Public Health England

Protecting and improving the nation's health

UK Recovery Handbooks for Radiation Incidents 2015

Drinking Water Supplies Handbook

Version 4

About Public Health England

Public Health England exists to protect and improve the nation's health and wellbeing, and reduce health inequalities. It does this through world-class science, knowledge and intelligence, advocacy, partnerships and the delivery of specialist public health services. PHE is an operationally autonomous executive agency of the Department of Health.

Public Health England
133–155 Waterloo Road
Wellington House
London SE1 8UG
T: 020 7654 8000

www.gov.uk/phe
Twitter: @PHE_uk
Facebook: www.facebook.com/PublicHealthEngland

Any enquiries regarding this publication should be sent to

Press and Information
Centre for Radiation, Chemical and Environmental Hazards
Public Health England
Chilton, Didcot, Oxfordshire OX11 0RQ
E: ChiltonInformationOffice@phe.gov.uk

Published June 2015
PHE publications gateway number: 2015067

UK Recovery Handbooks for Radiation Incidents 2015

Drinking Water Supplies Handbook

Version 4

J Brown, S Watson and A Nisbet

Abstract

This handbook to assist in the management of contaminated drinking water supplies following a radiation incident has been developed following a series of UK and European initiatives involving a wide range of stakeholders. It is aimed at national and local authorities, central government departments and agencies, radiological protection experts, the water industry and others who may be affected.

The handbook focuses on the management of drinking water as supplied to the public, ie at the tap and not that in drinking water sources such as reservoirs. It includes management options for application in the different phases of an incident. The handbook is divided into several sections which provide supporting scientific and technical information: an analysis of the factors influencing recovery; compendia of comprehensive, state-of-the-art datasheets for 7 management options; and guidance on planning in advance. A decision-aiding framework and worked examples are also included.

The handbook can be used as a preparatory tool, under non-crisis conditions, to engage stakeholders and to develop local and regional plans. It can also be applied as part of the decision-aiding process to develop a recovery strategy following an incident. In addition, the handbook is useful for training purposes and during emergency exercises. The handbook for drinking water supplies complements the other two handbooks for inhabited areas and food production systems.

This study was funded by Department for Environment, Food and Rural Affairs, Department for Transport, Food Standards Agency and UK Government Decontamination Service.

Centre for Radiation, Chemical and Environmental Hazards
Public Health England
Chilton, Didcot
Oxfordshire OX11 0RQ

Approval: May 2015
Publication: June 2015
ISBN 978-0-85951-770-6

This report from the PHE Centre for Radiation, Chemical and Environmental Hazards reflects understanding and evaluation of the current scientific evidence as presented and referenced in this document.

This work was undertaken under the Radiation Assessment Department's Quality Management System, which has been approved by Lloyd's Register Quality Assurance to the Quality Management Standard ISO 9001:2008, Certificate No: LRQ 0956546.

Report version 4.0

Government partners steering group

Department for Environment, Food and Rural Affairs (Defra)

Food Standards Agency (FSA)

Government Decontamination Service (GDS)

Department for Transport (DfT)

Acknowledgements for contributions

Derek Hammond (PHE), Antonio Pena-Fernandez (PHE), Nicholas Brooke (PHE)

Quick Guide to the Drinking Water Supplies Handbook

For what purpose do I want to use the Drinking Water Supplies Handbook?

Planning

Go to Section 4"Planning in advance"

Consider customising handbook for local conditions (eg water sources and water treatment used) using a stakeholder engagement process

Response

Go to Section 5 "Framework for making decisions on a management strategy"

Follow the 8-step process:

1. Determine nature of water contamination and identify water supplies of potential concern
2. Check if immediate action is required to prevent/reduce ingestion dose
3. Set up monitoring of water supplies
4. Identify affected supplies
5. Consult decision tree for management option for type of supply

ELIMINATE OPTIONS

6. Check constraints and applicability of management options for radionuclides released

ELIMINATE OPTIONS

7. Go to Section 7 "Datasheets" for detailed information on options
8. Use information to select and combine options and build management strategy

Training – new user

Go to all sections

Section 1"Introduction"
Section 2 "Management options"
Section 3 "Factors influencing implementation of management options"
Section 4 "Planning in advance"
Section 5 "Framework for making decisions on a management strategy"
Section 6 "Worked examples"
Section 7 "Datasheets"
Consult appendices for supporting information if required

Training – refresher

Go to Section 6 "Worked examples"

This goes through the 8-step process for three examples:

- contamination of water due to deposition from a contaminated plume
- direct contamination of water before treatment
- direct contamination of water after treatment

Contents

1 Introduction to Drinking Water Supplies Handbook

The Drinking Water Supplies Handbook has been developed as a result of a series of European and, in particular, UK initiatives that started in the early 1990s. The handbook should be regarded as a living document that requires updating from time to time to remain state-of-the-art.

Contaminated drinking water supplies - what's the problem?

Following a radiation incident, drinking water supplies may become contaminated and actions may be required to reduce activity concentrations in the drinking water if recommended UK action levels are exceeded. The UK water industry needs to know what the likely impact of such an incident may be on the drinking water that it supplies and how the incident may affect its normal water treatment facilities. Those responsible for private water supplies also need to know what can be done to minimise the radiological impact of any radioactive contamination reaching these water supplies.

How can the Drinking Water Supplies Handbook help?

The Drinking Water Supplies Handbook provides decision-makers and other stakeholders with guidance on how to manage the many facets of the impact of a radiation incident on drinking water supplies. It contains scientific and technical information to assist in the development of a recovery strategy, taking into account the wide range of influencing factors. The handbook is also helpful for contingency planning.

1.1 Objectives of the Drinking Water Supplies Handbook

The Drinking Water Supplies Handbook has been developed to meet several inter-related objectives:

- to provide up-to-date information on management options for reducing the consequences of contamination of drinking water supplies
- to outline the many factors that influence the implementation of these options
- to provide guidance on planning for recovery in advance of an incident
- to illustrate how to select management options and hence build a recovery strategy

1.2 Audience

The Drinking Water Supplies Handbook is specifically targeted at:

- central government departments and agencies

- experts in radiological protection
- the UK water industry
- local councils responsible for ensuring safety of private water supplies
- water laboratories involved in screening of water for radionuclides
- other stakeholders that may be affected or concerned, depending on the situation

1.3 Application

The Drinking Water Supplies Handbook can be considered as a reference document containing well-focused and generic state-of-the-art information on scientific, technical and societal aspects relevant to the management of contaminated drinking water. However, to realise the full potential of the handbook, it should be applied using a process of stakeholder participation. Examples of the most likely applications of this handbook are:

- in the preparation phase, under non-crisis conditions, to mobilise stakeholders and to develop local, regional and national plans, frameworks and tools
- in the post-accident phases by local and national stakeholders as part of the decision-aiding process. This will be part of the strategic multi-agency incident management and co-ordination structure set up to ensure consistency of approach across all aspects of the management of an incident
- for training purposes, for example in preparation for and during emergency exercises

1.4 Context

The primary focus of the Drinking Water Supplies Handbook is radiological protection or, in other words, reducing exposure of humans to radiation. However, experience from past contamination events, particularly the accidents at the Chernobyl nuclear power plant and Fukushima Dai-ichi nuclear power plant, have shown that the consequences of widespread and long-lasting contamination are complex and multi-dimensional. Radiological protection should be considered as only one aspect of the situation. A high level of water quality is an expectation of members of the public in the UK. There is therefore likely to be considerable pressure for water quality to be maintained in the event of a radiation incident. This may not be justified purely on radiological protection grounds and it has been recognised that, to be efficient and sustainable, the management of consequences of radioactive contamination must take into account other dimensions of living conditions, such as economic, social, cultural and ethical factors. Therefore this handbook also addresses aspects that go beyond those of radiological protection (see especially Section 3).

1.5 Scope

The primary aim of the Drinking Water Supplies Handbook is to provide guidance on management options for the reduction of contamination in drinking water and subsequent ingestion doses by those consuming the water. Emphasis is placed on the management of the radionuclide content in drinking water as supplied to the public (ie 'at the tap' and not that in drinking water sources such as reservoirs). The time for contaminated water to reach the point where it is consumed may vary markedly, as discussed further in Section 3.2. This is particularly the case for contaminated ground water sources, where the time could range from a few days to several decades. Also, the contamination in the water supplied 'at the tap' is likely to be considerably lower than that in the water source due to factors such as dilution, water treatment and radioactive decay. It is therefore more helpful to concentrate on managing contamination in the water as it is consumed by the public, rather than the water sources themselves. Some guidance is given on the likely timescales for contamination of different water sources to arise following a radiological incident (see Section 3.1). Bottled drinking water and the use of water as supplied 'at the tap' for other purposes, such as irrigation or drinking water for animals, are not covered in the handbook. General advice on the irrigation of crops in the event of an incident is given in the Food Production Systems Handbook.

The Drinking Water Supplies Handbook provides guidance that is relevant for any type of radioactive contamination of a drinking water supply. The main focus is to give guidance that is relevant for an accidental release from a nuclear site or from the transport of nuclear weapons, but many recovery options will also be relevant to other radiological emergencies such as malicious releases. For this reason the handbook considers a total of 23 radionuclides, chosen on the basis of their radiological importance and relevance; these are listed in Table 1.1. The term 'radiological emergency or incident' is used throughout the handbook to cover both accidents and other releases of radioactivity.

An additional handbook that has been developed to provide a tool for the water industry to manage the potential risks to operatives working within a treatment works (Brown et al, 2008); this is called the 'water treatment handbook' within the remainder of this document. It can be used to help the water industry to make decisions on how the treatment works can be operated in the event of a radiological incident and to manage any radiation exposures to the operatives at the works. It is also expected that the water treatment handbook will be used as a training tool. Worked examples are included to assist users in both planning for a radiological incident and the management of a radiological incident. Information from the water treatment handbook has been used to enhance this Drinking Water Supplies Handbook and key information and data have been included. The two handbooks should be seen as complementary, together providing guidance to the water industry and those decision-makers that would be responsible for managing the response to a radiological incident.

The Drinking Water Supplies Handbook does not attempt to cover all of the topics that could be of concern. In particular, it does not address:

- detailed pre-planning for radiological emergencies including pre-drafted press releases and standard answers
- lists/details of contacts, contractors etc; responsibilities of organisations in the event of a radiological emergency
- a communication strategy
- links between response at different levels (eg local, regional)
- the wider socio-economic issues of blight, compensation, recovery of business, personal and private losses

Table 1.1 Radionuclides considered in the Drinking Water Supplies Handbook

Radionuclide		Half-life*
^{60}Co	Cobalt-60	5.27 y
^{75}Se	Selenium-75	119.8 d
^{90}Sr + ^{90}Y	Strontium-90 + yttrium-90	29.12 y (^{90}Sr) 64 h (^{90}Y)
^{95}Zr	Zirconium-95	63.98 d
^{95}Nb	Niobium-95	35.15 d
^{99}Mo + ^{99m}Tc	Molybdenum-99 + technetium-99m	66 h (^{99}Mo) 6.02 h (^{99m}Tc)
^{103}Ru	Ruthenium-103	39.28 d
^{106}Ru	Ruthenium-106	368.2 d
^{131}I	Iodine-131	8.04 d
^{132}Te	Tellurium-132	78.2 h
^{134}Cs	Caesium-134	2.062 y
^{136}Cs	Caesium-136	13.1 d
^{137}Cs	Caesium-137	30 y
^{140}Ba	Barium-140	12.74 d
^{140}La	Lanthanum-140	40.27 h
^{144}Ce	Cerium-144	284.3 d
^{169}Yb	Ytterbium-169	32.01 d
^{192}Ir	Iridium-192	74.02 d
^{226}Ra	Radium-226	1600 y
^{235}U	Uranium-235	7.038 10^{8} y
^{238}Pu	Plutonium-238	87.74 y
^{239}Pu	Plutonium-239	2.41 10^{4} y
^{241}Am	Americium-241	432.2 y

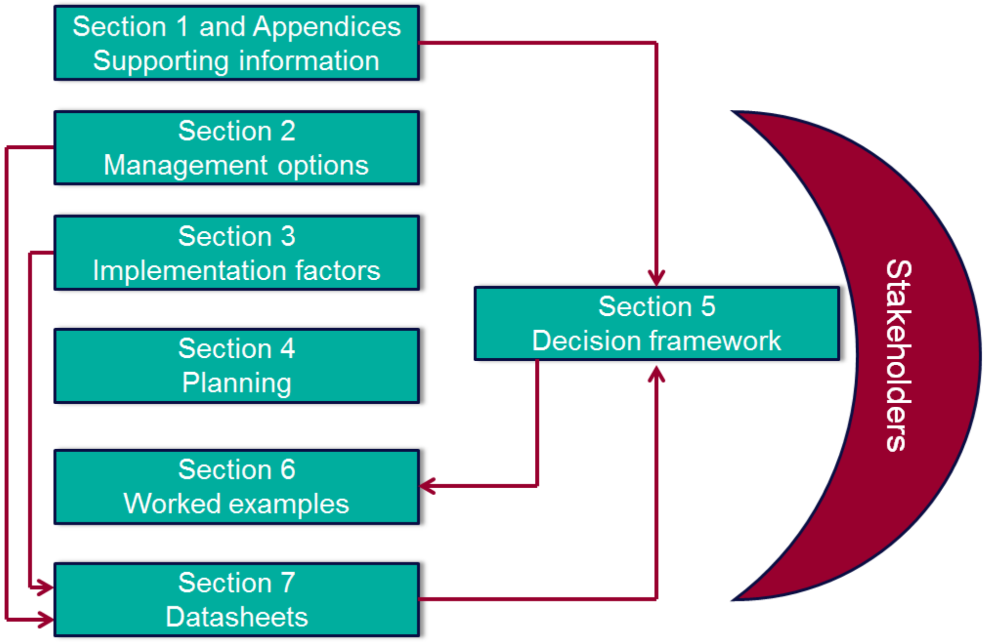
* Key: h = hours; d = days; y = years

1.6 Structure of the Drinking Water Supplies Handbook

The overall structure of the Drinking Water Supplies Handbook is illustrated in the top segment of Figure 1.1. Supporting and background information is provided in two appendices. The context, scope, audience and application of the handbook have been set out earlier in this section. The remainder of Section 1 covers the types of water supply that are considered in the handbook, together with the radiological protection criteria on drinking water quality. Section 2 provides an overview of management options for contaminated drinking water, with factors influencing the implementation of management options described in Section 3. Information to assist the planning for recovery in advance of an incident is given in Section 4. Section 5 contains the main decision-aiding framework including information to enable activity concentrations in drinking water to be estimated and guidance on the monitoring of drinking water supplies and on monitoring priorities. Section 6 gives worked examples to assist users to work through the main decision steps and to draw out the types of problems that they would need to deal with in the development of a recovery strategy. Datasheets for individual management options are presented in Section 7. A glossary of terms used in the handbook is given in Section 8.

As noted in Section 1.3, the handbook should be used as part of a participatory process involving members of the Recovery Working Group (RWG) and other stakeholders to develop a recovery strategy. The RWG will form part of the multi-agency response arrangements for a radiation incident. A key role of the RWG is to identify options for clean-up and waste disposal, including making recommendations on those considered to be the best.

Figure 1.1 Structure and audience for the Drinking Water Supplies Handbook



1.7 Water supplies included in the Drinking Water Supplies Handbook

Drinking water can come from one of three main types of water supply, and these are defined in Table 1.2. The Drinking Water Supplies Handbook concentrates on those factors relating to the minimisation of doses to the general public via the consumption of drinking water from public or private water supplies. Management options for unregulated water supplies of drinking water are not considered in detail. However, Section 7.4 includes a short section highlighting a few of the factors that should be considered with regard to unregulated water supplies following a release of radioactive contamination to the environment.

1.8 Radiological protection criteria for drinking water

1.8.1 Criteria for accidents

Criteria are required for implementing actions with regard to drinking water. The Commission of the European Communities, now known as the European Commission, has issued a number of regulations concerning contamination levels in food that apply for accidents (CEC, 1989a; CEC, 1989b; CEC, 1990). These regulations are intended to ensure uniformity of standards across the European Union (EU) and would become legally binding in the countries of the EU following an accident anywhere in the world. The regulations specify maximum permitted activity concentrations in marketed foods, termed MPLs. At the time of writing these regulations are under review, and it is therefore possible that the regulations may soon be consolidated and replaced, and that this may alter some or all of the MPLs. MPLs represent an EU judgement on the optimum balance between the beneficial and harmful consequences of introducing food restrictions in the EU. In case the MPLs should prove inappropriate under the specific circumstances of a future accident, provision has been made within the regulations for the MPLs to be revised shortly after an accident. Such a revision depends on a qualified majority agreement by the member states.

Table 1.2 Definition of drinking water supply categories in the Drinking Water Supplies Handbook

Water supply	Description
Public	Public water supplies are those delivered by statutorily appointed water companies to the majority of properties including private houses, commercial and public buildings, industrial premises and other properties*. Public water supplies come from both surface water and ground water sources. Surface water sources include reservoirs, lakes and rivers, while ground water sources are from aquifers, which are underground geological formations that store rainwater. The ground water is drawn through wells or boreholes drilled into the aquifers by the water companies. Ground water can also supply impoundment reservoirs. The water supplies delivered by water companies are subject to strict regulation regarding their quality. In order to comply with the water quality regulations, the water is treated at water treatment works prior to being delivered. The water companies take regular samples of the water throughout the treatment process to ensure the provision of high quality water that meets the required standards.
Private	Private water supplies are defined as any regular supply of water that is not provided by a statutorily appointed water company and where the responsibility for its maintenance and repair lies with the owner or person who uses it. Private water supplies only account for a small percentage of water usage. Less than 1% of the population of England and Wales obtain their water from an entirely private supply either on an individual or multiple property basis. In both Scotland and Northern Ireland, less than 1% of water comes from private supplies. However, the number of private water supplies can be significant. As examples, the Northern Ireland Environment Agency website states that in 2012 it had 122 registered private supplies and estimates about 4000 single dwellings have private supplies; data collected by Defra for 2012 indicates that there are about 45,000 private supplies in England, with about 60% of these being individual supplies to single private dwellings, typically drawn from a private well or borehole on the premises. Private water supplies can come from a variety of sources including: wells, boreholes, springs, streams, rivers and lakes. The majority of private supplies are likely to be for dwellings and farms situated in remote, rural areas. However, there may be some private supplies in urban areas, particularly those used for industrial purposes such as brewing and food and drink manufacturing. Private water supplies may also be found supplying places such as hospitals, hotels, schools or campsites. Unlike public supplies, many private water supplies are not treated to remove impurities that affect the quality of the water such as pesticides, nitrates or cryptosporidium.
Unregulated	Unregulated water supplies are defined as those drinking water supplies that are not maintained as public or private water supplies. The use of these water supplies will generally be confined to people using water from springs or collected rainwater while in recreational areas (eg campers and hikers).

* Water companies may have a number of minor water supplies, typically in rural areas that have minimal water treatment.

There is also a precedent for the European Commission to implement more restrictive levels using non-risk based criteria. For example, the regulations on imports from Japan following the Fukushima nuclear accident in 2011 introduced much lower maximum permitted levels to match those used internally by the Japanese authorities, despite this being non-proportionate. This was because it was felt by some member states that allowing higher levels of activity concentration than were allowed in Japan would be perceived by the public as a lower level of protection.

The regulations include the specification of MPLs for the radioactive contamination of liquid foods. Liquid foods are defined to include fruit and vegetable juices, non-alcoholic beverages and alcoholic beverages. 'Non-alcoholic beverages' include bottled waters but the regulations also state that these MPLs 'should be applied to drinking water supplies (eg tap water) at the discretion of member states'.

In the UK, it is recommended that the MPLs for liquid foods should be adopted as action levels for all drinking water supplies (NRPB, 1994). These action levels are listed in Table 1.3 and apply to all drinking water after an incident, regardless of the distance away from the source of the incident. They should be used to indicate whether action should be taken to reduce activity concentrations in drinking water following a radiation incident, for example, by providing an alternative supply.

The UK water industry makes extensive use of measurements of gross alpha and gross beta activity concentrations in drinking water as part of routine monitoring (see Section 5.3). This monitoring capability can also be very useful in the event of a radiological incident and the Environment Agency has published guidance on gross alpha and gross beta emergency screening levels that are linked to the UK action levels for drinking water supplies (Allott et al, 2002). Further information on these emergency screening levels and their use is given in Section 5.3.

Table 1.3 Recommended UK action levels for drinking water supplies*

Radionuclide	Action levels[#] (Bq l^{-1})	Categorisation of radionuclides considered in handbook (see Table 1.1)[†]
Isotopes of strontium	125	^{90}Sr
Isotopes of iodine	500	^{131}I
Alpha-emitting isotopes of plutonium and transplutonium elements	20	^{238}Pu, ^{239}Pu, ^{241}Am
All other radionuclides of half-life greater than 10 days, notably radioisotopes of caesium and ruthenium[‡]	1000	^{60}Co, ^{75}Se, ^{95}Zr, ^{95}Nb, ^{99}Mo, ^{103}Ru, ^{106}Ru, ^{132}Te, ^{134}Cs, ^{136}Cs, ^{137}Cs, ^{140}Ba, ^{140}La, ^{144}Ce, ^{169}Yb, ^{192}Ir, ^{226}Ra[¶]

* These action levels refer to all water supplies that are intended, at least in part, for drinking and food preparation purposes. See Section 1.8.3 for advice on the urgency with which contaminated drinking water supplies should be replaced

[#] It is the sum of the concentrations of all the radionuclides included within a category and detected in the water that should be compared with the action level

[†] For ^{235}U, action would be taken based on the chemical toxicity of uranium, since this is of more concern to health than the radioactive content of the water (WHO, 2011)

[‡] This category does not include ^{14}C, ^{3}H or ^{40}K (NRPB, 1994)

[¶] It should be noted that radon is unlikely to be a problem because any radiological emergency or incident involving contamination of a water supply with ^{226}Ra will not lead to radon gas being produced on the timescale that water contamination will be of concern

1.8.2 Criteria for routine situations

The World Health Organization (WHO) and the European Commission (EC) have issued guideline values of activity concentrations in potable drinking water that apply to routine operational conditions of existing or new water supplies (CEC, 2013; WHO, 2011). The values recommended by the WHO and the EC **do not** apply to water supplies contaminated during an emergency involving the release of radionuclides to the environment. In such circumstances the UK action levels given in Table 1.3, should be used, as discussed above.

In general terms, activity concentrations in water below the levels set by the WHO and the EC are acceptable for human consumption and action to reduce the radioactivity levels is not necessary. The EC Directive 2013/51/Euratom on the quality of water intended for human consumption (CEC, 2013) sets out an indicator parameter of 0.1 mSv y^{-1}. This quantity is referred to as 'total indicative dose', or TID, and covers all radionuclides excluding tritium and radon. Member states have a responsibility to monitor drinking water to ensure that the 'indicative dose' is not exceeded. The WHO gives some radionuclide-specific values (WHO, 2011) that correspond approximately to an annual dose of 0.1 mSv y^{-1} using a specified set of assumptions. The WHO states that these are also appropriate for use after the first year following a nuclear accident, that is to say they are **not** applicable for the first year following a radiological incident and therefore should not be used as criteria for determining recovery options within this timescale.

1.8.3 Use of action levels

Public Health England (PHE) advises that action levels or appropriate screening levels could be used to trigger the total substitution of any water supplies that are intended, at least in part, for drinking or food preparation purposes (NRPB, 1994). It needs to be recognised, however, that there can be public health problems associated with cutting off the normal water supplies and these need to be taken into account. Other methods to reduce activity concentrations in supplied drinking water, such as additional treatment, changes to the abstraction regime and controlled blending, may then be more appropriate. Substitution of solely that part of the supply intended for drinking or food preparation purposes may be considered as an interim measure while full substitution is organised, or in extreme situations where full substitution of the supply cannot be achieved. In such situations, advice needs to be given on when water exceeding the action levels may still be used safely for washing, toilet flushing and other (non-ingestion) purposes over protracted periods. This is discussed further in Section 7 within the datasheets for management options.

The substitution of supplies or the implementation of other options takes time during which water is likely to be consumed. Also, there may be a period after the incident when monitoring results are not available and water continues to be drunk by the public. It should be emphasised that if individuals were to drink water contaminated well in excess of the action levels for limited periods (eg a few weeks), this need not pose a significant radiological hazard. To illustrate this, estimates of ingestion doses have been made assuming that water is drunk for 3 weeks at levels 10 times the action levels for a selection of radionuclides (Table 1.4). It should be noted that this level of contamination is significantly higher than those that are likely to occur in the event of a radiological emergency. This is because any contamination will either become significantly diluted in the drinking water source over a short period of time or will only be present in the drinking water for a very short period of time at these high levels, in the case, for example, of a deliberate contamination event.

The estimated committed effective ingestion doses given in Table 1.4 can be placed in context by comparison with those received from natural background radiation, which for a typical individual in the UK is 2.2 mSv in a year (Watson et al, 2005). Mean values in some parts of the UK are 3-4 times higher. In general, therefore, the values in Table 1.4 are lower or comparable with typical exposures to natural background radiation that are incurred over a year. Thus the immediate withdrawal of drinking water supplies is in general not essential. However, every effort should be made to reduce activity concentrations in the water quickly (at least within a few weeks), in order to maximise the dose reduction achieved.

Table 1.4 Committed effective doses from the consumption of tap water* for a period of 3 weeks contaminated at 10 times the UK action levels for drinking water

	Committed effective dose (mSv)		
Radionuclide	**1 year old infant**	**10 year old child**	**Adult**
^{60}Co	2.7	1.2	0.9
^{90}Sr	0.9	0.9	0.9
^{106}Ru	6.0	1.8	1.5
$^{131}I^{\#}$	9.0	3.0	2.4
^{137}Cs	1.2	1.2	3.0
^{239}Pu	0.9	0.6	1.2

* Consumption rates for tap water: 1 year old infant = 172 l y^{-1}, 10 year old child = 197 l y^{-1}, adult = 391 l y^{-1} (NRPB, 1994). If site-specific data on consumption rates for tap water is available, values in the table can be scaled to reflect different consumption rates.

For ^{131}I, the radioactivity decays by 3 half-lives (ie a factor of 8) over the 3 week period and therefore doses calculated are an overestimate, as they assume that activity concentrations remain at 10 times the UK action level over the 3 week period.

If drinking water supplies do become contaminated in the event of an incident, it is likely that some of the contaminated water will be consumed. Consequently, it is important that the radiation doses and the risks associated with drinking such water are communicated effectively. This applies irrespectively of whether the water contains radioactivity at concentrations below the intervention or screening levels set or whether the concentrations are above these levels for a limited period of time. Public perception may also drive the need to provide ‘clean’ drinking water. This may conflict with other public health requirements and may not be justified purely on radiological protection grounds.

The doses that could be expected from ingestion of contaminated water at the UK action level for all the radionuclides considered in the handbook have been calculated. These are discussed further in Appendix A.

1.9 References

Allott R, Rowe J and Green N (2002). *Review of alpha and beta blue book methods: drinking water screening levels.* NCAS/TR/2002/003.

Brown J, Hammond D and Wilkins BT (2008). *Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives.* Health Protection Agency, Chilton, HPA-RPD-040.

CEC (1989a). Council Regulation (Euratom) No. 3954/87 laying down the maximum permitted levels of radioactive contamination of foodstuffs and feeding stuffs following a nuclear accident or any other case of radiological emergency. *Off J Eur Commun* **L211/1**(amended by Council Regulation 2218/89 from **L371/11** (1987)).

CEC (1989b). Council Regulations (Euratom) No 770/90 laying down maximum permitted levels in minor foodstuffs following a nuclear accident or any other case of radiological emergency. *Off J Eur Commun* **L101/17**.

CEC (1990). Council Regulation (Euratom) No. 770/70 laying down maximum permitted levels of radioactive contamination of feeding stuffs following a nuclear accident or any other case of radiological emergency. *Off J Eur Commun* **L83/78**.

CEC (2013). Council Directive 2013/51/Euratom laying down requirements for the provision of the health of the general public with regards to radioactive substances in water intended for human consumption. *Off J Eur Commun*.

NRPB (1994). Guidance on restrictions on food and water following a radiological accident. *Doc NRPB* **5**(1).

Watson SJ, Jones AL, Oatway WB and Hughes JS (2005). *Ionising Radiation Exposure of the UK Population: 2005 Review.* HPA, Chilton, HPA-RPD-001.

WHO (2011). *Guidelines for drinking-water quality, Fourth edition.*

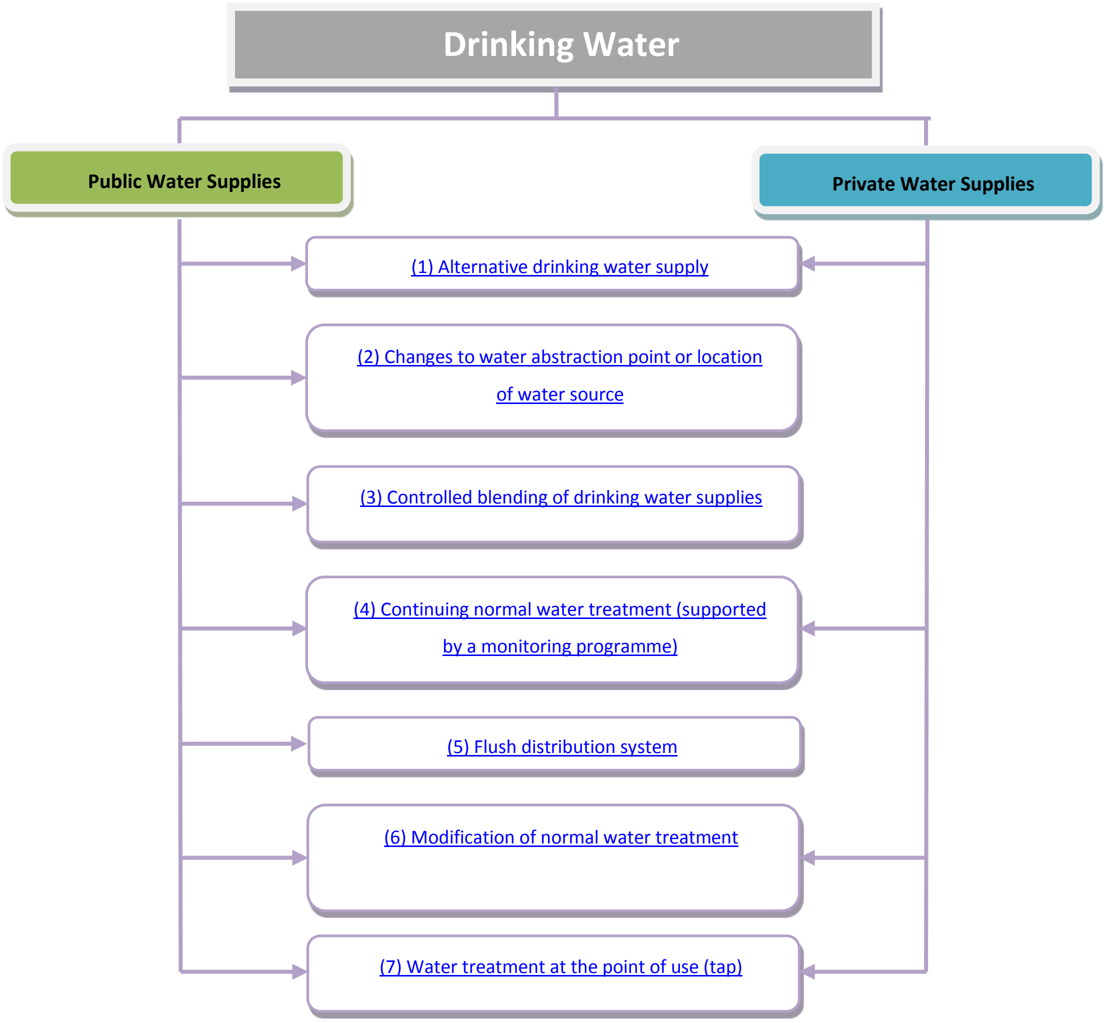
2 Management Options

The term management option is defined as an action intended to reduce or avert the exposure of people to radioactive contamination. Management options were previously referred to as countermeasures. This handbook has identified 7 potential management options that can be carried out on drinking water supplies to reduce the impact of radioactive contamination. These are listed in Table 2.1, with Figure 2.1 showing the distinction between those options that are appropriate for public and private water supplies. Section 7 provides a comprehensive set of datasheets for each management option that provides information on most of the criteria that decision makers might wish to consider when evaluating different options.

Table 2.1 List of management options considered for drinking water supplies

Number	Name
1	Alternative drinking water supply
2	Changes to water abstraction point or location of water source
3	Controlled blending of drinking water supplies
4	Continuing normal water treatment (supported by a monitoring programme)
5	Flush distribution system
6	Modification of normal water treatment
7	Water treatment at the point of use (tap)

Figure 2.1 Management options for drinking water supplies



3 Factors Influencing Implementation of Management Options

There are a number of complex factors that need to be taken into account when developing a good management strategy and implementing management options; this is further complicated by the complexity of the decision-making process itself. Figure 3.1 gives an overview of the most important factors that might need to be considered, although decision-makers, implementers and other stakeholders may identify additional ones. Not all the factors will necessarily be relevant for any particular incident and their relative importance is also likely to vary depending on the nature, severity and scale of an incident. Some of these factors can be considered in detail as part of planning, as discussed further in Section 4; other factors and their importance will only be able to be assessed at the time of an incident.

3.1 Impact of types of water sources and radiation incident on likely radiological impact

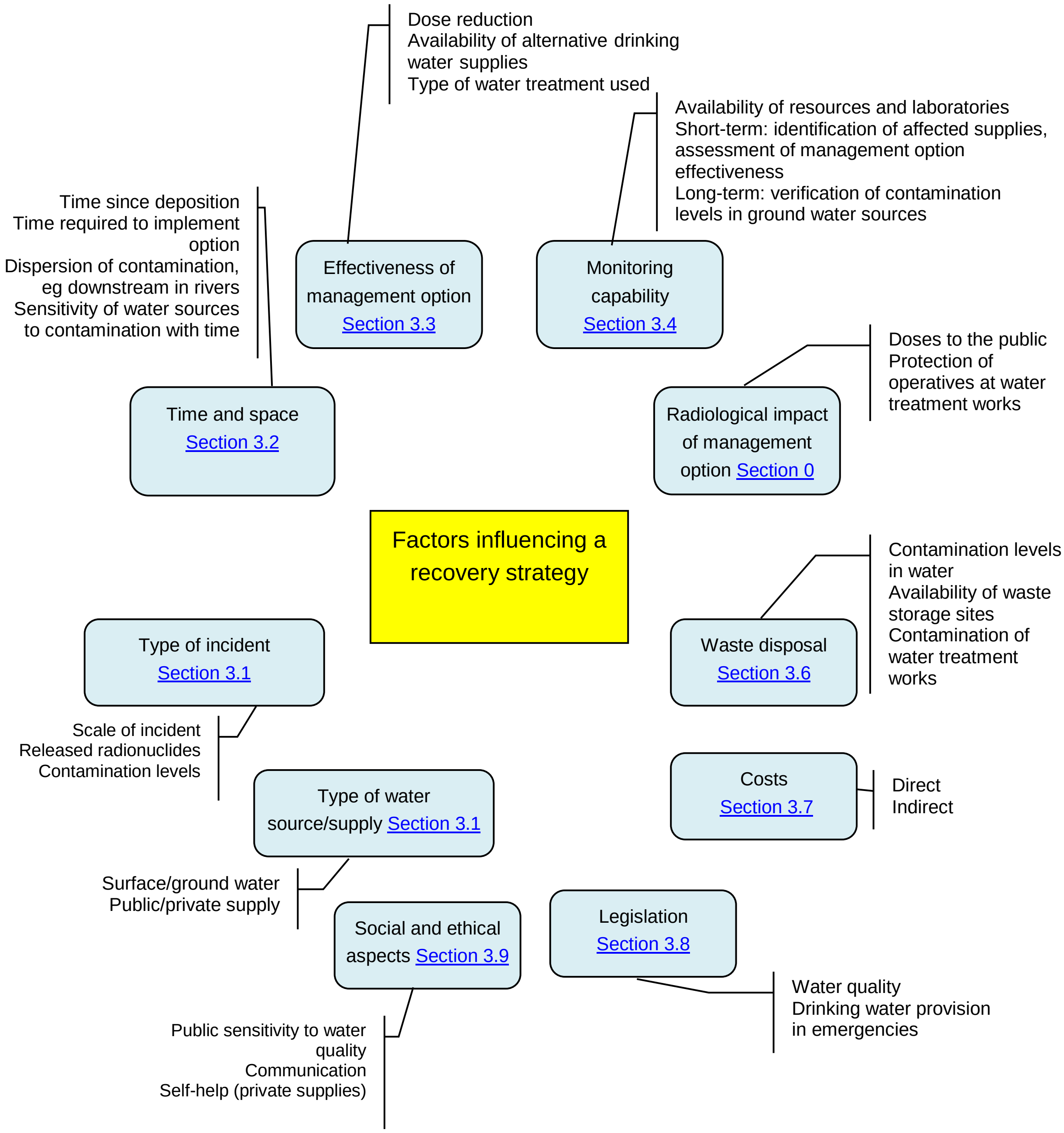
As described in Table 1.2 there are several different water sources that could become contaminated in the event of a radiological emergency and that could contribute to a supply of drinking water to the public. Any radiological emergency could lead to the contamination being distributed between these sources. The actual distribution could be very different depending on the type of radiological emergency. For example, a release to atmosphere will result in direct deposition to surface water supplies, such as rivers. These will also receive run-off from surrounding land. Direct contamination will not occur to underground aquifers; contamination of these supplies is only likely to occur in the longer term as radioactivity percolates down through the soil and reaches the water table. Deliberate contamination of a water supply could affect any water source and also could occur before, during or after water treatment. In general, therefore, surface water supplies are likely to be more vulnerable to contamination from a radiological emergency and will become contaminated more quickly following the event compared with ground water sources.

3.2 Impact of time and spatial factors

Water sources with the highest radioactive contamination in the environment will not necessarily be those that contribute most to the exposure of the population. This will depend on the extent to which they are used for drinking water. A given source may not be the major contributor to peoples' water supply.

To optimise the management options implemented and the timing of their implementation, the nature of the water sources used for drinking water supply, their vulnerability to contamination following the radiological emergency and the timescales over which they are likely to become contaminated are all important factors to take into account. These factors will also drive the monitoring programme required to support the assessment of doses to members of the public and the choice of management options.

Figure 3.1 Overview of key factors influencing choice of management options



3.3 Effectiveness

The likely effectiveness of the management options is described in the datasheets for each option (see Section 7). Normal water treatment can be effective in removing radionuclides from water, as shown in Datasheet 4. Section 5.2 provides information on activity concentrations in drinking water that could be expected following typical water treatment processes and a methodology is provided for estimating the effectiveness of water treatment for a specific water treatment works. The information provided can also be used to look at the likely effectiveness of adding additional treatment processes into a works, as described in Datasheet 6.

3.4 Monitoring

Guidance on monitoring of drinking water supplies, required analytical capabilities and monitoring priorities is given in Section 5.3.

3.5 Radiological impact

If a radiation incident affects a drinking water source in the UK, it is likely that the water would pass through an established treatment works prior to being supplied to the consumer. Consequently, any such incident could lead to exposure to radiation for both the consumer of drinking water and the operatives that work in any affected water treatment works.

In order to assess any radiological impact on the consumer, information is needed on whether the contaminated water has been treated or not, whether any subsequent normal water treatment will remove radioactivity from water and what factors are likely to influence removal. Information on the likely removal efficiency of various water treatments is discussed in Section 5.2.2 and given in Datasheet 4. Doses to consumers from ingesting contaminated water have also been estimated and are given in Appendix A.

If water treatment removes radionuclides from the water then the activity will either be concentrated in wastes such as sludge that arise from the treatment carried out or be held within the treatment works on various surfaces or within filter media. This contamination may give rise to doses to operatives working at treatment works. Appendix A provides information on how potential doses to operatives working in treatment works can be assessed.

3.6 Waste disposal

3.6.1 Generation of waste

If water treatment removes radionuclides from the water then the activity will either be concentrated in the wastes arising from the treatment carried out or be held within the treatment works on various surfaces or within filter media. Appendix B provides information on the likely activity concentrations in waste sludge and filter media for a typical UK treatment works for a unit activity concentration in the raw water entering the treatment works. Treated water may also constitute waste if the activity concentrations in it exceed the UK action levels and it is decided that the water cannot be used either for drinking or for other purposes such as washing and toilet flushing.

3.6.2 Disposal of waste

The large scale on which water treatment works operate means that considerable volumes of waste material could be generated, especially if large-scale sand filter beds are used. The types of waste that could be generated are:

- sludge from water treatment
- waste water from backwashing of filters
- waste water from the de-watering of sludge

- filter media (eg sand), from filter bed replenishment or replacement
- treated water deemed not to be potable

The specific wastes that could be generated from each *management option* are given in the datasheets for each of the 7 options.

Under normal operation, waste products from water treatment are disposed of via various routes (eg to sewers, water courses, landfill and land spreading), subject to consent by the relevant environment agency. In the event of a radiological incident, normal practices would need to be reviewed and specific authorisations may be required for disposal of such wastes depending on the radionuclide, activity concentrations and quantities. Guidance on the treatment and disposal of contaminated water and potentially contaminated water from water supply sites, water distribution networks and service reservoirs is given in general terms by Water UK (Environment Agency et al, 2012) This, however, does not consider radioactive contamination specifically. The evaluation and choice of waste disposal options are outside of the scope of this handbook and have been identified as an area of work warranting further consideration. Information to assist in the assessment of the impact of disposal of liquid and solid wastes is given in the Inhabited Areas Handbook.

3.7 Economic costs

Predicting the economic cost of implementing the management options and the supporting monitoring programme is difficult and this has not been included in the handbook. There will be direct costs such as those incurred through implementing the management options, from loss of normal water supply and handling of wastes, as well as indirect costs such as those incurred due to the impact of the incident on public confidence in the water industry. The magnitude of these costs will depend on many factors such as the period of time over which the management option is implemented and the spatial scale of the impact of the incident on drinking water supplies. Some important costs are listed in Table 3.1 and Table 3.2 for implementing management options and loss of normal water supply, respectively.

Table 3.1 Direct economic cost of implementing management options

Labour: salaries for the workforce involved (may need to be supplemented for work being undertaken), radiological protection costs, requirement for additional staff to be brought in
Specific equipment: some management options require dedicated equipment that may need to be hired or purchased (investment cost) and subsequently maintained or disposed of (eg bowsers and tankers, equipment for new additional treatment processes, reverse osmosis units and jug filters)
Consumables: specific products (eg additives for water treatment such as clay minerals or activated charcoal), cost of alternative potable water
Transportation (eg bottled water)
Sampling of water and laboratory analyses to support management option

Table 3.2 Direct economic cost of loss of normal water supply

Value of treated drinking water
Cost of disposal of treated water
Compensation paid to the consumers
Maintenance of treatment works and distribution network

3.8 Legislation for drinking water

The quality of drinking water from public and private water supplies in the UK is regulated as outlined below.

3.8.1 Public water supplies

The government has set legal standards for drinking water quality. Most of these standards come directly from an obligatory EC directive and are based on WHO guidelines. The UK has adopted additional standards to ensure an extremely high quality of water. The standards are strict and generally include wide safety margins. The regulations that govern the quality of water in the UK are listed in Table 3.3.

The water industry carries out its own tests for water quality to check compliance with the regulations. Failures must be reported to the appropriate regulating body. In England and Wales there are a number of privately owned water companies responsible for monitoring water supplies to ensure compliance with the regulations. Both Scotland and Northern Ireland have a single water company, these being Scottish Water and Northern Ireland Water.

England and Wales have an independent, government appointed water quality regulator, the Drinking Water Inspectorate (DWI), that regulates public water supplies. DWI is responsible for assessing the quality of drinking water in England and Wales, checking that water companies supply water that is safe to drink and meets the standards set in the regulations. DWI takes enforcement action if standards are not being met and appropriate action when water is unfit for human consumption.

In Scotland, a Drinking Water Quality Regulator for Scotland (DWQR) is appointed under the terms of the Water Industry (Scotland) Act 2002 (UK Parliament, 2002). The DWQR and his staff have the general functions of monitoring and enforcing drinking water quality standards on the public networks, provided by Scottish Water.

Within the Northern Ireland Environment Agency, the Drinking Water Inspectorate is responsible for regulating the drinking water quality in Northern Ireland. The Drinking Water Inspectorate regulates drinking water quality for public and registered private supplies, assessing and enforcing drinking water quality against regulatory standards and carrying out detailed inspections of water sampling and the subsequent analytical process.

The regulators listed above act as the contact points for emergencies affecting drinking water supplies in the UK.

The Secretary of State issued the Security and Emergency Measures Direction in 2006 (SEMD) and the Scottish Ministers issued a similar Direction to Scottish Water in 2002 (see Table 3.3). SEMD requires a water (or sewerage) undertaker to make, keep under review and revise such plans as it considers necessary to ensure the provision of essential water supply and sewerage services at all times including during a civil emergency or any event threatening national security. In the case of restrictions to the normal mains water supply, it is a requirement under SEMD that the water undertaker should make arrangements to supply water by alternative means. The minimum amount of water to be provided by alternative means in the event of a complete disruption in supply is notified to the undertaker by the Secretary of State. Currently water undertakers have to plan for not less than 10 litres per person per day of drinking water if the level of supply failure is within the local response plan.

In the event of a prolonged incident, water undertakers must plan for alternative water supplies of not less than 20 litres per person per day in order to provide customers with some scope to address broader hygiene and other needs, when there is total failure of the piped supply. Bottled water and water distribution from bowsers and tanks may form part of the overall water supply strategy. Under the requirements of the Direction, priority has to be given to hospitals and schools and vulnerable sectors of the population including the elderly and the sick. Regard has to also be made of the needs of non-domestic users such as livestock and essential food industries within the undertaker's area.

The legislation on public water supplies includes reference screening levels for gross alpha activity and gross beta activity concentrations in drinking water; exceedence of these values requires further detailed investigation. The use of screening levels for emergency situations is discussed in Section 5.3. Currently, no actions to reduce contamination levels are specified as part of the regulations for emergency situations. However, a new EC directive comes into force in November 2015 which requires remedial actions to be taken when levels of radioactive substances exceed the mandatory limits for routine situations.

Table 3.3 UK drinking water regulations relevant to the Drinking Water Supplies Handbook

Water quality
European Council directive 98/83/EC of 3 November 1998 on quality of water intended for human consumption. Official Journal L 330, 05/12/1998
The Water Supply (Water Quality) Regulations 2000 (England and Wales) (amended 2007and 2010)
The Water Supply (Water Quality) (Scotland) Regulations 2015
The Water Supply (Water Quality) Regulations (Northern Ireland) 2007 (amended 2009 and 2010)
Water (Scotland) Act 1980 (c.45) Sections 26 and 27
Private Water Supplies Regulations 2009
Private Water Supplies (Wales) Regulations 2010
Private Water Supplies (Scotland) Regulations 2006
Private Water Supplies Regulations (Northern Ireland) 2009
Emergencies
Security and Emergency Measures (Water Undertakers) Direction 2006
Security and Emergency Measures (Scottish Water) (Scotland) Directions 2002

3.8.2 Private water supplies

Private water supplies are monitored for water quality by local authorities under the Private Water Supplies Regulations (see Table 3.3). These regulations apply to private supplies for purely domestic purposes, for use in a commercial activity or food production, that is to say the making, processing, preserving, preparing or marketing of food or drink (including water) for sale for human consumption. Supplies to single domestic dwellings are exempt from the monitoring and risk assessment requirements of the regulations, but can request them. The regulations contain similar water quality standards as those for public drinking water supplies with the frequency of monitoring varies according to the nature of its use and the volume of water used. The risk assessment informs some of the parameters tested for.

There is a distinction in the regulation and registration of a private supply with the regulator between supplies for two or more dwellings/commercial use and supplies for single dwellings.

The regulations contain similar water quality standards as for public drinking water supplies and the frequency of monitoring varies according to the nature of its use and the volume of water used. The risk assessment informs some of the parameters that are tested for.

The regulations require only infrequent monitoring of small private water supplies and there is no specified sampling frequency for those supplies serving only a single dwelling for domestic purposes. Therefore owners and users of private water supplies need to be aware of the potential for water contamination and what can be done to reduce the risk. Private water supplies are not subject to the directions issued by the Secretary of State in respect of national security or emergency planning, and any emergency arrangements are entirely dependent upon what an individual local authority might have in place.

Local authorities may use powers under the Public Health Act 1936 (UK Parliament, 1936) to close or restrict the use of water from contaminated private sources of supply. Sections 26 and 27 of the Water (Scotland) Act 1980 (UK Parliament, 1980) provide local authorities in Scotland with the power to apply to the Sheriff to make an order to close or restrict the use of water from polluted sources including wells. However, there are currently no specific regulations for private supplies contaminated with radioactive substances although Section 80 of the Water Industry Act, 1991 (UK Parliament, 1991) gives local authorities powers to improve supplies where they are unwholesome or insufficient, but any relevant person on whom the notice is served has 28 days to appeal it. Contingencies for the replacement of a private supply in the event of a radiological incident need further consideration.

3.9 Societal and ethical factors

The consequences of a radiation incident raise technical, health-related and radiological problems, but in addition there are societal and ethical considerations. Radioactive contamination on a large scale has an impact on living conditions at an individual and community level (ie on health, economy and the environment) and can affect relationships at many different levels both within and outside the contaminated area. Societal and ethical factors are also relevant to the management of the contaminated areas. For example, when deciding which management option should be carried out it is important to understand the implication of any actions and to take into account individual and community concerns, particularly for long-term options. The need to engage with local stakeholders in the identification of problems and in the development of solutions should be recognised. In defining the recovery strategy, decision-makers should take account of societal and ethical points of view as well as technical criteria. For example, blending of water supplies to reduce the overall activity concentrations is a relatively straightforward and inexpensive option already used for other types of contaminant. However, this option could be perceived as diluting and dispersing radionuclides within the distributed water system, thereby affecting more consumers. Societal and ethical factors are included in the datasheets for each management option.

3.10 References

Environment Agency, Northern Ireland Environment Agency, Water UK and Chief Fire Officers Association (2012). *Protocol for the disposal of contaminated water and associated wastes at incidents.* Water UK.

UK Parliament (1936). The Public Health Act 1936. HMSO, London.

UK Parliament (1980). Water (Scotland) Act (c.45) (1980),
www.opsi.gov.uk/RevisedStatutes/Acts/ukpga/1980/cukpga_19800045_en_1

UK Parliament (1991). The Water Industry Act, 1991(amended 1999)
http://www.opsi.gov.uk/acts/acts1991/ukpga_19910056_en_1

UK Parliament (2002). The Water Industry (Scotland) Act 2002
http://www.opsi.gov.uk/legislation/scotland/acts2002/asp_20020003_en_1

4 Planning for Recovery in Advance of an Incident

The response to the effects of a major UK accident or emergency is managed primarily at the local level. It is a general principle that there should be a detailed emergency planning zone (a few square kilometres) for civil nuclear accidents up to the worst case most reasonably foreseeable accident (also known as the reference or design basis accident) and extendibility for larger accidents. Emergency plans are drawn up in advance of an incident in order to provide an effective response within an emergency planning zone. They are easily applied and are universally accepted. Emergency plans do not include actions to be taken in the post-emergency phase (ie recovery phase) when it is much more difficult to be prescriptive about actions to take due to variations in local circumstances. Nevertheless, it is recognised that there should be planning for recovery up to the reference basis accident, albeit in less detail.

All contingency planning should be undertaken in accordance with the guidance on combined response contained in the Home Office publication 'Dealing with Disaster - Revised Third Edition' (Cabinet Office, 2007) and the Scottish Government publication 'Preparing Scotland: Scottish Guidance on Preparing for Emergencies' (Scottish Government, 2008). Similarly, 'Civil Contingencies Act 2004: a short guide' (Cabinet Office, 2005) provides a context for recovery planning. Other guidance is given by Nuclear Emergency Planning Liaison Group (NEPLG) (DECC, 2013b) and in the strategic national guidance on the decontamination of the open environment exposed to CBRN substances or materials (GDS, 2015). This guidance provides an agreed set of basic recovery principles and a shared understanding of the key factors that may need to be addressed.

Consideration of topics such as ‘requirements for information’ and ‘outline arrangements’ prior to an emergency would aid the speed of recovery response in the event of an incident and also help ensure a more successful outcome. Table 4.1 provides a breakdown of topics covering data and information requirements that could usefully be gathered in advance of an incident. The list of information requirements presented in Table 4.1 appears quite wide ranging and it is not yet clear how much effort would be required to assemble such information. Clearly, priorities would need to be assigned to help make best use of available resources. Under the auspices of the NEPLG, a UK Nuclear Recovery Planning Group has been established to provide a focus for sharing and driving improvements in recovery planning for civil and military nuclear accidents. The Group has developed the UK Nuclear Recovery Plan Template (DECC, 2013a) which is a living document that provides guidance on all aspects of the decision-making process, including who to involve, issues to address and a template for a recovery action plan. Table 4.2 gives a list of factors, in addition to the information requirements listed in Table 4.1, that might need to be considered when developing an outline of a recovery strategy, focused at the local level, in advance of an incident.

Table 4.1 Information collection and knowledge of drinking water supplies

Topic	Comments
Monitoring	Monitoring facilities available to each water company/supplier. Turn-around time/capacity for analyses of different types
	Monitoring facilities available via agreements set up by the water laboratories mutual aid radioactivity sub-group
	Monitoring facilities available to the regulators, PHE, environment agencies and other government departments and agencies
	Alternative monitoring capabilities if normal facilities are in the affected area
	Identification of who will collect water supply samples
	Potential for monitoring at alternative points between source and point of consumption. If contamination has occurred after water treatment, then need to identify how to monitor within the distribution network. Identification of key monitoring points in the distribution system and estimates of the numbers of samples that would need to be taken
	Potential for monitoring, gross alpha and beta monitoring and more extensive radionuclide specific monitoring and capability for rapid radiochemical analyses
	Ability of local authorities to monitor private water supplies
	Equipment and analytical capability available for monitoring private water supplies
	Agreements between local authorities and water companies or suppliers regarding sharing monitoring resources
Alternative supply	Details of responsibilities for providing alternative supply to users of private water supply
	Source of bowsers, tankers and transport vehicles
	Agreements on who will deliver water and identification of potential risks to workers
	Agreement between water companies or suppliers and local and national authorities to arrange adequate protection at water distribution points
	Details of how long a water company or supplier can provide uncontaminated water supplies for and how large an area could be covered
	Access to other drinking water supplies and water distribution networks
	Capacity of water supplies from covered service reservoirs
Drinking water sources	Source of the drinking water supply in a given area. How this varies at different times of the year
	Likelihood that underground water sources will become contaminated and timescale over which this might happen following a radiological emergency. Depth of boreholes and aquifers
	Sensitivity of water sources to radioactive contamination within a given area
Water treatment	List of where each source of water goes to be treated and what water treatment is used
	Additional water treatment that can be provided
	Data on the effectiveness of water treatment in reducing radionuclide concentrations in water
	Identification of sites, processes and waste streams where radioactivity might be concentrated and development of appropriate protection and contingency measures for workers
Abstraction	List of abstraction points from each source
	Estimates of how long water can be provided from other abstraction points or water sources if abstraction from each abstraction point is stopped
	Agreements to temporarily exceed abstraction from a given source if required in an emergency
	Options for abstracting water from another water source. Distribution networks in place
General	List of private water supplies, their purpose and how many people use the supply
	Details of provision for alternative workers if water company workers refuse work in the affected area
	Surface areas and depths of reservoirs; scope for abstraction at different water depths
	Facilities for sharing information between organisations (eg adjacent water companies or suppliers, local authorities and environment agencies)
	Risk assessment of drinking water sources or points in the distributed water systems that are most vulnerable to deliberate contamination

Table 4.2 Strategy and outline arrangements

Topic	Comments
Generic strategy	Priorities and likely timescales for implementation of management options Management and review of recovery phase. Collection of data. Monitoring co-ordination
Recovery criteria	Identify appropriate criteria to be used to determine the need for and scale of recovery countermeasures and their success
Management options	Identify practicable and acceptable management options from datasheets in the Drinking Water Supplies Handbook in advance. Consider: • any constraints on use of option (from datasheets) • short-term management options that might require longer-term solutions Which countermeasure options might be applicable to the range of possible incident scenarios? How might they be implemented? How will waste be managed? Customise datasheets for country specific information and use by different water companies Identify aspects for each management option that will require consideration in advance of an incident and those that will be of particular importance to be taken into account in the event of an incident Consider trials of the longer term management options, to obtain a better understanding of the effectiveness and feasibility
Legislation	Radiological protection (ie workers and public) Radioactive waste management Specific legislation at local, regional or national level which may apply (eg provision of drinking water)
Roles and responsibilities	Make sure the roles and responsibilities of those agencies that would undertake tasks in the recovery response are well known (ie through dissemination of NEPLG and CBRN guidance). Identify leading agencies and legal responsibilities Establish how the roles and responsibilities change along the timeline Consider for each management option how available resources will be co-ordinated and moved to the affected area (eg the use of army, civil protection). This should be done at the national level to ensure consistency Explore the best role for the local government and local agencies
Training	Consider developing a training programme for the roles required to be performed (eg decision-makers, drinking water treatment operatives) Provision of information on the objectives of the management option to ensure that those implementing the option understand why it is being undertaken and how the objective can be achieved
Communication	Develop types of communication to meet the needs of different sectors of the population and to support the different stages of the recovery strategy. Consider how long countermeasures will be in place and when will they end
Role of stakeholders	Identify existing stakeholder groups in the area (eg parish councils, community groups, schools). Investigate whether these could/would be prepared to provide feedback on a recovery strategy for the area Consider processes that could be used to establish bespoke stakeholder panels where no relevant groups exist. Establish steps for each process considered

4.1 References

Cabinet Office (2005). Civil Contingencies Act 2004: a short guide (revised). Cabinet Office, London.

Cabinet Office (2007). Dealing with disaster. Revised Third Edition. Cabinet Office, London.

DECC (2013a). Nuclear Emergency Planning Consolidated Guidance. Chapter 18: UK Nuclear Recovery Plan Template. Department for Energy and Climate Change.

DECC (2013b). Nuclear Emergency Planning Liaison Group Consolidated Guidance. Department of Energy and Climate Change.

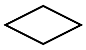
GDS (2015). Strategic National Guidance. The decontamination of buildings, infrastructure and open environment exposed to chemical, biological, radiological substances or nuclear materials. UK Government Decontamination Service, London.

Scottish Government (2008). Preparing Scotland: Scottish Guidance on Preparing for Emergencies. Scottish Government, Edinburgh.

5 Framework for Making Decisions on a Management Strategy

An overall decision framework for developing advice on drinking water supplies and considering management options is shown in a decision tree in Figure 5.1.

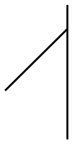
The decision tree guides the user through the decision-making process. The decision tree should be used in the following way:



Indicates a decision point

Indicates a step in the decision framework where action is required

Indicates an endpoint for the decision tree



This indicates where a further explanation of the decision step or other supporting information is given

Where further information or guidance is available on the topic described in the 'box' in the decision tree, the link to the information is indicated in blue. It is important that this information is read in conjunction with the decision tree.

To support the development of a recovery strategy as outlined in Figure 5.1. Section 5.1 gives a checklist of key constraints that need to be considered for each management option. Section 5.2 provides information to enable activity concentrations in drinking water to be estimated from measurement data. Section 5.3 provides generic information on the monitoring of drinking water supplies and monitoring priorities.

5.1 Checklist of key constraints for each management option

Management options invariably have constraints associated with their implementation. A detailed description of these constraints is provided in the datasheets for each option (Section 7). To assist in eliminating unsuitable options major and moderate constraints for each option are presented in Table 5.1, taking into account factors such as waste, societal needs, technical aspects, cost and timescales for implementation. The grey-scale colour coding in Table 5.2 is based on an evaluation of the evidence database and stakeholder feedback. The colour coding gives an indication of whether options have 'none or minor', 'moderate' or 'major' constraints associated with their implementation. The classification used is a generic guide and not radionuclide specific. If a major constraint is identified it does not indicate that the recovery option should necessarily be eliminated, although this may be done on a site- and incident-specific basis. These tables can be used in conjunction with the datasheets or beforehand to reduce the subset of options that require more in-depth analysis.

Figure 5.1 Decision tree for management options for drinking water: Part 1

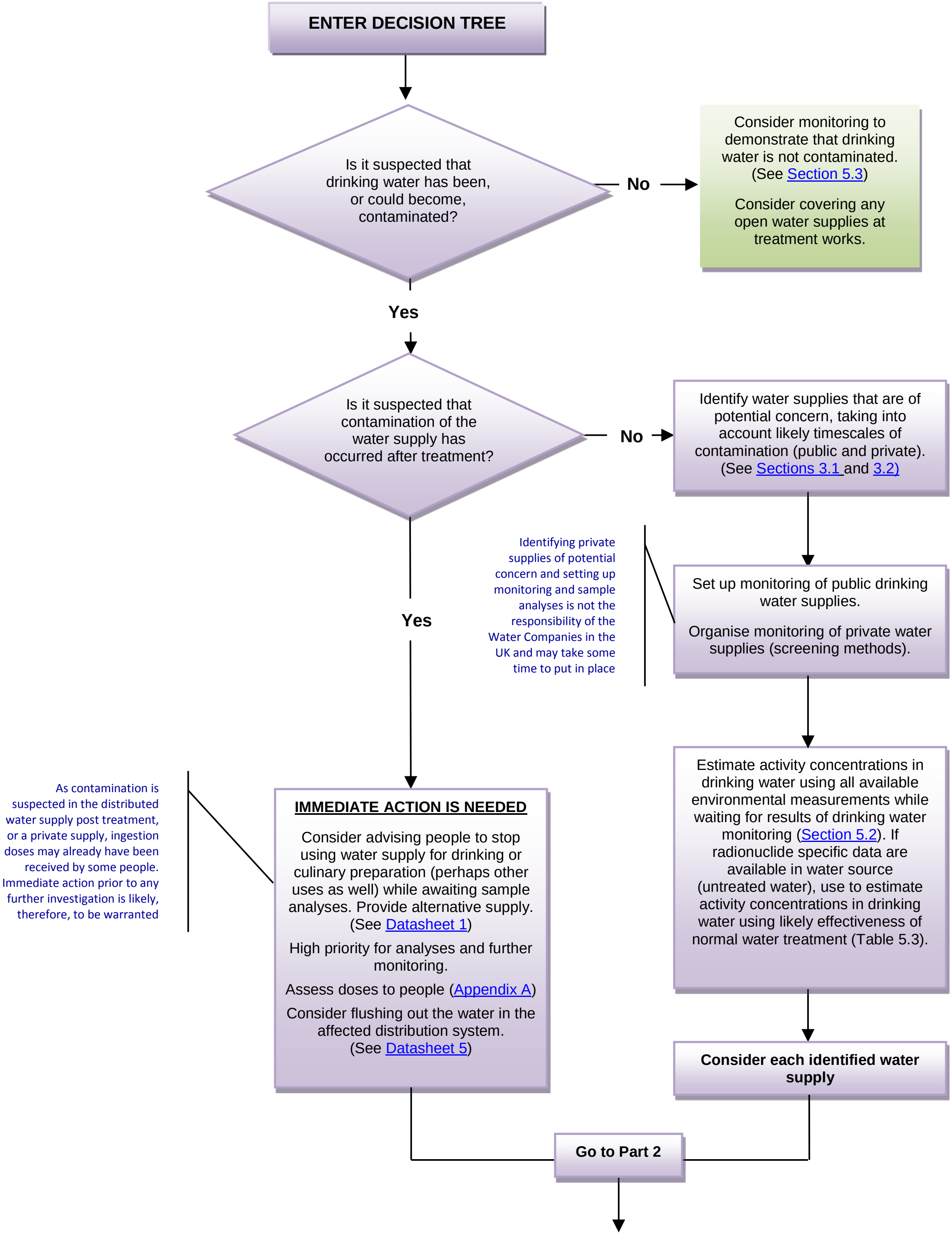


Figure 5.1 (cont.) Decision tree for management options for drinking water: Part 2

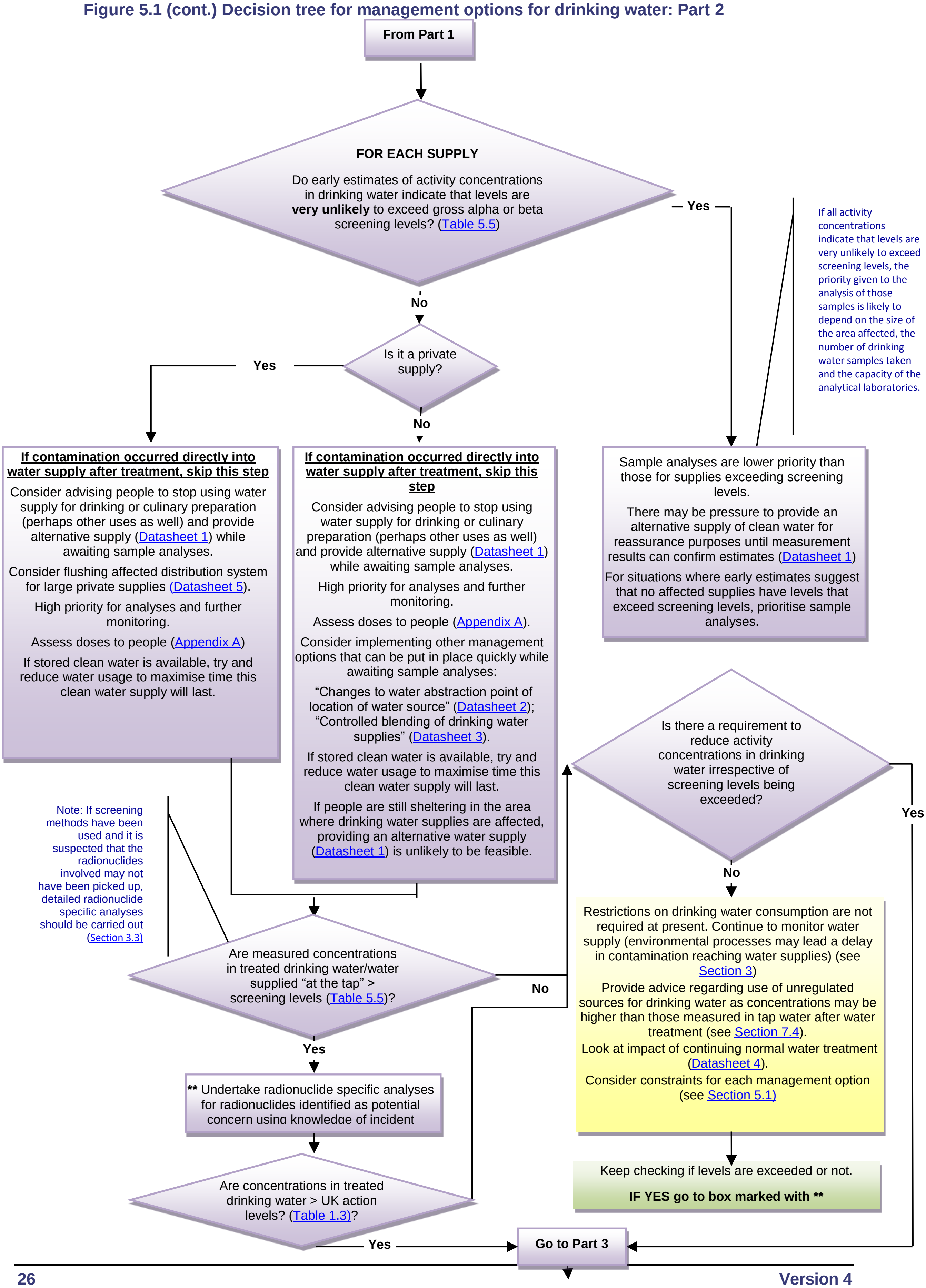


Figure 5.1 (cont.) Decision tree for management options for drinking water: Part 3

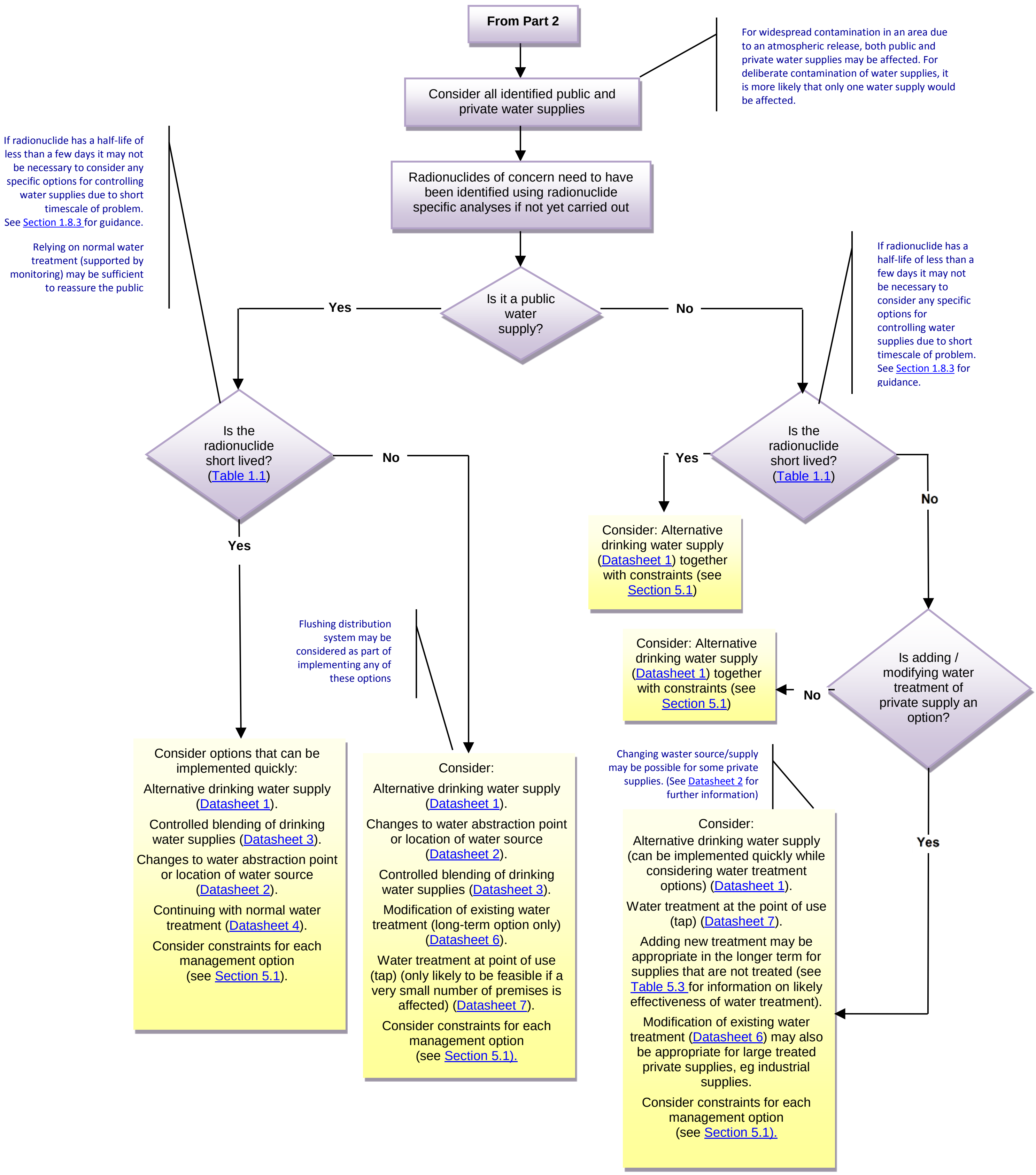


Table 5.1 Major and moderate constraints for management options

Recovery options	Major (key) considerations for selected recovery options	Moderate considerations for selected recovery options
(1) Alternative drinking water supply	None	**Social:** Although existing water supplies may be suitable for sanitation purposes, convincing people that water is safe to bath in, but not safe to drink or cook with may be difficult. People will not want to travel too far to water distribution points. Older people and people with disabilities will require assistance in getting water to their homes. It should be noted that water companies do keep records of vulnerable customers and key users in their region, and would therefore deliver water directly to these people. However the customer list is voluntary (ie depends on people registering themselves with their water companies) therefore these companies may need to work with local authorities to identify other vulnerable customers. Generally, members of the public prefer bottled water to bowsers/tanker water. Bulk buying at shops is very likely to lead to shortages of bottled water supplies. Rationing may be needed to extend available supplies. Social unrest, due to real or perceived shortages in supplies, could lead to problems at distribution points. **Technical -** Separate individual supplies would need to be provided for hospitals, schools, office buildings and any other large premises containing large numbers of people. If bowsers are used, there is a requirement to sample the water in them every 48 hours and analyse for a full suite of contaminants or to refresh the water on a regular basis. This would involve a number of personnel and significant resources in the laboratory depending on the number of bowsers/ tanks required and tankering requirements. **Cost:** May be high, considering; vehicle hire (tankers and bowsers); consumables (fuel, bottles or containers for transporting water) and personnel (ie travelling time for drivers, possibly unsociable hours).
(2) Changes to water abstraction point or location of water source	None	**Technical:** Widespread contamination or water shortages during periods of drought could result in fewer opportunities for changing abstraction points or water sources.
(3) Controlled blending of drinking water supplies	None	**Social:** There may be problems regarding the acceptability of residual levels of contamination in water supplies by the public. These are likely to be related to the availability of alternative supplies, such as bottled water. Blending contaminated water with uncontaminated water means that the contamination is diluted. This will need to be explained to the public, who might find this practice unacceptable, particularly if people who would have had a 'clean' supply now receive water contaminated with low levels of radioactivity.
(4) Continuing normal water treatment (supported by a monitoring programme)	None	**Waste:** Contaminated material from filter or resin beds, waste water or sludge may be concentrated in certain waste streams/sludges. This may necessitate more frequent cleaning of storage tanks and replenishment of filters and resins to prevent high concentrations of radioactive waste arising and potential recontamination of water. Changes to working practices may be required to minimise doses to operatives from wastes, and monitoring in the treatment works and of operatives may be required.
(5) Flush distribution system	None	**Technical:** Major undertaking for large distribution networks with widespread contamination. Usually used for clearance of local contamination in a distribution system.
(6) Modification of normal water treatment	**Technical:** Infrastructure needs to be in place to support the expansion of or changes to water treatment works if additional treatments are required (increased frequency of operations, 'new build', space requirements for new kit, etc). **Cost:** May be high, considering; infrastructure (adaption of current treatment plant or	**Waste:** Contaminated material from filter or resin beds, waste water or sludge may be concentrated in certain waste streams/sludges. This may necessitate more frequent cleaning of storage tanks and replenishment of filters and resins to prevent high concentrations of radioactive waste arising and potential recontamination of water. Changes to working practices may be required to minimise doses to operatives from wastes, and monitoring in the treatment works and of operatives may be required.

Table 5.1 Major and moderate constraints for management options

Recovery options	Major (key) considerations for selected recovery options	Moderate considerations for selected recovery options
	installation of a 'new build'); equipment; technology and personnel (builders, specialist engineers); timescale (could take months - years to install or build); disposal of contaminated water (availability of suitable disposal route). **Time:** it may take a long time (months - years) to implement this option.	
(7) Water treatment at the point of use [tap]	**Technical:** Jug filters only suitable for treating a few litres of water per day. Reverse osmosis and ion exchange units can be used to treat water for an entire premise. Likely spatial scale of implementation is small-medium due to availability of filter units.	**Waste:** Spent filter cartridges, spent salt and reverse osmosis membranes will need disposal. **Social:** The effectiveness of this option relies upon individuals using the equipment in an appropriate manner. Use of jug filters may involve changes in habits for the consumer eg remembering to use filtered water for drinking. Ion exchange and reverse osmosis units are not usually recommended for domestic drinking water and this may affect public acceptability of their use for this purpose. **Technical:** Availability of and installation of appropriate equipment. There is likely to be a high demand for jug filter units and cartridges which could rapidly become out-of-stock. Effectiveness depends on correct use and people heeding advice on the lifetime of the filter cartridges. **Cost:** Depends on the size of the area affected, and may be high, considering; equipment (jug filters are relatively inexpensive, whereas reverse osmosis units are more expensive); installation and maintenance (specialist engineers) and consumables (additional filters or pumps, if needed).

Table 5.2 Overview of key constraints for management options

Recovery options considerations	Waste	Social	Technical	Cost	Time
Alternative drinking water supply (1)					
Changes to water abstraction point or location of water source (2)					
Controlled blending of drinking water supplies (3)					
Continuing normal water treatment (4)					
Flush distribution system (5)					
Modification of existing water treatment (6)					
Water treatment at the point of use [tap] (7)					
Considerations/constraints	**None or minor**		**Moderate**		**Important (major)**
Time - when to implement recovery option	**No restrictions on time**		**Weeks to months/years**		**Hours - days**

5.2 Estimation of activity concentrations in drinking water

Some information is given in this section to enable activity concentrations in drinking water to be estimated from measurement data for other environmental materials. These methods should not be used in preference to measured activity concentrations in drinking water. However, they provide a useful scoping tool when measurements in drinking water supplies are not available. Measurements in environmental media such as air and ground deposition can also be used to provide information on the radionuclides that are likely to be present in drinking water before water samples have been collected and analysed.

The following information is provided in this section:

- how to provide a conservative estimate of activity concentrations in drinking water from surface water supplies based on ground deposition
- how to estimate activity concentrations in drinking water based on raw input water entering a drinking water treatment works
- how to estimate activity concentrations in rain water from ground deposition

5.2.1 Conservative estimate of activity concentrations in drinking water from ground deposition

If deposition has occurred on to a reservoir or other surface water source, the most conservative approach is to simply assume instant dilution in the top layer of water. For scoping purposes, a cautious value of 0.1 m can be assumed for the mixing depth. This gives an activity concentration in the surface water body and it may, pessimistically, be assumed that drinking water (ie tap water) levels are equivalent to these. This of course takes no account of further dilution, decay during transit in the water supply system or of any removal that may occur at water treatment works. This method does not account for the input from the overall catchment that will eventually occur; more detailed modelling would be required to predict this. However, this is only likely to be an issue in the medium to long term by which time adequate monitoring should be in place.

The basic calculation for the instant dilution model is:

Activity concentration in water (Bq l^{-1}) = Deposition (Bq m^{-2}) / Mixing depth (m) x 0.001 m^3 l^{-1}

Assuming a mixing depth of 0.1 m, a cautious conversion factor for activity concentrations in drinking water from ground deposition is therefore 0.01 Bq l^{-1} per Bq m^{-2}.

In some areas, people may drink water directly from upland streams or from water butts. In this case, the assumption of instant dilution may not be conservative. However, water is only likely to be consumed with activity concentrations at this level for short periods of time.

5.2.2 Estimation of activity concentrations in drinking water based on activity concentrations in raw water entering a water treatment works

Activity concentrations in drinking water following water treatment can be estimated using the compiled data on the likely effectiveness of different treatment processes in removing radionuclides from the water (see Table 5.3). Activity concentrations in drinking water per unit activity concentration in input water have been estimated for the two main combinations of drinking water treatment. These are flocculation/clarification followed by rapid gravity sand filtration (RGF) and flocculation/clarification followed by rapid gravity sand filtration and slow sand filtration (SSF). The estimated activity concentrations are given in Table 5.4. Conservative values of activity concentrations have been given. These have been calculated by using the minimum values from the ranges of efficiency factors for each treatment step, that is to say assuming that minimum removal of radioactive contamination occurs at each step during the treatment process.

5.2.2.1 How do I estimate activity concentrations in treated drinking water for a specific treatment works?

The main treatment processes and their order need to be identified.

For a single treatment, the activity concentration of a particular radionuclide in the water following treatment is calculated as follows:

Activity concentration (after treatment) = Activity concentration (before treatment) x F

where F = 1 – [Removal efficiency (%) / 100]

Removal efficiencies for different water treatment processes are given in Table 5.3. For combinations of processes, care needs to be taken in the use of the removal efficiency factors. For example, if flocculation/coagulation removes nearly all of a particular radionuclide or element, subsequent processes will only have an effect on the fraction of radioactive contamination that is left in the water after this process and not on the total initial contamination levels. Most water treatment works will have more than one of the processes listed in Table 5.3. Where this is the case, the effective removal for successive processes is multiplicative. This means that if the first process removes 50% and a subsequent process also removes 50%, then the total removal would be 75%. The activity concentration in water for any combination of treatments can be estimated in the following way:

Water concentration (after treatment A + B) = Water concentration (before treatment) x F_A x F_B

where F_A = 1 – [Removal A efficiency (%) / 100] and F_B = 1 – [Removal B efficiency (%) / 100]

for treatment A and B, respectively. Further information can be found in Brown et al (2008a) and Brown et al (2008b).

Table 5.3 Water treatment removal efficiencies as a function of element and treatment process[*,#] (taken from Brown et al, 2008a)

Element	Flocculation /coagulation /clarification	Gravity sand filtration[†] (rapid and slow)	Activated carbon	Lime-soda softening[‡]	Natural zeolites (clay minerals)	Ion-exchange[¶] (mixed media)	Reverse osmosis[§]
Cobalt	■■■	■■	■■	■	■■	■■■	■■■■
Selenium	■■■	■■	■■	■	■■■	■■■	■■■■
Strontium	■■	■■	■	■■■■[&]	■■■	■■■	■■■■
Zirconium	■■■■	■■	■■	■	■■■	■■■■	■■■■
Niobium	■■■■	■■	■■	■	■■■	■■■■	■■■■
Molybdenum /technetium	■■■	■■■	■■	■	■	■■■	■■■■
Ruthenium	■■■	■■	■■	■	■■	■■■	■■■■
Iodine	■■	■■	■■■	■	■■	■■■	■■■■
Tellurium	■■■	■■	■■	■	■■■	■■■	■■■■
Caesium	■■	■■	■	■■	■■■	■■■	■■■■
Barium	■■[Δ]	■■■	■■	■■■■[&Δ]	■■[Δ]	■■■■	■■■■
Lanthanum	■■[Δ]	■■■	■■	■■■■[&Δ]	■■[Δ]	■■■■	■■■■
Cerium	■■■■	■■■■	■■	■	■■■	■■■■	■■■■
Ytterbium	■■■	■■■	■	■	■■	■■■	■■■■
Iridium	■■■	■■	■■	■	■■	■■■	■■■■
Radium	■■	■■■	■■	■■■■[&]	■■	■■■■	■■■■
Uranium	■■■■	■	■■	■■■■	■■■	■■■■	■■■■
Plutonium	■■■■	■■	■■■	■	■■■	■■■■	■■■■
Americium	■■■■	■■	■■■	■	■■■	■■■■	■■■■
Key: Removal efficiency (% removed) ■ = 0 - 10%; ■■ = 10 - 40%; ■■■ = 40 - 70%; ■■■■ = >70%							

[*] Most water treatment works will have more than one of the processes listed in the table. Where this is the case, the effective removal from successive processes is multiplicative. This means that if the first process is 50% effective for removal and a subsequent process is also 50% effective, then the total removal would be 75%, as the second process will only act on the fraction of the element that remains.

[#] The values in the table are only for chemical removal. Therefore, any element that is attached to particulate material is not considered in the matrix, as any removal will be due to physical and not chemical properties. Further specific details are given in Section 3 of Brown et al, 2008b.

[†] The efficiencies reported are for the chemical process of gravity filtration, typically through sand, and not the mechanical removal of solids.

[‡] Where there is no information for a particular element, lime-soda softening has been considered to have little or no effect, and removal efficiencies of <10% have been chosen.

[¶] Data for ion exchange assume the use of a mixed cation/anion exchange media.

[§]: Reverse osmosis does not include microfiltration, used at membrane filtration plants, which is solely a physical removal process.

[&] The addition of lime (calcium oxide) during the flocculation process (for pH adjustment) is likely to increase the removal efficiencies for strontium and radium, because the addition of calcium may act as a carrier and help with co-precipitation. However, there is no information on the extent to which the addition of lime will increase the removal efficiency.

[Δ] Updated values due to revision of removal efficiencies for barium and lanthanum.

Table 5.4 Estimated activity concentrations in drinking water following typical water treatment processes in the UK (taken from Brown et al, 2008a)

	Activity concentration in water (Bq l^{-1} in treated water per Bq l^{-1} in input water)*	
Radionuclide	**Flocculation/clarification + RGF#**	**Flocculation/clarification + RGF + SGF#**
^{60}Co	$5.4\ 10^{-1}$	$4.9\ 10^{-1}$
^{75}Se	$5.4\ 10^{-1}$	$4.9\ 10^{-1}$
^{89}Sr	$8.1\ 10^{-1}$	$7.3\ 10^{-1}$
^{90}Sr	$8.1\ 10^{-1}$	$7.3\ 10^{-1}$
^{95}Zr	$2.7\ 10^{-1}$	$2.4\ 10^{-1}$
^{95}Nb	$2.7\ 10^{-1}$	$2.4\ 10^{-1}$
^{99}Mo	$3.6\ 10^{-1}$	$2.2\ 10^{-1}$
^{103}Ru	$5.4\ 10^{-1}$	$4.9\ 10^{-1}$
^{106}Ru	$5.4\ 10^{-1}$	$4.9\ 10^{-1}$
^{132}Te	$5.4\ 10^{-1}$	$4.9\ 10^{-1}$
^{131}I†	$8.1\ 10^{-1}$	$7.3\ 10^{-1}$
^{134}Cs	$8.1\ 10^{-1}$	$7.3\ 10^{-1}$
^{136}Cs	$8.1\ 10^{-1}$	$7.3\ 10^{-1}$
^{137}Cs	$8.1\ 10^{-1}$	$7.3\ 10^{-1}$
^{140}Ba	$5.4\ 10^{-1}$‡	$3.2\ 10^{-1}$‡
^{140}La	$5.4\ 10^{-1}$‡	$3.2\ 10^{-1}$‡
^{144}Ce	$9.0\ 10^{-2}$	$2.7\ 10^{-2}$
^{169}Yb	$3.6\ 10^{-1}$	$2.2\ 10^{-1}$
^{192}Ir	$5.4\ 10^{-1}$	$4.9\ 10^{-1}$
^{226}Ra	$5.4\ 10^{-1}$	$3.2\ 10^{-1}$
^{235}U	$3.0\ 10^{-1}$	$3.0\ 10^{-1}$
^{238}Pu	$2.7\ 10^{-1}$	$2.4\ 10^{-1}$
^{239}Pu	$2.7\ 10^{-1}$	$2.4\ 10^{-1}$
^{241}Am	$2.7\ 10^{-1}$	$2.4\ 10^{-1}$

* Assumes minimum removal of radionuclides at each process step (see Table 5.3 for removal efficiency factors; minimum value in range given has been used)

\# RGF: rapid gravity sand filtration; SGF: slow gravity sand filtration

† For ^{131}I, if granulated activated charcoal (GAC) is used within the filter beds, activity concentrations in treated water will be lower. Assuming minimum removal of iodine by GAC, the activity concentrations in water, Bq l^{-1} in treated water per Bq l^{-1} in input water are estimated to be 0.49 for use within RGF and 0.44 for use within SSF

‡ Updated values due to revision of removal efficiencies for barium and lanthanum for flocculation

5.2.3 Rainwater

A conservative estimate of the activity concentrations in rainwater can be made by assuming that all deposited activity has fallen in rain. Therefore if the amount of rain that has fallen is known, a calculation similar to that undertaken for surface waters can be done by substituting the rainfall amount for the water depth. For example, assuming a rainfall of 1 mm, the conversion factor for activity concentrations in rainwater from ground deposition is 1 Bq l^{-1} per Bq m^{-2}.

5.3 Monitoring of drinking water supplies and monitoring priorities

Following a release of radioactive material into the environment, the water company/supplier or responsible authority would be required to ascertain whether or not activity concentrations in the drinking water supplies were below specified screening levels or action levels. In an emergency involving widespread contamination in the environment, there could be very considerable pressure on analytical facilities, particularly those offering high-resolution gamma-ray spectrometry. Delays in the production of reliable data on water supplies could compromise operational decisions, which in turn could lead either to unnecessary restrictions or to a delay in intervention. As part of developing emergency planning it is therefore essential that monitoring capabilities are assessed and developed for a range of scenarios, for example, contamination arising pre- or post-water treatment. The UK water laboratories mutual aid radioactivity sub-group has a system in place whereby laboratories have indicated their analysis capabilities in the event of a radiological incident along with 24 hour contact details. Surface water monitoring of raw water would be overseen by the relevant environment agencies and would support the measurements made in drinking water supplies.

As part of the development of a monitoring strategy it is important to know which water sources used for drinking water supplies are likely to be susceptible to radioactive contamination following an incident. This will depend on the type of incident, for example whether it is a deliberate contamination of a water supply or widespread contamination following an atmospheric release, and on the nature of the water source (ie surface water or ground water). Ground water sources are much less likely to become contaminated and, if they do, contamination will occur on a much longer timescale than surface water sources. This information for a given area should be used to help prioritise the monitoring of drinking water supplies following an incident. To some extent, these priorities can be decided as part of emergency planning for a water supply distribution within identified geographical areas.

Detailed information on monitoring is outside the remit of this handbook. The extent and frequency of monitoring will in any case be specific to a given incident. However, some general guidance can be given. Broadly, the practical components of the monitoring of drinking water consist of sampling and analysis: both are important. An inappropriate sample will not give valid information. Similarly, an analytical method must be suitably validated to ensure that the measurements of activity concentrations in drinking water are reliable.

In terms of sampling, the water industry is likely to have relevant expertise, because even if there is no requirement for routine monitoring for radionuclides, similar considerations will apply to other potential pollutants such as trace metals. Similar expertise may also exist in other organisations. Generic guidance on sampling after an accident has been published (International Atomic Energy Agency, 1999).

For analytical work, the water industry, or other organisations, may have expertise in undertaking routine measurements. These are most likely to be measurements of gross alpha and beta activity, as this is suggested as a method to satisfy the EC directive on drinking water for routine situations (CEC, 2013). If suitable expertise and equipment is already in place, monitoring data for public supplies could, if necessary, be produced very quickly. It is therefore important to determine whether such measurements are appropriate for use in a particular incident. In many circumstances, gross alpha and beta screening methods can be used to demonstrate that activity concentrations are below the UK action levels.

The Environment Agency has published guidance on monitoring drinking water using gross alpha and beta screening methods (Allott et al, 2002). Emergency screening levels in terms of gross activity have been developed that can be used in the event of a radiation incident to determine if intervention is required to reduce activity concentrations in drinking water. The use of gross activity measurements is a good starting point for identifying activity concentrations in drinking water that may exceed the UK action levels. However, these measurements may not be enough on their own and further radionuclide-specific analysis may be required, as discussed further below.

The emergency screening levels are given in Table 5.5. If observed concentrations of gross activity in treated distributed drinking water supplies are below the values given in Table 5.5, then for most of the radionuclides considered in this handbook (see Table 1.1) there would be no need for further radionuclide-specific analyses to demonstrate conformance with the UK action levels in Table 1.3. It should be noted that these screening levels are calculated to demonstrate that UK action levels have not been exceeded.

For those radionuclides that are amenable to this approach, measurements in excess of the emergency screening levels given in Table 5.5 would not necessarily mean that the radionuclide-specific action level (see Table 1.3) had been exceeded. However, it should be assumed that activity concentrations have exceeded the action level until a more rigorous radionuclide-specific analysis has been undertaken.

Some radionuclides would not be detected using the monitoring equipment routinely used by the water industry to measure gross alpha and gross beta activity. Of those listed in Table 1.1, those that would not be detected by gross beta activity analysis are ^{75}Se, ^{95}Nb, ^{103}Ru or ^{169}Yb. Some of these radionuclides do not emit beta particles, while in the other cases the energy of the beta particle emission is too low to be detected by the method used. If it is suspected that these radionuclides are in the water supply it will be necessary to carry out more radionuclide-specific analyses. Radionuclides that emit photons can be measured easily by non-destructive techniques. However, for others, radiochemistry is required. Some guidance on the use of radiochemical methods after an incident has been published (Green, 1993).

Table 5.5 Emergency screening levels for gross alpha and beta activity concentrations in drinking water set to ensure UK action levels for drinking water are not exceeded

Type of monitoring	Emergency screening level (Bq l^{-1})
Gross alpha activity	5
Gross beta activity	30

Other more specialised measurement equipment may also be available. High-resolution gamma-ray spectrometry is a powerful technique that provides radionuclide-specific data without the need for any particular treatment or preparation of the drinking water sample. However, some radionuclides of potential importance do not emit gamma rays, and laboratories with expertise in the isolation of specific radionuclides, such as ^{90}Sr, would be needed to carry out the analyses.

Not all radioanalytical laboratories are set up to deal with the aftermath of an incident. Their normal working practices may then need some modification. Generally, when responding to a major radiological incident it is better to adapt existing procedures and practices rather than to invent new ones. Some of the factors to be considered are:

- a large number of samples may be collected by a range of people. Documentation and sample traceability are very important parts of the sampling part of the monitoring programme

- the large numbers of samples mean that the analytical laboratory needs to have a system of quality assurance and sample traceability. It should be noted that the UK water laboratories mutual aid radioactivity sub-group has set up proficiency testing of both the full scale and rapid gross alpha and gross beta methods for measuring radioactivity in water
- reliable analytical data will be needed quickly because they will be used in decisions on the need for intervention
- the UK action levels are much greater than the detection limits needed for many routine monitoring programmes. It should therefore be possible to demonstrate that activity concentrations in drinking water are above or below the action levels relatively quickly. The principles of rapid radionuclide analysis are set out in a paper by Green (1993); generic guidance on analytical methods has also been published (International Atomic Energy Agency, 1999)

As with any monitoring programme, the actual approach adopted will be defined by its objectives and will include defining the type of sample to be collected, how it is treated and how it is analysed. Consequently, it is essential that there is communication between those who define the objectives, the sample collectors, the analysts and those who will make use of the analytical data. Table 4.1 provides details of the information that is required as part of planning for a radiological incident and the things that need to be considered with respect to monitoring capabilities and resources.

5.4 References

Allott R, Rowe J and Green N (2002). *Review of alpha and beta blue book methods: drinking water screening levels.* NCAS/TR/2002/003.

Brown J, Hammond D and Wilkins BT (2008a). *Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives.* Health Protection Agency, Chilton, HPA-RPD-040.

Brown J, Hammond D and Wilkins BT (2008b). *Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives: Supporting report.* Health Protection Agency, Chilton, HPA-RPD-041.

CEC (2013). Council Directive 2013/51/Euratom laying down requirements for the provision of the health of the general public with regards to radioactive substances in water intended for human consumption. *Off J Eur Commun*.

Green N (1993). An evaluation of rapid methods of radionuclide analysis in the aftermath of an accident. *Sci Total Environ* **130/131**, 207-218.

International Atomic Energy Agency (1999). *Generic procedures for monitoring in a nuclear or radiological emergency.* Vienna, Austria, IAEA-TECDOC-1092.

6 Worked Examples

Generic scenarios and worked examples have been developed to help users become familiar with the content of the handbook and its structure. They also take the user, in a very general way, through the main decision steps and the types of problem that they would need to address in the development of a recovery strategy. In addition, the scenarios could be used as a training tool for potential users.

It is important to note that the scenarios and worked examples provided are only illustrative and have been included solely to support training in the use of the handbook. The worked examples should not be used as proposed solutions to the contamination scenarios selected. These scenarios have been chosen for the sole purpose of illustrating the breadth of the information in the handbook.

The scenarios and worked examples included are:

- contamination of water due to deposition from a contaminated plume
- direct contamination of water before treatment
- direct contamination of water after treatment

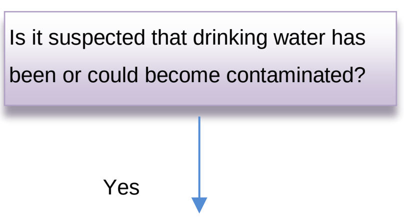
6.1 Example 1 - contamination of water due to deposition from a contaminated plume

6.1.1 Description

A large nuclear reactor accident has occurred which has resulted in a release of radioactive material into the atmosphere. It rained as the contaminated plume passed overhead, which has led to a wet deposition of contaminants over surface water supplies (open air) in a large area. At present, the contaminated plume has passed, deposition has occurred on to the surface water supplies but contamination levels have not yet been determined. The surface water supplies affected provide water for a large city and a number of other smaller areas.

6.1.2 Decision framework for developing a recovery strategy

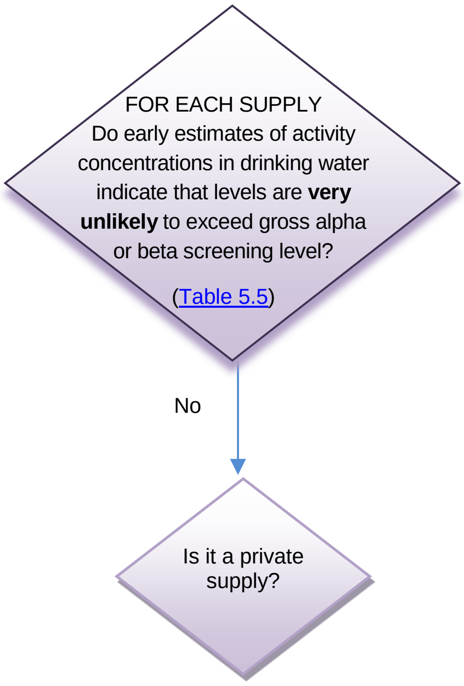
To develop a recovery strategy, start with the decision tree for recovery options for drinking water (see Figure 5.1). Information related to the progression of the scenario with time is given *in italics*.

	The radioactive plume has most likely contaminated surface water supplies. In most cases it will take one or more days before drinking water storage tanks containing uncontaminated water are depleted, and it could take from several hours up to 1-2 days for radioactive contamination to reach a water treatment plant. The immediate requirements are therefore to begin structured sampling and monitoring activities.

Is it suspected that contamination of the water supply has occurred after water treatment? ⇒ No (it has occurred before treatment) Identify water supplies that are of potential concern taking into account likely timescales of contamination (public and private) (see Sections 3.1 and 3.2)	At this stage, the main question is: 'Assuming normal usage, how long can a water company continue to supply uncontaminated water from the distribution network?' This gives the maximum time available for planning recovery actions if they are required. *There are no measurements of gross alpha and beta in drinking water available yet.* At this early stage, it is not clear whether contaminated water supplies will result in contaminated drinking water at the consumer's tap over the next few days or weeks. The primary objectives at this point are to set up the monitoring of the water used for drinking water supplies and to estimate whether activity concentrations in this water are likely to exceed the screening levels. A number of water supplies are potentially affected and could be of concern. One major treatment works that supplies a large population was under the passage of the plume (supply 1). A number of private supplies in the rural area have also been identified (supply 2).
Set up monitoring of public drinking water supplies Organise monitoring of private water supplies (screening methods) ↓ Estimate activity concentrations in drinking water using all available environmental measurements while waiting for results of drinking water monitoring (Section 5.2). If radionuclide specific data are available in water sources (untreated water), use to estimate activity concentrations in drinking water using likely effectiveness of normal water treatment (Table 5.3) ↓ Consider each identified water supply	The setting up of a sampling programme should be a high priority. Priority should be given to the sampling of treated drinking water (ie as consumed by the public). However, activity concentrations in untreated water will also provide a conservative estimate of levels in drinking water and these may be easier to collect or may already be being collected under other monitoring objectives to ascertain levels of radioactivity in the environment. Measurements of radioactivity levels in other environmental materials such as air or on the ground should provide valuable information on the radionuclides that have been released and deposited onto the open surface water sources. Ground deposition (Bq m^{-2}) can also be used to provide an estimate of the contamination of surface water sources (see Section 5.2). *Ground deposition measurements made in the environment indicate that the radionuclide most likely to be of concern is* ^{137}*Cs.* The likely effectiveness of normal drinking water treatment for ^{137}Cs should be evaluated. To do this the types of water treatment used in the works for supply 1 needs to be known. Table 5.3 provides information on how much radiocaesium is likely to be removed by existing treatment. This can be used to get a more realistic idea of what activity concentrations in tap water are likely to be and the level of immediate control of drinking water that is required before detailed measurements

<table>
<tr>
<td></td>
<td>
are available. These removal estimates need to be confirmed by monitoring both the input and output from the treatment plant(s).

Table 5.3 shows that normal water treatment is only likely to remove up to 25% of radiocaesium from water entering the treatment works.

If there is no information from other environmental media on the likely radionuclides of concern, early analysis of water samples for gross alpha and beta, gamma-ray spectrometry and other rapid radionuclide-specific analyses are a high priority (see Section 5.3). While waiting for these results, control of potentially contaminated drinking water should be considered (see below) taking into account the amount of stored drinking water in the distribution network. There is likely to be pressure to deliver an alternative uncontaminated supply of water until assurance can be given that screening levels have not been exceeded.
</td>
</tr>
<tr>
<td>


</td>
<td>
The estimates made can be used to identify whether levels of contamination in water used for drinking water supplies are likely to exceed adopted screening levels or UK action levels.

Assume that early estimates of activity concentrations in treated drinking water from public water supply 1, which is contaminated by the plume, indicate that gross beta screening levels values are very likely to be exceeded.

Supply 1: Public supply

Sampling and transport of large numbers of water samples in a contaminated area needs thorough organisation. Carrying out numerous measurements and analyses on these samples requires laboratories to be prepared to undertake such measurements and for laboratory capacities to have been assessed (see Section 5.3).

Using the information in Appendix A and estimates of activity concentrations in drinking water, doses to the public can be estimated. These can be used to estimate the impact on health of people drinking contaminated water for a limited period of time while management options are implemented. Further advice on this is given in Appendix A.

In the affected area there is a limited buffer supply of uncontaminated drinking water, which should last for 24 hours assuming normal consumption rates.

• immediate actions should be pointed towards short-term priorities:

• continuation of the delivery of (a minimum amount of) clean drinking water, assuming that spare stored
</td>
</tr>
</table>

No If contamination occurred directly into treated water supply, skip this step. Consider advising people to stop using water supply for drinking or culinary preparation (perhaps for other uses as well) and provide alternative supply (Datasheet1) while awaiting sample analyses. High priority for analyses and further monitoring. Assess doses to people (Appendix A) Consider implementing recovery options that can be put in place quickly while awaiting sample analyses: 'Changes to water abstraction or location of water source' (Datasheet 2); 'Controlled blending of drinking water supplies' (Datasheet 3); If stored clean water is available, try and reduce water consumption to maximise time this clean water supply will last. If people are still sheltering in the area where drinking water supplies are affected, providing an alternative supply (Datasheet 1) is unlikely to be feasible.	supplies have not been contaminated • change abstraction point or water source used to obtain uncontaminated water (Datasheet 2) • shut off contaminated water supplies; close the inlet pumps into the treatment installation. organise alternative water supplies (bowsers or bottled water) (Datasheet 1) • communicate to the public that a (temporary) reduction in water consumption is necessary • lower the water pressure when possible • carry out monitoring and dose assessments in order to communicate to the public
Are measured concentrations in treated drinking water/water supplied "at the tap" > screening levels (Table 5.5)? ⇒Yes Undertake radionuclide specific analyses for radionuclides identified as potential concern using knowledge of incident	The first analytical results become available for the treated water from the affected treatment works (supply 1). Analytical results show that the gross beta screening level has been exceeded. Other environmental measurements available indicate that the radionuclide of primary concern is ^{137}Cs. It is important that radionuclide specific analyses of the treated drinking water are undertaken to confirm this and any other radionuclides present.

Are concentrations in treated drinking water > UK action levels? (Table 1.3)? ⇒Yes	After some hours the first monitoring results start coming in. An activity concentration of 500 Bq l^{-1} for ^{134}Cs, and 1000 Bq l^{-1} for ^{137}Cs has been measured after water treatment. These activity concentrations exceed the UK action level of 1000 Bq l^{-1}. **Please note that this is very unlikely in reality. However, it has been assumed that the activity concentrations exceed the UK action level values to illustrate how the handbook can be used and the issues that would need to be considered in any radiation incident where this situation occurs.**
Consider all identified public and private water supplies	Two main supplies have been identified: supply 1 (public) and supply 2 (number of small private supplies).
Supply 1 Is it a public water supply? ⇒ Yes	Water from the contaminated water supply provides the public drinking water supply to a large number of members of the public including several hospitals.
Is the radionuclide short lived? (Table 1.1) ⇒ No	^{134}Cs and ^{137}Cs are classified as long-lived in the handbook.
	The water treatment in place is not sufficient to reduce activity concentrations to below the UK action level. However, measurements made in both the input water to the works and the treated water indicate that the treatment in place reduced the activity concentrations on ^{134}Cs and ^{137}Cs by 30%. This is slightly better than initially estimated and is leading to a valuable reduction in activity concentrations in drinking water. Continuing normal water treatment should therefore be considered (see Datasheet 4). However, the impact of continuing normal water treatment needs to be assessed (see Datasheet 4). Water treatment will lead to contaminated wastes being produced (eg sludge and filter media) and these may require special authorisations for their disposal depending on their activity concentrations. Appendix B provides guidance

Consider: Alternative drinking water supply (Datasheet 1) Changes to water abstraction point of location of water source (Datasheet 2) Controlled blending of drinking water supplies (Datasheet 3) Modification of existing water treatment (long-term option only) (Datasheet 6) Water treatment at point of use (tap) (only likely to be feasible is a very small number of people are affected) (Datasheet 7) Consider constraints for each management option (see Section 5.1)	on how to estimate activity concentrations in the waste. As an example, if measured activity concentrations in raw input water are 2100 Bq l^{-1} of total radiocaesium (based on 1500 Bq l^{-1} in treated water) and the treatment processes are flocculation and clarification, rapid gravity filtration and slow sand filtration, then an activity concentration in waste sludge could be broadly estimated at about 3000 Bq t^{-1} (see Table B2). As the concentrations in the input water decrease due to the contamination becoming diluted in the water sources, the activity concentrations in sludge will decrease very rapidly and so this is very unlikely to be a long-term problem. Doses to operatives working in the water treatment works also need to be assessed (see Appendix B for further guidance). Consider other options: • providing alternative supplies for drinking water (see Datasheet 1). Due to the size of the population affected, this is only likely to be feasible for a short period of time. Alternatively, if only done for sensitive population groups such as hospital patients, it could be implemented over a longer period. Advice on the need to minimise water use and the use of tap water for sanitary use would need to accompany the issue of bottled water or the provision of bowsers • changing abstraction regime or water source used (see Datasheet 2). Information on the distribution network and the water sources that input water into it needs to be available to see if ground water sources are available. Given that a large area has been affected, it is likely that this will encompass more than one abstraction point from rivers. However, the possibility of using alternative abstraction points should be considered, taking into account the wind direction and passage of the contaminated plume • controlled blending of drinking water (see Datasheet 3) may be feasible if more than one supply is available as activity concentrations in the drinking water are not significantly above the UK action level and blending could reduce these to significantly below the action level. Note: dilution of high activity concentrations is likely to be very difficult to explain to the public • water treatment 'at the tap' (see Datasheet 7) by using jug filters is only likely to be practicable on a small scale due to the commercial availability of jug filters which will limit the application. This will not be

	practicable for the number of people affected in this scenario • flushing the affected part of the distribution system could be considered as part of the implementation of any of these options. It is unlikely to be feasible for a large distribution network and may put a large pressure on water resources, particularly as water undertakers are likely to be stretched to provide adequate alternative supplies and members of the public will stock-pile bottled water A wide range of factors would need to be taken into account when choosing the most suitable option, such as: costs, social, political and ethical considerations, the likely timescales over which activity concentrations are likely to exceed the UK action levels, public concerns over water quality. These factors are discussed in more detail in the datasheets, Section 3 and in the tables of key constraints in Section 5.1. The long-term priority should be bringing the drinking water quality back to an acceptable level that meets drinking water quality regulations. This will need to be supported by a long-term monitoring programme to provide reassurance and to determine the effectiveness of the management options that have been put in place. In the longer-term, the following will need to be considered if monitoring indicates that activity concentrations are remaining above the UK action levels: • evaluation of the likely impact of run-off from water catchment areas for reservoirs and rivers and whether this is likely to keep activity concentrations in the water sources elevated over long periods of time • whether changes can be made to the water treatment implemented to remove more radiocaesium. For example, ion exchange and reverse osmosis processes could be considered, as these are likely to be very effective in removing radiocaesium (see Datasheet 6) • planned cleaning of the water treatment works to remove all contaminated precipitates, sludges and filters. This will provide public reassurance that remobilisation of radioactivity into drinking water cannot occur and will also reduce doses to people working on routine maintenance in the treatment works. Doses to the people implementing the clean-up of the treatment works would need to be assessed and controlled

	• continued monitoring in all relevant stages of water treatment until contamination levels are acceptable to all stakeholders
Supply 2 Is it a public water supply? ⇒ No	Going straight to Part 3 of decision tree (Figure 5.1).
Is the radionuclide short lived? (Table 1.1) ⇒ No	^{134}Cs and ^{137}Cs are classified as long-lived in the handbook.
Is adding / modifying water treatment of private supply an option? ⇒Yes Consider: Alternative drinking water supply (can be implemented quickly while considering water treatment options) (Datasheet 1) Water treatment at point of use (tap) (Datasheet 7) Adding new treatment may be appropriate for supplies that are not treated in the longer term (see Table 5.3 5.3) for information on likely effectiveness of water treatment) Modification of existing water treatment for larger water supplies (Datasheet 6) Consider constraints for each management	The private water supplies in the affected area are all in rural areas and are obtained from boreholes and wells. It is therefore very unlikely that these have been directly contaminated following the accident. A monitoring programme needs to be set up to measure activity concentrations in the drinking water obtained from these sources for reassurance and to check that they do not become contaminated in the long term. Consider providing alternative supplies for drinking water (Datasheet 1) and water treatment 'at the tap' (Datasheet 7) by using jug filters for reassurance until monitoring data are available. Consider key constraints for each management option - see Section 5.1.

6.2 Example 2 - direct contamination of water before treatment

6.2.1 Description

A radioactive contamination has occurred in a river, upstream from the intake location of a large scale water treatment plant. The river water has contaminated storage reservoirs in the distribution network by the time it was discovered. Regular monitoring of river water has shown that the radionuclide is ^{90}Sr and, based on a gross beta measurement, the screening level has not been exceeded.

6.2.2 Decision framework for developing a recovery strategy

To develop a recovery strategy, start with the decision tree for recovery options for drinking water (Figure 5.1) Information related to the progression of the scenario with time is given *in italics*.

Is it suspected that drinking water has been or could become contaminated? ⇒Yes	Contamination has been measured in the river that feeds a major drinking water treatment works. Information is needed on how long it takes from abstraction of the water to distribution into the drinking water network and what water treatment takes place. Water is stored post treatment in storage reservoirs, which feed into the distribution network as required to balance water usage. Information is also needed on whether there are other water abstraction points further downstream.
Is it suspected that contamination of the water supply has occurred after treatment? ⇒No Identify water supplies that are of potential concern taking into account likely timescales of contamination (public and private) (see Sections 3.1 and 3.2)	The contamination is clearly originating from the abstraction of contaminated water from the river. The river feeds 2 water treatment works, the second works being 50 km downstream. Contaminated water may already have entered the up-stream works and the water distribution system.

Set up monitoring of public drinking water supplies Organise monitoring of private water supplies (screening methods) Estimate activity concentrations in drinking water using all available environmental measurements while waiting for results of drinking water monitoring (Section 5.3). If radionuclide-specific data are available in water sources (untreated water), use to estimate activity concentrations in drinking water using likely effectiveness of normal water treatment (Table 5.3) ↓ Consider each identified water supply	The high priority is to measure activity concentrations of ^{90}Sr in the treated water, as this will be supplied into the distribution network. The monitoring programme should also include sampling of water at the abstraction point to demonstrate that no further contamination is entering the works and sampling of water as it leaves the treatment works (if it is supplied directly into the network bypassing the storage reservoirs).
FOR EACH SUPPLY Do early estimates of activity concentrations in drinking water indicate that levels are **very unlikely** to exceed gross alpha or beta screening level? (Table 5.5) ⇒ Yes	Early estimates indicate that the ^{90}Sr UK action level is unlikely to be exceeded as the gross beta emergency screening level has not been exceeded in the river water. Some water may have been consumed prior to the contamination in the river being identified. An estimate of the ingestion doses received can be made using default values of the effectiveness of drinking water treatment for ^{90}Sr (see Table 5.3 and Table 5.4) and knowledge of the treatment processes used (see Section 5.2) If we assume that the activity concentration in the river water is at the emergency screening level of 30 Bq l^{-1} (see Section 1.8.3) and that the water treatment processes used remove 30% of the contamination (see Table 5.4), a conservative estimate of ingestion doses that may have been received can be made using Table A1 in Appendix A. Assuming that the contaminated water is consumed for 1 week, ingestion doses would be of the order of 5 μSv. This is likely to be an overestimate as the contamination will become diluted rapidly as uncontaminated water is abstracted and passed into the distribution network following the passage of the deliberate contamination. Prior to measurements being made on the stored water, a conservative estimate of the doses that could have been received from drinking water from the storage reservoirs can be made by assuming it is the same as that given above. This assumes that there has been no dilution of the contamination in the storage reservoir due to mixing with clean water from both before and after the contamination entered the treatment works.

	Until monitoring can confirm that no further contaminated water is being abstracted, consideration could be given to shutting off abstraction from this point if alternative water sources or abstraction points are available. This will provide additional reassurance to the public that the situation is being controlled and the dose to the population is being minimised. There is also likely to be pressure to deliver an alternative uncontaminated supply of water (at least for drinking purposes) until further assurance can be given that screening levels have not been exceeded in the water in the distribution system and contaminated water is no longer being abstracted from the river.
Sample analyses are lower priority than those for supplies exceeding screening levels. There may be pressure to provide an alternative supply of clean water for reassurance purposes until measurement results can confirm estimates (Datasheet 1). For situations where early estimates suggest that no affected supplies have levels that exceed screening levels, prioritise sample analyses.	Monitoring of river water downstream should also be undertaken and concentrated initially on any other abstraction points for drinking water. These analyses are of lower priority because significant dilution will occur as the contamination moves downstream and the doses estimated from drinking water from the closest abstraction point indicate that immediate action is not required. *Monitoring data from the storage reservoirs are available after 2 days. Measurements suggest that activity concentrations of ^{90}Sr in the drinking water are in the range of 5-10% of the UK action level.*
Is there a requirement to reduce activity concentrations in drinking water irrespective of screening levels being exceeded? ⇒ Yes	Drinking water quality is extremely important to the public. Even if there is not a significant health risk, there is likely to be social and political pressure to reduce levels of radioactivity in water to background levels.

Consider all identified public and private water supplies Is it a public water supply? ⇒ Yes	Drinking water quality is extremely important to the public. Even if there is not a significant health risk, there is likely to be social and political pressure to reduce levels of radioactivity in water to background levels. Consider the types of water supply. *In this case only a public water supply has been contaminated and this supply is distributed to a number of large towns.*
Is the radionuclide short lived? (Table 1.1) ⇒ No	^{90}Sr is classified as long-lived in the handbook.
Consider: Alternative drinking water supply (Datasheet 1) Changes to water abstraction point of location of water source (Datasheet 2) Controlled blending of drinking water supplies (Datasheet 3) Modification of existing water treatment (long-term option only) (Datasheet 6) Water treatment at point of use (tap) (only likely to be feasible is a very small number of people are affected) (Datasheet 7) Consider constraints for each management option (see Section 5.1)	Measurements in treated water indicate that the normal water treatment is effectively reducing ^{90}Sr in the water entering the works to below the UK action level. However, due to the social and political pressure to reduce levels of radioactivity in water to background levels, the following options should be considered: Providing alternative supplies for drinking water (see Datasheet 1). Due to the size of the population affected and the low levels of contamination measured in the drinking water, this option is not justified and is also not practicable. Changing abstraction regime or water source used (see Datasheet 2). This is not required, as the contamination has passed downstream from the abstraction point. However, to provide reassurance, changing the water source could be considered, if practical, in the short term while further monitoring takes place. There may be public pressure for a thorough clean-up of the drinking water treatment works and distribution system to remove all contaminated precipitates, sludges and filters (see Datasheet 4 and Datasheet 5 for possible options). This would require planning to minimise the disruption to the water supply and to ensure sufficient water resources are available to avoid public health issues. The doses to the people implementing the clean-up of the treatment works

	would need to be assessed and controlled (see Appendix A). Changes could be made to the water treatment implemented to remove more radiostrontium (see Datasheet 6). For example, the use of lime during flocculation may increase the removal efficiency. However, changes to water treatment are unlikely to be justified on radiological protection grounds. Consider constraints for each management option (see Section 5.1). Monitoring of the drinking water supplies leaving the affected treatment works should continue until reassurance can be given that drinking water quality is acceptable to all stakeholders.

6.3 Example 3 - direct contamination of water after treatment

6.3.1 Description

The authorities have been informed by phone that a malicious release in a drinking water supply, providing water to a large city, has been dispersed in the drinking water distribution network. The identity of the radionuclide(s) is not yet known.

6.3.2 Decision framework for developing a recovery strategy

To develop a recovery strategy, start with the decision tree for recovery options for drinking water (Figure 5.1). Information related to the progression of the scenario with time is given *in italics*.

Is it suspected that drinking water has been or could become contaminated? ⇒ Yes Is it suspected that contamination of the water supply has occurred after treatment? ⇒ Yes	As you know (or strongly suspect from what you have been told), contamination of drinking water in the distribution network has occurred. Ingestion doses are likely to have been received already by some people. These doses will vary significantly and will decrease as the contamination becomes diluted as it moves away from the point of contamination. It is therefore very important to set up rapid monitoring and to control further doses as far as possible until more information is available. It is also important to know how many people are serviced by the water supply that has been contaminated and the likely dilution in the drinking water network. **Immediate action is necessary.**

IMMEDIATE ACTION IS NEEDED Consider advising people to stop using water supply for drinking or culinary preparation (perhaps for other uses as well) and provide alternative supply (Datasheet 1) while awaiting sample analyses. High priority for analyses and further monitoring. Assess doses to people (Appendix A). Consider flushing out the water in the affected distribution system (see Datasheet 5). FOR EACH SUPPLY Do early estimates of activity concentrations in drinking water indicate that levels are **very unlikely** to exceed gross alpha or beta screening level? (Table 5.5) Are measured concentrations in treated drinking water/water supplied "at the tap" > screening levels (Table 5.5)? ⇒ Yes	Samples should be taken from the network where access can be obtained and gross measurements of activity made. It may also be appropriate to undertake monitoring with handheld monitors at drinking water supply tanks and at main (water) pipelines. This approach is capable of identifying the presence of most radionuclides. *Let us assume that the location has been identified by sensors or suspect individuals have been spotted with security cameras.* *Early estimates of activity concentrations at the contamination location with handheld monitors indicate that radioactivity is present in the water supply. The first analyses of water samples show that the gross beta screening level has been exceeded. However, activity concentrations are not high enough to lead to a possible risk to health if the water is used for sanitary purposes.* Communicate to the public using all possible media that consumption of drinking water and use for culinary purposes must stop until further notice. People should be advised that using the water for sanitary purposes does not constitute a health risk. Alternative supplies such as bowsers and bottled water should be organised (see Datasheet 1). Meanwhile large numbers of water samples should be taken in order to establish the scale of the contamination. To carry out numerous gamma-ray spectrometry and gross-beta measurements requires adequate laboratory preparation and collaboration between laboratories (see Section 5.3).
Undertake radionuclide specific analyses for radionuclides identified as potential concern using knowledge of incident ⇒ Yes	After some hours the first monitoring results start coming in. An activity concentration of 2000 Bq l^{-1} of ^{131}I is found in 2 samples, equal to 4 times the UK action level. In the remainder of samples, activity concentrations ranging from below levels of detection up to 500 Bq l^{-1} have been measured (ie up to 50% of the UK action level). Specific information is available on the drinking water consumption rates of the local population. These are 50% higher than the values given in the handbook in Table A1.

Are concentrations in treated drinking water > UK action levels? (Table 1.3)? ⇒Yes	According to Table 1.4 and Table A1, scaling the drinking water consumption rates upwards by a factor of 1.5, this would lead to a maximum ingestion dose of 1-3 mSv based on the highest measurement if water was drunk for 1 month at this contamination level. Based on the other measurements, doses would be less than 1 mSv. These estimates assume that there has been no radioactive decay. ^{131}I is short-lived and has a radioactive half-life of about 8 days. If radioactive decay is taken into account, the ingestion doses would be lower by a factor of a few and the highest doses from consumption over a month are unlikely to be more than 1 mSv. It should be noted that the higher levels of contamination would decrease rapidly because the contamination will become significantly diluted in the drinking water over a short period of time and so the doses estimated above are likely to be very conservative. Consideration should be given to flushing the drinking water out of the supply at the locations with the highest activity concentrations (ie those nearest the point of contamination) and any affected part of the distribution system (see Datasheet 5). This could be achieved by opening taps and flushing the water to the sewer. Management of this water as contaminated waste would need to be considered (see Section 3.6).
Consider all identified public and private water supplies Is it a public water supply? ⇒ Yes	The distributed water network provides water to a large number of members of the public. Private water supplies are not affected.
Is the radionuclide short lived? (Table 1.1) ⇒ Yes	^{131}I is classified as short-lived in the handbook. It has a radioactive half-life of 8 days.

Consider options that can be implemented quickly: Alternative drinking water supply (Datasheet 1) Controlled blending of drinking water supplies (Datasheet 3) Changes to water abstraction point of location of water source (Datasheet 2) Continuing with normal water treatment (Datasheet 4) Consider constraints for each management option (see Section 5.1)	The majority of the ingestion doses from drinking the contaminated water is likely to have been received before controls were put on water consumption. However, smaller doses could continue to be received from drinking the water over the next few weeks until the ^{131}I has decayed. It is therefore important to consider management options that can be implemented quickly and to assess their likely effectiveness. Consider continuation of the provision of an alternative supply of drinking water (see Datasheet 1). It will be important to assess how long this can be maintained. Controlled blending of water supplies will not be of benefit in this case as water leaving the treatment works is uncontaminated. The issuing of jug filters on such a large scale is unlikely to be practicable (see Datasheet 7). However, it may be appropriate to issue these to people who were closest to the site of contamination and who received the highest ingestion doses at the time of the release if the provision of an alternative supply of drinking water is not practicable or cannot be sustained for a long enough period. Monitoring of the drinking water within the distribution network should continue until reassurance can be given that drinking water quality is acceptable to all stakeholders. Water leaving the treatment works should also be monitored to demonstrate that the treatment works have not become contaminated and to reassure the public of the water quality. This should only be required for a few months due to the short half-life of ^{131}I. There is likely to be considerable pressure from the public to flush out the water distribution network to provide guarantees that the water does not contain any residual contamination (Datasheet 5). This is unlikely to be justified on radiological protection grounds due to the short-lived nature of ^{131}I and the fact that the ingestion doses received from diluted contamination in the water will be very low. Consider constraints for each management option (see Section 5.1).

7 Datasheets of Management Options

7.1 Datasheet template

This handbook considers 7 management options that may be implemented for drinking water in the event of a nuclear accident or incident. There is a large amount of information on each of these management options that needs to be considered before a decision can be made on the most appropriate option(s) to select. As noted in Section 1.4, scientifically justified options based on radiological protection grounds may not be practicable when public perception and other social and ethical factors are considered. These factors are included in the datasheets. A datasheet template was designed to record information systematically in a standardised format, taking into account most of the criteria that decision-makers might wish to consider when evaluating different options. The template includes a short description of the option, its key attributes, constraints, effectiveness, feasibility, the waste generated, the types of incremental doses incurred, costs, side effects, and a summary of practical experience of implementing the option. Table 7.1 presents the template with a brief summary of the information that appears under each heading.

7.2 Datasheets and key updates

The datasheets are specific to the UK. The format and content of the datasheets are based largely on similar documents developed initially in version 1 of the UK Recovery Handbook (Health Protection Agency, 2005) based on work undertaken under the European STRATEGY project (STRATEGY, 2003) and further developed within the EURANOS project (Brown et al, 2009). Within EURANOS, new datasheets were developed as a consequence of peer review and feedback from European stakeholders. The new EURANOS datasheet, 'Water treatment at the point of use (tap)' is of relevance to the UK and is included here. In this handbook, the EURANOS datasheet 'Water treatment at water treatment works' has been divided into two to reflect the difference between maintaining normal water treatment during a radiation incident and the modification of existing water treatment. The second of these two new datasheets deals with the possibility of increasing the effectiveness of treatment in removing radionuclides from the water either by enhancing any treatment already in place or by adding new treatment processes. Additional information obtained from the UK water industry, in particular on water treatment, has also been included.

An index of the management options included is given in Table 7.2. The options are treated in a generic way in the datasheets and their actual implementation would depend on the normal practices used by a specific water company/supplier or, for private water supplies, those of the persons responsible for regulating the supplies.

7.3 Datasheet history

The history of the development of the datasheets is given in Table 7.3. Any additional relevant information, such as changes to the name of the management option is given in each datasheet in the document history field.

Table 7.1 Datasheet template (adapted from Nisbet et al, 2004)

Name of management option	
Objective	Primary aim of the option (eg reduction of external or internal dose).
Other benefits	Secondary aims of the option (if any). For instance, the primary objective may be reduction of internal dose, whereas an additional benefit may be a limited reduction in external dose.
Management option description	Short description of how to carry out the management option.
Target	Type of object, on or to which the option is to be applied (eg soil, drinking water supplies).
Targeted radionuclides	Radionuclide(s) that the option is aimed at. Radionuclides considered have been attributed to one of three categories: **Known applicability**: radionuclides for which there is evidence that the option will be effective **Probable applicability**: radionuclides for which there is no direct evidence the option will be effective but for which it could be expected to be so **Not applicable:** radionuclides for which there is evidence that the option will not be effective. Reasons for this are given
Scale of application	An indication of whether the option can be applied on a small or large scale.
Exposure pathway pre-intervention	The pathway(s) through which people may be exposed as a result of the contamination, prior to implementation of the option (eg inhalation, ingestion, external exposure).
Time of application	Time relative to the accident or incident when the option is applied. Can be pre-deposition phase (ie measures which can be implemented when a potential contamination risk has been identified but before passage of the contaminated air mass), early phase (days), medium-term phase (weeks-months), or late phase (months-years). An indication of the frequency of application is given where appropriate (eg annually).
Constraints	**Provides information on the various types of restrictions that have to be considered before applying the management option**
Legal constraints	Laws referring to, for example, provision of potable water and meeting quality standards.
Social constraints	Social constraints include the acceptability of the option to the affected population or to workers responsible for implementing it.
Environmental constraints	Constraints of a physical nature in the environment, such as availability of raw water supplies or alternative water supplies.
Effectiveness	**Provides information on the effectiveness of the management option and factors affecting effectiveness**
Management option effectiveness	Effectiveness is the reduction in activity concentration in the target (eg drinking water).
Factors influencing effectiveness of procedure	Technical (eg source of raw water and chemical and physical characteristics of the contamination) and social factors (eg is the option acceptable to members of the public?).
Feasibility	**Provides information on all of the equipment and facilities required to carry out the management option**
Required specific equipment	Primary equipment for carrying out the option.
Required ancillary equipment	Secondary equipment that may be required to implement the option (eg monitoring equipment, tankers).
Required utilities and infrastructure	Utilities (eg water and power supplies) and infrastructure (eg building and manufacturing plants) which may be required to implement the option.
Required consumables	Consumables which may be required to implement the option (eg containers, bottles and sorbents).
Required skills	Skills which may be required to implement the option, necessitating the training of operators.
Required safety precautions	Safety precautions which may be necessary before the operative can implement the option.
Other limitations	Feasibility limitations that are not covered under other headings (eg storage capacity).

Table 7.1 Datasheet template (adapted from Nisbet et al, 2004)

Name of management option	
Waste	**Some management options create waste, the management of which must be carefully considered at the time the option is selected**
Amount and type	Nature and volume of waste (eg sludge arising from water treatment, treated water). Also, indication of whether waste is contaminated and, if so, to what level compared with the original material.
Possible transport, treatment and storage routes	Type of vehicle required to transport waste. Requirement to treat waste in situ or at an off-site facility. Options for storage if no direct disposal option.
Factors influencing waste issues	Factors that may influence the way that wastes are dealt with (eg public acceptability and legal feasibility of the waste treatment or storage route).
Doses	**Provides information on how the management option leads to changes in the distribution of dose to individuals and populations**
Incremental dose	Incremental doses that may be received by individuals in connection with the implementation of the option (eg operators, members of the public). This dose is influenced by procedures adopted to protect operators. The inclusion of a pathway in the datasheets means that it needs to be considered; it may not be important in particular circumstances.
Intervention costs	**Provides information on the direct costs that may be incurred from implementing the management option**
Equipment	Cost of the primary equipment.
Consumables	Cost of the consumables.
Operator time	Time required to carry out the option per unit of the target that is treated.
Factors influencing costs	Size and accessibility of target to be treated. Seasonality. Availability of equipment and consumables within the contaminated area. Requirement for additional manpower. Wage level in the area.
Compensation costs	Cost of lost production, loss of use.
Waste cost	Cost of managing any wastes arising, including final disposal.
Assumptions	Any other assumptions which might significantly influence the intervention costs.
Communication needs	Identification of possible communication needs, mechanisms and recipients.
Side effect evaluation	**Provides information on side-effects incurred following implementation of the management option**
Ethical considerations	Possible positive and/or negative ethical aspects (eg promotion of self-help, requirement for informed consent of workers, distribution of costs and benefits).
Environmental impact	Impact that an option may have on the environment (eg natural water courses).
Agricultural impact	Impact that an option may have on the future suitability of land for agricultural use (eg soil amendment of soil using waste sludge, or reduced water for irrigation).
Social impact	Impact that an option may have on behaviour and on society's trust in institutions.
Other side-effects	Some options may have other side effects (eg rationing of water supplies or restrictions on the use of water).
Stakeholder opinion	Stakeholder opinion from the UK and the rest of Europe (via the EURANOS project) obtained as part of the development of recovery handbooks. **Not included for the Drinking Water Supplies Handbook**
Practical experience	State-of-the-art experience in carrying out the management option. Some options have only been tested on a limited scale, while others are standard practices.
Key references	References to key publications leading to other sources of information.
Comments	Any further comments not covered by the above.
Document history	History of previous publications that have led to the formulation of the datasheet.

Table 7.2 Index of management options for drinking water with hyperlinks to datasheets*

Number	Description of management option
Public water supplies	
1	Alternative drinking water supply
2	Changes to water abstraction point or location of water source
3	Controlled blending of drinking water supplies
4	Continuing normal water treatment (supported by a monitoring programme)
5	Flush distribution system
6	Modification of existing water treatment
7	Water treatment at the point of use (tap)
Private water supplies	
1	Alternative drinking water supply
4	Continuing normal water treatment (supported by a monitoring programme)
6	Modification of existing water treatment
7	Water treatment at the point of use (tap)

* The order in which the datasheets are presented should not be taken as the preferred order of their implementation. All options should be considered.

Table 7.3 Datasheet document history

Number	Document history
1-4, 6	**STRATEGY project, 2006.** Originators: A Liland, H Thørring and T Bergan (Norwegian Radiation Protection Authority). Contributors: NA Beresford and BJ Howard (Centre for Ecology and Hydrology, UK), D Oughton (Agricultural University of Norway, Norway), J Hunt (University of Lancaster, UK). **STRATEGY project peer reviewer(s):** J Brittain (University of Oslo, Norway). **UK Recovery Handbook 2005.** Originators: J Brown and G Roberts (HPA, UK). Updated for the UK and addition of new material. **EURANOS Recovery Handbook, 2007.** Developers: D Hammond and J Brown (HPA, UK). Updated and extended datasheet **EURANOS peer reviewer:** NA Beresford and J Smith (Centre for Ecology and Hydrology, UK): L Monte (Italian National Agency for New Technologies, Energy and the Environment (ENEA), Italy): R Saxen, A Rantavaara (Radiation and Nuclear Safety Authority (STUK), Finland): B Tangena (RIVM, Netherlands). **UK Recovery Handbook, 2009.** Developers: D Hammond and J Brown (HPA, UK). Updated EURANOS datasheet for the UK.
5	**UK Recovery Handbook, 2015.** Originators: J Brown and S Watson (PHE, UK). New data sheet called 'Flush distribution system' added for consistency with the Chemical Recovery Handbook (2012).
7	**EURANOS Recovery Handbook, 2007.** Originators: D Hammond and J Brown (HPA, UK). **EURANOS peer reviewers:** NA Beresford and J Smith (Centre for Ecology and Hydrology, UK): L Monte (Italian National Agency for New Technologies, Energy and the Environment (ENEA), Italy): R Saxen, A Rantavaara (Radiation and Nuclear Safety Authority (STUK), Finland): B Tangena (RIVM, Netherlands). **UK Recovery Handbook, 2009.** Originators: D Hammond and J Brown (HPA, UK). Updated EURANOS datasheet for the UK. Datasheet called ' water treatment at the point of use (tap).

7.4 Unregulated drinking water supplies

Management options for unregulated water supplies of drinking water are not considered in detail. However, some of the issues that should be considered with regard to unregulated water supplies following a release of radioactive contamination to the environment are listed below:

- if an incident has occurred in a rural area, campers and hikers etc in the affected area may be unaware of the incident. Warnings about consuming open water sources should be circulated through the media, although this may be insufficient to warn everybody that may potentially be affected. Additional measures such as displaying clear warnings in remote areas may also be required

- it may be necessary to provide personal monitoring for campers and hikers who have ingested water from contaminated sources. Some information to enable activity concentrations in rainwater to be estimated based on deposition levels can be found in Section 5.2

7.5 References

Brown J, Hammond DJ and Kwakman P (2009). Generic handbook for assisting in the management of contaminated drinking water in Europe following radiological emergency. EURANOS, EURANOS(CAT1)-TN(06)-09-02.

Health Protection Agency (2005). UK Recovery Handbook for Radiation Incidents. Chilton, HPA-RPD-002.

Nisbet AF, Mercer JA, Hesketh N, Liland A, Thørring H, Bergan T, Beresford NA, Howard BJ, Hunt J and Oughton DH (2004). Datasheets on countermeasures and waste disposal options for the management of food production systems contaminated following a nuclear accident. Chilton, NRPB-W58.

STRATEGY (2003). STRATEGY countermeasure compendium CD on practicability of individual countermeasures for rural and urban (including industrial) environments taking into account waste, doses and stakeholder opinion. Deliverable 2 of the STRATEGY project. EC Contract FIKR-CT-2000-00018.

Back to list of options

1 Alternative drinking water supply

Objective	To reduce ingestion doses to consumers by providing an alternative supply of potable drinking water in the event of activity concentrations in supplied (treated) water exceeding UK action levels.
Other benefits	None
Management option description	If restrictions were placed on the use of drinking water supplies due to activity concentrations exceeding UK action levels, alternative sources of water would need to be provided for drinking water and water used for food preparation. This datasheet considers the use of: • bottled water • water provided by water companies via tankers and bowsers at distribution points from other drinking water sources Advice is likely to be given that continued use of the water supply for sanitation is expected and this will not give rise to any significant hazard. If the level of contamination was sufficiently high, then, in extreme cases, the water supplies could be turned off completely. This has not been considered in detail in this datasheet (see comments).
Target	Drinking water.
Targeted radionuclides	Known applicability: all radionuclides.
Scale of application	Small/medium. Sufficient drinking water would need to be provided to sustain the population affected by any restrictions to their normal drinking water supply. Also sufficient drinking water would need to be provided to meet any legal obligations placed on the supplier. Currently, in the UK, water undertakers have to plan for not less than 10 litres per person per day of drinking water if the level of failure is within the local response plan. In the event of a prolonged incident, water undertakers must plan for alternative water supplies of not less than 20 litres per person per day in order to provide customers with some scope to address broader hygiene and other needs, when there is total failure of the piped supply. In general, the supply of alternative water could only be maintained for a short period (days) and then only to relatively small numbers of people in local or regional communities. Distribution of bottled water or water via tankers and bowsers is likely to take at least 8 hours to plan and arrange. It is important, therefore to encourage use of existing water supplies for sanitation purposes to avoid other public health issues.
Exposure pathway pre-intervention	Internal exposure from ingestion of drinking water.
Time of application	Early/medium-term phases. The management option will need to be in place for the duration of any drinking water restrictions.
Constraints	
Legal constraints	Alternative drinking water supplies would need to meet the quality standards for normal drinking water supplies. Sufficient water would need to be provided to meet any legal obligations placed on the water supplier. See Section 3.8.
Social constraints	People will not want to travel far to distribution points. Older people and people with disabilities will require assistance in getting water to their homes. It should be noted that water companies do keep records of vulnerable customers and key users in their region, and would therefore deliver water directly to these people. However the customer list is voluntary (ie depends on people registering themselves with their water companies) therefore these companies may need to work with local authorities to identify other vulnerable customers. Bulk buying at shops is likely to lead to shortages of bottled water supplies. Separate individual supplies would need to be provided for hospitals, schools, office buildings and any other large premises containing large numbers of people. Although existing water supplies may still be suitable for sanitation purposes, convincing people that water is safe to bath in, but not safe to drink or cook with, may be difficult. Generally, members of the public prefer bottled water to bowsers/tanker water.
Environmental constraints	Inclement weather could lead to disruption in the provision of alternative supplies. Remote areas may not receive alternative supplies. Widespread contamination could mean alternative supplies are limited. Drought conditions may mean alternative supplies are limited.
Effectiveness	
Management option effectiveness	If the alternative supply is free from contamination, and the restricted contaminated water is not used, then this management option will be 100% effective in preventing consumption of contaminated water. An alternative supply may be contaminated, but to a lesser extent than the primary supply, and consequently be acceptable for use as drinking water; in this case the reduction in contamination consumed will be lower. Bottled water from shops should be free from contamination, as the source is generally not local and it could have been bottled for some time prior to any incident. The quality of bottled water falls under the EC Drinking Water Directive (CEC, 2013).

Back to list of options

1 Alternative drinking water supply

Factors influencing effectiveness of procedure	Some people may ignore restrictions and continue to drink the contaminated water. Some people may not be aware that restrictions are in place and that an alternative supply is available. Shortages of alternative supplies could lead to people drinking the contaminated water. If the area affected involved large numbers of people, the supplies might not meet demand.
Feasibility	
Required specific equipment	Equipment used for the transport of water (lorries, tankers and bowsers). Storage facilities for the stockpiling of water. Containers for the transport of water from the distribution point to homes.
Required ancillary equipment	None
Required utilities and infrastructure	Co-ordination of distribution of supplies. Monitoring facilities to review effectiveness. Forward planning to determine how long capacity can be maintained. In extreme circumstances, a police presence may be required at distribution points. Sufficient number of drivers to transport the water and/or staff to hand out large quantities of bottled water. Suitable road networks required for distribution via large vehicles/tankers.
Required consumables	None
Required skills	None
Required safety precautions	Possible crowd control at distribution points. Protection of the distributor. Possible need for security at storage areas.
Other limitations	Availability of tankers and bowsers. Some water companies may have their own tankers or bowsers or may have service level agreements with companies to provide such equipment in the event of an incident. In both cases the equipment will be available locally, although may be not on the required timescales if large numbers are required. In large scale incidents, resources beyond those available to individual or groups of water companies may be needed.
Waste	
Amount and type	None unless water supply is stopped and contaminated treated water requires disposal (see **Comments**). If contaminated water has already been treated, wastes arising from water treatment may be contaminated (see Datasheet 4).
Possible transport, treatment and storage routes	Outline guidance on disposal of contaminated water is provided by Water UK (see Section 3.6).
Factors influencing waste issues	If disposal of contaminated water is required: volume of water requiring disposal; activity concentrations in water; radionuclides involved.
Doses	
Incremental dose	The distribution of alternative water supplies may give rise to incremental doses to those providing the alternative drinking water supplies from the following exposure pathways: • external gamma doses from material on the ground and other surfaces • inadvertent ingestion of contaminated dust • inhalation of suspended dust Further information on potential incremental doses can be found in an associated report (Oatway et al, 2007). Personal protection equipment, such as gloves or facemasks, may be effective in reducing the potential doses for the tasks undertaken depending on the radionuclides involved. It should be noted that the incremental doses would be significantly smaller than the doses to people living in the affected area.
Intervention costs	
Equipment	Vehicle hire including tankers and bowsers. Storage facilities for stock-piling bottled water. Containers for transport from distribution point to homes.
Consumables	
Operator time	Travelling time for drivers, possibly unsociable hours (weekends or outside normal working). If bowsers are used, there is a requirement to sample the water in them every 48 hours and analyse for a full suite of contaminants. This would involve a number of personnel and significant resources in the laboratory depending on the number of bowers/tanks required. Possible need for security at storage areas and distribution points.
Factors influencing costs	Demand for water. Availability of supplies. Fuel prices.
Compensation costs	There may be compensation costs associated with the loss of the normal water supplies.
Waste cost	None unless normal water supply is stopped and contaminated treated water requires disposal. See Datasheet 4 for potential wastes arising from water treatment of contaminated water.
Assumptions	None

Back to list of options

1 Alternative drinking water supply

Communication needs	People will need information on: where restrictions are in place and details of alternative water supplies; where the water distribution points are; the times when water will be distributed; how long the situation will last.
Side effect evaluation	
Ethical considerations	The use of alternative supplies of drinking if the new supply is also contaminated, albeit to a lesser extent than the original supply. Any increase in ingestion dose (compared with an uncontaminated supply) would need to be measured against the need for drinking water. Selection of distribution points would need to be considered to best meet the needs of the majority. Possible increased profits for providers of bottled water. Increased costs to the public if bottled water is not subsidised.
Environmental impact	If undue pressure was put on a particular source of water such as rivers or reservoirs, then there could be an environmental impact. This would be exacerbated during the summer when water levels are generally at their lowest. There is potential impact from requirement to dispose of large quantities of plastic bottles. A large quantity of heavy tankers to supply water could worsen air pollution in an area.
Agricultural impact	There may be an agricultural impact if water was diverted from agricultural use, which could lead to a shortage of water for irrigation, particularly in conditions of limited water resources. Licenses to abstract water for agricultural use may be withdrawn.
Social impact	There would be a short-term social impact. People would have to make provisions for collecting the water. Rationing may be needed to extend available supplies. Social unrest, due to real or perceived shortages in supplies, could lead to problems at distribution points. Loss of confidence in the quality of water provided by water companies to the public (and other parties for private supplies).
Other side effects	None
Practical experience	Water companies have experience in providing water using tankers or bowsers in emergency situation involving other contaminants and natural disaster (eg floods.) There are extensive bottled water resources in the UK.
Key references	CEC (2013). Council Directive 2013/51/Euratom laying down requirements for the provision of the health of the general public with regard to radioactive substances in water intended for human consumption. Official Journal of the European Communities, Brussels. Oatway WB, Smith JG and Hesketh N (2007). Incremental doses from the implementation of drinking water, aquatic, forest or social countermeasures. EURANOS report, HPA, Chilton. Smith JT, Voitsekhovitch OV, Håkanson L and Hilton J (2001). A critical review of measures to reduce radioactive doses from drinking water and consumption of freshwater foodstuffs. *J Env Radioact* **56***,* No.1-2. Voitsekhovitch O, Nasvit O, Los`y I and Berkovsky V (1997). Present thoughts on the aquatic countermeasures applied to regions of the Dnieper river catchment contaminated by the 1986 Chernobyl accident. Studies in Environmental Science 68. Freshwater and Estuarine Radioecology. Proceedings of an International Seminar, Lisbon, Portugal, 21-25 March 1994, Elsevier, Oxford, 75-85*.*
Comments	Although water may not be acceptable for use as drinking water, it may still be suitable for sanitation. However, water supplies could be turned off completely in the most extreme circumstances. This option should only be considered for a very short time (hours) to allow an initial flush of contamination to pass through the water supply system or to allow for very short-lived radionuclides to decay. Water companies in the UK have contingency plans to provide an alternative supply of drinking water during emergency situations (SEMD). These plans specify a daily amount of 10 litres of drinking water per person that must be supplied and a time limit in which this alternative supply is provided.
Document history (see Table 7.3)	**STRATEGY project, 2006**: Datasheet called 'Bans on drinking water consumption'. **UK Recovery Handbook 2005**: Datasheet called 'Alternative Supply'. **UK Recovery Handbook 2009**: Updated EURANOS datasheet for the UK.

Back to list of options

2 Changes to water abstraction point or location of water source

Objective	To reduce ingestion doses to consumers by reducing radioactive contamination in drinking water in the event of activity concentrations in the normal water supply (treated) exceeding UK action levels.
Other benefits	None
Management option description	This datasheet considers changes in abstraction points from within a reservoir, changing abstraction points from rivers, the use of alternative water sources and movement of water within distributed water networks. It can take several days or more for contamination to be evenly distributed through the water column of reservoirs due to their size and depth or climate (eg ice cover, hydrological cycling). It may be possible to use water from deeper parts of a reservoir before contamination has reached it by opening lower sluice gates and using water that has not yet been contaminated. For rivers, water could be abstracted upstream of any contamination if several abstraction points are available. Water could also be used from downstream of the contamination if the abstraction point is sufficiently far away that the contamination has not reached there yet. It may be possible to change to alternative sources of water (eg change from river abstraction to bore holes). It may also be possible for water companies to use other reservoirs under their responsibility that have not been contaminated. It may be possible for other nearby water companies to share uncontaminated water, if there is sufficient spare capacity and distributed networks exist to transfer the water to the desired location.
Target	Public drinking water supplies. Not appropriate for private drinking water supplies in general (see comments).
Targeted radionuclides	Known applicability: all radionuclides.
Scale of application	Small/medium. The water companies or suppliers could apply this option as long as sufficient drinking water supplies can be maintained, or until the contamination has been sufficiently dispersed or diluted.
Exposure pathway pre-intervention	Internal exposure from ingestion of drinking water.
Time of application	Early phase. Priorities need to be decided depending on the vulnerability of water supplies to the radiological emergency. Surface water supplies, such as rivers and reservoirs, are likely to be of higher priority than boreholes in the short term and this should be taken into account when formulating a monitoring strategy and identifying supplies of potential concern. In the longer-term, monitoring and the implementation of this option may need to focus more on ground water sources, such as boreholes. Changes to abstraction or water sources would be used as soon as contamination of a water source had been confirmed and implemented quickly. Can be used only for a few days or weeks, until contamination is fully mixed (eg in reservoirs, or until contamination has spread to the new abstraction point, such as rivers, except where the new abstraction point is upstream of the release). Unlikely to be used in the longer-term unless switching to deep boreholes unaffected by surface water contamination is an option. Changes made to water supply sources need to be linked very closely to a detailed monitoring programme to ensure the optimal timing of the changes.
Constraints	
Legal constraints	Any drinking water supplies would need to meet the normal quality standards for drinking water. See Section 3.8.
Social constraints	There may be problems regarding the acceptability of any remaining contamination in water supplies; this is likely to be related to the availability of alternative supplies, such as bottled water.
Environmental constraints	Widespread contamination or water shortages during periods of drought could result in fewer opportunities for changing abstraction.
Effectiveness	
Management option effectiveness	If the water at the new abstraction point or water source is uncontaminated then this management option would be 100% effective in reducing activity concentrations in supplied drinking water.
Factors influencing effectiveness of procedure	The extent to which the water at the new abstraction point or water source is contaminated. For reservoir abstraction, the water would need to have sufficient depth to ensure that abstraction is from water containing lower activity concentrations. The time taken for contamination to reach abstraction points or new water supply (eg water from a borehole would require monitoring).
Feasibility	
Required specific equipment	None in the short-term other than monitoring equipment. However, if this countermeasure was being considered as a longer-term option (switching to deep boreholes) then pipe work/infrastructure may be needed.

Back to list of options

2 Changes to water abstraction point or location of water source

Required ancillary equipment	Additional monitoring may be needed at new abstraction points to ensure contamination has not reached the abstraction point and/or supplied water is below UK action levels.
Required utilities and infrastructure	Water companies or suppliers would have to have a sufficiently flexible and integrated system of water supply control to allow them to change abstraction points and/or water sources. This would mean that probably only the larger suppliers would be able to implement this option.
Required consumables	None
Required skills	No specific skills are required other than those already employed by the water company/supplier.
Required safety precautions	None
Other limitations	None
Waste	
Amount and type	This option will not produce any contaminated waste water. However, there may be contaminated treated water from the original supply that requires disposal. If contaminated water has already been treated, wastes arising from water treatment may be contaminated (see Datasheet 4).
Possible transport, treatment and storage routes	Outline guidance on disposal of contaminated water is provided by Water UK (see Section 3.6).
Factors influencing waste issues	If disposal of contaminated water is required: volume of water requiring disposal; activity concentrations in water; radionuclides involved.
Doses	
Incremental dose	The implementation of this option is very unlikely to give rise to any incremental doses and they have not been assessed.
Intervention costs	
Equipment	None
Consumables	None
Operator time	There will be no additional time costs for the operator as any actions can be taken during the course of normal work practices, with the exception of monitoring at the abstraction points.
Factors influencing costs	N/A
Compensation costs	None
Waste cost	Disposal of contaminated treated water if required (see Datasheet 4 for potential wastes arising from water treatment of contaminated water).
Assumptions	None
Communication needs	Routes already in use by the water companies/suppliers could be used to give instructions to their operators. However, communication with the affected communities about the rationale for choosing this option would be desirable and should form part of a wider communication and information strategy.
Side effect evaluation	
Ethical considerations	Possible water shortages in other areas. Water from a new abstraction point may also be contaminated, but to a lesser extent. Any increase in dose compared with that prior to the incident would need to be weighed against the need to supply drinking water to the affected population.
Environmental impact	Management of abstraction would need to be monitored more closely to ensure that permanent damage to natural water sources is avoided. For example, changes in the manipulation of reservoir water may affect downstream biota.
Agricultural impact	There may be an agricultural impact if water was diverted from agricultural use, which could lead to a shortage of water for irrigation, particularly in conditions of limited water resources. Licenses to abstract water for agricultural use may be withdrawn.
Social impact	Demand for bottled water may increase sharply if people prefer drinking bottled water for any reason, eg water is discloloured.
Other side effects	None
Practical experience	Changes to water abstraction are implemented routinely as part of the management of drinking water supplies for other hazards. However, there is only limited experience following incidents involving radioactive contamination. The implementation of this countermeasure in Kiev, following the Chernobyl accident, provides practical experience and, although it is now thought to have been done wrongly, shows the importance of choosing new abstraction points wisely and for the right reason (Smith JT et al, 2001; Voitsekhovitch et al, 1997).
Key references	Oatway WB, Smith JG and Hesketh N (2007). Incremental doses from the implementation of drinking water, aquatic, forest or social countermeasures. EURANOS

Back to list of options

2 Changes to water abstraction point or location of water source

	report, HPA, Chilton. Smith JT, Voitsekhovitch OV, Håkanson L and Hilton J (2001). A critical review of measures to reduce radioactive doses from drinking water and consumption of freshwater foodstuffs. *J Env Radioact* **56***,* No.1-2. Voitsekhovitch O, Nasvit O, Los`y I and Berkovsky V (1997). Present thoughts on the aquatic countermeasures applied to regions of the Dnieper river catchment contaminated by the 1986 Chernobyl accident. Studies in Environmental Science 68. Freshwater and Estuarine Radioecology. Proceedings of an International Seminar, Lisbon, Portugal, 21-25 March 1994, Elsevier, Oxford, 75-85.
Comments	Changing from river abstraction to deep boreholes may only be an option in the short-term if the boreholes only have a limited water capacity compared to rivers. The effectiveness of implementing in surface reservoirs is likely to be low and short-term and would have limited acceptability. Changing water source or abstraction point is unlikely to be an option for private water supplies since it is unlikely that a second source of uncontaminated water would be available. However, some private water supplies do have an additional source of supply where one source can dry up during the summer. It should be noted that the water from the alternative source is often not very palatable and so probably could not be used in the long-term.
Document history (see Table 7.3)	**STRATEGY project, 2006**: Datasheet called 'Regulation of flow of contaminated water through reservoirs'. **UK Recovery Handbook 2005**: Datasheet called 'Change Abstraction Regime'. **EURANOS Recovery Handbook, 2007**: Name of datasheet revised to 'Changes to water abstraction point or location of water source'. **UK Recovery Handbook 2009**: Updated EURANOS datasheet for the UK.

Back to list of options

3 Controlled blending of drinking water supplies

Objective	To reduce ingestion doses to consumers by dilution of radioactive contamination in drinking water in the event of activity concentrations in the supplied (treated) water exceeding UK action levels.
Other benefits	None
Management option description	Contaminated water could be mixed with uncontaminated or less contaminated water if more than one supply is available at the point of water treatment or post treatment. This is an effective method of reducing activity concentrations in water to below action levels and is done when required for other contaminants.
Target	Public drinking water supplies. Not appropriate for private drinking water supplies, in general.
Targeted radionuclides	Known applicability: all radionuclides.
Scale of application	Medium/large. This could be used on a medium/large-scale depending on the options there are for blending different water sources either after or before treatment and the size of water distribution networks in place. Blending should not reduce the amount of drinking water produced or supplied to homes.
Exposure pathway pre-intervention	Internal exposure from ingestion of drinking water.
Time of application	Early/medium-term phases. Blending would be used as soon as contamination of a water source had been confirmed and implemented quickly. Blending would be required for the duration of time that a contaminated water source was above the action level.
Constraints	
Legal constraints	Blended drinking water supplies would need to meet the quality standards for normal drinking water supplies (see Section 3.8).
Social constraints	There may be problems regarding the acceptability of residual levels of contamination in water supplies by the public. These are likely to be related to the availability of alternative supplies, such as bottled water. Blending contaminated water with uncontaminated water means that the contamination is diluted. This will need to be explained to the public, who might find this practice unacceptable, particularly if people who would have had a 'clean' supply now receive water contaminated with low levels of radioactivity.
Environmental constraints	Widespread contamination or water shortages during periods of drought could result in fewer opportunities for blending.
Effectiveness	
Management option effectiveness	The effectiveness of this option in reducing contamination levels in water depends on the extent to which the contamination has been diluted. Monitoring after the point of blending/mixing would be required to ensure that contamination levels have been reduced sufficiently.
Factors influencing effectiveness of procedure	The extent to which the cleaner source of water is free from contamination and the speed with which blending can be implemented. The availability of alternative (less contaminated) drinking water sources.
Feasibility	
Required specific equipment	None
Required ancillary equipment	None
Required utilities and infrastructure	The water company/provider must have access to different water sources/supplies and be able to adjust the amount of water from each that enters the distributed drinking water supply.
Required consumables	None
Required skills	No specific skills are required other than those already employed by the water company.
Required safety precautions	None
Other limitations	There can be problems associated with mixing of very soft and very hard water.
Waste	
Amount and type	This option will not produce any contaminated waste water directly. However, there may be contaminated treated water from the original supply that requires disposal. If contaminated water has already been treated, wastes arising from water treatment may be contaminated (see Datasheet 4).
Possible transport, treatment and storage routes	Outline guidance on disposal of contaminated water is provided by Water UK (see Section 3.6).
Factors influencing waste issues	If disposal of contaminated water is required: volume of water requiring disposal; activity concentrations in water; radionuclides involved.
Doses	
Incremental dose	The implementation of this option is very unlikely to give rise to any incremental doses and they have not been assessed.
Intervention costs	

Back to list of options

3 Controlled blending of drinking water supplies

Equipment	None in the short term. If this option is implemented as a long-term countermeasure and the existing infrastructure was inadequate, new build/infrastructure would be required.
Consumables	None
Operator time	It may be possible to undertake blending during the course of normal work practices. However, there may be additional time costs for the operator due to the need to undertake a full risk assessment to ensure that re-zoning supplies to enable blending would not create another problem, such as the supply of discoloured water or causing bursts in distribution pipes.
Factors influencing costs	N/A
Compensation costs	Unlikely to be applicable.
Waste cost	None directly (see Datasheet 4 for potential wastes arising from water treatment of contaminated water).
Assumptions	None
Communication needs	Communication with the affected communities about the rationale for choosing this option would be desirable and should form part of a wider communication and information strategy.
Side effect evaluation	
Ethical considerations	Possible water shortages in other areas. People may receive doses from blended drinking water that otherwise they would not. Any increase in dose to these people would need to be balanced against the need to supply drinking water for the larger population.
Environmental impact	If undue pressure was put on a particular source of water such as a river or a reservoir, then there could be an environmental impact. This would be exacerbated during the summer months when water levels are generally at their lowest.
Agricultural impact	There may be an agricultural impact if water was diverted from agricultural use, which could lead to a shortage of water for irrigation, particularly in conditions of limited water resources. Licenses to abstract water for agricultural use may be withdrawn.
Social impact	Blending clean water with contaminated water, no matter how slight the contamination, may lead to public loss of confidence in tap water supplies. Demand for bottled water may increase sharply if people prefer drinking bottled water (for any reason), but particularly if people lose confidence in tap water supplies.
Other side effects	Restrictions on the use of water where there are shortages.
Practical experience	Water companies already have experience in blending and mixing water supplies. They would have to decide if the contaminated source could be diluted sufficiently, given their available water sources. This countermeasure was widely used in the former Soviet Union following the Chernobyl accident.
Key references	Oatway WB, Smith JG and Hesketh N (2007). Incremental doses from the implementation of drinking water, aquatic, forest or social countermeasures. EURANOS report, HPA, Chilton. Smith JT, Voitsekhovitch OV, Håkanson L and Hilton J (2001). A critical review of measures to reduce radioactive doses from drinking water and consumption of freshwater foodstuffs. *J Env Radioact* **56**, No.1-2. Voitsekhovitch O, Nasvit O, Los`y I and Berkovsky V (1997). Present thoughts on the aquatic countermeasures applied to regions of the Dnieper river catchment contaminated by the 1986 Chernobyl accident. Studies in Environmental Science 68. Freshwater and Estuarine Radioecology. Proceedings of an International Seminar, Lisbon, Portugal, 21-25 March 1994, Elsevier, Oxford, 75-85.
Comments	None
Document history (see Table 7.3)	**STRATEGY project, 2006**: Datasheet called 'Switching or blending of drinking water supplies'. **UK Recovery Handbook 2005**: Datasheet called 'Controlled blending'. **EURANOS Recovery Handbook, 2007**: Datasheet renamed to 'Controlled blending of drinking water supplies'. **UK Recovery Handbook 2009**: Updated EURANOS datasheet for the UK.

Back to list of options

4 Continuing normal water treatment (supported by a monitoring programme)

Objective	Continuing the use of normal water treatment to remove or partially remove radioactive contamination in drinking water and hence ingestion doses to consumers.
Other benefits	No changes to existing practices.
Management option description	There are several processes used routinely to treat water to remove impurities from drinking water. All of these processes will remove radionuclides to some extent. The main processes used are flocculation or clarification, slow or rapid gravity sand filtration, carbon filtration, membrane filtration, ion exchange and reverse osmosis. For private water supplies, single or multiple units can be used for purifying water by the removal of solids, chemicals and disinfectants using the methods listed above. Point of entry systems are located outside the premises and water can be stored post treatment. Point of use systems are located within the premises, normally at the point of supply, ie kitchen sink and water cannot be stored following treatment. Point of use systems are considered further in Datasheet 7) A full monitoring programme would be needed to support this option and to confirm that water treatment is effective for the radionuclides of concern and will maintain activity concentrations in the treated water below the action levels over the period of concern. It should be noted that activity concentrations higher than UK action levels may be acceptable in the short-term particularly for short-lived radionuclides (see Section 3.8 for further guidance).
Target	Public drinking water supplies. Private drinking water supplies where water treatment is undertaken.
Targeted radionuclides	**Known applicability:** all radionuclides to some extent, except tritium (see removal efficiency table at end of datasheet).
Scale of application	Small -large. All drinking water supplied by water companies undergoes treatment to some extent. Private water supplies will undergo treatment to varying extents, although basic disinfection alone will not have any impact on radioactive contamination.
Exposure pathway pre-intervention	Internal exposure from ingestion of drinking water.
Time of application	Early/late phases. As there are no changes to existing practices, water treatment will remove/reduce contamination levels in water while the treatment continues.
Constraints	
Legal constraints	Drinking water undergoes treatment normally to comply with water quality standards. Any waste arising from treatment may need a new authorisation (see Section 3.8).
Social constraints	Continuing treatment of contaminated water will give rise to exposure to personnel working in water treatment plants. This could be as a direct result of exposure to contaminated water or to the accumulation and storage of contaminated waste from treatment (see Section 0). Public acceptability and trust in water treatment processes to remove or reduce radioactive contamination. Acceptability of residual levels of contamination by the public; this is likely to be related to the availability of alternative supplies (eg bottled water).
Environmental constraints	If normal disposal routes for waste water and other solid wastes from water treatment works continues, this could lead to the spread of low levels of contamination in the environment, eg in natural water courses.
Effectiveness	
Management option effectiveness	A table of chemical removal efficiencies for a range of radionuclides and water treatment processes is given at the end of the datasheet (Table 5.3). Section 5.2 gives estimated activity concentrations in treated water for typical water treatment in the UK and provides guidance on how to use the removal efficiency table for a specific treatment works or set of treatment processes. Generally, treatments used to remove a high content of solids (which lead to colour or turbidity in treated water) from surface water sources would be particularly effective at removing radioactive contamination because many radionuclides will attach to the particulate material in the water. Physical filtration is very effective at removing this particulate material. 'Clean' ground water sources (some boreholes and aquifers) only undergo minimal treatment and this would be less effective at removing contamination due to less chemical manipulation and low levels of particulate material in the water. Membrane filtration is a physical process used for 'clean' water sources with a very low content of solids and there are no chemical processes involved. Membrane filtration has no effect on the chemical removal of radionuclides and the effectiveness of membrane filtration to remove radionuclides is likely to be small (see Brown et al, 2008b).
Factors influencing effectiveness of procedure	Effectiveness will be dependent on the types and number of treatment processes used and also the radionuclide(s) involved and their physical and chemical properties (see Brown et al, 2008b).

Back to list of options

4 Continuing normal water treatment (supported by a monitoring programme)

Feasibility	
Required specific equipment	No additional specific equipment would be required for treatment processes already in use at the water treatment works (or for private supplies).
Required ancillary equipment	Additional monitoring equipment at treatment works
Required utilities and infrastructure	Already in place.
Required consumables	May need additional treatment materials, eg due to more frequent replenishment of filtration media.
Required skills	No specific skills are required other than those already employed.
Required safety precautions	Monitoring in the treatment works and of operatives may be required to ensure that any limits on operative exposures are not exceeded. Changes to other working and safety practices may be required to minimise doses to operatives (see Brown et al, 2008a, and Appendix A).
Other limitations	None
Waste	
Amount and type	Waste is produced following water treatment. It may be contaminated material from filter or resin beds, waste water or sludge. Sludge is generated continuously as part of treatment, the quality depending on the content of solids in the raw water. Larger quantities of sludge are often stored on site prior to disposal. Sludge is also generated during cleaning of storage tanks. Cleaning of storage tanks and the replenishment of filters and resins may take place more frequently following radioactive contamination to prevent high concentrations of radioactive waste arising. Large quantities of waste material could be generated (eg contaminated sand and activated charcoal from filter beds and sludge) (see Section 3.6 and Brown et al, 2008a, 2008b).
Possible transport, treatment and storage routes	Waste arising from treatment of water will require disposal and/or storage under a Radioactive Substances Act authorisation.
Factors influencing waste issues	The availability of a suitable disposal route; the cost of radioactive waste disposal; radionuclides involved and levels of contamination; amounts of waste requiring disposal.
Doses	
Incremental dose	Doses to operatives at treatment works should be monitored and controlled, if necessary. There may be additional doses received if tasks are performed more frequently, eg replenishment of filter media.
Intervention costs	
Equipment	None
Consumables	Increased frequency of replenishing treatment materials (eg filter beds and resins will give rise to additional costs).
Operator time	There could be additional operator time if operations were performed more frequently. Monitoring will require additional personnel.
Factors influencing costs	If operations were performed outside normal working patterns/shifts.
Compensation costs	Unlikely to be applicable.
Waste cost	Disposal of radioactive material generated from water treatment may be expensive as large quantities of contaminated waste could be generated (eg sand from filter beds and sludge).
Assumptions	None
Communication needs	Overall management of the treatment and waste arising. There would be a need to assure consumers that the water produced was potable and met the required quality standards. Any restrictions on the use of drinking water need to be explained. Workers would need to be informed that they could be exposed to radioactive contamination.
Side effect evaluation	
Ethical considerations	Consideration should be given to possible doses to operatives (not incremental doses, see Section 0 and Brown et al, 2008a, 2008b). There may be inequity between beneficiaries (water consumers) and those living by waste facilities.
Environmental impact	Utilisation or disposal of radioactive sludge needs to be considered as the activity concentrations in the sludge may be above the levels permitted for normal use (land spreading or landfill).
Agricultural impact	Sludge may not be acceptable for amendment of agricultural soil. The use of drinking water supplies may not be acceptable for irrigating or watering crops although this contamination pathway is very unlikely to be significant (see the Food Production Systems Handbook for further information).
Social impact	Loss of confidence in the quality of water provided by water companies to the public (and

Back to list of options

4 Continuing normal water treatment (supported by a monitoring programme)

	other parties for private water supplies). Increased demand for bottled water. Possible increase in public confidence that the problem of contamination is being effectively managed.
Other side effects	None
Practical experience	This is normal practice. Some experience of the consequences of continuing normal water treatment in the UK is given in Jones and Castle, 1987. Experience following the Fukushima accident supports the removal efficiencies given in the table for caesium (coagulation/filtration) and iodine (activated carbon).
Key references	Annanmäki M, Turtiainen T, Jungclas H and Rauβe C (2000). Disposal of radioactive waste arising from water treatment: Recommendations for the EC. STUK-A175, Helsinki. Brown J, Hammond D and Wilkins BT (2008a). Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives. HPA-RPD-040. Available at http://dwi.defra.gov.uk/research/completed-research/reports/DWI70-2-192_radionuclides.pdf Brown J, Hammond D and Wilkins BT (2008b). Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives: supporting report. HPA-RPD-041. Available at http://dwi.defra.gov.uk/research/completed-research/reports/DWI70-2-192_supporting.pdf. Goossens R, Delville A, Genot J, Halleux R and Masschelein WJ (1989). Removal of the typical isotopes of the Chernobyl fall-out by conventional water treatment, *Wat Res* **23**, No. 6, 693-97. Jones F and Castle RG (1987). Radioactivity monitoring in the water cycle following the Chernobyl accident. *J Inst Water Poll*, 205-217. Oatway WB, Smith JG and Hesketh N (2007). Incremental doses from the implementation of drinking water, aquatic, forest or social countermeasures. EURANOS report, HPA, Chilton. Saxén, R (1997). Freshwater and fish, in: Reclamation of contaminated urban and rural environments following a severe nuclear accident. Strand P, Skuterud L and Melin J Eds. *Nordic Nuclear Safety Research*, NKS(97) 18 97-10-10, 98-116. Smith JT, Voitsekhovitch OV, Håkanson L and Hilton J (2001). A critical review of measures to reduce radioactive doses from drinking water and consumption of freshwater foodstuffs. *J Env Radioact* **56**, No.1-2*.* Tsarik N (1993). Supplying water and treating sewage in Kiev after the Chernobyl accident. *J Am Water Works Assoc,* **85**, 42-45.
Comments	None
Document history (see Table 7.3)	**STRATEGY project, 2006**: Datasheet called 'Purification of water at treatment plants'. **UK Recovery Handbook 2005**: Datasheet called 'Water Treatment'. **UK Recovery Handbook, 2009**: New datasheet developed to only cover maintaining normal water treatment supported by a monitoring programme. Modifications to water treatment considered in a separate datasheet (Datasheet 5).

Table 5.3 (reproduced for convenience) Water treatment removal efficiencies as a function of element and treatment process[*, #] (taken from Brown et al, 2008a)

Element	Flocculation /coagulation /clarification	Gravity sand filtration[†] (rapid and slow)	Activated carbon	Lime-soda softening[‡]	Natural zeolites (clay minerals)	Ion-exchange[¶] (mixed media)	Reverse osmosis[§]
Cobalt	■■■	■■	■■	■	■■	■■■	■■■■
Selenium	■■■	■■	■■	■	■■■	■■■	■■■■
Strontium	■■	■■	■	■■■■[&]	■■■	■■■	■■■■
Zirconium	■■■■	■■	■■	■	■■■	■■■■	■■■■
Niobium	■■■■	■■	■■	■	■■■	■■■■	■■■■
Molybdenum /technetium	■■■	■■■	■■	■	■	■■■	■■■■
Ruthenium	■■■	■■	■■	■	■■	■■■	■■■■
Iodine	■■	■■	■■■	■	■■	■■■	■■■■
Tellurium	■■■	■■	■■	■	■■■	■■■	■■■■
Caesium	■■	■■	■	■■	■■■	■■■	■■■■
Barium	■■[Δ]	■■■	■■	■■■■[&Δ]	■■[Δ]	■■■■	■■■■
Lanthanum	■■[Δ]	■■■	■■	■■■■[&Δ]	■■[Δ]	■■■■	■■■■
Cerium	■■■■	■■■■	■■	■	■■■	■■■■	■■■■
Ytterbium	■■■	■■■	■	■	■■	■■■	■■■■
Iridium	■■■	■■	■■	■	■■	■■■	■■■■
Radium	■■	■■■	■■	■■■■[&]	■■	■■■■	■■■■
Uranium	■■■■	■	■■	■■■■	■■■	■■■■	■■■■
Plutonium	■■■■	■■	■■■	■	■■■	■■■■	■■■■
Americium	■■■■	■■	■■■	■	■■■	■■■■	■■■■

Key: Removal efficiency (% removed) ■ = 0 - 10%; ■■ = 10 - 40%; ■■■ = 40 - 70%; ■■■■ = >70%

[*] Most water treatment works will have more than one of the processes listed in the table. Where this is the case, the effective removal from successive processes is multiplicative. This means that if the first process is 50% effective for removal and a subsequent process is also 50% effective, then the total removal would be 75%, as the second process will only act on the fraction of the element that remains.

[#] The values in the table are only for chemical removal. Therefore, any element that is attached to particulate material is not considered in the matrix, as any removal will be due to physical and not chemical properties. Further specific details are given in Section 3 of Brown et al, 2008b.

[†] The efficiencies reported are for the chemical process of gravity filtration, typically through sand, and not the mechanical removal of solids.

[‡] Where there is no information for a particular element, lime-soda softening has been considered to have little or no effect, and removal efficiencies of <10% have been chosen.

[¶] Data for ion exchange assume the use of a mixed cation/anion exchange media.

[§]: Reverse osmosis does not include microfiltration, used at membrane filtration plants, which is solely a physical removal process.

[&] The addition of lime (calcium oxide) during the flocculation process (for pH adjustment) is likely to increase the removal efficiencies for strontium and radium, because the addition of calcium may act as a carrier and help with co-precipitation. However, there is no information on the extent to which the addition of lime will increase the removal efficiency.

[Δ] Updated values due to revision of removal efficiencies for barium and lanthanum.

Back to list of options

5 Flush distribution system	
Objective	To reduce ingestion doses to consumers of drinking water by flushing uncontaminated water through the water distribution system to reduce activity concentrations in consumed water.
Other benefits	None
Management option description	Flushing is a routine operation that water companies use to remove sediments that may affect the water's taste and colour and it is an essential preventive maintenance strategy for the water distribution system. While a loss of water pressure is common, the process does not typically interrupt water service. It could also be used to flush through contaminated water once the affected part of the distribution system is isolated or to provide reassurance that the water distribution system is 'clean' of radioactivity following a radiation incident. Flushing of the distribution system should continue until the contamination has been completely removed from the distribution system or diluted to a level, which is below water quality standards, or an agreed level which does not pose a long term risk to health. This recovery option should be supported by a suitable monitoring strategy.
Target	Public drinking water supplies (may also be viable for larger private water supplies with a distribution network)
Targeted radionuclides	Known applicability: all radionuclides.
Scale of application	Small/medium. Will depend on the size of the water network/ distribution system contaminated. Likely to only be practicable for localised contamination in a distribution system.
Exposure pathway pre-intervention	Internal exposure from ingestion of drinking water.
Time of application	Primarily early phase but may be used later to provide reassurance on water quality following the earlier passage of contaminated water through the distribution system.
Constraints	
Legal constraints	Drinking water supplies following flushing will have to comply with standards on water quality (see Section 3.8).
Social constraints	Public acceptability and trust in the flushing processes to remove or reduce radionuclide contamination. There may be issues regarding the acceptability of any residual levels of contamination by the public and perceived health risks.
Environmental constraints	In most cases the contaminated water will pass through a sewage treatment process or be diverted in its diluted state to storm tanks. However, despite best endeavours, it may not be possible to divert contaminated water into the foul sewer and the flow will be direct into a water course. If this happens, the EA in England, Natural Resources in Wales, SEPA in Scotland or Northern Ireland Environment Agency will take the appropriate action to mitigate the effect on the environment.
Effectiveness	
Management option effectiveness	Flushing the affected part of a distribution system will be effective at removing or reducing contamination levels in the system. Monitoring will be required to demonstrate that water quality standards are met. While flushing is carried out and the subsequent effectiveness is being determined, it may be necessary to provide an alternative source of drinking water (Datasheet 1).
Factors influencing effectiveness of procedure	Some people may ignore instructions regarding water use, or may not be aware that restrictions are in place and that an alternative supply is available. Shortages of alternative supplies could lead to people drinking the contaminated water. If the area affected involved large numbers of people, the supplies might not meet demand.
Feasibility	
Required specific equipment	Monitoring equipment to determine effectiveness.
Required ancillary equipment	None
Required utilities and infrastructure	None
Required consumables	Alternative water supply will need to be considered if the procedure and associated monitoring are protracted (see Datasheet 2).
Required skills	No specific skills are required other than those already employed by the water company/supplier.
Required safety precautions	None
Other limitations	There may be costs associated with provision of alternative water supplies if this is implemented.

Back to list of options

5 Flush distribution system

Waste	
Amount and type	Contaminated water. The relevant environmental regulator should be consulted for any planned discharges to a wastewater collection systems or surface waters.
Possible transport, treatment and storage routes	Outline guidance on disposal of contaminated water is provided by Water UK (see Section 3.6).
Factors influencing waste issues	If disposal of contaminated water is required: volume of water requiring disposal; activity concentrations in water; radionuclides involved.
Doses	
Incremental dose	Doses could be received by individuals in connection with disposing of any waste water and associated sludges.
Intervention costs	
Equipment	None
Consumables	Costs associated with provision of alternative drinking water supplies.
Operator time	Staff and personnel costs should not be significantly in excess of normal working practices.
Factors influencing costs	None
Compensation costs	There may be requests for compensation for costs associated with loss of normal water supplies provided by water companies and suppliers (ie manufacturing, production or farming practices). Financial and legal advice relating to compensation after a major incident can be found at www.gov.uk.
Waste cost	Any treatment of waste water prior to authorised disposal.
Assumptions	None
Communication needs	Planned work on the water supply: advance notices are delivered to each building in the affected streets. The notice will give details of the work, particularly the timing of any shut down of the supply. For example, it may advise that water may be discoloured when the supply is restored and what to do if this does not clear on flushing the mains tap.
Side effect evaluation	
Ethical considerations	None
Environmental impact	If use normal disposal routes for waste water and other solid wastes, this could lead to the spread of low levels of contamination in the environment, eg in natural water courses.
Agricultural impact	There may be an agricultural impact if water for flushing is diverted from agricultural use, which could lead to a shortage of water for irrigation, particularly in conditions of limited water resources. Licenses to abstract water for agricultural use may be withdrawn.
Social impact	There may be loss of confidence in the quality of water provided by water companies to the public (and other parties for private water supplies). Possible increase in public confidence that the problem of contamination is being effectively managed. Social impacts depend on whether the flushing process is protracted requiring water companies to provide alternative water supplies, such as bottled water. Otherwise there is only likely to be a short-term social impact.
Other side effects	None
Practical experience	Water companies will have considerable experience in flushing water systems following pipe repairs or maintenance.
Key references	
Comments	
Document history (see Table 7.3)	New datasheet included to be consistent with Version 1 of the UK Recovery Handbook for Chemical Incidents (2012).

Back to list of options

6 Modification of existing water treatment

Objective	To reduce ingestion doses to consumers by modifying existing water treatment to enhance removal or partial removal of radioactive contamination in supplied (treated) drinking water in which activity concentrations exceed UK action levels.
Other benefits	Will remove other impurities.
Management option description	Any changes to existing water treatment processes to enhance removal of specific radionuclides from water, such as, for example, increased frequency of replenishing or cleaning filter material or application of sorbents such as activated charcoal or natural clay minerals. The introduction of completely new processes will often require major extensions to treatment works and new buildings ranging from ion exchange units to new treatment works). This option would be for longer-term strategies for dealing with chronic contamination.
Target	Mainly for public drinking water supplies, although the introduction of new treatment could apply to private supplies if the current treatment was ineffective at reducing/removing contamination or no chemical treatment is currently undertaken.
Targeted radionuclides	Modification to existing treatment would be targeted at removing/reducing specific radionuclides. Modifications would take place after the incident had occurred and the radionuclide(s) of concern had been identified and measured. The effectiveness of treatments for specific elements is given in Table 5.3.
Scale of application	Large. Building of new water treatment works. Medium. Introduction of chemicals (sorbents etc) to raw water at treatment works or to raw water sources, or adding new treatment systems (reverse osmosis or ion exchange for example) to existing treatment regimes. Small. Introduction of new treatments for private water supplies.
Exposure pathway pre-intervention	Internal exposure from ingestion of drinking water.
Time of application	Early/medium-term phases. Changes to water treatment processes should be identified as soon as contamination is confirmed and the radionuclides of concern have been identified. However, there will be a delay in implementing changes to existing water treatment process that could be several days to weeks. Late phase - If new processes ('new build') requiring equipment and infrastructure need to be installed this could take months-years to be implemented and would only be considered for a chronic situation.
Constraints	
Legal constraints	Drinking water produced following any changes to water treatment will have to comply with standards on water quality (see Section 3.8).
Social constraints	Changes to water treatment processes used may give rise to increased exposure to water treatment operatives. This could be as a direct result of exposure to contaminated water or to the accumulation and storage of contaminated waste from treatment (see Section 0). Public acceptability and trust in water treatment processes to remove or reduce radioactive contamination. Acceptability of residual levels of contamination by the public; this is likely to be related to the availability of alternative supplies (eg bottled water).
Environmental constraints	Disposal routes for waste water and other solid wastes from treatment could lead to the spread of low levels of contamination in the environment (eg in natural water courses).
Effectiveness	
Management option effectiveness	Table 5.3 gives chemical removal efficiencies for a range of elements and water treatment processes. Section 5.2 gives estimated activity concentrations in treated water for typical water treatment in the UK and provides guidance on how to use the removal efficiency table for a specific treatment works/set of treatment processes. Generally, treatments used to remove a high content of solids (which lead to colour or turbidity in treated water) from surface water sources would be particularly effective at removing radioactive contamination because many radionuclides will attach to the particulate material in the water. Physical filtration is very effective at removing this particulate material. 'Clean' ground water sources (some boreholes and aquifers) only undergo minimal treatment and this would be less effective at removing contamination due to less chemical manipulation and low levels of particulate material in the water. Membrane filtration is a physical process used for 'clean' water sources with a very low content of solids and there are no chemical processes involved. Membrane filtration has no effect on the removal of radionuclides (see Brown et al, 2008b).
Factors influencing effectiveness of procedure	Effectiveness will be dependent on the types and number of treatment processes used and also the radionuclide(s) involved and their physical and chemical properties (see Brown et al, 2008b).
Feasibility	
Required specific equipment	Specific equipment is likely to be required for additional treatment options.

Back to list of options

6 Modification of existing water treatment

Required ancillary equipment	None
Required utilities and infrastructure	Infrastructure needs to be in place to support the expansion of or changes to treatment works if additional treatments are to be brought 'on line' (increased frequency of operations, etc, 'new build').
Required consumables	Sorbent materials such as activated charcoal or natural clay minerals.
Required skills	Training of operatives may be required if new treatment processes are implemented.
Required safety precautions	Monitoring in the treatment works and of operatives may be required to ensure that any limits on operative exposures are not exceeded and to confirm that the new treatment is having the desired effect. Changes to other working and safety practices may be required to minimise doses to operatives (see Brown et al, 2008a, and Appendix A).
Other limitations	Availability of raw materials and the time needed to deliver them. Capacity to store any additional waste.
Waste	
Amount and type	Waste is produced following water treatment. It may be contaminated material from filter or resin beds, waste water or sludge. Sludge is generated continuously as part of treatment, the quality depending on the content of solids in the raw water. Larger quantities of sludge are often stored on site prior to disposal. Sludge is also generated during cleaning of storage tanks. Cleaning of storage tanks and the replenishment of filters and resins may take place more frequently following radioactive contamination to prevent high concentrations of radioactive waste arising. Large quantities of waste material could be generated (eg contaminated sand and graphite from filter beds and sludge) (see Section 3.6 and Brown et al, 2008a, 2008b).
Possible transport, treatment and storage routes	Waste arising from treatment of water will require disposal and/or storage under environmental permitting legislation.
Factors influencing waste issues	The availability of a suitable disposal route; the cost of radioactive waste disposal; radionuclides involved and levels of contamination; amounts of waste requiring disposal.
Doses	
Incremental dose	If working practices change due to the modification of a treatment works (eg sand filters are replenished more frequently than normal or new processes are added), this may give rise to an incremental dose. Due to specific nature of these tasks and the wide variation in treatment works, it is not possible to estimate likely incremental doses. They would, however, need to be assessed on a case-by-case basis in the event of any incident involving contaminated water prior to treatment. Further guidance on estimating doses from tasks undertaken in treatment works can be found in Appendix A and Brown et al, 2008a, 2008b.
Intervention costs	
Equipment	The installation of new equipment and infrastructure required to enable additional treatment processes to be used will be very expensive and is likely to take a long time to install. The cost will also depend on whether the equipment is available and whether it can be easily installed as part of an existing plant. If new technologies are required, their development will also be very costly and will take a long time.
Consumables	Additional natural sorbents. Increased frequency of replenishing treatment materials will give rise to additional costs.
Operator time	There could be additional operator time if operations were performed more frequently. Transport of raw materials and waste to and from treatment works will require additional operator time (loading and driving). 'New build' may require additional staff.
Factors influencing costs	If operations were performed outside normal working patterns/shifts. Availability and demand of raw materials and new equipment. Availability of suitable disposal routes for contaminated waste.
Compensation costs	Unlikely to be applicable.
Waste cost	Disposal of radioactive material generated from water treatment may be expensive as large quantities of contaminated waste could be generated (eg sand from filter beds and sludge).
Assumptions	None
Communication needs	Overall management of the treatment and waste arising. There would be a need to assure consumers that the water produced was potable and met the required quality standards. Any restrictions on the use of drinking water need to be explained. Workers would need to be informed that they could be exposed to radioactive contamination.
Side effect evaluation	
Ethical considerations	Any risks associated with additional tasks undertaken by operatives at the water treatment plants would need to be assessed. There may be inequity between beneficiaries ('water drinkers') and those living by waste facilities.

Back to list of options

6 Modification of existing water treatment

Environmental impact	Utilisation or disposal of radioactive sludge needs to be considered as the activity concentrations in the sludge may be above the levels permitted for normal use (land spreading or landfill).
Agricultural impact	Sludge may not be acceptable for amendment of agricultural soil.
Social impact	Loss of confidence in the quality of water provided by water companies to the public (and other parties for private water supplies). Increased demand for bottled water. Possible increase in public confidence that the problem of contamination is being effectively managed. Possible social disruption if modification of existing water treatment requires a new construction or facility.
Other side effects	None
Practical experience	None linked to a radiological incident.
Key references	Brown J, Hammond D and Wilkins BT (2008a). Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives. HPA-RPD-040. Available at http://dwi.defra.gov.uk/research/completed-research/reports/DWI70-2-192_radionuclides.pdf Brown J, Hammond D and Wilkins BT (2008b). Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives: supporting report. HPA-RPD-041. Available at http://dwi.defra.gov.uk/research/completed-research/reports/DWI70-2-192_supporting.pdf Oatway WB, Smith JG and Hesketh N (2007). Incremental doses from the implementation of drinking water, aquatic, forest or social countermeasures. EURANOS report, HPA, Chilton.
Comments	None
Document history (see Table 7.3)	**STRATEGY project, 2006**: Datasheet called 'Purification of water at treatment plants'. **UK Recovery Handbook 2005**: Datasheet called 'Water Treatment'. **UK Recovery Handbook, 2009**: New datasheet developed to only cover modifications to water treatment. Maintaining normal water treatment considered in a separate datasheet (Datasheet 4).

Back to list of options

7 Water treatment at the point of use (tap)

Objective	To reduce ingestion doses to consumers by adding additional treatment 'at the tap' to remove or partially remove radioactive contamination from drinking water in the event of activity concentrations in supplied water exceeding the UK action levels.
Other benefits	Other impurities may be removed. Self-help option. May provide additional reassurance regarding the quality of drinking water and the levels of radionuclides in the water even if the water is deemed potable.
Management option description	There are commercially available options that can be used in the home or private premises that will reduce radioactive contamination of drinking water from public or private water supplies. This datasheet considers the use of: • water filter systems for softening water that use a carbon filter with some ion exchange material (jug filters) • Ion exchange devices plumbed directly into the water supply in the premises. These are commonly used as water softeners. For general use, consumers are advised to retain an unsoftened supply for drinking and cooking purposes • small reverse osmosis units. Flow rate of treated water is very low at the pressures used in a domestic unit and treated water is collected in a storage tank to buffer supply and demand. Water passed through a reverse osmosis unit is not generally considered suitable for domestic purposes and is only normally considered if no alternative treatment could make raw water safe to drink
Target	Drinking water from private supplies. Is also an additional measure that could be used on a very small scale public water supplies, particularly if it is suspected that contamination has occurred after water treatment.
Targeted radionuclides	**Known applicability:** all radionuclides except tritium. Effectiveness will vary between radionuclides (see Table 5.3 for details on efficiency removal).
Scale of application	Small/medium. Jug filters would be suitable for very small scale use by an individual household producing a few litres of drinking water a day. The scale of application will depend on the availability of equipment and resources and the numbers of properties affected. In most cases sanitary water needs no purification. Ion exchange and reverse osmosis units would be suitable for larger scale use such as for entire premises.
Exposure pathway pre-intervention	Internal exposure from ingestion of drinking water.
Time of application	Early/medium-term phases. Jug filters could be used soon after contamination has been identified. The only delay would be the time taken to source supplies and purchases. Ion exchange and reverse osmosis systems would need to be fitted by a specialist engineer and the delay in purchasing and fitting one of these units could be several weeks. Given the Department of Health advice that, due to its higher sodium content, softened water consumption may increase the risk of cardiovascular disease, careful consideration would be needed to the overall health risks before installing these units as a medium term option for reducing activity concentrations in water.
Constraints	
Legal constraints	Private water supplies have to meet water quality standards (see Section 3.8).
Social constraints	This option may require individuals needing to purchase jug filters, and in the case of ion exchange and reverse osmosis units, arranging installation either individually or with the person responsible for the supply. Appropriate use of designated drinking water in the premises depends on the individual.
Environmental constraints	None
Effectiveness	
Management option effectiveness	Options are effective at reducing the amount of radioactive contamination in the water as supplied at 'the tap'. Based on the understanding of the chemistry involved and manufacturers advertising literature for stable elements, it would be reasonable to expect a reduction of contamination of at least 50% for a new filter cartridge in a jug filter: for reverse osmosis units, the reduction could be in excess of 90%. This has been substantiated by experimental research at PHE for Cs, Sr, Am and Co (Hammond, 2013). It should be noted that for Cs, the effectiveness dropped off rapidly during continued filtering of contaminated water at activity concentrations similar to the UK action levels. Investigation of the retention of contamination on the filters showed that Sr, Am and Co remained on the filters but that subsequent use of the jug filter with uncontaminated water resulted in small amounts of Cs (about 5% per litre of water) being removed from the filter into the filtered water. The research carried out by PHE showed that the efficiency of jug filter systems for removing cobalt, americium, strontium and caesium is not affected by the age of the filter up to the recommended lifetime of the filter (150 litres water throughput or 1 month).

Back to list of options

7 Water treatment at the point of use (tap)

	For a rough guide to efficiency of removal for other elements, see Table 5.3.
Factors influencing effectiveness of procedure	Effectiveness will be dependent on the radionuclide(s) involved and their physical and chemical properties. Jug filtration, for example, would be very effective at removing contamination associated with particulate material. Correct use of jug filters filters and heeding manufacturers filter cartridge lifetime and advice provided at the time of the incident.
Feasibility	
Required specific equipment	Jug filter. Ion exchange unit. Reverse osmosis (RO) unit.
Required ancillary equipment	A pump may be needed to ensure that there is adequate water pressure for the reverse osmosis units to work effectively. A minimum water pressure is a requirement. The installer would be able to advise whether a pump is needed. Buffer storage tank for RO unit.
Required utilities and infrastructure	The initial installation of ion exchange and RO units requires a trained engineer (plumber).
Required consumables	Filter cartridges for the jugs. Salt for ion exchange units. Membranes for RO units.
Required skills	Experienced plumber for ion exchange and RO units.
Required safety precautions	Gloves and protective clothing may be needed for the removal of contaminated filter media (eg carbon cartridges, ion exchange resins) due to accumulation of radioactive contamination.
Other limitations	Availability of jug filters and ion exchange/RO units and qualified fitters. Stocks of jug filters could run out very quickly.
Waste	
Amount and type	Spent filter cartridges from the jugs will be produced every 2-4 weeks. Lifetime of filters is about 1 month (or 150 litres). Spent salt from ion exchange units. Membranes for RO units may need changing after 6 months.
Possible transport, treatment and storage routes	It is possible that spent filters may be considered ‘radioactive waste’ and so require special consideration for collection, transport and disposal/storage under environmental permitting legislation.
Factors influencing waste issues	The number and rate of spent filters produced. Activity concentrations within the spent filters will have to be assessed.
Doses	
Incremental dose	Fitting and removal of filter units may give rise to incremental doses if not carried out by the householder. However, the task that is likely to give rise to the highest incremental dose is the removal of installed contaminated filters. Doses may be received from the following exposure pathways: • external gamma doses from material on the filters to the whole body • external gamma and beta doses from contaminated material on the skin • external doses may also be received while the filters are in situ Further information on potential incremental doses can be found in Oatway et al, 2007. Personal protection equipment, such as gloves or facemasks, may be effective in reducing the potential dose for the tasks undertaken depending on the radionuclides involved.
Intervention costs	
Equipment	Jug filters are relatively inexpensive (<£40). Ion exchange units and RO units are comparatively expensive. Additional costs for pump and storage tanks, if needed.
Consumables	Replacement filter cartridges and filters are inexpensive compared with the rest of the equipment (<£10).
Operator time	Only for fitting of ion exchange and RO units and for the collection, transport and disposal of spent filters.
Factors influencing costs	Availability of equipment. The number of households or premises affected.
Compensation costs	None
Waste cost	Collection, transport and disposal.
Assumptions	None
Communication needs	Communication with householders and individuals is needed on the following: advice on whether existing water treatment is adequate for private water supply users; what type of equipment should be purchase; the length of time that these options should be in place; correct usage of filters, particularly with respect to the disposal of filter cartridges.
Side effect evaluation	
Ethical considerations	Who should pay for the cost of equipment, ie the householder or individual responsible for a premises. Also relies on implementation by individuals.
Environmental impact	None

Back to list of options

7 Water treatment at the point of use (tap)

Agricultural impact	None
Social impact	There could be a change in personal habits with regard to which tap is used for drinking water if a designated tap has to be used for drinking water. Also water from a tap has to be placed in the jug if that option is being used. Potential loss of confidence in water for other uses like sanitation if the water has not gone through water treatment. Increased demand for bottled water. Provision of alternative water supply (bottled or tankered water) may be more effective and acceptable than reliance on individuals to employ a self-help option.
Other side effects	Department of Health advice is that, due to its higher sodium content, softened water consumption (produced by ion exchange and RO units) may increase the risk of cardiovascular disease.
Practical experience	Ion exchange units and jug filters are used routinely in domestic and commercial properties to reduce other contaminants in drinking water. No direct experience is known about for use to reduce radioactive contamination.
Key references	Hammond, DJ. The use of jug filtration to remove radioactive and chemical contamination from drinking water. In: Proc Water Contamination Emergencies 5: Managing the threats, 2012. Ed: KC Thompson, U Borchers and J Gray. Royal Society Chemistry, 2013, p 64. Oatway WB, Smith JG and Hesketh N (2007). Incremental doses from the implementation of drinking water, aquatic, forest or social countermeasures. EURANOS report, HPA, Chilton.
Comments	None
Document history (see Table 7.3)	**EURANOS Recovery Handbook, 2007.** Originators: D Hammond and J Brown (HPA, UK). **EURANOS peer reviewers:** NA Beresford and J Smith (Centre for Ecology and Hydrology, UK): L Monte (Italian National Agency for New Technologies, Energy and the Environment (ENEA), Italy): R Saxen, A Rantavaara (Radiation and Nuclear safety Authority (STUK), Finland): B Tangena (RIVM, Netherlands) **UK Recovery Handbook, 2009.** Originators: D Hammond and J Brown (HPA, UK). Updated EURANOS datasheet for the UK. Datasheet called ' water treatment at the point of use (tap). Datasheet update with results of experimental work on effectiveness of jug filters and current DWI advice on water filters and other home treatment units.

8 Glossary

Term	Definition
Abstraction	Abstraction is the process of taking water from any source, either temporarily or permanently, for example from rivers, boreholes.
Action level	The level of dose rate, activity concentration or any other measurable quantity above which intervention should be undertaken during chronic or emergency exposure.
Activity	The rate at which nuclear decays occur in a given amount of radioactive material. Unit: becquerel, Bq (1 Bq = 1 decay s^{-1})
Activity concentration	The activity per unit mass of a radioactive material. Unit: Bq kg^{-1}.
Becquerel (Bq)	The becquerel is the unit for radioactivity, ie the rate at which nuclear decays occur in a given amount of radioactive material. Defined as one nuclear decay per second.
Beta particle	A negatively charged electron emitted from the nucleus of a radionuclide following radioactive decay.
Contamination/radioactive contamination	The deposition of radioactive material on the surfaces in inhabited areas or on to or into drinking water sources and supplies.
Clarification	A water treatment process in which the floc produced during the flocculation process is separated from the water. The floc is either allowed to sink by gravity or is made to float and is then removed.
Countermeasure	See management option.
Datasheet	A compilation of data and information about a management option designed to support decision-makers in the evaluation of an option and the impact of its implementation.
Decision-makers	People, or groups of people, who evaluate the various recovery options and decide on a recovery strategy or options within a recovery strategy. For instance, decision-makers may include local councils/representatives, water and health authorities, police force and fire brigade, environment agencies, national authorities and radiation specialists.
Deterministic effect	Previously known as a non-stochastic effect. A radiation-induced health effect characterised by a severity which increases with dose above some clinical threshold, and above which threshold such effects are always observed. Examples of deterministic effects are nausea and radiation burns.
Distribution system	The pipes, pumping stations and reservoirs through which water is conveyed to consumers under the responsibility of a public water supplier.
Dose	General term used for a quantity of ionising radiation. Unless used in a specific context, it refers to the effective dose.
Drinking water	Water used for drinking and preparation of food as supplied at the point of consumption, which for most people is at 'the tap'.
Effective dose	The effective dose is the sum of the weighted equivalent doses in all the tissues and organs of the body. It takes account of the relative biological effectiveness of different types of radiation and variation in the susceptibility of organs and tissues to radiation damage. Unit sievert, Sv.
Emergency countermeasures	Actions taken during the emergency phase with the aim of protecting people from short-term relatively high radiation exposures, eg evacuation, sheltering, taking stable iodine tablets.
Emergency phase (early phase)	The time period during which urgent actions are required to protect people from short-term relatively high radiation exposures in the event of a radiological emergency or incident.
Exposure pathways	The pathways by which people are exposed to radiation. The pathways of main relevance for drinking water are the ingestion of drinking water.
Flocculation	A water treatment process in which chemicals are added to the water to remove very fine suspended particulate material. The chemicals combine with the particulate material in the water to form a floc which can be removed by clarification.
Ground water sources	See water sources
Half-life	The time taken for the activity of a radionuclide to lose half its value by decay. Symbol $t_{1/2}$.

Term	Definition
Incident	See radiation incident
Incremental dose	The additional dose received by an individual as a result of implementing a management option that specifically does not take into account exposure to activity already present in the environment as a result of deposition of radionuclides on the ground.
Ingestion dose	Effective dose received through ingestion of radioactivity into the body.
Inhabited areas	Places where people spend their time, eg at home, at work and during recreation.
Isotope	Nuclides with the same number of protons (ie same atomic number) but different numbers of neutrons. Not a synonym for nuclide.
Long-lived radionuclides	Defined for the handbook as radionuclides with a radioactive half-life of more than 3 weeks.
Management option	An action, which is part of an intervention, intended to reduce or avert the contamination or likelihood of contamination of food production systems. Previously known as a 'countermeasure'.
Management strategy	See recovery strategy.
Operative	An individual implementing a management option (eg a worker at a water treatment works).
Options	See management options.
Photon	A quantum or packet of electromagnetic radiation (eg gamma rays or visible light) which may be considered a particle.
Potable drinking water	Water fit for drinking that meets all legislation on water quality.
Private water supplies	A supply of water that is not provided by a statutory water undertaker, or by a licensed water supplier, including water distributed by a third party to individual premises by means of a private distribution system.
Public water supplies	Drinking water supplies that a water undertaker or a licensed water supplier provides to premises.
Radioactive contamination	See contamination.
Radioactive decay	The process by which radionuclides undergo spontaneous nuclear change, thereby emitting ionising radiation
Radioactivity	The spontaneous emission of ionising radiation from a radionuclide as a result of atomic or nuclear changes. Measured in becquerel's, Bq.
Radioactive half-life	The time taken for the activity concentration of a radionuclide to fall to half its initial value due to its physical decay.
Radiation emergency or incident	Any event, accidental or otherwise, which involves a release of radioactivity into the environment.
Radionuclide	A type of atomic nucleus which is unstable and which may undergo spontaneous decay to another atom by emission of ionising radiation, usually alpha, beta or gamma radiation.
Raw water	Water that has not been treated to make it suitable for human consumption from surface water sources, from natural and man-made reservoirs and from ground water sources.
Recovery phase	The time period during which activities focus on the restoration of normal lifestyles for all affected populations. There are no exact boundaries between the emergency phase and the recovery phase. However, within the handbook the recovery phase should be seen as starting after the incident has been contained.
Recovery strategy	A strategy which aims for a return to normal living. It covers all aspects of the long-term management of the contaminated area and the implementation of specific management options. The development of the strategy should involve all stakeholders.
Recovery Working Group	A group comprising government departments and agencies, local authorities, site operator, water utilities and others as required, that meets during the early phase to consider the long-term implications of the emergency. The RWG develops strategies for return to normality.
Short-lived radionuclides	Defined for the handbook as radionuclides with a radioactive half-life of less than 3 weeks.
Stakeholders	A person or group of people with a direct or perceived interest, involvement, or

Term	Definition
	investment in something
Surface water sources	Untreated water from inland surface sources, eg lakes.
Surface water supplies	Drinking water supplies that come from surface water sources, eg rivers and reservoirs.
Water sources	These are grouped for the purpose of the handbook into ground water sources, eg aquifers, and surface water sources, eg rivers and reservoirs.
Worker	In the handbook, a worker is defined as an individual who is formally involved with the practical implementation of a recovery strategy. Exposures to workers must be controlled.

Appendix A Estimation of Doses following the Contamination of Water

Some information is given in this appendix to enable doses that could be received following the contamination of water used for drinking water supplies to be estimated.

The following information is provided:

- committed effective doses from ingestion of drinking water contaminated at the UK action levels for 1 week and 1 month
- committed effective doses from ingestion of drinking water for one year with an initial contamination level of 1 Bq l^{-1}, allowing for radioactive decay over the year and with no further contamination of the water
- information on a methodology that has been developed to estimate doses to operatives working in drinking water treatment works through which contaminated water has passed

A1 Ingestion doses from consumption of contaminated drinking water

Estimates have been made of doses that could be received from drinking contaminated water. For illustrative purposes, water consumption rates have been taken from NRPB (1994) and it is assumed that approximately half of an individual's total water intake comes from tap water. The remainder is consumed in the form of milk, fruit juice or bottled drinks, and these are not considered in this handbook. These doses are illustrative and should be used to scope the levels of dose that could be expected from drinking tap water. They can also be used to estimate the effect on doses that implementation of management options may have. It should be noted that all the doses estimated could be scaled directly to take into account different consumption rates.

The ingestion dose can be calculated in the following way:

Committed effective ingestion dose (Sv) = activity concentration in drinking water (Bq l^{-1}) x consumption rate (l y^{-1}) x dose coefficient for ingestion (Sv Bq^{-1})

Table A1 and Table A2 show the committed effective ingestion dose in millisievert that 1 year olds, 10 year olds and adults would receive if they were to consume drinking water from the tap at a normal rate that is contaminated with the radionuclides considered in the handbook. Table A1 gives the doses for consumption of drinking water contaminated at the UK action level for 1 week and 1 month. It should be noted that the estimates of doses for consumption over 1 month will be cautious for many types of incident as it is highly unlikely that activity concentrations in water will persist at this level for the entire time. However, for some radionuclides, such as ^{226}Ra, persistent activity concentrations at the UK action level would cause concern. Table A2 shows doses from drinking water for 1 year with an initial contamination level of 1 Bq l^{-1}, allowing for radioactive decay over the year and with no further contamination of the water. It should be noted, however, that it is highly unlikely that activity concentrations in drinking water would remain at a constant level over a period of a year as contamination will become diluted in the water sources.

Table A1 Committed effective doses from the consumption of tap water contaminated at the UK action levels for drinking water

Radionuclide[#]	UK action level (Table 1.3) (Bq l^{-1})	Committed effective dose (mSv)*					
		1 week consumption			1 month consumption		
		1 y old	10 y old	Adult	1 y old	10 y old	Adult
^{60}Co	1000	9 10^{-2}	4 10^{-2}	3 10^{-2}	4 10^{-1}	2 10^{-1}	1 10^{-1}
^{75}Se	1000	4 10^{-2}	2 10^{-2}	2 10^{-2}	2 10^{-1}	1 10^{-1}	8 10^{-2}
^{90}Sr	125	3 10^{-2}	3 10^{-2}	3 10^{-2}	1 10^{-1}	1 10^{-1}	1 10^{-1}
^{95}Zr	1000	2 10^{-2}	7 10^{-3}	7 10^{-3}	8 10^{-2}	3 10^{-2}	3 10^{-2}
^{95}Nb	1000	1 10^{-2}	4 10^{-3}	4 10^{-3}	5 10^{-2}	2 10^{-2}	2 10^{-2}
^{99}Mo	1000	1 10^{-2}	4 10^{-3}	5 10^{-3}	5 10^{-2}	2 10^{-2}	2 10^{-2}
^{103}Ru	1000	2 10^{-2}	6 10^{-3}	6 10^{-3}	7 10^{-2}	2 10^{-2}	2 10^{-2}
^{106}Ru	1000	2 10^{-1}	6 10^{-2}	5 10^{-2}	7 10^{-1}	2 10^{-1}	2 10^{-1}
^{131}I	500	3 10^{-1}	1 10^{-1}	8 10^{-2}	1	4 10^{-1}	4 10^{-1}
^{132}Te	1000	1 10^{-1}	3 10^{-2}	3 10^{-2}	4 10^{-1}	1 10^{-1}	1 10^{-1}
^{134}Cs	1000	5 10^{-2}	5 10^{-2}	1 10^{-1}	2 10^{-1}	2 10^{-1}	6 10^{-1}
^{136}Cs	1000	3 10^{-2}	2 10^{-2}	2 10^{-2}	1 10^{-1}	7 10^{-2}	1 10^{-1}
^{137}Cs	1000	4 10^{-2}	4 10^{-2}	1 10^{-1}	2 10^{-1}	2 10^{-1}	4 10^{-1}
^{140}Ba	1000	6 10^{-2}	2 10^{-2}	2 10^{-2}	3 10^{-1}	9 10^{-2}	8 10^{-2}
^{140}La	1000	4 10^{-2}	2 10^{-2}	2 10^{-2}	2 10^{-1}	7 10^{-2}	6 10^{-2}
^{144}Ce	1000	1 10^{-1}	4 10^{-2}	4 10^{-2}	6 10^{-1}	2 10^{-1}	2 10^{-1}
^{169}Yb	1000	2 10^{-2}	6 10^{-3}	5 10^{-3}	7 10^{-2}	2 10^{-2}	2 10^{-2}
^{192}Ir	1000	3 10^{-2}	1 10^{-2}	1 10^{-2}	1 10^{-1}	5 10^{-2}	5 10^{-2}
^{226}Ra	1000	3	3	2	1 10^{1}	1 10^{1}	9
^{235}U†	Not applicable						
^{238}Pu	20	3 10^{-2}	2 10^{-2}	3 10^{-2}	1 10^{-1}	8 10^{-2}	2 10^{-1}
^{239}Pu	20	3 10^{-2}	2 10^{-2}	4 10^{-2}	1 10^{-1}	9 10^{-2}	2 10^{-1}
^{241}Am	20	2 10^{-2}	2 10^{-2}	3 10^{-2}	1 10^{-1}	7 10^{-2}	1 10^{-1}

* Consumption rates for tap water: 1 year old = 172 l y^{-1}, 10 year old = 197 l y^{-1}, adult = 391 l y^{-1} (NRPB, 1994). If site-specific data on tap water consumption rates are available, values in the table can be scaled directly to reflect different consumption rates.

[#] For short-lived radionuclides (half-life <3 weeks) the committed effective dose after 1 year of ingestion was calculated for a period equivalent to 8 radioactive half-lives (see Table 1.1 for half-lives).

† For ^{235}U, action would be taken based on the chemical toxicity of uranium, since this is of more concern to health than the radioactive content of the water (see Table 1.3).

Table A2 Committed effective doses from one year's consumption of drinking water initially contaminated at 1 Bq l^{-1}

	Committed effective dose (mSv)*, #		
Radionuclide	**1 year old**	**10 year old**	**Adult**
^{60}Co	$4\ 10^{-3}$	$2\ 10^{-3}$	$1\ 10^{-3}$
^{75}Se	$9\ 10^{-4}$	$5\ 10^{-4}$	$4\ 10^{-4}$
^{90}Sr	$1\ 10^{-2}$	$1\ 10^{-2}$	$1\ 10^{-2}$
^{95}Zr	$2\ 10^{-4}$	$9\ 10^{-5}$	$9\ 10^{-5}$
^{95}Nb	$8\ 10^{-5}$	$3\ 10^{-5}$	$3\ 10^{-5}$
^{99}Mo	$7\ 10^{-6}$	$2\ 10^{-6}$	$3\ 10^{-6}$
^{103}Ru	$1\ 10^{-4}$	$5\ 10^{-5}$	$4\ 10^{-5}$
^{106}Ru	$6\ 10^{-3}$	$2\ 10^{-3}$	$2\ 10^{-3}$
^{131}I	$1\ 10^{-3}$	$3\ 10^{-4}$	$3\ 10^{-4}$
^{132}Te	$7\ 10^{-5}$	$2\ 10^{-5}$	$2\ 10^{-5}$
^{134}Cs	$2\ 10^{-3}$	$2\ 10^{-3}$	$6\ 10^{-3}$
^{136}Cs	$8\ 10^{-5}$	$4\ 10^{-5}$	$6\ 10^{-5}$
^{137}Cs	$2\ 10^{-3}$	$2\ 10^{-3}$	$5\ 10^{-3}$
^{140}Ba	$2\ 10^{-4}$	$6\ 10^{-5}$	$5\ 10^{-5}$
^{140}La	$1\ 10^{-5}$	$5\ 10^{-6}$	$5\ 10^{-6}$
^{144}Ce	$4\ 10^{-3}$	$1\ 10^{-3}$	$1\ 10^{-3}$
^{169}Yb	$1\ 10^{-4}$	$4\ 10^{-5}$	$4\ 10^{-5}$
^{192}Ir	$4\ 10^{-4}$	$2\ 10^{-4}$	$2\ 10^{-4}$
^{226}Ra	$2\ 10^{-1}$	$2\ 10^{-1}$	$1\ 10^{-1}$
^{235}U	$2\ 10^{-2}$	$1\ 10^{-2}$	$2\ 10^{-2}$
^{238}Pu	$7\ 10^{-2}$	$5\ 10^{-2}$	$9\ 10^{-2}$
^{239}Pu	$7\ 10^{-2}$	$5\ 10^{-2}$	$1\ 10^{-1}$
^{241}Am	$6\ 10^{-2}$	$4\ 10^{-2}$	$8\ 10^{-2}$

* Consumption rates for tap water: 1 year old = 172 l y^{-1}, 10 year old = 197 l y^{-1}, adult = 391 l y^{-1} (NRPB, 1994). If site-specific data on tap water consumption rates are available, values in the table can be scaled directly to reflect different consumption rates.

Only radioactive decay is taken into account over the year; no other dilution of the contamination levels in the water is assumed. This is a very conservative assumption in most cases.

A2 Assessing doses to operatives working in drinking water treatment works

If a radiological incident led to the contamination of a drinking water supply, then the water would probably pass through an established treatment works prior to being supplied to the consumer. Consequently, any such incident could lead to exposure to radiation for the operatives that work in any affected water treatment works. If water treatment removes radionuclides from the water then these will either be concentrated in the wastes arising from the treatment carried out or be held within the treatment works on various surfaces or within filter media. It is important therefore that there is information and guidance so that the radiological impact on operatives at treatment works can be quantified.

A separate handbook (Brown et al, 2008a) has been produced to assist the water industry assess the impact that any radiological incident may have on the people carrying out operations at an affected treatment works. A calculation tool is provided to enable users to assess the potential doses to operatives working with a treatment works. It can be used to help the water industry to make decisions on how the treatment works can be operated in the event of a radiological incident and to manage any radiation exposures to the operatives at the works. It is also expected that the handbook will be used as a training tool. Worked examples are included to assist users in both planning for a radiological incident and the management of a radiological incident. Typical tasks undertaken at a drinking water treatment works have been considered and these tasks have been grouped into 'generic' tasks to reflect sets of tasks for which any radiation exposure is likely to be broadly similar. The generic tasks and the exposure routes considered are given in Table A3. This approach has been adopted so that the radiation exposures can be estimated for operatives in any drinking water treatment works. Obviously, these estimates can only be used to scope the doses that may be received by operatives as very generic assumptions have been made about each exposure scenario. Details of the assumptions made for estimating doses for each of the generic tasks are given in Brown et al (2008b).

A3 References

Brown J, Hammond D and Wilkins BT (2008a). Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives. Health Protection Agency, Chilton, HPA-RPD-040.

Brown J, Hammond D and Wilkins BT (2008b). Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives: supporting report. Health Protection Agency, Chilton, HPA-RPD-041.

NRPB (1994). Guidance on restrictions on food and water following a radiological accident. Doc NRPB 5(1).

Table A3 Generic tasks and potential exposure pathways

Generic task name	Potential exposure pathways	Typical tasks included
General maintenance and inspection	External gamma	Water quality testing
		Inspection of gravity settling plant
		General plant maintenance unspecified
		Inspection of flocculation/clarification units (not dissolved air floatation (DAF)
Inspection of backwashing of filter beds	External gamma and beta, inhalation of resuspended spray and filter media	
Maintenance of dissolved air flotation (DAF) units*	External gamma and beta	Inspection of DAF plant
Filter bed maintenance	External gamma and beta, inhalation of resuspended material either in dry conditions, if windy outdoors or if hosing	Replenishing rapid gravity filters (indoor/outdoor)
		Cleaning rapid gravity filters (indoor/outdoor)
		Emptying and replacing rapid gravity filter media (indoor/outdoor)
		Removing/replenishing top 0.1 m of slow sand filter media
		Emptying and replacing slow sand filter media
Cleaning settling tanks	External gamma and beta, inhalation of resuspended material in dry conditions, if windy outdoors or if hosing	Cleaning lamellas (indoor/outdoor)
		Cleaning settling tanks/clarifiers
Transporting sludge	External gamma (outdoor in vehicle)	Driving sludge to storage bunkers/landfill/lagoons/sewage works etc
Working with processed sludge	External gamma and beta, ingestion via hands, inhalation of resuspended material if sludge is air dried in bunkers or lagoons	Emptying on site storage of sludge bunkers
		Emptying sludge lagoons
		Working with stored sludge
Operating sludge press	External gamma and beta, ingestion via hands, inhalation of resuspended material if dry or using pressure hose	Emptying sludge press
		Maintenance, servicing and cleaning of sludge press
		Maintenance, servicing and cleaning of centrifuges
Maintenance of the membrane/reverse osmosis/ion exchange unit	External gamma/beta	Repairing/checking membrane filters
		Replacing ion exchange media
		Replacing reverse osmosis membranes

* Also relevant to other plants where flocculation forms a layer on top of the water during flocculation/clarification stage.

Appendix B Estimating Activity Concentrations in Waste Sludge and Filter Media following Drinking Water Treatment

Radioactive contamination that is removed by flocculation and clarification will accumulate in any waste sludge generated. The mass of sludge produced will vary depending on the amount of colour and turbidity in the raw water and, for a given level of water throughput, higher levels of turbidity will give rise to more sludge per unit volume of water being produced. Consequently, for a given activity concentration in the raw input water, the activity concentrations in sludge from water having low turbidity will be higher than those from water with a high turbidity.

Filtration of water containing radionuclides will give rise to the filter media becoming contaminated. The filter beds will accumulate radioactive contamination over the period that contaminated water passes through them. The contamination levels in filter beds will decrease if the filter media are replaced or as a result of activity concentrations decreasing due to radioactive decay. Typically the contamination will be associated with a very large mass of filter media across a number of filter beds. The activity concentrations in filter media per unit mass are therefore likely to be significantly lower than those that could be expected in sludge for the same activity concentration in the input water. Further information on the accumulation of radionuclides in waste sludge and filter media can be found in Brown et al (2008a, 2008b).

B1 Activity concentrations in filter media

A methodology to estimate activity concentrations in filter bed media for a specific treatment works is described elsewhere (Brown et al, 2008b). Default data that can be used to scope the activity concentrations that could be expected in filter bed media is given in Table B1. An estimated range of activity concentrations for two combinations of processes (flocculation/clarification followed by rapid gravity sand filtration and flocculation/clarification followed by rapid gravity sand filtration and slow sand filtration) are given for a typical treatment works. Activity concentrations are given as a function of radionuclide for an activity concentration in the untreated input water of 1 Bq l^{-1}. The assumptions made are listed in the table and further details can be found in Brown et al (2008b).

There is a lot of uncertainty associated with the estimated concentrations in Table B1 as assumptions have been made on the combinations of processes used, the size of the filter beds and water throughput. However, the estimated activity concentrations are useful to scope the levels that could be expected in filter media requiring disposal. They can also be used to estimate doses to those operatives working with the contaminated filter bed media (see Appendix A). Guidance on how to estimate activity concentrations in filter bed media for a given water treatment works is given in Brown et al (2008b). It should be noted that measurements of activity concentrations should always be used in the event of an incident to confirm actual levels in the filter media.

Table B1 Estimated activity concentrations in filter bed media for 1 Bq l^{-1} in the input water (taken from Brown et al, 2008b)

Radionuclide	Range in estimated activity concentration in filter bed media* (Bq kg^{-1} per Bq l^{-1})#,†	
	Flocculation/clarification + RGF‡	Flocculation/clarification + RGF + SSF‡
^{60}Co	$4.2 - 3.3\ 10^{1}$	$3.8\ 10^{-2} - 7.5\ 10^{-2}$
^{75}Se	$4.2 - 3.3\ 10^{1}$	$3.8\ 10^{-2} - 7.5\ 10^{-2}$
^{89}Sr	$8.3 - 5.0\ 10^{1}$	$7.5\ 10^{-2} - 1.1\ 10^{-1}$
^{90}Sr	$8.3 - 5.0\ 10^{1}$	$7.5\ 10^{-2} - 1.1\ 10^{-1}$
^{95}Zr	$0.0 - 1.7\ 10^{1}$	$0.0 - 3.8\ 10^{-2}$
^{95}Nb	$0.0 - 1.7\ 10^{1}$	$0.0 - 3.8\ 10^{-2}$
^{99}Mo	$1.7\ 10^{1} - 5.8\ 10^{1}$	$2.6\ 10^{-1} - 5.3\ 10^{-1}$
^{103}Ru	$4.2 - 3.3\ 10^{1}$	$3.8\ 10^{-2} - 7.5\ 10^{-2}$
^{106}Ru	$4.2 - 3.3\ 10^{1}$	$3.8\ 10^{-2} - 7.5\ 10^{-2}$
^{131}I	$4.2 - 3.3\ 10^{1}$	$3.8\ 10^{-2} - 7.5\ 10^{-2}$
^{132}Te	$8.3 - 5.0\ 10^{1}$	$7.5\ 10^{-2} - 1.1\ 10^{-1}$
^{134}Cs	$8.3 - 5.0\ 10^{1}$	$7.5\ 10^{-2} - 1.1\ 10^{-1}$
^{136}Cs	$8.3 - 5.0\ 10^{1}$	$7.5\ 10^{-2} - 1.1\ 10^{-1}$
^{137}Cs	$8.3 - 5.0\ 10^{1}$	$7.5\ 10^{-2} - 1.1\ 10^{-1}$
^{140}Ba	$3.3\ 10^{1} - 8.8\ 10^{1\Delta}$	$5.3\ 10^{-1} - 7.9\ 10^{-1\Delta}$
^{140}La	$3.3\ 10^{1} - 8.8\ 10^{1\Delta}$	$5.3\ 10^{-1} - 7.9\ 10^{-1\Delta}$
^{144}Ce	$0.0 - 4.2\ 10^{1}$	$0.0 - 6.6\ 10^{-1}$
^{169}Yb	$1.7\ 10^{1} - 5.8\ 10^{1}$	$2.6\ 10^{-1} - 5.3\ 10^{-1}$
^{192}Ir	$4.2 - 3.3\ 10^{1}$	$3.8\ 10^{-2} - 7.5\ 10^{-2}$
^{226}Ra	$3.3\ 10^{1} - 8.8\ 10^{1}$	$5.3\ 10^{-1} - 7.9\ 10^{-1}$
^{235}U	$0.0 - 4.2\ 10^{1}$	0.0
^{238}Pu	$0.0 - 1.7\ 10^{1}$	$0.0 - 3.8\ 10^{-2}$
^{239}Pu	$0.0 - 1.7\ 10^{1}$	$0.0 - 3.8\ 10^{-2}$
^{241}Am	$0.0 - 1.7\ 10^{1}$	$0.0 - 3.8\ 10^{-2}$

* A total mass of filter media has been assumed per Ml throughput. For RGF this is assumed to be $7.2\ 10^{3}$ kg; for SSF this is assumed to be $3.2\ 10^{5}$ kg. A water throughput of 10^{5} m^{3} (100 Ml) is assumed. If throughput continues over a period of time, activity concentrations in the filter media will increase proportionally to throughput, assuming the activity concentration in the input water remains constant and there is no radioactive decay

Maximum value in range assumes minimum removal of radionuclides at each previous process step and maximum removal at final filtration step; minimum value in range assumes maximum removal of radionuclides at each previous process step and minimum removal at final filtration step (see Table 5.3 for removal efficiency factors)

† The estimate of 0.0 Bq kg^{-1} in water arises from the assumption that 100% of radioactivity has been removed from the water due to treatment processes (maximum value in range >70% in Table 5.3). In reality, it is very unlikely that any treatment will be 100% efficient in removing radioactivity, although the removal could be very high

‡ RGF = rapid gravity sand filtration; SSF - slow sand filtration

Δ Updated values due to revision of removal efficiencies for barium and lanthanum for flocculation

B2 Activity concentrations in waste sludge

Assuming that waste sludge is formed from the flocculation and clarification process the activity concentrations in the sludge can be estimated for contaminated input water entering the treatment works. A methodology to estimate activity concentrations in waste sludge for a specific treatment works is described elsewhere (Brown et al, 2008b). Default data that can be used to scope the activity concentrations that could be expected in sludge within a treatment works is given in Table B2. An estimated range of activity concentrations is given for de-watered sludge per unit activity concentration in the untreated input water for all the radionuclides considered in the handbook. The assumptions made are listed in the table and further details can be found in Brown et al (2008b).

Table B2 Range in estimated activity concentrations in sludge per unit concentration in input water (taken from Brown et al, 2008b)

Radionuclide	Range* in activity concentration in sludge#,† per unit concentration in input water ($Bq\ kg^{-1}$ per $Bq\ l^{-1}$)
^{60}Co	$5.7\ 10^{3}$ - $1.0\ 10^{4}$
^{75}Se	$5.7\ 10^{3}$ - $1.0\ 10^{4}$
^{89}Sr	$1.4\ 10^{3}$ - $5.7\ 10^{3}$
^{90}Sr	$1.4\ 10^{3}$ - $5.7\ 10^{3}$
^{95}Zr	$1.0\ 10^{4}$ - $1.4\ 10^{4}$
^{95}Nb	$1.0\ 10^{4}$ - $1.4\ 10^{4}$
^{99}Mo	$5.7\ 10^{3}$ - $1.0\ 10^{4}$
^{103}Ru	$5.7\ 10^{3}$ - $1.0\ 10^{4}$
^{106}Ru	$5.7\ 10^{3}$ - $1.0\ 10^{4}$
^{131}I	$5.7\ 10^{3}$ - $1.0\ 10^{4}$
^{132}Te	$1.4\ 10^{3}$ - $5.7\ 10^{3}$
^{134}Cs	$1.4\ 10^{3}$ - $5.7\ 10^{3}$
^{136}Cs	$1.4\ 10^{3}$ - $5.7\ 10^{3}$
^{137}Cs	$1.4\ 10^{3}$ - $5.7\ 10^{3}$
^{140}Ba	$1.4\ 10^{3}$ - $5.7\ 10^{3}$‡
^{140}La	$1.4\ 10^{3}$ - $5.7\ 10^{3}$‡
^{144}Ce	$1.0\ 10^{4}$ - $1.4\ 10^{4}$
^{169}Yb	$5.7\ 10^{3}$ - $1.0\ 10^{4}$
^{192}Ir	$5.7\ 10^{3}$ - $1.0\ 10^{4}$
^{226}Ra	$1.4\ 10^{3}$ - $5.7\ 10^{3}$
^{235}U	$1.0\ 10^{4}$ - $1.4\ 10^{4}$
^{238}Pu	$1.0\ 10^{4}$ - $1.4\ 10^{4}$
^{239}Pu	$1.0\ 10^{4}$ - $1.4\ 10^{4}$
^{241}Am	$1.0\ 10^{4}$ - $1.4\ 10^{4}$

* Maximum value in range assumes maximum removal of radionuclides at flocculation/clarification step; minimum value in range assumes minimum removal at flocculation/clarification step (see Table 5.3 for removal efficiency factors)

\# A default value of 7000 kg of de-watered sludge produced per $10^{5}\ m^{3}$ (100 Ml) of water throughput is assumed

† It is recognised that sludge may continue to dry out if it is stored prior to disposal. However, any additional loss of water is unlikely to influence the activity concentrations estimated significantly

‡ Updated values due to revision of removal efficiencies for barium and lanthanum for flocculation

There is less uncertainty associated with the estimated concentrations in sludge than those in filter bed media as only one removal process is considered and assumptions on the combinations of processes used in a treatment works are not required. However, the values have been calculated for a specific sludge production rate as stated in the table. It is appropriate to use the values presented in Table B2 to provide a robust estimate of activity concentrations that could be expected in sludge requiring disposal if activity concentrations of the order of 1 Bq l^{-1} in raw water entered a treatment works. Activity concentrations in sludge can be scaled directly to any different activity concentration in the untreated input water.

The activity concentrations can also be used to estimate doses to those operatives working with the contaminated sludge (see Appendix A). Guidance on how to estimate activity concentrations in sludge for a given water treatment works is given in Brown et al (2008b). It should be noted that measurements of activity concentrations should always be used in the event of an incident to confirm actual levels in sludge.

B3 References

Brown J, Hammond D and Wilkins BT (2008a). Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives. Health Protection Agency, Chilton, HPA-RPD-040.

Brown J, Hammond D and Wilkins BT (2008b). Handbook for assessing the impact of a radiological incident on levels of radioactivity in drinking water and risks to water treatment plant operatives: supporting report. Health Protection Agency, Chilton, HPA-RPD-041.