Handbook for Assessing the Impact of a Radiological Incident on Levels of Radioactivity in Drinking Water and Risks to Operatives at Water Treatment Works

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ABSTRACT

Incidents or accidents involving radionuclides could lead to contamination of the drinking water supply. If such an event occurred near an open source of 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 both the consumer of drinking water and the operatives that work in any affected water treatment works. This Handbook provides information and guidance for the drinking water industry so that the radiological impact on operatives at treatment works can be quantified and estimates of the likely effectiveness of drinking water treatment in removing radionuclides from water can be made. Worked examples are included to assist users in both planning for a radiological incident and the management of a radiological incident.

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EXECUTIVE SUMMARY

Incidents or accidents involving radionuclides could lead to contamination of the drinking water supply. If such an event occurred near an open source of 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 both the consumer drinking the water and the operatives that work in any affected water treatment works.

The water industry has a responsibility to provide a potable source of drinking water. This Handbook is intended to help the Water Industry in two ways. These are as follows:

- to assess the impact that any radiological incident may have on the drinking water that it supplies;
- to assess the impact that any radiological incident may have on the people carrying out operations at an affected treatment works.

The main focus of the Handbook is to provide a tool for the water industry to manage the potential risks to operatives working with a treatment works. It can be used to help the water industry to make decisions on how the treatment works can be operated in the event of a radiological incident and to manage any radiation exposures to the operatives at the works. It is also expected that the Handbook will be used as a training tool.

Worked examples are included to assist users in both planning for a radiological incident and the management of a radiological incident.

A supporting report is available that provides a detailed description of how the data have been evaluated and parameter values derived. It also describes the methodology used to develop the calculation tools, contains a review of the effectiveness of drinking water treatment in removing radionuclides from water and gives the input data used for assessing doses to people carrying out operations within drinking water treatment works.

CONTENTS

1 INTRODUCTION

Incidents or accidents involving radionuclides could lead to contamination of the drinking water supply. If such an event occurred near an open source of 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 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 drinking water treatment will remove radioactivity from water, and what factors are likely to influence removal. 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 the drinking water industry has information and guidance so that the radiological impact on operatives at treatment works can be quantified. Guidance is also needed so that the likely levels of radioactive contamination that could be in waste generated from the drinking water treatment process can be evaluated.

The aim of this Handbook is to provide a tool to help the drinking water industry to evaluate the following in the event of a radiological incident:

a the effectiveness of drinking water treatment processes in removing radionuclides;

b the radiation exposures to operatives working within drinking water treatment works for both routine and infrequent tasks;

c the prediction of where radionuclides may concentrate within treatment works and the impact of this on concentrations of radionuclides in waste products.

Worked examples are included to assist users in both planning for a radiological incident and the management of a radiological incident. A glossary of the main technical terms used in the Handbook is given in Section 8.

A supporting report is available that provides a detailed description of how the data have been evaluated and parameter values derived. It also describes the methodology used to develop the calculation tools, contains a review of the effectiveness of drinking water treatment in removing radionuclides from water and gives the input data used in the assessment of doses to people carrying out operations within drinking water treatment works.

* Ground water supplies are unlikely to be directly contaminated with radioactivity; 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. This Handbook can be used for contamination of both ground and surface water supplies entering a works, although the emphasis has been placed on surface supplies, particularly with respect to the timescales discussed.

1.1 Scope and audience

The water industry has a responsibility to provide a potable source of drinking water. This Handbook is intended to help the Water Industry in two ways. These are as follows:

a to assess the impact that any radiological incident may have on the drinking water that it supplies;

b to assess the impact that any radiological incident may have on the people carrying out operations at the treatment works.

The main focus of the Handbook is however to provide a tool for the water industry to manage the potential risks to operatives working with a treatment works. It can be used to help the water industry to make decisions on how the treatment works can be operated in the event of a radiological incident and to manage any radiation exposures to the operatives at the works. It is also expected that the Handbook will be used as a training tool.

This Handbook should be used in conjunction with the UK Recovery Handbook for Radiation Incidents: Drinking Water Section [HPA, 2005]. The Recovery Handbook provides guidance on recovery options for reducing doses from the ingestion of drinking water by members of the public. This document provides guidance on the likely effectiveness of drinking water treatment in removing radionuclides from water and as such gives additional and up-dated information to support that in the UK Recovery Handbook*.

This Handbook does not attempt to cover all the problems that could be of concern in a radiological incident. In particular, it does not address the following:

a the disposal of contaminated waste material arising from drinking water treatment works (sludge and filter bed media);

b methods to obtain appropriate samples of contaminated water and other media within a treatment works;

c radiochemical and radiometric analyses and other measurement techniques.

In addition, the effectiveness of membrane filtration (micro-filtration) has not been specifically evaluated. This process relies on the physical removal of suspended particulate material (down to a few microns in size). The raw water that is treated in this way usually has very low turbidity and colour and there are no chemical processes involved in the treatment. Membrane filtration would therefore have no effect on the removal of soluble radionuclides or radionuclides attached to very small particles (<1 micron).

The audience for the Handbook will depend on the structure of individual Water Companies but will include:

* Data on the effectiveness of drinking water treatment processes in removing radionuclides in the UK Recovery Handbook will be up-dated to be consistent with those provided in this Handbook. The next version of the UK Recovery Handbook is due for release in autumn 2008.

a emergency planners;
b operations managers;
c duty managers;
d heads of science;
e company public health advisors.

It is also envisaged that the Handbook will be used by those who regulate the drinking water industry.

1.2 Radioactivity and radiation effects

The amount of a radionuclide in a particular material is measured in terms of its activity, for which the unit is the Becquerel (Bq). However, radionuclides differ in their modes of decay, their radioactive half-life and their biokinetic behaviour, ie, their distribution and retention in body organs and tissues. In addition, individual organs and tissues differ in their sensitivity to radiation. To provide a method for bringing the effects of different radionuclides on people on to a common basis, the International Commission on Radiological Protection (ICRP) uses the concepts of equivalent dose and effective dose [ICRP, 1991, ICRP 2007]. These have units of Sieverts (Sv). Briefly, equivalent doses take account of the different forms of radiation emitted in a given organ or tissue and effective doses then take account of the sensitivity of that organ or tissue to radiation.

People receive doses of radiation via exposure pathways. The two broad categories are external irradiation when the source of the radiation is outside the body and internal irradiation when the source is inside the body. The two main routes of internal irradiation are via inhalation or ingestion. In the case of operatives in a water treatment works, doses can be received via external irradiation, inhalation of material that has been resuspended in the air or the inadvertent ingestion of material adhering to fingers, gloves, etc.

In a given situation, the overall radiological impact can be assessed by adding together the effective doses from external radiation and from different radionuclides following inhalation or ingestion. In practical terms, effective doses in the environment are normally expressed in terms of the milliSievert (mSv), which is one thousandth of a Sievert, or the microSievert (μSv), which is one millionth of a Sievert.

1.3 Radionuclides considered

The following factors were taken into account when deciding on the elements and radionuclides to be considered in the Handbook:

a the current use of a radionuclide, where it can be obtained and/or how it is produced, eg, as a by-product of nuclear reactor operations;
b the form of the radionuclide and its ability to contaminate drinking water supplies;
c the likely exposure risk.

Radionuclides have also been chosen to reflect the range of hazards that operatives of drinking water treatment plants could be exposed to and exemplify a range of chemical and physical behaviours in drinking water treatment works. Methodologies and illustrative calculations that are provided in the Handbook therefore give enough information for the users to apply a rigorous approach to assessing potential doses to operatives, even if a specific radionuclide is not considered in detail. Table 1 lists the radionuclides included in the Handbook. The radionuclides have been grouped according to whether their hazard arises predominantly from emissions from gamma photons or beta or alpha particles. The potential hazards from radionuclides within drinking water treatment works are discussed further in Section 2.1. The justification for the choice of radionuclides is given in the supporting report [Brown et al, 2008].

Table 1: Radionuclides considered in the Handbook

Radionuclide [a]		Internal [b]	External [c]	
		Alpha	Beta	Gamma
^{60}Co	Cobalt-60	-	x	✓
^{75}Se	Selenium-75	-	-	✓
^{89}Sr	Strontium-89	-	✓	-
^{90}Sr	Strontium-90	-	✓	-
^{95}Zr	Zirconium-95	-	x	✓
^{95}Nb	Niobium-95	-	x	✓
^{99}Mo	Molybdenum-99	-	S	✓
^{103}Ru	Ruthenium-103	-	x	✓
^{106}Ru	Ruthenium-106	-	S	✓
^{131}I	Iodine-131	-	x	✓
^{132}Te	Tellurium-132	-	x	✓
^{134}Cs	Caesium-134	-	x	✓
^{136}Cs	Caesium-136	-	x	✓
^{137}Cs	Caesium-137	-	x	✓
^{140}Ba	Barium-140	-	x	✓
^{140}La	Lanthanum-140	-	x	✓
^{144}Ce	Cerium-144	-	S	✓
^{169}Yb	Ytterbium-169	-	x	✓
^{192}Ir	Iridium-192	-	x	✓
^{226}Ra	Radium-226	✓	x	✓
^{235}U	Uranium-235	✓	x	g
^{238}Pu	Plutonium-238	✓	-	g
^{239}Pu	Plutonium-239	✓	-	g
^{241}Am	Americium-241	✓	-	g

Key:

✓	dominant exposure pathway
S	external dose-rate to skin may need to be considered
x	minor contribution to exposure. Can be ignored
g	minor contribution to exposure from gamma-ray emissions. Can be ignored compared with internal pathway. However, note that if resuspension is not present, a small external dose will be received
-	no exposure from this pathway

a) all radioactive daughters are taken into account

b) Inhalation doss from resuspension

c) Beta and gamma-ray emitters may also give rise to small resuspension doses

2 WHAT HAPPENS TO RADIOACTIVITY WITHIN A DRINKING WATER TREATMENT WORKS?

As Table 1 indicates, the radionuclides considered cover a wide range of chemical elements. Their behaviour within a water treatment works will vary according to the element involved and the chemical processes used during water treatment. There are a number of stages that are used in drinking water treatment and the main process stages are shown in Figure 1. In any given treatment works, the number of these main stages that are used depends on the quality of the raw water. The minimum water treatment used is disinfection, which is appropriate for some deep aquifer sources. For clean sources of water from reservoirs or lakes, flocculation and clarification may not be required and treatment only involves filtration and disinfection. Additional stages in the treatment process are then added as required. Examples are further filtration at the raw water inlet or ion exchange for the removal of nitrates.

The important main treatment processes with respect to removal of radioactivity from the water being treated are:

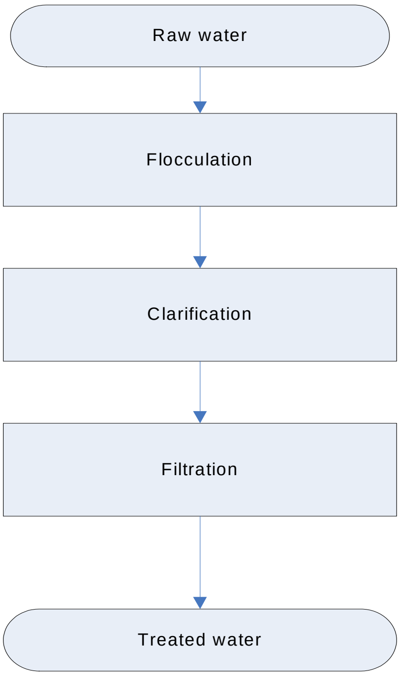
a flocculation and coagulation;
b clarification;
c filtration.

The two main treatment processes that remove radionuclides from the water can be given the general classification of flocculation / clarification and filtration. These processes are discussed in detail in the supporting report.

Flocculation / clarification ⟶ contaminated sludge

Any flocculation / clarification treatment processes will give rise to waste sludge. This is a concentration mechanism as, typically, the amount of sludge produced is small compared with the water throughput of the plant. The amount of sludge produced depends on the quality of the raw input water and its level of turbidity. For a given level of water throughput, higher levels of turbidity will give rise to more sludge per unit volume of water being produced. Conversely, water with low turbidity produces very small amounts of sludge per unit volume of water. 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. It should be noted that, in many cases, where very low levels of sludge are produced, the sludge waste stream often passes directly to local sewage treatment works and the sludge is not handled at the drinking water treatment plant. Further information can be found in Section 2 of the supporting report [Brown et al, 2008].

Figure 1: Main drinking water treatment processes involving chemical removal



Filtration ⟶ contaminated filter bed media

Filtration of water containing radionuclides will give rise to the filter media becoming contaminated. This is also a concentration mechanism as the filter beds will accumulate radioactive contamination over the period that contaminated water passes through them and the activity concentration per unit mass of filter media will increase with time over this period. The levels of contamination will decrease if the filter media are replaced or as a result of activity concentrations decreasing due to radioactive decay. However, 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 can be found in Section 4.2 of the supporting report [Brown et al, 2008].

A scoping calculation can be made to help put the relative importance of contamination of sludge and filter media into context. The activity concentrations in sludge and filter media compared with that in the input water have been estimated based on a throughput of 100 megalitres (Ml) of water, an input activity concentration of 1 Bq l^{-1} and information on the removal of radionuclides from the water by the different treatment processes (Section 3.1). The results are given in Table 2.

It should be noted that if contaminated water continues to flow through rapid gravity filter beds over a significant period of time (about 6 months) at a constant level, and no replenishment of filter media takes place, activity concentrations in the filter media will approach those in sludge. However, this is a very unlikely scenario. For slow sand filters, which are much larger, activity concentrations will always be very small compared to those in the sludge at a given treatment works.

Table 2: Indication of likely relative activity concentrations in sludge and filter media

Treatment process / process combinations	Material[a]	Activity concentration relative to that in input water[b,c]
Input raw water	Water	1
Flocculation/clarification	Sludge	10 000
Rapid gravity filtration (RGF) (following flocculation / clarification[d])	Filter media	50
Slow sand filtration (SSF) (following flocculation / clarification and rapid gravity filtration)	Filter media	1

a) Assumptions: 7000 kg of sludge produced per100 Ml of throughput; typical mass of sand in rapid gravity filters is 720 tonnes per100 Ml of throughput; typical mass of filter media in slow sand filter beds is 32000 tonnes per 100Ml of throughput. Justification of these values can be found in Section 4.2 of the supporting report [Brown *et al*, 2008].

b) Values are broadly applicable for any of the radionuclides considered. Radionuclide specific values can be found in the supporting report (Section 4.2) [Brown *et al*, 2008]

c) In all cases, maximum activity concentrations have been selected. These assume that minimum removal has occurred in any preceding treatment process, where appropriate

d) If contaminated water continues to flow through the filter beds over a significant period of time (about 6 months) at a constant level, and no replenishment of filter media takes place, activity concentrations in the filter media will approach those in sludge.

2.1 What are the potential exposure pathways for operatives?

People could be exposed to radioactive contamination within the treatment works while they are working on either day-to-day tasks or undertaking routine maintenance. Figure 2 shows the most important routes for radionuclide transfer in a treatment works, the different hazards posed and the exposure pathways for humans. The main exposure pathways are as follows:

a external irradiation from gamma-ray emitting radionuclides residing within the treatment works, for example waste sludge or filter media;

b external irradiation from beta emitting radionuclides residing within the treatment works, for example waste sludge or filter media;

c inhalation of contaminated material resuspended into the air from contaminated material residing in the plant, for example sludge being dried in bunkers.

In certain cases, other exposure pathways may warrant consideration. An example could be the inadvertent ingestion of contamination from tasks involving working with sludge or filter media. The likely relative importance of the different exposure pathways is considered further below.

In a radiological emergency a mix of radionuclides might be expected and it is important to determine what the main hazards from the mix of radionuclides are. As shown in Table 1, one type of emission from a radionuclide is usually by far the most important and hence for a single radionuclide one exposure pathway is generally more important than the others. However, there may be cases where other, usually minor, exposure pathways should be considered depending on the incident and the nature of the treatment works and the tasks undertaken. For a mix of radionuclides, the most important exposure pathways for each radionuclide should be considered and, taking into account the amounts of each radionuclide involved, the overall hazards identified and current and projected doses estimated.

Further information on estimating doses is given in Section 4 and in Section 5 of the supporting report [Brown et al, 2008].

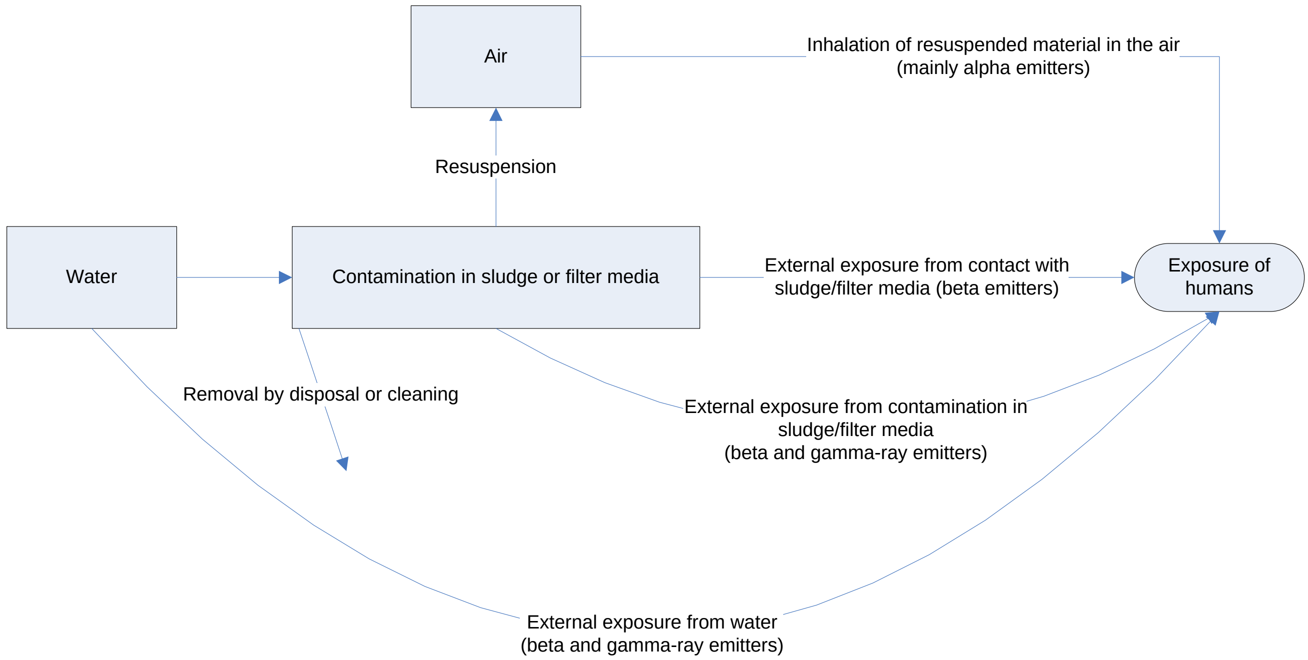


Figure 2: Primary exposure pathways of relevance for drinking water treatment plant operatives after a radiological incident

2.2 What tasks and exposure pathways are likely to be most important in terms of radiation doses to operatives at treatment works?

The tasks and exposure pathways that are likely to be most important in terms of any exposure to contamination within a treatment works need to be identified. This requires an evaluation of the types of tasks undertaken and the proximity of operatives to any contamination left in the works following the throughput of contaminated water. A detailed list of typical tasks undertaken is given in the supporting report. 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 3. 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 the supporting report (Section 5) [Brown et al, 2008].

Table 3 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)
Inspection of backwashing of filter beds	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.

As explained in Section 2.2, within the drinking water treatment process, sludge is the most effective means by which radioactive contamination can become concentrated. Therefore, tasks involving the handling of sludge give rise to the highest radiation exposures per hour of exposure. This is illustrated in Table 4, which gives an indication of the likely ranking of tasks with respect to the radiation doses received per hour of carrying out the task. Other generic tasks give rise to very small doses in comparison.

Table 4: Relative importance of different generic tasks in contributing to radiation exposures

Sludge handled				Sludge not handled			
Gamma-ray emitters[a]		Alpha emitters[a]		Gamma-ray emitters[a]		Alpha emitters[a]	
Task	Relative importance[b]	Task	Relative importance[b]	Task	Relative importance[b]	Task	Relative importance[b]
Working with processed sludge	1	Sludge press work & working with produced sludge	1	Filter media maintenance(rapid gravity) & inspection of back-washing of filters (rapid gravity)	1	Filter media maintenance (rapid gravity) & inspection of back-washing of filters (rapid gravity)	1
Sludge press work	0.7						
Tank cleaning	0.4						
Transporting sludge	0.2						
Maintenance DAF[c]	0.02	Inspection of back-washing of filters & filter media maintenance (rapid gravity)	0.01	General inspection	0.03		
				Other tasks	<0.01		
Other tasks	<0.003	Other tasks	<0.001			Other tasks	<0.0001

a) For gamma-ray emitting radionuclides and alpha emitting radionuclides, see Table 1. For the purposes of this Table, ^{60}Co and ^{239}Pu have been used as examples of gamma-ray emitting and alpha emitting radionuclides, respectively. The relative importance given is, however, broadly applicable to all of the radionuclides in each of the 2 categories.

b) Task giving rise to highest potential dose per hour is given unit of 1.

c Maintenance of floc generic task is only appropriate for dissolved air flotation (AF) plant.

For treatment works that handle waste sludge, tasks involving working with sludge will be the most important in terms of dose rates, ie, the radiation doses per hour of exposure.

If sludge is not handled in the treatment works, then the tasks that give rise to the highest exposures per hour of exposure are those involving the replenishment of filter media and inspection of the back-washing of rapid gravity filters, or, in the case of works only using membrane filters or ion exchange, the replacement of these units. This is also shown in Table 4. These dose rates are, however, at least 100 times lower that the corresponding dose rates received from working with sludge for gamma-ray emitting radionuclides and at least a factor of 10 lower for alpha-emitting radionuclides.

For treatment works that do not handle waste sludge, tasks involving working with filter media (or being exposed to filter media in the case of inspection of backwashing of filters) will be most important in terms of the radiation doses per hour of exposure. BUT these dose rates are at least 10 times lower than the corresponding dose rates from working with sludge.

As shown in Table 1, the most important exposure pathway for gamma-ray emitting radionuclides is external exposure from contaminated material within the treatment works. In contrast, for alpha-emitting radionuclides, exposure arises from material being taken into the body via inhalation or inadvertent ingestion.

For tasks where operatives are not in direct contact with sludge or filter media, operatives will only receive external exposure from being in close proximity to contaminated water or waste floc.

For tasks involving close working with sludge, exposures can be received from inadvertently taking material into the body via inhalation or ingestion as well as from being in close proximity to the sludge. Doses arising from contaminated sludge being on the skin are not significant relative to the other exposure pathways. These doses can in any case be avoided if the normal practice of wearing gloves is followed. Inhalation doses can be minimised by the use of respirators or face masks, if required. Further information can be found on the likely effectiveness of this type of protection and factors that can influence the effectiveness in Section 5.5 of the supporting report [Brown *et al*, 2008]

For sludge handling tasks:

- **external gamma exposure is by far the most important contributor to the total dose for all gamma-emitting radionuclides;**
- **inhalation of resuspended sludge is by far the most important contributor to the total doses for alpha emitting radionuclides (isotopes of U, Pu, Am) and isotopes of Sr IF THE SLUDGE IS DRY;**
- **for operatives working with produced sludge, inadvertent ingestion of sludge is by far the most important contributor to the total doses for isotopes of plutonium IF THE SLUDGE IS WET. For all other radionuclides, external exposure is the most important contributor to the total dose.**

For tasks involving working with filter media, exposures can be received from inadvertently taking material into the body via inhalation as well as from being in close proximity to the filter media. As for working with sludge, any doses arising from contaminated filter media being on the skin are not significant relative to the other exposure pathways and can be avoided if the normal practice of wearing gloves is followed.

For working directly with filter media:

- **external gamma exposure is by far the most important contributor to the total dose for all radionuclides IF THE FILTER MEDIA ARE WET;**
- **inhalation of resuspended filter media is by far the most important contributor to the total doses for alpha emitting radionuclides (isotopes of U, Pu, Am) and Sr isotopes IF THE FILTER MEDIA ARE DRY.**

For inspection of back-washing of rapid gravity filters (FILTER MEDIA ARE WET):

- **external gamma exposure is by far the most important contributor to the total dose for all gamma-emitting radionuclides;**
- **inhalation of resuspended filter media is by far the most important contributor to the total doses for alpha emitting radionuclides (isotopes of U, Pu, Am) and Sr isotopes.**

3 ESTIMATION OF RADIONUCLIDE CONCENTRATIONS IN DRINKING WATER

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. The ranges for these removal efficiency factors are given in Table 5. Activity concentrations in drinking water have been estimated for the two main combinations of drinking water treatment, flocculation / clarification followed by rapid gravity filtration and flocculation / clarification followed by rapid gravity filtration and slow sand filtration; the estimated activity concentrations are given in Table 6. 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, ie, assuming that minimum removal of radioactive contamination occurs at each step during the treatment process.

Table 5: Water Treatment Removal Efficiencies as a function of element and treatment process[a,b]

Element	Flocculation / coagulation / clarification	Sand Filtration[c] (Rapid & Slow)	Activated carbon	Lime-soda Softening[d]	Natural Zeolites (clay minerals)	Ion-exchange[e] (mixed media)	Reverse Osmosis[f]	Key: Removal efficiency, % removed
Cobalt	XXX	XX	XX	X	XX	XXX	XXXX	X = 0 – 10%
Selenium	XXX	XX	XX	X	XXX	XXX	XXXX	
Strontium	XX	XX	X	XXXX[g]	XXX	XXX	XXXX	XX = 10 – 40%
Zirconium	XXXX	XX	XX	X	XXX	XXXX	XXXX	
Niobium	XXXX	XX	XX	X	XXX	XXXX	XXXX	XXX = 40 – 70%
Mol/Technetium	XXX	XXX	XX	X	X	XXX	XXXX	
Ruthenium	XXX	XX	XX	X	XX	XXX	XXXX	XXXX = >70%
Iodine	XX	XX	XXX	X	XX	XXX	XXXX	
Tellurium	XXX	XX	XX	X	XXX	XXX	XXXX	
Caesium	XX	XX	X	XX	XXX	XXX	XXXX	
Barium	XXXX	XXX	XX	X	XXX	XXXX	XXXX	
Lanthanum	XXXX	XXX	XX	X	XXX	XXXX	XXXX	
Cerium	XXXX	XXXX	XX	X	XXX	XXXX	XXXX	
Ytterbium	XXX	XXX	X	X	XX	XXX	XXXX	
Iridium	XXX	XX	XX	X	XX	XXX	XXXX	
Radium	XX	XXX	XX	XXXX[g]	XX	XXXX	XXXX	
Uranium	XXXX	X	XX	XXXX	XXX	XXXX	XXXX	
Plutonium	XXXX	XX	XXX	X	XXX	XXXX	XXXX	
Americium	XXXX	XX	XXX	X	XXX	XXXX	XXXX	

a) 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.

b) 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 the supporting report [Brown *et al*, 2008].

c) The efficiencies reported are for the chemical process of sand filtration and not the mechanical removal of solids.

d) 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.

e) Data for ion exchange assume the use of a mixed cation / anion exchange media.

f) Reverse osmosis does not include microfiltration, used at membrane filtration plants which is solely a physical removal process.

g) 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.

Table 6: Estimated activity concentrations in treated drinking water for 1 Bq l^{-1} in the input water

	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	$1.8\ 10^{-1}$	$1.1\ 10^{-1}$
^{140}La	$1.8\ 10^{-1}$	$1.1\ 10^{-1}$
^{144}Ce	$9.0\ 10^{-2}$	$2.7\ 10^{-2}$
^{169}Yb	$3.6\ 10^{-1}$	$2.2\ 10^{-1}$
^{192}Ir	$5.4\ 10^{-1}$	$4.9\ 10^{-1}$
^{226}Ra	$5.4\ 10^{-1}$	$3.2\ 10^{-1}$
^{235}U	$3.0\ 10^{-1}$	$3.0\ 10^{-1}$
^{238}Pu	$2.7\ 10^{-1}$	$2.4\ 10^{-1}$
^{239}Pu	$2.7\ 10^{-1}$	$2.4\ 10^{-1}$
^{241}Am	$2.7\ 10^{-1}$	$2.4\ 10^{-1}$

a) Assumes minimum removal of radionuclides at each process step (see Table 5 for removal efficiency factors; minimum value in range given has been used).

b) RGF = rapid gravity 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.

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

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

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

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

Where:

F = 1 - (removal efficiency /100) taken from Table 5.

For combinations of processes, care needs to be taken in the use of the removal efficiency factors in Table 5. 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 5. 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

There are a number of important factors to note when using the table of removal efficiency factors (Table 5).

a The values in Table 5 are only for chemical removal. Therefore, any element that is attached to particulate material is not considered, as any removal will be due to physical and not chemical properties. This is discussed further below for sand filtration and microfiltration.

b Sand filtration usually follows a flocculation / coagulation / clarification step. This means that much of the suspended solids present in the raw water are removed during the first stage of the process, thereby preventing the sand filters from becoming too clogged up and not working efficiently. Sand filtration also retains any suspended solids still present after the initial clarification step and these are removed by backwashing for further clarification. The efficiencies reported in Table 5 are for the chemical process of sand filtration and not the mechanical removal of solids. Secondary filtration, such as that used for manganese removal would have the same removal efficiency as the initial filtration.

Reverse osmosis should not be confused with microfiltration, used at membrane filtration plants. Microfiltration removes particles down to a diameter of a few microns. Microfiltration changes none of the chemical properties of the solution passing through the membrane. Any removal will be due to elements being attached to particles and mechanically stopped by the filter (if the particles are sufficiently large). Reverse osmosis can retain ions and molecules with a molar mass of over a few tens of grammes per mole, and so does change the chemical properties of the solution passing through the membrane.

4 ESTIMATING WHAT POTENTIAL DOSES TO OPERATIVES IN DRINKING WATER TREATMENT WORKS COULD BE

It is anticipated that this would be done as part of the planning process.

Step 1

Compile essential information about the treatment works.

General information required about the treatment works
Daily throughput of water, Ml
Treatment processes used and combinations
Number and type of filter beds, eg, rapid gravity filters and slow sand filters
Total area and depth of filter bed media in each type of filter per daily Ml water throughput
Mass of de-watered sludge produced per daily Ml of water throughput [If the amount of sludge produced is variable, it is recommended that a value towards the lower end of the range of values is selected]
Background activity concentrations of radionuclides in drinking water supplies, sludge and filter media.

Step 2

Consider work involving the handling and management of waste sludge. Use the flowchart in Figure 3.

Step 3

Consider work involving the handling and management of used filter media. Use the flowchart in Figure 4.

Step 4

Consider other tasks carried out within the treatment works.

IF Step 2 and Step 3 are not relevant, the only radiation exposures will come from these other tasks.

IF Step 2 AND/OR Step 3 have been considered, additional tasks should be considered for completeness but doses from these tasks are unlikely to be significant compared with those from working with waste sludge or filter media (see Section 2.2).

List other tasks carried out within the treatment works.

Compile information on the time spent on each of these tasks, how often the tasks are carried out and how many staff are involved.

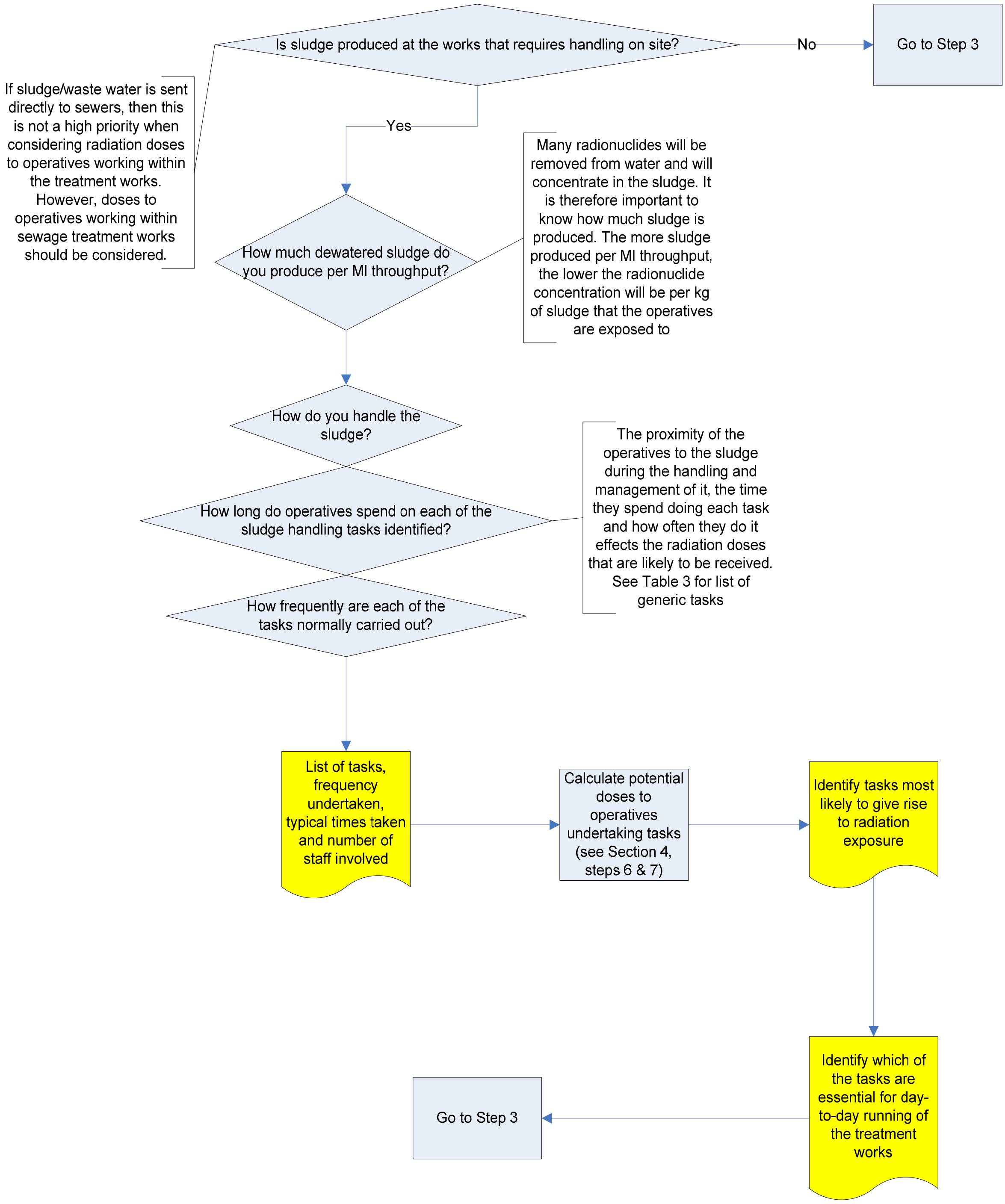


Figure 3: Flow chart for consideration of work with waste sludge (STEP 2)

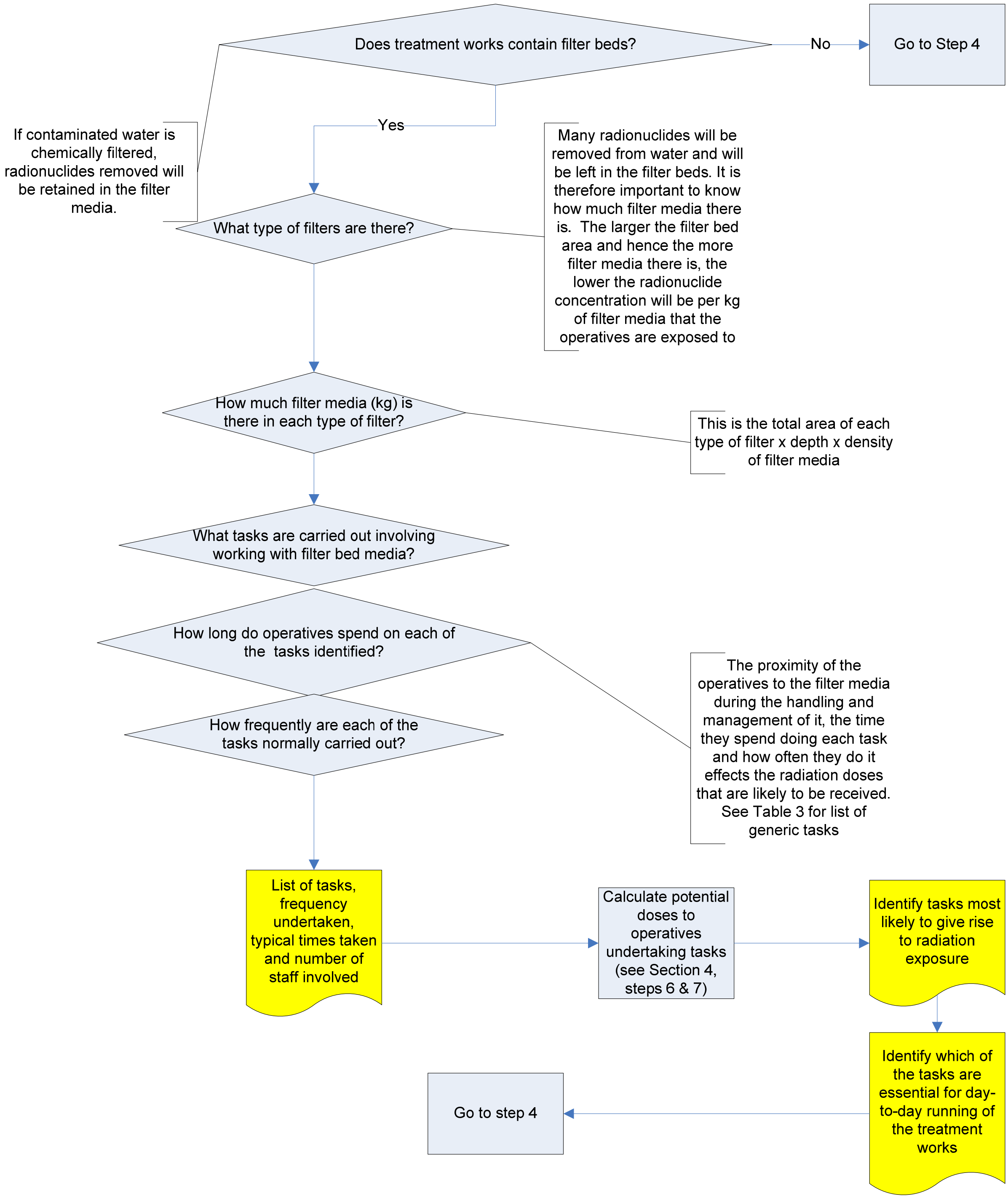


Figure 4: Flow chart for consideration of work with filter media (STEP 3)

Step 5

Match specific tasks identified in Steps 2 - 4 to generic tasks in Table 3 for the purposes of estimating radiation doses. A full description of the exposure situation that has been assumed for each generic task is given in Section 5 of the supporting report [Brown *et al*, 2008]. This information may help in the matching of more unusual tasks to one of the generic tasks.

Step 6

Estimate doses for each 'day-to-day' task for 1 week of operation for a unit activity concentration in the contaminated media being exposed to, ie, water, filter media or sludge.

Estimate doses for each routine maintenance (infrequent) task taking into account the total time taken each time it is carried out for a unit activity concentration in the contaminated media being exposed to, ie. water, filter media or sludge.

For each identified task:

Dose for each task (mSv per Bq kg^{-1} or Bq l^{-1}) = dose factor for relevant generic task (mSv h^{-1} per Bq kg^{-1} or Bq l^{-1}) x hours spent doing task by an individual (h)

Use Table 7 to obtain the dose factor (mSv h^{-1} per Bq kg^{-1} or Bq l^{-1}) in the contaminated medium being exposed to for each generic task.

Use data compiled in steps 2 – 4 for hours spent on each task; hours in 1 week for day-to-day tasks and total hours spent for an infrequent task.

If further information on the breakdown by exposure pathway is required, this information is given in Tables 12 - 20 in Section 5 of the supporting report [Brown *et al*, 2008].

Table 7: Dose factors for generic tasks for a unit contamination in the media operatives are exposed to

	Generic Task, Dose factor (mSv h^{-1}) per unit concentration in contaminated medium being exposed to									
	General maintenance /inspection	Maintenance DAF	Inspection of back-washing of filters	Maintenance filter beds	Cleaning storage tanks	Transport of sludge	Working with processed sludge	Sludge press work	Membrane maintenance	Ion exchange / reverse osmosis unit maintenance
Radionuclide	Bq l^{-1} water	Bq kg^{-1} sludge	Bq kg^{-1} filter media	Bq kg^{-1} filter media	Bq kg^{-1} sludge	Bq kg^{-1} sludge	Bq kg^{-1} sludge	Bq kg^{-1} sludge	Bq l^{-1} water	Bq l^{-1} water
^{60}Co	5.5 10^{-7}	9.1 10^{-9}	5.7 10^{-7}	5.7 10^{-7}	2.0 10^{-7}	1.3 10^{-7}	5.5 10^{-7}	4.0 10^{-7}	3.5 10^{-8}	1.9 10^{-7}
^{75}Se	8.7 10^{-8}	1.6 10^{-9}	6.3 10^{-8}	6.3 10^{-8}	3.9 10^{-8}	1.3 10^{-8}	6.1 10^{-8}	6.5 10^{-8}	8.7 10^{-9}	4.0 10^{-8}
^{89}Sr	1.8 10^{-11}	3.5 10^{-13}	9.1 10^{-11}	9.1 10^{-11}	8.0 10^{-11}	4.9 10^{12}	1.0 10^{-10}	1.0 10^{-10}	1.4 10^{-12}	7.2 10^{-12}
^{90}Sr	6.5 10^{-15}	5.3 10^{-14}	4.3 10^{-10}	4.3 10^{-10}	4.3 10^{-10}	0.0	5.7 10^{-10}	5.7 10^{-10}	3.4 10^{-15}	8.0 10^{-15}
^{95}Zr	1.6 10^{-7}	6.2 10^{-9}	1.5 10^{-7}	1.5 10^{-7}	6.2 10^{-8}	8.0 10^{-8}	1.5 10^{-7}	2.6 10^{-7}	2.5 10^{-8}	1.3 10^{-7}
^{95}Nb	1.6 10^{-7}	3.1 10^{-9}	1.6 10^{-7}	1.6 10^{-7}	6.5 10^{-8}	4.0 10^{-8}	1.6 10^{-7}	1.3$10^{-7}$	1.2 10^{-8}	6.3 10^{-8}
^{99}Mo	6.2 10^{-8}	1.1 10^{-9}	4.7 10^{-8}	4.7 10^{-8}	2.7 10^{-8}	7.4 10^{-9}	4.5 10^{-8}	4.5 10^{-8}	5.9 10^{-9}	2.7 10^{-8}
^{103}Ru	9.8 10^{-8}	1.9 10^{-9}	9.2 10^{-8}	9.2 10^{-8}	4.1 10^{-8}	2.1 10^{-8}	8.9 10^{-8}	7.6 10^{-8}	8.1 10^{-9}	3.9 10^{-8}
^{106}Ru	4.3 10^{-8}	7.8 10^{-10}	4.2 10^{-8}	4.2 10^{-8}	1.8 10^{-8}	9.3 10^{-9}	4.0 10^{-8}	3.2 10^{-8}	3.3 10^{-9}	1.6 10^{-8}
^{132}Te	4.8 10^{-8}	1.6 10^{-9}	3.4 10^{-8}	3.4 10^{-8}	2.2 10^{-8}	1.7 10-$^{-8}$	3.3 10^{-8}	6.5 10^{-8}	7.3 10^{-9}	3.5 10^{-8}
^{131}I	8.1 10^{-8}	9.5 10^{-9}	7.2 10^{-8}	7.2 10^{-8}	3.5 10^{-8}	1.2 10^{-7}	6.9 10^{-8}	3.9 10^{-7}	3.9 10^{-8}	2.0 10^{-7}
^{134}Cs	3.3 10^{-7}	6.1 10^{-9}	3.2 10^{-7}	3.2 10^{-7}	1.3 10^{-7}	7.6 10^{-8}	3.1 10^{-7}	2.5 10^{-7}	2.5 10^{-8}	1.2 10^{-7}
^{136}Cs	4.6 10^{-7}	7.9 10^{-9}	4.6 10^{-7}	4.6 10^{-7}	1.8 10^{-7}	1.0 10^{-7}	4.9 10^{-7}	3.3 10^{-7}	3.2 10^{-8}	1.6 10^{-7}
^{137}Cs	1.3 10^{-7}	2.0 10^{-9}	1.2 10^{-7}	1.2 10^{-7}	5.1 10^{-8}	2.4 10^{-8}	1.2 10^{-7}	8.2 10^{-8}	8.4$10^{-9}$	4.2 10^{-8}
^{140}Ba	5.5 10^{-7}	8.8 10^{-9}	5.6 10^{-7}	5.6 10^{-7}	1.9 10^{-7}	1.2 10^{-7}	5.4 10^{-7}	3.8 10^{-7}	3.5 10^{-8}	1.9 10^{-7}
^{140}La	5.1 10^{-7}	8.1 10^{-9}	5.2 10^{-7}	5.2 10^{-7}	1.9 10^{-7}	1.2 10^{-7}	5.0 10^{-7}	3.6 10^{-7}	3.2 10^{-8}	1.7 10^{-7}
^{144}Ce	1.1 10^{-8}	1.9 10^{-10}	9.8 10^{-9}	9.8 10^{-9}	5.2 10^{-9}	1.8 10^{-9}	9.6 10^{-9}	7.8 10^{-9}	9.5 10^{-10}	4.5 10^{-9}
^{169}Yb	6.5 10^{-8}	1.3 10^{-9}	3.4 10^{-8}	3.4 10^{-8}	3.5 10^{-8}	4.7 10^{-9}	3.3 10^{-8}	3.7 10^{-8}	7.9 10^{-9}	3.2 10^{-8}
^{192}Ir	1.8 10^{-7}	3.2 10^{-9}	1.5 10^{-7}	1.5 10^{-7}	7.5 10^{-8}	3.2 10^{-8}	1.5 10^{-7}	1.3 10^{-7}	1.5 10^{-8}	7.1 10^{-8}
^{226}Ra	3.3 10^{-7}	5.2 10^{-9}	3.8 10^{-7}	3.8 10^{-7}	1.6 10^{-7}	7.9 10^{-8}	3.7 10^{-7}	2.8 10^{-7}	2.1 10^{-8}	1.1 10^{-7}
^{235}U	3.5 10^{-8}	6.8 10^{-10}	5.9 10^{-8}	5.9 10^{-8}	5.3 10^{-8}	3.7 10^{-9}	5.9 10^{-8}	6.2 10^{-8}	4.0 10^{-9}	1.8 10^{-8}
^{238}Pu	1.3 10^{-11}	1.2 10^{-12}	5.5 10^{-7}	5.5 10^{-7}	5.5 10^{-7}	1.1 10^{-13}	5.5 10^{-7}	5.5 10^{-7}	2.7 10^{-12}	7.7 10^{-12}
^{239}Pu	1.5 10^{-11}	6.9 10^{-13}	6.0 10^{-7}	6.0 10^{-7}	6.0 10^{-7}	1.4 10^{-12}	6.0 10^{-7}	6.0 10^{-7}	2.3 10^{-12}	8.3 10^{-12}
^{241}Am	4.4 10^{-9}	1.1 10^{-10}	5.1 10^{-7}	5.1 10^{-7}	5.1 10^{-7}	1.6 10^{-11}	5.1 10^{-7}	5.1 10^{-7}	7.1 10^{-10}	2.6 10^{-9}

HANDBOOK FOR ASSESSING THE IMPACT OF A RADIOLOGICAL INCIDENT ON LEVELS OF RADIOACTIVITY IN DRINKING WATER AND RISKS TO OPERATIVES AT WATER TREATMENT WORKS

<u>Step 7</u>

To identify tasks likely to give rise to the highest exposure, it is necessary to consider all of the doses relative to each other for a given initial contamination in the input water entering the treatment works. This takes into account any partitioning of the contamination within the works. When estimating the doses, conservative values of activity concentrations in the materials that are being exposed to have been used. These have been calculated by using the maximum values from the ranges of efficiency factors for the treatment step giving rise to the contaminated material being exposed to and minimum values from the ranges of efficiency factors for the treatment steps occurring before the one of interest. This is explained further in Section 4.2 of the supporting report, where equations are given to assist the user estimate activity concentrations in the various waste materials within a treatment works [Brown *et al*, 2008].

Estimate doses for each 'day-to-day' task for 1 week of operation for a unit activity concentration in the input water.

Estimate doses for each routine maintenance (infrequent) task taking into account the total time taken each time it is carried out for a unit activity concentration in the input water.

The doses that are being compared are calculated assuming that there is a continuous input of water at a contamination of 1 Bq l^{-1} for duration of 1 week. It is assumed that doses received from day-to day tasks occur over the whole week and no allowance is made of any initial delay between the contamination entering the works and the contamination reaching the material that the individual is exposed to. For infrequent tasks, the implicit assumption is that the operative will be exposed to the contamination level in the medium at the end of 1 week, which, in the case of working with filter media, will be the accumulated contamination from 1 week of water passing through the filters. No account is taken of any radioactive decay between the end of the week and the time when the task is undertaken; the estimates of doses may therefore be conservative for some radionuclides.

Option 1:

This option uses default values for the following parameters:

a water throughput;
b amounts of sludge produced per Ml of water throughput;
c estimated quantities of filter media used per Ml of water throughput.

It is advised that this option should only be used for outline scoping calculations where data for the above parameters are not available for a specific treatment works.

For each identified task:

Use data compiled in steps 2 – 4 for hours spent on each task by an individual; hours in 1 week for day-to-day tasks and total hours spent for an infrequent task. If data on the hours spent on each of the tasks are not available, some generic values are given in Table 7 in the supporting report [Brown *et al*, 2008].

The duration of water throughput (F_W) is 7 days, ie, $F_W = 7$

Use Table 8 to obtain the dose factor (mSv h^{-1} per Bq l^{-1}) in the contaminated input water for each generic task.

<u>For tasks involving exposure to contaminated water or sludge:</u>

Dose for each task (mSv per Bq l^{-1}) = dose factor for relevant generic task (mSv h^{-1} per Bq l^{-1}) x hours spent doing task by an individual (h)

<u>For tasks involving exposure to contaminated filter media</u>:

Dose for each task (mSv per Bq l^{-1}) = dose factor for relevant generic task (mSv h^{-1} per Bq l^{-1}) x F_W x hours spent doing task by an individual (h)

Option 2 (preferred option):

- Calculate scaling factors to modify the generic dose-rates given in Table 8 to take account of water throughput, amounts of sludge produced and amount of filter media.

Scaling factor for throughput of water in period contaminated water enters the treatment works: default value of 7 days (F_W) = 7

Scaling factor for sludge produced (F_{SL}) = 70 / amount of sludge produced / Ml of water (kg).

Scaling factor for amount of filter media in rapid gravity filters (F_{RGF}) = 7.2 10^3 / mass of filter media (kg) per Ml throughput.

Scaling factor for amount of filter media in slow sand filters (F_{SSF}) = 3.2 10^5 / mass of filter media (kg) per Ml throughput.

Where mass of filter media = total area of filter beds (m^2) x depth (m) x density (kg m^{-3}) per Ml throughput. Density of sand is assumed for all calculations.

- Calculate doses for each identified task

For all tasks, use data compiled in steps 2 – 4 for hours spent on each task; hours in 1 week for day-to-day tasks and total hours spent for an infrequent task.

Use Table 8 to obtain the dose factor (mSv h^{-1} per Bq l^{-1}) in the contaminated input water for each generic task.

<u>For tasks involving exposure to contaminated water:</u>

Dose for each task (mSv per Bq l^{-1}) = dose factor for relevant generic task (mSv h^{-1} per Bq l^{-1}) x hours spent doing task by an individual (h)

<u>For tasks involving exposure to contaminated sludge</u>:

Dose for each task (mSv per Bq l^{-1}) = dose factor for relevant generic task (mSv h^{-1} per Bq l^{-1}) x hours spent doing task by an individual (h) x F_{SL}

<u>For tasks involving exposure to contaminated filter media (RGF only)</u>:

Dose for each task (mSv per Bq l^{-1}) = dose factor for relevant generic task (mSv h^{-1} per Bq l^{-1}) x hours spent doing task by an individual (h) x F_{RGF} x F_W

<u>For tasks involving exposure to contaminated filter media (SSF)</u>:

Dose for each task (mSv per Bq l^{-1}) = dose factor for relevant generic task (mSv h^{-1} per Bq l^{-1}) x hours spent doing task by an individual (h) x F_{SSF} x F_W

<u>Step 8</u>

Using results calculated in Step 7, proceed as follows.

- Identify those tasks that are likely to give rise to the highest radiation doses within the normal operation on the treatment works.
- Identify the radionuclides that are likely to give rise to the highest radiation doses.
- Identify the exposure pathways likely to the most significant for those tasks that give rise to the highest radiation doses using the information in Section 2.1.
- Estimate the potential dose to a notional individual carrying out all of the day-to-day tasks in a week. For the purposes of this Handbook, this individual is called the *'critical individual'*. This value provides a conservative estimate of the dose that could be received by an individual who carries out all of the day-to-day tasks identified. It is then very unlikely that any individual working at the treatment works will receive a radiation dose higher than this value, and likely that most if not all operatives will receive lower doses. It is, therefore, a useful quantity that can be determined during planning and used when estimating potential doses in the event of a radiological incident. It should be noted that doses can only be added over tasks when they are normalised to the same activity concentration, in this case 1 Bq l^{-1} in the input water.

Table 8: Dose factors for generic tasks for an input activity concentration of 1 Bql^{-1} entering the treatment works

Radionuclide	Generic Task, Dose factor (mSv h^{-1}) per Bq l^{-1} in the input water[a,b,c] General maintenance / inspection[d]	Maintenance DAF[e]	Inspection of back-washing of filters	Maintenance filter beds[f] RGF	SSF	Cleaning storage tanks[e]	Transport of sludge[e]	Working with processed sludge[e]	Sludge press work[e]	Membrane maintenance[d]	Ion exchange / reverse osmosis unit maintenance[d]
^{60}Co	5.5 10^{-7}	9.1 10^{-5}	1.9 10^{-5}	1.9 10^{-5}	4.3 10^{-8}	2.0 10^{-3}	1.3 10^{-3}	5.5 10^{-3}	4.0 10^{-3}	3.5 10^{-8}	1.9 10^{-7}
^{75}Se	8.7 10^{-8}	1.6 10^{-5}	2.1 10^{-6}	2.1 10^{-6}	4.7 10^{-9}	3.9 10^{-4}	1.3 10^{-4}	6.1 10^{-4}	6.5 10^{-4}	8.7 10^{-9}	4.0 10^{-8}
^{89}Sr	1.8 10^{-11}	2.0 10^{-9}	4.6 10^{-9}	4.6 10^{-9}	1.0 10^{-11}	4.0 10^{-8}	2.8 10^{-8}	5.9 10^{-7}	5.8 10^{-7}	1.4 10^{-12}	7.2 10^{-12}
^{90}Sr	6.5 10^{-15}	3.0 10^{-10}	2.2 10^{-8}	2.2 10^{-8}	4.9 10^{-11}	3.7 10^{-11}	0.0	3.3 10^{-6}	3.3 10^{-6}	3.0 10^{-15}	7.7 10^{-15}
^{95}Zr	1.6 10^{-7}	8.9 10^{-5}	2.6 10^{-6}	2.6 10^{-6}	5.8 10^{-9}	8.9 10^{-4}	1.1 10^{-3}	2.1 10^{-3}	3.7 10^{-3}	2.5 10^{-8}	1.3 10^{-7}
^{95}Nb	1.6 10^{-7}	4.5 10^{-5}	2.7 10^{-6}	2.7 10^{-6}	6.0 10^{-9}	9.2 10^{-4}	5.7 10^{-4}	2.2 10^{-3}	1.8 10^{-3}	1.2 10^{-8}	6.3 10^{-8}
^{99}Mo	6.2 10^{-8}	1.1 10^{-5}	2.7 10^{-6}	2.7 10^{-6}	2.4 10^{-8}	2.7 10^{-4}	7.4 10^{-5}	4.5 10^{-4}	4.5 10^{-4}	5.9 10^{-9}	2.7 10^{-8}
^{103}Ru	9.8 10^{-8}	1.9 10^{-5}	3.1 10^{-6}	3.1 10^{-6}	6.9 10^{-9}	4.1 10^{-4}	2.1 10^{-4}	8.9 10^{-4}	7.6 10^{-4}	8.1 10^{-9}	3.9 10^{-8}
^{106}Ru	4.3 10^{-8}	7.8 10^{-6}	1.4 10^{-6}	1.4 10^{-6}	3.1 10^{-9}	1.8 10^{-4}	9.3 10^{-5}	4.0 10^{-4}	3.2 10^{-4}	3.3 10^{-9}	1.6 10^{-8}
^{132}Te	4.8 10^{-8}	1.6 10^{-5}	1.1 10^{-6}	1.1 10^{-6}	2.5 10^{-9}	2.2 10^{-4}	1.7 10^{-4}	3.3 10^{-4}	6.5 10^{-4}	7.3 10^{-9}	3.5 10^{-8}
^{131}I	8.1 10^{-8}	5.4 10^{-5}	3.6 10^{-6}	3.6 10^{-6}	8.1 10^{-9}	2.0 10^{-4}	6.6 10^{-4}	4.0 10^{-4}	2.2 10^{-3}	3.9 10^{-8}	2.0 10^{-7}
^{134}Cs	3.3 10^{-7}	3.5 10^{-5}	1.6 10^{-5}	1.6 10^{-5}	3.6 10^{-8}	7.5 10^{-4}	4.4 10^{-4}	1.8 10^{-3}	1.4 10^{-3}	2.5 10^{-8}	1.2 10^{-7}
^{136}Cs	4.6 10^{-7}	4.5 10^{-5}	2.3 10^{-5}	2.3 10^{-5}	5.1 10^{-8}	1.0 10^{-3}	5.7 10^{-4}	2.8 10^{-3}	1.9 10^{-3}	3.2 10^{-8}	1.6 10^{-7}
^{137}Cs	1.3 10^{-7}	1.2 10^{-5}	6.1 10^{-6}	6.1 10^{-6}	1.4 10^{-8}	2.9 10^{-4}	1.4 10^{-4}	6.8 10^{-4}	4.7 10^{-4}	8.4 10^{-9}	4.2 10^{-8}
^{140}Ba	5.5 10^{-7}	1.3 10^{-4}	1.6 10^{-5}	1.6 10^{-5}	1.5 10^{-7}	2.7 10^{-3}	1.8 10^{-3}	7.7 10^{-3}	5.5 10^{-3}	3.5 10^{-8}	1.9 10^{-7}
^{140}La	5.1 10^{-7}	1.2 10^{-4}	1.5 10^{-5}	1.5 10^{-5}	1.4 10^{-7}	2.7 10^{-3}	1.7 10^{-3}	7.2 10^{-3}	5.1 10^{-3}	3.2 10^{-8}	1.7 10^{-7}
^{144}Ce	1.1 10^{-8}	2.7 10^{-6}	4.1 10^{-7}	4.1 10^{-7}	6.4 10^{-9}	6.7 10^{-5}	2.6 10^{-5}	1.4 10^{-4}	1.1 10^{-4}	9.5 10^{-10}	4.5 10^{-9}
^{169}Yb	6.5 10^{-8}	1.3 10^{-5}	2.0 10^{-6}	2.0 10^{-6}	1.8 10^{-8}	3.5 10^{-4}	4.7 10^{-5}	3.3 10^{-4}.	3.7 10^{-4}	7.9 10^{-9}	3.2 10^{-8}
^{192}Ir	1.8 10^{-7}	3.2 10^{-5}	5.1 10^{-6}	5.1 10^{-6}	1.1 10^{-8}	7.5 10^{-4}	3.2 10^{-4}	1.5 10^{-3}	1.3 10^{-3}	1.5 10^{-8}	7.1 10^{-8}
^{226}Ra	3.3 10^{-7}	2.9 10^{-5}	3.3 10^{-5}	3.3 10^{-5}	3.0 10^{-7}	7.0 10^{-4}	4.5 10^{-4}	2.1 10^{-3}	1.6 10^{-3}	2.1 10^{-8}	1.1 10^{-7}
^{235}U	3.5 10^{-8}	9.7 10^{-6}	2.5 10^{-7}	2.5 10^{-7}	0.0	2.3 10^{-4}	5.2 10^{-5}	8.4 10^{-4}	8.9 10^{-4}	4.0 10^{-9}	1.8 10^{-8}
^{238}Pu	1.3 10^{-11}	1.8 10^{-8}	9.2 10^{-6}	9.2 10^{-6}	2.1 10^{-8}	1.6 10^{-7}	1.6 10^{-9}	7.9 10^{-3}	7.9 10^{-3}	2.7 10^{-12}	7.7 10^{-12}
^{239}Pu	1.5 10^{-11}	9.8 10^{-9}	1.0 10^{-5}	1.0 10^{-5}	2.3 10^{-8}	1.3 10^{-7}	2.0 10^{-8}	8.6 10^{-3}	8.6 10^{-3}	2.3 10^{-12}	8.3 10^{-12}
^{241}Am	4.4 10^{-9}	1.6 10^{-6}	8.4 10^{-6}	8.4 10^{-6}	1.9 10^{-11}	3.9 10^{-8}	2.2 10^{-7}	7.2 10^{-3}	7.2 10^{-3}	7.1 10^{-10}	2.6 10^{-9}

1. Assumes 100 Ml throughput of water. Flocculation/clarification followed by filtration is assumed.
2. Efficiency factors for removal of radionuclides from water have been chosen for flocculation / clarification and filtration that give rise to the maximum activity concentrations in sludge and filter media.
3. Further information on the assumptions made and the calculations can be found in the supporting report.
4. For tasks where operatives are exposed to water, it is assumed the activity concentration in the water is the same as that in the input water (1 Bq l^{-1})
5. For sludge related tasks it is assumed that 70 kg of sludge is produced per Ml throughput.
6. A total mass of filter media has been assumed per Ml throughput. For rapid gravity filters (RGF) this is assumed to be 7200 kg; for slow sand filters (SSF) this is assumed to be 320,000 kg.

4.1 Worked example for a notional works

A worked example is included for a notional drinking water treatment works to illustrate how a user should work through steps 1 - 8 for any specific treatment works. Doses have been estimated for 2 radionuclides, ^{60}Co and ^{239}Pu. The worked example is given in Appendix A.

5 IDENTIFYING RISKS TO OPERATIVES IN THE EVENT OF AN INCIDENT

The identification of risks to operatives involves the estimation of radiation exposures. These relate to the doses of radiation that could be received by the operatives in the future as a result of normal working. These estimated doses then need to be placed into context to support the management of the situation, and a system of guidance levels has been developed for this purpose. The derivation of the guidance levels on doses for operatives is described in Section 6 of the supporting report [Brown *et al*, 2008]. Briefly however, the primary guidance level is 2 mSv in a year, but since many common tasks are carried out on a weekly basis a secondary guidance level of 0.1 mSv in a week has also been adopted.

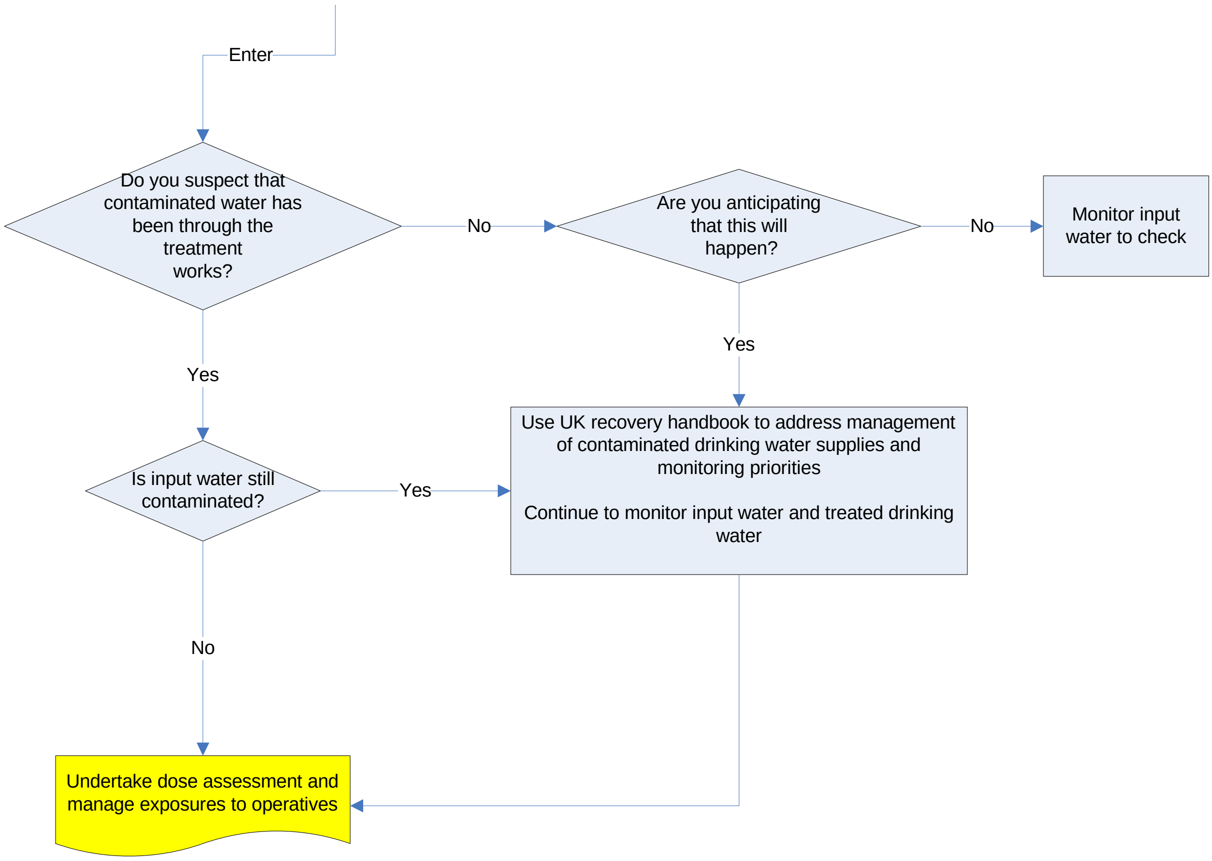
In order to provide a generic tool to aid the water industry assess and manage the potential radiation exposures to operatives working in a drinking water treatment works, three scenarios have been considered. For each scenario the user is taken through the steps involved and guidance is given on the factors that need to be considered.

In Appendix B, a worked example is provided for each scenario to illustrate how to use the Handbook. It should be emphasised that **the worked examples provided for each scenario 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 generic contamination scenarios listed below.

The three scenarios are as follows.

1. It is suspected or known that contaminated water has passed through the treatment works. No measurements in input or output water are available.
2. Contaminated water has passed through the treatment works and measurements indicate that the input water is still contaminated.
3. It is suspected that contaminated water is going to pass through the treatment works in the near future, for example an airborne release from a nuclear reactor that has deposited radioactive material on to the water catchment area.

The early stages of managing the actual or potential incident are shown in the scheme below.



5.1 Scenario 1: contaminated water has passed through treatment works, input water is no longer contaminated; no measurements are available

Text in blue indicates that supporting information is available to assist users undertake the calculations required. Guidance is given in Section 6.

Step 1: Prioritise sampling within the treatment works If waste sludge handled on the site the highest priority is to measure activity concentrations in the sludge at the points that it is handled. If treatment works contains rapid gravity filters and their back-washing is checked on a day-to-day basis, measure activity concentrations in the filter media. Consider reducing the time spent on inspections / stopping them until further information is available.	Doses may have been received by the operatives as the contaminated water passed through the plant. Contamination may remain in the works, primarily in sludge and filter media (see Section 2). The highest priority is, therefore, to assess and control any further doses that could be received by operatives due to routine day-to-day tasks. If routine maintenance is imminent and it is difficult to delay this, the assessment of doses to operatives undertaking these tasks is the next priority. Any future doses from routine inspection and water testing are likely to be very low as the contaminated water and any associated floc has already passed

If any routine maintenance is imminent (within a few days) that involves working with sludge or filter bed media and it cannot be delayed, the next priority is to measure activity concentrations in the filter bed media or sludge that the operatives will be working with or will be close to. For longer term maintenance tasks, go to step 9.	through the plant. Therefore, these tasks can continue as normal as the risks of any exposure, if any, are very low. However, doses from inspection of the back-washing of rapid gravity filters should be considered separately as this task can potentially give rise to inhalation doses over the longer term due to accumulation of contamination in the filter media over the duration of the incident. Exposure will continue until the filter media are replenished / replaced or the activity concentrations reduce due to radioactive decay. This pathway is only of potential concern if contamination contains alpha-emitting radionuclides (see Table 1).
Step 2: Using measured activity concentrations, estimate potential future doses from tasks identified in Step 1 for 1 week of exposure for a *'critical individual'* (see user assistance 1). If alpha emitting radionuclides are measured, include estimates of potential future doses from the inspection of back-washing of rapid gravity filters. If urgent routine maintenance tasks need to be carried out, estimate doses from these tasks.	This step is based on cautious, default assumptions. The doses calculated as part of emergency planning assume that the activity concentration in each contaminated material is at a constant level for 1 week and that day-to-day tasks are carried out for 1 week with operatives being exposed to this contamination. Doses from routine maintenance tasks are estimated by assuming that the activity concentration remains constant for the length of time that the maintenance takes place. For routine maintenance tasks involving sludge or filter bed media, the contamination is static within the environment where the maintenance is taking place. It is therefore reasonable to assume that operatives will be exposed to this contamination throughout the length of the maintenance task. Future doses are only likely to be received from most day-to-day tasks over a short period and, indeed, may not be received at all if the contamination passed through the works a while ago. However, if inspection of the back-washing of rapid gravity filters is undertaken, this task can potentially give rise to inhalation doses over the longer term due to accumulation of contamination in the filter media. This pathway is only of potential concern if the contamination contains alpha-emitting radionuclides (see Table 1).
Step 3: As a first screening, check to see if the dose to the *'critical individual'* from the identified tasks is > 0.1 mSv in a week. For any urgent routine maintenance	If the same individuals undertake day-to-day tasks and the identified urgent routine maintenance task, the doses from both of these activities should be summed and it should be checked that the individual does not receive more than 2 mSv in a year.

tasks, check if the dose an individual receives from carrying out this task is > 2 mSv in a year. ➢ If the doses are lower than the guidance levels, go to Step 4. ➢ If the doses are higher than the guidance levels, go to Step 6.	
Step 4: Doses are lower than the guidance levels given in Step 3. ➢ For day-to-day tasks involving working with sludge, continue tasks as normal but ensure that activity concentrations are measured in the sludge over the next 7-14 days to check that the situation does not worsen. Consider possible ways to reduce doses to individuals to provide reassurance to the operatives. ➢ For day-to-day inspection of back-washing of rapid gravity filters, continue task as normal but measure activity concentrations in the filter media to check that the situation does not worsen and to monitor any decrease in activity concentrations. Consider ways to reduce the time spent undertaking this task to provide reassurance to the operatives. Consider bringing the replacement of filter media forward. ➢ For routine maintenance tasks involving working with sludge or filter bed media, continue planned maintenance but ensure that activity concentrations are measured in the appropriate media prior to undertaking the maintenance and reassess doses to operatives if activity concentrations have changed. Consider possible ways to reduce doses to individuals to provide	<u>Doses < 0.1 mSv in a week</u> As most day-to-day tasks are only likely to give rise to doses over a short period of time, if doses are lower than 0.1 mSv assuming a week of exposure at constant levels of contamination, it is likely that the actual doses will be lower than those estimated. For inspection of back-washing of rapid gravity filters, very conservative assumptions that have been made in estimating potential doses. It is therefore very likely that the actual doses will be lower than those estimated. It is reasonable, therefore, on radiological protection grounds, to continue operation of these day-to-day tasks. Operatives will require reassurance and so a suitable monitoring programme needs to be put in place to support the decision to continue normal practices and to provide reassurance. If simple changes can be made to the working practices to reduce any further doses to operatives, then these should be considered. The Water Company may wish to seek specialist radiation protection advice. However, this is not urgent. <u>Doses < 2 mSv in a year</u> For day-to-day tasks that will not give rise to a dose higher than 2 mSv in a year, tasks can also continue as normal. The Water Company should consider seeking specialist radiation protection advice. For planned routine maintenance tasks that are urgent, if the potential doses are lower than 2 mSv (taking into account any additional doses operatives may have from day-to-day tasks in the short term) the planned maintenance can go ahead. The Water Company should consider seeking specialist radiation protection advice.

reassurance to the operatives. Go to step 7.	
Step 5: If the dose to a critical individual from undertaking the identified day-to-day tasks in Step 1 is higher than 0.1 mSv in a week then carry out the following. ➢ Recalculate doses to specific individuals / groups of operatives with similar jobs using best estimates of how long individuals spend on each tasks and how long the operatives are likely to be working with contaminated sludge (see user assistance 2). ➢ For inspection of back-washing of rapid gravity filters take account of the time operatives may be exposed for, ie, time until next planned replenishment / replacement of filter media (see user assistance 2). Check to see if the doses to individuals undertaking any of the identified day-to-day tasks are > 2mSv in a year. ➢ If the doses are higher than 2 mSv in a year, go to Step 6. ➢ If the doses are lower than 2 mSv in a year, go to Step 4. If the doses from tasks for routine maintenance tasks involving working with sludge or filter bed media are higher than 2 mSv in a year, go to Step 6.	For day-to-day tasks involving the management of produced sludge, the contaminated sludge has a finite length of time on site and will soon either become highly diluted by uncontaminated sludge or will be removed from the site. For day-to-day inspection of the back-washing of rapid gravity filters, operatives can potentially continue to be exposed over a long period as contamination will remain in the filters until the filter media is replaced or contamination levels reduce due to radioactive decay.
Step 6: Seek specialist radiation protection advice urgently. Stop undertaking non-urgent tasks until specialist advice is available. Look at ways to reduce exposures to operatives carrying out tasks giving	The Water Company will need specialist radiation protection advice. The measures put in place to reduce doses to the operatives will depend on how high the predicted potential weekly doses are and how long these doses

the highest doses while awaiting specialist advice. These would include the following. ➢ Delaying undertaking tasks. ➢ Changing working practices, eg, reducing hours for each individual, wearing respirators for dusty tasks.	are likely to continue. Specialist advice is needed. Delaying the undertaking of a task can lead to significant reductions in the doses that would be received by operatives for radionuclides with short radioactive half-lives. Table 9 provides information on how activity concentrations in the contaminated media will reduce with time due to radioactive decay. Reducing the time any individual is exposed to the contaminated material reduces the exposures pro rata. If alpha emitting radionuclides are present, then the use of respirators will reduce the exposure from inhalation which is the dominant contributor to the doses if operatives are working with dry material. Further information on the use of respirators and the problems associated with their use can be found in the supporting report [Brown *et al*, 2008].
Step 7: Estimate doses that have already been received by operatives undertaking tasks prior to the Water Company becoming aware that the incident had occurred (see user assistance 3).	These estimates will only give a very broad indication of the doses that operatives may have received for both day-to-day task and any maintenance tasks that have taken place. This is because activity concentrations in the input water during the incident and the period of time over which the contaminated water entered the works are not known. It is important, however, to try to estimate these doses for reassurance purposes. In addition, they need to be taken into account when assessing overall impact, which would include any potential future doses that may be received by operatives. The most robust approach is to use measured activity concentrations in filter bed media. Filter media act as an integrator of all the contaminated water that has passed through the plant. Using information on the likely length of the incident and the throughput of water, a very crude estimate can be made of the average activity concentration in the input water up to the time the filter bed media are measured. If the duration over which contamination entered the works is not known, 1 week should be assumed which is likely to be conservative for this scenario. The use of measured activity concentrations in sludge is more problematic. It may not be possible to collect samples of sludge that represent the period over which contamination was passing through the works, since several days production may already have been mixed in any sludge storage facility.

	This could include uncontaminated sludge from both before and after the 'incident'. It should be recognised that estimating doses that have been received in the past using this approach involves making a number of modelling assumptions and so this process will only give very broad order of magnitude estimates of radiation doses. For works where sludge is not handled and chemical filtration is not used, ie, there are no other measurements available in filter media or waste sludge, it will not be possible to estimate the doses that may have been received. These are, however, very unlikely to be of concern. Note that if maintenance tasks have taken place, this may significantly reduce or prevent any future doses being received, ie, if sludge tanks have been cleaned out or filter bed media have been replenished.
Step 8: Estimate doses from any other future maintenance tasks involving sludge or filter media and any other maintenance tasks that could give rise to doses to operatives using measured activity concentrations (see user assistance 4). Consider ways to reduce doses for reassurance purposes. If doses are of concern (> 2 mSv in a year) go to Step 6.	For other types of treatment works, eg, membrane plants or works that pump water from underground aquifers and undertake minimum additional treatment or for works with less common treatment steps such as ion exchange, there may be other maintenance tasks that could give rise to doses to operatives. Doses for any maintenance tasks other than those involving sludge and filter media are unlikely to be of concern. For list of some other possible maintenance tasks, see Table 10. When estimating doses from these additional maintenance tasks, it is important to take account of whether the individuals undertaking these tasks also carry out day-to-day tasks. The doses from all the activities an individual undertakes should be summed before comparing with the guidance level.

5.2 Scenario 2: contaminated water has passed through treatment works, measurements indicate that the input water is still contaminated.

Text in blue indicates that supporting information is available to assist users undertake the calculations required. Guidance is given in Section 6.

Step 1: Prioritise sampling within the treatment works. If waste sludge handled on the site the highest priority is to measure activity concentrations in the sludge at the points it is handled. If measurements in water indicate that alpha emitting radionuclides are present and inspection of the back-washing of rapid gravity filters takes place, a high priority is to measure activity concentrations in the filter media. Consider stopping or reducing the inspection if possible until further information on potential doses to operatives is available. Continue to measure activity concentrations in input water. Any imminent routine maintenance (within a few weeks) that involves working with sludge or filter bed media, should be delayed if at all possible. If it is not possible, the next priority is to measure activity concentrations in the filter bed media or sludge that the operatives will be working with or close to. For longer term maintenance tasks, go to step 8.	Doses may have been received by the operatives as the contaminated water passed through the plant. Doses may continue to be received by operatives undertaking day-to-day tasks. Contamination will remain in the works, primarily in sludge and filter media during the remainder of the time the contaminated input continues and is likely to remain in the works subsequently for some time (see Section 2). The highest priority is, therefore, to assess and control any further doses that could be received by operatives due to routine day-to-day tasks. If routine maintenance is imminent and it is difficult to delay this, the assessment of doses to operatives undertaking these tasks is the next priority.
Step 2: Using measured activity concentrations, estimate potential future doses from tasks identified in Step 1 for 1 week of exposure for a *'critical individual'* (see user assistance 1). If alpha emitting radionuclides are	Activity concentrations in sludge should be used in preference to those in the input water for estimating future doses from sludge related tasks. Note that for some tasks the operatives may be exposed to contaminated sludge after contaminated water has stopped entering the works, eg, for tasks involving handling processed sludge and transporting it off site.

measured, include estimates of potential future doses from the inspection of back-washing of rapid gravity filters. If urgent routine maintenance tasks need to be carried out, estimate doses from these tasks. If you suspect that the contaminated water will continue to enter the works for more than 4-5 months, the estimated *'critical individual'* dose for day-to-day tasks should also be calculated for the potential duration of contamination entering the works (see user assistance 2).	Regular measurements in sludge should be made until it is known that the input water is no longer contaminated. It should be noted that care is needed to ensure that the measurements in sludge that are made are those in the sludge that has been produced from the contaminated water entering the works. This will provide a conservative approach for tasks where operatives may be exposed to sludge that has been produced over a period significantly longer than the duration of the incident, eg, working with stored sludge. Activity concentrations in filter media should be used for estimating doses from tasks where operatives are exposed to contaminated filter media. The activity concentration in the input water should be used for estimating doses from tasks where operatives are exposed to contaminated water and can be used as a supplementary check for doses from sludge related tasks or if measurements of activity concentrations in sludge are not yet available. The doses calculated as part of emergency planning assume that the activity concentration in each contaminated material is at a constant level for 1 week and that day-to-day tasks are carried out for 1 week with operatives being exposed to this contamination. Doses from routine maintenance tasks are estimated by assuming that the activity concentration remains constant for the length of time the maintenance takes place. For routine maintenance tasks involving sludge or filter bed media, the contamination is static within the environment where the maintenance is taking place. It is therefore reasonable to assume that operatives will be exposed to this contamination throughout the length of the maintenance task. This is also the case for day-to-day inspection of the back-washing of rapid gravity filters, where operatives can potentially continue to be exposed over a long period as contamination will remain in the filters until the filter media is replaced or contamination levels reduce due to radioactive decay. Doses should be adjusted if it is believed that contaminated water may continue to enter the works for periods longer than 4 - 5 months.

Step 3: As a first screening, check to see if the dose to the *'critical individual'* from the identified tasks is > 0.1 mSv in a week. If the doses have been adjusted because it is expected that contamination will enter the works for more than 4-5 months, check to see if the dose to the 'critical individual' from the identified tasks is > 2 mSv in a year. For any urgent routine maintenance tasks that cannot be delayed, check if the dose an individual receives from carrying out this task is > 2 mSv in a year. ➢ If the doses are lower than the guidance levels go to Step 4. ➢ If the doses are higher than the guidance levels, go to Step 6.	
Step 4: Doses are lower than the guidance levels given in Step 3. For day-to-day tasks involving working with sludge, continue tasks as normal but ensure that activity concentrations are measured in the sludge over the next 7-14 days (or the duration of the incident) to check that the situation does not worsen. The Water Company should consider seeking specialist radiation protection advice. Consider possible ways to reduce doses to individuals to provide reassurance to the operatives. If day-to-day inspection of back-washing of rapid gravity filters is included in the *'critical individual'* dose, continue task as normal but recalculate the dose from this task taking into account how long it will be before the next planned replacement of filter media (see user assistance 2). Check if the dose from this task is >	<u>Doses < 0.1 mSv in a week</u> As the assumption has been made that all the sludge is contaminated at a constant level for a week (or longer), it is unlikely that the doses have been significantly underestimated. It is reasonable, therefore, on radiological protection grounds, to continue operation of these tasks. Operatives will require reassurance and so a monitoring programme needs to be put in place to support the decision to continue normal practices and to provide reassurance. If working practices can be changed to minimise further any doses to operatives, this should be considered. Further measurements in sludge at the points where operatives come into contact with it need to be made throughout the duration of the incident and subsequently to ensure that activity concentrations do not increase. The Water Company may wish to seek specialist radiation protection advice; however, this is not urgent. <u>Doses < 2 mSv in a year</u> For day-to-day tasks that will not give rise to a dose higher than 2mSv in a year, tasks can also continue as

2 mSv in a year. ➢ If the recalculated dose from inspection of backwashing is > 2 mSv in a year, go to Step 6. ➢ If the recalculated dose from inspection of backwashing is < 2 mSv in a year, continue to measure activity concentrations in the filter media to check that the situation does not worsen and to monitor any decrease in activity concentrations to support the dose estimate. Consider ways to reduce the time spent undertaking this task to provide reassurance to the operatives. Consider bringing the replacement of filter media forward. The Water Company should consider seeking specialist radiation protection advice. For routine maintenance tasks involving working with sludge or filter bed media, continue planned maintenance but ensure that activity concentrations are measured in the appropriate media prior to undertaking the maintenance and reassess doses to operatives if activity concentrations have changed. Consider possible ways to reduce doses to individuals to provide reassurance to the operatives. Go to Step 7.	normal. The Water Company should consider seeking specialist radiation protection advice. For planned routine maintenance tasks that are urgent, if the potential doses are lower than 2 mSv in a year (taking into account any additional doses operatives may have from day-to-day tasks in the short term) the planned maintenance can go ahead. The Water Company should consider seeking specialist radiation protection advice. <u>Doses from inspection of backwashing of filters</u> It should be noted that very conservative assumptions have been made in the estimation of doses from the inspection of back-washing of rapid gravity filters. If, therefore, doses are estimated from this task over the period up to the next planned maintenance that exceed 2 mSv in a year, these estimates are likely to be much higher than the doses that will actually be received. Seeking specialist advice in the case is recommended to develop the best practicable strategy, eg, undertaking direct measurements of activity concentrations in air during the back-washing process and the use of personal monitoring or bringing the planned maintenance forward.
Step 5: If the dose to a *'critical individual'* from undertaking the identified day-to-day tasks in Step 1 is higher than 0.1 mSv in a week: ➢ Recalculate doses to specific individuals / groups of operatives with similar jobs using best estimates of how long individuals spend on each tasks and how long the operatives are likely to be working with contaminated sludge	Note that for day-to-day tasks involving the management of produced sludge, the contaminated sludge has a finite length of time on site and will soon either be removed from the site (if waste disposal is allowed) or will become highly diluted by uncontaminated sludge after contaminated water has stopped entering the works.

<table>
<tr><td>(see user assistance 2).

Check to see if the doses to individuals undertaking any of the identified day-to-day tasks are > 2 mSv in a year.

➢ If the doses are higher than 2 mSv in a year, go to Step 6.

➢ If the doses are lower than 2 mSv in a year, go to Step 4.

If the doses from routine maintenance tasks involving working with sludge or filter bed media are higher than 2 mSv in a year, go to Step 6.</td><td></td></tr>
<tr><td>Step 6: Seek specialist radiation protection advice urgently. Stop undertaking non-urgent tasks until specialist advice is available.

Look at ways to reduce exposures to operatives carrying out tasks giving the highest doses while awaiting specialist advice. This would include the following.

➢ Delaying undertaking tasks.

➢ Changing working practices, eg, reducing hours for each individual, wearing respirators for dusty tasks.</td><td>The Water Company will need specialist radiation protection advice.

The measures put in place to reduce doses to the operatives will depend on how high the predicted potential weekly doses are and how long these doses are likely to continue. Specialist advice is needed.

Delaying the undertaking of a task can lead to significant reductions in the doses that would be received by operatives for radionuclides with short radioactive half-lives. Table 9 provides information on how activity concentrations in the contaminated media will reduce with time due to radioactive decay.

Reducing the time any individual is exposed to the contaminated material reduces the exposures pro rata. If alpha emitting radionuclides are present, then the use of respirators will reduce the exposure from inhalation which is the dominant contributor to the doses if operatives are working with dry materials. Further information on the use of respirators and the problems associated with their use can be found in the supporting report [Brown et al, 2008].</td></tr>
<tr><td>Step 7: Estimate doses that have already been received by operatives undertaking tasks prior to the Water Company becoming aware that the incident had occurred (see user assistance 3).</td><td>These estimates will only give a very broad indication of the doses that operatives may have received for both day-to-day task and any maintenance tasks that have taken place as measurements of activity concentrations in the input water over the period are not available.

It is important, however, to try and estimate these doses for reassurance purposes and also so that they can be</td></tr>
</table>

	taken into account when assessing any potential future doses that may be received by operatives. The most robust approach is to use measured activity concentrations in filter bed media. Filter media act as an integrator of all the contaminated water that has passed through the works. Using measurements in filter bed media and the likely length of the incident and the throughput of water, a very crude estimate can be made of the average activity concentration in the input water up to the time the filter bed media are measured. This will therefore provide a better estimate of the amount of radioactivity that has passed through the works and hence average activity concentrations in the input water over the duration of the 'incident' than spot measurements made on the input water. See user assistance 3 for guidance on how to estimate doses that may have been received form day-to day tasks based on measurements in filter bed media. The use of measured activity concentrations in sludge is more problematic. It may not be possible to collect samples of sludge that represent the period during which contamination was passing through the works, since several days production may already have been mixed in any sludge storage facility including uncontaminated sludge from both before and after the 'incident'. It should be recognised that estimating doses that have been received in the past using this approach involves a number of modelling assumptions being made and so it will only give very broad order of magnitude estimates of radiation doses. For works where sludge is not handled and chemical filtration is not used, ie, there are no other measurements available in filter media or waste sludge, it will not be possible to estimate the doses that may have been received. These are, however, very unlikely to be of concern. Note that if maintenance tasks have taken place, this may significantly reduce or prevent any future doses being received, ie, if sludge tanks have been cleaned out or filter bed media have been replenished.

Step 8: Estimate doses from any other future maintenance tasks involving sludge or filter media and any other maintenance tasks that could give rise to doses to operatives using measured activity concentrations (see user assistance 4). Consider ways to reduce doses for reassurance purposes. If doses are of concern (> 2 mSv in a year) go to Step 6.	For other types of treatment works, eg, membrane plants or works that pump water from underground aquifers and undertake minimum additional treatment or for works with less common treatment steps such as ion exchange, there may be other maintenance tasks that could give rise to doses to operatives. Doses for any maintenance tasks other than those involving sludge and filter media are unlikely to be of concern. For list of some other possible maintenance tasks, see Table 10. When estimating doses from these additional maintenance tasks, it is important to take account of whether the individuals undertaking these tasks also carry out day-to-day tasks. The doses from all the activities an individual undertakes should be summed before comparing with the guidance level.

5.3 Scenario 3: it is suspected that contaminated water is going to pass through the treatment works in the near future

Text in blue indicates that supporting information is available to assist users undertake the calculations required. Guidance is given in Section 6.

Step 1: As soon as radioactivity is measured in the input water (or treated water), prioritise sampling within the treatment works. If waste sludge handled on the site the highest priority is to measure activity concentrations in the sludge at the points it is handled. If measurements in water indicate that alpha emitting radionuclides are present and inspection of the back-washing of rapid gravity filters takes place, a high priority is to measure activity concentrations in the filter media. Consider stopping or reducing the inspection if possible. Continue to measure activity concentrations in the input water (and treated water). It would be prudent to plan to delay any imminent routine maintenance (within a few weeks) that involves working with sludge or filter bed media if at all possible until estimates of radiation doses are available. If tasks cannot be delayed then the next priority is to measure activity concentrations in the filter bed media or sludge that the operatives will be working with or close to. For longer term maintenance tasks, go to step 9.	Contamination will concentrate in the works, primarily in sludge and filter media and is likely to remain in the works for some time after the end of the incident (see Section 2). The highest priority is, therefore, to assess and control doses that could be received by operatives due to routine day-to-day tasks involving sludge and filter media. The main advantage of delaying maintenance tasks is to reduce potential exposures of the operatives. However, an added advantage is that this may remove the need for the task to be carried out again shortly after the contamination has passed through the works to provide reassurance to the public that no further radioactivity is entering the drinking water supply from contamination held within the works. If routine maintenance is imminent and it is difficult to delay this, the assessment of doses to operatives undertaking these tasks is the next priority. Care is needed to ensure that the measurements in sludge that are made are those in the sludge that has been produced from the contaminated water entering the works. This will provide a conservative approach for tasks where operatives may be exposed to sludge that has been produced over a period significantly longer than the duration of the incident, eg, working with stored sludge.
Step 2: As soon as radioactivity is measured in the input water (or treated water), estimate the potential dose from the day-to-day tasks identified in Step 1 for 1 week of exposure for a '*critical individual*' using	The doses calculated as part of emergency planning assume that the activity concentration in each contaminated material is at a constant level for 1 week and that day-to-day tasks are carried out for 1 week with operatives being exposed to this contamination. Doses from routine maintenance tasks are estimated by

doses calculated as part of pre-planning and these measurements (see user assistance 1). If alpha emitting radionuclides have been measured, include potential future doses from the inspection of back-washing of rapid gravity filters (if task is undertaken). If routine maintenance tasks cannot be delayed, estimate doses to operatives using the doses calculated as part of preplanning and measured activity concentrations in the appropriate material (see user assistance 1). If you suspect that the contaminated water will continue to enter the works for more than 4-5 months, the estimated *'critical individual'* dose for day-to-day tasks should also be calculated for the potential duration of contamination entering the works (see user assistance 2).	assuming that the activity concentration remains constant for the length of time the maintenance takes place. For routine maintenance tasks involving sludge or filter bed media, the contamination is static within the environment where the maintenance is taking place. It is therefore reasonable to assume that operatives will be exposed to this contamination throughout the length of the maintenance task. This is also the case for day-to-day inspection of the back-washing of rapid gravity filters, where operatives can potentially continue to be exposed over a long period as contamination will remain in the filters until the filter media is replaced or contamination levels reduce due to radioactive decay. For day to day tasks, this approach is likely to be conservative for radionuclides with half-lives of a few days of less (use Table 9 to see how quickly activity concentrations can decrease for different radionuclides). This approach will also be conservative for a very short contamination event, particularly for tasks that result in doses only being received as contaminated water passes through the works. Doses should be adjusted if it is believed that contaminated water may continue to enter the works for periods longer than 4 - 5 months.
Step 3: As a first screening, check to see if the dose to *the 'critical individual'* from the identified day-to-day tasks is > 0.1 mSv in a week. If the doses have been adjusted because it is expected that contamination will enter the works for more than 4-5 months, check to see if the dose to the *'critical individual'* from the identified day-to-day tasks is > 2 mSv in a year. For any urgent routine maintenance tasks that cannot be delayed, check if the dose an individual receives from carrying out this task is > 2 mSv in a year. ➢ If the doses are lower than the	

guidance levels go to Step 4. If the doses are higher than the guidance levels, go to Step 6.	
Step 4: Doses are lower than the guidance levels given in Step 3. For day-to-day tasks involving working with sludge, continue tasks as normal but ensure that activity concentrations in the sludge continue to be measured to check that the situation does not worsen. Consider possible ways to reduce doses to individuals to provide reassurance to the operatives. If day-to-day inspection of back-washing of rapid gravity filters is included in the *'critical individual'* dose, continue task as normal but recalculate the dose from this task taking into account how long it will be before the next planned replacement of filter media (see user assistance 2). Check if the dose from this task is > 2 mSv in a year. ➢ If the recalculated dose from inspection of backwashing is > 2 mSv in a year, go to Step 6. ➢ If the recalculated dose from inspection of back-washing is < 2 mSv in a year, continue to measure activity concentrations in the filter media to check that the situation does not worsen and to monitor any decrease in activity concentrations to support the dose estimate. Consider ways to reduce the time spent undertaking this task to provide reassurance to the operatives. Consider bringing the replacement of filter media forward. The Water Company should consider seeking specialist	<u>Dose <0.1 mSv in a week</u> As the assumption has been made that the water is contaminated at a constant level for a week (or longer), it is unlikely that the doses have been significantly underestimated. It is reasonable, therefore, on radiological protection grounds, to continue operation of these tasks. Operatives will require reassurance and so a monitoring programme needs to be put in place to support the decision to continue normal practices and to provide reassurance. If working practices can be changed to minimise further any doses to operatives, this should be considered. Further measurements in sludge and filter media at the points where operatives come into contact with it need to be made throughout the duration of the incident and subsequently to ensure that activity concentrations do not significantly increase. The Water Company may wish to seek specialist radiation protection advice; however, this is not urgent. <u>Doses < 2 mSv in a year</u> For day-to-day tasks that will not give rise to a dose higher than 2 mSv in a year, tasks can also continue as normal. The Water Company should consider seeking specialist radiation protection advice. For planned routine maintenance tasks that are urgent, if the potential doses are lower than 2 mSv in a year (taking into account any additional doses operatives may have from day-to-day tasks in the short term) the planned maintenance can go ahead. The Water Company should consider seeking specialist radiation protection advice. <u>Doses from inspection of backwashing of filters</u> It should be noted that very conservative assumptions have been made in the estimation of doses from the inspection of back-washing of rapid gravity filters. If, therefore, the doses that are estimated from this task

radiation protection advice. For routine maintenance tasks involving working with sludge or filter bed media, continue planned maintenance but ensure that activity concentrations are measured in the appropriate media prior to undertaking the maintenance and reassess doses to operatives if activity concentrations have changed. Consider possible ways to reduce doses to individuals to provide reassurance to the operatives. For all other tasks, continue tasks as normal but ensure that doses do not change significantly by monitoring any changes in the measured activity concentrations in the input water. Go to Step 7.	over the period up to the next planned maintenance exceed 2 mSv in a year, these estimates are likely to be much higher than the doses that will actually be received. Seeking specialist advice in the case is recommended to advise on the best strategy, eg, undertaking direct measurements of activity concentrations in air during the back-washing process and the use of personal monitoring or bringing the planned maintenance forward.
Step 5: If the dose to a *'critical individual'* from undertaking the identified day-to-day tasks in Step 1 is higher than 0.1 mSv in a week: Recalculate doses to specific individuals / groups of operatives with similar jobs using best estimates of how long individuals spend on each task and how long the operatives are likely to be working with contaminated materials (see user assistance 2). Also, recalculate doses using measured activity concentrations in the sludge at the points where operatives have contact with the sludge (see user assistance 1). Check to see if the doses to individuals undertaking any of the identified day-to-day tasks are > 2 mSv in a year. ➢ If the doses are higher than 2 mSv in a year, go to Step 6 ➢ If the doses are lower than 2 mSv	Note that for day-to-day tasks involving the management of produced sludge, the contaminated sludge has a finite length of time on site and will soon either be removed from the site (if waste disposal is allowed) or will become highly diluted by uncontaminated sludge after contaminated water has stopped entering the works.

in a year, go to Step 4. ➢ If the doses from tasks for routine maintenance tasks involving working with sludge or filter bed media are higher than 2 mSv, go to Step 6.	
Step 6: Seek specialist radiation protection advice urgently. Stop undertaking non-urgent tasks until specialist advice is available. Look at ways to reduce exposures to operatives carrying out tasks giving the highest doses while awaiting specialist advice: ➢ Delaying undertaking tasks ➢ Changing working practices, eg, reducing hours for each individual, wearing respirators for dusty tasks.	The Water Company will need specialist radiation protection advice. The measures put in place to reduce doses to the operatives will depend on how high the predicted potential weekly doses are and how long these doses are likely to continue. Specialist advice is needed. Delaying the undertaking of a task can lead to significant reductions in the doses that would be received by operatives for radionuclides with short radioactive half-lives. Table 9 provides information on how activity concentrations in the contaminated media will reduce with time due to radioactive decay. Reducing the time any individual is exposed to the contaminated material reduces the exposures pro rata. If alpha emitting radionuclides are present, then the use of respirators will reduce the exposure from inhalation which dominates the doses if operatives are working with dry media. Further information on the use of respirators and the problems associated with their use can be found in the supporting report [Brown *et al*, 2008].
Step 7: Continue to reassess doses as more monitoring data become available. Go to steps 4-6 as required.	It is important that any estimates of doses are reassessed as monitoring data, either in the input water, filter media or sludge become available.
Step 8: If the incident continues for longer than a few weeks, specialist radiation protection advice should be sought even if doses to operatives are lower than 2 mSv in a year.	In order to support any assessments of doses, it is important to have measurements of activity concentrations in the affected treatment works as a function of time if the incident occurs over a period of more than a few weeks. This is because the conservative assumptions made in the dose assessment about levels of contamination remaining constant in the works become less valid as the duration of the incident increases. For example, even though contaminated water could still enter the works due to run-off from catchment areas into open water sources, the levels of contamination will decrease due to dilution with clean water and rainfall. Direct measurement of external

	gamma dose-rates or activity concentrations in the air in environments of concern within the treatment works will provide a more accurate estimate of the on-going doses received by operatives working in these environments. These measurements will also provide reassurance to the operatives. Specialist advice should be sought on appropriate measurements to be made and how these can be used to provide estimates of doses to the operatives.
Step 9: Estimate doses from any other future maintenance tasks involving sludge or filter media and any other maintenance tasks that could give rise to doses to operatives using measured activity concentrations (see user assistance 4). Consider ways to reduce doses for reassurance purposes. Ensure that measurements in the relevant contaminated media are made before the start of any maintenance tasks to ensure that the situation has not changed and dose estimates are still relevant. If doses are of concern (> 2 mSv in a year) go to Step 6.	The only maintenance tasks that may give rise to doses that are higher than 2 mSv in a year, taking into account the duration of the maintenance task, are those involving filter beds or sludge. Any residual sludge could still have high activity concentrations in it. Activity concentrations in the filter media will increase with time as contaminated water passes through them. For other types of treatment works, eg, membrane plants or works that pump water from underground aquifers and undertake minimum additional treatment or for works with less common treatment steps such as ion exchange, there may be other maintenance tasks that could give rise to doses to operatives. Doses for any maintenance tasks other than those involving sludge and filter media are unlikely to be of concern. For list of some other possible maintenance tasks, see Table 10. When estimating doses from these additional maintenance tasks, it is important to take account of whether the individuals undertaking these tasks also carry out day-to-day tasks. The doses from all the activities an individual undertakes should be summed before comparing with the guidance level.

Table 9: Effect of delaying tasks on the activity concentrations in contaminated media within a treatment works

Radionuclide	Activity concentrations in contaminated media after given time following initial contamination[a]						
	1 week	1 month	3 months	6 months	1 year	2 years	10 years
^{60}Co	$9.97\ 10^{-1}$	$9.89\ 10^{-1}$	$9.68\ 10^{-1}$	$9.37\ 10^{-1}$	$8.77\ 10^{-1}$	$7.69\ 10^{-1}$	$2.69\ 10^{-1}$
^{75}Se	$9.60\ 10^{-1}$	$8.41\ 10^{-1}$	$5.95\ 10^{-1}$	$3.54\ 10^{-1}$	$1.21\ 10^{-1}$	$1.47\ 10^{-2}$	0
^{89}Sr	$9.09\ 10^{-1}$	$6.65\ 10^{-1}$	$2.94\ 10^{-1}$	$8.66\ 10^{-2}$	$7.01\ 10^{-3}$	$4.91\ 10^{-5}$	0
^{90}Sr	$1.00\ 10^{0}$	$9.98\ 10^{-1}$	$9.94\ 10^{-1}$	$9.88\ 10^{-1}$	$9.76\ 10^{-1}$	$9.54\ 10^{-1}$	$7.88\ 10^{-1}$
^{95}Zr	$9.27\ 10^{-1}$	$7.23\ 10^{-1}$	$3.77\ 10^{-1}$	$1.42\ 10^{-1}$	$1.92\ 10^{-2}$	$3.68\ 10^{-4}$	0
^{95}Nb	$8.71\ 10^{-1}$	$5.53\ 10^{-1}$	$1.70\ 10^{-1}$	$2.87\ 10^{-2}$	$7.48\ 10^{-4}$	$5.60\ 10^{-7}$	0
^{99}Mo	$1.71\ 10^{-1}$	$5.20\ 10^{-4}$	0	0	0	0	0
^{103}Ru	$8.84\ 10^{-1}$	$5.89\ 10^{-1}$	$2.04\ 10^{-1}$	$4.17\ 10^{-2}$	$1.59\ 10^{-3}$	$2.54\ 10^{-6}$	$1.07\ 10^{-28}$
^{106}Ru	$9.87\ 10^{-1}$	$9.45\ 10^{-1}$	$8.44\ 10^{-1}$	$7.13\ 10^{-1}$	$5.03\ 10^{-1}$	$2.53\ 10^{-1}$	$1.04\ 10^{-3}$
^{132}Te	$2.26\ 10^{-1}$	$1.70\ 10^{-3}$	$4.89\ 10^{-9}$	0	0	0	0
^{131}I	$5.47\ 10^{-1}$	$7.53\ 10^{-2}$	$4.27\ 10^{-4}$	$1.82\ 10^{-7}$	0	0	0
^{134}Cs	$9.94\ 10^{-1}$	$9.73\ 10^{-1}$	$9.21\ 10^{-1}$	$8.47\ 10^{-1}$	$7.15\ 10^{-1}$	$5.11\ 10^{-1}$	$3.48\ 10^{-2}$
^{136}Cs	$6.90\ 10^{-1}$	$2.04\ 10^{-1}$	$8.55\ 10^{-3}$	$7.31\ 10^{-5}$	$4.10\ 10^{-9}$	$1.68\ 10^{-17}$	0
^{137}Cs	$1.00\ 10^{0}$	$9.98\ 10^{-1}$	$9.94\ 10^{-1}$	$9.89\ 10^{-1}$	$9.77\ 10^{-1}$	$9.55\ 10^{-1}$	$7.94\ 10^{-1}$
^{140}Ba	$6.83\ 10^{-1}$	$1.95\ 10^{-1}$	$7.47\ 10^{-3}$	$5.58\ 10^{-5}$	$2.37\ 10^{-9}$	0	0
^{140}La	$5.55\ 10^{-2}$	$4.15\ 10^{-6}$	0	0	0	0	0
^{144}Ce	$9.83\ 10^{-1}$	$9.29\ 10^{-1}$	$8.03\ 10^{-1}$	$6.45\ 10^{-1}$	$4.11\ 10^{-1}$	$1.69\ 10^{-1}$	$1.37\ 10^{-4}$
^{169}Yb	$8.59\ 10^{-1}$	$5.22\ 10^{-1}$	$1.42\ 10^{-1}$	$2.03\ 10^{-2}$	$3.68\ 10^{-4}$	$1.36\ 10^{-7}$	0
^{192}Ir	$9.37\ 10^{-1}$	$7.55\ 10^{-1}$	$4.31\ 10^{-1}$	$1.85\ 10^{-1}$	$3.28\ 10^{-2}$	$1.07\ 10^{-3}$	0
^{226}Ra	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$9.99\ 10^{-1}$	$9.96\ 10^{-1}$
^{235}U	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$
^{238}Pu	$1.00\ 10^{0}$	$9.99\ 10^{-1}$	$9.98\ 10^{-1}$	$9.96\ 10^{-1}$	$9.92\ 10^{-1}$	$9.84\ 10^{-1}$	$9.24\ 10^{-1}$
^{239}Pu	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$
^{241}Am	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$1.00\ 10^{0}$	$9.99\ 10^{-1}$	$9.98\ 10^{-1}$	$9.97\ 10^{-1}$	$9.84\ 10^{-1}$

a) Initial contamination 1.0 (arbitrary unit).

Table 10: Possible other maintenance tasks identified for UK drinking water treatment works

Recycling of microsand used in filter media	For estimating doses, assume this tasks is the same as working with processed sludge generic task
Recycling of granulated activated charcoal (GAC)	For estimating doses, assume this tasks is the same as working with processed sludge generic task

6 GUIDANCE ON USE OF DOSES ESTIMATED AS PART OF CONTINGENCY IN THE RESPONSE TO AN INCIDENT

This section gives guidance on how the doses estimated as part of contingency planning can be used in the event of an incident.

6.1 User assistance 1

Using measured activity concentrations, estimate potential future doses from these tasks.

Use measured activity concentrations in sludge and/or filter bed media in Bq kg^{-1}.

Use measured activity concentrations in input water in Bq l^{-1} (if available).

Use doses for 1 week's exposure estimated for each task for the relevant radionuclides calculated in Section 4, step 6.

This will give the doses (mSv) from working with the contaminated media for 1 week (day-to-day tasks) or for the duration of the maintenance task (assuming the contamination event lasted for 1 week).

6.2 User assistance 2

Recalculate doses using best estimate of how long contaminated water is likely to enter the works and/or operatives are likely to be working with the contaminated sludge or filter media for each task.

Adjust doses estimated for radiation exposure in 1 week by best estimate of duration of exposure to contaminated media.

Multiply doses by the factor 'revised exposure time (days)' / 7 (days).

6.3 User assistance 3

Estimate doses that have already been received by operatives undertaking tasks prior to the Water Company becoming aware that the incident had occurred. Use measured activity concentrations in filter media.

Note that this approach will only give very broad estimates of doses that have already been received.

Using measured activity concentration in filter media, estimate total activity in filter beds.

Activity in filter beds, Bq = measured activity concentration (Bq kg^{-1}) x total mass of filter media (kg).

Use the activity in filter bed media, Bq kg^{-1}, calculate the implied average activity in the input water, Bq l^{-1} (over the period of the 'incident' (Scenario 1) or the period prior to the first measurements being available in the input water (Scenario 2)).

Activity in input water (Bq) = Activity in filter media (Bq) / EFF

where:

For a 2 step process (flocculation / clarification(FL/CL) and rapid gravity filtration (RGF))

EFF = [1 - EFF1] x EFF2

For a 3 step process (flocculation / clarification(FL/CL), rapid gravity filtration (RGF) and slow sand filtration (SSF))

EFF = 1 - EFF1] x [1 - EFF2] x EFF3

Where:

EFF1 = amount removed in FL/CL (Bq removed per Bq input)

EFF2 = amount removed in RGF (Bq removed per Bq input)

EFF3 = amount removed in SSF (Bq removed per Bq input)

EFF = amount removed by last filtration step (Bq removed per Bq in the untreated input water)

For this calculation, values for EFF1 - EFF3 should be taken as the mean value within the ranges given for each treatment process in Table 5. The estimation of EFF is described in detail in Section 4.2 of supporting report.

Estimate average activity concentration in input water (over the period of the 'incident' (Scenario 1) or the period prior to the first measurements being available in the input water (Scenario 2)).

Average activity concentration (Bq l^{-1}) = total activity in input water (Bq) / throughput of water over the period chosen (l).

For example, if the works has a throughput of 80 Ml per day and 1 week is assumed for the duration of the 'incident', the total throughput is 80 10^6 l/d x 7 d = 5.6 10^8 l.

Use the average activity concentration in water to estimate doses for 1 weeks exposure estimated to the *'critical individual'* for the relevant radionuclides (see Section 4, step 7). If the duration is known and it is not 1 week, multiply any doses by the factor 'revised exposure time (days)' / 7 (days).

6.4 User assistance 4

Estimate doses from any other future maintenance tasks involving sludge or filter media and any other maintenance tasks that could give rise to doses to operatives using measured activity concentrations.

For tasks involving working with sludge or filter bed media, see Sections 6.1 and 6.2 above.

For tasks involving exposure to water, doses will be negligible as there is no further contamination of the water.

For any other tasks where it is not clear where contamination may be residing, seek specialist advice as to what measurements should be made prior to undertaking the task in order to estimate potential risks to operatives.

7 OTHER ASPECTS REQUIRING CONSIDERATION

There are some aspects of contamination of the raw water supply that have not been covered in this Handbook. These are summarised here because they need to be borne in mind as part of the planning process and in the response to an actual incident. These are as follows.

- Contamination of hitherto clean water from residual contamination held within the treatment works. Treatments such as rapid sand filtration might be left for several months before any routine maintenance would be needed. In that time a large volume of uncontaminated water would pass through the beds, and for some radionuclides this could result in the remobilisation of activity back into the water supply. The resultant concentrations are likely to be small compared with those in the original contaminated raw water, but there is no practical evidence on which to base any predictions.
- A similar process could apply to raw water in impounding reservoirs. Activity originally adsorbed on to sediment in a reservoir could be remobilised as levels in the water declined. Again, the resultant activity concentrations would be much lower than those observed during the original incident. For some radionuclides, there are some data from the marine environment that might be used to make some long-term predictions.
- Waste disposal. The large scale on which water treatment works operate means that substantial amounts of waste material could be generated, especially if large scale sand filter beds are involved. Possible management options for this waste and any associated regulatory aspects merit consideration.
- Every time that back-washing of filters occurs, a small amount of contamination that has been chemically adsorbed onto the filter media will be leached from the filter media into the back-wash water. This desorption occurs at a much slower rate than adsorption and occurs due to very small changes in chemical conditions over long periods of time. The amount removed by desorption will only be a very small fraction of the activity that is attached to the filter media by adsorption, although there is no practical evidence on which to base any predictions. As back-wash water is often returned to the head of the works, a review of this practice may warrant consideration in the event of a radiological incident.

A similar process could occur with the supernatant from the de-watering of sludge that is also often returned to the head of the works to conserve water.

8 GLOSSARY

Activity
Attribute of an amount of a *radionuclide.* Describes the rate at which nuclear decays occur in it. Unit becquerel, symbol Bq.

Bq (becquerel) is the SI unit for radioactivity, ie, the rate at which nuclear decays occur in a given amount of radioactive material. Defined as one nuclear decay per second.

Activity concentration
The level of radioactive contamination per unit area, volume, or mass. The following are examples:
Bq m^{-2}: activity concentration of deposited radioactive material on a surface.
Bq l^{-1}: activity concentration of radioactive material in drinking water or liquid waste

Alpha emitters
Radioactive materials for which the most hazardous type of radiation emitted is alpha particles, eg, the radionuclide plutonium-239 is an alpha emitter.

Beta emitters
Radioactive materials for which the most hazardous type of radiation emitted is beta particles, eg, the daughter of strontium-90 (yttrium-90) is a beta emitter.

Contamination / radioactive contamination
The deposition of radioactive material on the *surfaces* within a treatment works or onto or into *drinking water sources* and *supplies.*

Critical individual
For the purposes of this handbook, the critical individual is defined as a person that carries out all day-to-day tasks within a treatment works. It is therefore very unlikely that any individual will receive a radiation dose within a working week that is higher than this dose.

Dose
General term used for a quantity of ionising radiation. Unless used in a specific context, it refers to the *effective dose.*

Dose factor
This term is used in this Handbook to represent the *dose* received from spending 1 hour on a task within a treatment works given a unit *activity concentration* of 1 Bq l^{-1} in water or 1 Bq kg^{-1} in sludge or sand, ie, the media giving rise to the *exposure*. The units are mSv h^{-1} per Bq l^{-1} or Bq kg^{-1}.

Drinking water supplies
Water used for drinking and preparation of food as supplied to members of the public at the point of consumption, which for most people is at 'the tap'.

Effective dose
A quantity used in radiological protection that incorporates the sensitivity of different types of living tissue to damage by different types of *ionising radiation* received by a body. It is a measure of radiation exposure. Unit: Sv (*Sievert*)

Equivalent dose
A quantity used in radiological protection that incorporates the effectiveness of the various *ionising radiations* in causing harm to tissues. Unit: Sv (*Sievert*)

Exposure pathways
The pathways by which people are exposed to radiation. The pathways of main relevance for *operatives* working in drinking water treatment works are *external irradiation* from *radioactive contamination* within the treatment works and *internal irradiation* following the ingestion or inhalation of radioactive contamination.

External irradiation
The source of the radiation is outside the body. The main route of external irradiation is from radiation in the environment in which an individual spends time.

Gamma emitters / gamma-emitting
Radioactive materials for which the most hazardous type of radiation emitted is in the form of gamma rays, eg, the radionuclide cobalt-60 is a gamma emitter.

Ground water sources
See *water sources*

Ground water supplies
Drinking water supplies that come from underground water sources, eg, aquifers

Incident
See *radiological incident*

Ingestion dose
Effective dose received from ingestion of radioactivity into the body.

Internal irradiation
The source of the radiation is inside the body. The two main routes of internal irradiation are via inhalation or ingestion.

Ionising radiation
Radiation that produces ionisation in matter. Examples are alpha particles, gamma rays, X-rays and neutrons. When these radiations ass through the tissues of the body, they have sufficient energy to damage DNA.

Operative
In the handbook, an operative is defined as an individual who is formally involved with the operation of a drinking water treatment works.

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 water sources prior to treatment.

Radionuclide
An unstable nuclide that emits *ionising radiation*. A nuclide is a species of an atom characterised by the number of protons and neutrons and, in some cases, by the energy state of the nucleus.

Removal efficiency
The efficiency of a water treatment process in removing a *radionuclide* from the water entering the treatment process. Expressed as a percentage removal, eg, sand filtration may remove x% of a certain radionuclide from the water entering the filter.

Sievert, Sv
The SI unit of effective dose. Symbol: Sv.

Surface water sources
See *water sources.*

Surface water supplies
Drinking water supplies that come from *surface water sources*, eg, reservoirs

Water Sources
These are grouped for the purposes of the handbook into *ground water sources*, eg, aquifers and *surface water sources*, eg, rivers and reservoirs.

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APPENDIX A Planning what potential doses to operatives could be: worked example for a notional works

A worked example is included for a notional drinking water treatment works to illustrate how a user should work through steps 1 to 8 in Section 4 for any specific treatment works. Doses have been estimated for 2 radionuclides, ^{60}Co and ^{239}Pu.

Worked Example for notional works

Steps		
Step 1: compile essential information about the treatment works	Required information	Answer/result
	Daily water throughput	80 Ml per day
	Treatment processes	Flocculation / clarification (DAF) and rapid gravity filtration (RGF).
	Number of rapid gravity filters = 6 with area = 5m x 10m and depth 0.8 m	total volume of sand is therefore 6 x 40 m^3 = 240m^3 for a daily 80 Ml throughput
		mass of sand = 4.8 10^5 kg (assuming a density of sand of 1600 kg m^{-3})
	Amount of sludge produced	5000 kg sludge produced per 80 Ml
Step 2: Work involving handling and management of waste sludge	Filling and emptying sludge press (2.5 h every day)	17.5 h per week
	Shovelling sludge to bunkers and trailers (0.5 h every day)	3.5 h per week
	Transporting sludge to landfill (once a week)	1.5 hr per week
Step 3: Work involving handling and management of used filter media	Emptying and replacing filter sand	Infrequent task
	(5 days every 5 years)	35 h
Step 4: Other tasks carried out	Daily checking of DAF (1 h every day)	7 h per week
	Daily checking of treatment works (1 h every day)	7 h per week
	Inspection of back-washing (0.5 h every day)	3.5 h per week
Step 5: Match specific tasks to generic tasks within methodology to estimate potential doses	Specific tasks	Generic tasks
	Filling and emptying sludge press	Operating sludge press
	Shovelling sludge to bunkers	Working with processed sludge
	Transporting sludge	Transporting sludge
	Emptying/replacing filter sand	Filter bed maintenance
	Daily checking of DAF	Maintenance DAF
	Daily checking of treatment works	General maintenance/inspection
	Inspection of back-washing	Inspection of back-wash process

Step 6: Doses mSv received per Bq/kg in the contaminated media exposed to

Use data in Table 7

Day - to-day tasks, doses calculated for 1 weeks operation of treatment works		
	Doses, mSv in a week / Bq kg^{-1} in contaminated medium	Calculation
Filling and emptying sludge press	^{60}Co = 7.0 10^{-6}	4.0 10^{-7} mSv/h x 17.5 (hrs/wk)
	^{239}Pu = 1.1 10^{-5}	6.0 10^{-7} mSv/h x 17.5 (hrs/wk)
Shovelling sludge to bunkers	^{60}Co = 1.9 10^{-6}	5.5 10^{-7} mSv/h x 3.5 (hrs/wk)
	^{239}Pu = 2.1 10^{-6}	6.0 10^{-7} mSv/h x 3.5 (hrs/wk)
Transporting sludge	^{60}Co = 2.0 10^{-7}	1.3 10^{-7} mSv/h x 1.5 (hrs/wk)
	^{239}Pu = 2.1 10^{-12}	1.4 10^{-12} mSv/h x 1.5 (hrs/wk)
Daily checking of DAF	^{60}Co = 6.4 10^{-8}	9.1 10^{-9} mSv/h x 7 (hrs/wk)
	^{239}Pu = 4.8 10^{-12}	6.910^{-13} mSv/h x 7 (hrs/wk)
Daily checking of treatment works	^{60}Co = 3.9 10^{-6}	5.5 10^{-7} mSv/h x 7 (hrs/wk)
	^{239}Pu = 1.0 10^{-10}	1.510^{-11} mSv/h x 7 (hrs/wk)
Inspection of back-washing	^{60}Co = 2.0 10^{-6}	5.7 10^{-7} mSv/h x 3.5 (hrs/wk)
	^{239}Pu = 2.1 10^{-6}	6.010^{-7} mSv/h x 3.5 (hrs/wk)
Infrequent maintenance tasks, doses calculated for length of task		
Emptying/replacing filter sand	^{60}Co = 2.0 10^{-5}	5.7 10^{-7} mSv/h x 35(hrs)
	^{239}Pu = 2.1 10^{-5}	6.0 10^{-7} mSv/h x 35 (hrs)

Step 7: Identify tasks likely to give highest doses

Doses mSv received per Bq/l in the input water

Use data in Table 8

Option 1 (assuming no information available on water throughput, amounts of sludge produced and amounts of filter media in filter beds). Default values assumed: daily water throughput = 100 Ml; kg sludge/Ml = 70 kg; kg sand/Ml = 4.5 m3 x 1.6 10^3 kg m^{-3} (density) = 7.2 10^3 kg/Ml

F_w = 7

Day - to-day tasks, doses calculated Doses, mSv for 1 weeks operation of treatment works		
	Doses, mSv in a week / Bq l^{-1} in input water	Calculation
Filling and emptying sludge press	^{60}Co = 7.0 10^{-2}	4.0 10^{-3} mSv/h x 17.5 h/wk
	^{239}Pu = 1.5 10^{-1}	8.6 10^{-3} mSv/h x 17.5 h/wk
Shovelling sludge to bunkers	^{60}Co = = 1.9 10^{-2}	5.5 10^{-3} mSv/h x 3.5 h/wk
	^{239}Pu = 3.0 10^{-2}	8.6 10^{-3} mSv/h x 3.5 h/wk
Transporting sludge	^{60}Co = 2.0 10^{-3}	1.3 10^{-3} mSv/h x 1.5 h/wk
	^{239}Pu = 3.0 10^{-8}	2.0 10^{-8} mSv/h x 1.5 h/wk
Daily checking of DAF	^{60}Co = 6.4 10^{-4}	9.1 10^{-5} mSv/h x 7 h/wk
	^{239}Pu = 6.9 10^{-8}	9.8 10^{-9} mSv/h x 7 h/wk
Daily checking of treatment works	^{60}Co = 3.9 10^{-6}	5.5 10^{-7} mSv/h x 7 h/wk
	^{239}Pu = 1.1 10^{-10}	1.5 10^{-11} mSv/h x 7 h/wk
Inspection of back-washing	^{60}Co = 4.7 10^{-4}	1.9 10^{-5} mSv/h x 3.5h/wk x 7 (F_w)
	^{239}Pu = 2.5 10^{-4}	1.0 10^{-5} mSv/h x 3.5 h/wk x 7 (F_w)
Infrequent maintenance tasks, doses calculated for length of task		
Emptying / replacing filter sand	^{60}Co = 4.7 10^{-3} mSv	1.9 10^{-5} mSv/h x 7 days x 35 h
	^{239}Pu = 2.5 10^{-3} mSv	1.0 10^{-5} mSv/h x 7 days x 35 h

Option 2 (using site specific values on water throughput, amounts of sludge produced and amounts of filter media in filter beds)

daily water throughput = 80 Ml;

mass of sand = 240m^3 x 1.6 10^3 / 80= 4.8 10^5 kg for an 80 Ml throughput.

5000 kg sludge produced per 80 Ml. This is equivalent to 62.5 kg per Ml throughput

F_W = 7

F_{SL} = 70 / 62.5 = 1.12

F_{RGF} = 7.2 10^5 / 4.8 10^5 = 1.5

Day - to-day tasks, doses calculated works for 1 weeks operation of treatment		
	Doses, mSv in a week / Bq l^{-1} in input water	Calculation
Filling and emptying sludge press	^{60}Co = 7.8 10^{-2}	4.0 10^{-3} mSv/h x 17.5 h/wk x 1.12
	^{239}Pu = 1.7 10^{-1}	8.6 10^{-3} mSv/h x 17.5 h/wk x 1.12
Shovelling sludge to bunkers	^{60}Co = = 2.2 10^{-2}	5.5 10^{-3} mSv/h x 3.5 h/wk x 1.12
	^{239}Pu = 3.4 10^{-2}	8.6 10^{-3} mSv/h x 3.5 h/wk x 1.12
Transporting sludge	^{60}Co = 2.2 10^{-3}	1.3 10^{-3} mSv/h x 1.5 h/wk x 1.12
	^{239}Pu = 3.4 10^{-8}	2.0 10^{-8} mSv/h x 1.5 h/wk x1.12
Daily checking of DAF	^{60}Co = 6.4 10^{-4}	9.1 10^{-5} mSv/h x 7 h/wk
	^{239}Pu = 6.9 10^{-8}	9.8 10^{-9} mSv/h x 7 h/wk]
Daily checking of treatment works	^{60}Co = 3.9 10^{-6}	5.5 10^{-7} mSv/h x 7 h/wk
	^{239}Pu = 1.1 10^{-10}	1.5 10^{-11} mSv/h x 7 h/wk
Inspection of back-washing	^{60}Co = 7.0 10^{-4}	1.9 10^{-5} mSv/h x 3.5h x 1.5 x 7
	^{239}Pu = 3.7 10^{-4}	1.0 10^{-5} mSv/h x 3.5h x 1.5 x 7

Infrequent maintenance tasks, doses calculated for length of task		
Emptying/replacing filter sand	^{60}Co = 7.0 10^{-3}	1.9 10^{-5} mSv/h x 35 h x 1.5 x 7
	^{239}Pu = 3.7 10^{-3}	1.0 10^{-5} mSv/h x 35 h x 1.5 x 7

Step 8: Identify important tasks, radionuclides and exposure pathways

Use the doses estimated in Step 7.

Relative importance of tasks in terms of potential doses received and important exposure pathways for worked example only

^{60}Co		^{239}Pu	
Tasks in order of importance[a]	Dose, mSv for 1 Bq l^{-1} in input water over a week	Tasks in order of importance[a]	Dose, mSv for 1 Bq l^{-1} in input water over a week
Operating sludge press	8 10^{-2}	Operating sludge press[b]	2 10^{-1}
Shovelling sludge from bunkers	2 10^{-2}	Shovelling sludge from bunkers[b]	3 10^{-2}
Emptying / replacing filter sand (infrequent task)[c]	7 10^{-3}	Emptying / replacing filter sand (infrequent task)[c]	4 10^{-3}
Transporting sludge	2 10^{-3}	Inspection of back-washing of rapid gravity filters	4 10^{-4}

a) Doses from other tasks are very small. However, assessment of these doses would be required if the operatives involved were not the same as those carrying out the tasks identified as giving rise to the highest doses. The tasks listed in the Table are those to which priority should be given when planning for a radiological incident.

b) Assumes that sludge is dry and is resuspended into the air and hence is taken into the body via inhalation. If the sludge is wet or damp, inhalation will not be significant and doses from ^{239}Pu will be about 500 times lower, ie, comparable with those from filter bed maintenance.

c) These tasks can be planned for. It is assumed that the operatives are exposed to the accumulated contamination following contaminated water entering the treatment works for 1 week.

In summary, for this worked example, doses from both ^{60}Co and ^{239}Pu would need to be considered if operatives are exposed to dry sludge during the operation of a sludge press and during shovelling sludge from bunkers. If the sludge being worked with is always wet / damp then the doses from ^{60}Co will be the most significant for day-to-day tasks. Doses from the inspection of the back-washing of rapid gravity filters would need to be considered for ^{239}Pu. This is a task where it may be possible to reduce exposures by suspending inspection or limiting the amount of time spent inspecting the back-washing process. For infrequent tasks, ie, maintenance of the rapid gravity filter beds, doses from both ^{60}Co and ^{239}Pu would need to be considered as part of the planning of these tasks.

In relative terms, the doses from other tasks are very small. However, assessment of these doses would be required if the operatives involved are not the same as those carrying out the tasks identified as giving rise to the highest doses. The tasks listed in the Table are those to which priority should be given when planning for a radiological incident for the scenario considered in the worked example.

For ^{60}Co, external exposure due to the operatives being in close proximity to the contaminated sludge is by far the most important route of exposure. Other exposure pathways can be ignored. The only way to minimise these doses is to limit the time that an operative spends carrying out the task.

For ^{239}Pu, if the sludge is dry, inhalation is the most important route of exposure; this is also the case for inspection of back-washing of rapid gravity filters and replenishing and replacing sand within the rapid gravity filters. In the latter case, the assumption is also made that the sand will have dried out prior to its removal. Inhalation doses can be minimised by the use of respirators or face masks. This is discussed further in the supporting report, Section 5.3 [Brown *et al*, 2008]. If the sludge is wet or damp, then by far the most important exposure pathway is the inadvertent ingestion of sludge.

Dose to *'critical individual'* for day-to-day tasks

Dose for ^{60}Co = 1.0 10^{-1} mSv /week per Bq l^{-1} in input water

[7.8 10^{-2} + 2.2 10^{-2} + 2.2 10^{-3} + 6.4 10^{-4} + 3.9 10^{-6} + 7.0 10^{-5}]

Dose for ^{239}Pu = 2.0 10^{-1} mSv /week per Bq l^{-1} in input water

[1.7 10^{-1} + 3.4 10^{-2} + 3.4 10^{-8} + 6.9 10^{-8} + 1.1 10^{-10} + 3.7 10^{-4}]

APPENDIX B Worked examples for scenarios identified to help the water industry to assess and manage potential radiation exposures to operatives in drinking water treatment works

The worked examples provided for each scenario 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 generic contamination scenarios listed below.

The three scenarios considered are as follows.

1. It is suspected or known that contaminated water has passed through the treatment works. No measurements in input or output water are available.
2. Contaminated water has passed through the treatment works and measurements indicate that the input water is still contaminated.
3. It is suspected that contaminated water is going to pass through the treatment works in the near future, for example an airborne release from a nuclear reactor that has deposited radioactive material onto the water catchment area. Scenario 3a deals with iodine-131 (^{131}I), which has a radioactive half-life of about 8 days, while scenario 3b considers caesium-137 (^{137}Cs), which has a radioactive half-life of about 30 years.

B1 SCENARIO 1: CONTAMINATED WATER HAS PASSED THROUGH TREATMENT WORKS, INPUT WATER IS NO LONGER CONTAMINATED; NO MEASUREMENTS ARE AVAILABLE

Scenario description

The Water Company has been notified that the water source for a treatment works was contaminated 2 days ago. Measurements have been made of water supplies leaving the works and the input water. No activity concentrations have been measured above normal background levels.

The impact of the incident on the operatives at the treatment works needs to be assessed.

Information about the treatment works

Assumed to be the same as that used in Appendix A.

No routine maintenance is planned. The next scheduled replacement of sand in the 6 rapid gravity filters is in 9 months time.

Step 1: Priorities for sampling within treatment works	Sludge is handled on site. Measure activity concentrations in sludge. Inspection of back-washing of rapid gravity filters occurs. Measure activity concentrations in sand in filters. No routine maintenance is imminent.	Measurements indicate that the contamination is from ^{60}Co. This is a long-lived gamma-ray emitting radionuclide. Measured activity concentration is 10,000 Bq kg^{-1} in the sludge from the pressing done at the time of the incident. Measured activity concentration in filter media is 20 Bq kg^{-1}.		
Step 2: Using measured activity concentrations, estimate potential future doses for *'critical individual'* carrying out all day-to-day tasks	Day-to-day tasks	mSv in a week / Bq kg^{-1} in sludge (^{60}Co) [calculated as part of planning, Step 6 (see Section 4)]	Activity concentration in sludge or filter media, Bq kg^{-1}	Dose from ^{60}Co, mSv in a week
	Filling and emptying sludge press	$7.0\ 10^{-6}$	$1.0\ 10^{4}$	$7.0\ 10^{-2}$
	Shovelling sludge to bunkers	$1.9\ 10^{-6}$	$1.0\ 10^{4}$	$1.9\ 10^{-2}$
	Transporting sludge	$2.0\ 10^{-7}$	$1.0\ 10^{4}$	$2.0\ 10^{-3}$
	'Critical individual'			$9.1\ 10^{-2}$
Step 3: Check to see if doses exceed 0.1 mSv in a week	Dose in a week is < 0.1 mSv Incident has ceased			
Step 4: Doses are lower than 0.1 mSv in a week	The treatment works should continue to operate as normal. Continue monitoring activity concentrations in sludge and filter media for 7-14 days to ensure levels do not increase. Consider possible ways to reduce doses to individuals for reassurance purposes only. Consider seeking specialist radiation protection advice but this is not urgent.			
Step 7: Estimate doses that have already been received	As no information is available on actual duration of contaminated water entering the works, assume it was for 1 week. Estimate dose to 'critical individual'.			
	Measured activity concentration in filter media	20 Bq kg^{-1}		
	Total activity in filter beds	$9.6\ 10^{6}$ Bq	[20 x 4.8 10^{5} kg]	
	Total Bq in input water	$8.5\ 10^{7}$ Bq	[9.6 10^{6} / EFF] where EFF = (1- 0.55) x 0.25)	
	Average Bq l^{-1} in input water	$1.5\ 10^{-1}$	[8.5 10^{7} / (80 10^{6} x 7)]	

Day-to-day tasks	mSv in a week / Bq l^{-1} in input water (^{60}Co) [calculated as part of planning, Step 7 (see Section 4)]	Activity concentration in input water, Bq l^{-1}	Dose from ^{60}Co, mSv in a week
Filling and emptying sludge press	$7.8\ 10^{-2}$	$1.5\ 10^{-1}$	$1.2\ 10^{-2}$
Shovelling sludge to bunkers	$2.2\ 10^{-2}$	$1.5\ 10^{-1}$	$3.3\ 10^{-3}$
Transporting sludge	$2.2\ 10^{-3}$	$1.5\ 10^{-1}$	$3.3\ 10^{-4}$
'Critical individual'			$1.6\ 10^{-2}$

The dose to the critical individual estimated for the time contaminated water may have entered the works prior to the Water Company being aware of the incident is < 0.1 mSv in a week. Future predicted doses to a 'critical individual' are also < 0.1 mSv in a week. The works can continue to operate as normal.

Step 8: Estimate doses from any future routine maintenance tasks

Replacement of sand in rapid gravity filters is planned for 9 months time.

Assuming the incident lasted for 1 week, ie, 1 week of water throughput was contaminated, and using the measured activity concentration in filter media of 20 Bq kg^{-1}, the estimate of the dose to operatives undertaking this maintenance is $4.0\ 10^{-4}$ mSv [$5.7\ 10^{-7}$ (mSv h^{-1} per Bq kg^{-1} in filter media) x 35 (h) x 20 (Bq kg^{-1} in filter media)]

This dose is lower than the 2 mSv in a year guidance level and so the planned maintenance can take place. Measure activity concentrations in filter media prior to undertaking maintenance and reassess doses if activity concentrations have changed.

B2 SCENARIO 2: CONTAMINATED WATER HAS PASSED THROUGH TREATMENT WORKS, MEASUREMENTS INDICATE THAT THE INPUT WATER IS STILL CONTAMINATED

Scenario description

The Water Company has been notified that the water source for a treatment works has been contaminated. Measurements have been made of water supplies leaving the works and the input water. Activity concentrations have been measured above normal background levels and the radionuclide of concern has been identified as plutonium-239 (^{239}Pu). Measurements have been made over a period of 3 days and the input water is still contaminated although levels are decreasing.

The impact of the incident on the operatives at the treatment works and the on-going running of the works need to be assessed.

Information about the treatment works

Assumed to be the same as that used in Appendix A.

No routine maintenance is planned. The next scheduled replacement of sand in the 6 rapid gravity filters is in 9 months time.

Step 1: priorities sampling within treatment works	Measurements made daily on input water and drinking water supply. Sludge is handled on site. Measure activity concentrations in sludge. Inspection of back-washing of rapid gravity filters occurs. Measure activity concentrations in sand in filters. No routine maintenance is imminent.	Measurements indicate that the contamination is from ^{239}Pu. This is a long-lived alpha emitting radionuclide. Measured activity in input water is 1 Bq l^{-1} Measured activity concentration is 10,000 Bq kg^{-1} in the sludge from the pressing done at the time of the incident. Measured activity concentration in filter media is 5 Bq kg^{-1}		
Step 2: Using measured activity concentrations, estimate potential future doses for *'critical individual'* carrying out all day-to-day tasks Adjust for predicted time incident will carry on for and operatives may be exposed	Day-to-day tasks	mSv in a week / Bq l^{-1} in input water (^{239}Pu) [calculated as part of planning, Step 7 (see Section 4)]	Activity concentration in water, Bq l^{-1}	Dose from ^{239}Pu, mSv in a week
	Filling and emptying sludge press	$1.7\ 10^{-1}$	1.0	$1.7\ 10^{-1}$
	Shovelling sludge to bunkers	$3.4\ 10^{-2}$	1.0	$3.4\ 10^{-2}$
	Transporting sludge	$3.4\ 10^{-8}$	1.0	negligible
	Inspection of back-washing	$3.7\ 10^{-4}$	1.0	$3.7\ 10^{-4}$
	DAF checking	$6.9\ 10^{-8}$	1.0	negligible
	Daily checking	$1.1\ 10^{-10}$	1.0	negligible
	'Critical individual'			$2.0\ 10^{-1}$
	Predicted duration of incident	5 weeks		
	'Critical individual' for 5 weeks			1.0 mSv
	Also estimate doses using measured activity concentrations in filter media and sludge that have been obtained.			
	Day-to-day tasks	mSv in a week / Bq kg^{-1} in sludge or filter media (^{239}Pu) [calculated as part of planning, step 6 (see Section 4)]	Activity concentration in sludge or filter media, Bq kg^{-1}	Dose from ^{239}Pu, mSv in a week

	Filling and emptying sludge press	$1.1\ 10^{-5}$	$1.0\ 10^{4}$	$1.1\ 10^{-1}$
	Shovelling sludge to bunkers	$2.1\ 10^{-6}$	$1.0\ 10^{4}$	$2.1\ 10^{-2}$
	Transporting sludge	$2.1\ 10^{-12}$	$1.0\ 10^{4}$	negligible
	Inspection of back-washing	$2.1\ 10^{-6}$	5.0	$1.1\ 10^{-5}$
	'Critical individual'			$1.3\ 10^{-1}$
	Agrees with calculation performed using measured activity concentration in input water.			
Step 3: Check to see if doses exceed 0.1 mSv in a week	Using initial measurements in input water of 1 Bq l^{-1} or measured activity concentrations in filter media and sludge, dose estimated to a 'critical individual' for 1 week exceeds 0.1 mSv secondary guidance level. Dose to *'critical individual'* using best estimate that incident may last for 5 weeks does not exceed 2 mSv in a year. Therefore doses from individual tasks will not exceed 2 mSv in a year.			
Step 5: Dose to *'critical individual'* exceeds 0.1 mSv in a week. Look at doses to individuals / groups of individuals	Dose to *'critical individual'* using best estimate that incident may last for 5 weeks does not exceed 2 mSv in a year. Therefore doses from individual tasks will not exceed 2 mSv in a year. Adjusting doses for the time spent on tasks by each individual confirms that no individual will receive doses higher than 2 mSv in a year. All estimated doses to individuals are lower than 0.2 mSv.			
Step 4: Doses are lower than 2 mSv in a year	The treatment works should continue to operate as normal. Continue monitoring activity concentrations in sludge and filter media for 7-14 days to ensure levels do not increase. Consider possible ways to reduce doses to individuals for reassurance purposes only. Consider seeking specialist radiation protection advice but this is not urgent.			
Inspection of backwashing of filters considered because alpha emitter present	The next planned replenishment of sand filters is in 9 months time. Adjust dose from inspection of backwashing of filters. Dose for 9 months = $1.4\ 10^{-2}$ mSv [$3.7\ 10^{-4}$ mSv in a week x 39 weeks] Dose estimated for inspection of backwashing of filters is < 2 mSv in a year. So continue task as normal. Consider seeking specialist radiation protection advice and look at ways to reduce exposure for reassurance purposes, if required.			
Step 7: Estimate doses that have already been received	Measured activity concentration in filer media	5 Bq kg^{-1}		
	As no information is available on actual duration of contaminated water entering the works, assume it was for 1 week. Estimate dose to *'critical individual'.*			
	Total activity in filter beds	$2.4\ 10^{6}$ Bq [$5 \times 4.8\ 10^{5}$ kg]		
	Total Bq in input water	$6.4\ 10^{7}$ Bq [$2.4\ 10^{-6}$ / EFF] where EFF = (1- 0.15) x 0.25		
	Average Bq l^{-1} in input water	$1.1\ 10^{-1}$ [$6.4\ 10^{7}$ / ($80\ 10^{6}$ x 7)]		

		mSv in a week / Bq l^{-1} in input water (^{239}Pu) [calculated as part of planning, Step 7 (see Section 4)]	Activity concentration in input water, Bq l^{-1}	Dose from ^{239}Pu, mSv
	Filling and emptying sludge press	$1.7\ 10^{-1}$	$1.1\ 10^{-1}$	$1.9\ 10^{-2}$
	Shovelling sludge to bunkers	$3.4\ 10^{-2}$	0.11	$3.9\ 10^{-3}$
	Transporting sludge	$3.4\ 10^{-8}$	0.11	negligible
	Inspection of back-washing	$3.7\ 10^{-4}$	0.11	$4.2\ 10^{-5}$
	'Critical individual'			$2.3\ 10^{-2}$
	The dose to the *'critical individual'* estimated for the period contaminated water may have entered the works prior to the Water Company being aware of the incident is < 0.1 mSv in a week. Future predicted doses to a 'critical individual' are also < 0.1 mSv in a week. The works can continue to operate as normal.			
Step 8: Doses from planned routine maintenance	Next planned replacement of sand in rapid gravity filters due in 9 months. Estimated dose if carry out in 9 months time assuming incident duration is 5 weeks using measured activity concentration in filter media of 5 Bq kg^{-1}= $5.3\ 10^{-4}$ mSv [$2.1\ 10^{-5}$ x 5.0 x 5 weeks] Estimated dose if carry out now using measured activity concentration in filter media of 5.0 Bq kg^{-1}= $1.1\ 10^{-4}$ mSv [$2.1\ 10^{-5}$ x 5.0] Neither of the estimated doses exceeds 2 mSv in a year. Planned maintenance can be carried out. Measure activity concentrations in filter media prior to undertaking maintenance and reassess doses if activity concentrations have changed.			

B3 SCENARIO 3A: IT IS SUSPECTED THAT CONTAMINATED WATER IS GOING TO PASS THROUGH THE TREATMENT WORKS, IN THE NEAR FUTURE

Scenario description

The Water Company has been notified that an accident has occurred at a nuclear reactor site and that there has been an atmospheric release. The wind is blowing the contaminated plume over the water source for a treatment works and deposition will occur onto the surface water supply and surrounding catchment. No measurements have been made of water supplies leaving the works and the input water. However, other monitoring made around the site indicates that iodine-131 (^{131}I) has been released.

The impact of the incident on the operatives at the treatment works and the on-going running of the works need to be assessed.

Information about the treatment works

Assumed to be the same as that used in Appendix A.

No routine maintenance is planned. The next scheduled replacement of sand in the 6 rapid gravity filters is in 9 months time.

Step 1: priorities sampling within treatment works	Measurements are being made daily on input water and drinking water supply. Sludge is handled on site. Measure activity concentrations in sludge as a high priority. Inspection of back-washing of rapid gravity filters occurs. However, no alpha emitters have been released so measurements in filter media are not a priority. No routine maintenance is imminent.	First measurements made confirm that the contamination is from ^{131}I. This is a short-lived gamma-ray emitting radionuclide. Measured activity in input water is 2.5 Bq l^{-1}.		
Step 2: Using measured activity concentrations, estimate potential future doses for *'critical individual'* carrying out all day-to-day tasks Adjust for predicted time incident will carry on for and operatives may be exposed	Day-to-day tasks	mSv in a week / Bq l^{-1} in input water (^{131}I) [calculated as part of planning, Step 7 (see Section 4)]	Activity concentration in water, Bq l^{-1}	Dose from ^{131}I, mSv in a week
	Filling and emptying sludge press	$4.3\ 10^{-2}$	2.5	$1.1\ 10^{-1}$
	Shovelling sludge to bunkers	$1.6\ 10^{-3}$	2.5	$4.0\ 10^{-3}$
	Transporting sludge	$1.0\ 10^{-3}$	2.5	$2.8\ 10^{-3}$
	DAF checking	$3.8\ 10^{-4}$	2.5	$9.5\ 10^{-4}$
	Daily checking	$5.7\ 10^{-7}$	2.5	negligible
	'Critical individual'		2.5	$1.2\ 10^{-1}$
	Although an incident of this type could be expected to lead to contaminated water entering the works for up to a year, ^{131}I has a short radioactive half-life. Activity concentrations in the input water are therefore likely to decrease to very low levels within a couple of months (see Table 9). A reasonable duration of incident of 6 weeks has therefore been chosen. Using a duration of 6 weeks, the dose to the 'critical individual' can be calculated as $7.2\ 10^{-1}$ mSv.			

Step 3: Check to see if doses exceed 0.1 mSv in a week and 2 mSv in a year

Using initial measurements in input water of 2.5 Bq l^{-1}, dose estimated to a 'critical individual' for 1 week exceeds 0.1 mSv secondary guidance level.

Iodine-131 is short-lived (activity concentrations will drop by a factor of 2 every 8 days) and the dose in the first week (assuming no radioactive decay) is only just above the 0.1 mSv in a week secondary guidance level. It is therefore very unlikely that, in reality, the dose would exceed 0.1 mSv in a week.

If the dose to the critical individual is recalculated taking into account radioactive decay over the week for which doses have been estimated (see Table 9), the revised dose to the 'critical individual' is 6.3 10^{-2} mSv in a week. The dose is therefore below the secondary guidance level of 0.1 mSv in a week.

The dose to the 'critical individual' taking into account the estimated duration of the incident is below the 2 mSv in a year guidance level. It should be noted that this estimated dose is very conservative as it assumes no radioactive decay during the 6 week period.

Step 4: Doses are lower than 0.1 mSv in a week

The treatment works should continue to operate as normal.

Continue monitoring activity concentrations in input water and sludge to ensure levels do not increase.

Consider seeking specialist radiation protection advice but this is not urgent.

Step 7: Continue to reassess doses as measurements become available

A measurement made in the input water after 2 weeks of 1.0 Bq l^{-1} confirms the assumption made about radioactive decay and that doses do not exceed the guidance levels.

A measurement in sludge made 1 week after the start of the incident is now available. Measured activity concentration of 10,000 Bq kg^{-1} ^{131}I is made.

Doses from sludge related tasks are reassessed.

Day-to-day tasks	mSv in a week / Bq kg^{-1} in sludge or filter media (^{131}I) [calculated as part of planning, step 6 (see Section 4)]	Activity concentration in sludge, Bq kg^{-1}	Dose from ^{131}I, mSv in a week
Filling and emptying sludge press	6.8 10^{-6}	1.0 10^{4}	6.8 10^{-2}
Shovelling sludge to bunkers	2.4 10^{-7}	1.0 10^{4}	2.4 10^{-3}
Transporting sludge	1.8 10^{-7}	1.0 10^{4}	1.8 10^{-3}
'Critical individual'			7.3 10^{-2}

This confirms that the dose to a critical individual is < 0.1 mSv in a week and none of the tasks involving working with sludge will give rise to doses in excess of 0.1 mSv in a week.

The treatment works should continue to operate as normal.

Step 9: Doses from planned routine maintenance

Next planned replacement of sand in rapid gravity filters due in 9 months.

Estimated dose if carry out now using highest measured activity concentration in input water of 2.5 Bq l^{-1}= 3.3 10^{-3} mSv [1.3 10^{-3} x 2.5]

Estimated dose if carried out in 9 months time is 0.0 mSv due to radioactive decay.

Neither of the estimated doses exceeds 2 mSv in a year. Planned maintenance can be carried out. Measure activity concentrations in filter media prior to undertaking maintenance and reassess doses if activity concentrations have changed.

B4 SCENARIO 3B: IT IS SUSPECTED THAT CONTAMINATED WATER IS GOING TO PASS THROUGH THE TREATMENT WORKS, IN THE NEAR FUTURE

Scenario description

The Water Company has been notified that an accident has occurred at a nuclear reactor site and that there has been an atmospheric release. The wind is blowing the contaminated plume over the water source for a treatment works and deposition will occur onto the surface water supply and surrounding catchment. No measurements have been made of water supplies leaving the works and the input water. However, other monitoring made around the site indicates that caesium-137 (^{137}Cs) has been released.

The impact of the incident on the operatives at the treatment works and the on-going running of the works need to be assessed.

Information about the treatment works

Assumed to be the same as that used in Appendix A.

No routine maintenance is planned. The next scheduled replacement of sand in the 6 rapid gravity filters is in 9 months time.

Step 1: priorities sampling within treatment works	Measurements are being made daily on input water and drinking water supply. Sludge is handled on site. Measure activity concentrations in sludge as a high priority. Inspection of back-washing of rapid gravity filters occurs. However, no alpha emitters have been released so measurements in filter media are not a priority. No routine maintenance is imminent.	First measurements made confirm that the contamination is from ^{137}Cs. This is a long-lived gamma-ray emitting radionuclide. Measured activity in input water is 10 Bq l^{-1}.		
Step 2: Using measured activity concentrations, estimate potential future doses for 'critical individual' carrying out all day-to-day tasks Adjust for predicted time incident will carry on for and operatives may be exposed	Day-to-day tasks	mSv in a week / Bq l^{-1} in input water (^{137}Cs) [calculated as part of planning, Step 7 (see Section 4)]	Activity concentration in water, Bq l^{-1}	Dose from ^{137}Cs, mSv in a week
	Filling and emptying sludge press	$9.2\ 10^{-3}$	$1.0\ 10^{1}$	$9.2\ 10^{-2}$
	Shovelling sludge to bunkers	$2.7\ 10^{-3}$	$1.0\ 10^{1}$	$2.7\ 10^{-2}$
	Transporting sludge	$2.4\ 10^{-4}$	$1.0\ 10^{1}$	$2.4\ 10^{-3}$
	DAF checking	$8.4\ 10^{-5}$	$1.0\ 10^{1}$	$8.4\ 10^{-4}$
	Daily checking	$9.1\ 10^{-7}$	$1.0\ 10^{1}$	negligible
	'Critical individual'			$1.2\ 10^{-1}$
	Predicted duration of incident	1 year.		
		Expect that contamination could continue to enter the works for up to a year. Contamination levels are likely to decrease with time as run-off from the catchment becomes diluted due to rainfall.		
	'Critical individual' dose for 1 year	6.5 mSv (assuming no decrease of activity concentrations in input water with time due to dilution).		
Step 3: Check to see if doses exceed 0.1 mSv in a week	Using initial measurements in input water of 10 Bq l^{-1}, dose estimated to a 'critical individual' for 1 week exceeds 0.1 mSv secondary guidance level. Adjusting for expected duration of the incident, dose to *'critical individual'* also exceeds 2 mSv in a year (as ^{137}Cs is very long-lived, there will be negligible radioactive decay over the year (see Table 9).			

Step 5: Doses are higher than

0.1 mSv in a week and 2 mSv in a year

Reassess doses to specific individuals using best estimates of how long each individual spend on each task

Individuals operating sludge press work on this task for 15 hours a week

DAF checking only takes 5 hours a week

Individuals carrying out daily checking also carry out DAF checking.

Day-to-day tasks	mSv h^{-1} per Bq l^{-1} in input water	Hours /week for individuals	Site adjustment for 1 year	Activity concentration in input water, Bq l^{-1}	Dose, mSv in a year (predicted duration of incident)
Filling and emptying sludge press	$4.7\ 10^{-4}$	15	58.24 [1.12 x 52]	$1.0\ 10^{1}$	4.1
Shovelling sludge to bunkers	$6.8\ 10^{-4}$	3.5	58.24 [1.12 x 52]	$1.0\ 10^{1}$	1.4
Transporting sludge	$1.4\ 10^{-4}$	1.5	58.24 [1.12 x 52]	$1.0\ 10^{1}$	$1.2\ 10^{-1}$
DAF checking	$1.2\ 10^{-5}$	5	52 [1 x 52]	$1.0\ 10^{1}$	$3.1\ 10^{-2}$
Daily checking	$1.3\ 10^{-7}$	7	52 [1 x 52]	$1.0\ 10^{1}$	$4.7\ 10^{-4}$
DAF checking + Daily checking					$3.2\ 10^{-2}$

The only individuals that are likely to exceed the dose guidance level of 2 mSv in a year are sludge press workers. Specialist radiation protection advice must be sought urgently. If sludge pressing can be stopped until advice is sought, stop sludge press operation. If the sludge press has to be run, try to reduce the time any individual spends undertaking task until specialist advice is sought.

All other task can continue as normal. The Water Company should consider seeking specialist advice for all tasks involving working with sludge.

Step 7: Continue to reassess doses as more monitoring data become available

Measurement of ^{137}Cs in sludge becomes available after 1 week. Activity concentration is 30,000 Bq kg^{-1}.

Reassess doses to operatives working with sludge using the measurement in sludge.

Day-to-day tasks	mSv h^{-1} per Bq kg^{-1} in sludge (see Table 7)	Hours /week for individuals	Site adjustment for 1 year	Activity concentration in sludge, Bq kg^{-1}	Dose, mSv in a year (for predicted duration of incident)
Filling and emptying sludge press	$8.2\ 10^{-8}$	15	52	$3.0\ 10^{4}$	1.9
Shovelling sludge to bunkers	$1.2\ 10^{-7}$	3.5	52	$3.0\ 10^{4}$	$6.6\ 10^{-1}$
Transporting sludge	$2.4\ 10^{-8}$	1.5	52	$3.0\ 10^{4}$	$5.6\ 10^{-2}$
DAF checking	$2.0\ 10^{-9}$	5	52	$3.0\ 10^{4}$	$1.6\ 10^{-2}$

Estimated doses using this measurement indicate that activity concentrations in the sludge have already dropped due to lower activity concentrations in the input water.

Doses estimated for tasks involving sludge are now predicted to be lower than 2 mSv in a year. Specialist advice should still be sought and further measurements made to confirm that activity concentrations in the sludge continue to decrease.

Step 8: Seek specialist advice if incident is expected to last for more than a few weeks

Seek specialist radiation protection advice as indicated above.

Step 9: Doses from planned routine maintenance

Next planned replacement of sand in rapid gravity filters due in 9 months.

Estimated dose if carry out now using highest measured activity concentration in input water of 10.0 Bq l^{-1}= $2.2\ 10^{-2}$ mSv [$6.1\ 10^{-6}$ (mSv h^{-1} per Bq l^{-1}) x 35 (h) x 10.5 (site adjustment) x 10 (Bq l^{-1})]

Estimated dose if carry out in 9 months time is $8.7\ 10^{-1}$ mSv [$6.1\ 10^{-6}$ (mSv h^{-1} per Bq l^{-1}) x 35 (h) x 10.5 (site adjustment) x 39 (weeks) x 10 (Bq l^{-1})]

Neither of the estimated doses exceed 2 mSv in a year. Planned maintenance can be carried out. Measure activity concentrations in filter media prior to undertaking maintenance and reassess doses if activity concentrations have changed.