Generic handbook for assisting in the management of contaminated drinking water in Europe following a radiological emergency

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GENERIC HANDBOOK FOR ASSISTING IN THE MANAGEMENT OF CONTAMINATED DRINKING WATER IN EUROPE FOLLOWING RADIOLOGICAL EMERGENCY

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For what purpose do I want to use the Drinking Water 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
2. Check if immediate action is required to prevent/reduce ingestion doses
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 applicability of management options for radionuclides released

ELIMINATE OPTIONS

7. Go to Section 3 ‘Datasheets’ for detailed information on options
8. Use information to select and combine options and build a management strategy

Training – new user

Go to all Sections

Section 1 “Introduction”
Section 2 “Factors influencing implementation of options”
Section 3 “Datasheets”
Section 4 “Planning in advance”
Section 5 “Framework for management strategy”
Section 6 “Worked examples”

Consult Appendices for supporting information if required

Training – refresher

Go to Section 6 “Worked examples”
This goes through the 8-step process for 3 different types of incident:

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

1 INTRODUCTION TO THE DRINKING WATER HANDBOOK

2 FACTORS INFLUENCING IMPLEMENTATION OF MANAGEMENT OPTIONS

3 DATASHEETS OF MANAGEMENT OPTIONS

4 PLANNING FOR RECOVERY IN ADVANCE OF AN INCIDENT

CONTENTS OF SECTION 1

1 INTRODUCTION TO THE DRINKING WATER HANDBOOK

The Handbook for Drinking Water Supplies, or Drinking Water Handbook in short, has been developed as a result of a series of European and, in particular, UK initiatives that started in the early 1990s. The Drinking Water Handbook should be regarded as a living document that requires updating from time to time to remain state-of-the-art. Individual countries need to follow their national regulations, for example, on water quality, public dose limits, protection of workers, management and transport of wastes, and the handbook does not provide a substitute for this. Customisation of the generic handbook is an essential part of its use within individual countries and any planning for the recovery phase after a radiological emergency.

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 CFILs are exceeded. The 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 minimize the radiological impact of any radioactive contamination reaching their water supplies.

How can the Drinking Water Handbook help?

The Drinking Water 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 Drinking Water Handbook is also helpful for contingency planning.

1.1 Objectives of the Drinking Water Handbook

The Drinking Water 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 Handbook is specifically targeted at:

- central government departments and agencies;
- experts in radiation protection;
- the Water Industry;
- 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 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 Drinking Water 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 mobilize stakeholders and to develop local, regional and national plans/frameworks/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 Handbook is radiological protection, i.e. reducing exposure of humans to radiation. However, experience from past contamination events, particularly the accident at the Chernobyl nuclear power plant, has 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. There is therefore likely to be considerable pressure for water quality to be maintained in the event of a radiological incident. This may not be justified purely on radiological protection grounds and it has been recognized 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 2).

1.5 Scope

The primary aim of the 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 (i.e. '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 2.2. 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 (Section 2.1). 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 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.

The Drinking Water 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 organizations in the event of a radiological emergency;
- a communication strategy;
- links between response at different levels (e.g. 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 Handbook

Radionuclide		Half-life[a]
^{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	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

a) Half-life: h = hours; d = days; y = years

1.6 Structure of the Drinking Water Handbook

The overall structure of the Drinking Water Handbook is illustrated in the top segment of Figure 1.1. Supporting and background information is provided in three 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. Factors influencing the implementation of management options for contaminated drinking water are described in Section 2, whilst datasheets for individual management options are presented 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. A glossary of terms used in the Drinking Water Handbook is given in Section 7.

As noted in Section 1.3, the Drinking Water Handbook should be used as part of a participatory process involving stakeholders to develop a recovery strategy (i.e. lower segment of Figure 1.1).

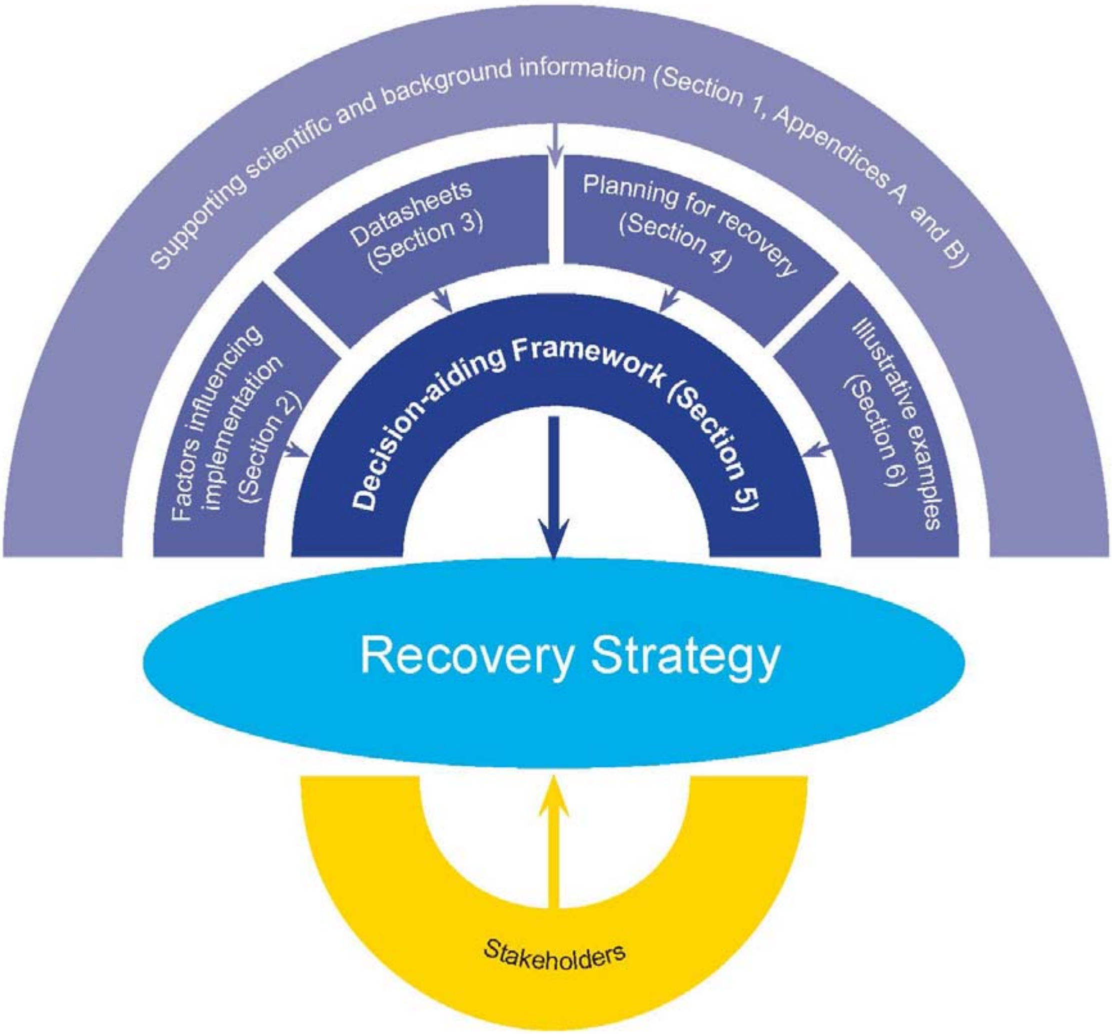

Figure 1.1 Structure and audience for the Drinking Water Handbook

1.7 Drinking water supplies included in the Handbook

Drinking water can come from one of three main types of water supply, and these are defined in Table 1.2.

The Handbook concentrates on those factors relating to the minimization of doses to the general public via the consumption of drinking water from public or private water supplies. Management options for un-regulated water supplies of drinking water are not considered in detail. However, Section 3 includes a short section highlighting a few of the factors that should be considered with regard to un-regulated water supplies following a release of radioactive contamination to the environment.

Table 1.2 Definition of drinking water supply categories in the Handbook

Water Supply	Description
Public	Public water supplies are those delivered by statutorily appointed water companies to properties including private houses, commercial and public buildings, industrial premises etc[a]. In many countries, this will account for the majority of water supplies. 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. In general, samples of the water are taken 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 can come from a variety of sources including: wells, boreholes, springs, rivers, lakes and ponds. In most countries, the majority of private supplies are likely to be for dwellings and farms situated in remote or rural areas. However there may be some private supplies in urban areas, particularly those used for industrial purposes such as brewing. 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.
Un-regulated	Un-regulated 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 whilst in recreational areas (e.g. campers and hikers).

a) Water Companies may have a number of minor water supplies, typically in rural areas, that have little or no water treatment.

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. These should be set by the competent authorities in individual member states. The Council of the European Communities has specified intervention levels (ILs) for radioactive contamination in marketed food and animal feeds (here termed CFILs – Council Food Intervention Levels) following an emergency [CEC, 1989a; CEC, 1989b; CEC, 1990]. The CFILs represent an EU judgment on the optimum balance between the beneficial and harmful consequences of introducing food restrictions in the EU. In case these CFILs should prove inappropriate under the specific circumstances of a future accident, provision has been made within the regulations for the CFILs to be revised shortly after an accident. Such a revision depends on a qualified majority agreement by the Member States.

The Council Regulations include the specification of CFILs 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 CFILs ‘should be applied to drinking water supplies (eg, ‘tap’ water) at the discretion of member states’. In the UK, for example, it is recommended that the CFILs for liquid foods should be adopted as Action Levels (Intervention Levels) for all drinking water supplies [NRPB, 1994].

The CFILs are listed in Table 1.3 and could be applied to all drinking water after an incident, regardless of the distance away from the source of the incident. They could be used to indicate whether action should be taken to reduce activity concentrations in drinking water following a radiological incident, for example, by providing an alternative supply.

IAEA also provides generic action levels for foodstuffs, including drinking water [IAEA, 2002]. It is stated that these apply in situations where alternative food supplies are readily available. Where supplies are scarce, it is suggested that higher levels could be applicable. The values are shown in Table 1.4. They are based on and are consistent with the Codex Alimentarius Commission’s guideline levels for radionuclides in food moving in international trade [FAO/WHO, 1991]. The use of these generic action levels is intended to be limited to the first year after a nuclear or radiological emergency.

The EC drinking water directive on water quality [EC, 1998] puts forward a system that enables Member States to use simple screening methods involving the determination of gross alpha or beta activity in water as a first step towards compliance with the regulations. This monitoring capability can also be very useful in the event of a radiological incident. In the UK, as an example, screening levels have been derived that are linked to the CFILs and these would be used by the water industry in the event of a radiological incident. Further information on these emergency screening levels and their use is described in Appendix A.

Table 1.3 CFILs for liquid foods applied for drinking water supplies[a]

Radionuclide	CFIL[b] (Bq l^{-1})	Categorisation of radionuclides considered in Handbook[c,d]
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[e]	1,000	^{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[f]

Notes:

a) CFILs refer to all water supplies that are intended, at least in part, for drinking and food preparation purposes. See text (Section 1.8.3) for advice on the urgency with which contaminated drinking water supplies should be replaced.

b) 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 Intervention Level.

c) The radionuclides considered are listed in Table 1.1.

d) 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, 2003].

e) This category does not include ^{14}C, ^{3}H or ^{40}K (see CEC, 1989a; CEC, 1989b; CEC, 1990)

f) 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.

Table 1.4 IAEA generic action levels for drinking water [IAEA, 2002]

Radionuclide	Generic action level[a] (Bq l^{-1})	Categorisation of radionuclides considered in handbook[b,c]
Isotopes of strontium, notably ^{90}Sr	100	^{90}Sr
Isotopes of iodine, notably ^{131}I	100	^{131}I
Alpha-emitting isotopes of plutonium and transplutonium elements	1	^{238}Pu, ^{239}Pu, ^{241}Am
All other radionuclides of half-life greater than 10 days, notably radioisotopes of caesium and ruthenium	1,000	^{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[d]

Notes:

a) It is the sum of the concentrations of all the radionuclides included within a category and detected in the water, which should be compared with the generic action levels.

b) The radionuclides considered are listed in Table 1.1.

c) For uranium isotopes, action would be taken based on the chemical toxicity of uranium which is of more concern to health than the radioactive content of the water [WHO, 2003].

d) 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 [WHO, 2004; EC, 1998; EC, 2005]. The values recommended by 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 CFILs given in Table 1.3, or other appropriate intervention levels such as the IAEA values in Table 1.4 should be used, as discussed above.

In general terms, activity concentrations in water below the levels set by the EC and WHO are acceptable for human consumption and action to reduce the radioactivity levels is not necessary. The European Commission Directive 98/83/EC on the quality of water intended for human consumption [EC, 1998] 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, ^{40}K, radon and radon decay products. Member States have a responsibility to monitor drinking water to ensure that the ‘indicative dose’ is not exceeded. Further draft guidance provided by the EC [EC, 2005 (draft)] suggests an approach using screening methods for gross alpha and gross beta activities to monitor for the parametric indicator of TID. WHO gives some radionuclide specific values [WHO, 2004] that correspond approximately to an annual dose of 0.1 mSv y^{-1} using a specified set of assumptions. WHO states that these are also appropriate for use after the first year following a nuclear accident, i.e. 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 Intervention Levels

Intervention 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. It needs to be recognized 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 organized, 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 Intervention Levels may still be used safely for washing, toilet flushing and other (non-ingestion) purposes over protracted periods. This is discussed further in Section 3 within the data sheets 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 emphasized that if individuals were to drink water contaminated well in excess of the Action Levels for limited periods (e.g. 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 CFILs for a selection of radionuclides (Table 1.5). 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 are given in Table 1.5. In general therefore the values in Table 1.5 are lower or comparable with typical exposures to natural background radiation that are incurred over a year (e.g. 2.2 mSv in a year in the UK [Watson *et al*, 2005]). 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 maximize the dose reduction achieved.

Table 1.5 Committed effective doses from the consumption of tap water[a] for a period of 3 weeks contaminated at 10 times the CFILs for drinking water

	Committed effective dose, mSv, following consumption for:		
	3 weeks		
Radionuclide	1 yr old	10 yr old	Adult
^{60}Co	2.7	1.2	$9\ 10^{-1}$
^{90}Sr	$9\ 10^{-1}$	$9\ 10^{-1}$	$9\ 10^{-1}$
^{106}Ru	6.0	1.8	1.5
^{131}I[b]	9.0	3.0	2.4
^{137}Cs	1.2	1.2	3.0
^{239}Pu	$9\ 10^{-1}$	$6\ 10^{-1}$	1.2

Notes:

a) Consumption rates for tap water (expressed as litres per year): 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 consumption rates for tap water are available, values in the table can be scaled directly to reflect different consumption rates.

b) For the short-lived radionuclide, ^{131}I, the radioactivity will have decayed by 3 half-lives, i.e. a factor of 8, over the 3 week period and so the doses estimated are an overestimate, as they assume that the activity concentrations will remain at the CFILs 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 irrespective 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 CFIL for all the radionuclides considered in the Handbook have been calculated. These are discussed further in Appendix B.

1.9 General radiological protection principles and criteria

The International Commission on Radiological Protection (ICRP) is the primary international body for recommending radiological protection standards. After a consultation process lasting several years, in 2007 the ICRP published new recommendations for a system of radiological protection in Publication 103 [ICRP 2007] replacing the 1990 Recommendations [ICRP 1991]. However, it will take several years before Publication 103 becomes incorporated into national legislation.

1.9.1 Practices and Intervention

The 1990 Recommendations distinguishes two situations for which the system of radiological protection applies, 'practices' and 'interventions'.

1.9.1.1 Practices

Practices are situations that are under control and that lead to increases in the exposure of individuals such as during the operation of nuclear power stations. Emphasis is on the control of the source of exposure and this can generally be planned for before commencing the practice. ICRP's principles of protection for practices are:

- no practice involving exposures to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes. This is known as the justification of a practice;
- in relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received should all be kept as low as reasonably achievable, economic and social factors being taken into account. This procedure should be constrained by restrictions on the doses to individuals (dose constraints), or the risks to individuals in the case of potential exposures (risk constraints), so as to limit the inequity likely to result from the inherent economic and social judgments. This is known as the optimization of protection;
- the exposure of individuals resulting from the combination of all the relevant practices should be subject to dose limits, or to some control of risk in the case of potential exposures. These are aimed at ensuring that no individual is exposed to radiation risks that are judged to be unacceptable from these practices in any normal circumstances.

In simpler terms, these principles may be phrased as follows: radiation can cause harm and therefore any intended use should be worthwhile (justification) and, this being the case, all reasonable steps should be taken to reduce exposures from a single source below predefined constraints (optimization). Doses and risks to an individual from all relevant sources of radiation should be kept within pre-defined limits (dose and risk limitation).

1.9.1.2 Intervention

Interventions are situations where the sources, pathways and exposed individuals are already in place when a decision on control has to be taken such as during actions taken to reduce existing radon exposures. In such situations, protection can only be achieved by removing or modifying existing sources or pathways, or reducing the numbers of people exposed. ICRP [ICRP, 1991b] has recommended the following general principles governing the system of radiological protection for intervention:

- countermeasures should be introduced if they are expected to achieve more good than harm. This is known as the justification of intervention
- the quantitative criteria used for the introduction and withdrawal of countermeasures should be such that the protection of the public is optimised. This is known as the optimisation of intervention
- serious deterministic health effects should be avoided by introducing countermeasures to keep doses to individuals to levels below the thresholds for these effects.

In most cases, intervention cannot be applied to the source of the exposure and has to be applied in the environment and, particularly in the case of accidents, to an individual's freedom of action. Thus a program of intervention will always have some disadvantages but should always be justified in the sense that it does more good than harm. It follows that the use of dose limits, or constraints, specified for practices as the basis for deciding on a level at which intervention is invoked might involve measures that would be out of proportion to the benefit obtained and, therefore, would conflict with the principle of justification. Thus, dose limits for practices (and, by inference, dose constraints) do not determine whether or not intervention should be undertaken. There will, of course, be some level of dose approaching that which would cause serious deterministic effects, where some form of intervention will almost always be required.

Clearly, intervention aims to avoid or avert exposure to radiation. Hence one important quantity in taking decisions on intervention is the level of dose averted by taking the remedial action (avertable dose). However, for actions undertaken during the recovery phase, it should be recognised that an equally important aim is to promote an early return to ‘normal living’. Thus decision makers should consider not only the expected consequences of implementing the strategy (e.g. the avertable dose, the costs, resources required, likely duration, level of disruption etc), but also how implementing this strategy will contribute to the re-establishment of ‘normality’, including, specifically, the criteria on which protective measures will be considered successful (and so can be terminated).

For situations requiring intervention, the concept of a level of dose, or directly measurable quantity, above which action should be taken, can be useful. Such criteria are termed CFILs. Generic CFILs may be developed before an accident (e.g. those adopted for food) or in the event of an accident, taking account of the specific circumstances.

1.9.2 Which system of protection for the recovery phase?

The systems of protection for both practices and intervention are relevant for the recovery phase. The system of protection for intervention would be used in the process of deciding on the form and scale of the actions taken to recover from contamination of the environment from accidental releases of radioactivity. However, the workers undertaking such actions would be potentially exposed to an additional source of radiation so their exposure would be controlled under the system of protection for practices. Similarly, the handling and disposal of any wastes produced during the recovery actions away from the contaminated area would be controlled under the system of protection for practices.

1.9.3 Key features of the new 2007 Recommendations relating to the recovery phase

The fundamental principles of radiological protection – justification, optimization and application of dose limits, remain the same and the dose limits are unchanged from the 1990 Recommendations. ICRP has, however, made some changes to the structure of the system of protection in order to improve clarity.

In the 2007 Recommendations, ICRP has divided exposure situations into three types, which encompass the entire range of plausible exposure situations: planned exposure situations which involve the deliberate legitimate introduction and operation of sources; existing exposure situations which are situations where exposures already exist when a decision on protection has to be taken; and emergency exposure situations which require urgent action to avoid or reduce undesirable exposures. Within the framework described in the 2007 Recommendations, emergency response and its aftermath will evolve through two types of exposure situations: emergency exposure situations and existing exposure situations. ICRP uses the categorization of exposure situations to highlight differences in the way the situations are managed: there may not be clear cut boundaries between the physical attributes of the exposures themselves. The management of the emergency exposure situations is characterized by recognition that the situation is ‘abnormal’ and that actions are required to protect people and to help restore the situation to ‘normal’. Emergency response management is therefore concerned with initiating and managing change on a short timescale. Existing exposure situations resulting from emergencies, on the other hand, are situations where the on-going radiation risks are tolerable, even with only limited, or no, further protective actions, although the environmental contamination and potential exposures are recognized as being higher than would be accepted for planned situations. In short it is recognized that the impact of significant further environmental remediation on the people affected and on society more generally would outweigh any expected benefits. Thus a new normality can be established, which requires sustaining. The management of existing exposure situations is therefore characterized by enabling and promoting normal living in an area recognized as having higher potential exposures than other areas. This may involve continuing less disruptive protective actions, such as regular environmental monitoring, but the focus of management would be on the maintenance of normal living, not a change to normal living. This Generic Drinking Water Handbook is likely to be applicable to both emergency exposure situations and existing exposure situations, although emergency countermeasures such as sheltering, evacuation and stable iodine prophylaxis have been deliberately excluded.

1.10 References

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.

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 (1998). Council Directive 98/83/EC on the quality of water intended for human consumption. Official Journal of the European Communities, Brussels.

CEC (2005, draft). Commission Directives on defining requirements for monitoring the quality of water with regard to the parameters for radioactivity laid down in Council Directive 98/83 on the quality of water intended for human consumption. European Commission, Brussels.

IAEA (2002). Safety requirements on preparedness and response for a nuclear or radiological emergency. Safety Standards Series No. GS-R-2, IAEA, Vienna.

ICRP (1991). 1990 Recommendations of the ICRP. ICRP Publication 60. Ann ICRP, 21 (1-3)

ICRP (1991b). Principles for intervention for protection of the public in a radiological emergency. ICRP Publication 63. Ann ICRP, 22 (4)

ICRP (2007) Recommendations of the ICRP. ICRP Publication 103. Annals of ICRP 37 (2-4)

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

WHO (2003). Media Centre Fact Sheet No 257 (revised 2003) for uranium and depleted uranium. Geneva World Health Organisation.

WHO (2004). Guidelines for drinking water quality, Chapter 9. Third Edition Volume 1, Recommendations. World Health Organisation, Geneva.

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CONTENTS OF SECTION 2

2 FACTORS INFLUENCING IMPLEMENTATION OF MANAGEMENT OPTIONS

The 6 management options described in this Handbook encompass the main actions that can be carried out on drinking water supplies to reduce the impact of radioactive contamination. Table 2.1 provides a list of the management options considered, with a distinction being made between those options that are appropriate for public and private water supplies. Section 3 provides a comprehensive set of datasheets for each management option that take into account most of the criteria that decision makers might wish to consider when evaluating different options.

The implementation of these management options is not trivial. There are a number of complex factors that need to be taken into account when developing a good management strategy and this is further complicated by the complexity of the decision-making process itself. Figure 2.1 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.

Table 2.1 List of management options for drinking water supplies

PUBLIC WATER SUPPLIES
Alternative drinking water supply
Changes to water abstraction points or location of water source
Controlled blending of drinking water supplies
Continuing normal water treatment (at treatment works)
Modification of normal water treatment (at treatment works)
Water treatment at the point of use (tap)
PRIVATE WATER SUPPLIES
Alternative drinking water supply
Continuing normal water treatment
Modification of normal water treatment
Water treatment at the point of use (tap)

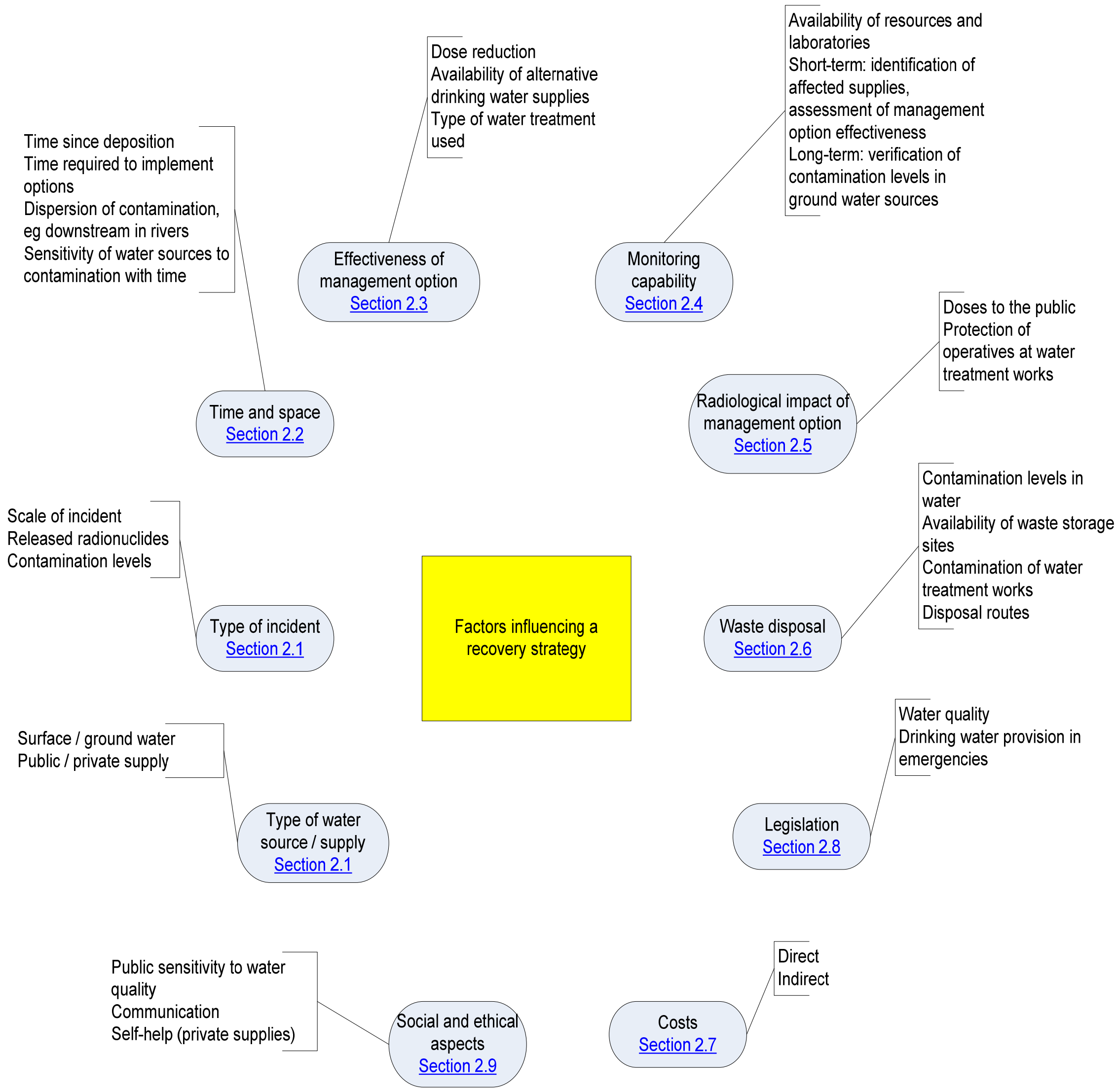

Figure 2.1 Overview of key factors influencing choice of management options

2.1 Impact of types of water sources and radiological 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.

2.2 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 program required to support the assessment of doses to members of the public and the choice of management options.

2.3 Effectiveness

The likely effectiveness of the management options is described in the datasheets for each option (see Section 3). Normal water treatment can be effective in removing radionuclides from water as shown in Datasheet 4. Section 5.1 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 5).

2.4 Monitoring

Guidance on monitoring of drinking water supplies, required analytical capabilities and monitoring priorities is given in Section 5.2.

2.5 Radiological impact

If a radiological incident affects a drinking water source, then 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 4 and given in Datasheet 4. Doses to consumers from ingesting contaminated water have also been estimated and are given in Appendix B.

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 B provides information on how potential doses to operatives working in treatment works can be assessed.

2.6 Waste disposal

2.6.1 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, as an example, provides information on the likely activity concentrations in waste sludge and filter media for typical water treatment of flocculation/clarification and filtration 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 CFILs and it is decided that the water cannot be used either for drinking or other purposes such as washing and toilet flushing.

2.6.2 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, e.g. 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 6 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 authorizations may be required for disposal of such wastes depending on the radionuclide, activity concentrations and quantities. 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.

2.7 Economic costs

Predicting the economic cost of implementing the management options and the supporting monitoring program 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 2.2 and Table 2.3 for implementing management options and loss of normal water supply, respectively.

Table 2.2 Direct economic cost of implementing management options

Labour: salaries for the workforce involved (may need to be supplemented for work being undertaken), radiation 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 2.3 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

2.8 Legislation for drinking water

The Drinking Water Directive 98/83/EC issued by the European Commission (EC) specifies values for two radiological indicator parameters for water quality [EC, 1998]. This Directive must be used as the basis for specific legislation on water quality in Member States. While implementing the Drinking Water Directive into their own national legislation, the Member States of the European Union can include additional requirements e.g. regulate additional substances that are relevant within their territory or set higher standards. The Directive allows Member States may exempt water supplies serving less than 50 persons or providing less than 10 m^3 of drinking water per day as an average. This means that the quality of drinking water from public and private water supplies in individual countries may be regulated differently. Individual countries may also have other specific legislation relating to emergency situations.

The national legislation and regulations should be included in this section as part of customisation of the handbook as described further in Section 4.

2.9 Societal and ethical factors

The consequences of a radiological incident raise technical, health-related and radiological problems but in addition there are societal and ethical considerations. Radiological contamination on a large scale has an impact on living conditions at an individual and community level (i.e. 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 recognized. 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.

2.10 References

EC (1998). Council Directive 98/83/EC on the quality of water intended for human consumption. Official Journal of the European Communities, Brussels.

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CONTENTS OF SECTION 3

3 DATASHEETS OF MANAGEMENT OPTIONS

3.1 The datasheet template

This Handbook considers 6 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 standardized 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 3.1 presents the template with a brief summary of the information that appears under each heading.

3.2 The datasheets and key updates

The format and content of the datasheets are based largely on similar documents developed initially in version 1 of the UK Recovery Handbook (HPA-RPD, 2005) based on work undertaken under the European STRATEGY project (STRATEGY, 2003) and further developed within the EURANOS project (Brown *et al*., 2007) and in version 3 of the UK Recovery Handbook (HPA-RPD, 2009). Within EURANOS, new datasheets were developed as a consequence of peer review and feedback from European stakeholders. In this Handbook, the previous EURANOS datasheet for 'water treatment at water treatment works' has been divided into two to reflect the difference between maintaining normal water treatment during a radiological 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 and could be further customized by individual countries.

An index of the management options included is given in Table 3.2. 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.

3.3 Datasheet history

The history of the development of the datasheets is given in Table 3.3. 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 3.1 Datasheet template*

Name of management option	
Objective	Primary aim of the option (e.g. 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 (e.g. soil, drinking water supplies).
Targeted radionuclides	Radionuclide(s) that the option is aimed at. Radionuclides considered within the EURANOS project 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 (e.g. inhalation, ingestion, external exposure).
Time of application	Time relative to the accident or incident when the option is applied. Can be pre-deposition (i.e. 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 (e.g. annually etc.).
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 (e.g. drinking water).
Factors influencing effectiveness of procedure	Technical (e.g. source of raw water and chemical and physical characteristics of the contamination) and social factors (e.g. 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 (e.g. monitoring equipment, tankers).
Required utilities and infrastructure	Utilities (e.g. water and power supplies) and infrastructure (e.g. building and manufacturing plants) which may be required to implement the option.
Required consumables	Consumables which may be required to implement the option (e.g. 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 (e.g. storage capacity).
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 (e.g. 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 (e.g. 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 (e.g. operators, members of the public). This dose is influenced by procedures (if any) 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 (e.g. 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 (e.g. natural water courses).
Agricultural impact	Impact that an option may have on the future suitability of land for agricultural use (e.g. 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 (e.g. rationing of water supplies or restrictions on the use of water).
Stakeholder opinion	Stakeholder opinion from the UK and Europe (via the EURANOS project) obtained as part of the development of recovery handbooks. Not included for the drinking water handbook
Practical experience	State-of-the-art experience in carrying out the management option. Some options have only been tested on a limited scale, whilst 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.

*adapted from Nisbet et al., 2004.

Table 3.2 Index of management options for drinking water with hyperlinks to datasheets[a]

Number	Description of management option
PUBLIC WATER SUPPLIES	
11	Alternative drinking water supply
12	Changes to water abstraction point or location of water source
13	Controlled blending of drinking water supplies
14	Continuing normal water treatment (supported by a monitoring programme)
15	Modification of existing water treatment
16	Water treatment at the point of use (tap)
PRIVATE WATER SUPPLIES	
11	Alternative drinking water supply
14	Continuing normal water treatment (supported by a monitoring programme)
15	Modification of existing water treatment
16	Water treatment at the point of use (tap)

a) 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 3.3 Datasheet document history

Number	Document history
1-5	**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), J Hunt (University of Lancaster, UK) **STRATEGY project peer reviewer(s):** John Brittain, University of Oslo, Norway. **UK Recovery Handbook 2005.** Originators J Brown and G Roberts (HPA-RPD, UK). Up-dated for the UK and addition of new material. **EURANOS Recovery Handbook, 2007.** Developers: D Hammond and J Brown, HPA, UK. Up-dated and extended data sheet **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: Brown, J and Hammond, D, HPA-RPD, UK
6	**EURANOS Recovery Handbook, 2007.** Originators: D Hammond and J Brown, HPA. **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-RPD. Up-dated EURANOS datasheet for the UK. Datasheet called ' water treatment at the point of use (tap).

3.4 Un-regulated drinking water supplies

Management options for un-regulated water supplies of drinking water are not considered in detail. However, some of the issues that should be considered with regard to un-regulated 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 that 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 5.1.

3.5 References

Brown J, Hammond D and Kwakman P (2007). Generic Handbook for assisting in the management of contaminated inhabited areas in Europe following a radiological emergency. Part VI: Management of Drinking Water. Can be obtained from the EURANOS website http://www.euranos.fzk.de.

HPA-RPD (2005). UK Recovery Handbook for Radiation Incidents. HPA-RPD-002 (ISBN 0-85951-559-1). Available at http://www.hpa.org.uk.

HPA-RPD (2009). UK Recovery Handbook for Radiation Incidents. HPA-RPD (in press). Will be available at http://www.hpa.org.uk

Nisbet AF, Mercer JA, Hesketh N, Liland A, Thørring H, Bergen 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). 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 No: FIKR-CT-2000-00018. Available from: http://www.strategy-ec.org.uk/output/outputs.htm.

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 CFILs.
Other benefits	None
Management option description	If restrictions were placed on the use of drinking water supplies due to activity concentrations exceeding intervention levels, alternative sources of water would need to be provided for drinking water and water used for food preparation. This data sheet 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 data sheet (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. 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 up to a day 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. 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 2.8.
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. 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.
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 was free from contamination, and the restricted water not used, then this management option will be 100% effective in reducing activity concentrations in the water. An alternative supply may be less contaminated but still acceptable for use as drinking water; in this case the reduction in activity concentrations 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. Bottled water has already gone through screening to meet quality control requirements.
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.

1 Alternative drinking water supply	
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.
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 2.6).
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). PPE (such as gloves or facemasks) maybe 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.
Consumables	Fuel and bottles or containers for transporting water. Bottled water from shops/warehouses.
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 analyze 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.
Factors influencing costs	Demand for water. Availability of supplies. Fuel prices.
Compensation costs	There may be compensation costs associated with the loss of normal water supplies provided by water companies/suppliers.
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.

1 Alternative drinking water supply	
Assumptions	None
Communication needs	People will need information on: where restrictions are in place and that alternative water is available; 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 subsidized.
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.
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 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	Many water companies will have experience in providing water using tankers or bowsers in emergency situation involving other contaminants and natural disasters, e.g. floods.
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-RPD, 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**, 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, pp 75-85. Oxford, Elsevier.
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.
Document History (see Table 3.3)	STRATEGY project, 2006. Datasheet called ‘Bans on drinking water consumption’. UK Recovery Handbook 2005. Datasheet called 'Alternative Supply'.

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 CFILs.
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 (ice cover, hydrological cycling etc.). 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, e.g. change from river abstraction to bore holes. 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/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. 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, e.g. in reservoirs, or until contamination has spread to the new abstraction point, e.g. in 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 program 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 2.8.
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 drinking water.
Factors influencing effectiveness of	The extent to which the water at the new abstraction point or water source is

2 Changes to water abstraction point or location of water source	
procedure	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, e.g. borehole (requires 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.
Required ancillary equipment	Additional monitoring may be needed at abstraction points to ensure contamination has not reached there or is below intervention levels.
Required utilities and infrastructure	Water companies/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	Waste arising from treatment of water will require disposal and/or storage under an appropriate authorisation.
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.

2 Changes to water abstraction point or location of water source	
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).
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	Comans JA, Fernandez, Hilton J and de Bettencourt A. Studies in Environmental Science 68. Freshwater and Estuarine Radioecology. Proceedings of an International Seminar, Lisbon, Portugal, 21-25 March 1994, pp 75-85. Oxford, Elsevier. Oatway WB, Smith JG and Hesketh N (2007). Incremental doses from the implementation of drinking water, aquatic, forest or social countermeasures. EURANOS report, HPA-RPD, Chilton, Smith JT, Voitsekhovitch OV, Håkanson L, Hilton J (2001). A critical review of measures to reduce radioactive doses from drinking water and consumption of freshwater foodstuffs. *J Env Radioact*, **56**, 1-2. Voitsekhovitch O, Nasvit I, Los`y and Berkovsky V (1997). Present thoughts on the aquatic countermeasures applied to regions of the Dnieper river catchment contaminated by the 1986 Chernobyl accident. IN. Desmet G, Blust RNJ.
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 3.3)	STRATEGY project, 2006. Data sheet called ‘Regulation of flow of contaminated water through reservoirs’. UK Recovery Handbook 2005. Data sheet called 'Change Abstraction Regime'. EURANOS Recovery Handbook, 2007. Name of datasheet revised to 'Changes to water abstraction point or location of water source'.

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 CFILs.
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. This could be used on a 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	Reduction of internal exposure from ingestion of drinking water.
Time of application	Early – medium. 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 2.8.
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	None
Waste	
Amount and type	This option will not produce any contaminated waste water directly. However,

3 Controlled blending of drinking water supplies	
	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	Waste arising from treatment of water will require disposal and/or storage under an appropriate authorisation.
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 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-RPD, 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**,1-2.

3 Controlled blending of drinking water supplies	
	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, pp 75-85. Oxford, Elsevier.
Comments	
Document History (see Table 3.3)	STRATEGY project, 2006. Data sheet called ‘Switching or blending of drinking water supplies’. UK Recovery Handbook 2005. Data sheet called 'Controlled blending'. EURANOS Recovery Handbook, 2007. Datasheet renamed to 'Controlled blending of drinking water supplies'.

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 at water treatment plants 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 sand filtration, carbon filtration, membrane filtration, ion exchange and reverse osmosis. A full monitoring program 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 CFILs over the period of concern. It should be noted that activity concentrations higher than CFILs may be acceptable in the short-term particularly for short-lived radionuclides. See Section 2.8 for further guidance.
Target	Public drinking water supplies. Appropriate for private drinking water supplies if 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	Large. All drinking water supplied by water companies undergoes treatment to some extent. Private water supplies may undergo treatment.
Exposure pathway pre intervention	Reduction of internal exposure from ingestion of drinking water.
Time of application	Short – long. 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 2.8).
Social constraints	Continuing treatment of contaminated water will 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 2.5). 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 e.g. bottled water.
Environmental constraints	If normal disposal routes for waste water and other solid wastes from treatment continues, this could lead to the spread of low levels of contamination in the environment, e.g. 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 in Table 3.4 at the end of the data sheet. Section 5.1 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 chemical removal of radionuclides and the effectiveness of membrane filtration to remove radionuclides is likely to be small (see Brown *et al*, 2008b).

4 Continuing normal water treatment (supported by a monitoring programme)	
Factors influencing effectiveness of procedure	Effectiveness will be dependant 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	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	None
Required utilities and infrastructure	Already in place
Required consumables	None
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 minimize 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, e.g. contaminated sand and activated charcoal from filter beds and sludge (see Section 2.6 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 an appropriate authorization.
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	None
Intervention Costs	
Equipment	None
Consumables	Increased frequency of replenishing treatment materials, e.g. 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, e.g. 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 2.5 and Brown *et al*, 2008a, 2008b. There may be inequity

4 Continuing normal water treatment (supported by a monitoring programme)	
	between beneficiaries (water consumers) and those living by waste facilities.
Environmental impact	Utilization 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 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 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.
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://www.hpa.org.uk. 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://www.hpa.org.uk. Goossens R, Delville A, Genot J, Halleux R andMasschelein WJ (1989). Removal of the typical isotopes of the Chernobyl fall-out by conventional water treatment. *Wat. Res.,* **23**, 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-RPD, Chilton, Saxén R. Freshwater and fish, in: P Strand, L Skuterud and J Melin (eds.). Reclamation of contaminated urban and rural environments following a severe nuclear accident. Nordic Nuclear Safety Research, NKS(97) 18 97-10-10, ISBN 87-7893-017-0, pp 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**, 12. Tsarik N (1993) Supplying water and treating sewage in Kiev after the Chernobyl accident. *J American Water Works Association*, **85**, 42-45.
Comments	None
Document History (see Table 3.3)	STRATEGY project, 2006. Data sheet called 'Purification of water at treatment plants'. UK Recovery Handbook 2005. Data sheet called 'Water Treatment'. UK Recovery Handbook, 2009. New datasheet developed to only cover maintaining normal water treatment supported by a monitoring program. Modifications to water treatment considered in a separate datasheet (Datasheet 5).

Table 3.4 Water treatment removal efficiencies as a function of element and treatment process[*, #, **]

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]	■■	■■■■	■■■■
Lanthanum	■■	■■■	■■	■■■■[&Δ]	■■	■■■■	■■■■
Cerium	■■■■	■■■■	■■	■	■■■	■■■■	■■■■
Ytterbium	■■■	■■■	■	■	■■	■■■	■■■■
Iridium	■■■	■■	■■	■	■■	■■■	■■■■
Radium	■■	■■■	■■	■■■■[&]	■■	■■■■	■■■■
Uranium	■■■■	■	■■	■■■■	■■■	■■■■	■■■■
Plutonium	■■■■	■■	■■■	■	■■■	■■■■	■■■■
Americium	■■■■	■■	■■■	■	■■■	■■■■	■■■■

Key:

Removal efficiency (% removed) ■ = 0 – 10%; ■■ = 10 – 40%; ■■■ = 40 – 70%; ■■■■ = >70%

Notes:

*****: 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.

** Taken from Brown *et al*, 2008a.

[#]: 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.

5 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 CFILs.
Other benefits	Will remove other impurities.
Management option description	Any changes to existing water treatment processes to enhance removal of specific radionuclides from water. 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 the removal efficiency matrix in Table 3.4.
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	Short/medium term: 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. Long term: If new processes 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 2.8).
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 2.5). 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 e.g. 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, e.g. in natural water courses.
Effectiveness	
Management option effectiveness	Table 3.4 at the end of Datasheet 4 gives chemical removal efficiencies for a range of elements and water treatment processes. Section 5.1 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

5 Modification of existing water treatment	
	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.
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" (e.g. increased frequency of operations, '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 B).
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, e.g. contaminated sand and graphite from filter beds and sludge (see Section 2.6 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 an appropriate authorization.
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, e.g. 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 B 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

5 Modification of existing water treatment	
	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, e.g. 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 (those consuming water) 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.
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.
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://www.hpa.org.uk. 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://www.hpa.org.uk. Oatway WB, Smith JG and Hesketh N (2007). Incremental doses from the implementation of drinking water, aquatic, forest or social countermeasures. EURANOS report, HPA-RPD, Chilton,
Comments	None
Document History (see Table 3.3)	STRATEGY project, 2006. Data sheet called ‘Purification of water at treatment plants’. UK Recovery Handbook 2005. Data sheet 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).

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 CFILs.
Other benefits	Will remove other impurities.
Management option description	Any changes to existing water treatment processes to enhance removal of specific radionuclides from water. 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 the removal efficiency matrix in Table 3.4.
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	Short/medium term: 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. Long term: If new processes 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 2.8).
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 2.5). 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 e.g. 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, e.g. in natural water courses.
Effectiveness	
Management option effectiveness	Table 3.4 at the end of Datasheet 4 gives chemical removal efficiencies for a range of elements and water treatment processes. Section 5.1 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

6 Modification of existing water treatment	
	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.
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” (e.g. increased frequency of operations, '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 B).
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, e.g. contaminated sand and graphite from filter beds and sludge (see Section 2.6 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 an appropriate authorization.
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, e.g. 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 B 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

6 Modification of existing water treatment	
	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, e.g. 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 (those consuming water) 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.
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.
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://www.hpa.org.uk. 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://www.hpa.org.uk. Oatway WB, Smith JG and Hesketh N (2007). Incremental doses from the implementation of drinking water, aquatic, forest or social countermeasures. EURANOS report, HPA-RPD, Chilton,
Comments	None
Document History (see Table 3.3)	STRATEGY project, 2006. Data sheet called 'Purification of water at treatment plants'. UK Recovery Handbook 2005. Data sheet 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).

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CONTENTS OF SECTION 4

4 PLANNING FOR RECOVERY AND CUSTOMISATION OF THE GENERIC HANDBOOK IN ADVANCE OF AN INCIDENT

There is a broad diversity of climatic conditions, types of drinking water supply, culture, infrastructure and regulatory frameworks across Europe. Organisations at the local, regional or national level may need to develop their own approach for preparing for a radiological emergency, according to their responsibilities and involvement. As these may be very different, it is important that the handbook can be customised at the national, regional or local level according to the needs of each country. The types of information required by different users and the level of detail they require will vary and needs to be taken into account as part of the customisation process.

Customisation of the generic European handbook is an essential part of planning for the recovery phase after a radiological emergency. The purpose of this Section is to support this planning process by identifying the key topics that would need to be addressed and information that is needed to support the development of recovery strategies. Although much will depend on the nature of the radiological emergency or incident, eg. its magnitude and the extent of radioactive contamination, there are topics for which consideration prior to an emergency will aid recovery planning and speed the recovery response in the event of an incident and also 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 effort would be required to assemble such information. Clearly, priorities would need to be assigned to help make best use of available resources. 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 in advance of an incident. The strategy should be focussed at the local level.

As with planning for the initial response, recovery planning should be a co-ordinated activity between all relevant agencies. An essential component of the planning and customisation process is the involvement of stakeholders, including future users of the handbook, to better identify and include the specific factors in the customisation,. Communication between different stakeholders is important to get a balanced view on various aspects of the problems to be faced at the national, regional or local level. This approach facilitates the development of a common language and a shared understanding of the challenges to be developed. Various approaches for co-developing national handbooks with stakeholders can be used, including scenario-based workshops, feedback sessions on the data sheets and handbook and the establishment of subgroups for more detailed planning on specific topics (e.g. waste management).

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 to the regulators, local authorities, 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 α and β monitoring and more extensive radionuclide specific monitoring *and capability for rapid radiochemical analyses*. Monitoring and radioanalytical capability for private supplies. Agreements between Local Authorities and Water Companies/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/suppliers and Local and National Authorities to arrange adequate protection at water distribution points. Details of how long a Water Company/supplier can provide uncontaminated water supplies for and how large an area could be covered. What access is there to other drinking water supplies and water distribution networks? What is the capacity of water supplies from covered service reservoirs?
Drinking water sources	Where does the drinking water supply in a given area come from? Does this vary at different times of the year? How likely is it that underground water sources will become contaminated and over what timescales following a radiological emergency? How deep are boreholes and aquifers? How sensitive are the water sources to radiological 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. Collection of data on the effectiveness of water treatment in reducing radionuclide concentrations in water. Identification of sites/processes/waste streams where radioactivity might be concentrated and development of appropriate protection/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. What options are there for abstracting water from another water source? Are there 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, e.g. adjacent Water Companies/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 management options and their success.
Management options	Identify practicable and acceptable management options from data sheets in Drinking Water Handbook in advance. Consider: any constraints on use of option (from data sheets) short-term management options that might require longer-term solutions. Which management options might be applicable to the range of possible incident scenarios? How might they be implemented? How will waste be managed? Customize data sheets 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	Radiation protection (i.e. workers and public). Radioactive waste management. Specific legislation at local, regional or national level which may apply (e.g. 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. 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 coordinated and moved to the affected area, e.g. 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 program for the roles required to be performed, e.g. 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 management options will be in place and when will they end.
Role of stakeholders	Identify existing stakeholder groups in the area. 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

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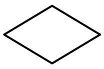
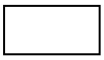
CONTENTS OF SECTION 5

5 FRAMEWORK FOR MAKING DECISIONS ON A MANAGEMENT STRATEGY

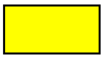
An overall decision framework for developing advice on drinking water supplies and considering management options is shown in a decision tree in Figure 5.1. The decision tree guides the user through the decision making process. The decision tree should be used in the following way:



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 provides information to enable activity concentrations in drinking water to be estimated from environmental measurement data that may be available. Section 5.2 provides generic information on the monitoring of drinking water supplies and monitoring priorities.

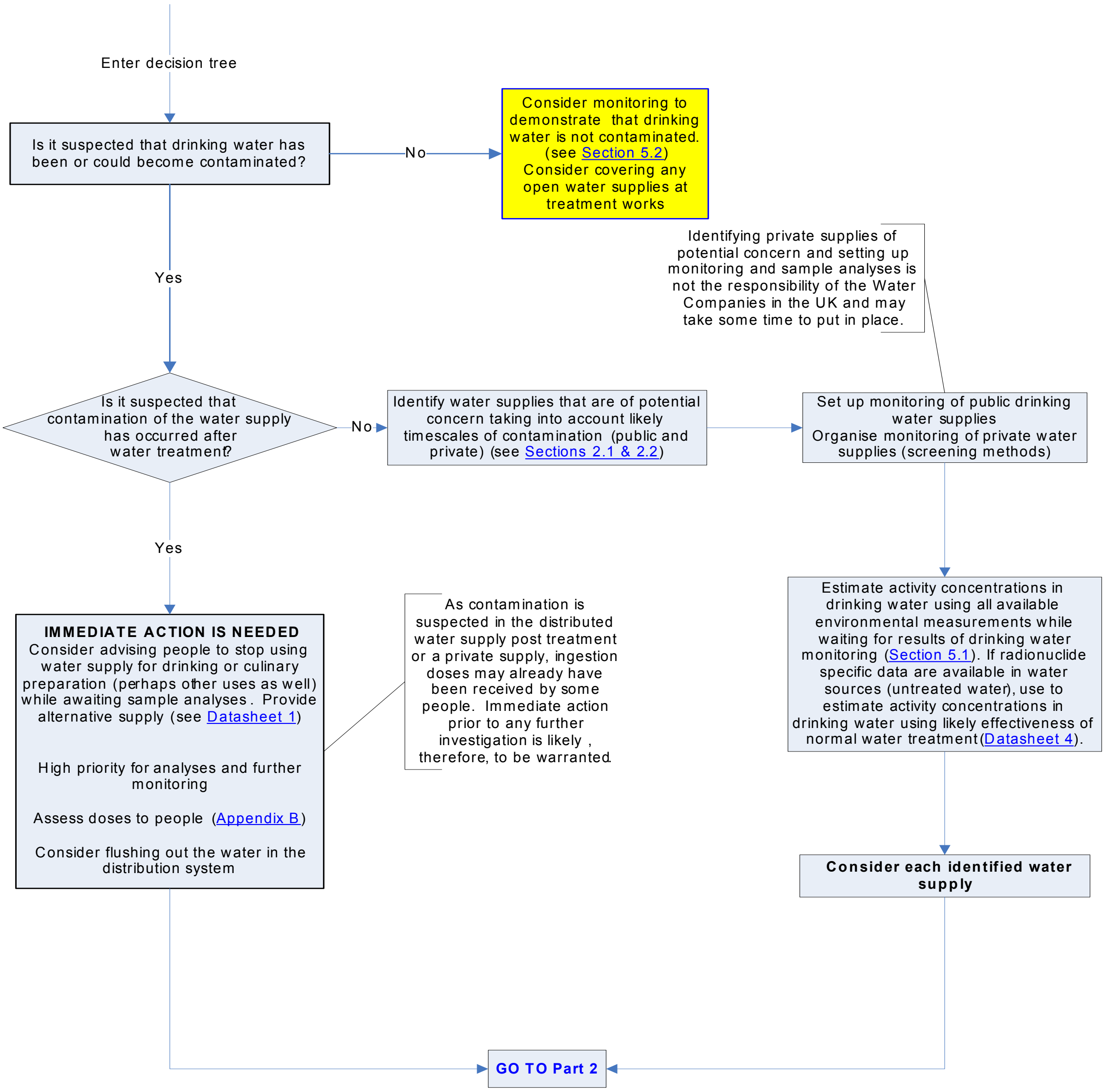


Figure 5. 1 Decision tree for management options for drinking water: Part I

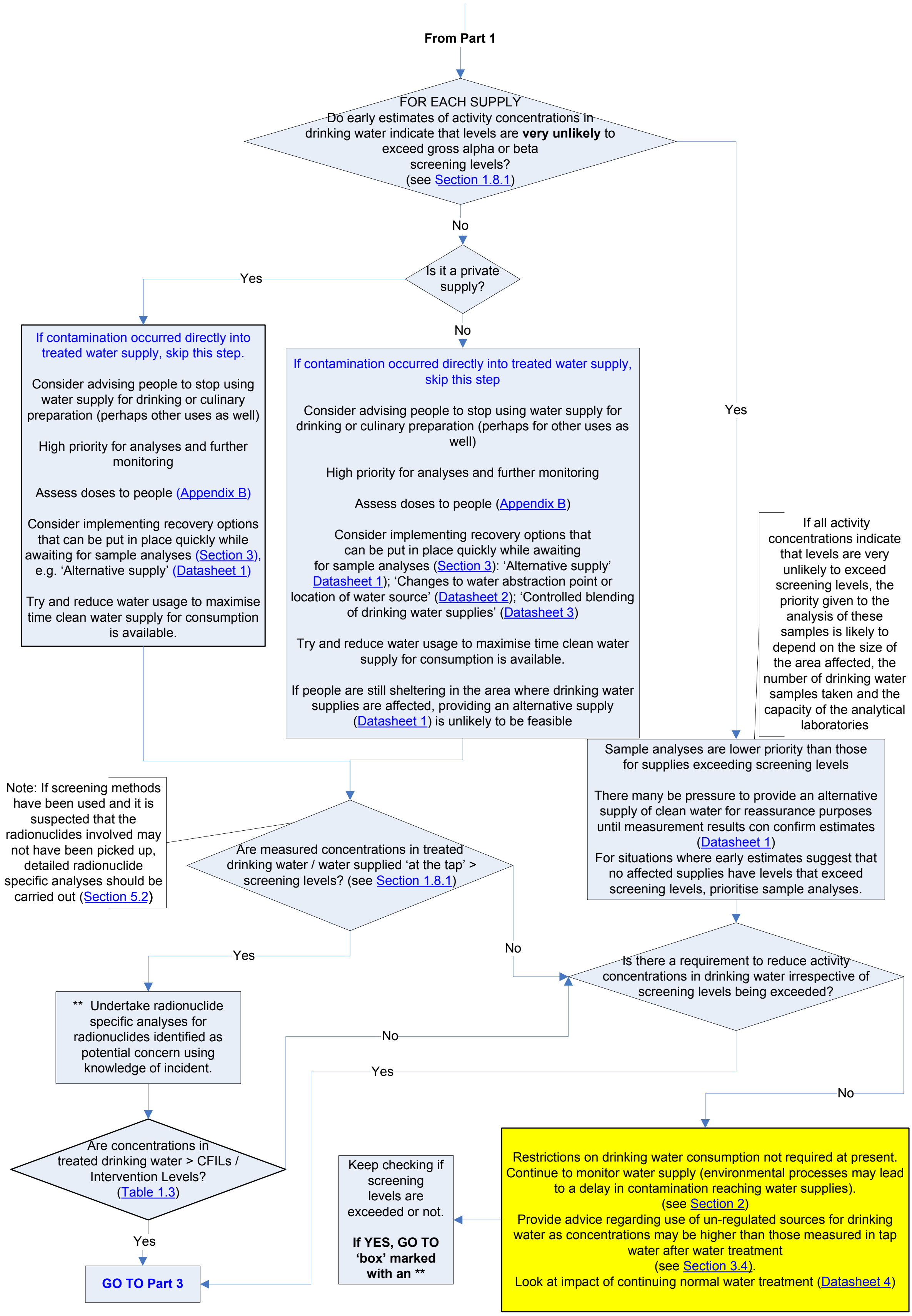


Figure 5.1 (cont) Decision tree for management options for drinking water: Part II

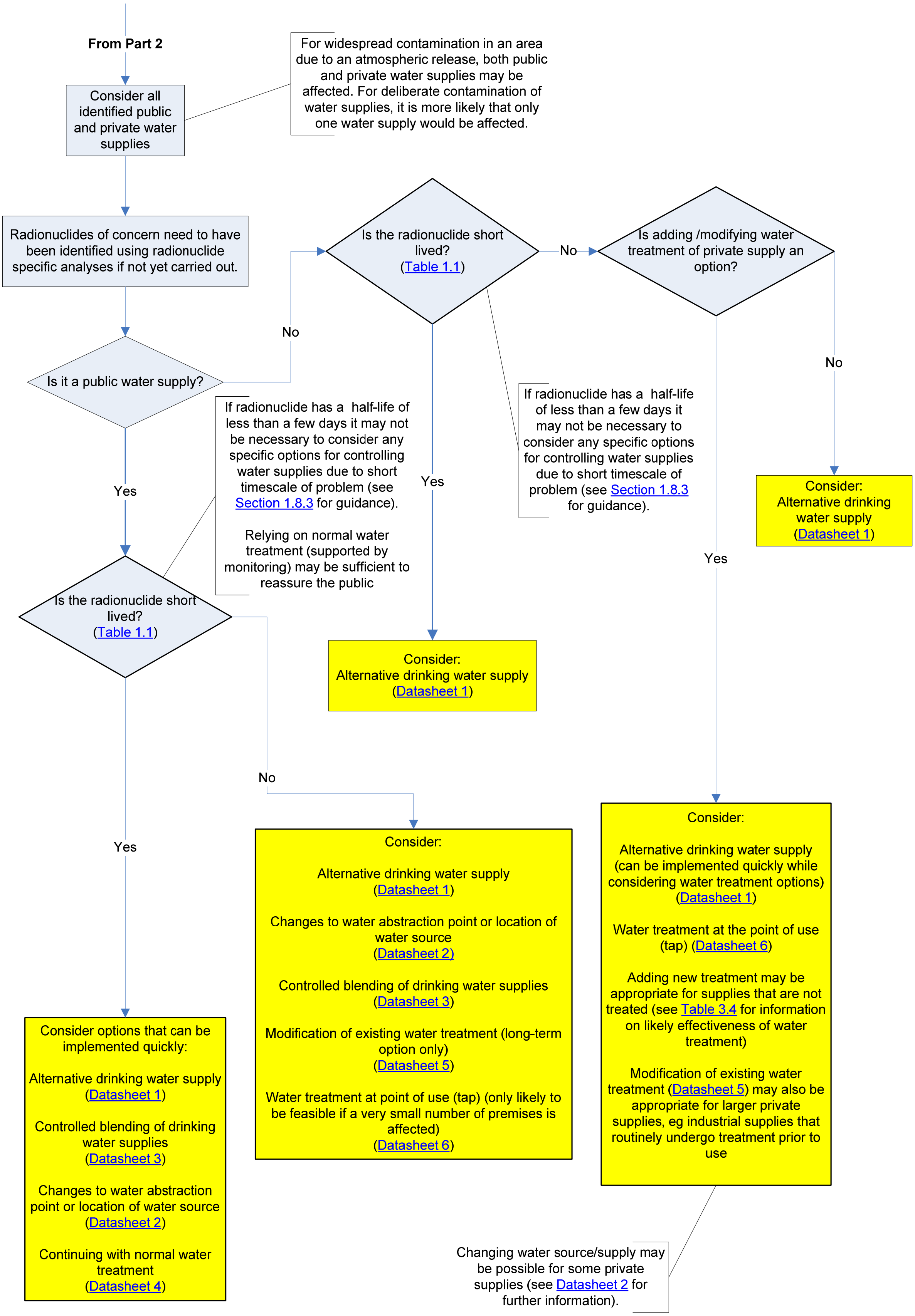


Figure 5.1 (cont) Decision tree for management options for drinking water: Part III

5.1 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 analyzed.

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.

5.1.1 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 has been assumed for a mixing depth. This gives an activity concentration in the surface water body and it may, pessimistically, be assumed that drinking water (i.e. 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; and 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}) =

$$\text{Deposition (Bq m}^{-2}\text{)/Mixing Depth (m)} \times 0.001 \text{ m}^3 \text{ l}^{-1}$$

QUICK ESTIMATE – Assuming a conservative mixing depth of 0.1 m, the conversion factor for activity concentration in water = 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.

5.1.2 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 3.4). Activity concentrations in drinking water per Bq per litre in input water have been estimated for the two main combinations of drinking water treatment. These are flocculation/clarification (referred to in the table as floc/clar) 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 5.1. 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, i.e. assuming that minimum removal of radioactive contamination occurs at each step during the treatment process.

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 in water post treatment = activity concentration in water before treatment x F

Where:

F = 1 - (removal efficiency /100)

Removal efficiencies for different water treatment processes are given in Table 3.4. 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/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 3.4. 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 overall removal efficiency for any combination of treatments can be estimated in the following way:

Activity concentration in water post treatment A = activity concentration in water before treatment x F_a

Activity concentration in water post treatments A and B = activity concentration in water after treatment A x F_b

Where:

F_a = 1- (removal efficiency /100) for treatment A and

F_b = 1- (removal efficiency /100) for treatment B

Further information can be found in Brown *et al*, 2008a and Brown *et al*, 2008b.

Table 5.1 Estimated activity concentrations in drinking water following typical water treatment in the UK*

	Activity concentration in water, Bq l^{-1} in treated water per Bq l^{-1} in input water[a]	
Radionuclide	Floc/clar + RGF[b]	Floc/clar + RGF + SSF[b]
^{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[c]	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}[d]	3.2 10^{-1}[d]
^{140}La	5.4 10^{-1}[d]	3.2 10^{-1}[d]
^{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}

*taken from Brown *et al*, 2008a

a) Assumes minimum removal of radionuclides at each process step (see Table 3.4 for removal efficiency factors; minimum value in range given has been used).

b) Floc/clar = flocculation and clarification; RGF = rapid gravity sand filtration; SSF – slow sand filtration.

c) 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.

d) Updated values due to revision of removal efficiencies for barium and lanthanum for flocculation.

5.1.3 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.

5.2 Monitoring of drinking water supplies and monitoring priorities

QUICK ESTIMATE – Assuming 1mm of rainfall, a conservative estimate of the activity concentration in rainwater = 1 Bq l^{-1} per Bq m^{-2}

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 intervention 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. Surface water monitoring of raw water by the relevant environment agencies 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, i.e. surface water or ground water. Ground water sources are much less likely to become contaminated and, if they do, this will be on a much longer timescale than surface water sources. This information for a given area should be used to help prioritize 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 due to the requirements of the Drinking Water Directive issued by the European Commission [EC, 1998]. Even if there is no requirement for routine monitoring for radionuclides in a country, similar considerations will apply to other potential pollutants such as trace metals. Similar expertise may also exist in other organizations. Generic guidance on sampling after an accident has been published [IAEA 1999].

For analytical work, the Water Industry, or other organizations, 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 Drinking Water Directive for routine situations [EC, 1998]. 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 a specified intervention level (in this case the CFILs) for drinking water. An example of this application of gross measurements of activity is given in Appendix A. The applicability of this approach for the radionuclides considered in the handbook is also discussed.

Other more specialized 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 would be needed to carry out the analyses. Strontium-90 would be an example.

Not all radioanalytical laboratories will be 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 set out below.

- 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 program.
- 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.
- Intervention levels such as CFILs 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 an intervention level 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 [IAEA 1999].

As with any monitoring program, 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 analyzed. 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.

5.3 References

Brown, J, Hammond, D and Wilkins, B T (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 www.hpa.org.uk.

Brown, J, Hammond, D and Wilkins, B T (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 www.hpa.org.uk.

EC (1998). 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.

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

IAEA (1999). Generic procedures for monitoring in a nuclear or radiological emergency. IAEA-TECDOC-1092.

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CONTENTS OF SECTION 6

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. The scenarios could also 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 post treatment.

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

6.1.1 Description

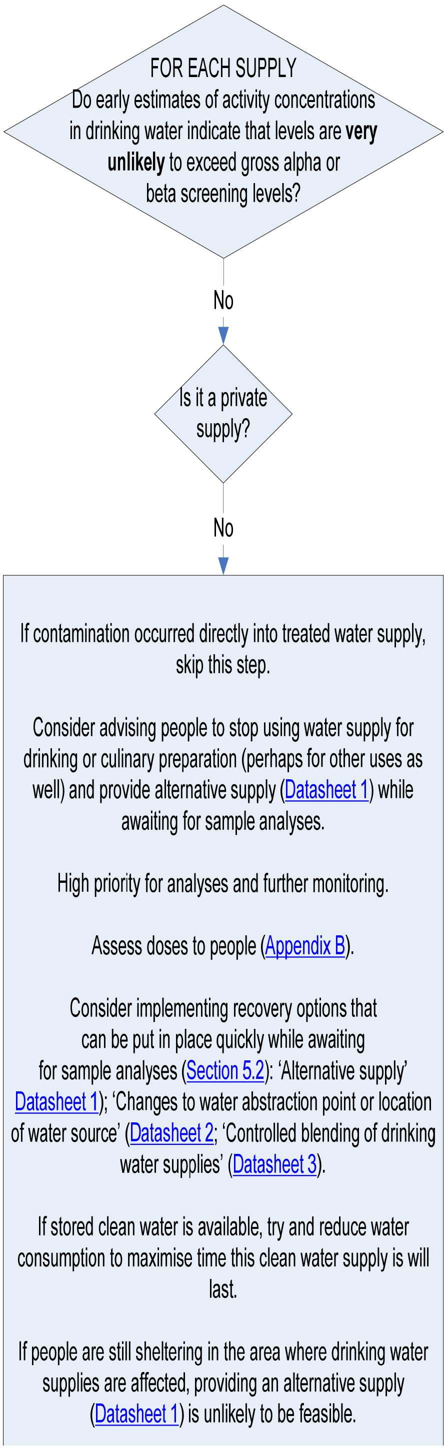
A large nuclear reactor accident occurred which resulted in a release of radioactive material into the atmosphere. It rained as the contaminated plume passed overhead, which has led to a wet deposition of contaminants over surface water supplies (open air) in a large area. At present, the contaminated plume has passed, deposition has occurred onto 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 inhabited 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 (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 water treatment ? ⇒ No (it has occurred before treatment).	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. 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.
Identify water supplies that are of potential concern taking into account likely timescales of contamination (public and private) (see Sections 2.1 & 2.2)	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 5.1). 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 (Datasheet 4). ↓ **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, i.e. 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 5.1). *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. Datasheet 4 (Table 3.4) 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 are available. These removal estimates need to be confirmed by monitoring both the input and output from the treatment plant(s). Table 5.1 shows us that normal water treatment is only likely to remove up to 25% of radiocaesium in 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 5.2). 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.



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 intervention levels.

Assume that early estimates of activity concentrations in treated drinking water from the public water supply 1 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 5.2).

Using the information in Appendix B 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 Section 1.8.3.
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 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? Yes	*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.
** Undertake radionuclide specific analyses for radionuclides identified as potential concern using knowledge of incident.	
Are concentrations in treated drinking water > CFILs ? (Table 1.3) Yes ⇒ 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 CFILs 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 CFIL values to illustrate how the handbook can be used and the issues that would need to be considered in any radiological incident where this situation occurs.**
Consider all identified public and private water supplies	2 main supplies have been identified: Supply 1 (public) 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.

Consider: Alternative drinking water supply (datasheet 1) Changes to water abstraction point or location of water source (datasheet 2) Controlled blending of drinking water supplies (datasheet 3) Modification of existing water treatment (long-term option only) (datasheet 5) Water treatment at point of use (tap) (only likely to be feasible if a very small number of premises is affected) (datasheet 6)	The water treatment in place is not sufficient to reduce activity concentrations to below the CFIL 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 (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 C provides guidance on how to estimate activity concentrations in the waste. As an example, if measured activity concentrations in raw input water are 2100 Bq/l of total radiocaesium (based on 1500 Bq/l 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 3,000 Bq/tonne (see Table C2, Appendix C). 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 (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 (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 (Datasheet 3) may be feasible if more than one supply is available as activity concentrations in the drinking water are not significantly above the CFILs and blending could reduce these to significantly below the CFILs. (Dilution of high activity concentrations is likely to be very difficult to explain to the public). Water treatment at the tap (Datasheet 6) 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. 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 CFILs; • public concerns over water quality. These factors are discussed in more detail in the datasheets and in Section 2. 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 program 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 intervention 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. • Can changes 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 5). • Planned cleaning of the water treatment works to remove all contaminated precipitates, sludges and filters. This will provide public reassurance that remobilization 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.

	• Continue 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	There are also a number of people who live in the affected area with private water supplies.
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	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: Alternative drinking water supply (can be implemented quickly while considering water treatment options) (datasheet 1) Water treatment at the point of use (tap) (datasheet 6) Adding new treatment may be appropriate for supplies that are not treated (see datasheet 4 for information on likely effectiveness of water treatment) Modification of existing water treatment treatment (datasheet 5) may also be appropriate for larger private supplies, eg industrial supplies that routinely undergo treatment prior to use	Consider providing alternative supplies for drinking water (Datasheet 1) and water treatment at the tap (Datasheet 6) by using jug filters for reassurance until monitoring data are available.

6.2 Example 2 – Direct contamination of water before treatment

6.2.1 Description

Radioactive contamination has occurred in a river, upstream from the intake location of a large scale water treatment plant. It is believed that the river water has contaminated storage reservoirs in the distribution network by the time the incident 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 ⇒ 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 water treatment ? ⇒ No Identify water supplies that are of potential concern taking into account likely timescales of contamination (public and private) (see Sections 2.1 & 2.2)	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 miles 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 5.1). 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 (datasheet 4). **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 levels? ⇒ Yes	*Early estimates indicate that the ^{90}Sr CFIL is unlikely to be exceeded as the gross beta emergency screening level has not been exceeded.* Some water may have been consumed prior to the contamination in the river being identified. An estimate of the ingestion doses received can be

Sample analyses are lower priority than those for supplies exceeding screening levels There many be pressure to provide an alternative supply of clean water for reassurance purposes until measurement results con confirm estimates (Datasheet 1) For situations where early estimates suggest that no affected supplies have levels that exceed screening levels, prioritise sample analyses.	made using default values of the effectiveness of drinking water treatment for ^{90}Sr (see Table 5.1and Table 3.4 in Datasheet 4) and knowledge of the treatment processes used (see Section 5.1). If we assume that the activity concentration in the drinking water is at the gross beta emergency screening level of 30 Bq l^{-1} set in the UK (see Appendix A) and that the water treatment processes used remove 30% of the contamination (see Table 5.1), a conservative estimate of ingestion doses that may have been received can be made using Table B1. 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 minimized. 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. 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 CFIL.*
Is there a requirement to reduce activity concentrations in drinking water irrespective of intervention 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	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 or location of water source (datasheet 2) Controlled blending of drinking water supplies (datasheet 3) Modification of existing water treatment (long-term option only) (datasheet 5) Water treatment at point of use (tap) (only likely to be feasible if a very small number of premises is affected) (datasheet 6)	Measurements in treated water indicate that the normal water treatment is effectively reducing the ^{90}Sr in the water entering the works to below the CFIL. 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 (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 (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. For reassurance, it is likely that thorough clean-up of the drinking water treatment works would be required to remove all contaminated precipitates, sludges and filters (see Datasheet 4). This would require planning to minimize the disruption to the water supply. The doses to the people implementing the clean-up of the treatment works would need to be assessed and controlled (see Appendix B). Changes could be made to the water treatment implemented to remove more radiostrontium (see Datasheet 5). 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. 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 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 ⇒ Yes Is it suspected that contamination of the water supply has occurred after water 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 other uses as well) while awaiting for sample analyses. Provide alternative supply (see Datasheet 1) High priority for analyses and further monitoring Assess doses to people (Appendix B) Consider flushing out the water in the distribution system 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 levels?	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. *Le 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 5.2).
** Undertake radionuclide specific analyses for radionuclides identified as potential concern using knowledge of incident.	*After some hours the first monitoring results start coming in. An activity concentration of 2000 Bq/l of ^{131}I is found in 2 samples, equal to 4 times the CFIL. In the remainder of samples, activity concentrations ranging from below levels of detection to 500 Bq l^{-1} have been measured, i.e. up to 50% of the CFIL.*

Are concentrations in treated drinking water > CFILs ? (Table 1.3) Yes ⇒ Yes	*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 B1.* According to Table B1, and 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, i.e. those nearest the point of contamination. 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 2.6).
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 or location of water source (datasheet 2) Continuing with normal water treatment (datasheet 4)	The majority of the ingestion doses from drinking the contaminated water are 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 for. 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 6). 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. 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.

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7 GLOSSARY

Term	Definition
Abstraction	Abstraction is the process of taking water from any source, either temporarily or permanently, for example from rivers, boreholes etc.
Activity concentration	The level of radioactive contamination per unit area, volume, or mass. The following are examples: Bq m^{-2} (Bq per square metre): activity concentration of deposited radioactive material on a surface. Bq l^{-1} (Bq per litre): activity concentration of radioactive material in drinking water, rainwater run-off or liquid waste.
Bq (Becquerel)	The Becquerel is the unit for radioactivity, i.e. the rate at which nuclear decays occur in a given amount of radioactive material. Defined as one nuclear decay per second.
Alpha emitters	Radioactive materials for which the most hazardous type of radiation emitted is alpha particles, e.g. the radionuclide plutonium-239 is an alpha emitter.
Alpha particles	A particle consisting of two protons and two neutrons emitted from the nucleus of a radionuclide following radioactive decay. Alpha particles do not penetrate the skin and are only hazardous if taken into the body through breathing or eating.
Beta emitters	Radioactive materials for which the most hazardous type of radiation emitted is beta particles, e.g. the daughter of strontium-90 (yttrium-90) is a beta emitter. Beta particles may penetrate a cm or so of tissue, so radionuclides that emit them are hazardous to superficial tissues but not to internal organs unless they are taken into the body through breathing or eating.
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 onto 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.
Datasheet	A compilation of data and information about a recovery option or a pre-release or emergency phase countermeasure designed to support decision-makers in the evaluation of an option and the impact of its implementation.
Decision-makers	Persons, 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.
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 ionizing 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’.
Drinking water options	See management options.
Effective dose	A quantity used in radiological protection that incorporates the sensitivity of different types of living tissue to damage by different types of radiation received by a body. It is a measure of radiation exposure. Unit: Sv (Sievert) .

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.
Gamma emitters/gamma-emitting	Radioactive materials for which the most hazardous type of radiation emitted is in the form of gamma rays, e.g. the radionuclide cobalt-60 is a gamma emitter.
Gamma rays	High energy photons, without mass or charge, emitted from the nucleus of a radionuclide following radioactive decay, as an electromagnetic wave. They are very penetrating, so radionuclides that emit them may be hazardous whether on the outside or inside the body.
Ground water sources	See water sources
Ground water supplies	Drinking water supplies that come from sources that are below the surface of the ground and in direct contact with the ground or subsoil, e.g. boreholes.
Incident	See radiological incident.
Ingestion dose	Effective dos received from ingestion of radioactivity into the body.
Inhabited areas	Places where people spend their time, e.g. at home, at work and during recreation.
Long-lived radionuclides	Defined for the Handbook as radionuclides with a radioactive half-life of more than three weeks.
Management option	An action intended to avert doses to the affected population or reduce the contamination levels in drinking water, which is carried out in the recovery phase.
Management strategy	See recovery strategy.
Millisievert (mSv)	One thousandth of a Sievert (Sv)
Options	See management options.
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 half-life	The time taken for the activity concentration of a radionuclide to fall to half its initial value due to its physical decay.
Radiological incident/radiological emergency	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 groundwater 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 and continuing until agreed recovery criteria have been met.

Recovery strategy	The aim of a recovery strategy is the return to normal living, i.e. people can live and work in an area without the radiological emergency/incident and its consequences being foremost in their minds. It covers all aspects of the long-term management of the contaminated area and the implementation of specific recovery options. The development of the strategy should involve all stakeholders including members of the public.
Short-lived radionuclides	Defined for the Handbook as radionuclides with a radioactive half-life of less than three weeks.
Sievert, Sv	The standard unit of effective dose. Symbol: Sv.
Stakeholders	Individuals, groups or organisations that are affected by the recovery strategy and should be involved in its development.
Surface water sources	Untreated water from inland surface sources, e.g. lakes.
Surface water supplies	Drinking water supplies that come from surface water sources, e.g. rivers and reservoirs.
Water sources	These are grouped for the purpose of the handbook into ground water sources, e.g. aquifers and surface water sources, e.g. 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.

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APPENDIX A

Example of application of gross alpha and beta screening methods in the UK

The UK Environment Agency (EA) has published guidance on monitoring drinking water using gross alpha and beta screening methods [EA, 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 CFILs. 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 A1. If observed concentrations of gross activity in treated distributed drinking water supplies are below the values given in Table A1, 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 CFILs in Table 1.3. It should be noted that these screening levels are calculated to demonstrate that CFILs have not been exceeded. If other intervention levels are used (such as those suggested by IAEA [IAEA, 2002]), then different screening levels would need to be set.

For those radionuclides that are amenable to this approach, measurements in excess of the Emergency Screening Levels given in Table A1 would not necessarily mean that the radionuclide-specific CFIL (see Table 1.3) had been exceeded. However, it should be assumed that activity concentrations have exceeded the CFIL until a more rigorous radionuclide specific analysis has been undertaken.

Some radionuclides will not be detected using the monitoring equipment routinely used by the water industry to measure gross α and gross β activity. Of those listed in Table 1.1, those that would not be detected by gross β 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. Those 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 A1 Emergency screening levels for gross alpha and beta activity concentrations in drinking water set to ensure CFILs for drinking water are not exceeded

Type of monitoring	Emergency Screening Level (Bq l^{-1})
Gross α activity	5
Gross β activity	30

Table A1 Emergency screening levels for gross alpha and beta activity concentrations in drinking water set to ensure CFILs for drinking water are not exceeded

Type of monitoring	Emergency Screening Level (Bq l^{-1})
Gross α activity	5
Gross β activity	30

A1 REFE RENCES

EA (2002). Review of alpha and beta blue book methods: Drinking water screening levels. National Compliance Assessment Service Technical Report, NCAS/TR/2002/003, UK.

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

IAEA (2002). Safety requirements on preparedness and response for a nuclear or radiological emergency. Safety Standards Series No. GS-R-2, IAEA, Vienna.

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APPENDIX B

Estimation of doses following the contamination of water

Some information is given in this Section 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 ingestion doses for consumption of drinking water contaminated at the CFILs for 1 week and 1 month;
- committed effective ingestion doses from 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.

B1 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[a]. 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, mSv =

Activity concentration in drinking water (Bq l^{-1}) x consumption rate (l y^{-1}) x ingestion dose per unit intake of activity (Sv Bq^{-1}) x 1000 (mSv per Sv)

Table B1 and Table B2 show the committed effective ingestion dose in mSv 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 B1 gives the doses for consumption of drinking water contaminated at the CFIL for 1 week and 1 month. It should be noted that the estimates of doses for consumption over one month will be cautious for many types of incident as it is highly unlikely that activity concentrations in water will persist at

[A] NOTE THAT DOSES CAN BE SCALED DIRECTLY TO REFLECT DIFFERENT CONSUMPTION RATES.

this level for the entire time. However, for some radionuclides, such as ^{226}Ra, persistent activity concentrations at the CFILs would cause concern. Table B2 shows doses from 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.

Table B1 Committed effective doses from the consumption of tap water contaminated at the *CFILs* for drinking water

Radionuclide	Committed effective dose[a], mSv, following consumption for:						
	CFIL	1 week			1 month		
	Bq l^{-1}	1 yr old	10 yr old	Adult	1 yr old	10 yr 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[b]	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[c]	500	$3\ 10^{-1}$	$1\ 10^{-1}$	$8\ 10^{-2}$	1	$4\ 10^{-1}$	$4\ 10^{-1}$
^{132}Te[b]	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[b]	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[b]	1000	$6\ 10^{-2}$	$2\ 10^{-2}$	$2\ 10^{-2}$	$3\ 10^{-1}$	$9\ 10^{-2}$	$8\ 10^{-2}$
^{140}La[b]	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[b]	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[c]	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	$2\ 10^{-2}$	$2\ 10^{-2}$	$3\ 10^{-2}$	$1\ 10^{-1}$	$7\ 10^{-2}$	$1\ 10^{-1}$

Notes:

(a) Consumption rates for tap water (litres per year): 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.

(b) 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.

(c) For ^{235}U, action would be taken 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 B2 Committed effective doses from one year's consumption of drinking water initially contaminated at 1 Bq l^{-1} [a,b]

Radionuclide	Committed effective dose, mSv		
	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	$6\ 10^{-2}$	$4\ 10^{-2}$	$8\ 10^{-2}$

Note:

a) Consumption rates for tap water (litres per year): 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.

b) 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.

B2 ASSESSING DOSES TO OPERATIVES WORKING IN DRINKING WATER TREATMENT WORKS

If a radiation 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 Handbook [Brown *et* al, 2008a] has been produced in the UK 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 and to people working at 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 B3. 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].

B3 REFE RENCES

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 www.hpa.org.uk.

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 scientific report. HPA-RPD-041 available at www.hpa.org.uk.

NRPB (1994). Guidance on restrictions on food and water following a radiological accident. Chilton, *Docs NRPB* **5**.

Table B3 Generic tasks and potential exposure pathways

Generic Task name	Potential exposure pathways	Typical tasks included
General maintenance/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)
`	External gamma, external beta, inhalation of resuspended spray and filter media	
Maintenance of dissolved air flotation (DAF) units[a]	External gamma + beta	Inspection oft DAF plant
Filter bed maintenance	External gamma/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/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/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/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
Membrane/reverse osmosis /ion exchange unit maintenance	External gamma/beta	Repairing/checking membrane filters
		Replacing ion exchange media
		Replacing reverse osmosis membranes

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

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APPENDIX C

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].

C1 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 a*l, 2008b]. Default data that can be used to scope the activity concentrations that could be expected in filter bed media are given in Table C1. 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 as Table C1 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 B). 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 C1 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[b], Bq kg^{-1} in filter media per Bq l^{-1} in input water[a,c]	
	Floc/clar + RGF[d]	Floc/clar + RGF + SSF[d]
^{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}
^{132}Te	8.3 - 5.0 10^{1}	7.5 10^{-2} - 1.1 10^{-1}
^{131}I	4.2 - 3.3 10^{1}	3.8 10^{-2} - 7.5 10^{-2}
^{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}[e]	5.3 10^{-1} - 7.9 10^{-1}[e]
^{140}La	3.3 10^{1} - 8.8 10^{1}[e]	5.3 10^{-1} - 7.9 10^{-1}[e]
^{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) 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 3.4 in Datasheet 4 for removal efficiency factors).

b) A total mass of filter media has been assumed per Megalitre (Ml) throughput. For RGF this is assumed to be 7200 kg; for SSF this is assumed to be 320,000 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.

c) 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 3.4). In reality, it is very unlikely that any treatment will be 100% efficient in removing radioactivity, although the removal could be very high.

d) RGF = rapid gravity sand filtration; SSF – slow sand filtration.

e) Updated values due to revision of removal efficiencies for barium and lanthanum for flocculation.

C2 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 are given in Table C2. 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 C2 Estimated activity concentrations in sludge for 1 Bq l^{-1} in the input water (taken from Brown *et al*, 2008b)

Radionuclide	Range[a] in estimated activity concentration in sludge[b,c], Bq kg^{-1} in sludge per Bq l^{-1} in input water
^{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	$5.7\ 10^3$ - $1.0\ 10^4$
^{132}Te	$1.4\ 10^3$ - $5.7\ 10^3$
^{131}I	$5.7\ 10^3$ - $1.0\ 10^4$
^{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	$1.4\ 10^3$ - $5.7\ 10^3$[d]
^{140}La	$1.4\ 10^3$ - $5.7\ 10^3$[d]
^{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	$1.0\ 10^4$ - $1.4\ 10^4$

a) 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 3.4 in Datasheet 4 for removal efficiency factors).

b) A default value of 7000 kg of de-watered sludge produced per 100Ml throughput is assumed. A water throughput of 10^5 m^3 (100 Ml) is assumed.

c) It is recognized 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.

d) 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 C2 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 B). 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.

C3 REFE RENCES

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 www.hpa.org.uk.

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 www.hpa.org.uk.

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