantly below that count rate and is the count rate where it is statistically unlikely that the activity exceeds the limit, allowing for reasonable measurement uncertainties, including the statistical fluctuation of the indication. The other is one above the theoretical acceptance limit where it is statistically unlikely that the material is below the limit. Material that meets the first count rate limit goes into the comply stack, material that exceeds the second value goes into the fails to comply stack and any material in between goes into a stack for further examination.

For more difficult objects, timed counts can be used. This removes the subjective nature of ratemeter measurements and allows for the statistical power of each measurement to be selected. The longer the counting time, the less the uncertainty in the final estimate of count rate. The detector does not need to be held still during this process. It can be moved over the surface to be monitored (provided it isn't taken too near the edge) and thus give an average answer for the surface. Using reasonable monitoring times of up to 60 seconds per side can reduce the maximum missable average activity by a factor of 3 compared to ratemeter measurement.

**(b) Monitoring using a relatively small hand-held detector and a counting window**

This generally uses the same type of equipment as for gross monitoring but with the addition of an electronic energy counting window which helps to reduce background count rate.

Detector type:

Sodium iodide or caesium iodide scintillation detectors attached to a simple analyser with a lower and upper energy threshold

Essential attributes:

These units use one of the types of detector and monitoring techniques as for gross gamma monitoring, except that they have an element of energy selection. This can reduce the maximum missable activity compared to the simple case, particularly for materials which naturally have significant and variable levels of gamma emitters with energies above those of the potential contaminants.  $^{40}\text{K}$ , which is found in many minerals, is the commonest example. The usual way to employ these is to set the energy threshold (if there is only one) just above the energy of the potential contaminant. For  $^{137}\text{Cs}$  ( $E = 662 \text{ keV}$ ) this would be set at about 720 keV. Counts in the top channel are unaffected by the presence of  $^{137}\text{Cs}$ . If the material under examination is uncontaminated then the ratio of the count rate in the high channel ( $> 720 \text{ keV}$ ) to that in the lower channel will be effectively constant and will not depend on the natural activity level.

Potential problems:

The technique cannot be used where the energy of the contaminant is close to that of the naturally present gamma emitter. Good examples are  $^{60}\text{Co}$  as the contaminant (1.17 and 1.33 MeV) and  $^{40}\text{K}$  as the natural nuclide (1.41 MeV). Similarly there are problems with  $^{137}\text{Cs}$  (662 keV) and  $^{214}\text{Bi}$ , derived from  $^{238}\text{U}$ , which has its major line at 609 keV.

The technique also shows no advantage over gross gamma counting where the contaminant is the same nuclide or nuclides which are present in the natural activity. For example, where the natural activity is mainly the  $^{238}\text{U}$  chain, the major gamma emitters are below  $^{226}\text{Ra}$ . Hence the technique cannot be used where the potential contaminant is  $^{226}\text{Ra}$ .

Compton interactions from higher energy natural activity will also contribute to the background in the counting window, increasing the maximum missable activity.

Signal processing:

The count rate in the high channel can be used to predict the count rate in the lower channel. This predicted value can be subtracted from the measured count rate in the lower channel to leave a net count produced by contamination which can be compared to the limit. The main problem with this is that both numbers have a significant statistical variation. Even for uncontaminated materials, the subtraction of one quite large number (the reference background count) from another (the observed count from the sample under examination) can give quite large positive or negative results. These some people may find difficult to accept.

The net count rate can then be compared with the value predicted from a calibration exercise similar to the process used for gross gamma measurement. Again, the best approach is to separate materials into the definitely acceptable for clearance, the definitely unacceptable and those where the uncertainty in the measurement is such that a confident decision cannot be made. This last group can then be examined more thoroughly to establish its true level.

**(c) Monitoring using a relatively small hand-held detector with spectrometry**

This approach is a further advance on the use of an energy window, as discussed above. It offers the ability to deal with more complicated situations by producing a detailed energy spectrum which the user can interpret.

Detector type:

Sodium iodide or caesium iodide scintillation detectors attached to a multi-channel analyser. Manufacturers have also recently introduced portable high purity or hyper-pure Germanium (hpGe) units which have much better energy resolution but are quite bulky and expensive. See section (d) below.

Essential attributes:

The important characteristic of these detectors is the ability to produce a gamma spectrum measurement. The presence of a peak at a particular energy shows the presence of a particular nuclide and the area under the peak above background can be used to determine the activity.

This process can reduce the maximum missable activity in materials with relatively high natural activities and has the advantage over the use of a simple counting window in that it can handle materials where the natural gamma emitters present are more variable, such as road tarmac. Multiple resurfacing and patching can lead to wide variation in the activity and nuclide content of tarmac. Some roadstones have high levels of potassium whereas materials such as tin slag can have a  $^{226}\text{Ra}$  content of several Bq/g, which leads to a  $^{214}\text{Bi}$  and  $^{214}\text{Pb}$  level of close to the same level. These materials emit gamma radiations close to  $^{60}\text{Co}$  for natural  $^{40}\text{K}$  and close to  $^{137}\text{Cs}$  for the radium progeny.

Another very obvious advantage is that the measurement will generally identify the presence of any significant gamma emitter. This can be important as, for example, it can detect the presence of unanticipated gamma emitters, such as  $^{137}\text{Cs}$  derived from fuel failure where only  $^{60}\text{Co}$  from activation was expected.

#### Potential problems:

Sodium iodide crystals are only mediocre spectrometers in that they do not produce a very narrow spectrum for photopeak events. For example, the full width at half maximum spectrum height is about 8% of the peak energy. In the case of  $^{137}\text{Cs}$ , there are significant numbers of counts in channels from energy 610 keV to 710 keV. One energy line from  $^{214}\text{Bi}$  is at 609keV, which will spread up to 662 keV visibly in the absence of  $^{137}\text{Cs}$ . Care is required to separate the signal from the two peaks.

The technique also shows no advantage over gross gamma counting where the contaminant is the same nuclide or nuclides which are present in the natural activity. For example, where the natural activity is mainly the  $^{238}\text{U}$  chain, the major gamma emitters are below  $^{226}\text{Ra}$ . Hence the technique cannot be used where the potential contaminant is  $^{226}\text{Ra}$ .

Another problem is that many of the interactions from a potential contaminant do not appear in the peak channel, because they have either been scattered in the material to be assessed or are imperfectly detected in the crystal. A close study has to be made of this effect to see if using multi-channel analysis actually improves matters.

Sodium iodide detectors also have a significant temperature coefficient. This can lead to a peak energy drift of several percent over normal indoor/outdoor temperature differences. Some instruments use an in-built standardisation source, which will slightly increase the maximum missable activity compared to an equivalent unit without the source. Some use an optical system while others use electronic temperature compensation combined with regular energy calibration, generally using a small  $^{137}\text{Cs}$  source. Whichever technique is employed, it is important that the operators follow the manufacturer's recommendations.

#### Signal processing:

The spectrum from the material under examination should be measured and any peaks identified. Most instruments do this automatically and most also give a net area under the peak, which is the total number of counts in the peak above the background. This value is then compared with the value derived from the calibration process which uses either a measurement of a real sample or a mathematically predicted value, both of which are described above.

#### **(d) Monitoring using a small detector and a rotating load platform**

This reduces the problem of manually monitoring a volume in sufficient detail to identify hot spots

Detector types:

Larger scintillation detectors, hyper-pure germanium (hpGe) detectors

Essential attributes:

This technique keeps the detector stationary and rotates the material to be assessed. There are many advantages to this. One is that the process can be made essentially automatic. Once the bag or load has been placed on the turntable, the process is started and operates in a defined and predictable way, removing the variability associated with hand held monitoring. Another is that the averaging process takes place automatically, at least in one plane.

The system can also sometimes be set up to identify a lack of uniformity in the signal from the load. The third advantage is that it allows the use of either larger scintillation detectors which would be too heavy (or too expensive) to be hand held. These will reduce the maximum missable activity compared to smaller ones at rate proportional (approximately) to the ratio of the diameters. A fourth advantage is that the detector can be collimated with heavy shielding which can reduce the background by a factor of approximately four quite easily which, in turn, will reduce the maximum missable average activity by a factor of approximately two.

For materials with complicated artificial and/or complicated natural activities, using a fixed monitor also allows the easy use of a hyper-pure germanium detector. These have a vastly improved spectral resolution (compared to scintillation detectors) of about 0.5% which allows the clear separation of gamma lines from natural emitters and contaminants but require either cooling with liquid nitrogen or electrically, both of which are inconvenient (although possible) with portable equipment.

The improved spectral resolution is particularly useful where the potential contaminating nuclide is part of the decay chain of a naturally present nuclide. For example, using the case above, where the natural nuclide is  $^{238}\text{U}$ , the level of  $^{234}\text{Th}$  can be measured with reasonable confidence and used to predict the level of  $^{214}\text{Bi}$  and  $^{214}\text{Pb}$ . These predicted values can then be subtracted from the observed peak heights and the resultant net values used to calculate the level of contaminating  $^{226}\text{Ra}$ .

Potential problems:

There are no real problems with the use of a turntable and sodium iodide and plastic scintillators. Robust turntables are not expensive and do not represent a large safety problem. The detector should not be exposed to vibration from the turntable.

Hyper-pure Germanium (hpGe) detectors pose no real operating problems provided cooling can be assured. The only real problem is in the interpretation of the spectra from the hpGe detectors. One is that it is difficult to separate the 185 keV line from  $^{235}\text{U}$  and the 186 keV line from  $^{226}\text{Ra}$  directly. The normal way of doing this is to look at other lines from  $^{235}\text{U}$  which are present in lower numbers, such as the 142 keV line, and use this to predict the 185 keV line. The problem with this is that the lower energy line is more highly, and less predictably, attenuated than the higher line, particularly if the material being monitored has a high atomic number component. The other method is to measure the activity of the  $^{226}\text{Ra}$  progeny and use that to predict the 186 keV line intensity.

Unfortunately, between  $^{226}\text{Ra}$  and  $^{214}\text{Bi}$  is Rn-222, which is a noble gas with a 3.825 day half-life. This will escape in an unpredictable way from excavated or crushed materials which, in turn, leads to difficulty in predicting the activity of its relatively short half-life progeny,  $^{214}\text{Pb}$  and  $^{214}\text{Bi}$ , leading in turn to a large uncertainty in the true  $^{226}\text{Ra}$  level.

*As discussed in the introduction to A8.2.3, a clean sample of the material of interest is useful to act as a background.*

Signal processing:

This only really differs for the hpGe detectors. Normally, to make the best use of their enhanced spectral resolution, the multi-channel analyser uses at least 1024 and more usually 2048 or 4096 channels.

### **(e) In-situ Ground Monitoring**

In-situ monitoring is often used early in clearance projects to characterise potential surface soil contamination and to make the results available in the shape of a map. The map is then used to guide any soil removal exercise. The equipment can either be man portable or vehicle mounted.

Detector types:

Man-portable equipment generally uses medium sized (76 mm x 76 mm) sodium iodide scintillation detectors. These are about as large as can be carried comfortably for any length of time. Vehicle mounted detectors are generally bigger, up to 100 mm x 100 mm x 400 mm. There is little point going beyond this size as the ability to detect hot spots begins to fall if the detector dimensions are increased. This is because all the detector contributes to the background count rate whereas parts of the detector which are relatively distant from the source do not add to the signal to a significant extent. Vehicles generally carry several detectors to produce a wide monitoring area.

Large volume plastic scintillators have also been employed. These have the disadvantage of poor spectral resolution. They do not, normally, show a photopeak, but it is possible to perform some analysis using the Compton edge.

Essential attributes:

The detectors have to be moved over the area of interest at a reasonably constant height and a reasonably constant speed in order to produce a consistent detection probability. The person guiding the detectors has also to be confident that the area of interest is being covered at the correct pitch, i.e. there are no areas left unmonitored which could compromise the survey. The data has also to be logged against position with sufficient accuracy. This is normally performed by logging the information from the radiation detectors against a reference from a Global Positioning System (GPS) unit. Normally the aim is to produce information at a 1 metre pitch.

Potential problems:

GPS systems require a good view of the sky in order to pick up the satellite signals. This means that GPS does not work in buildings, very close to buildings and under dense tree cover. There are other ranging systems, such as ultrasonic, which can be used in confined spaces. Man-portable systems are easy to move at a slow pace but this is more difficult for vehicles and it is essential that the vehicle is chosen with care. For many desired maximum missable activities for point sources or hot spots, the maximum speed will be about  $1 \text{ m.s}^{-1}$ . This, in a more familiar unit, is just over 2 mph, which is below most vehicles' minimum speed i.e. the speed in the lowest gear at idling rpm.

Background changes are also likely, especially on a big site. These can be caused by changes in geology, the presence of roads and buildings and the influence of radiation leakage from active buildings. Collimation is not possible for man-portable units as it would be too heavy. This means that the radiation signal changes with position are more blurred than would be the case if a collimator was used.

The results are heavily biased towards the surface activity. The radiation from buried activity will be quickly attenuated by any covering. Hence, the process has to be used with care where there is any possibility that unacceptable activity has been buried by top dressing or by building floor slabs.

*For units used outdoors, temperature stabilisation or correction is required. See section (c)*

### Signal processing:

The normal approach is to perform limited pulse height analysis. One common set-up is to have 3 channels, one from the minimum energy threshold up to the low energy side of the photopeak for the energy of interest, one encompassing the photopeak and one from the high energy side of the photopeak upwards. In many situations, the shape of the background spectrum does not change drastically, only its intensity. The high energy channel is unaffected by the contaminant of interest. The photopeak channel will include any full energy detection of the energy of interest and a proportion of the background radiation signal and the low energy channel will contain more of the background, Compton interactions produced within the detector by the radiation of interest and Compton scattered radiation generated in the soil etc by the contaminant.

Fairly efficient background correction is then performed by determining the photopeak to high energy channel count rate ratio in a known uncontaminated area. During the actual survey, the high energy channel count rate is multiplied by this ratio and the number subtracted from the photopeak counts to remove, as far as possible, the background contribution. The low energy channel can also be corrected in the same way to leave the Compton scattered signal from the radiation of interest. The ratio of the photopeak channel to the background corrected low energy channel depends, to an extent, on the depth of burial of the contaminant.

Depending on the circumstances (nuclide of interest, background level, desired maximum missable activity etc) the calculation algorithm may use corrected photopeak counts or the sum of the corrected photopeak counts and the corrected low energy channel for detection of the presence of a particle or contaminated area. Increasingly, once a possible area has been identified, an alarm is sounded, the vehicle is manoeuvred to maximise the signal and the same detectors used with full multi-channel analysis and a longer count time to produce a definite identification. The decision on when to sound the alarm has a big influence on the cost of a survey.

A low alarm level will give a low maximum missable activity but will also give more false positives and slow the process down. Once all the radiation and GPS data has been gathered, it is plotted using a Geographical Information System (GIS). Generally this uses colour coding based on count rate to produce a picture of any potential problem areas.

Measurements are typically on a 1 metre grid. Plotting the raw results will often result in areas which are hovering between one colour and another. Part of the GIS operation is to set rules for averaging over adjacent areas. It is important that these rules are set carefully, particularly when dealing with potential hot spots, otherwise it is possible to blur over a real hot spot.

## **(f) Conveyor belt monitoring**

Bulk monitoring is subject to the criticism that concentrated activity (a hot spot) can be buried in the centre of the averaging volume and thus be difficult, or impossible, to detect. Conveyor belt monitoring is a way of tackling this problem.

### Detector types:

Larger scintillation detectors, hyper-pure germanium (hpGe) detectors.

### Essential attributes:

This technique has been mentioned above as a useful means of dealing with demolition rubble etc which potentially contains high activity particles or objects. It is, in principle, easy. The material under examination is crushed to a reproducible size and loaded into a hopper. This then feeds a conveyor belt which moves under a collimated detector. Any of the types described above can be used. If an excessive activity is observed then the conveyor can be set to stop automatically so the area in view can be hand searched or it can be automatically diverted to feed the “non-compliant” container rather than the “compliant” container.

The material to be monitored is in a much thinner layer than for bulk monitoring. This means that the whole volume of the material is monitored fairly evenly, rather than having a strong bias towards the surface layer

### Potential problems:

Generally the technique demands several extra stages in the process compared to monitoring in a loader bucket, for example. Equipment such as conveyors and crushers require maintenance and pose their own safety hazards. There is additional noise, the potential for increased airborne dust and radioactivity levels and power consumption. The equipment is also much more expensive than that required for static monitoring.

Processing large volumes of material close to the detectors can also lead to background changes. It is important that large volumes of material, whether clean or active, are not stored close to the detectors.

### Signal processing:

The material to be monitored passes under the detector or detectors. An essential attribute is that any potentially unacceptable volume or object is under the detector long enough for the system to identify its presence reliably and also long enough so that normal background levels do not lead to false alarms. This speed is readily calculable. The bigger the detector and the larger the permitted averaging volume, the quicker the conveyor belt can run.

**(g) Box Monitors**

Surrounding a volume of interest with detector in the form of a box means that a very large fraction of the radiation escaping from that volume will be detected. The external walls of the box can also be designed to provide efficient background shielding. The unit can also include a weighing machine. The weight of the sample can be used to correct for self-attenuation and also to calculate results directly in Bq/g when combined with the fingerprint.

Detector types:

Large plastic scintillation detectors

Essential attributes:

These are monitors where the material in question is placed inside a monitor which effectively surrounds the load. In some monitors, all six sides of the monitor volume are detectors, in others only some are detectors. In any event, the design leads to a vastly increased probability of a gamma photon escaping from the load actually striking the detector. Not only is the detection probability increased but the background shielding is also greatly increased, generally using lead built into the doors, base and sides. Hence, the contribution from external background is greatly reduced, often by a factor of ten or more compared to the unshielded condition. It makes no change to the contribution from natural activity within the load, however. Hence the equipment makes a much better assessment of the number of gamma photons escaping from the load.

The size is varied to match the monitoring volume, with small monitoring volumes for small objects such as tools and plastic bags of low current electrical cable and small diameter conduit, up to large ones capable of taking a 200 litre drum or bigger. These are often equipped with a roller conveyor onto which the object is loaded, pushed into the chamber, the conveyor lowered and the door shut.

These monitors are only suitable for gamma emitters but can achieve dramatically low maximum missable activities approaching 30 Bq for small bags of cable potentially contaminated with  $^{60}\text{Co}$ . This level is below anything which could be achievable with hand beta monitoring for distributed activity, and is comparable with the limit for a careful technician for an individual spot.

Another common material for which they are particularly suited is paper, such as old process records which have been stored technically in an active area but for which the history indicates that contamination should be zero or close to negligible. Paper is impossible to surface contamination monitor to levels suitable for unrestricted release because of its low mass per unit area. This is discussed elsewhere in this document and box monitoring is really the only practicable way of assessing it, particularly if the potential fingerprint has a low gamma to total activity ratio.

Most types use plastic scintillation detectors in the gross gamma mode. Plastic scintillators can be made in very large sizes much more cheaply than other effective gamma detectors. Some units also include a large sodium iodide scintillator to give spectrometric capability.

### Potential problems:

The units, even the small ones, are very heavy and are best built up and left in one place. The background reduction relies heavily on good shielding continuity and clumsy assembly or transport can lead to shielding damage. They are best used for materials with very low natural gamma activity levels as the majority have no spectral resolution. Even though they are very well shielded, keeping the external background relatively constant will reduce uncertainties in the final result.

The maximum mass of material to be monitored will also be limited where there is a possibility of hot spots. The dimensions of the sampling mass have to be sufficiently small so that a hot spot of the maximum acceptable activity can be detected even at the centre of the mass.

### Signal processing:

These are normally used in the gross gamma mode. The count from each detector is integrated for the selected counting time and compared with a previously measured background. The resultant net count is then compared with the limit derived, generally, from theory and backed up by experiment. If the level is exceeded, the alarm is shown. Some types go further and show which detector or detectors are over the limit. This allows the operator to search the load and perhaps identify and remove any contaminated object.

### **(h) Vehicle monitors**

Many sites use monitors to check on vehicles leaving the site. It is essential to appreciate that these monitors should not be used for sentencing. They are very useful as a final check to follow that there has been no failure in determining the history of materials, that procedures have been followed correctly and that no unexpected activity has been found. Typical reasons for legitimate alarms include radium luminised instruments, radium based lightning attractors and, on occasions, steel which has been carefully monitored for surface contamination but which has unexpectedly been activated by neutrons from a reactor.

The other reason is that material may well comply with the clearance criteria adopted but may be unacceptable to recycling companies. These companies normally take a simple approach to scrap metal. That is that they will not accept scrap which sets off their vehicle monitor. Hence, it is important for the nuclear site to be able to despatch loads for recycling with a good degree of confidence that they will be accepted at the far end.

Detector type:

The detectors employed are generally large slabs of plastic scintillator up to a total of 60 kg on each side of the vehicle. These are supported on stands at about the mid height of a typical scrap load. Untreated random steel scrap has a surprisingly low density of around unity which means that the boxes in which it is transported are approximately 2.5 metres deep. The stands are generally made of thick steel, mainly to produce some back shielding. Each slab has one or two photomultipliers coupled to it.

Essential attributes:

The local background should be as low as possible. The units have only very simple energy analysis and generally on gross count rate above a low energy threshold. They are thus more susceptible to background interference than sodium iodide based detectors, for example.

There is another dimension to the influence of background. This is that a vehicle carrying 20 tonnes of scrap steel will produce significant background attenuation. A clean load can depress the background by 25%. The unit makes an attempt to predict this depression while it is analysing the count rates produced as the vehicle passes between the detectors but the higher the local background the more difficult and uncertain this prediction becomes.

Potential problems:

The units work well for steel, which has a low normal activity. However, they will often alarm if asked to check material with a high level of natural activity such as red brick, granite blocks, fertiliser and ceramics.

They can only detect gamma radiation outside the vehicle and work best for sources close to one side of the load. If a shielded source is buried within a dense load, such as a set of RSJs aligned on the floor of the vehicle, then the maximum missable activity can be many orders of magnitude higher.

Another use of these units is for security applications where they are sometimes used in parallel with an X-ray system to check for areas that are very well shielded. This approach is not normally employed in the monitoring of scrap metal etc.

They also interpret voids in a load as a potential source. The voids give much reduced local shielding and thus a peak in the count rate. See below.

### Signal processing:

The area has to be sufficiently large to allow trucks to pass slowly between the detectors. The units continuously monitor the background count rate in the absence of a vehicle and thus can accommodate changes in background caused by rainfall (radon progeny washout) and site operations. The recommended speed is generally about 3 mph. It is measured using a pair of light beams which detect the arrival of the vehicle and estimate its speed. As the truck passes between the detectors, the unit records the count rate several times per second from each detector. It will alarm in 2 circumstances. One is when the count rate exceeds the previously measured background by a statistically significant value. This would correspond to a light weight vehicle with a source in it or to a loaded vehicle with a significant generalised activity within the load. The other is where the count rate falls as the vehicle enters, then rises and falls again before rising when the vehicle leaves. This would correspond to a source within a load of scrap. The alarm may be triggered even if the peak count rate does not reach normal background level. The same effect can also be produced by a void in the load.

### **A8.2.4 Direct Alpha Surface Monitoring**

This normally uses either standard radiation protection monitoring equipment or the same ratemeter but with a larger area detector.

#### Detector types:

Zinc sulphide based scintillators, gas flow and gas refillable proportional counters, large area silicon diode detectors and blown ion chambers.

#### **(a) Direct probe monitoring**

##### Essential attributes for direct probe monitoring:

- Large area, at least 100 cm<sup>2</sup> for clearance. This is essential to allow reasonably fast coverage of a surface at clearance levels.
- A thin window. Alphas have a very short range. The limiting window thickness is about 1 mg/cm<sup>2</sup>
- Good beta and gamma rejection. Acceptable residual alpha surface activity levels are generally not more than 0.1 Bq/cm<sup>2</sup>. At this level, for a 100 cm<sup>2</sup> detector, a typical count rate is about 2 to 3 counts per second. Any response to the all pervasive gamma radiation will produce a background count rate which completely masks the alpha signal.
- Virtually no alpha contamination of the detector. Again, any significant alpha contamination will conceal the count rate from the acceptable residual alpha surface activity level.
- The ability to be held close to, and at a consistent distance from, the surface of interest. For practical detectors the count rate can halve if the detector is moved from

a 3mm surface to detector separation to 10mm. For clearance monitoring of objects with flat surfaces, where the object is virtually always clean, stick-on feet on the detector are useful because they allow it to be placed directly on the surface in a fixed geometry. This increases the quality of the measurement. The feet can be replaced easily if there is any reasonable chance they have become contaminated.

#### Potential problems:

*Some scintillator based types are very sensitive to magnetic fields.*

These cannot be used on anything with a significant magnetic field such as a steel beam, many tools and some electrical equipment. As an illustration, a large screwdriver which had been magnetised to the point where it would just hold 4 normal paperclips reduced the count rate from an alpha source by a factor of 4 when held close to the source. Some manufacturers incorporate mu-metal shields as standard which greatly reduce the magnetic susceptibility of the probe. The other manufacturers can generally offer such shields as an option.

Window damage is very likely for any alpha detector. This has to be repaired before further use.

Gas refillable detectors are best regularly filled with counting gas. They do not like being brought back into service after a long period of disuse. The gas is also generally flammable.

Large area silicon diode detectors are generally very susceptible to radiofrequency and other electromagnetic interference.

#### Signal processing:

**Ratemeter mode** - In this method, the count rate is averaged over a few seconds and displayed. Interpretation of a fluctuating signal requires skill and is difficult to audit. Detection is by an audio signal, a beep for each alpha detected. The user moves the detector slowly over the surface of interest. When a significant beep rate is found, the user maximises it, watches the ratemeter for a few seconds and estimates the average.

**Counter-timer mode** - In this method, the detector is placed on the surface and the count rate integrated for a short, pre-determined, time. This value is generally recorded and compared with a pre-determined limiting value. The detector is then moved to the adjacent area and the process repeated. The advantage of this technique over the use of a ratemeter is that the level of skill is much less and is far easier to audit.

#### **(b) Blown ion chamber alpha monitoring**

This is analogous to the use of box monitors for gamma radiation monitoring in that the object of interest is placed inside a chamber.

#### Detector Type:

Ionisation chamber

### Essential Attributes:

This technique involves placing dust-free objects in a moving stream of air which subsequently enters an ionisation chamber. Any ions generated in the air can be collected and measured. The ion current is then a reasonable measure of the alpha activity on the object. The technique works really well for objects such as pipes with diameters in excess of 25 mm and will even work for complicated objects such as valve bodies with blind holes, provided that the air stream at some point blows directly over or onto the end of the hole.

The normal technique is to load the object into a closed space through which filtered air is sucked. The air then passes through an ion chamber and into a high efficiency particulate air (HEPA) filter to avoid any contamination being released.

The technique has a very much lower beta contamination sensitivity because alpha particles deposit large amounts of energy in a few cm whereas beta particles either have a much lower average energy or have a range which is a factor of more than 100 times higher. Hence restricting the collecting volume of the machine means that the charge deposited per unit activity is much lower for betas than alphas.

### Potential Problems:

Like all direct alpha monitoring, the alpha activity has to be on the surface to be detected efficiently and not concealed by paint or rust.

The object has to be reasonably dust free. Dust blown off the surface can lead to high leakage currents from the ion chamber.

The technique does not work well for activity inside long, thin, pipes as the average charge deposited per alpha drops as the diameter decreases. This is because the path length in air decreases and much of the energy of the alpha particle is deposited in the walls of the pipe. It is very effective for scaffolding poles, for example, but far less so for pipes below about 10mm in diameter.

It will work for some painted metal objects well but not for objects with a very high surface insulation level such as plastic. The electrostatic potentials which build up on insulating objects will tend to collect ions.

Inside very long pipes, the air velocity tends to be low and the transit time long, which means more of the positive and negative ion pairs will recombine, leading to a loss of signal.

Signal processing:

Unlike other alpha techniques, the signal is a current rather than a pulse. This is collected in a multi-plate ion chamber and amplified. Generally the mean current is determined during the monitoring period, divided by a calibration factor derived from placing a source of known activity in a variety of positions on and in a test object and displayed. For monitors with a rotating table, additional information is provided by a current against time graph. A skilled operator can determine from this display whether the activity is on the outside of a valve body, for example, which is exposed constantly to the air flow, or inside the object where the air flow is periodic.

Maximum missable activity in or on a full length (6 metre) scaffolding pole can be as low as 30 Bq in good conditions.

**(a) Use of a Sorting Table**

Instead of hand monitoring, where the detector is moved over the surface of interest, the objects can be placed on a large surface detector.

Detector type:

Thin windowed, gas flow, proportional counters

Essential attributes:

Hand alpha monitoring is demanding, slow and repetitive. One way round this for objects which are basically thin and which cannot be placed in a blown ion-chamber monitor is the use of a sorting table. This technique works for relatively non-absorbent materials such as rubber gloves. The table is generally derived from a personnel walk-in monitor and comprises an array of thin windowed, gas flow, proportional counters protected by a grille. Objects to be monitored are placed on the table and counted for a fixed period. At the end of the period, they are turned over and the process repeated. As a variation on the technique, the objects can be passed between two position sensitive gas flow proportional counters.

Limitations:

The technique cannot achieve levels for unrestricted release for alphas and absorbent materials such as fabric coveralls because of the potential for very high levels of self-absorption within the material. It is also difficult to use for many-sided objects. For conventional counters, the signal is recorded on a detector by detector basis, which means that the count is automatically averaged over the detector area, even for objects which are much smaller than the detectors.

Even with non-absorbent materials, the technique will not work for very thin samples, simply because the bulk activity level has to be translated into a surface level. This is considered in detail elsewhere but, essentially, as the bulk activity level is 0.4 Bq/g, the total activity (sum of both sides) of a surface contaminated object must be less than  $0.4/T$ , where  $T$  is the mass per unit area in  $\text{g/cm}^2$ . For a pair of thick gloves, this works out at approximately  $0.02 \text{ Bq/cm}^2$  on each side, assuming the inside is clean and that there is no significant absorption within the material. This level is achievable. However, it is not achievable for a sheet of paper, where the one side limit is approximately  $1.6 \text{ mBq/cm}^2$ . Other methods must be used and provenance is of key importance.

#### Signal Processing:

For static monitors, the count rate is integrated during the counting period and compared with a background measured with the table empty. The net count rate is then compared with a limit derived from experiment.

For units with position sensitive counters and a moving belt the counts are integrated for each area as the object moves and presented to the operator on a colour display. The operator can then take out any demonstrably active object.

#### **A8.2.5 Direct Surface Beta Monitoring**

This normally uses either standard radiation protection monitoring equipment or a standard ratemeter but with a larger area detector.

#### Detector types:

Large area, thin window, thin beta scintillators and large area proportional counters (Conventional GM types, either thin wall or thin window, have an inadequate area for use at low levels).

#### Essential Attributes:

Large area, at least  $100 \text{ cm}^2$  for clearance. This is essential to allow reasonably fast coverage of a surface at clearance levels.

Detectors can be used hand-held or in the form of a sorting table or conveyor belt monitor, as described above for alpha monitoring. Blown ion chambers do not work well for beta contamination because of lower energy of even energetic beta particles, combined with a longer range.

A thin window. In most circumstances the bulk of the beta radiations present will have relatively low energies. A thin window is essential to allow efficient detection. Sometimes, if there is a major energetic component such as  $^{90}\text{Sr} + ^{90}\text{Y}$ , then a thicker window gives better robustness and also makes the count rate less dependent on the self absorption within the surface of short range components. These will not get through the thicker window.

Good gamma rejection. Acceptable residual beta surface activity levels are generally not more than  $0.4 \text{ Bq/cm}^2$ . At this level, for a  $100 \text{ cm}^2$  detector, a typical count rate is about 10 counts per second. Any excessive response to the all pervasive gamma radiation will produce a background count rate which completely masks the beta signal. The thinner the scintillator the better, provided it is strong enough.

Virtually no alpha or beta contamination of the detector. Any significant alpha or beta contamination will mask the count rate from the acceptable residual beta surface activity level. Note that all detectors with a response to low energy beta emitters will detect alpha activity.

The ability to be held close to, and at a consistent distance from, the surface of interest. For practical detectors the count rate for soft beta emitters such as  $^{14}\text{C}$  can halve if the detector is moved from a 3mm surface to detector separation to 10mm. For clearance monitoring of objects with flat surfaces, where the object is virtually always clean, stick-on feet on the detector are useful and allow it to be placed directly on the surface in a fixed geometry. This improves the quality of the measurement. The feet can be replaced easily if there is any reasonable chance they have become contaminated.

If the nuclides of interest have a higher energy, e.g.  $^{90}\text{Sr} + ^{90}\text{Y}$ , the detector can be held further from the surface. For uniform contamination the count rate will not change out to a few cm. The major change is that the further from the surface the detector, the bigger the averaging area and the lower the count rate from a localised spot of contamination.

#### Potential problems:

Some scintillator based types are very sensitive to magnetic fields. These cannot be used on anything with significant magnetic field such as a steel beam, many tools and some electrical equipment.

Window damage is very likely for any beta detector. This has to be repaired before further use.

Gas refillable detectors are best regularly filled with counting gas. They do not like being brought back into service after a long period of disuse. The gas is also generally flammable.

#### Signal processing:

Processing generally follows the previous section. However, for clearance monitoring using scintillation detectors particularly, it can sometimes be possible to set a counting window, rather than just a simple threshold, particularly if relatively low beta energies are expected. The low energy threshold is set as normal, but, in addition, a high energy limit is set, using either an appropriate calibration source or a real contaminated object, which allows most of the signal from the contaminant to be detected but reduces the background count rate. This reduces the maximum missable activity.

### **A8.2.6 Direct Surface X and Low Energy Gamma Monitoring**

This normally uses either standard radiation protection monitoring equipment or a standard ratemeter but with a larger area detector.

Detector Types :

Thin sodium iodide scintillators, thin caesium iodide scintillators, extended energy range beta scintillators and Xenon filled proportional counters.

#### Essential Attributes:

In a similar way to beta monitoring, the detectors can be used hand-held or as part of sorting tables or conveyor belt monitors.

They require a reasonable area. Unlike alpha and low energy beta radiation, the effective range in air of even the lowest X-ray emitter of interest,  $^{55}\text{Fe}$ , is several cm. Monitoring does not have to take place in contact with the surface. This reduces the number of separate measurements required to cover a given area. However, the background count rate of such detectors is generally higher per unit area than for beta detectors. Hence it is important to have a reasonably large detector area to improve detection of the radiations of interest. Perhaps counter-intuitively, increasing the response to a particular activity level and increasing the background by the same factor produces an answer of greater statistical significance for a given counting time. The variability between successive measurements on average reduces as a percentage with a higher count rate although it increases as a number of counts. Subtracting background thus gives a result which shows a smaller fractional variation on average over a number of measurements.

Popular sizes of sodium iodide and caesium iodide scintillation detector range from 32 mm diameter to 125 mm. Detector thickness is generally 2 to 3 mm. This gives a high detection efficiency for X radiation from  $^{55}\text{Fe}$  (activated steel), plutonium and  $^{241}\text{Am}$  and for  $^{241}\text{Am}$  gamma radiation. For the detection of the very low energy radiation from  $^{55}\text{Fe}$ , the window should be beryllium but for high energies thin aluminium is satisfactory. Normal beta detecting scintillators can also be used for very low energy nuclides such as  $^{55}\text{Fe}$  (5.9 keV) provided very efficient light detection is used, together with very low noise photomultiplier tubes. These can use normal aluminised melinex windows.

#### Potential Problems:

Some scintillator based types are very sensitive to magnetic fields. These cannot be used on anything with significant magnetic field such as a steel beam, many tools and some electrical equipment. There is also a relatively limited set of calibration sources available which can make the prediction of the response difficult.

#### Signal Processing:

See the previous section. For low energy X-radiation detection, the technique of using a counting window, rather than a simple threshold, is particularly useful for detectors with reasonable energy resolution such as the sodium and caesium iodide scintillation detectors.

### **A8.2.7 Tritium Surface Activity Monitoring**

*It cannot be emphasised too much that the assessment of surface tritium activity is close to meaningless.*

The mobility of tritium is such that it can diffuse into surfaces to depths of millimetres relatively easily. In some real cases, the concentration gradient of tritium reverses. Instead of falling with depth, as for most contaminants, it increases for a significant depth, peaks and then falls. This is common where the tritium exposure has stopped some time previously. The tritium then begins to diffuse back out of the surface, reversing the concentration gradient.

Tritium must be treated as a bulk contaminant. In painted surfaces, for example, the tritium concentration in the paint can be much higher than in the underlying concrete or brick, by up to a factor of 10. The first bulk layer is thus the paint. This topic is discussed further in bulk monitoring.

However, there have been cases where careful wiping (see below) has yielded reasonably consistent results against the activity in a paint layer. If there is a large area of painted surface to be assessed, it may well be worth taking a series of wipes and adjacent samples from areas where the paint is the same and comparing the two sets. If the results are reasonably consistent, wiping will enable a much bigger fraction of the surface of interest to be assessed than sampling followed by radiochemistry.

### **A8.2.8 Surface Monitoring by Wipe (Excluding Tritium)**

This code requires that the level of removable surface activity is essentially zero. Wiping is normally used in the fingerprinting process and as a confirmation that removable activity is indistinguishable from zero, given reasonable counting times etc. This is discussed fully in section 7.3

In effect, during the fingerprinting process, at least part of the surface of interest has to be capable of reasonably accurate assessment by direct monitoring. This can then be wiped and the count rate from the wipe compared with the estimated removable surface activity generated by direct monitoring to produce a calibration for the wiping process. Even where the bulk of any activity is expected to be firmly fixed to a surface, wiping can be useful. This is where it would be attractive to be able to estimate removable activity to a much lower level than can be achieved by direct monitoring assuming all activity is removable. (It is impossible to demonstrate that the level of removable activity on any contaminated surface is truly zero) If the surface is smooth, it may be possible, with care, to monitor up to an area of 1 m<sup>2</sup> by wipe, which can lead to maximum missable activities of less than 0.01 Bq cm<sup>-2</sup> of both alpha and beta activity.

It is important to emphasise at this point that monitoring by wipe is a very uncertain process. The various aspects of this uncertainty will be discussed in each section.

Procedure:

The area to be wiped should be identified and gridded out. The material for the wipe should be selected. Generally, glass fibre based wipes are used as these are reasonably robust, have a good pick-up factor and leave the activity close to the surface of the wipe. However, depending on the chemistry of the expected contaminant, other materials such as thin polystyrene sheet have been used. Wipes can be used dry or moistened with either water or alcohol. The decision between wet and dry wiping depends on the chemistry and physical characteristics of the contaminant, on the condition of the surface being wiped and on the process used to count the activity on the wipes. Dry wiping generally has a lower pick-up factor but leaves activity close to the surface of the wipe where it is easier to count in conventional sample counters. Wipes also tend to be damaged more quickly when used wet and often should be dried before counting.

The wipe should be rubbed with uniform pressure over the area of interest. This is difficult to achieve consistently. Many users fold the wipe twice to give a quarter circle shape. This makes the wipe reasonably stiff which helps the application of a consistent pressure. It is then held in the fingers and wiped over the surface. There are two major uncertainties. One is the effective pressure on the wipe and the other is the fraction of the surface which is actually wiped. There have been holders used which impose a constant pressure which are useful for flat surfaces but that technique is impossible for complicated objects. Both these potential problems, pressure and fraction of the area wiped, can be minimised by training and supervision.

#### Counting:

The completed wipe is, essentially, just another potentially contaminated object for checking. For direct monitoring, the wipe should be unfolded carefully, flattened out and, if necessary, dried. Care should be taken not to knock activity off the wipe. The wipe can then be placed into a counting drawer. For alpha nuclides, these are usually large area silicon diode based but scintillation detectors can also be used. For beta counting, either a pancake GM detector is used or, increasingly, the measurement of beta activity can be made using the same silicon diode detector used for alpha assessment. For the relatively rare situations where the contaminant is a pure gamma emitter, counting will have to take place in a well shielded enclosure using a sodium iodide or hpGe detector. Even when the material is a beta emitter, such as  $^{137}\text{Cs}$  or  $^{60}\text{Co}$ , there may be advantages to using the gamma emissions, as these are not affected by the grubbiness of the wipe. The counting time is selected to give an answer of sufficient statistical power, taking into account background count rate and the efficiency (as a source) of the wipe to demonstrate that the removable activity on the surface is statistically indistinguishable from zero, within the constraints adopted.

For many materials and conditions, it is often better to count the wipe by liquid scintillation. Unless the surface under test is perfectly clean, in terms of grease and grime, the wipe will become distinctly soiled. For short range emissions, this grime may effectively screen the bulk of the activity from a normal alpha or beta detector. Liquid scintillation can help overcome these problems. The activity of wipes placed in the scintillant will often float off, as will the grime. This means that the activity will be in intimate contact with the scintillant. The main problem with this approach is that the grime may adversely affect the scintillant cocktail (quenching), leading to less light generation per decay and may also produce chemiluminescence, leading to false counts.

#### Calculation:

The aim of the process is to make an estimate of the fraction of loose surface activity on a defined surface area which may be missed. This is not trivial. Assessment of the activity on the wipe is difficult, with major uncertainties produced by the effects of attenuation by grime and of driving the activity into the surface. An easy way to get a reasonable correction factor is to count, by whatever preferred routine method, a number of wipes from a known contaminated area which is representative of the total area in question and then to bulk these wipes and analyse these radiochemically. This will yield a good measure of the count rate from the routine instrument per becquerel on the wipe.

The main use of conventional calibration sources is to demonstrate that the counting equipment is typical of type and that it is operating consistently. Using the apparent efficiency in counts  $s^{-1} Bq^{-1}$  to calculate the response to real contamination is only really valid where the condition of the wipe is unimportant. This is the case for direct counting of gamma counting and hard beta radiation. However it is not valid for alpha and soft beta activity assessed using a normal alpha or beta drawer unit.

The most effective approach is to wipe the whole area of interest. However, for large areas it is often satisfactory to wipe a consistent fraction of the area, provided any contaminant is likely to be relatively evenly distributed. The thoroughness and consistency of the area wiped is likely to be one of the major considerations in clearance monitoring. Training can be performed using a light coating of fine but visible powder on a trial surface. Consistency of performance is much more difficult where there is no visible track.

Pick-up factor is conventionally taken as 10%. This has stood the test of time and a variety of practical tests have yielded values between, generally, 10 and 30% for a variety of surfaces, wiping techniques and contaminants but ISO recommends a cautious value of 10%. Moist wipes can yield higher values.

This gives the following equation:

$$K = ((N - B) \times R \times 10) / (T \times A \times F)$$

where K = activity per unit area (Bq)

N = total count over time T

B = background over the same time, T

R = radiochemically derived activity (Bq) per unit count rate

T = counting time

A = area addressed

F = fraction of the area wiped

The factor of 10 corrects for the assumed 10% pick-up

The same equation can be used for liquid scintillation counting.

The uncertainties are extremely large. The aim has to be to produce a value which is conservative even assuming a relatively pessimistic assessment of the uncertainties. If the apparent activity is acceptable then we can have confidence that the real activity meets the criterion.