Initial radiological assessment tool 2: part 1 user guide

Chief Scientist's Group report

November 2022

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Acting to reduce the impacts of a changing climate on people and wildlife is at the heart of everything we do.

We reduce the risks to people, properties and businesses from flooding and coastal erosion.

We protect and improve the quality of water, making sure there is enough for people, businesses, agriculture and the environment. Our work helps to ensure people can enjoy the water environment through angling and navigation.

We look after land quality, promote sustainable land management and help protect and enhance wildlife habitats. And we work closely with businesses to help them comply with environmental regulations.

We can't do this alone. We work with government, local councils, businesses, civil society groups and communities to make our environment a better place for people and wildlife.

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Dr Robert Bradburne
Chief Scientist

Executive summary

The Environmental Permitting (England and Wales) Regulations 2016 (EPR 2016) provide the framework for controlling the generation and disposal of solid, liquid and gaseous radioactive waste so as to protect the public and the environment from radioactive wastes. EPR 2016 requires the disposal or discharge of radioactive waste to the environment to be permitted. When deciding whether to grant a permit for a disposal or discharge of radioactive waste, the Environment Agency is required to ensure that radiation doses to the public do not exceed specified dose constraints. We must also ensure that permitted discharges do not have adverse effects on wildlife to protect ecosystems, designated conservation areas and protected species.

Our initial radiological assessment methodology provides a system for undertaking a simple and cautious prospective assessment of the dose arising from discharges of radioactive waste into the environment. The methodology allows assessment of the release of over 100 radionuclides via the following routes:

- to air
- to estuary/coastal water
- to river/stream
- to public sewer

Doses can be calculated for eight different groups of the public, and to four age groups (adult, 10 year old, 1 year old and the fetus) who may receive doses as a result of discharges via these routes. Dose rates can also be calculated for wildlife inhabiting terrestrial, coastal or river environments.

The initial radiological assessment methodology is supported by four spreadsheet tools, which perform the calculations set out in the methodology. The spreadsheets are available on request from the Environment Agency.

The initial radiological assessment methodology was first published in 2006. We have now revised our initial radiological assessment methodology to use up to date models and data, include additional radionuclides and exposure groups and formally incorporate an assessment of dose rates to wildlife. We refer to the updated version of the methodology and spreadsheets as the Initial Radiological Assessment Tool 2 or ‘IRAT2’, and it is described in 2 reports.

The initial radiological assessment methodology is based on pre-calculated dose per unit release (DPUR) factors. The key assumptions which have been used to calculate DPUR factors for IRAT2 are described in the accompanying report ‘Initial Radiological Assessment Tool 2 – Part 2 Methods and Input Data’. In that Part 2 report, the methods used are described in detail and all input data and intermediate output data used to derive the DPUR factors are listed.

In this Part 1 report we describe how to apply the initial radiological assessment methodology, how to carry out initial assessments using the IRAT2 spreadsheets and provide some worked examples. This document also contains all the DPUR factors required to carry out initial assessment calculations.

Contents

List of tables and figures

1 Introduction

The Environmental Permitting (England and Wales) Regulations 2016 (EPR 2016) provide the framework for controlling the generation and disposal of solid, liquid, and gaseous radioactive waste to protect people and the environment. EPR 2016 requires disposals or discharges of radioactive waste to the environment to be permitted. When deciding whether to grant a permit for a disposal or discharge or radioactive waste we are required to ensure that prospective radiological doses to the public do not exceed specified dose constraints. We must also ensure that permitted discharges do not have adverse effects on wildlife to protect ecosystems, designated conservation areas and protected species.

The environment agencies, in collaboration with the Food Standards Agency and the Health Protection Agency (now UK Health Security Agency) defined a set of principles providing guidance on how to assess public doses for the purpose of authorising planned discharges of radioactive waste to the environment [1]. The principles recommend a staged approach to the assessment of doses for permitting purposes. The first stage consists of a simple and cautious assessment of the dose to a representative person.

Our initial radiological assessment methodology provides a system for undertaking a simple and cautious prospective assessment of the dose to people and dose rate the wildlife arising from discharges of radioactive waste into the environment.

Our initial radiological assessment methodology is supported by four spreadsheet tools, which perform the calculations set out in the methodology. We refer to the spreadsheets as the ‘Initial Radiological Assessment Tool2’ (IRAT2). We do not publish the spreadsheet tools, but they are available on request from the Environment Agency to anyone making an application for a permit to dispose of radioactive waste.

We developed the initial assessment methodology in 2005 [2] and published it as the ‘Initial Radiological Assessment Methodology (IRAT)’ in 2006 [3,4]. Since its publication our initial radiological assessment methodology has been widely used for simple and cautious screening radiological assessments. We have now developed the second version of the methodology and associated spreadsheet tools which we refer to as ‘IRAT2’. IRAT2 takes advantage of more recently available information and supporting mathematical models, as well as including a wider range of radionuclides and some additional exposure pathways. The key assumptions and methods used in IRAT2, together with all input data, are presented in detail in the accompanying report ‘Initial Radiological Assessment Tool 2 – Part 2 methods and input data’ [5].

The purpose of this report is to provide guidance on how to carry out initial assessments using the IRAT2 spreadsheets and present the data necessary to undertake initial assessments using the IRAT2 methodology.

2 Overview of the initial radiological assessment methodology

The initial radiological assessment methodology uses dose per unit release (DPUR) factors which can be scaled using information about the disposal or discharge being assessed. The DPUR values are pre-calculated based on generic assumptions about selected exposure pathways and release types. Section 4 details all the data used in the initial radiological assessment methodology. The accompanying report 'Initial Radiological Assessment Tool 2 – Part 2 methods and input data' [5] describes in detail how the DPUR factors have been derived.

The initial radiological assessment methodology can be applied to discharges of radioactive waste to the environment via the following routes:
- direct to air, and to air following incineration
- to estuary/coastal water
- to river
- to public sewer (and then on to a stream/brook, river and estuary)

For each of the discharge scenarios DPUR factors have been derived for selected exposure groups. Within each exposure group, four age groups have been considered (adult, child, infant and offspring). The term 'offspring' has been applied here to collectively represent the embryo, fetus and newborn child. The worst affected age group is used when applying the initial radiological assessment methodology. DPUR factors have also been derived for reference organisms used to represent a range of wildlife in each release scenario. Only the worst affected reference organism is used when applying the initial radiological assessment methodology.

We have listed below the exposure groups and exposure pathways considered for each discharge scenario.

Release to air

For releases to air the exposure group considered is a local resident family and the relevant exposure pathways are:
- Inhalation of radionuclides in the effluent plume
- External radiation from radionuclides in the effluent plume and deposited to the ground
- Consumption of terrestrial food incorporating radionuclides deposited to the ground

Terrestrial reference organisms inhabiting areas exposed to the effluent plume and deposition on the ground are also considered.

Release to estuary/coastal water

For releases to an estuary or coastal water the exposure group considered is a coastal fishing family who are exposed to the radioactive discharge via:
- External radiation from radionuclides deposited in shore sediments
- Consumption of seafood incorporating radionuclides

Marine reference organisms inhabiting the coastal environment are also considered.

Release to river

For releases to river, 2 exposure groups are considered.

A river angler family, exposed via:
- External radiation from radionuclides deposited in bank sediments
- Consumption of freshwater fish incorporating radionuclides
- Consumption of drinking water containing radionuclides

And an irrigated food consumer family, exposed via:
- External radiation from radionuclides in contaminated soil
- Consumption of terrestrial food irrigated with river water and incorporating radionuclides
- Consumption of drinking water containing radionuclides

Freshwater reference organisms inhabiting the river are also considered.

Release to sewer

Several exposure groups are considered for releases to public sewer, these are listed below along with the exposure pathways considered. Note that for some of these exposure groups not all age groups are considered.

Sewage treatment workers (adults only), exposed via:
- External radiation from radionuclides in raw sewage and sludge
- Inadvertent inhalation and ingestion of raw sewage and sludge containing radionuclides

Children playing in brook which receives treated effluent from sewage works (children only), exposed via:
- External radiation from radionuclides deposited in bank sediments
- Inadvertent consumption of water and sediment containing radionuclides

A farming family living on land conditioned with sewage sludge, exposed via:
- Consumption of food produced on land conditioned with sludge and incorporating radionuclides
- External radiation from radionuclides in sludge conditioned soil
- Inadvertent inhalation and ingestion of sludge conditioned soil

A river angler family (river receives treated effluent from sewage works), exposed via:
- External radiation from radionuclides deposited in bank sediments
- Consumption of freshwater fish incorporating radionuclides
- Consumption of water containing radionuclides

An irrigated food consumer family (river receives treated effluent from sewage works), exposed via:
- External radiation from radionuclides in contaminated soil
- Consumption of terrestrial food irrigated with river water and incorporating radionuclides

- Consumption of drinking water containing radionuclides

A coastal fishing family (estuary/coastal water receives treated effluent from sewage works), exposed via:
- External radiation from radionuclides deposited in sediments
- Consumption of seafood incorporating radionuclides

A local resident family living close to an incinerator that accepts sewage sludge, exposed via:
- Inhalation of radionuclides in effluent plume
- External radiation from radionuclides in the effluent plume and deposited to the ground
- Consumption of terrestrial food incorporating radionuclides deposited to the ground

Terrestrial reference organisms inhabiting land conditioned with sewage sludge, freshwater reference organisms inhabiting the river receiving treated effluent from sewage works and marine reference organisms inhabiting the estuary or coastal water receiving treated effluent from sewage works are also considered.

Table 1 lists the radionuclides included for each discharge scenario. Some discharges result in a delay (e.g., transition through a sewage treatment works) before people or wildlife might be exposed to the radionuclides, so some short half-life radionuclides are not included in some scenarios as they will have decayed to insignificant levels before people or wildlife could be exposed.

To apply the methodology, the DPUR factors are multiplied by the current or proposed annual discharge of radionuclides to calculate a dose to both people and dose rate to wildlife resulting from the discharge. Some scaling can be applied to refine the assessment and take account of some site-specific dispersion conditions. For example, different release heights during releases to air, partitioning during incineration, river flow during releases to river, water exchange rate during releases to estuary or the sea and sewage input rate for releases to sewer. These calculations can be done manually using the data in this report in combination with information about the release, or by inputting and selecting data about the release scenario in the relevant spreadsheet tool.

Section 3 provides guidance on how to carry out an assessment using the spreadsheet tools and Appendix A shows how assessments can be carried out by manually performing the calculations using the data in this report. Appendix A simply shows step by step the calculations which are performed by the spreadsheet tool to give the user a more comprehensive understanding of how the IRAT2 spreadsheet tools works.

There are some limitations to the methodology as follows:

- The methodology should be used with caution if it is applied to discharges into still or slow-moving water bodies such as lakes or canals as the methodology assumes discharges will be dispersed in flowing water rather than build up in water bodies where flow is slow or absent. Situations of this type will likely need site-specific consideration.

- The methodology is not appropriate for assessing the impact of short-term releases. The DPUR factors in IRAT2 assume long-term averaged meteorological conditions and a continuous discharge at a constant rate.

- The methodology does not apply to the disposal of solid radioactive waste
- The methodology cannot be used to assess exposure from direct radiation from a site i.e., off-site external radiation exposure from sources on-site. Where direct exposure is reasonable and will make a material difference to the dose we suggest that direct external radiation doses should be determined by measurement or separate calculation and added to the dose calculated using the initial radiological assessment methodology.

At the Environment Agency we use IRAT2 as part of our staged approach to the assessment of prospective doses from the disposal or discharge of radioactive waste. The staged process we apply at the Environment Agency when making decisions about the disposal or discharge of radioactive waste is shown in Figure 1. This user guide is applicable to Stage 1 and Stage 2 IRAT2 screening assessments.

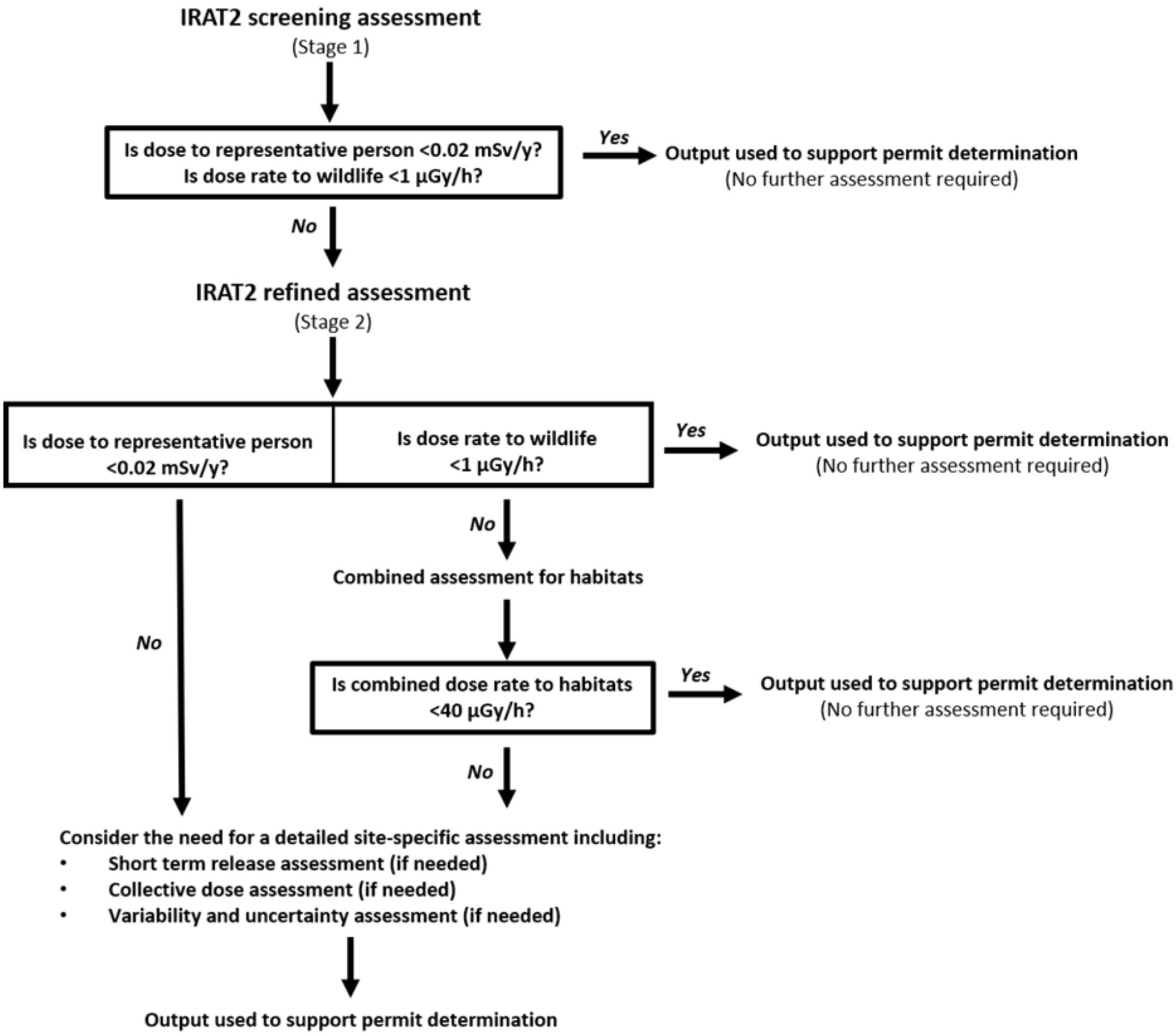


Figure 1. Stages of Environment Agency dose assessment process used when permitting discharges of radioactive waste

3 Guidance on using the initial radiological assessment methodology

We have used 3 examples in this guide to illustrate how to use the IRAT2 spreadsheet tools and how to apply the methodology using the data in this report. The examples we have used are for illustrative purposes only and are not based on real case studies, all data referring to site-specific and discharge data is fictitious.

The steps in Sections 3.1 and 3.2 below outline how to carry out an initial radiological assessment using the IRAT2 spreadsheet tools. The spreadsheets are available on request from the Environment Agency. Appendix A shows how an initial radiological assessment of Examples 1-3 can be undertaken by performing manual calculations using the data in this report. Appendix A sets out in full the calculations which are being performed by the spreadsheet tool.

Throughout this section we use the term ‘you’, when we use the term ‘you’ we are referring to any user of the IRAT2 methodology and spreadsheet tools.

Example 1: A hospital in the Thames Valley

A hospital in the Thames Valley has an incinerator permitted to discharge 420 MBq/month (5.04 GBq/y) of carbon-14 to air and 120 GBq/month (1.44 TBq/y) of iodine-131 to sewer.

The incinerator uses a dry gas abatement system. The treated effluent from the Sewage Treatment Works (STW) flows to a brook, which then enters the lower reaches of the freshwater Thames River and then goes into the mid-section of the Thames Estuary. After periods of dry weather, the brook flow is maintained by the treated effluent from the sewage treatment works. Downstream of where the brook joins the freshwater Thames, the Thames is a source of drinking water and is used by many anglers for coarse fishing. The coarse fish are mostly thrown back. Data about the receiving environments has been established as follows:

Raw throughput of sewage to sewage treatment works:	30000 m^3/d
Average volumetric flow rate in the brook:	0.3 m^3/s
Average volumetric flow rate in River Thames:	30 m^3/s

Example 2: A university research department

A research department in a large university is seeking a permit to discharge radionuclides to air and to river.

The following discharge limits for air are proposed: 2 MBq/month (24 MBq/y) of tritium, 4.2 MBq/month (50.4 MBq/y) of carbon-14, 4.2 MBq/month (50.4 MBq/y) of sulphur-35, 1.5 MBq/month (18 MBq/y) of iodine-125 and 260 MBq/month (3.12 GBq/y) of iodine-131.

The discharges to river will made from two release points from the university, the flow rate at the first discharge point is 5 m^3/s and is 25 m^3/s at the second discharge point. The proposed discharge limits are: 3.33 MBq/month (40 MBq/y) of carbon-14 from discharge point 1, 2.5 MBq/month (30 MBq/y) of carbon-14 from discharge point 2 and 2.5 MBq/month (30 MBq/y) of iodine-131 from discharge point 2.

Example 3: A nuclear power station

A nuclear power station is permitted to discharge radionuclides to air and to sea. The following rolling 12-month limits for discharges to air are included in the permit: 6 TBq of tritium, 5 TBq of carbon-14, 160 GBq of sulphur-35, 60 TBq of argon-41, 5 GBq of iodine-131 and 1 GBq of 'beta particulates'. The 'beta-particulate' group is known to be comprised mostly of cobalt-60.

The following rolling 12-month limits for discharges to sea are included: 1.2 PBq of tritium, 3 TBq of sulphur-35, 30 GBq of cobalt-60 and 300 GBq of 'other beta-gamma'.

The effective stack height is 20 m. Releases are made via pipeline directly to the sea. Local beaches are used for bait digging and recreational use. Some fish and seafood are caught locally and sold on regionally. The water exchange rate of the receiving water is 130 m^3/s. Local habits data show that the fishing family do not live close to the site

Information about direct radiation has also been provided by the operator of the power station which states that there is an annual dose to the local resident family from direct radiation of 19 μSv/y.

3.1 Initial radiological assessment using default data

We recommend that when using the initial radiological assessment methodology, you should first carry out an assessment using unmodified DPUR factors with the default assumptions. This aligns with Stage 1 of our Environment Agency process shown in Figure 1.

You must first establish which receiving environment the discharge is being made to and then select the appropriate spreadsheet tool. The spreadsheet tools are available on request from the Environment Agency to those applying for, or varying, permits to discharge radioactive waste.

There are four spreadsheet tools:

- Initial radiological assessment – air
- Initial radiological assessment – river
- Initial radiological assessment – estuary/coast
- Initial radiological assessment – sewer

For Example 1 you would need the 'Initial radiological assessment – air' and the 'Initial radiological assessment – sewer' spreadsheets.

For Example 2 you would need the 'Initial radiological assessment – air' and the 'Initial radiological assessment – river' spreadsheets.

For Example 3 you would need the 'Initial radiological assessment – air' and the 'Initial radiological assessment –estuary/coast' spreadsheets.

You will need to enter some basic information about the release. The information required about the release differs depending on which spreadsheet tool is being used. The sections below outline the steps to take in each of the four release scenarios.

3.1.1 Releases to air

The 'Assessment details' tab will prompt you to provide some basic information about the release.

In a stage 1 assessment, you do not need to change the Effective Stack Height from 'Default Values'. For Example 3 the release is not from an incinerator so the only information required is the name of the premises, a reference, and you should select 'No' to 'Are these discharges from an incinerator?'

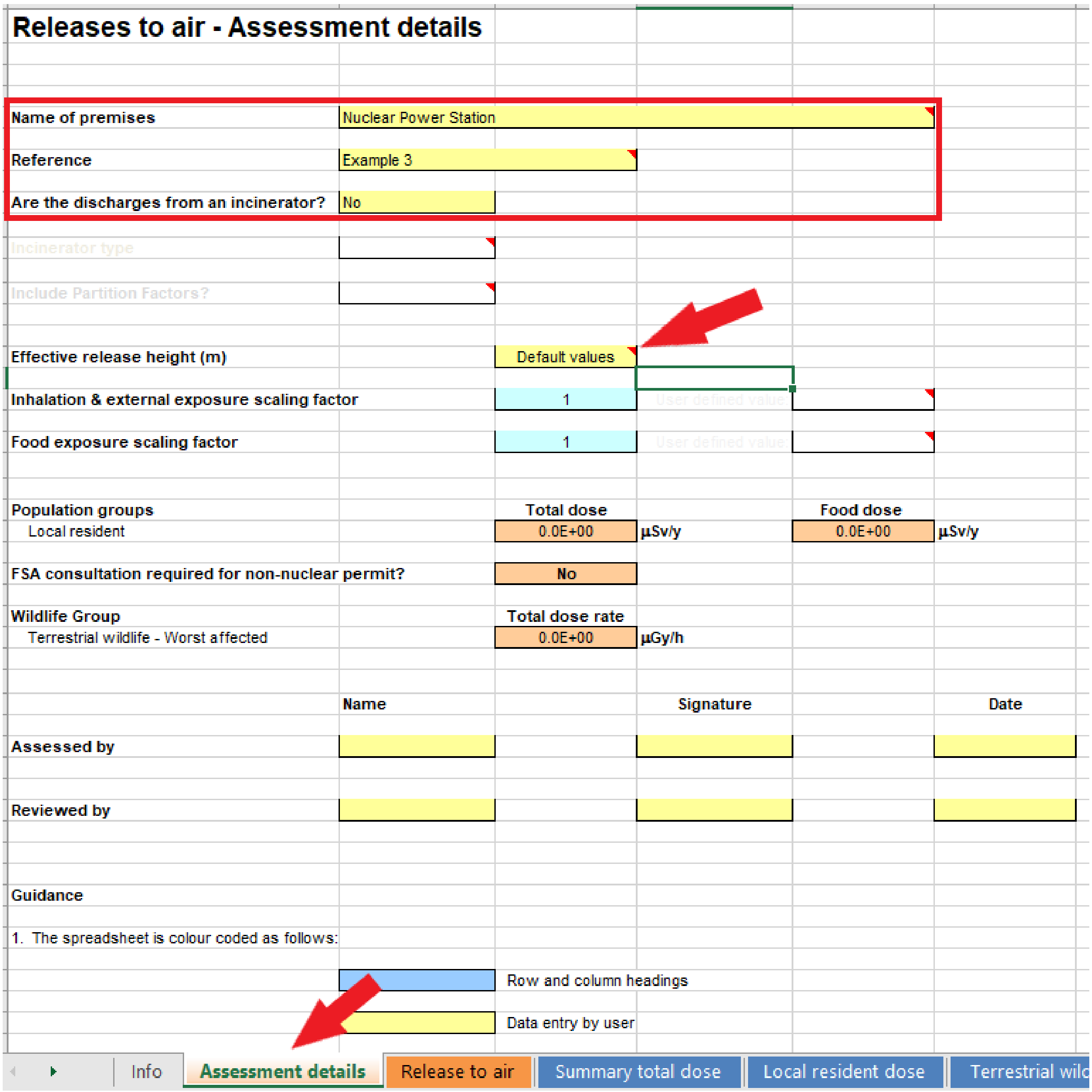


Figure 2. IRAT2 release to air stage 1 assessment with the assessment details tab completed for Example 3

Permit limits for incinerators can be expressed as annual feedstock activity to the incinerator, annual discharge limits from the incinerator or both.

Where the limits are expressed as an annual feedstock activity, in a stage 1 assessment you can assume that the discharge to air is made at the annual feedstock activity limits (i.e. no partitioning or abatement occurs within the incinerator). This is a cautious assumption and can be refined during the next phase of assessment if required. Where this is the case, in the ‘Assessment details’ worksheet, you should select ‘Yes’ to ‘Are these discharges from an incinerator?’, select an incinerator type and then select ‘No’ to ‘Include partitioning factors’.

Refinements are possible by applying partitioning factors in the tool to account for the behaviour and abatement of radionuclides in the incinerator prior to discharge (see section 3.2.1)

For Example 1, the information provided is the annual discharge limit not the annual feedstock activity so partitioning in the incinerator should not be accounted for. For Example 1 in the ‘Assessment details’ tab, you should select ‘Yes’ to ‘Are these discharges from an incinerator?’, select an incinerator type, then select ‘No’ to ‘Include partitioning factors’. As with Example 3, for a Stage 1 assessment you do not need to change the effective release height from ‘Default values’.

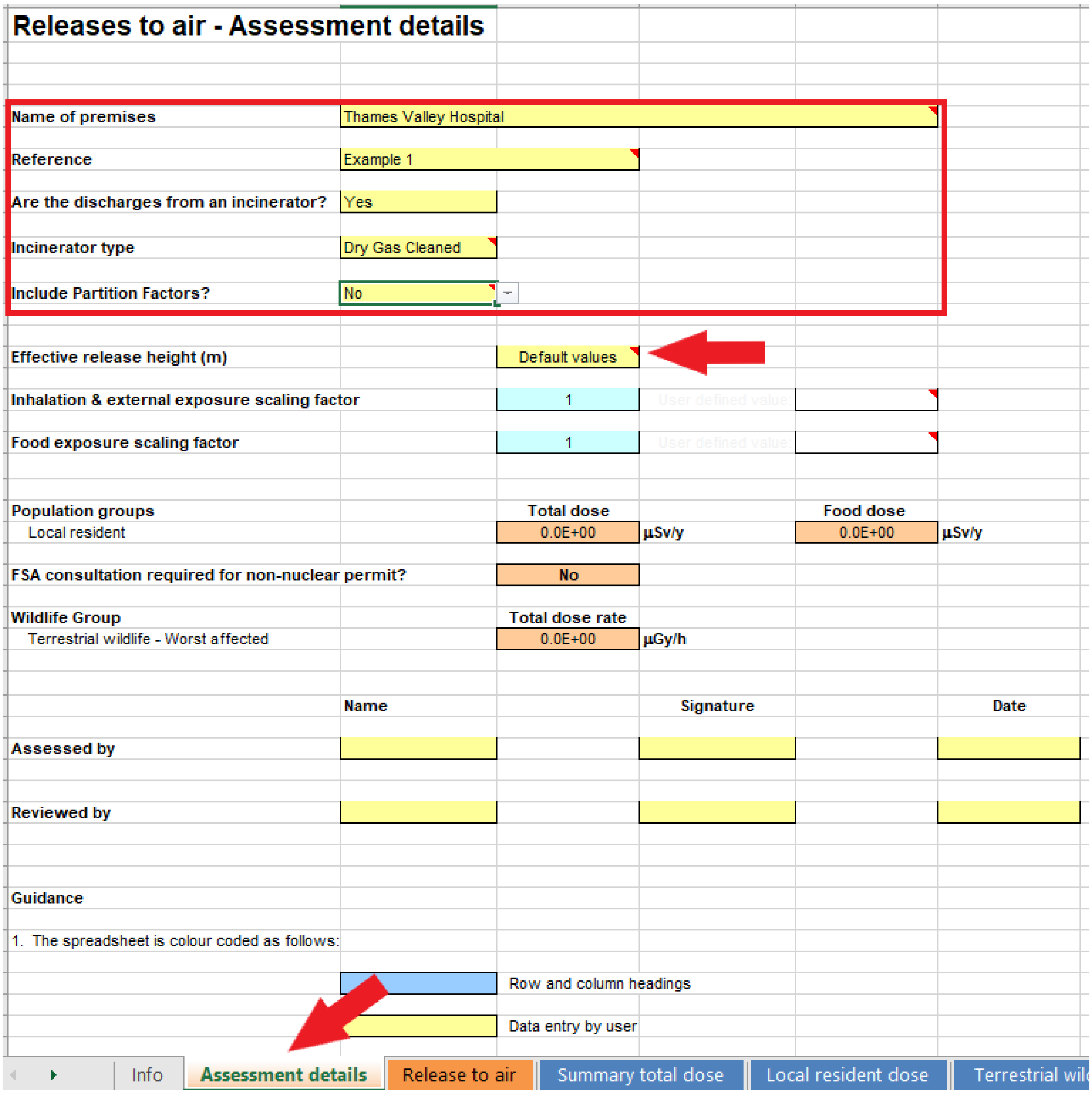


Figure 3. IRAT2 release to air stage 1 assessment with the assessment details tab completed for Example 1

3.1.2 Release to estuary or coast

The ‘Assessment details’ tab will prompt you to provide some basic information about the release.

In a stage 1 assessment, you do not need to specify the coastal location and ‘Default value’ can be selected. Selecting ‘Default value’ will set the average coastal exchange rate to 30 m^3/s, in a stage 1 assessment you do not need to change this. The only other information required is the name of the premises and a reference.

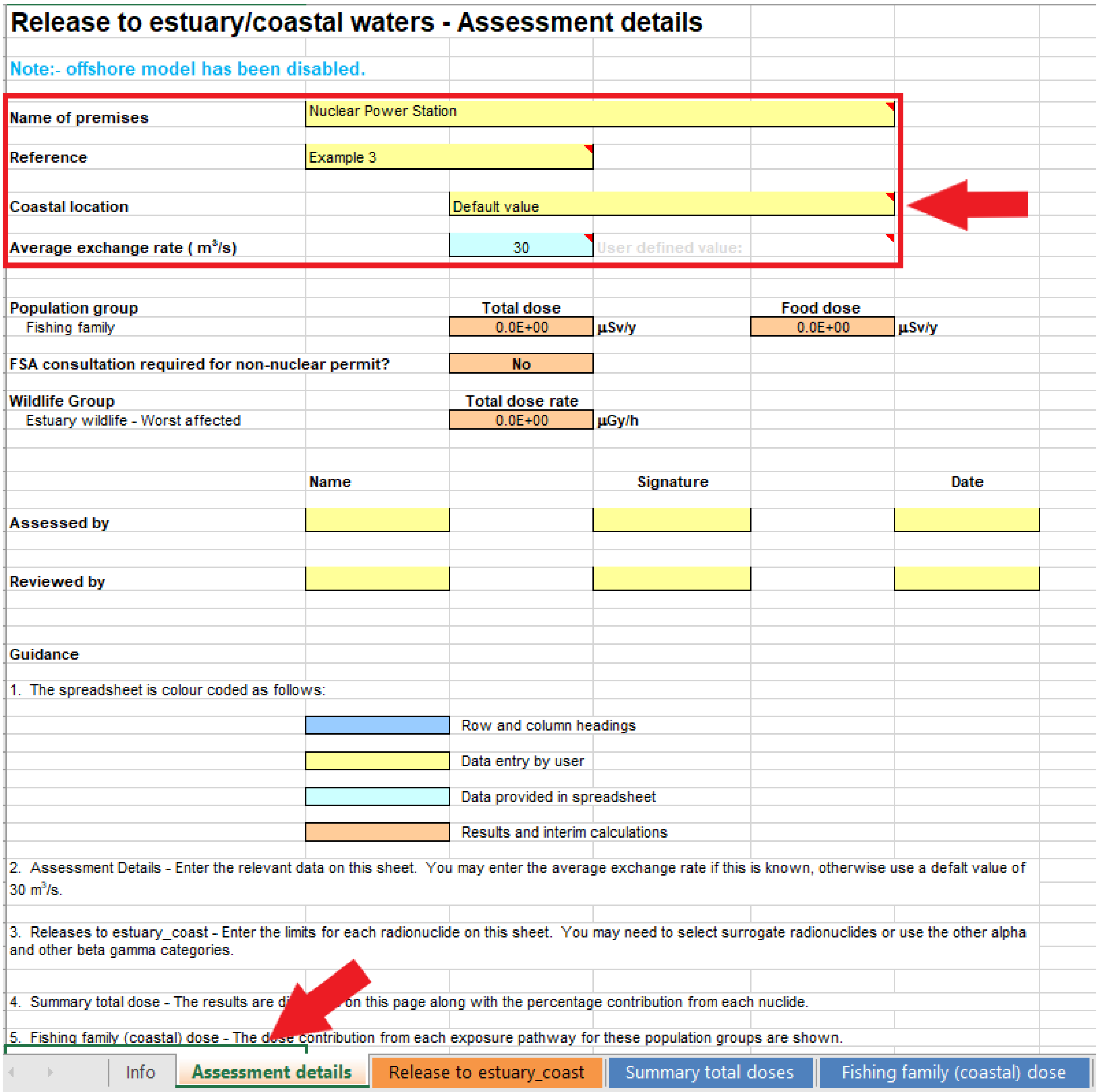


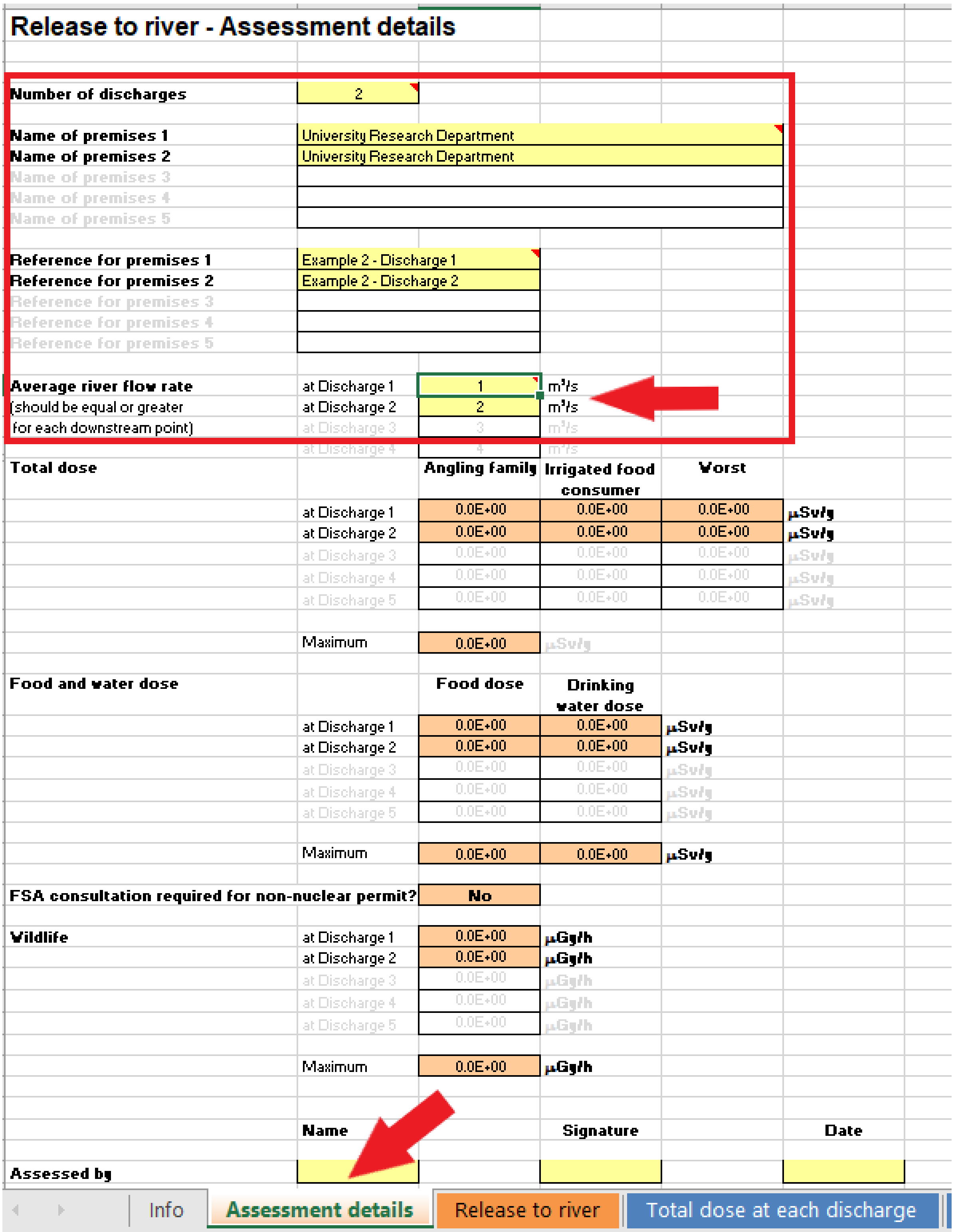
Figure 4. IRAT2 release to estuary/coast stage 1 assessment with assessment details tab completed for Example 3

3.1.3 Release to river

The ‘Assessment details’ tab will prompt you to provide some basic information about the release.

In the release to river scenario, it is possible to assess the impact of multiple discharges which occur at different points along the same river so you will need to enter the number of discharge points.

For Example 2, there are 2 discharge points so in the ‘Assessment details’ tab you should select ‘2’ to ‘Number of discharges’ and enter the name of the premises and a reference. The IRAT2 release to river tool assumes that the flow of the river increases downstream, it is set with a default river flow rate of 1 m^3/s for discharge point 1, 2 m^3/s for discharge point 2, 3 m^3/s for discharge point 3 etc. In a Stage 1 assessment you do not need to change the default river flow rates.



Release to river - Assessment details

Number of discharges	2				
Name of premises 1	University Research Department				
Name of premises 2	University Research Department				
Name of premises 3					
Name of premises 4					
Name of premises 5					
Reference for premises 1	Example 2 - Discharge 1				
Reference for premises 2	Example 2 - Discharge 2				
Reference for premises 3					
Reference for premises 4					
Reference for premises 5					
Average river flow rate	at Discharge 1	1	m³/s		
(should be equal or greater	at Discharge 2	2	m³/s		
for each downstream point)	at Discharge 3	3	m³/s		
	at Discharge 4	4	m³/s		
Total dose		Angling family	Irrigated food consumer	Worst	
	at Discharge 1	0.0E+00	0.0E+00	0.0E+00	µSv/y
	at Discharge 2	0.0E+00	0.0E+00	0.0E+00	µSv/y
	at Discharge 3	0.0E+00	0.0E+00	0.0E+00	µSv/y
	at Discharge 4	0.0E+00	0.0E+00	0.0E+00	µSv/y
	at Discharge 5	0.0E+00	0.0E+00	0.0E+00	µSv/y
	Maximum	0.0E+00	µSv/y		
Food and water dose		Food dose	Drinking water dose		
	at Discharge 1	0.0E+00	0.0E+00	µSv/y	
	at Discharge 2	0.0E+00	0.0E+00	µSv/y	
	at Discharge 3	0.0E+00	0.0E+00	µSv/y	
	at Discharge 4	0.0E+00	0.0E+00	µSv/y	
	at Discharge 5	0.0E+00	0.0E+00	µSv/y	
	Maximum	0.0E+00	0.0E+00	µSv/y	
FSA consultation required for non-nuclear permit?		No			
Wildlife	at Discharge 1	0.0E+00	µGy/h		
	at Discharge 2	0.0E+00	µGy/h		
	at Discharge 3	0.0E+00	µGy/h		
	at Discharge 4	0.0E+00	µGy/h		
	at Discharge 5	0.0E+00	µGy/h		
	Maximum	0.0E+00	µGy/h		
	Name		Signature		Date
Assessed by					

Info | Assessment details | Release to river | Total dose at each discharge

Figure 5. IRAT2 release to river stage 1 assessment with the assessment details tab completed for Example 2

3.1.4 Release to sewer

The ‘Assessment details’ tab will prompt you to provide some basic information about the release. When using the release to sewer spreadsheet tool you must account for all the receiving environments a discharge passes through.

In Example 1, the treated effluent from the sewage treatment works flows to a brook, which then enters a river and then goes into an estuary. Where this is the case, you should select ‘Yes’ to all these receiving environments in the assessment details tab of the tool.

In a stage 1 assessment, you do not need to specify which sewage works the discharge is made to and ‘Default value’ can be selected. Selecting ‘Default value’ will set the average raw sewage flow rate to 60 m^3/s.

The IRAT2 release to sewer tool is set with a default brook flow rate of 0.1 m^3/s and a default river flow rate of 1 m^3/s, in a Stage 1 assessment you do not need to change these values.

In a stage 1 assessment you do not need to specify the coastal location and ‘Default value’ can be selected. Selecting ‘Default value’ will set the average coastal exchange rate to 30 m^3/s, in a stage 1 assessment you do not need to change this.

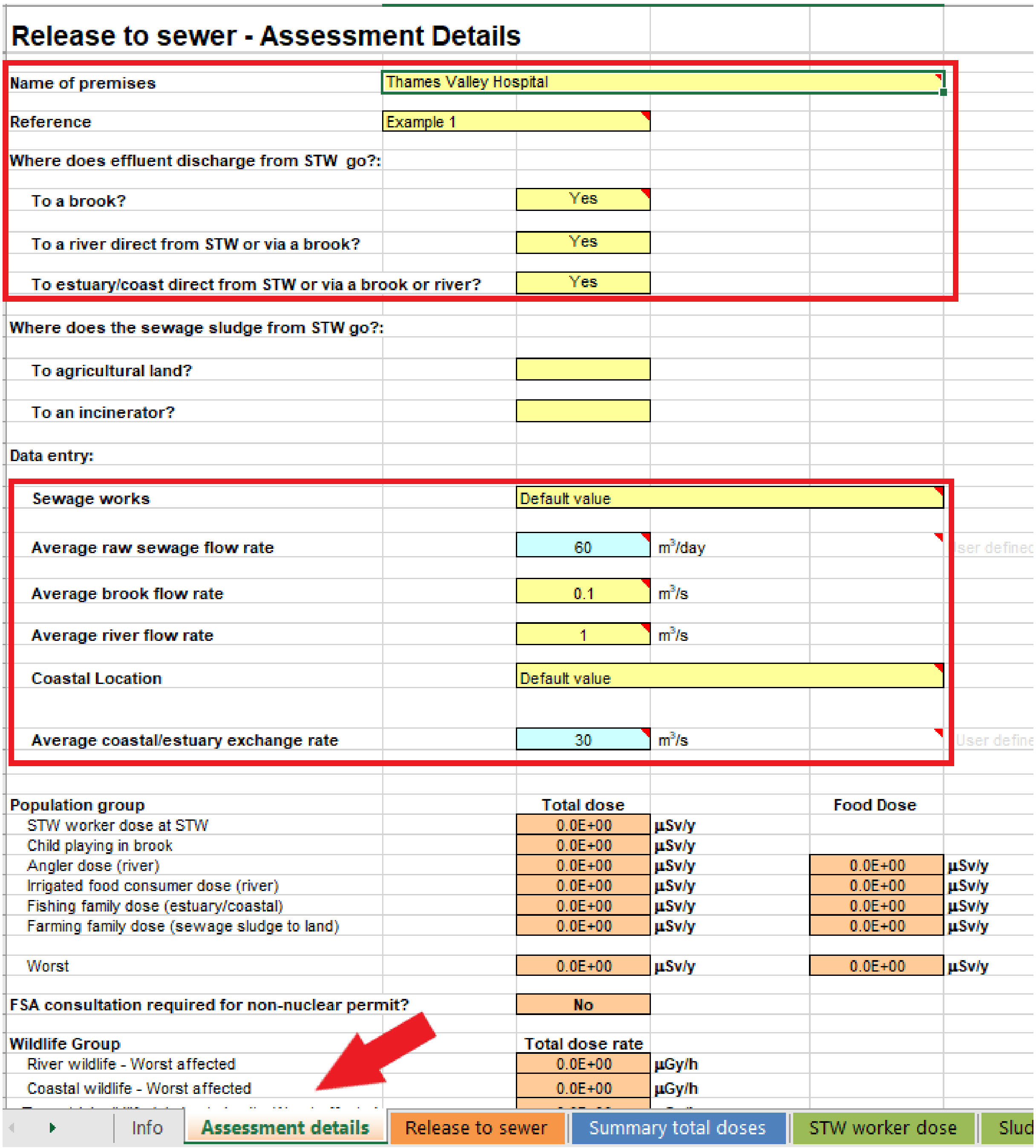
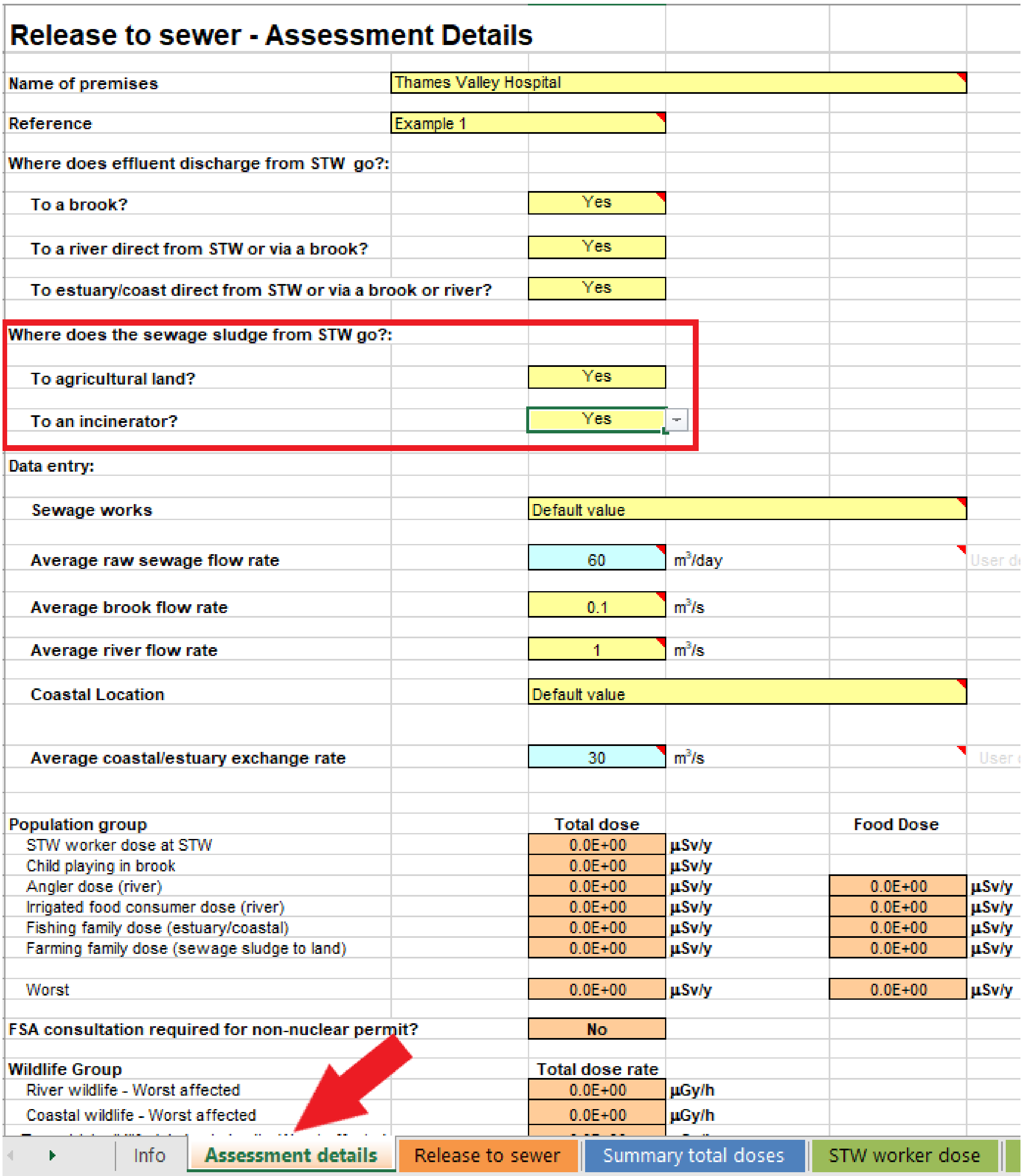


Figure 6. IRAT 2 release to sewer stage 1 assessment with assessment details tab partially completed for Example 1

The release to sewer spreadsheet also allows the user to assess the impact of applying the sewage sludge to land and can be used to begin an assessment of the impact from incinerating the sewage sludge.

In Example 1 no information is provided about what happens to the sewage sludge from the treatment works, where this is the case you should assume that both disposal to land and incineration occur. You should select 'Yes' to both 'To agricultural land?' and 'To an incinerator?' in the 'Assessment details' tab.



Release to sewer - Assessment Details

Name of premises	Thames Valley Hospital				
Reference	Example 1				
Where does effluent discharge from STW go?:					
To a brook?	Yes				
To a river direct from STW or via a brook?	Yes				
To estuary/coast direct from STW or via a brook or river?	Yes				
Where does the sewage sludge from STW go?:					
To agricultural land?	Yes				
To an incinerator?	Yes				
Data entry:					
Sewage works	Default value				
Average raw sewage flow rate	60	m^3/day			User d
Average brook flow rate	0.1	m^3/s			
Average river flow rate	1	m^3/s			
Coastal Location	Default value				
Average coastal/estuary exchange rate	30	m^3/s			User
Population group	Total dose		Food Dose		
STW worker dose at STW	0.0E+00	µSv/y			
Child playing in brook	0.0E+00	µSv/y			
Angler dose (river)	0.0E+00	µSv/y	0.0E+00	µSv/y	
Irrigated food consumer dose (river)	0.0E+00	µSv/y	0.0E+00	µSv/y	
Fishing family dose (estuary/coastal)	0.0E+00	µSv/y	0.0E+00	µSv/y	
Farming family dose (sewage sludge to land)	0.0E+00	µSv/y	0.0E+00	µSv/y	
Worst	0.0E+00	µSv/y	0.0E+00	µSv/y	
FSA consultation required for non-nuclear permit?	No				
Wildlife Group	Total dose rate				
River wildlife - Worst affected	0.0E+00	µGy/h			
Coastal wildlife - Worst affected	0.0E+00	µGy/h			

Info | Assessment details | Release to sewer | Summary total doses | STW worker dose

Figure 7. IRAT2 release to sewer stage 1 assessment with assessment details tab completed for Example 1

The impact of disposal of sewage sludge to agricultural land will be assessed within the release to sewer spreadsheet tool. To assess the impact of a release to sewer where the sludge from the sewage treatment works is sent for incineration, a two-step process must be followed. First, you should use the Initial radiological assessment- sewer tool, selecting 'Yes' to 'To an incinerator?' in the 'Assessment details' tab, as shown in Figure 7. Once you have entered information about the release (see section 3.1.5 below), the spreadsheet tool will calculate a radionuclide inventory in the sludge, which is displayed in the 'Release to Sewer' tab, see Figure 8.

Release to Sewer

Radionuclide	Discharge at Limits	Discharge to incinerator feedstock
	Bq/y	Bq/y
Tritium		0.0E+00
Tritium (Organically Bound)		0.0E+00
Carbon-11		0.0E+00
Carbon-14	6.00E+04	9.0E+03
Fluorine-18		0.0E+00
Sodium-22		0.0E+00
Sodium-24		0.0E+00
Phosphorus-32	4.50E+08	3.0E+08
Phosphorus-33		0.0E+00
Sulphur-35		0.0E+00
Chlorine-36		0.0E+00
Calcium-45		0.0E+00
Calcium-47		0.0E+00
Vanadium-48		0.0E+00
Chromium-51		0.0E+00
Manganese-52		0.0E+00
Manganese-54		0.0E+00
Manganese-56		0.0E+00
Iron-55		0.0E+00
Iron-59		0.0E+00
Cobalt-56		0.0E+00
Cobalt-57		0.0E+00
Cobalt-58		0.0E+00
Cobalt-60	5.00E+07	4.5E+07
Nickel-63		0.0E+00
Copper-61		0.0E+00
Copper-64		0.0E+00
Zinc-62		0.0E+00
Zinc-65		0.0E+00
Gallium-67		0.0E+00
Gallium-68		0.0E+00
Selenium-75		0.0E+00
Bromine-76		0.0E+00
Bromine-77		0.0E+00
Bromine-82		0.0E+00
Rubidium-81		0.0E+00
Rubidium-82		0.0E+00
Rubidium-83		0.0E+00
Strontium-83		0.0E+00
Strontium-85		0.0E+00

Info | Assessment details | Release to sewer | Summary total doses

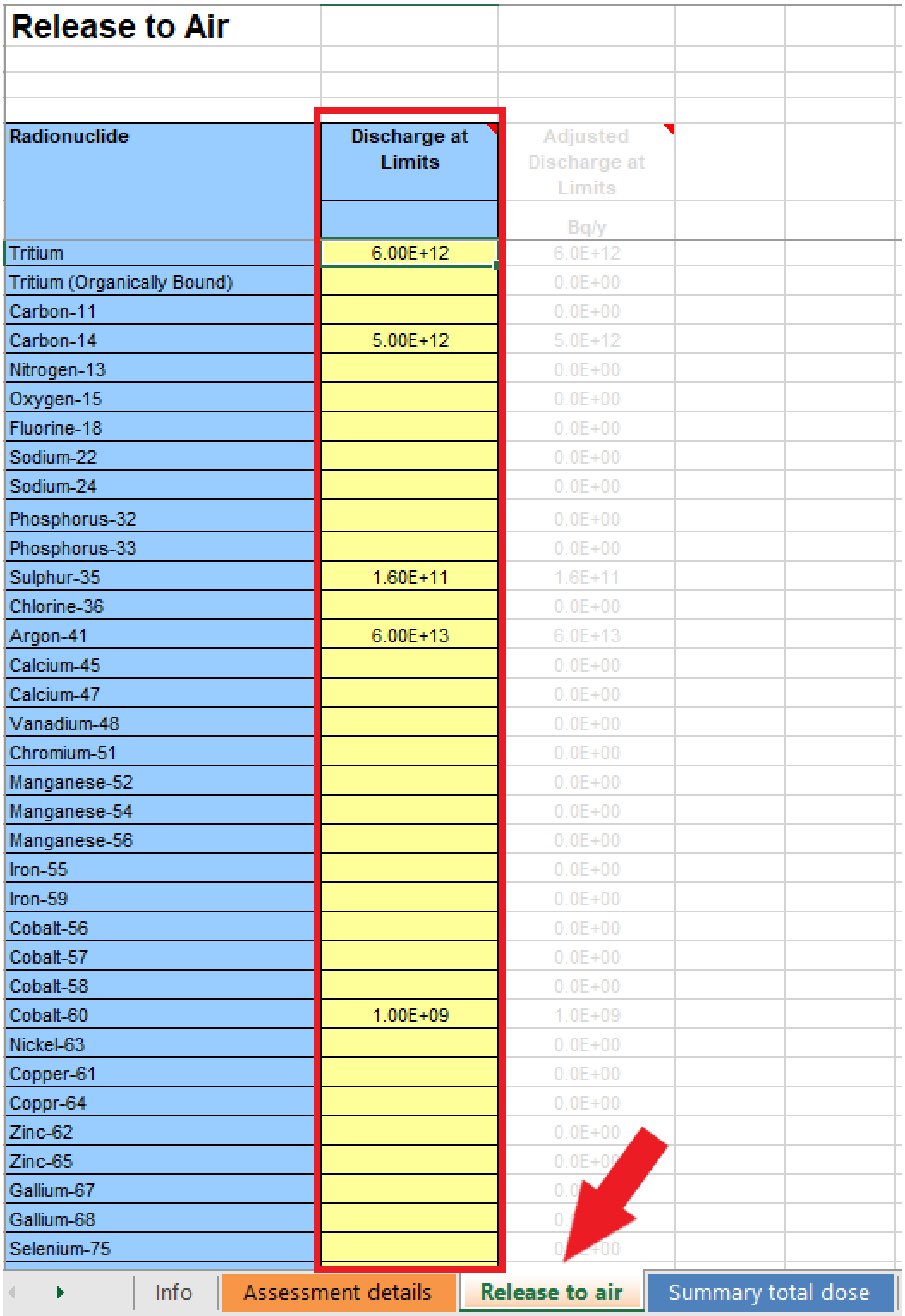
Figure 8. IRAT2 release to sewer stage 1 assessment release to sewer tab with incineration inventory displayed. Discharge figures are illustrative and not related to any of the examples

Once you have completed the steps outlined in section 3.1.5, you can take the values listed in the 'Discharge to incinerator feedstock' column and use this as the annual release data for a new assessment using the release to air tool, following the instructions in section 3.1.1 and 3.2.1.

3.1.5 Inputting the release data

To perform an initial radiological assessment, you must have radionuclide specific information on the discharges to be made to atmosphere, river, estuary or sewer, expressed on an annual basis (that is, Bq/y). This may be in the form of current or proposed annual permit limits or recent annual discharge returns.

This step in any IRAT2 assessment is always the same, you should input the annual discharge information, in Bq/y, into the ‘Release to’ tab of the relevant spreadsheet tool.

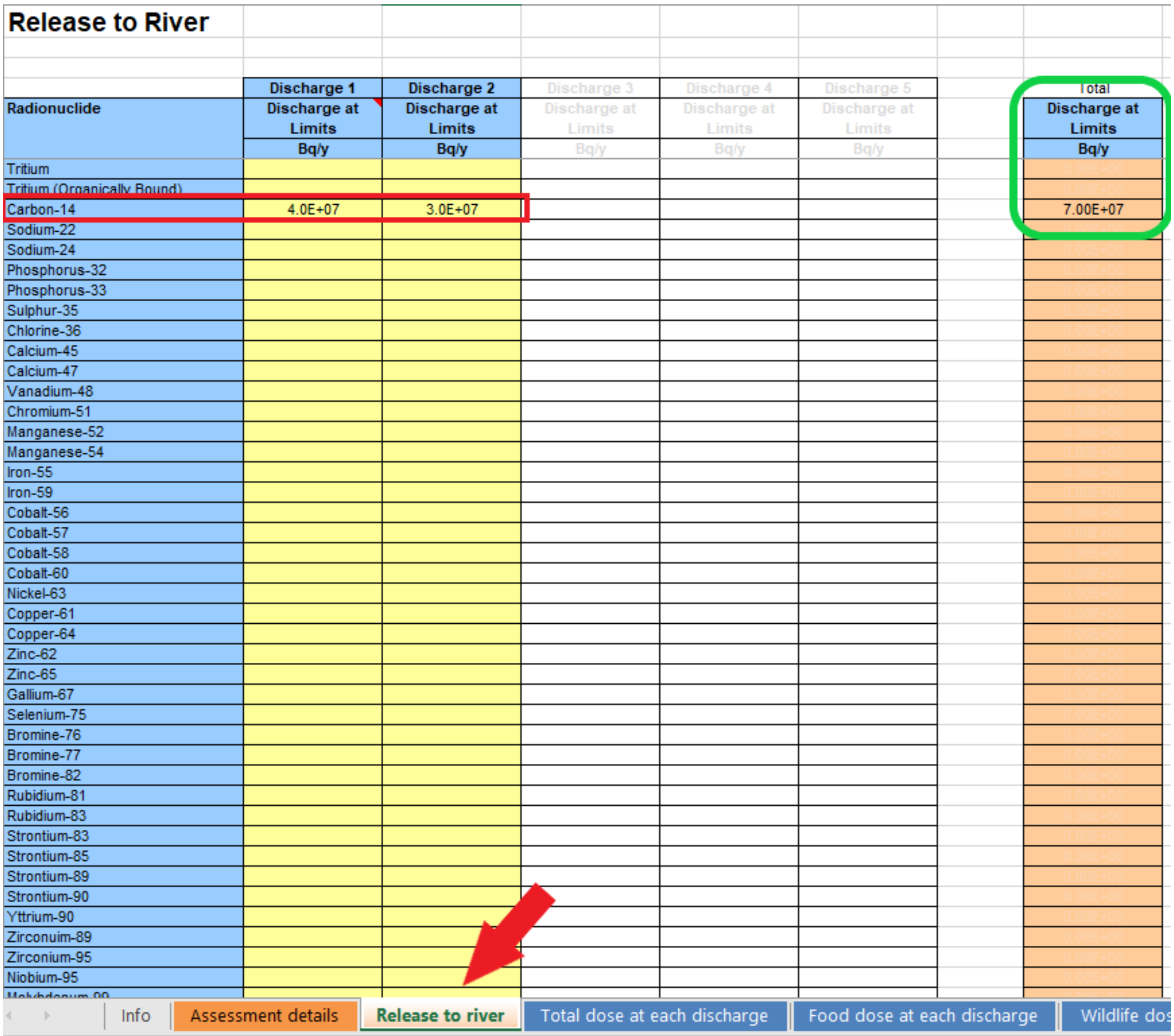


Release to Air

Radionuclide	Discharge at Limits	Adjusted Discharge at Limits Bq/y
Tritium	6.00E+12	6.0E+12
Tritium (Organically Bound)		0.0E+00
Carbon-11		0.0E+00
Carbon-14	5.00E+12	5.0E+12
Nitrogen-13		0.0E+00
Oxygen-15		0.0E+00
Fluorine-18		0.0E+00
Sodium-22		0.0E+00
Sodium-24		0.0E+00
Phosphorus-32		0.0E+00
Phosphorus-33		0.0E+00
Sulphur-35	1.60E+11	1.6E+11
Chlorine-36		0.0E+00
Argon-41	6.00E+13	6.0E+13
Calcium-45		0.0E+00
Calcium-47		0.0E+00
Vanadium-48		0.0E+00
Chromium-51		0.0E+00
Manganese-52		0.0E+00
Manganese-54		0.0E+00
Manganese-56		0.0E+00
Iron-55		0.0E+00
Iron-59		0.0E+00
Cobalt-56		0.0E+00
Cobalt-57		0.0E+00
Cobalt-58		0.0E+00
Cobalt-60	1.00E+09	1.0E+09
Nickel-63		0.0E+00
Copper-61		0.0E+00
Coppr-64		0.0E+00
Zinc-62		0.0E+00
Zinc-65		0.0E+0
Gallium-67		0.0
Gallium-68		0.
Selenium-75		0 E+00

Figure 9. IRAT2 release to air stage 1 assessment release to air tab with discharges entered for Example 3

The 'Release to...' tab looks the same for most of the spreadsheet tools, the only exception is the release to river spreadsheet tool which allows the user to enter discharge information for multiple releases. For Example 2, there are 2 discharge points so in the 'Release to river' tab you should add the information about each discharge into separate columns. When you add discharges from multiple release points the tool will automatically calculate a total, you cannot adjust the total column.

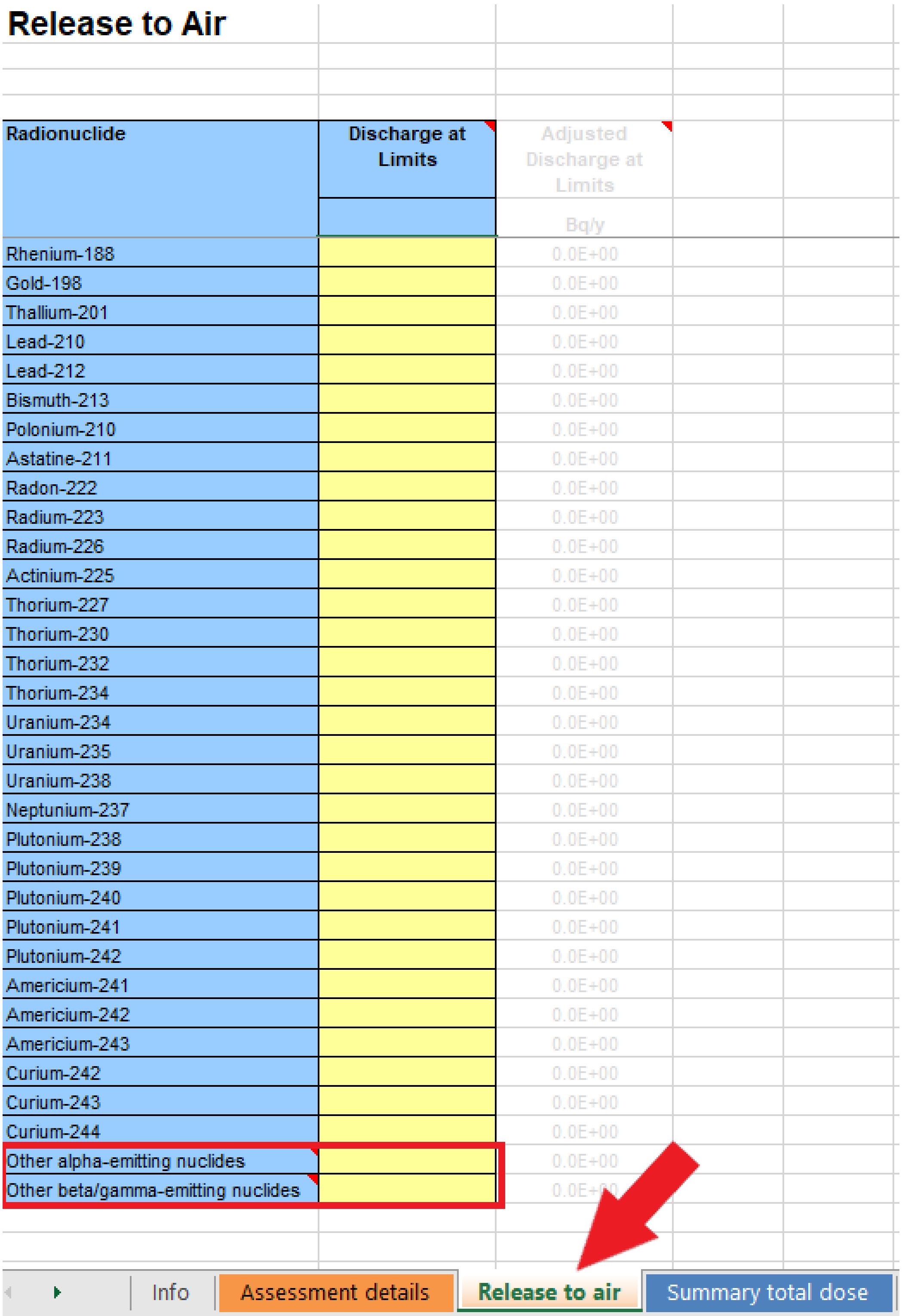


Release to River

Radionuclide	Discharge 1 Discharge at Limits Bq/y	Discharge 2 Discharge at Limits Bq/y	Discharge 3 Discharge at Limits Bq/y	Discharge 4 Discharge at Limits Bq/y	Discharge 5 Discharge at Limits Bq/y	Total Discharge at Limits Bq/y
Tritium						
Tritium (Organically Bound)						
Carbon-14	4.0E+07	3.0E+07				7.00E+07
Sodium-22						
Sodium-24						
Phosphorus-32						
Phosphorus-33						
Sulphur-35						
Chlorine-36						
Calcium-45						
Calcium-47						
Vanadium-48						
Chromium-51						
Manganese-52						
Manganese-54						
Iron-55						
Iron-59						
Cobalt-56						
Cobalt-57						
Cobalt-58						
Cobalt-60						
Nickel-63						
Copper-61						
Copper-64						
Zinc-62						
Zinc-65						
Gallium-67						
Selenium-75						
Bromine-76						
Bromine-77						
Bromine-82						
Rubidium-81						
Rubidium-83						
Strontium-83						
Strontium-85						
Strontium-89						
Strontium-90						
Yttrium-90						
Zirconuim-89						
Zirconium-95						
Niobium-95						

Figure 10. IRAT2 release to river stage 1 assessment release to river tab with discharges entered for Example 2

In some cases radionuclide-specific information may not be available, and the discharges may be expressed as ‘other radionuclides ’or ‘other beta/gamma etc. In the absence of more detailed information on the release, the default ‘other alpha’ and ‘other beta/gamma’ categories, found at the bottom of the list of radionuclides, in IRAT2 can be used.



Release to Air

Radionuclide	Discharge at Limits	Adjusted Discharge at Limits Bq/y
Rhenium-188		0.0E+00
Gold-198		0.0E+00
Thallium-201		0.0E+00
Lead-210		0.0E+00
Lead-212		0.0E+00
Bismuth-213		0.0E+00
Polonium-210		0.0E+00
Astatine-211		0.0E+00
Radon-222		0.0E+00
Radium-223		0.0E+00
Radium-226		0.0E+00
Actinium-225		0.0E+00
Thorium-227		0.0E+00
Thorium-230		0.0E+00
Thorium-232		0.0E+00
Thorium-234		0.0E+00
Uranium-234		0.0E+00
Uranium-235		0.0E+00
Uranium-238		0.0E+00
Neptunium-237		0.0E+00
Plutonium-238		0.0E+00
Plutonium-239		0.0E+00
Plutonium-240		0.0E+00
Plutonium-241		0.0E+00
Plutonium-242		0.0E+00
Americium-241		0.0E+00
Americium-242		0.0E+00
Americium-243		0.0E+00
Curium-242		0.0E+00
Curium-243		0.0E+00
Curium-244		0.0E+00
Other alpha-emitting nuclides		0.0E+00
Other beta/gamma-emitting nuclides		0.0E+00

Figure 11. IRAT2 release to air spreadsheet tool showing the other alpha and other beta categories at the bottom of the release to air tab

3.1.6 Assessing the doses to people and dose rate to wildlife

Once you have entered information about the release you can read off the calculated dose or dose rate from the ‘Assessment details’ tab.

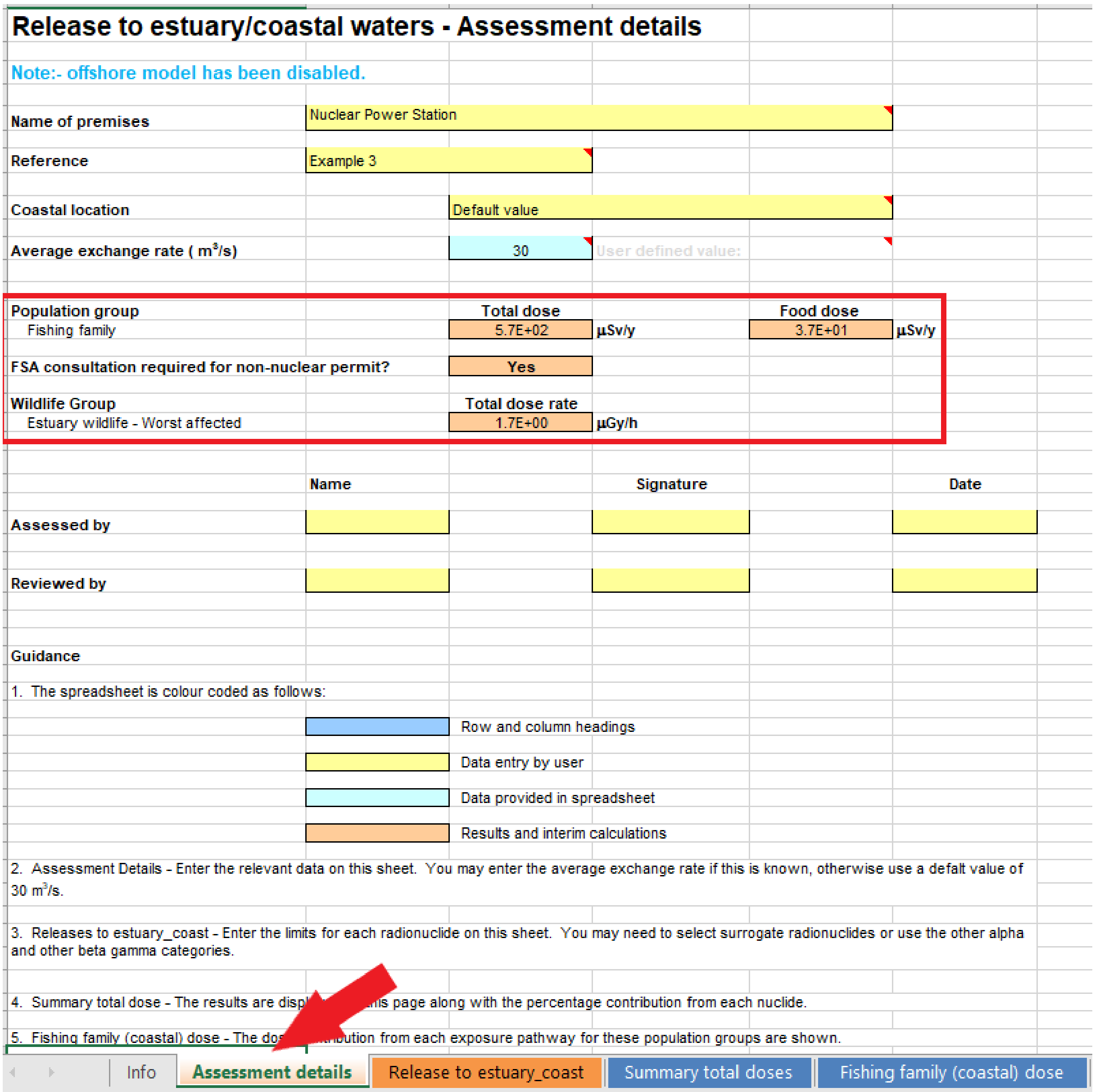
This information is displayed slightly differently in each spreadsheet tool due to the number of population exposure groups assessed. However, all the spreadsheet tools provide the total dose to the worst affected population exposure group, the contribution to the dose from food pathways and the dose rate to the worst affected reference organism.

For the release to air and estuary/coast scenarios, only one population exposure group is assessed so the tool will display the annual dose to that exposure group. The dose displayed is for the worst affected age group.

For the river and sewer release scenarios, doses to more than one population exposure group are assessed so the spreadsheet tool will display the total dose to each population exposure group and identify which is the worst affected.

The spreadsheet tools will also display the dose rate to the wildlife exposure group. The dose rate displayed is for the worst affected reference organism. As with population exposure groups, in the sewer scenario there may be more than one environment and wildlife exposure group affected. The spreadsheet tool will display the highest dose rate to wildlife in each environment. The user will need to identify which receives highest dose rate.

Figures 12-15 show what the assessment details tab looks like for each of the spreadsheet tools, completed using data from Examples 1-3.



Release to estuary/coastal waters - Assessment details

Note:- offshore model has been disabled.

Name of premises	Nuclear Power Station			
Reference	Example 3			
Coastal location		Default value		
Average exchange rate (m^3/s)		30	User defined value:	
Population group		Total dose		Food dose
Fishing family		5.7E+02	µSv/y	3.7E+01 µSv/y
FSA consultation required for non-nuclear permit?		Yes		
Wildlife Group		Total dose rate		
Estuary wildlife - Worst affected		1.7E+00	µGy/h	

	Name	Signature	Date
Assessed by			
Reviewed by			

Guidance

1. The spreadsheet is colour coded as follows:

Row and column headings

Data entry by user

Data provided in spreadsheet

Results and interim calculations

2. Assessment Details - Enter the relevant data on this sheet. You may enter the average exchange rate if this is known, otherwise use a defalt value of 30 m^3/s.

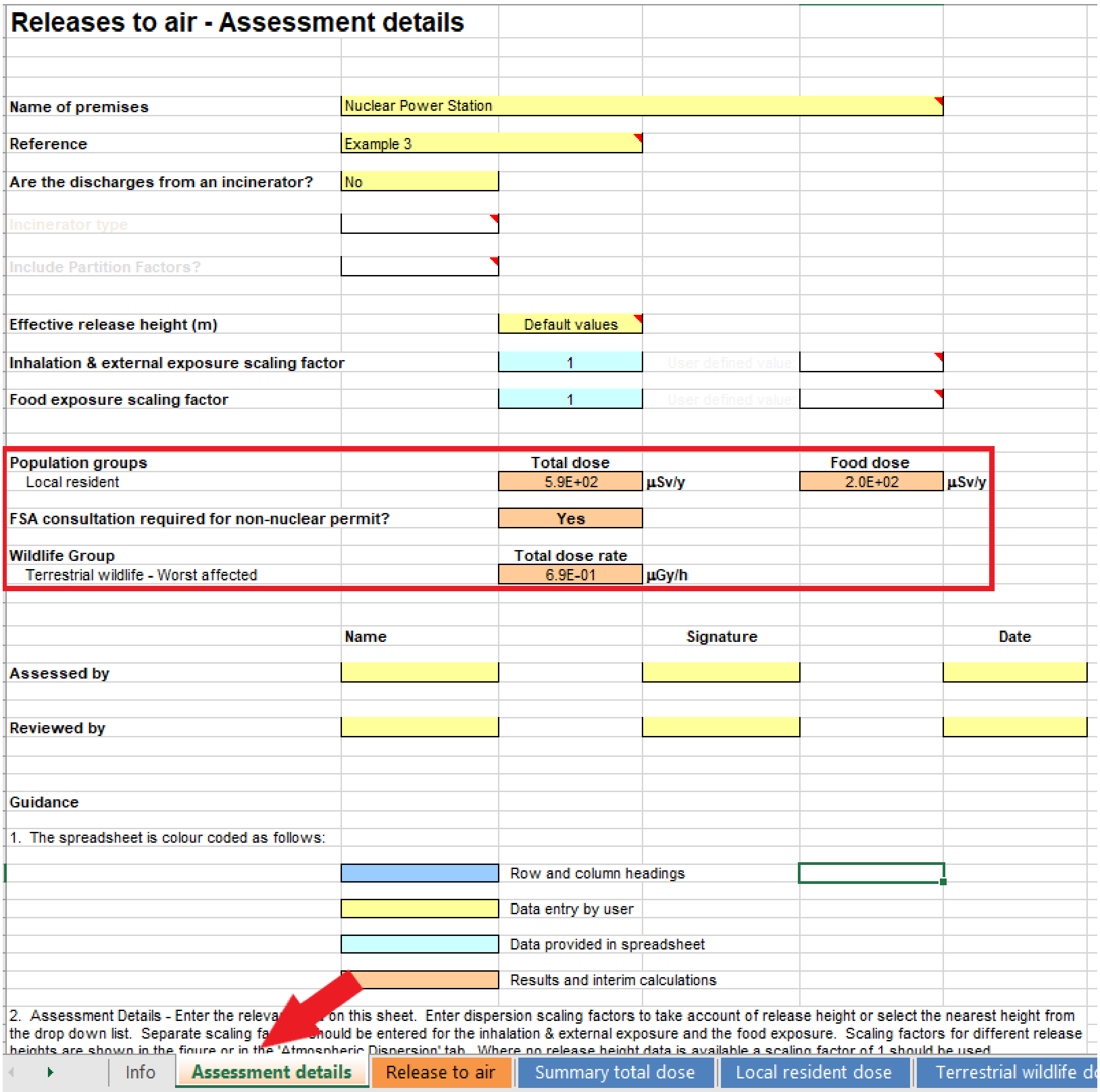
3. Releases to estuary_coast - Enter the limits for each radionuclide on this sheet. You may need to select surrogate radionuclides or use the other alpha and other beta gamma categories.

4. Summary total dose - The results are displ[...]is page along with the percentage contribution from each nuclide.

5. Fishing family (coastal) dose - The dos[...]ribution from each exposure pathway for these population groups are shown.

Info | Assessment details | Release to estuary_coast | Summary total doses | Fishing family (coastal) dose

Figure 12. IRAT2 release to estuary/coast stage 1 assessment results for Example 3



Releases to air - Assessment details

Name of premises	Nuclear Power Station				
Reference	Example 3				
Are the discharges from an incinerator?	No				
Incinerator type					
Include Partition Factors?					
Effective release height (m)		Default values			
Inhalation & external exposure scaling factor		1	User defined value		
Food exposure scaling factor		1	User defined value		
Population groups		Total dose		Food dose	
Local resident		5.9E+02	µSv/y	2.0E+02	µSv/y
FSA consultation required for non-nuclear permit?		Yes			
Wildlife Group		Total dose rate			
Terrestrial wildlife - Worst affected		6.9E-01	µGy/h		
	Name		Signature		Date
Assessed by					
Reviewed by					

Guidance

1. The spreadsheet is colour coded as follows:

Row and column headings

Data entry by user

Data provided in spreadsheet

Results and interim calculations

2. Assessment Details - Enter the releva[...] on this sheet. Enter dispersion scaling factors to take account of release height or select the nearest height from the drop down list. Separate scaling fa[...]hould be entered for the inhalation & external exposure and the food exposure. Scaling factors for different release heights are shown in the figure or in the 'Atmospheric Dispersion' tab. Where no release height data is available a scaling factor of 1 should be used.

Info | Assessment details | Release to air | Summary total dose | Local resident dose | Terrestrial wildlife d

Figure 13. IRAT2 release to air spreadsheet tool stage 1 assessment results for Example 3

Release to river - Assessment details

Number of discharges	2			
Name of premises 1	University Research Department			
Name of premises 2	University Research Department			
Name of premises 3				
Name of premises 4				
Name of premises 5				
Reference for premises 1	Example 2 - Discharge 1			
Reference for premises 2	Example 2 - Discharge 2			
Reference for premises 3				
Reference for premises 4				
Reference for premises 5				

Average river flow rate	at Discharge 1	1	m^3/s
(should be equal or greater	at Discharge 2	2	m^3/s
for each downstream point)	at Discharge 3	3	m^3/s
	at Discharge 4	4	m^3/s

Total dose		Angling family	Irrigated food consumer	Worst	
	at Discharge 1	7.5E+00	6.3E-03	7.5E+00	µSv/y
	at Discharge 2	6.6E+00	2.6E-02	6.6E+00	µSv/y
	at Discharge 3	0.0E+00	0.0E+00	0.0E+00	µSv/y
	at Discharge 4	0.0E+00	0.0E+00	0.0E+00	µSv/y
	at Discharge 5	0.0E+00	0.0E+00	0.0E+00	µSv/y
	Maximum	7.5E+00	µSv/y		

Food and water dose		Food dose	Drinking water dose	
	at Discharge 1	7.5E+00	5.6E-04	µSv/y
	at Discharge 2	6.6E+00	1.9E-02	µSv/y
	at Discharge 3	0.0E+00	0.0E+00	µSv/y
	at Discharge 4	0.0E+00	0.0E+00	µSv/y
	at Discharge 5	0.0E+00	0.0E+00	µSv/y
	Maximum	7.5E+00	1.9E-02	µSv/y

FSA consultation required for non-nuclear permit?	No

		Total dose rate	
Wildlife	at Discharge 1	6.2E-03	µGy/h
	at Discharge 2	5.9E-03	µGy/h
	at Discharge 3	0.0E+00	µGy/h
	at Discharge 4	0.0E+00	µGy/h
	at Discharge 5	0.0E+00	µGy/h
	Maximum	6.2E-03	µGy/h

Info | Assessment details | Release to river | Total dose at each discharge | Food d

Figure 14. IRAT2 release to river stage 1 assessment results for Example 2

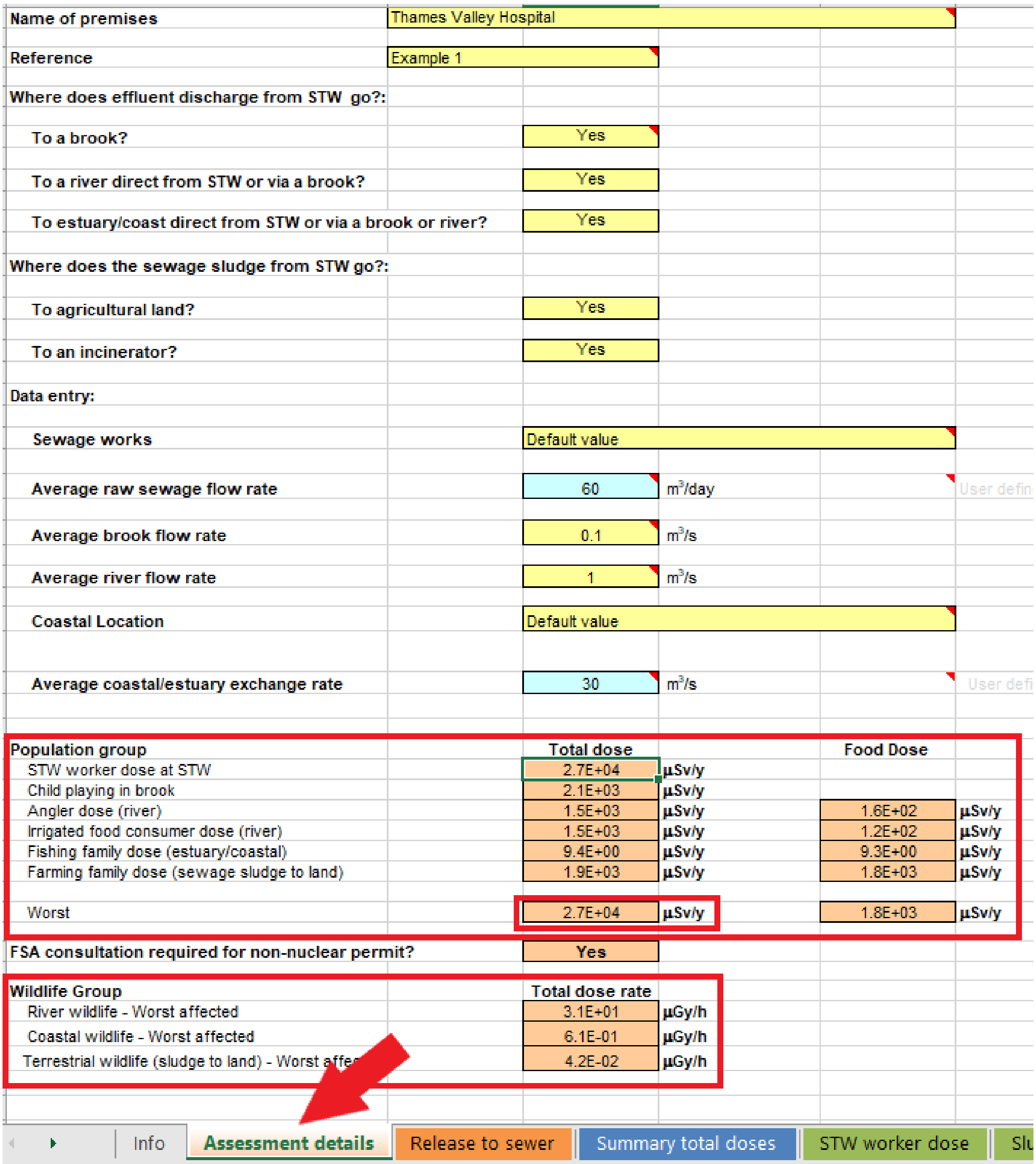


Figure 15. IRAT2 release to sewer stage 1 assessment results for Example 1

Where discharges from a site occur by more than one route (for example, to air and to sewer) you can sum up the initial assessment doses calculated for each discharge route to give a total.

For wildlife you should sum up the dose rates for the worst affected terrestrial and freshwater organisms and the dose rates for the worst affected terrestrial and estuary/coastal organisms. This leads to a cautious initial assessment allowing for the fact that some organisms can occupy more than one type of environment and may be exposed to several discharge routes. You can refine this in stage 2.

You can also establish if direct radiation exposure of the public outside the site is known to occur from on-site sources and include this in the total. We do not prescribe a methodology for the assessment of direct radiation, but this can be done by measurement or calculation.

Now you have an estimate of the impact you can compare the predicted doses with relevant thresholds to determine if further assessment is required. The Environment Agency uses a screening threshold of 20 uSv/y for people and 1 µGy/h for wildlife to decide if further assessment is necessary. If the total dose to the worst affected group is >20 uSv/y or the dose rate to wildlife is > 1 µGy/h then we would follow the steps in Section 3.2 to undertake a refined assessment using IRAT2.

3.2 Refining assessments made using the initial radiological assessment methodology

Now you have an assessment set up, refinements can be made to each scenario to make the assessment more realistic. These refinements can be made by manually adjusting the calculations (see Appendix A) or by entering more specific information about the release into the relevant spreadsheet tool. This aligns with a Stage 2 assessment in our Environment Agency process shown in Figure 1.

To make refinements it's important to understand some of the key assumptions built into the DPUR factors so that you can assess whether they are realistic and whether adjustments are appropriate. The key assumptions built into the DPUR factors for each release scenario are listed in sections 3.2.1 – 3.2.4.

A key refinement for all discharge scenarios which can be made during a Stage 2 assessment is to review how realistic any use of the default 'other alpha' and 'other beta/gamma' categories has been. You may be able to substitute them with specific radionuclides if the typical composition of the discharge is known. If no such information is available, Table 16 shows suggested radionuclides which result in the highest doses in each category. You should consider how appropriate the suggested substitutions listed in Table 16 are for the assessment before using them (e.g. fission products would not be suitable for a non-nuclear site).

3.2.1 Releases to air

Key assumptions built into the DPUR factor:

- the release is at ground level
- the local resident is assumed to be located 100 m from the release point, residing there for 100% of the time
- Food is assumed to be produced at 500 m from the release point.
- Radionuclides with half-lives of less than 3 hours have not been considered for the consumption of terrestrial food as the radionuclides would have decayed before any significant exposure can occur
- Terrestrial wildlife, assessed as terrestrial reference organisms, are assumed to be 100 m from the release point

Refining the assessment

Stacks may discharge to the atmosphere well above ground level which affects how the discharge is dispersed in the environment. Scaling factors can be used to account for different release heights and dispersion. A graph of dispersion scaling factors for releases to air is provided in Figure 16, this is also displayed in the ‘Assessment details’ tab of the ‘Release to air’ spreadsheet tool.

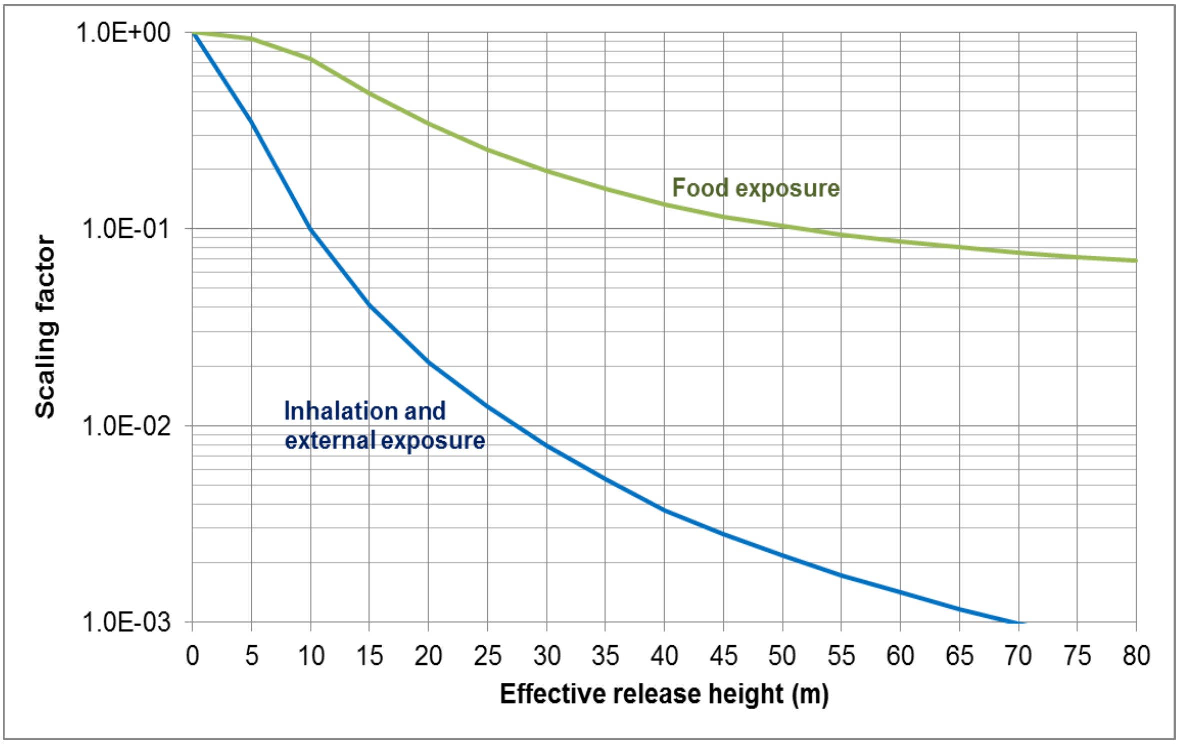


Figure 16. Scaling factors for different release heights for releases to air

The scaling factors for the inhalation and external dose pathways have been derived from the maximum ground-level concentration for each release height (at a distance no closer than 100 m to the release point) divided by the maximum ground-level concentration at 100 m for a ground-level release (7E-05 Bq/m^3 per Bq/s). Similarly, the scaling factors for the food dose pathway are derived from the maximum ground-level concentration for each release height (at a distance no closer than 500 m to the release point) divided by the maximum ground-level concentration at 500 m for a ground-level release (4E-06 Bq/m^3 per Bq/s).

There are two sets of scaling factors, one scaling factor which can be applied to the inhalation and external radiation exposure pathways while another scaling factor is applied to the food consumption exposure pathways. There are separate scaling factors for these pathways because the location at which the local resident is exposed to the discharge via the inhalation and external pathways is assumed to be nearer to the release point than the location where they source their food. For terrestrial wildlife, the food exposure scaling factors from Figure 16 are applied.

To refine the assessment you can adjust the effective release height (Figure 17) or adjust the scaling factors (Figure 18). In Example 3, the effective stack height is known to be 20 m, so in the ‘Assessment details’ tab you can change the ‘Effective release height’ to 20 m. Changing the effective release height will automatically adjust the scaling factors. The stack height adjustment is in 5m steps. For intermediate stack heights scaling factors (Figure 16) can be used.

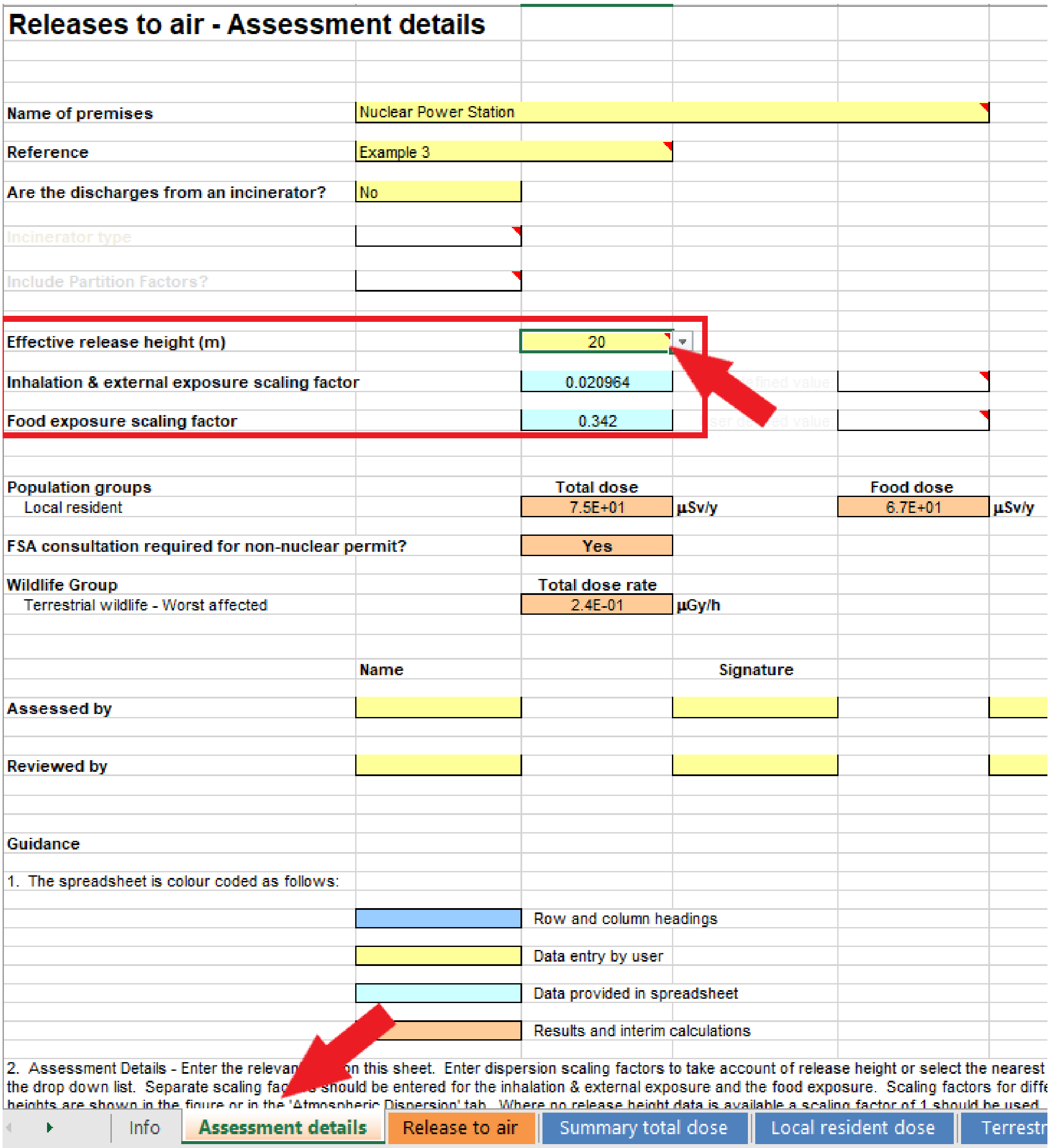


Figure 17. IRAT2 release to air stage 2 refined assessment with assessment details completed for Example 3, with an effective release height selected

You can also manually change the scaling factors by selecting ‘User defined’ for the ‘Effective release height’ and then manually entering scaling factors in the ‘User defined value’ cells. You can do this by reading scaling factors off the graph (Figure 16) for a given release height.

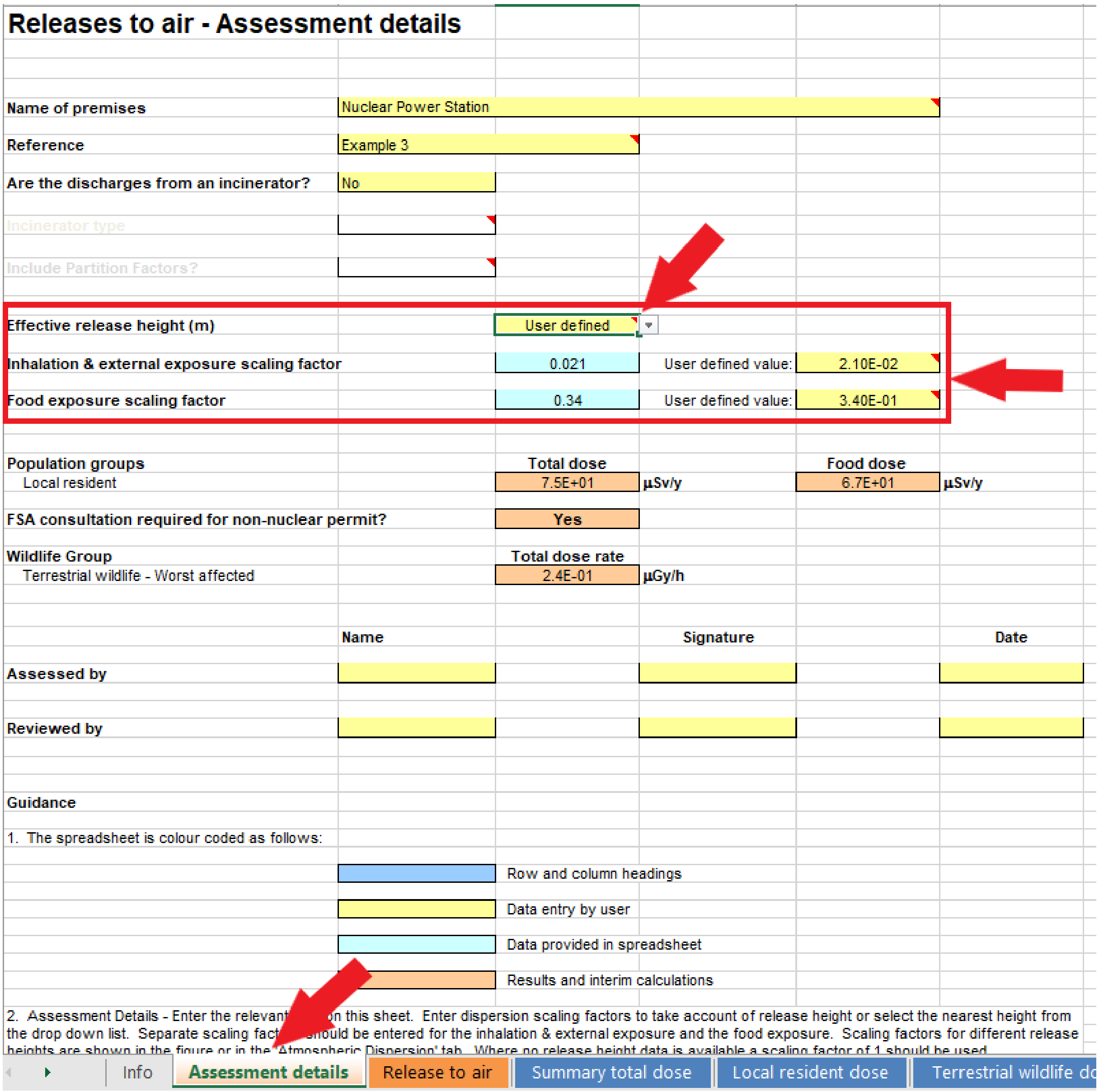


Figure 18. IRAT 2 release to air stage 2 refined assessment with assessment details completed for Example 3, selecting user defined scaling factors

Incineration of waste

Where the release to air is from an incinerator, and the permit is defined in terms of quantities of radionuclides disposed of in feedstock to the incinerator, you can refine the assessment to account for the behaviour of the radionuclides within the incinerator. i.e. their partitioning between the various waste streams produced; including exhaust or off-gases, ash and abatement by-products.

In a stage 1 assessment you can assume that the disposal in the feedstock is equivalent to the discharge from the top of the stack, i.e. the quantity of radionuclides disposed of by incineration is discharged 100% to air.

In a stage 2 assessment, partitioning factors can be applied. The partitioning factors we have used in the methodology are radioelement specific and take account of the retention of less volatile radionuclides (including metals) in bottom ash, fly ash and in abatement materials such as filters and wet abatement waste products in the incineration process.

The partitioning factors used are described in the accompanying report Initial Radiological Assessment Tool 2 – Part 2 methods and input data [5] and are shown in Table 15. They are also visible in the 'incinerator partitioning' tab in the spreadsheet tool.

To apply incineration partitioning factors you need to know what kind of abatement system is used in the incinerator. The spreadsheet tool offers two sets of generalised partitioning factors, one for wet-gas cleaned incineration and one for dry-gas cleaned incineration.

To refine the assessment using incineration partitioning factors, in the 'Assessment details' tab you can select 'Yes' to 'Are these discharges to an incinerator?', then select an incineration type and then select 'Yes' to 'Include partition factors?'. You can also refine the effective release height as described above.

The IRAT methodology can also be used to assess the impact of sewage sludge disposal via incineration using a two-step process which is described in section 3.1.4.

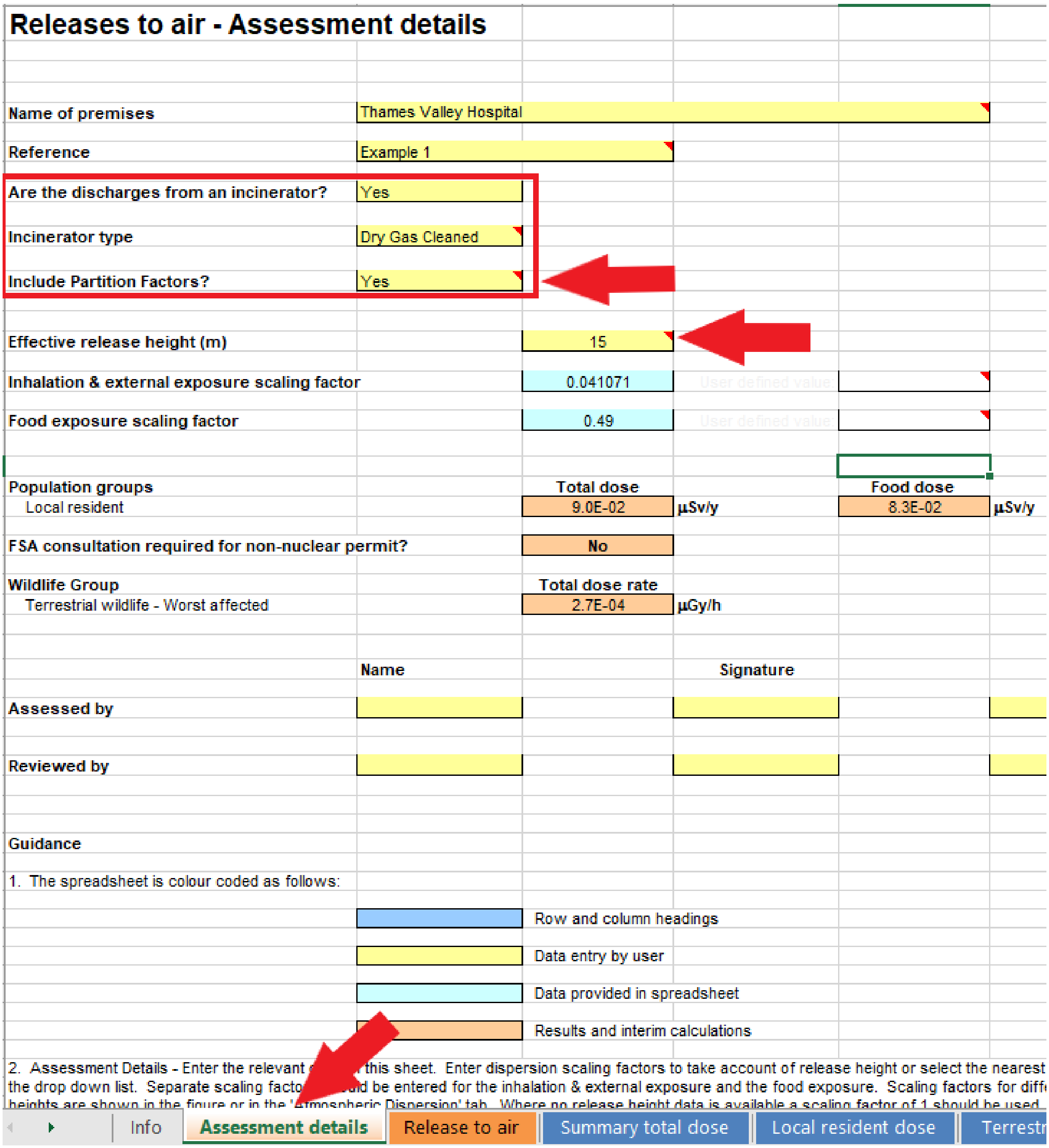


Figure 19. IRAT2 release to air stage 2 refined assessment with assessment details tab completed for Example 1 applying partitioning factors and selecting an effective release height

Once you have refined the assessment, you can follow the same steps outlined in section 3.1.6 to assess the total impact on people and wildlife and compare the outcomes to relevant thresholds or criteria.

3.2.2 Releases to estuary or coast

Key assumptions built into the DPUR factors:

- Radionuclides with half-lives of less than 3 hours have not been considered as the half-life is sufficiently short that the radionuclide would have decayed before any significant exposure can occur
- All shellfish and 50% of the fish are caught from a ‘local compartment’, which might be an estuary or the coastal area immediately local to the discharge. The other 50% of the fish are assumed to be caught in a larger surrounding region, termed the ‘regional compartment’.
- DPUR factors are calculated using a volumetric exchange rate of 100 m^3/s
- Coastal wildlife, assessed as marine reference organisms, are assumed to dwell in the sea immediately offshore from the point of release.

Refining the assessment

A key parameter of the model used to generate the DPURs is the rate at which water flows through the compartments of the coastal environment. This is termed the water ‘volumetric exchange rate’ and is related to the net current through the region. A default water exchange of 100 m^3/s is assumed in the DPUR calculation, however, for some small estuaries lower exchange rates (e.g. 30 m^3/s) may occur so in a stage 1 assessment the DPUR is automatically scaled by the tool to assume a volumetric exchange rate of 30 m^3/s. The water exchange rate affects how the discharge is dispersed in the environment.

To refine the assessment, site-specific data about the volumetric water exchange rate can be used. For Example 3, the water exchange rate at the discharge location is known to be 130 m^3/s so in the Assessment details tab you can select ‘User defined’ for the coastal location and then enter the water exchange rate into the ‘User defined value’ cell.

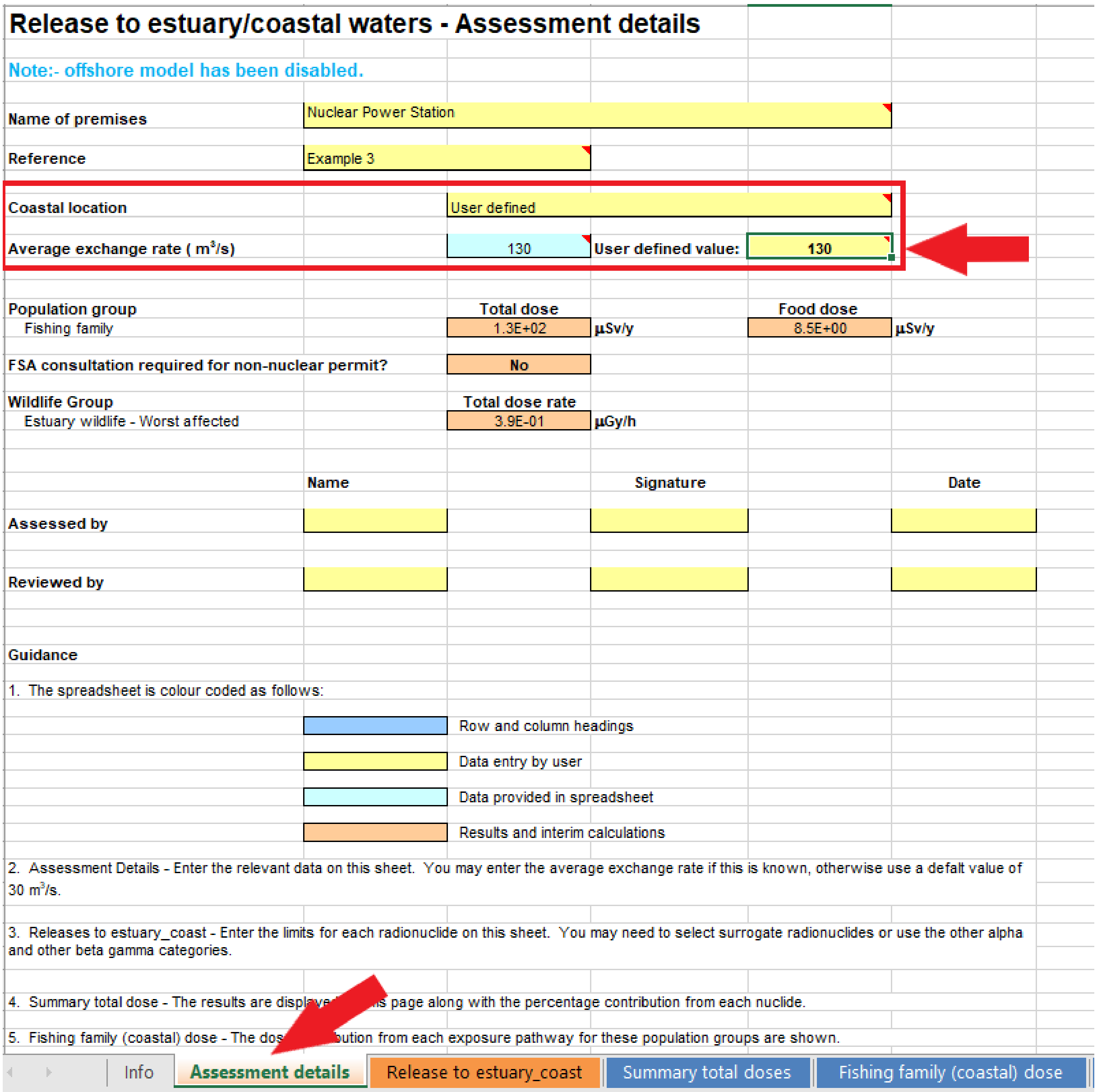


Figure 20. IRAT2 release to estuary/coast stage 2 assessment with assessment details tab completed for Example 3 selecting a user defined average coastal exchange rate

The IRAT2 release to estuary/coast tool includes information about the volumetric exchange rate for various locations around England and Wales. So, if the coastal location is known, this can be selected from the 'Coastal location' drop down list and the tool will populate the average exchange rate with the water exchange rate at the selected location. The full list, and some further details about the coastal exchange rates included in the tool can be found in the 'Coastal exchange rates tab', a random selection is shown below.

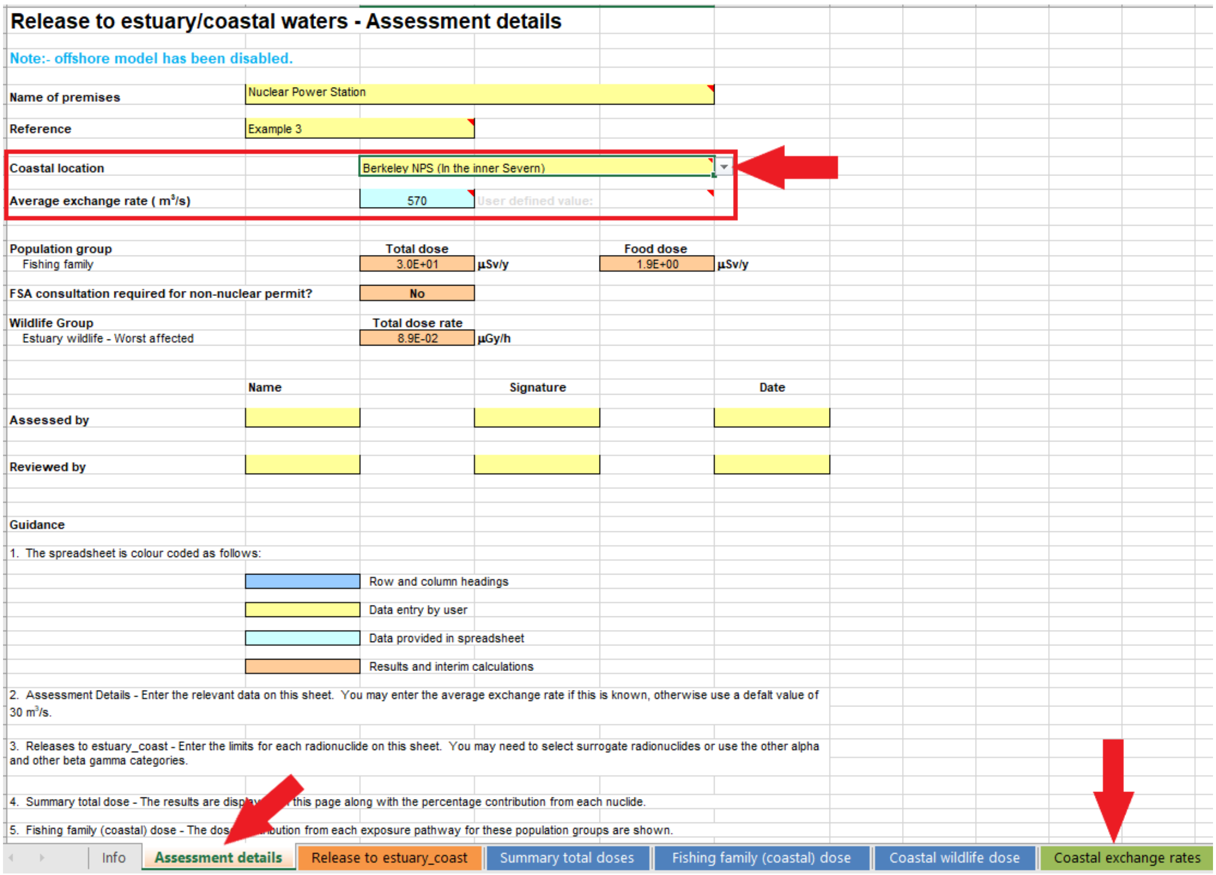


Figure 21. IRAT2 release to estuary/coast stage 2 assessment with assessment details tab completed for Example 3, selecting a coastal location

Once you have refined the assessment, you can follow the same steps outlined in section 3.1.6 to assess the total impact on people and wildlife and compare the outcomes to relevant thresholds or criteria.

3.2.3 Releases to river

Key assumptions built into the DPUR factors:

- Radionuclides with half-lives of less than 3 hours have not been considered as the half-life is sufficiently short that the radionuclide would have decayed before any significant exposure can occur via these scenarios.
- The river has a default flow rate of 1 m^3/s
- Fish are caught and water is abstracted close to the release point into the river.
- River wildlife, assessed as freshwater reference organisms, are assumed to be located close to the release point into the river.

Refining the assessment

A low default volumetric flow rate of 1 m^3/s is assumed in the in the DPUR calculation, most rivers have a higher flow rate than this which will affect how the discharge is dispersed in the environment. You can refine the river flow rate in the release to river spreadsheet tool.

For Example 2, there are two discharge points so you on the ‘Assessment details’ tab you can enter the average river flow rate at each discharge point.

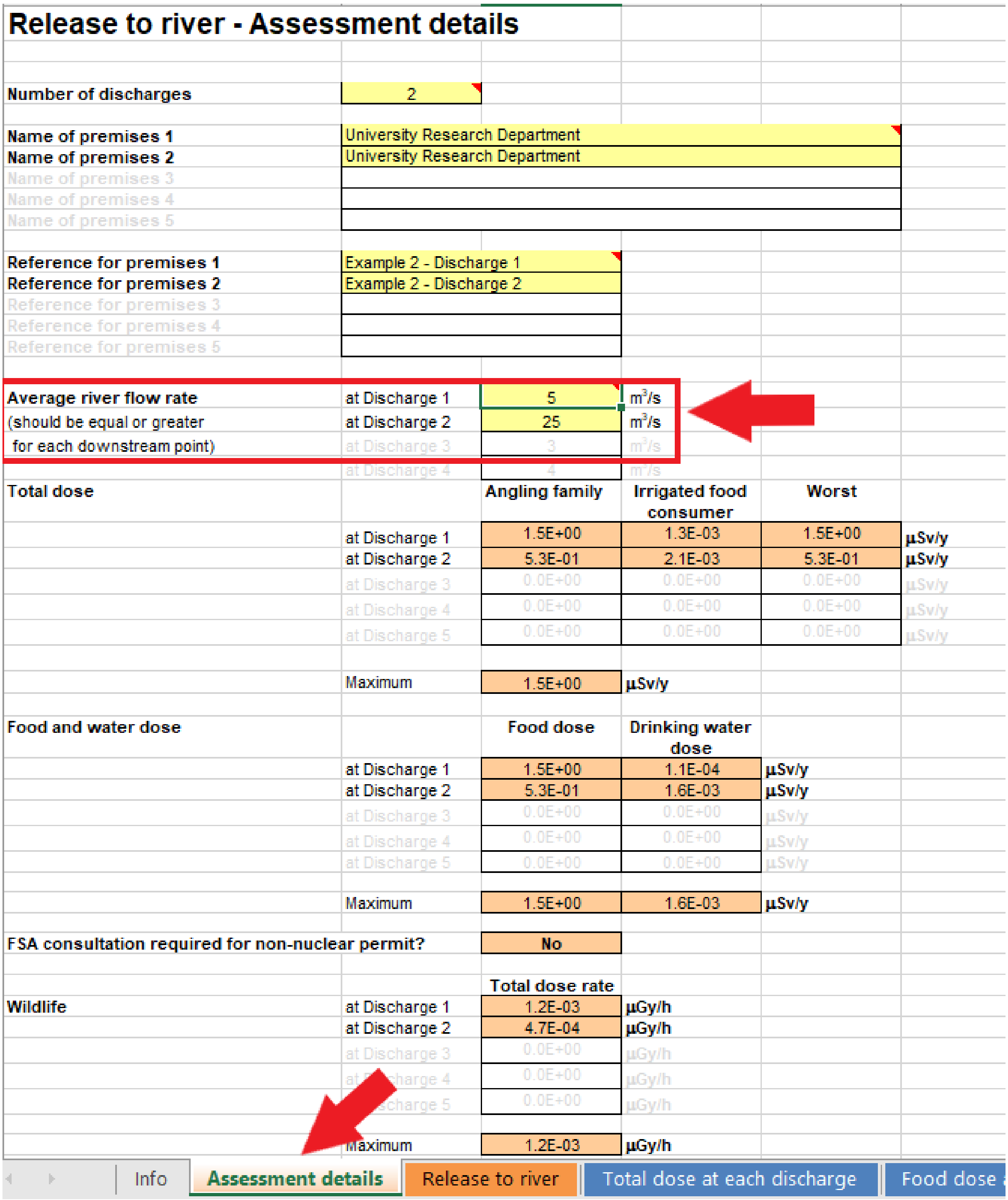


Figure 22. IRAT2 release to river stage 2 assessment with assessment details tab completed for Example 2 with average river flow rate data entered for two discharge points

Once you have refined the assessment, you can follow the same steps outlined in section 3.1.6 to assess the total impact on people and wildlife and compare the outcomes to relevant thresholds or criteria.

3.2.4 Releases to sewer

Key assumptions built into the DPUR factors:

- Exposure of sewage treatment workers does not assume any decay of radionuclides after discharge
- For all other exposure pathways decay has been taken into account as follows:
    - radionuclides with half-lives of less than 3 hours have not been considered
    - radionuclides with half-lives of less than 4 days have not been considered for the farming family or wildlife living on land conditioned with sewage sludge
    - radionuclides with half-lives of less than 30 days have not been considered for exposure through consumption of vegetables grown on sludge-conditioned land.
- For sewage sludge, it is assumed that sludge is applied to land after 23 days and that sludge is assumed to be sent for incineration after 4 days
- The sewage sludge is assumed to be either applied to land to condition pasture which is used for milk and meat production and soil which is used for vegetable production, or sent for incineration
- The raw sewage flow rate through the sewage treatment works is assumed to be 60 m^3/d
- The default water flow rate in a brook receiving treated effluent from a sewage treatment works is assumed to be 0.1 m^3/s
- Assumptions for the river angler family and irrigated food consumer are the same as described in the release to river and assumptions for the coastal fishing family are the same as release to estuary/coast sections
- Assumptions for freshwater and marine wildlife are the same as described in the release to river and release to estuary/coast sections
- Terrestrial wildlife are assumed to be exposed to sludge conditioned land

In the release to sewer scenario, there are more potential exposure pathways and hence there are more refinements which can be made.

The IRAT2 release to sewer tool includes information about the sewage flow rate through various sewage treatment works across England and Wales. So, if the sewage treatment works which receives the discharge is known, this can be selected from the 'Sewage works' drop down list and the tool will populate the average exchange rate with the water exchange rate at the selected location.

The IRAT2 sewage works flow data set is relatively old and does not cover all sewage works. It is possible or apply different data by selecting "user defined" to fill data gaps or use updated data where available.

For Example 1, the actual sewage flow rate is known so on the 'Assessment details' tab, you can select 'User defined' for the sewage works and enter the sewage flow rate into the 'user defined value' cell. In Example 1, information is also known about the brook and river flow rates and the coastal location so all of this information can also be entered.

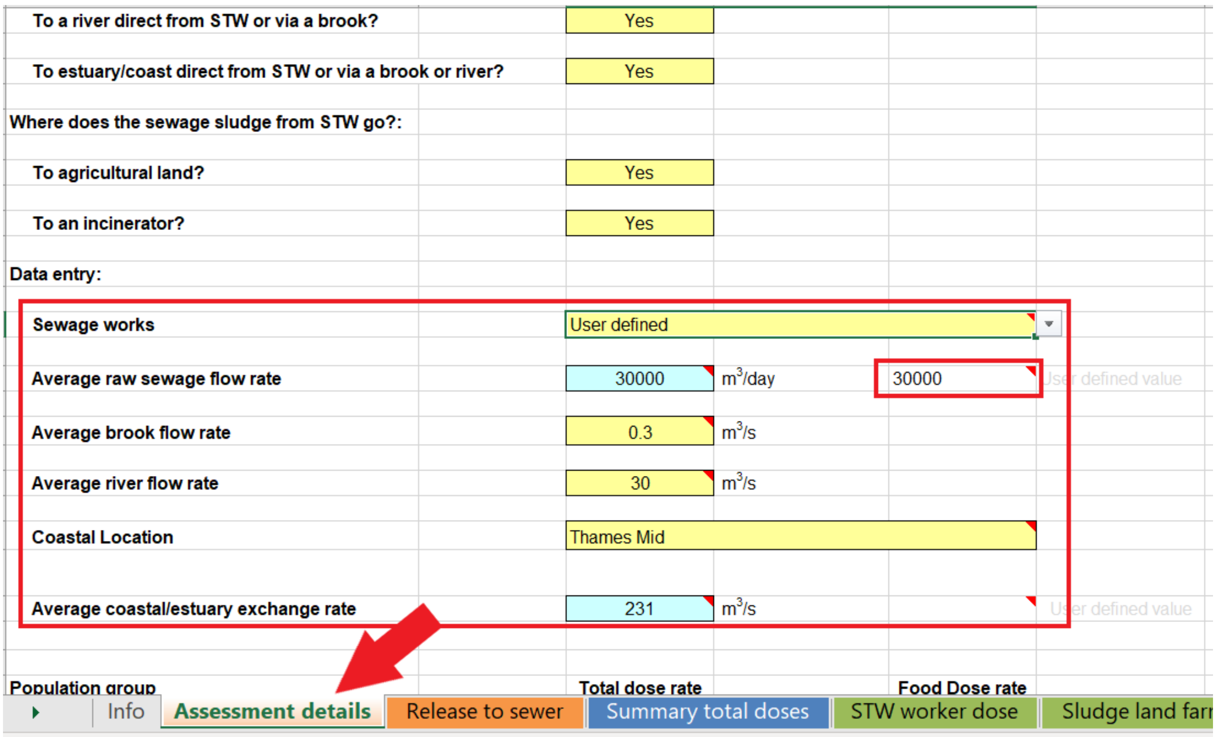


Figure 23. IRAT2 release to sewer stage 2 refined assessment with assessment details tab completed for Example 1 with a user defined sewage flow rate entered

3.2.5 Further Refinements

Cases modelled using IRAT2 are largely fixed and relatively inflexible. It is not possible to undertake a detailed site-specific radiological assessment, which follows the process and guidance set out for a ‘detailed source and site assessment’ in the dose principles document [1], using IRAT2. However, there may be cases where some site-specific data can be used to indicate that the real situation is different to the case modelled in IRAT-2 and the results may be adjusted accordingly.

The IRAT2 methodology is based around commonly occurring exposure pathways and groups which are likely to be the worst affected for a particular discharge route. If one of these exposure pathways or groups is found not to be present at a given site, then it may be reasonable not to consider the dose from that exposure pathway in the assessment. It is also important to decide whether doses from any other exposure pathways or groups not considered in the methodology need to be assessed by another means.

In some circumstances it may be appropriate to consider doses arising from different discharge routes from the same site separately. If the total doses in Stage 1 or Stage 2 have been assessed from the sum of initial assessment results from more than one discharge route and/or direct radiation exposure from the same site, consideration should be given as to whether it is realistic to assume that a group exposed via one discharge route may also be exposed to another. For example, for exposures to aqueous discharges the location where the discharges reach the environment has not been specified in the IRAT2 methodology whereas for exposures to atmospheric discharges the IRAT2 methodology assumes the nearest dwelling and food production point are 100m and 500 m from the discharge point respectively. Unless liquid discharges reach the environment close to the site (within a few hundred metres) then overlap between groups exposed to atmospheric discharges and liquid discharges is less likely. In these cases, it may be appropriate to consider two separate groups: one for liquid discharges and one for discharges to atmosphere. If direct radiation exposure also occurs, the highest direct radiation exposure is likely to occur close to the site within a few hundred metres. Therefore, where atmospheric discharges occur and direct radiation is important, the exposed group may be common to both routes and the estimated doses can be added.

The IRAT2 system calculates the DPUR factors for 4 age groups but only uses the age group with the highest DPUR when calculating the dose. This may over-estimate the dose to a specific age group when doses are summed for different radionuclides and across different discharge pathways. To overcome this, you can calculate the doses for each age group, using the age specific DPUR factors in the IRAT2 Part 2 report [5], and sum doses for each age group to produce a more representative total.

The sections below outline some examples of how site-specific data can be used to adjust the outputs of an IRAT2 assessment for each exposure scenario. Generally, these adjustments must be made by manual calculation as the spreadsheet tools do not support this level of refinement.

Releases to air

Site-specific dispersion modelling data can be used to adjust the exposures of groups living near the site from atmospheric releases. Site-specific scaling factors for inhalation and external exposure and food exposure can be calculated using site-specific dispersion modelling data and can replace those derived from Figure 16 using annual average air concentrations per unit release. The scaling factors are calculated by dividing the annual average air concentration per unit release (s/m^3) by 7E-05 s/m^3 for the inhalation and external exposure scaling factor and by 4E-06 s/m^3 for the food production scaling factors.

IRAT2 assumes that food production occurs close to the site at a distance of 500m. If local habits data shows that all food production is further than 500m away from the release point, the resulting ingestion DPURs could be scaled accordingly. For IRAT2, the PLUME atmospheric dispersion model in PC-CREAM 08 was used to predict air concentrations at ground level from continuous releases. PLUME is based on a widely used Gaussian plume model, suitable for generic assessments, described in a report of the UK Atmospheric Dispersion Working Group known as ‘R91’ [8]. It is possible to use the data predicted by models such as these to determine the ratio between the average air concentration at 500m and the air concentration at the known distance at which food is produced, provided the same model is used. The DPUR can then be scaled by this factor.

Site-specific data may show that the wind direction at a site has a significant prevailing direction rather than the uniform windrose used in IRAT2. Depending on the prevailing wind direction and the location of food production, this may increase or decrease the resulting dose as more or less activity may be deposited in each region. Windrose can be accounted for by up to a factor of 2 depending on the site data.

Releases to estuary/coastal water

Habit survey data may be available for time spent on inter-tidal sediment around the estuary into which the discharges flow, for example from fishing. The DPUR factors for external dose can be multiplied by the known site-specific occupancy rate divided by the occupancy rate used in the IRAT2 methodology, which is detailed in the IRAT2 Part 2 report [5].

Releases to river

If the location of drinking water abstraction downstream is known relative to the release point, the flow rate may be much higher than that at the release point. However, fish may be caught at a different location relative to the release point and water may be abstracted for irrigation at a different location again. Rather than scaling the DPURs by the same river flow-rate, as is done in the IRAT2 river spreadsheet tool, each of the DPUR factors can be scaled individually to take account of river flow rates at the different locations where each exposure occurs. This is done by dividing the DPURs by the river flow rate at each location (m^3/s).

Drinking water is usually stored in reservoirs and then treated, usually no raw water is abstracted for consumption. The DPUR factors do not take account decay of radionuclides or removal of radionuclides by treatment processes before consumption of water. If appropriate, the DPUR factors for drinking water can be multiplied by drinking water treatment factors provided in reference [6].

If habit survey data are available on the consumption of freshwater fish in the river, this can be used to scale the outcomes of the assessment accordingly. Site-specific consumption rates are likely to be lower than those assumed to derive the DPUR factors, unless there is a fish farm on the river. The DPUR factor for ingestion of fish can be scaled by multiplying it by the known site-specific consumption rate divided by the consumption rates used in IRAT2 (age dependent), detailed in the IRAT2 Part 2 report [5].

If there is no abstraction of water for irrigation of food crops in the area then doses from irrigated food consumers can be ignored.

Releases to sewer

If the sewerage undertaker has provided information on actual occupancy of sewage treatment workers around sludge tanks and facilities containing raw sewage the DPUR factors for sewage treatment workers can be scaled. This can be done by multiplying the DPURs for sewage treatment workers by the site-specific occupancy around sludge tanks raw sewage facilities divided by the occupancy data detailed in the IRAT2 Part 2 report [5]. It may also be appropriate to disregard the external radiation from pure beta-emitting radionuclides, if there is no contact with sludge or raw sewage.

If the sewerage undertaker has provided information on the quantity of sewage sludge produced each year and the area of land over which it is spread then the spreading rate in units of $kg/m^2/y$ can be calculated. This can be divided by the values assumed in the assessment, detailed in the IRAT2 Part 2 report [5]. This factor can then be multiplied by the DPUR factors for the farming family exposed to sludge conditioned land. In IRAT2 the dry matter content of sludge is assumed to be 5%, giving a dry matter application rate of 0.4 $kg/m^2/y$. Some sewage sludges may contain more dry matter than 5%, so the effective dry matter application rate should be taken into account when scaling the application results.

The assessment assumes a time period of 408 h between raw sewage entering the sewage treatment works and the time at which sludge is used to condition land. If information has been provided on the actual time between raw sewage entering the sewage treatment works and the time at which sludge is used to condition land then further decay of radionuclides beyond the 408 h may be taken into account.

If the sludge is only used to condition land upon which grain and cereal crops are produced the resultant doses may be lower than predicted in IRAT2 as grain is usually produced by mixing a variety of sources. However, it is necessary to know whether sludge could be treated and used for conditioning pasture or soil on which vegetables are grown in the future. If it is considered appropriate to discount doses resulting from consumption of food stuffs grown on sludge conditioned land due to local information, you should identify the possible disposal routes for the sewage sludge for the type of treatment in place at the sewage treatment works, based on the Safe Sludge Matrix [7]. Any plans by the sewerage undertaker to upgrade the sewage treatment works in the near future (3–5 years) should be taken into account. If sludge can be used for conditioning pasture or soil or will likely to be used in this way in the future, then the assessment remains valid. Otherwise, it can be assumed that only the external dose, inhalation and inadvertent ingestion pathways need to be included in the dose assessment.

Children may not be able to access the brook receiving treated effluent from a sewage treatment works, for example due to culverts. The assessment of doses to a child playing in a brook can be excluded if it can be shown that this is the case.

3.2.6 Assessing the dose to people and the dose rate to wildlife

Once you have refined the assessment, following the steps set out in sections 3.2.1 – 3.2.5, you can follow the same steps outlined in section 3.1.6 to assess the total impact on people and wildlife and compare the outcomes to relevant thresholds or criteria.

4 Data used in the initial radiological assessment methodology

Table 1. Radionuclides considered in the initial assessment methodology

Radionuclide	Half-life^	Release to air	Release to estuary/coastal water	Release to river	Release to public sewer
H-3	12.32 y	✓	✓	✓	✓
H-3 organic	12.32 y	✓	✓	✓	✓
C-11	20.39 m	✓	not considered	not considered	✓
C-14	5,730 y	✓	✓	✓	✓
N-13	9.965 m	✓	gas	gas	gas
O-15	2.04 m	✓	gas	gas	gas
F-18	1.83 h	✓	not considered	not considered	✓
Na-22	2.602 y	✓	✓	✓	✓
Na-24	14.96 h	✓	✓	✓	✓
P-32	14.263 d	✓	✓	✓	✓
P-33	25.34 d	✓	✓	✓	✓
S-35	87.51 d	✓	✓	✓	✓
Cl-36	301,000 y	✓	✓	✓	✓
Ar-41	1.827 h	✓	gas	gas	gas
Ca-45	162.67 d	✓	✓	✓	✓
Ca-47	4.536 d	✓	✓	✓	✓
V-48	15.974 d	✓	✓	✓	✓
Cr-51	27.703 d	✓	✓	✓	✓
Mn-52	5.591 d	✓	✓	✓	✓
Mn-54	312.12 d	✓	✓	✓	✓
Mn-56	2.5789 h	✓	not considered	not considered	✓
Fe-55	2.737 y	✓	✓	✓	✓
Fe-59	44.495 d	✓	✓	✓	✓
Co-56	77.23 d	✓	✓	✓	✓
Co-57	271.74 d	✓	✓	✓	✓
Co-58	70.86 d	✓	✓	✓	✓
Co-60	5.271 y	✓	✓	✓	✓
Ni-63	100.1 y	✓	✓	✓	✓
Cu-61*	3.333 h	✓	✓	✓	✓
Cu-64*	12.701 h	✓	✓	✓	✓
Zn-62*	9.186 h	✓	✓	✓	✓
Zn-65	243.9 d	✓	✓	✓	✓
Ga-67	3.26 d	✓	✓	✓	✓
Ga-68*	1.129 h	✓	not considered	not considered	✓
Se-75	119.8 d	✓	✓	✓	✓
Br-76*	16.2 h	✓	✓	✓	✓
Br-77*	57 h	✓	✓	✓	✓
Br-82	35.3 h	✓	✓	✓	✓
Kr-79	35.04 h	✓	gas	gas	gas
Kr-81m	13.1 s	✓	gas	gas	gas
Kr-85	10.756 y	✓	gas	gas	gas
Kr-85m	4.48 h	✓	gas	gas	gas
Rb-81*	4.576 h	✓	✓	✓	✓

Radionuclide	Half-life^	Release to air	Release to estuary/coastal water	Release to river	Release to public sewer
Rb-82	1.273 m	✓	not considered	not considered	✓
Rb-83	86.2 d	✓	✓	✓	✓
Sr-83*	32.41 h	✓	✓	✓	✓
Sr-85*	64.84 d	✓	✓	✓	✓
Sr-89	50.53 d	✓	✓	✓	✓
Sr-90	28.79 y	✓	✓	✓	✓
Y-90	64.1 h	✓	✓	✓	✓
Zr-89*	3.27 d	✓	✓	✓	✓
Zr-95	64.032 d	✓	✓	✓	✓
Nb-95	34.991 d	✓	✓	✓	✓
Mo-99	65.94 h	✓	✓	✓	✓
Tc-94m*	52 m	✓	not considered	not considered	✓
Tc-99	211,100 y	✓	✓	✓	✓
Tc-99m	6.015 h	✓	✓	✓	✓
Ru-103	39.26 d	✓	✓	✓	✓
Ru-106	373.59 d	✓	✓	✓	✓
Ag-110m	249.76 d	✓	✓	✓	✓
In-111	67.32 h	✓	✓	✓	✓
In-113m	1.658 h	✓	not considered	not considered	✓
Sb-125	2.76 y	✓	✓	✓	✓
I-123	13.27 h	✓	✓	✓	✓
I-124*	4.176 d	✓	✓	✓	✓
I-125	59.4 d	✓	✓	✓	✓
I-129	1.57E+07 y	✓	✓	✓	✓
I-131	8.02 d	✓	✓	✓	✓
I-132	2.3 h	✓	not considered	not considered	✓
I-133	20.8 h	✓	✓	✓	✓
I-134	52.5 m	✓	not considered	not considered	✓
I-135	6.57 h	✓	✓	✓	✓
Xe-133	5.243 d	✓	gas	gas	gas
Cs-134	2.065 y	✓	✓	✓	✓
Cs-136	13.16 d	✓	✓	✓	✓
Cs-137	30.167 y	✓	✓	✓	✓
Ba-140	12.752 d	✓	✓	✓	✓
La-140	40.274 h	✓	✓	✓	✓
Ce-141	32.508 d	✓	✓	✓	✓
Ce-144	284.91 d	✓	✓	✓	✓
Pm-147	2.6234 y	✓	✓	✓	✓
Sm-153	46.5 h	✓	✓	✓	✓
Eu-152	13.537 y	✓	✓	✓	✓
Eu-154	8.593 y	✓	✓	✓	✓
Eu-155	4.7611 y	✓	✓	✓	✓
Er-169	9.4 d	✓	✓	✓	✓
Lu-177	6.647 d	✓	✓	✓	✓
Re-188*	17.004 h	✓	✓	✓	✓
Au-198	64.68 h	✓	✓	✓	✓
Tl-201	3.038 d	✓	✓	✓	✓
Pb-210	22.2 y	✓	✓	✓	✓

Radionuclide	Half-life^	Release to air	Release to estuary/coastal water	Release to river	Release to public sewer
Pb-212*	10.64 h	✓	✓	✓	✓
Bi-213*	45.59 m	✓	not considered	not considered	✓
Po-210	138.38 d	✓	✓	✓	✓
At-211*	7.214 h	✓	✓	✓	✓
Rn-222	3.8235 d	✓	gas	gas	gas
Ra-223	11.43 d	✓	✓	✓	✓
Ra-226	1,600 y	✓	✓	✓	✓
Ac-225*	10 d	✓	✓	✓	✓
Th-227*	18.68 d	✓	✓	✓	✓
Th-230	75,380 y	✓	✓	✓	✓
Th-232	1.405E+10 y	✓	✓	✓	✓
Th-234	24.1 d	✓	✓	✓	✓
U-234	244,500 y	✓	✓	✓	✓
U-235	7.04E+08 y	✓	✓	✓	✓
U-238	4.468E+09 y	✓	✓	✓	✓
Np-237	2.144E+06 y	✓	✓	✓	✓
Pu-238	87.7 y	✓	✓	✓	✓
Pu-239	24,110 y	✓	✓	✓	✓
Pu-240	6,564 y	✓	✓	✓	✓
Pu-241	14.35 y	✓	✓	✓	✓
Pu-242	375,000 y	✓	✓	✓	✓
Am-241	432.2 y	✓	✓	✓	✓
Am-242	16.02 h	✓	✓	✓	✓
Am-243	7,370 y	✓	✓	✓	✓
Cm-242	162.8 d	✓	✓	✓	✓
Cm-243	29.1 y	✓	✓	✓	✓
Cm-244	18.1 y	✓	✓	✓	✓

* Radionuclide added for IRAT2 (radionuclide was not included in the original version of IRAT).

^ Half-lives taken from ICRP recommended nuclear data [9], y=years, d=days, h=hours, m=minutes, s=seconds.

not considered: Radionuclides are 'not considered' where their half-life is sufficiently short that they have decayed to insignificant concentrations during their release to environmental media. Further information is provided in the IRAT2 Part 2 report [5].

gas: Radionuclides are released in gaseous form only and therefore not included in the aquatic assessments.

Table 2. Dose per unit release factors for local resident family – atmospheric release scenario

Radionuclide	DPUR for worst age group local resident family (µSv/y per Bq/y of discharge to atmosphere)*				
	Inhalation DPUR	External radiation DPUR	Terrestrial food consumption DPUR	Total DPUR	Age group
H-3	7.1E-13	0.0E+00	2.8E-13	9.8E-13	Offspring
H-3 organic	1.4E-12	0.0E+00	5.6E-13	2.0E-12	Offspring
C-11	4.0E-13	2.4E-12	0.0E+00	2.8E-12	Adult
C-14	3.6E-11	6.5E-17	3.4E-11	7.0E-11	Infant
N-13	0.0E+00	2.4E-12	0.0E+00	2.4E-12	Adult
O-15	0.0E+00	2.0E-12	0.0E+00	2.0E-12	Adult
F-18	1.3E-12	2.7E-12	0.0E+00	4.1E-12	Adult
Na-22	2.7E-11	6.0E-09	1.2E-10	6.2E-09	Offspring
Na-24	6.1E-12	2.0E-11	4.9E-14	2.6E-11	Adult
P-32	1.5E-10	2.8E-14	2.2E-10	3.6E-10	Offspring
P-33	2.7E-11	7.7E-16	6.2E-11	8.9E-11	Offspring
S-35	2.4E-11	7.7E-17	3.3E-11	5.7E-11	Infant
Cl-36	1.4E-10	8.0E-13	2.0E-09	2.1E-09	Infant
Ar-41	0.0E+00	3.3E-12	0.0E+00	3.3E-12	Adult
Ca-45	3.8E-11	8.1E-16	3.0E-10	3.4E-10	Offspring
Ca-47	4.2E-11	8.8E-12	4.9E-11	9.9E-11	Infant
V-48	5.4E-11	1.9E-10	1.5E-12	2.5E-10	Adult
Cr-51	8.3E-13	3.5E-12	7.9E-14	4.5E-12	Adult
Mn-52	3.2E-11	8.4E-11	3.5E-12	1.2E-10	Adult
Mn-54	3.4E-11	9.2E-10	2.9E-11	9.8E-10	Adult
Mn-56	2.7E-12	5.0E-12	0.0E+00	7.7E-12	Adult
Fe-55	7.6E-12	2.7E-15	3.1E-11	3.8E-11	Infant
Fe-59	8.3E-11	2.0E-10	8.2E-12	3.0E-10	Adult
Co-56	1.1E-10	1.0E-09	1.1E-11	1.2E-09	Adult
Co-57	1.2E-11	1.1E-10	1.7E-12	1.2E-10	Adult
Co-58	3.6E-11	2.7E-10	3.2E-12	3.1E-10	Adult
Co-60	2.3E-10	1.1E-08	5.0E-11	1.2E-08	Adult
Ni-63	1.0E-11	0.0E+00	4.5E-12	1.5E-11	Infant
Cu-61	1.8E-12	2.4E-12	3.0E-15	4.2E-12	Adult
Cu-64	3.1E-12	4.8E-13	3.0E-14	3.6E-12	Child
Zn-62	1.9E-11	1.3E-12	5.8E-13	2.1E-11	Infant
Zn-65	3.6E-11	5.0E-10	1.4E-10	6.8E-10	Adult
Ga-67	5.4E-12	2.3E-12	6.2E-14	7.7E-12	Adult
Ga-68	1.1E-12	2.4E-12	4.4E-16	3.5E-12	Adult
Se-75	3.2E-11	6.0E-11	1.2E-09	1.2E-09	Infant
Br-76	9.3E-12	1.3E-11	5.0E-13	2.3E-11	Adult
Br-77	2.8E-12	1.4E-12	2.5E-12	6.6E-12	Infant
Br-82	1.4E-11	2.2E-11	1.5E-12	3.8E-11	Adult
Kr-79	0.0E+00	6.0E-13	0.0E+00	6.0E-13	Adult
Kr-81m	0.0E+00	5.8E-14	0.0E+00	5.8E-14	Adult
Kr-85	0.0E+00	1.3E-14	0.0E+00	1.3E-14	Adult
Kr-85m	0.0E+00	3.7E-13	0.0E+00	3.7E-13	Adult
Rb-81	7.7E-13	2.2E-12	4.8E-15	3.0E-12	Adult
Rb-82	3.3E-14	1.9E-12	0.0E+00	2.0E-12	Adult
Rb-83	2.1E-11	5.8E-11	1.4E-10	2.2E-10	Infant

Radionuclide	DPUR for worst age group local resident family (µSv/y per Bq/y of discharge to atmosphere)*				
	Inhalation DPUR	External radiation DPUR	Terrestrial food consumption DPUR	Total DPUR	Age group
Sr-83	7.0E-12	1.8E-10	7.5E-14	1.8E-10	Adult
Sr-85	1.4E-11	1.3E-10	1.2E-12	1.4E-10	Adult
Sr-89	1.3E-10	1.6E-14	2.2E-11	1.5E-10	Infant
Sr-90	5.9E-10	2.5E-15	1.4E-09	2.0E-09	Infant
Y-90	4.7E-11	2.0E-14	1.0E-12	4.9E-11	Infant
Zr-89	1.2E-11	1.8E-11	2.0E-13	3.0E-11	Adult
Zr-95	1.1E-10	4.9E-10	1.2E-12	6.0E-10	Adult
Nb-95	3.4E-11	1.1E-10	6.1E-13	1.4E-10	Adult
Mo-99	2.4E-11	1.2E-12	1.5E-12	2.7E-11	Infant
Tc-94m	1.0E-12	4.8E-12	0.0E+00	5.8E-12	Adult
Tc-99	7.0E-11	7.1E-16	1.2E-08	1.2E-08	Infant
Tc-99m	4.3E-13	4.0E-13	1.2E-14	8.4E-13	Adult
Ru-103	5.4E-11	7.5E-11	7.9E-13	1.3E-10	Adult
Ru-106	6.3E-10	2.6E-10	1.2E-11	9.1E-10	Adult
Ag-110m	1.7E-10	2.5E-09	3.1E-10	3.0E-09	Adult
In-111	5.2E-12	5.2E-12	8.0E-14	1.0E-11	Adult
In-113m	4.5E-13	6.6E-13	0.0E+00	1.1E-12	Adult
Sb-125	1.1E-10	1.2E-09	1.9E-11	1.4E-09	Adult
I-123	1.5E-12	1.8E-10	1.7E-13	1.9E-10	Adult
I-124	2.2E-10	5.6E-11	1.4E-09	1.7E-09	Infant
I-125	1.1E-10	7.1E-12	3.2E-09	3.3E-09	Infant
I-129	9.6E-10	1.8E-10	1.9E-08	2.0E-08	Child
I-131	3.5E-10	3.9E-11	4.1E-09	4.4E-09	Infant
I-132	1.9E-12	1.3E-11	0.0E+00	1.5E-11	Adult
I-133	8.8E-11	7.5E-12	6.3E-11	1.6E-10	Infant
I-134	9.2E-13	9.2E-12	0.0E+00	1.0E-11	Adult
I-135	6.6E-12	2.1E-11	2.5E-13	2.8E-11	Adult
Xe-133	0.0E+00	7.1E-14	0.0E+00	7.1E-14	Adult
Cs-134	1.5E-10	3.6E-09	5.8E-10	4.3E-09	Adult
Cs-136	2.7E-11	1.2E-10	2.0E-11	1.6E-10	Adult
Cs-137	1.0E-10	6.6E-09	4.7E-10	7.1E-09	Adult
Ba-140	1.2E-10	1.4E-10	2.1E-12	2.5E-10	Adult
La-140	2.5E-11	2.1E-11	2.9E-13	4.6E-11	Adult
Ce-141	7.2E-11	9.0E-12	7.9E-13	8.2E-11	Adult
Ce-144	8.6E-10	1.6E-11	2.9E-11	9.1E-10	Infant
Pm-147	1.1E-10	9.9E-15	5.6E-13	1.1E-10	Adult
Sm-153	1.6E-11	2.4E-13	1.2E-13	1.6E-11	Child
Eu-152	9.5E-10	9.0E-09	3.6E-12	1.0E-08	Adult
Eu-154	1.2E-09	7.8E-09	4.9E-12	9.0E-09	Adult
Eu-155	1.6E-10	1.9E-10	7.1E-13	3.4E-10	Adult
Er-169	2.4E-11	9.4E-16	2.2E-13	2.4E-11	Child
Lu-177	2.7E-11	9.6E-13	2.4E-13	2.8E-11	Adult
Re-188	2.4E-11	1.3E-13	2.7E-11	5.1E-11	Infant
Au-198	2.4E-11	2.0E-12	5.7E-13	2.6E-11	Infant
Tl-201	1.8E-12	3.9E-13	5.9E-13	2.8E-12	Infant
Pb-210	2.4E-08	3.2E-12	4.9E-09	2.8E-08	Child
Pb-212	3.8E-09	9.3E-13	2.8E-13	3.8E-09	Adult

Radionuclide	DPUR for worst age group local resident family (µSv/y per Bq/y of discharge to atmosphere)*				
	Inhalation DPUR	External radiation DPUR	Terrestrial food consumption DPUR	Total DPUR	Age group
Bi-213	6.8E-10	2.1E-13	0.0E+00	6.8E-10	Child
Po-210	5.9E-08	1.5E-15	4.1E-08	1.0E-07	Infant
As-211	2.5E-09	1.8E-08	1.1E-12	2.0E-08	Adult
Rn-222	3.8E-10	4.5E-16	0.0E+00	3.8E-10	Infant
Ra-223	1.7E-07	1.3E-11	9.4E-11	1.7E-07	Adult
Ra-226	7.9E-08	2.7E-08	1.6E-09	1.1E-07	Adult
Ac-225	1.9E-07	7.2E-12	1.3E-11	1.9E-07	Adult
Th-227	2.3E-07	4.1E-11	6.8E-12	2.3E-07	Adult
Th-230	3.2E-07	2.7E-08	3.4E-10	3.4E-07	Adult
Th-232	5.6E-07	1.9E-08	3.7E-10	5.8E-07	Adult
Th-234	1.7E-10	3.9E-12	2.9E-12	1.8E-10	Adult
U-234	7.9E-08	2.0E-10	2.5E-10	7.9E-08	Adult
U-235	7.0E-08	2.0E-09	2.4E-10	7.2E-08	Adult
U-238	6.5E-08	3.2E-10	2.3E-10	6.6E-08	Adult
Np-237	5.2E-07	2.9E-09	4.2E-10	5.2E-07	Adult
Pu-238	1.0E-06	1.6E-12	6.0E-10	1.0E-06	Adult
Pu-239	1.1E-06	2.0E-09	6.6E-10	1.1E-06	Adult
Pu-240	1.1E-06	1.2E-12	6.6E-10	1.1E-06	Adult
Pu-241	2.0E-08	1.4E-10	1.2E-11	2.0E-08	Adult
Pu-242	1.1E-06	3.3E-10	6.3E-10	1.1E-06	Adult
Am-241	9.5E-07	3.0E-09	6.1E-10	9.5E-07	Adult
Am-242	3.8E-10	8.9E-12	1.8E-14	3.9E-10	Adult
Am-243	9.3E-07	2.4E-09	6.1E-10	9.3E-07	Adult
Cm-242	1.2E-07	5.1E-13	1.8E-11	1.2E-07	Adult
Cm-243	7.0E-07	3.6E-09	3.8E-10	7.0E-07	Adult
Cm-244	6.1E-07	2.4E-12	3.0E-10	6.1E-07	Adult

*For a release at ground level

Table 3. Dose rate per unit release factors for terrestrial wildlife – atmospheric release scenario

Radionuclide	Worst total DPUR ($\mu Gy\ h^{-1}$ per $Bq\ y^{-1}$)	Worst affected reference organism
H-3	3.5E-15	Amphibian, Annelid, Arthropod - detritivorous, Bird, Grasses & Herbs, Mammal - large, Mammal - small-burrowing, Mollusc - gastropod, Reptile, Shrub, Tree
H-3 organic	3.1E-14	Amphibian, Bird, Mammal - large, Mammal - small-burrowing, Reptile
C-11	2.2E-12	Mammal - large
C-14	1.1E-13	Bird, Mammal - large, Mammal - small-burrowing, Reptile
N-13	4.6E-15	Mammal – large
O-15	1.1E-16	Tree
F-18	2.2E-16	Mammal – large
Na-22	2.5E-12	Mammal – large
Na-24	2.7E-15	Mammal – large
P-32	1.5E-12	Mammal – large
P-33	1.7E-13	Amphibian, Bird, Mammal - large, Mammal - small-burrowing, Reptile
S-35	1.2E-14	Grasses & Herbs, Shrub, Tree
Cl-36	1.9E-11	Grasses & Herbs
Ar-41	1.8E-15	Grasses & Herbs
Ca-45	6.4E-14	Mammal – large
Ca-47	3.4E-14	Mammal – large
V-48	2.1E-14	Annelid
Cr-51	3.8E-16	Annelid
Mn-52	8.3E-15	Arthropod – detritivorous
Mn-54	1.4E-13	Arthropod – detritivorous
Mn-56	1.6E-16	Shrub
Fe-55	3.0E-14	Shrub
Fe-59	2.6E-14	Arthropod – detritivorous
Co-56	1.5E-13	Arthropod – detritivorous
Co-57	1.2E-14	Amphibian
Co-58	3.6E-14	Annelid
Co-60	2.0E-12	Amphibian
Ni-63	2.7E-14	Reptile
Cu-61	1.7E-16	Mammal – large
Cu-64	1.9E-16	Mammal – large
Zn-62	1.2E-15	Mammal – large
Zn-65	1.6E-13	Mammal – large
Ga-67	1.8E-16	Annelid
Ga-68	2.1E-17	Annelid
Se-75	2.8E-14	Annelid
Br-76	8.1E-16	Amphibian
Br-77	3.1E-16	Amphibian
Br-82	1.7E-15	Amphibian
Kr-79^	5.4E-17	Shrub

Radionuclide	Worst total DPUR (μGy h^{-1} per Bq y^{-1})	Worst affected reference organism
Kr-81m^	5.4E-17	Shrub
Kr-85	5.4E-17	Shrub
Kr-85m^	5.4E-17	Shrub
Rb-81	1.9E-16	Mammal – large
Rb-82	2.2E-18	Mammal – large
Rb-83	7.2E-14	Mammal – large
Sr-83	7.5E-16	Mammal – large
Sr-85	2.4E-14	Mammal – large
Sr-89	4.3E-14	Lichen & Bryophytes
Sr-90	7.6E-12	Lichen & Bryophytes
Y-90	1.5E-16	Bird
Zr-89	1.6E-15	Arthropod – detritivorous
Zr-95	2.5E-14	Amphibian
Nb-95	1.3E-14	Annelid
Mo-99	3.4E-16	Annelid
Tc-94m	1.4E-16	Grasses & Herbs
Tc-99	2.4E-12	Grasses & Herbs
Tc-99m	4.2E-17	Grasses & Herbs
Ru-103	1.9E-14	Lichen & Bryophytes
Ru-106	5.5E-13	Lichen & Bryophytes
Ag-110m	3.9E-13	Annelid
In-111	4.0E-16	Arthropod – detritivorous
In-113m	7.1E-18	Arthropod – detritivorous
Sb-125	1.9E-13	Annelid
I-123	2.9E-16	Amphibian
I-124	1.9E-14	Amphibian
I-125	9.6E-15	Mammal – large
I-129	1.8E-12	Mammal – large
I-131	1.4E-14	Amphibian
I-132	9.0E-16	Amphibian
I-133	2.6E-15	Amphibian
I-134	3.9E-16	Amphibian
I-135	1.8E-15	Amphibian
Xe-133	6.2E-17	Grasses & Herbs
Cs-134	1.5E-12	Mammal – large
Cs-136	3.3E-14	Mammal – large
Cs-137	6.4E-12	Mammal – large
Ba-140	1.0E-13	Bird
La-140	1.8E-15	Amphibian
Ce-141	8.0E-16	Amphibian
Ce-144	1.7E-14	Bird
Pm-147	2.1E-15	Bird
Sm-153	2.8E-17	Bird
Eu-152	1.9E-12	Annelid
Eu-154	1.5E-12	Arthropod – detritivorous
Eu-155	5.1E-14	Bird
Er-169	3.4E-17	Bird
Lu-177	7.8E-17	Annelid

Radionuclide	Worst total DPUR ($\mu Gy\ h^{-1}$ per $Bq\ y^{-1}$)	Worst affected reference organism
Re-188	2.8E-15	Grasses & Herbs
Au-198	5.6E-15	Grasses & Herbs
Tl-201	6.6E-16	Mammal – large
Pb-210	2.3E-12	Lichen & Bryophytes
Pb-212	4.6E-14	Lichen & Bryophytes
Bi-213	3.1E-15	Lichen & Bryophytes
Po-210	1.1E-11	Lichen & Bryophytes
As-211	3.8E-15	Mammal - small-burrowing
Rn-222	2.6E-15	Arthropod – detritivorous
Ra-223	1.0E-12	Lichen & Bryophytes
Ra-226	8.3E-10	Lichen & Bryophytes
Ac-225	5.0E-13	Lichen & Bryophytes
Th-227	2.1E-13	Lichen & Bryophytes
Th-230	8.7E-11	Lichen & Bryophytes
Th-232	7.5E-11	Lichen & Bryophytes
Th-234	2.1E-15	Lichen & Bryophytes
U-234	2.1E-10	Lichen & Bryophytes
U-235	2.0E-10	Lichen & Bryophytes
U-238	1.9E-10	Lichen & Bryophytes
Np-237	2.3E-10	Lichen & Bryophytes
Pu-238	2.9E-11	Lichen & Bryophytes
Pu-239	3.3E-11	Lichen & Bryophytes
Pu-240	3.3E-11	Lichen & Bryophytes
Pu-241	3.7E-15	Lichen & Bryophytes
Pu-242	3.1E-11	Lichen & Bryophytes
Am-241	2.6E-10	Lichen & Bryophytes
Am-242	5.2E-17	Lichen & Bryophytes
Am-243	2.6E-10	Lichen & Bryophytes
Cm-242	5.8E-12	Lichen & Bryophytes
Cm-243	1.7E-10	Lichen & Bryophytes
Cm-244	1.3E-10	Lichen & Bryophytes

^dose factors not available for this radioactive noble gas so used DPUR for krypton-85 for which dose factors were derived.

Table 4. Dose per unit release factors for fishing family – coastal release scenario

These DPURs are multiplied by the factor Q_{eff} (Table 13) when assessing exposure of fishing family via the sewer release scenario.

Radionuclide	DPUR for worst age group fishing family (µSv/y per Bq/y of discharge to estuary/coastal water)*			
	External radiation DPUR	Seafood consumption DPUR	Total DPUR	Age group
H-3	0.0E+00	9.0E-16	9.0E-16	Offspring
H-3 organic	0.0E+00	3.6E-11	3.6E-11	Offspring
C-14	2.1E-16	4.5E-10	4.5E-10	Offspring
Na-22	1.9E-13	6.7E-14	2.5E-13	Offspring
Na-24	4.4E-16	5.7E-16	1.0E-15	Adult
P-32	2.5E-16	1.2E-08	1.2E-08	Offspring
P-33	1.3E-18	2.7E-09	2.7E-09	Offspring
S-35	1.5E-19	7.6E-15	7.6E-15	Offspring
Cl-36	5.6E-17	1.6E-15	1.6E-15	Adult
Ca-45	3.8E-17	6.8E-13	6.8E-13	Offspring
Ca-47	2.6E-13	2.3E-13	4.8E-13	Offspring
V-48	5.4E-11	4.7E-13	5.5E-11	Adult
Cr-51	6.2E-13	1.9E-13	8.2E-13	Adult
Mn-52	1.9E-11	6.4E-12	2.5E-11	Adult
Mn-54	3.1E-10	3.7E-12	3.2E-10	Adult
Fe-55	0.0E+00	2.3E-13	2.3E-13	Adult
Fe-59	6.9E-11	1.1E-12	7.0E-11	Adult
Co-56	3.4E-10	3.8E-11	3.7E-10	Adult
Co-57	2.7E-11	3.3E-12	3.1E-11	Adult
Co-58	8.0E-11	1.1E-11	9.1E-11	Adult
Co-60	3.6E-09	6.0E-11	3.7E-09	Adult
Ni-63	0.0E+00	3.4E-12	3.4E-12	Adult
Cu-61	4.1E-15	2.9E-12	2.9E-12	Adult
Cu-64	1.2E-14	9.9E-12	9.9E-12	Adult
Zn-62	4.9E-14	5.9E-11	5.9E-11	Adult
Zn-65	1.3E-10	2.7E-09	2.8E-09	Adult
Ga-67	2.0E-15	1.1E-12	1.1E-12	Adult
Se-75	5.0E-12	6.4E-10	6.5E-10	Offspring
Br-76	3.2E-16	6.2E-15	6.5E-15	Adult
Br-77	3.5E-16	3.8E-15	4.1E-15	Adult
Br-82	1.3E-15	1.5E-14	1.6E-14	Adult
Rb-81	5.0E-16	2.2E-15	2.7E-15	Adult
Rb-83	6.5E-12	2.8E-12	9.3E-12	Adult
Sr-83	8.8E-14	1.3E-14	1.0E-13	Adult
Sr-85	6.0E-14	7.1E-14	1.3E-13	Adult
Sr-89	2.8E-16	1.5E-12	1.5E-12	Offspring
Sr-90	5.3E-15	6.2E-12	6.2E-12	Offspring
Y-90	1.4E-14	5.5E-13	5.7E-13	Adult
Zr-89	3.0E-12	2.1E-13	3.2E-12	Adult
Zr-95	1.3E-10	4.7E-13	1.3E-10	Adult
Nb-95	3.3E-11	1.5E-13	3.3E-11	Adult
Mo-99	1.9E-14	2.2E-13	2.4E-13	Adult
Tc-99	1.8E-16	7.0E-12	7.0E-12	Adult

Radionuclide	DPUR for worst age group fishing family (µSv/y per Bq/y of discharge to estuary/coastal water)*			
	External radiation DPUR	Seafood consumption DPUR	Total DPUR	Age group
Tc-99m	5.3E-18	7.2E-15	7.2E-15	Adult
Ru-103	1.3E-11	1.0E-12	1.4E-11	Adult
Ru-106	5.5E-11	1.1E-11	6.6E-11	Adult
Ag-110m	2.2E-10	3.6E-09	3.9E-09	Adult
In-111	3.4E-13	5.5E-12	5.9E-12	Adult
Sb-125	2.6E-11	1.5E-11	4.1E-11	Adult
I-123	2.5E-17	3.0E-15	3.1E-15	Adult
I-124	8.9E-15	1.0E-12	1.0E-12	Adult
I-125	6.8E-16	3.0E-12	3.0E-12	Adult
I-129	1.1E-14	2.5E-11	2.5E-11	Adult
I-131	8.4E-15	2.6E-12	2.6E-12	Offspring
I-133	3.1E-16	9.4E-14	9.4E-14	Adult
I-135	1.0E-16	6.9E-15	7.0E-15	Adult
Cs-134	1.5E-10	3.8E-11	1.8E-10	Adult
Cs-136	3.1E-12	3.8E-12	7.0E-12	Adult
Cs-137	1.7E-10	2.7E-11	2.0E-10	Adult
Ba-140	8.1E-12	3.5E-13	8.5E-12	Adult
La-140	2.2E-12	3.7E-13	2.6E-12	Adult
Ce-141	2.3E-12	1.2E-13	2.4E-12	Adult
Ce-144	2.0E-11	9.7E-13	2.1E-11	Adult
Pm-147	8.0E-15	2.9E-13	3.0E-13	Adult
Sm-153	3.3E-14	2.3E-13	2.7E-13	Adult
Eu-152	2.8E-09	1.8E-12	2.8E-09	Adult
Eu-154	2.5E-09	2.5E-12	2.5E-09	Adult
Eu-155	4.7E-11	3.8E-13	4.8E-11	Adult
Er-169	2.4E-16	5.4E-14	5.4E-14	Adult
Lu-177	1.9E-13	7.2E-14	2.6E-13	Adult
Re-188	2.5E-17	1.2E-12	1.2E-12	Adult
Au-198	1.1E-13	3.1E-12	3.2E-12	Adult
Tl-201	2.9E-14	2.4E-12	2.4E-12	Adult
Pb-210	3.1E-12	1.6E-07	1.6E-07	Adult
Pb-212	1.7E-14	1.4E-10	1.4E-10	Adult
Po-210	1.5E-15	4.8E-10	4.8E-10	Adult
At-211	1.3E-18	8.9E-14	8.9E-14	Adult
Ra-223	1.6E-13	1.6E-10	1.6E-10	Adult
Ra-226	3.3E-10	8.8E-10	1.2E-09	Offspring
Ac-225	1.8E-12	4.2E-12	6.1E-12	Adult
Th-227	7.8E-12	2.3E-10	2.3E-10	Adult
Th-230	2.3E-11	6.8E-11	9.1E-11	Adult
Th-232	4.5E-09	3.0E-09	7.6E-09	Adult
Th-234	6.4E-13	6.4E-13	1.3E-12	Adult
U-234	6.7E-15	1.3E-11	1.3E-11	Adult
U-235	1.3E-11	1.2E-11	2.5E-11	Adult
U-238	2.3E-12	1.2E-11	1.4E-11	Adult
Np-237	1.8E-11	3.4E-10	3.6E-10	Adult
Pu-238	5.9E-14	1.4E-09	1.4E-09	Adult
Pu-239	1.4E-13	1.5E-09	1.5E-09	Adult

Radionuclide	DPUR for worst age group fishing family (µSv/y per Bq/y of discharge to estuary/coastal water)*			
	External radiation DPUR	**Seafood consumption DPUR**	**Total DPUR**	**Age group**
Pu-240	6.1E-14	1.5E-09	1.5E-09	Adult
Pu-241	2.2E-13	2.7E-11	2.8E-11	Adult
Pu-242	5.4E-14	1.5E-09	1.5E-09	Adult
Am-241	2.6E-11	4.0E-11	6.6E-11	Adult
Am-242	1.8E-15	1.5E-14	1.7E-14	Adult
Am-243	5.8E-10	4.0E-11	6.2E-10	Adult
Cm-242	5.4E-15	2.6E-12	2.6E-12	Adult
Cm-243	3.0E-10	2.8E-11	3.3E-10	Adult
Cm-244	4.8E-14	2.2E-11	2.2E-11	Adult

*For a water exchange rate of 100 m^3/s.

Table 5. Dose rate per unit release factors for coastal wildlife – coastal release scenario

These DPURs are multiplied by the factor Q_{eff} (Table 13) when assessing exposure of coastal wildlife via the sewer release scenario.

Radionuclide	Worst total DPUR ($\mu Gy\ h^{-1}$ per $Bq\ y^{-1}$)	Worst affected reference organism
H-3	2.6E-18	Mollusc - bivalve, Polychaete worm
H-3 organic	2.6E-14	Polychaete worm
C-14	8.9E-14	Polychaete worm
Na-22	1.2E-13	Reptile
Na-24	1.5E-14	Reptile
P-32	7.8E-12	Crustacean
P-33	1.1E-12	Sea anemones & True coral
S-35	2.7E-17	Sea anemones & True coral
Cl-36	4.7E-17	Phytoplankton
Ca-45	2.2E-15	Mammal
Ca-47	5.2E-13	Polychaete worm
V-48	1.2E-11	Polychaete worm
Cr-51	8.8E-14	Polychaete worm
Mn-52	1.2E-11	Polychaete worm
Mn-54	4.2E-12	Polychaete worm
Fe-55	7.2E-16	Polychaete worm
Fe-59	5.7E-12	Polychaete worm
Co-56	1.6E-11	Polychaete worm
Co-57	5.7E-13	Polychaete worm
Co-58	4.3E-12	Polychaete worm
Co-60	1.3E-11	Polychaete worm
Ni-63	1.6E-14	Sea anemones & True coral
Cu-61	2.7E-13	Crustacean
Cu-64	3.2E-13	Crustacean
Zn-62	4.3E-12	Crustacean
Zn-65	2.2E-12	Crustacean
Ga-67	5.4E-14	Zooplankton
Se-75	3.5E-13	Reptile
Br-76	8.0E-14	Mollusc – bivalve
Br-77	1.2E-14	Mollusc – bivalve
Br-82	5.6E-14	Mollusc – bivalve
Rb-81	1.0E-14	Polychaete worm
Rb-83	2.9E-13	Polychaete worm
Sr-83	4.0E-15	Polychaete worm
Sr-85	8.3E-15	Mammal
Sr-89	1.5E-14	Bird
Sr-90	3.4E-14	Reptile
Y-90	4.9E-13	Polychaete worm
Zr-89	3.4E-12	Polychaete worm
Zr-95	3.8E-12	Polychaete worm
Nb-95	3.4E-12	Polychaete worm
Mo-99	2.6E-13	Zooplankton
Tc-99	9.9E-13	Vascular plant
Tc-99m	9.9E-15	Mammal
Ru-103	1.2E-12	Polychaete worm

Radionuclide	Worst total DPUR ($\mu Gy\ h^{-1}$ per $Bq\ y^{-1}$)	Worst affected reference organism
Ru-106	1.9E-12	Polychaete worm
Ag-110m	4.5E-12	Mammal
In-111	5.1E-13	Polychaete worm
Sb-125	5.3E-13	Mammal
I-123	4.9E-15	Mollusc - bivalve
I-124	1.2E-13	Mollusc – bivalve
I-125	6.9E-14	Mollusc – bivalve
I-129	1.4E-13	Mollusc – bivalve
I-131	1.7E-13	Mollusc – bivalve
I-133	6.5E-14	Mollusc – bivalve
I-135	2.2E-14	Mollusc – bivalve
Cs-134	9.8E-13	Polychaete worm
Cs-136	8.5E-13	Polychaete worm
Cs-137	3.8E-13	Polychaete worm
Ba-140	1.4E-11	Polychaete worm
La-140	4.8E-12	Polychaete worm
Ce-141	3.7E-13	Mammal, Polychaete worm
Ce-144	1.8E-12	Polychaete worm
Pm-147	2.4E-15	Macroalgae
Sm-153	1.6E-13	Polychaete worm
Eu-152	7.1E-12	Polychaete worm
Eu-154	7.5E-12	Polychaete worm
Eu-155	3.4E-13	Polychaete worm
Er-169	5.3E-15	Macroalgae
Lu-177	1.4E-13	Polychaete worm
Re-188	5.6E-13	Vascular plant
Au-198	7.8E-13	Vascular plant
Tl-201	6.6E-14	Polychaete worm
Pb-210	3.9E-12	Phytoplankton
Pb-212	5.2E-10	Phytoplankton
Po-210	6.3E-12	Polychaete worm
At-211	3.9E-12	Mollusc – bivalve
Ra-223	9.9E-12	Phytoplankton
Ra-226	4.8E-11	Phytoplankton
Ac-225	2.1E-09	Phytoplankton
Th-227	6.6E-11	Phytoplankton
Th-230	8.0E-11	Phytoplankton
Th-232	6.9E-11	Phytoplankton
Th-234	8.0E-13	Polychaete worm
U-234	8.6E-12	Polychaete worm
U-235	8.0E-12	Polychaete worm
U-238	7.4E-12	Polychaete worm
Np-237	3.3E-12	Polychaete worm
Pu-238	3.5E-10	Phytoplankton
Pu-239	3.3E-10	Phytoplankton
Pu-240	3.3E-10	Phytoplankton
Pu-241	1.8E-13	Phytoplankton
Pu-242	3.2E-10	Phytoplankton
Am-241	4.0E-11	Phytoplankton
Am-242	1.5E-13	Phytoplankton

Radionuclide	Worst total DPUR ($\mu Gy\ h^{-1}$ per $Bq\ y^{-1}$)	Worst affected reference organism
Am-243	3.9E-11	Phytoplankton
Cm-242	4.2E-11	Phytoplankton
Cm-243	5.2E-11	Phytoplankton
Cm-244	5.0E-11	Phytoplankton

Table 6. Dose per unit release factors for angler family – river release scenario

These DPURs are multiplied by the factor Q_{eff} (Table 13) when assessing exposure of angler family via the sewer release scenario.

Radionuclide	DPUR for worst age group angler family (µSv/y per Bq/y of discharge to river)*				
	Fish consumption DPUR	External radiation DPUR	Drinking water consumption DPUR	Total DPUR	Age group
H-3	2.0E-14	0.0E+00	5.9E-13	6.1E-13	Offspring
H-3 organic	1.5E-08	0.0E+00	1.1E-12	1.5E-08	Offspring
C-14	1.9E-07	4.0E-15	1.4E-11	1.9E-07	Offspring
Na-22	1.7E-10	2.5E-13	6.8E-11	2.4E-10	Offspring
Na-24	2.1E-11	8.5E-14	8.2E-12	2.9E-11	Adult
P-32	2.2E-06	1.2E-13	4.7E-10	2.2E-06	Offspring
P-33	4.3E-07	4.9E-16	9.1E-11	4.3E-07	Offspring
S-35	1.0E-10	4.7E-16	3.8E-12	1.0E-10	Offspring
Cl-36	9.3E-12	1.4E-15	5.2E-11	6.1E-11	Infant
Ca-45	6.3E-11	1.1E-14	1.6E-10	2.2E-10	Offspring
Ca-47	5.6E-11	2.7E-10	1.4E-10	4.6E-10	Offspring
V-48	1.2E-10	6.3E-11	3.8E-11	2.2E-10	Adult
Cr-51	5.4E-13	3.5E-10	4.0E-13	3.5E-10	Adult
Mn-52	6.6E-11	1.4E-08	8.2E-12	1.4E-08	Adult
Mn-54	2.6E-11	1.8E-08	3.2E-12	1.8E-08	Adult
Fe-55	3.0E-11	0.0E+00	5.2E-12	3.5E-11	Adult
Fe-59	1.6E-10	5.9E-09	2.9E-11	6.1E-09	Adult
Co-56	4.4E-11	7.0E-08	1.7E-11	7.0E-08	Adult
Co-57	3.7E-12	1.4E-09	1.4E-12	1.4E-09	Adult
Co-58	1.3E-11	1.7E-08	5.1E-12	1.7E-08	Adult
Co-60	5.9E-11	4.8E-08	2.3E-11	4.8E-08	Adult
Ni-63	4.0E-13	0.0E+00	4.9E-12	5.3E-12	Infant
Cu-61	1.7E-11	9.0E-11	2.2E-12	1.1E-10	Adult
Cu-64	1.7E-11	2.1E-11	2.2E-12	4.0E-11	Adult
Zn-62	2.0E-09	1.6E-10	1.8E-11	2.2E-09	Adult
Zn-65	8.2E-09	3.4E-10	7.3E-11	8.6E-09	Adult
Ga-67	4.8E-11	9.7E-12	3.6E-12	6.1E-11	Adult
Se-75	8.9E-09	1.2E-09	4.4E-11	1.0E-08	Offspring
Br-76	2.4E-11	1.2E-09	8.0E-12	1.2E-09	Adult
Br-77	5.1E-12	1.5E-10	1.7E-12	1.5E-10	Adult
Br-82	2.9E-11	1.2E-09	9.4E-12	1.3E-09	Adult
Rb-81	7.8E-11	1.8E-09	4.8E-13	1.9E-09	Adult
Rb-83	2.7E-09	7.2E-09	1.7E-11	1.0E-08	Adult
Sr-83	8.6E-13	2.0E-10	8.9E-12	2.1E-10	Adult
Sr-85	9.8E-13	6.2E-10	1.0E-11	6.3E-10	Adult
Sr-89	2.1E-11	3.4E-12	2.2E-10	2.4E-10	Offspring

Radionuclide	DPUR for worst age group angler family (µSv/y per Bq/y of discharge to river)*				
	Fish consumption DPUR	External radiation DPUR	Drinking water consumption DPUR	Total DPUR	Age group
Sr-90	7.5E-11	9.1E-12	7.8E-10	8.6E-10	Offspring
Y-90	2.4E-11	1.3E-13	1.6E-10	1.8E-10	Infant
Zr-89	1.1E-11	2.4E-10	1.4E-11	2.7E-10	Adult
Zr-95	1.3E-11	1.6E-09	1.7E-11	1.7E-09	Adult
Nb-95	1.1E-10	8.6E-11	1.1E-11	2.1E-10	Adult
Mo-99	4.9E-13	4.6E-10	7.7E-12	4.7E-10	Adult
Tc-99	3.0E-12	3.2E-18	4.0E-11	4.3E-11	Infant
Tc-99m	8.2E-14	4.0E-15	1.1E-12	1.2E-12	Infant
Ru-103	1.1E-11	7.1E-09	6.1E-12	7.1E-09	Adult
Ru-106	1.1E-10	3.4E-09	5.8E-11	3.6E-09	Adult
Ag-110m	1.7E-11	7.2E-08	4.5E-12	7.2E-08	Adult
In-111	6.1E-10	1.4E-09	1.8E-12	2.0E-09	Adult
Sb-125	2.1E-11	1.9E-09	1.7E-11	1.9E-09	Adult
I-123	3.4E-12	1.2E-10	3.4E-12	1.3E-10	Adult
I-124	2.1E-10	8.8E-10	2.1E-10	1.3E-09	Adult
I-125	2.4E-10	8.7E-12	2.4E-10	4.9E-10	Adult
I-129	1.8E-09	7.0E-12	1.8E-09	3.6E-09	Adult
I-131	1.5E-10	9.5E-12	1.3E-09	1.4E-09	Infant
I-133	7.0E-11	5.1E-10	7.0E-11	6.4E-10	Adult
I-135	1.5E-11	1.3E-09	1.5E-11	1.3E-09	Adult
Cs-134	1.4E-08	2.3E-08	1.7E-10	3.7E-08	Adult
Cs-136	2.2E-09	6.3E-09	2.6E-11	8.5E-09	Adult
Cs-137	9.5E-09	8.4E-09	1.1E-10	1.8E-08	Adult
Ba-140	1.8E-12	9.9E-10	4.6E-11	1.0E-09	Adult
La-140	1.4E-11	8.8E-09	1.1E-11	8.8E-09	Adult
Ce-141	1.1E-12	1.3E-09	1.4E-12	1.3E-09	Adult
Ce-144	8.4E-12	1.5E-09	1.0E-11	1.5E-09	Adult
Pm-147	1.5E-12	1.0E-15	1.3E-11	1.5E-11	Infant
Sm-153	3.0E-12	2.0E-10	3.0E-12	2.0E-10	Adult
Eu-152	1.1E-10	6.3E-10	2.6E-11	7.7E-10	Adult
Eu-154	1.6E-10	7.0E-10	3.7E-11	8.9E-10	Adult
Eu-155	2.6E-11	1.5E-11	6.0E-12	4.7E-11	Adult
Er-169	2.3E-13	6.6E-15	2.4E-12	2.6E-12	Infant
Lu-177	1.0E-12	1.6E-10	1.0E-12	1.7E-10	Adult
Re-188	6.9E-12	2.0E-13	8.9E-11	9.6E-11	Infant
Au-198	1.3E-11	2.1E-09	1.6E-12	2.1E-09	Adult
Tl-201	3.0E-11	1.9E-10	1.0E-12	2.2E-10	Adult
Pb-210	2.0E-09	3.1E-13	2.1E-08	2.3E-08	Infant
Pb-212	6.8E-11	2.3E-09	8.1E-11	2.5E-09	Adult
Po-210	3.9E-09	4.4E-15	2.8E-08	3.2E-08	Infant
At-211	3.2E-11	9.0E-13	5.5E-10	5.8E-10	Infant
Ra-223	1.1E-10	1.1E-11	7.0E-09	7.1E-09	Infant
Ra-226	6.3E-10	1.2E-08	4.7E-09	1.7E-08	Offspring
Ac-225	4.9E-11	9.6E-10	9.8E-11	1.1E-09	Adult
Th-227	3.9E-12	1.9E-09	1.9E-11	1.9E-09	Adult
Th-230	9.3E-11	4.6E-12	4.6E-10	5.6E-10	Adult
Th-232	1.0E-10	6.6E-08	5.1E-10	6.7E-08	Adult

Radionuclide	DPUR for worst age group angler family (µSv/y per Bq/y of discharge to river)*				
	Fish consumption DPUR	External radiation DPUR	Drinking water consumption DPUR	Total DPUR	Age group
Th-234	1.5E-12	5.9E-10	7.5E-12	6.0E-10	Adult
U-234	3.9E-12	1.0E-16	1.1E-09	1.1E-09	Infant
U-235	3.9E-12	2.0E-13	1.1E-09	1.1E-09	Infant
U-238	3.6E-12	4.0E-14	9.9E-10	9.9E-10	Infant
Np-237	2.1E-09	2.0E-12	2.1E-09	4.2E-09	Adult
Pu-238	2.9E-07	5.2E-13	4.1E-10	2.9E-07	Adult
Pu-239	3.1E-07	1.2E-12	4.5E-10	3.1E-07	Adult
Pu-240	3.1E-07	5.0E-13	4.5E-10	3.1E-07	Adult
Pu-241	6.0E-09	2.3E-14	8.6E-12	6.0E-09	Adult
Pu-242	3.0E-07	4.4E-13	4.3E-10	3.0E-07	Adult
Am-241	5.2E-09	1.5E-10	6.6E-10	6.1E-09	Adult
Am-242	7.9E-12	5.7E-11	9.8E-13	6.6E-11	Adult
Am-243	5.2E-09	3.3E-09	6.6E-10	9.2E-09	Adult
Cm-242	6.0E-11	3.1E-15	5.2E-10	5.8E-10	Infant
Cm-243	2.4E-09	4.4E-10	2.4E-09	5.2E-09	Adult
Cm-244	1.9E-09	7.3E-14	1.9E-09	3.8E-09	Adult

*For a river flow rate of 1 m^3/s

Table 7. Dose per unit release factors for irrigated food consumer family – river release scenario

These DPURs are multiplied by the factor Q_{eff} (Table 13) when assessing exposure of irrigated food consumer family via the sewer release scenario.

Radionuclide	DPUR for worst age group irrigated food consumer family (µSv/y per Bq/y of discharge to river)*				
	Terrestrial food consumption DPUR	External radiation DPUR	Drinking water consumption DPUR	Total DPUR	Age group
H-3	1.4E-13	0.0E+00	5.9E-13	7.3E-13	Offspring
H-3 organic	5.9E-14	0.0E+00	1.1E-12	1.2E-12	Offspring
C-14	1.4E-10	0.0E+00	1.4E-11	1.6E-10	Offspring
Na-22	8.8E-11	6.3E-10	1.2E-10	8.5E-10	Infant
Na-24	5.7E-14	9.6E-13	1.9E-11	2.0E-11	Infant
P-32	9.5E-11	0.0E+00	4.7E-10	5.7E-10	Offspring
P-33	3.0E-11	0.0E+00	9.1E-11	1.2E-10	Offspring
S-35	4.0E-12	0.0E+00	7.1E-12	1.1E-11	Infant
Cl-36	1.2E-09	2.4E-13	5.2E-11	1.3E-09	Infant
Ca-45	4.3E-11	2.7E-20	1.6E-10	2.0E-10	Offspring
Ca-47	5.5E-12	2.3E-12	1.4E-10	1.5E-10	Offspring
V-48	3.6E-12	1.9E-11	9.0E-11	1.1E-10	Infant
Cr-51	8.4E-14	3.6E-13	1.1E-12	1.5E-12	Infant
Mn-52	1.5E-12	8.0E-12	1.7E-11	2.7E-11	Infant
Mn-54	3.5E-12	9.6E-11	6.1E-12	1.1E-10	Infant
Fe-55	1.8E-12	8.2E-16	1.6E-11	1.8E-11	Infant
Fe-59	6.5E-12	2.1E-11	8.9E-11	1.2E-10	Infant
Co-56	8.8E-12	1.1E-10	4.5E-11	1.6E-10	Infant
Co-57	1.1E-12	1.1E-11	4.8E-12	1.7E-11	Infant
Co-58	2.5E-12	2.8E-11	1.3E-11	4.4E-11	Infant
Co-60	2.5E-11	1.2E-09	8.1E-11	1.3E-09	Infant
Ni-63	1.5E-12	0.0E+00	4.9E-12	6.4E-12	Infant
Cu-61	4.2E-15	5.0E-14	6.1E-12	6.1E-12	Infant
Cu-64	1.7E-14	4.3E-14	6.7E-12	6.8E-12	Infant
Zn-62	9.9E-14	2.4E-13	5.3E-11	5.3E-11	Infant
Zn-65	2.3E-11	5.3E-11	1.3E-10	2.1E-10	Infant
Ga-67	1.3E-13	2.0E-13	9.8E-12	1.0E-11	Infant
Se-75	7.1E-11	1.8E-11	9.2E-11	1.8E-10	Infant
Br-76	7.2E-14	7.1E-13	2.0E-11	2.1E-11	Infant
Br-77	4.9E-14	3.1E-13	3.3E-12	3.7E-12	Infant
Br-82	1.6E-13	1.6E-12	2.0E-11	2.1E-11	Infant
Rb-81	2.4E-15	5.0E-14	1.2E-12	1.3E-12	Infant
Rb-83	3.6E-11	1.8E-11	3.2E-11	8.6E-11	Infant
Sr-83	1.3E-13	1.8E-11	2.1E-11	4.0E-11	Infant
Sr-85	1.8E-12	1.3E-11	2.4E-11	3.9E-11	Infant
Sr-89	2.9E-11	1.7E-15	2.2E-10	2.5E-10	Offspring
Sr-90	5.5E-10	1.3E-17	7.8E-10	1.3E-09	Offspring
Y-90	1.8E-12	6.6E-20	1.6E-10	1.6E-10	Infant
Zr-89	4.7E-13	1.6E-12	3.6E-11	3.8E-11	Infant
Zr-95	3.1E-12	5.1E-11	4.4E-11	9.9E-11	Infant
Nb-95	1.5E-12	1.1E-11	2.6E-11	3.9E-11	Infant

Radionuclide	DPUR for worst age group irrigated food consumer family (µSv/y per Bq/y of discharge to river)*				
	Terrestrial food consumption DPUR	External radiation DPUR	Drinking water consumption DPUR	Total DPUR	Age group
Mo-99	3.2E-13	3.2E-13	1.9E-11	2.0E-11	Infant
Tc-99	1.4E-09	0.0E+00	4.0E-11	1.4E-09	Infant
Tc-99m	2.5E-15	1.2E-14	1.1E-12	1.1E-12	Infant
Ru-103	1.9E-12	7.7E-12	1.7E-11	2.6E-11	Infant
Ru-106	2.6E-11	2.7E-11	1.8E-10	2.3E-10	Infant
Ag-110m	1.1E-11	2.6E-10	9.8E-12	2.8E-10	Infant
In-111	1.6E-13	4.5E-13	4.7E-12	5.3E-12	Infant
Sb-125	4.6E-12	1.3E-10	4.2E-11	1.8E-10	Infant
I-123	4.1E-14	2.2E-12	1.3E-11	1.6E-11	Infant
I-124	2.7E-11	1.9E-12	7.7E-10	8.0E-10	Infant
I-125	2.1E-10	2.4E-13	4.0E-10	6.1E-10	Infant
I-129	2.4E-09	4.2E-12	1.8E-09	4.2E-09	Child
I-131	1.1E-10	1.3E-12	1.3E-09	1.4E-09	Infant
I-133	1.5E-12	2.3E-13	3.1E-10	3.1E-10	Infant
I-135	9.6E-14	2.0E-13	6.2E-11	6.3E-11	Infant
Cs-134	3.0E-10	3.8E-10	1.7E-10	8.4E-10	Adult
Cs-136	1.1E-11	1.2E-11	3.6E-11	5.9E-11	Infant
Cs-137	2.2E-10	6.9E-10	1.1E-10	1.0E-09	Adult
Ba-140	5.1E-12	1.4E-11	1.4E-10	1.6E-10	Infant
La-140	7.7E-13	1.6E-12	3.2E-11	3.4E-11	Infant
Ce-141	2.0E-12	9.2E-13	4.3E-12	7.2E-12	Infant
Ce-144	2.0E-11	4.9E-12	3.3E-11	5.8E-11	Infant
Pm-147	1.3E-12	9.9E-16	1.3E-11	1.4E-11	Infant
Sm-153	3.6E-13	3.7E-14	9.6E-12	1.0E-11	Infant
Eu-152	4.8E-12	9.5E-10	6.0E-11	1.0E-09	Infant
Eu-154	7.4E-12	8.2E-10	9.7E-11	9.3E-10	Infant
Eu-155	1.3E-12	2.0E-11	1.8E-11	3.9E-11	Infant
Er-169	6.1E-13	8.4E-20	2.4E-12	3.0E-12	Infant
Lu-177	6.9E-13	9.3E-14	3.3E-12	4.1E-12	Infant
Re-188	6.2E-13	1.6E-14	8.9E-11	9.0E-11	Infant
Au-198	6.4E-13	4.7E-13	5.0E-12	6.1E-12	Infant
Tl-201	8.7E-14	9.4E-14	2.5E-12	2.7E-12	Infant
Pb-210	3.7E-09	6.7E-13	2.1E-08	2.5E-08	Infant
Pb-212	1.1E-12	6.3E-14	3.7E-10	3.7E-10	Infant
Po-210	4.3E-08	4.6E-16	2.8E-08	7.0E-08	Infant
At-211	9.1E-13	1.9E-09	5.5E-10	2.4E-09	Infant
Ra-223	2.9E-10	1.3E-12	7.0E-09	7.3E-09	Infant
Ra-226	2.7E-09	2.8E-09	6.8E-09	1.2E-08	Child
Ac-225	4.1E-11	7.5E-13	3.2E-10	3.6E-10	Infant
Th-227	2.2E-11	4.3E-12	6.7E-11	9.3E-11	Infant
Th-230	5.8E-10	2.8E-09	4.6E-10	3.9E-09	Adult
Th-232	6.3E-10	2.0E-09	5.1E-10	3.1E-09	Adult
Th-234	8.7E-12	4.0E-13	2.4E-11	3.3E-11	Infant
U-234	8.8E-11	2.1E-11	1.1E-09	1.2E-09	Infant
U-235	8.8E-11	2.1E-10	1.1E-09	1.4E-09	Infant
U-238	8.1E-11	3.4E-11	9.9E-10	1.1E-09	Infant

Radionuclide	DPUR for worst age group irrigated food consumer family (µSv/y per Bq/y of discharge to river)*				
	Terrestrial food consumption DPUR	External radiation DPUR	Drinking water consumption DPUR	Total DPUR	Age group
Np-237	3.9E-10	3.1E-10	2.1E-09	2.8E-09	Adult
Pu-238	6.2E-10	1.7E-13	4.1E-10	1.0E-09	Adult
Pu-239	6.8E-10	2.1E-10	4.5E-10	1.3E-09	Adult
Pu-240	6.8E-10	1.2E-13	4.5E-10	1.1E-09	Adult
Pu-241	1.3E-11	1.4E-11	8.6E-12	3.6E-11	Adult
Pu-242	6.5E-10	3.5E-11	4.3E-10	1.1E-09	Adult
Am-241	5.4E-10	3.2E-10	6.6E-10	1.5E-09	Adult
Am-242	5.5E-14	9.3E-13	3.1E-12	4.1E-12	Infant
Am-243	5.4E-10	2.6E-10	6.6E-10	1.5E-09	Adult
Cm-242	3.8E-11	5.3E-14	5.2E-10	5.6E-10	Infant
Cm-243	4.1E-10	3.7E-10	2.4E-09	3.2E-09	Adult
Cm-244	3.3E-10	2.5E-13	1.9E-09	2.2E-09	Adult

*For a river flow rate of 1 m^3/s

Table 8. Dose rate per unit release factors for river wildlife – river release scenario

These DPURs are multiplied by the factor Q_{eff} (Table 13) when assessing exposure of river wildlife via the sewer release scenario.

Radionuclide	Worst total DPUR (µGy h^{-1} per Bq y^{-1})	Worst affected reference organism
H-3	2.6E-16	Vascular plant
H-3 organic	4.4E-11	Mollusc – bivalve
C-14	1.6E-10	Benthic fish
Na-22	3.4E-11	Reptile
Na-24	6.8E-11	Reptile
P-32	8.4E-09	Reptile
P-33	9.6E-10	Benthic fish
S-35	2.2E-13	Mollusc – gastropod
Cl-36	6.3E-12	Mollusc – bivalve
Ca-45	2.0E-12	Benthic fish
Ca-47	4.1E-11	Benthic fish
V-48	5.7E-11	Mammal
Cr-51	6.6E-12	Insect larvae
Mn-52	1.2E-09	Insect larvae
Mn-54	2.9E-10	Insect larvae
Fe-55	2.4E-12	Mollusc – bivalve
Fe-59	1.1E-10	Insect larvae
Co-56	1.1E-09	Insect larvae
Co-57	3.6E-11	Insect larvae
Co-58	2.8E-10	Insect larvae
Co-60	7.1E-10	Insect larvae
Ni-63	5.2E-13	Insect larvae
Cu-61	1.8E-10	Reptile
Cu-64	6.4E-11	Reptile
Zn-62	6.2E-10	Reptile
Zn-65	4.0E-11	Reptile
Ga-67	7.0E-12	Mammal
Se-75	2.6E-11	Insect larvae
Br-76	1.2E-10	Insect larvae
Br-77	1.2E-11	Insect larvae
Br-82	1.0E-10	Insect larvae
Rb-81	1.7E-10	Insect larvae
Rb-83	1.2E-10	Insect larvae
Sr-83	6.8E-11	Mammal
Sr-85	2.7E-11	Mammal
Sr-89	1.2E-10	Mammal
Sr-90	2.3E-10	Mammal
Y-90	2.0E-11	Reptile
Zr-89	2.2E-11	Insect larvae
Zr-95	1.5E-11	Insect larvae
Nb-95	1.6E-11	Mammal
Mo-99	7.1E-11	Insect larvae
Tc-99	1.8E-13	Reptile
Tc-99m	9.7E-14	Mammal

Radionuclide	Worst total DPUR (μGy h^{-1} per Bq y^{-1})	Worst affected reference organism
Ru-103	1.2E-10	Insect larvae
Ru-106	3.6E-10	Insect larvae
Ag-110m	1.2E-09	Insect larvae
In-111	1.2E-10	Insect larvae
Sb-125	3.4E-11	Insect larvae
I-123	1.2E-11	Insect larvae
I-124	8.4E-11	Insect larvae
I-125	2.9E-12	Insect larvae
I-129	1.9E-12	Insect larvae
I-131	2.9E-11	Insect larvae
I-133	5.6E-11	Insect larvae
I-135	1.3E-10	Insect larvae
Cs-134	3.9E-10	Insect larvae
Cs-136	5.6E-10	Insect larvae
Cs-137	1.6E-10	Insect larvae
Ba-140	1.2E-10	Insect larvae
La-140	8.5E-10	Insect larvae
Ce-141	4.2E-11	Insect larvae
Ce-144	4.3E-10	Insect larvae
Pm-147	7.7E-12	Phytoplankton
Sm-153	4.6E-11	Insect larvae
Eu-152	3.7E-11	Mammal
Eu-154	5.6E-11	Mammal
Eu-155	9.4E-12	Mammal
Er-169	4.3E-12	Insect larvae
Lu-177	2.3E-11	Insect larvae
Re-188	5.1E-12	Insect larvae
Au-198	2.2E-10	Insect larvae
Tl-201	2.0E-11	Insect larvae
Pb-210	5.2E-11	Insect larvae
Pb-212	9.5E-09	Insect larvae
Po-210	4.7E-08	Insect larvae
At-211	3.4E-10	Reptile
Ra-223	2.5E-08	Insect larvae
Ra-226	8.2E-08	Insect larvae
Ac-225	1.1E-07	Vascular plant
Th-227	1.2E-08	Vascular plant
Th-230	9.7E-09	Vascular plant
Th-232	8.3E-09	Vascular plant
Th-234	2.6E-10	Insect larvae
U-234	4.9E-10	Mollusc – gastropod
U-235	4.5E-10	Mollusc – bivalve
U-238	4.2E-10	Mollusc – gastropod
Np-237	4.8E-10	Mollusc – gastropod
Pu-238	5.6E-10	Reptile
Pu-239	5.2E-10	Reptile
Pu-240	5.2E-10	Reptile
Pu-241	1.4E-13	Reptile
Pu-242	5.0E-10	Reptile

Radionuclide	Worst total DPUR (µGy h^{-1} per Bq y^{-1})	Worst affected reference organism
Am-241	1.8E-09	Crustacean
Am-242	2.1E-11	Insect larvae
Am-243	1.8E-09	Crustacean
Cm-242	5.5E-09	Phytoplankton
Cm-243	5.2E-09	Phytoplankton
Cm-244	5.2E-09	Phytoplankton

Table 9. Dose per unit release factors for sewage treatment workers – sewage release scenario

Radionuclide	DPUR for sewage treatment workers (µSv/y per Bq/y of discharge to sewer)*			
	External radiation DPUR	Inadvertent ingestion and inhalation DPUR	Total DPUR	Age group
H-3	0.0E+00	3.8E-14	3.8E-14	Adult
H-3 organic	0.0E+00	8.8E-14	8.8E-14	Adult
C-11	4.6E-10	3.2E-16	4.6E-10	Adult
C-14	1.4E-13	1.3E-12	1.4E-12	Adult
F-18	2.3E-09	3.4E-15	2.3E-09	Adult
Na-22	1.2E-07	4.8E-12	1.2E-07	Adult
Na-24	5.2E-08	1.3E-13	5.2E-08	Adult
P-32	8.2E-10	1.6E-11	8.4E-10	Adult
P-33	2.4E-12	2.1E-12	4.5E-12	Adult
S-35	1.1E-13	2.3E-13	3.4E-13	Adult
Cl-36	2.3E-11	1.6E-12	2.4E-11	Adult
Ca-45	1.6E-12	3.7E-12	5.2E-12	Adult
Ca-47	8.4E-08	3.2E-12	8.4E-08	Adult
V-48	8.2E-07	1.6E-11	8.2E-07	Adult
Cr-51	8.7E-09	3.4E-13	8.7E-09	Adult
Mn-52	6.2E-07	8.9E-12	6.2E-07	Adult
Mn-54	3.3E-07	8.2E-12	3.3E-07	Adult
Mn-56	1.2E-08	4.6E-14	1.2E-08	Adult
Fe-55	0.0E+00	3.6E-12	3.6E-12	Adult
Fe-59	4.2E-07	1.8E-11	4.2E-07	Adult
Co-56	1.4E-06	2.6E-11	1.4E-06	Adult
Co-57	2.9E-08	2.3E-12	2.9E-08	Adult
Co-58	3.4E-07	7.6E-12	3.4E-07	Adult
Co-60	1.0E-06	3.9E-11	1.0E-06	Adult
Ni-63	0.0E+00	1.7E-12	1.7E-12	Adult
Cu-61	6.6E-09	2.9E-14	6.6E-09	Adult
Cu-64	4.6E-09	8.9E-14	4.6E-09	Adult
Zn-62	1.2E-08	2.3E-13	1.2E-08	Adult
Zn-65	3.2E-08	5.7E-12	3.2E-08	Adult
Ga-67	1.3E-08	6.0E-13	1.3E-08	Adult
Ga-68	2.5E-09	7.8E-15	2.5E-09	Adult
Se-75	6.5E-08	1.5E-11	6.5E-08	Adult
Br-76	3.2E-08	1.5E-13	3.2E-08	Adult

Radionuclide	DPUR for sewage treatment workers (μSv/y per Bq/y of discharge to sewer)*			
	External radiation DPUR	Inadvertent ingestion and inhalation DPUR	Total DPUR	Age group
Br-77	5.6E-09	5.3E-14	5.6E-09	Adult
Br-82	4.2E-08	2.4E-13	4.2E-08	Adult
Rb-81	3.1E-09	8.4E-15	3.1E-09	Adult
Rb-82	2.9E-11	3.7E-20	2.9E-11	Adult
Rb-83	2.4E-08	2.7E-12	2.4E-08	Adult
Sr-83	2.3E-08	4.1E-13	2.3E-08	Adult
Sr-85	7.7E-08	2.6E-12	7.7E-08	Adult
Sr-89	4.1E-10	1.2E-11	4.2E-10	Adult
Sr-90	1.2E-09	1.4E-10	1.4E-09	Adult
Y-90	6.8E-10	7.5E-12	6.9E-10	Adult
Zr-89	7.7E-08	1.5E-12	7.7E-08	Adult
Zr-95	1.5E-07	5.9E-12	1.5E-07	Adult
Nb-95	1.4E-07	3.2E-12	1.4E-07	Adult
Mo-99	4.6E-09	3.6E-13	4.6E-09	Adult
Tc-94m	2.1E-09	3.2E-15	2.1E-09	Adult
Tc-99	9.9E-13	1.1E-12	2.1E-12	Adult
Tc-99m	5.8E-10	4.2E-15	5.8E-10	Adult
Ru-103	2.1E-08	1.0E-12	2.1E-08	Adult
Ru-106	1.1E-08	1.1E-11	1.1E-08	Adult
Ag-110m	1.0E-06	3.1E-11	1.0E-06	Adult
In-111	3.0E-08	8.1E-13	3.0E-08	Adult
In-113m	9.4E-10	3.3E-15	9.4E-10	Adult
Sb-125	2.1E-08	1.8E-12	2.1E-08	Adult
I-123	1.4E-09	7.3E-14	1.4E-09	Adult
I-124	4.3E-08	1.4E-11	4.3E-08	Adult
I-125	1.8E-10	3.6E-11	2.1E-10	Adult
I-129	1.5E-10	2.9E-10	4.5E-10	Adult
I-131	1.9E-08	3.4E-11	1.9E-08	Adult
I-132	7.6E-09	2.7E-14	7.6E-09	Adult
I-133	9.2E-09	1.9E-12	9.2E-09	Adult
I-134	3.4E-09	4.0E-15	3.4E-09	Adult
I-135	1.4E-08	2.1E-13	1.4E-08	Adult
Cs-134	8.1E-08	2.8E-11	8.1E-08	Adult
Cs-136	8.4E-08	3.3E-12	8.4E-08	Adult
Cs-137	2.9E-08	1.9E-11	2.9E-08	Adult
Ba-140	3.1E-07	9.0E-12	3.1E-07	Adult
La-140	1.3E-07	2.9E-12	1.3E-07	Adult
Ce-141	9.1E-09	4.0E-12	9.2E-09	Adult
Ce-144	1.2E-08	3.6E-11	1.2E-08	Adult
Pm-147	1.6E-12	2.3E-12	3.9E-12	Adult
Sm-153	1.1E-09	9.3E-13	1.1E-09	Adult
Eu-152	2.5E-07	1.5E-11	2.5E-07	Adult
Eu-154	2.7E-07	2.0E-11	2.7E-07	Adult
Eu-155	6.0E-09	2.9E-12	6.0E-09	Adult
Er-169	2.7E-12	1.4E-12	4.1E-12	Adult

Radionuclide	DPUR for sewage treatment workers (µSv/y per Bq/y of discharge to sewer)*			
	External radiation DPUR	Inadvertent ingestion and inhalation DPUR	Total DPUR	Age group
Lu-177	2.7E-09	1.7E-12	2.7E-09	Adult
Re-188	6.2E-10	4.6E-13	6.2E-10	Adult
Au-198	2.1E-08	1.6E-12	2.1E-08	Adult
Tl-201	2.7E-09	1.7E-13	2.7E-09	Adult
Pb-210	4.9E-10	7.6E-09	8.1E-09	Adult
Pb-212	3.6E-08	6.1E-12	3.6E-08	Adult
Bi-213	2.4E-10	3.7E-14	2.4E-10	Adult
Po-210	3.1E-12	1.3E-08	1.3E-08	Adult
At-211	1.9E-10	3.3E-12	1.9E-10	Adult
Ra-223	3.3E-08	1.1E-09	3.5E-08	Adult
Ra-226	4.0E-07	2.2E-09	4.0E-07	Adult
Ac-225	4.6E-08	1.5E-09	4.7E-08	Adult
Th-227	9.2E-08	2.0E-09	9.4E-08	Adult
Th-230	7.0E-11	5.8E-09	5.9E-09	Adult
Th-232	3.0E-11	8.8E-09	8.8E-09	Adult
Th-234	7.5E-09	3.2E-11	7.6E-09	Adult
U-234	3.1E-12	2.0E-10	2.0E-10	Adult
U-235	6.3E-09	1.8E-10	6.5E-09	Adult
U-238	1.2E-09	1.7E-10	1.4E-09	Adult
Np-237	6.4E-10	9.8E-10	1.6E-09	Adult
Pu-238	1.1E-12	2.0E-09	2.0E-09	Adult
Pu-239	2.4E-12	2.2E-09	2.2E-09	Adult
Pu-240	1.0E-12	2.2E-09	2.2E-09	Adult
Pu-241	4.8E-14	3.9E-11	3.9E-11	Adult
Pu-242	9.1E-13	2.1E-09	2.1E-09	Adult
Am-241	1.4E-09	7.3E-09	8.7E-09	Adult
Am-242	1.6E-10	4.1E-13	1.6E-10	Adult
Am-243	3.0E-08	7.2E-09	3.7E-08	Adult
Cm-242	8.1E-12	1.4E-09	1.4E-09	Adult
Cm-243	3.5E-08	9.5E-09	4.4E-08	Adult
Cm-244	5.8E-12	8.1E-09	8.1E-09	Adult

*For a raw sewage flow rate into the sewage treatment works of 60 m^3/d

Table 10. Dose per unit release factors for children playing in brook

Decay and partitioning of radionuclides going through the sewage treatment works has not been taken into account in the derivation of these DPURs. These DPURs are multiplied by the decay and partitioning factor, Q_{eff} (Table 13) for use in the sewer release scenario.

Radionuclide	DPUR for children playing in brook (µSv/y per Bq/y of discharge to sewer)*			
	External radiation DPUR	Inadvertent ingestion DPUR	Total DPUR	Age group
H-3	0.0E+00	3.6E-14	3.6E-14	Child
H-3 organic	0.0E+00	2.6E-13	2.6E-13	Child
C-14	2.0E-14	3.6E-12	3.6E-12	Child
Na-22	1.3E-12	8.7E-12	1.0E-11	Child
Na-24	4.2E-13	1.2E-12	1.6E-12	Child
P-32	6.0E-13	8.8E-12	9.4E-12	Child
P-33	2.5E-15	8.8E-13	8.8E-13	Child
S-35	2.4E-15	5.1E-13	5.2E-13	Child
Cl-36	2.4E-13	3.3E-12	3.5E-12	Child
Ca-45	5.5E-14	5.9E-12	5.9E-12	Child
Ca-47	1.3E-09	9.8E-12	1.3E-09	Child
V-48	3.1E-10	6.8E-12	3.2E-10	Child
Cr-51	1.8E-09	1.5E-12	1.8E-09	Child
Mn-52	7.1E-08	1.1E-10	7.1E-08	Child
Mn-54	9.0E-08	4.1E-11	9.0E-08	Child
Fe-55	0.0E+00	9.0E-12	9.0E-12	Child
Fe-59	3.0E-08	3.8E-11	3.0E-08	Child
Co-56	3.5E-07	1.6E-10	3.5E-07	Child
Co-57	7.1E-09	1.6E-11	7.1E-09	Child
Co-58	8.7E-08	4.6E-11	8.7E-08	Child
Co-60	2.4E-07	3.0E-10	2.4E-07	Child
Ni-63	0.0E+00	3.6E-12	3.6E-12	Child
Cu-61	4.5E-10	5.4E-13	4.5E-10	Child
Cu-64	1.0E-10	5.9E-13	1.0E-10	Child
Zn-62	8.0E-10	4.7E-12	8.0E-10	Child
Zn-65	1.7E-09	1.5E-11	1.7E-09	Child
Ga-67	4.8E-11	8.2E-13	4.9E-11	Child
Se-75	6.2E-09	4.2E-11	6.2E-09	Child
Br-76	5.9E-09	4.3E-12	5.9E-09	Child
Br-77	7.3E-10	8.4E-13	7.3E-10	Child
Br-82	6.1E-09	4.7E-12	6.1E-09	Child
Rb-81	9.1E-09	2.3E-12	9.1E-09	Child
Rb-83	3.6E-08	7.3E-11	3.6E-08	Child
Sr-83	9.9E-10	3.1E-12	1.0E-09	Child
Sr-85	3.1E-09	5.1E-12	3.1E-09	Child
Sr-89	1.7E-11	2.0E-11	3.7E-11	Child
Sr-90	4.6E-11	2.0E-10	2.5E-10	Child
Y-90	2.2E-11	1.8E-11	4.0E-11	Child
Zr-89	1.2E-09	5.0E-12	1.2E-09	Child
Zr-95	8.1E-09	5.9E-12	8.1E-09	Child
Nb-95	4.3E-10	1.9E-12	4.3E-10	Child
Mo-99	2.3E-09	1.6E-11	2.3E-09	Child
Tc-99	5.3E-16	2.1E-12	2.1E-12	Child

Radionuclide	DPUR for children playing in brook (µSv/y per Bq/y of discharge to sewer)*			
	External radiation DPUR	Inadvertent ingestion DPUR	Total DPUR	Age group
Tc-99m	6.6E-13	6.8E-14	7.3E-13	Child
Ru-103	3.5E-08	3.6E-11	3.5E-08	Child
Ru-106	1.7E-08	3.6E-10	1.7E-08	Child
Ag-110m	3.6E-07	2.0E-10	3.6E-07	Child
In-111	7.0E-09	1.7E-11	7.0E-09	Child
Sb-125	9.3E-09	1.7E-11	9.3E-09	Child
I-123	6.1E-10	3.7E-12	6.1E-10	Child
I-124	4.4E-09	2.3E-10	4.7E-09	Child
I-125	4.3E-11	2.3E-10	2.8E-10	Child
I-129	3.5E-11	1.4E-09	1.5E-09	Child
I-131	1.6E-09	3.9E-10	2.0E-09	Child
I-133	2.5E-09	7.5E-11	2.6E-09	Child
I-135	6.3E-09	1.7E-11	6.3E-09	Child
Cs-134	1.2E-07	3.2E-10	1.2E-07	Child
Cs-136	3.2E-08	1.0E-10	3.2E-08	Child
Cs-137	4.2E-08	2.3E-10	4.2E-08	Child
Ba-140	5.0E-09	2.6E-11	5.0E-09	Child
La-140	4.4E-08	1.2E-10	4.4E-08	Child
Ce-141	6.4E-09	5.6E-11	6.4E-09	Child
Ce-144	7.3E-09	4.1E-10	7.7E-09	Child
Pm-147	1.7E-13	4.7E-12	4.8E-12	Child
Sm-153	9.9E-10	5.2E-11	1.0E-09	Child
Eu-152	3.2E-09	6.1E-12	3.2E-09	Child
Eu-154	3.5E-09	9.7E-12	3.5E-09	Child
Eu-155	7.7E-11	1.6E-12	7.9E-11	Child
Er-169	1.1E-12	3.0E-11	3.2E-11	Child
Lu-177	8.2E-10	4.5E-11	8.6E-10	Child
Re-188	3.3E-11	6.5E-12	3.9E-11	Child
Au-198	1.0E-08	8.3E-11	1.0E-08	Child
Tl-201	9.3E-10	3.5E-12	9.3E-10	Child
Pb-210	5.2E-11	2.5E-08	2.5E-08	Child
Pb-212	1.2E-08	2.6E-10	1.2E-08	Child
Po-210	7.4E-13	6.7E-08	6.7E-08	Child
At-211	1.5E-10	1.7E-10	3.2E-10	Child
Ra-223	1.8E-09	4.8E-09	6.6E-09	Child
Ra-226	5.9E-08	8.5E-09	6.8E-08	Child
Ac-225	4.8E-09	1.8E-09	6.6E-09	Child
Th-227	9.5E-09	8.4E-10	1.0E-08	Child
Th-230	2.3E-11	8.8E-09	8.8E-09	Child
Th-232	3.3E-07	1.1E-08	3.4E-07	Child
Th-234	2.9E-09	2.7E-10	3.2E-09	Child
U-234	1.7E-14	1.2E-10	1.2E-10	Child
U-235	3.4E-11	1.2E-10	1.5E-10	Child
U-238	6.7E-12	1.1E-10	1.2E-10	Child
Np-237	9.9E-12	1.8E-10	1.9E-10	Child
Pu-238	2.6E-12	9.0E-09	9.0E-09	Child
Pu-239	5.8E-12	1.0E-08	1.0E-08	Child

Radionuclide	DPUR for children playing in brook (µSv/y per Bq/y of discharge to sewer)*			
	External radiation DPUR	Inadvertent ingestion DPUR	Total DPUR	Age group
Pu-240	2.5E-12	1.0E-08	1.0E-08	Child
Pu-241	1.2E-13	1.9E-10	1.9E-10	Child
Pu-242	2.2E-12	9.7E-09	9.7E-09	Child
Am-241	7.5E-10	7.6E-09	8.3E-09	Child
Am-242	2.8E-10	2.2E-11	3.1E-10	Child
Am-243	1.6E-08	7.6E-09	2.4E-08	Child
Cm-242	5.2E-13	2.0E-10	2.0E-10	Child
Cm-243	2.2E-09	1.3E-09	3.5E-09	Child
Cm-244	3.6E-13	1.1E-09	1.1E-09	Child

*For a brook flow rate of 0.1 m^3/s

Table 11. Dose per unit release factors for farming family using sludge-amended soil– sewage release scenario

Radionuclide	DPUR for worst age group farming family (µSv/y per Bq/y of discharge to sewer)*^				
	Terrestrial food consumption DPUR	External radiation DPUR	Inadvertent ingestion and inhalation DPUR	Total DPUR	Age group
H-3	5.1E-11	0.0E+00	6.5E-18	5.1E-11	Infant
H-3 organic	6.9E-12	0.0E+00	1.8E-15	6.9E-12	Infant
C-14	8.4E-08	0.0E+00	1.4E-14	8.4E-08	Offspring
Na-22	2.7E-08	2.4E-07	2.4E-14	2.7E-07	Offspring
P-32	3.8E-08	0.0E+00	7.4E-15	3.8E-08	Offspring
P-33	3.2E-08	0.0E+00	3.7E-15	3.2E-08	Offspring
S-35	9.2E-09	0.0E+00	4.7E-16	9.2E-09	Infant
Cl-36	1.3E-06	3.2E-11	2.3E-13	1.3E-06	Infant
Ca-45	4.0E-07	3.8E-17	3.2E-14	4.0E-07	Offspring
Ca-47	3.5E-11	2.6E-10	4.2E-17	3.0E-10	Offspring
V-48	7.0E-14	3.2E-08	2.7E-15	3.2E-08	Adult
Cr-51	6.0E-12	8.2E-10	1.0E-16	8.3E-10	Adult
Mn-52	1.5E-11	3.5E-09	1.5E-16	3.5E-09	Adult
Mn-54	8.5E-08	3.4E-07	7.6E-14	4.2E-07	Adult
Fe-55	2.4E-08	9.7E-13	6.3E-14	2.4E-08	Infant
Fe-59	1.1E-09	5.6E-08	1.8E-14	5.7E-08	Adult
Co-56	3.7E-09	3.2E-07	5.1E-14	3.2E-07	Adult
Co-57	1.5E-09	3.7E-08	2.2E-14	3.8E-08	Adult
Co-58	9.2E-10	8.2E-08	1.5E-14	8.3E-08	Adult
Co-60	1.2E-07	4.1E-06	2.4E-12	4.2E-06	Adult
Ni-63	2.1E-08	0.0E+00	2.6E-13	2.1E-08	Infant
Zn-65	9.0E-08	6.7E-09	1.2E-14	9.7E-08	Infant
Se-75	2.3E-06	1.1E-08	2.4E-14	2.3E-06	Infant
Rb-83	1.4E-08	2.0E-09	2.1E-15	1.6E-08	Infant
Sr-85	2.5E-10	1.7E-08	2.5E-15	1.7E-08	Adult
Sr-89	6.8E-09	7.2E-13	1.1E-14	6.8E-09	Infant
Sr-90	3.8E-06	7.0E-15	6.2E-12	3.8E-06	Infant
Zr-95	5.0E-12	8.2E-08	2.1E-14	8.2E-08	Adult
Nb-95	1.8E-13	1.5E-08	2.9E-15	1.5E-08	Adult
Tc-99	8.7E-06	0.0E+00	7.0E-14	8.7E-06	Infant
Ru-103	1.6E-12	2.2E-09	1.1E-15	2.2E-09	Adult
Ru-106	4.6E-10	1.0E-08	1.6E-13	1.1E-08	Adult
Ag-110m	3.6E-06	3.0E-07	1.4E-13	3.9E-06	Infant
Sb-125	3.1E-09	5.0E-08	6.9E-14	5.3E-08	Adult
I-124	2.2E-12	8.6E-11	4.4E-17	8.8E-11	Adult
I-125	1.7E-08	5.3E-11	1.8E-14	1.8E-08	Infant
I-129	8.5E-07	1.7E-09	1.3E-11	8.5E-07	Child
I-131	1.3E-09	8.1E-11	1.8E-15	1.3E-09	Infant
Cs-134	9.7E-08	1.4E-07	1.0E-13	2.4E-07	Adult
Cs-136	1.1E-10	1.8E-09	1.2E-16	1.9E-09	Adult
Cs-137	1.1E-07	2.6E-07	5.7E-13	3.8E-07	Adult
Ba-140	6.1E-12	8.7E-09	1.5E-15	8.7E-09	Adult
Ce-141	2.5E-11	1.2E-09	5.4E-15	1.3E-09	Adult
Ce-144	2.4E-08	3.1E-09	3.2E-13	2.7E-08	Infant

Radionuclide	DPUR for worst age group farming family (µSv/y per Bq/y of discharge to sewer)*^				
	Terrestrial food consumption DPUR	External radiation DPUR	Inadvertent ingestion and inhalation DPUR	Total DPUR	Age group
Pm-147	4.0E-10	6.5E-13	8.1E-14	4.0E-10	Infant
Eu-152	2.2E-09	1.8E-06	1.2E-11	1.8E-06	Adult
Eu-154	2.6E-09	1.6E-06	1.0E-11	1.6E-06	Adult
Eu-155	3.0E-10	3.8E-08	8.2E-13	3.8E-08	Adult
Er-169	1.1E-12	1.6E-17	1.2E-16	1.1E-12	Infant
Lu-177	7.1E-14	3.0E-11	9.7E-17	3.0E-11	Adult
Pb-210	3.0E-05	7.9E-10	5.6E-10	3.0E-05	Infant
Po-210	1.6E-05	5.1E-13	4.1E-11	1.6E-05	Infant
Ra-223	7.6E-09	3.2E-10	3.3E-13	7.9E-09	Infant
Ra-226	6.5E-06	2.8E-06	1.0E-09	9.3E-06	Child
Ac-225	2.7E-12	8.0E-10	3.2E-12	8.0E-10	Adult
Th-227	5.8E-12	7.9E-09	1.3E-11	7.9E-09	Adult
Th-230	2.9E-07	9.8E-06	1.8E-08	1.0E-05	Adult
Th-232	3.1E-07	6.9E-06	3.2E-08	7.2E-06	Adult
Th-234	6.1E-12	9.6E-10	1.8E-14	9.7E-10	Adult
U-234	2.2E-07	2.8E-09	7.7E-11	2.2E-07	Infant
U-235	2.2E-07	2.8E-08	7.0E-11	2.5E-07	Infant
U-238	2.0E-07	4.5E-09	6.6E-11	2.1E-07	Infant
Np-237	1.2E-07	1.2E-07	3.2E-09	2.4E-07	Adult
Pu-238	5.8E-08	6.6E-11	5.4E-09	6.4E-08	Adult
Pu-239	6.7E-08	8.2E-08	7.0E-09	1.6E-07	Adult
Pu-240	6.7E-08	4.7E-11	7.0E-09	7.4E-08	Adult
Pu-241	9.9E-10	5.5E-09	5.0E-11	6.5E-09	Adult
Pu-242	6.4E-08	1.3E-08	6.7E-09	8.4E-08	Adult
Am-241	5.8E-07	6.1E-07	2.8E-08	1.2E-06	Adult
Am-243	5.9E-07	4.9E-07	2.9E-08	1.1E-06	Adult
Cm-242	3.3E-09	5.9E-11	2.0E-11	3.4E-09	Infant
Cm-243	3.2E-07	1.3E-06	2.3E-08	1.6E-06	Adult
Cm-244	2.4E-07	8.7E-10	1.6E-08	2.6E-07	Adult

*For a raw sewage flow rate into the sewage treatment works of 60 m^3/d.
^Decay and partitioning of radionuclides at the sewage treatment works is already accounted for in these DPURs.

Table 12. Dose rate per unit release factors for terrestrial wildlife – use of sludge on land

Radionuclide	Worst total DPUR (µGy h^{-1} per Bq y^{-1})^	Worst affected reference organism
H-3	1.8E-12	Amphibian, Annelid, Arthropod – detritivorous, Bird, Grasses & Herbs, Mammal – large, Mammal - small-burrowing, Mollusc – gastropod, Reptile, Shrub, Tree
H-3 organic	1.9E-09	Amphibian, Bird, Mammal – large, Mammal - small-burrowing, Reptile
C-14	6.7E-09	Bird, Mammal – large, Mammal - small-burrowing, Reptile
Na-22	1.0E-10	Mammal - large
P-32	9.1E-10	Mammal - large
P-33	2.7E-10	Amphibian, Bird, Mammal – large, Mammal - small-burrowing, Reptile
S-35	1.4E-11	Grasses & Herbs, Shrub, Tree
Cl-36	7.6E-10	Grasses & Herbs
Ca-45	9.6E-12	Mammal - large
Ca-47	4.1E-13	Mammal - large
V-48	3.7E-12	Annelid
Cr-51	9.0E-14	Annelid
Mn-52	3.9E-13	Arthropod – detritivorous
Mn-54	5.2E-11	Arthropod - detritivorous
Fe-55	1.1E-11	Shrub
Fe-59	7.0E-12	Arthropod - detritivorous
Co-56	4.5E-11	Arthropod - detritivorous
Co-57	4.3E-12	Amphibian
Co-58	1.1E-11	Annelid
Co-60	7.4E-10	Amphibian
Ni-63	9.6E-12	Reptile
Zn-65	6.2E-12	Mammal – large
Se-75	5.3E-12	Annelid
Rb-83	2.5E-12	Mammal - large
Sr-85	3.2E-12	Mammal – large
Sr-89	5.7E-12	Lichen & Bryophytes
Sr-90	1.2E-09	Lichen & Bryophytes
Zr-95	4.2E-12	Amphibian
Nb-95	1.9E-12	Annelid
Tc-99	9.3E-11	Grasses & Herbs
Ru-103	5.9E-13	Lichen & Bryophytes
Ru-106	2.1E-11	Lichen & Bryophytes
Ag-110m	1.3E-10	Annelid
Sb-125	7.7E-12	Annelid
I-124	1.0E-14	Amphibian
I-125	7.1E-14	Mammal – large
I-129	1.7E-11	Mammal – large
I-131	2.9E-14	Amphibian
Cs-134	6.1E-11	Mammal – large
Cs-136	5.3E-13	Mammal – large
Cs-137	2.5E-10	Mammal – large

Ba-140	6.5E-12	Bird
Ce-141	1.1E-13	Amphibian
Ce-144	3.2E-12	Bird
Pm-147	4.2E-13	Bird
Eu-152	4.0E-10	Annelid
Eu-154	3.1E-10	Arthropod – detritivorous
Eu-155	1.0E-11	Bird
Er-169	2.0E-15	Bird
Lu-177	2.7E-15	Annelid
Pb-210	8.2E-10	Lichen & Bryophytes
Po-210	3.8E-09	Lichen & Bryophytes
Ra-223	7.4E-11	Lichen & Bryophytes
Ra-226	1.7E-07	Lichen & Bryophytes
Ac-225	5.6E-11	Lichen & Bryophytes
Th-227	4.0E-11	Lichen & Bryophytes
Th-230	3.2E-08	Lichen & Bryophytes
Th-232	2.7E-08	Lichen & Bryophytes
Th-234	5.4E-13	Lichen & Bryophytes
U-234	8.7E-09	Lichen & Bryophytes
U-235	8.1E-09	Lichen & Bryophytes
U-238	7.6E-09	Lichen & Bryophytes
Np-237	9.4E-09	Lichen & Bryophytes
Pu-238	1.2E-09	Lichen & Bryophytes
Pu-239	1.3E-09	Lichen & Bryophytes
Pu-240	1.3E-09	Lichen & Bryophytes
Pu-241	1.5E-13	Lichen & Bryophytes
Pu-242	1.3E-09	Lichen & Bryophytes
Am-241	5.2E-08	Lichen & Bryophytes
Am-243	5.2E-08	Lichen & Bryophytes
Cm-242	2.0E-09	Lichen & Bryophytes
Cm-243	6.2E-08	Lichen & Bryophytes
Cm-244	4.8E-08	Lichen & Bryophytes

^Decay and partitioning of radionuclides at the sewage treatment works is already accounted for in these DPURs.

Table 13. Discharge rate of radionuclides from the sewage treatment works in treated effluent per unit release rate into sewage treatment works

The factors in this table should be applied to take account of losses during transit through a sewage treatment works when assessing the doses to the fishing family, river angler, and irrigated food consumer families and child in brook as a result of releases to sewer. These factors should be applied when assessing dose rates to wildlife in the coastal and river environments, which receive discharges via a sewage treatment works. Q_{eff} factors are not considered for radionuclides with a half-life of less than 3 hours as the radionuclide would have decayed before leaving the sewage treatment works.

Radionuclide	Partitioning and decay factor, expressed as a discharge rate (Q_{eff}) (Bq/y discharge from STW in treated effluent per Bq/y of discharge into STW)
H-3	8.5E-01
H-3 organic	8.5E-01
C-14	8.5E-01
Na-22	9.0E-01
Na-24	4.5E-01
P-32	1.9E-01
P-33	2.0E-01
S-35	9.0E-01
Cl-36	9.0E-01
Ca-45	6.0E-01
Ca-47	5.5E-01
V-48	9.7E-02
Cr-51	9.8E-02
Mn-52	4.6E-02
Mn-54	5.0E-02
Fe-55	1.0E-01
Fe-59	9.9E-02
Co-56	9.9E-02
Co-57	1.0E-01
Co-58	9.9E-02
Co-60	1.0E-01
Ni-63	1.0E-01
Cu-61	2.3E-03
Cu-64	2.2E-02
Zn-62	2.9E-01
Zn-65	9.0E-01
Ga-67	8.8E-02
Se-75	5.0E-01
Br-76	4.7E-01
Br-77	7.5E-01
Br-82	6.7E-01
Rb-81	9.3E-02
Rb-83	9.0E-01
Sr-83	4.4E-01
Sr-85	6.0E-01
Sr-89	5.9E-01
Sr-90	6.0E-01
Y-90	4.3E-02
Zr-89	4.4E-01

Radionuclide	Partitioning and decay factor, expressed as a discharge rate (Q_{eff}) (Bq/y discharge from STW in treated effluent per Bq/y of discharge into STW)
Zr-95	5.0E-01
Nb-95	4.9E-01
Mo-99	7.7E-01
Tc-99	9.0E-01
Tc-99m	1.6E-01
Ru-103	8.9E-01
Ru-106	9.0E-01
Ag-110m	1.0E-01
In-111	8.6E-02
Sb-125	9.0E-01
I-123	3.6E-01
I-124	7.2E-01
I-125	7.9E-01
I-129	8.0E-01
I-131	7.6E-01
I-133	4.9E-01
I-135	1.7E-01
Cs-134	9.0E-01
Cs-136	8.7E-01
Cs-137	9.0E-01
Ba-140	5.8E-01
La-140	2.3E-01
Ce-141	4.9E-01
Ce-144	5.0E-01
Pm-147	5.0E-01
Sm-153	4.0E-01
Eu-152	5.0E-01
Eu-154	5.0E-01
Eu-155	5.0E-01
Er-169	4.8E-01
Lu-177	4.7E-01
Re-188	4.9E-01
Au-198	4.3E-01
Tl-201	4.3E-01
Pb-210	1.0E-01
Pb-212	3.8E-02
Po-210	1.0E-01
At-211	1.9E-01
Ra-223	4.8E-01
Ra-226	5.0E-01
Ac-225	9.6E-02
Th-227	9.8E-02
Th-230	1.0E-01
Th-232	1.0E-01
Th-234	9.9E-02
U-234	9.0E-01
U-235	9.0E-01
U-238	9.0E-01
Np-237	9.0E-01

Radionuclide	Partitioning and decay factor, expressed as a discharge rate (Q_{eff}) (Bq/y discharge from STW in treated effluent per Bq/y of discharge into STW)
Pu-238	9.0E-01
Pu-239	9.0E-01
Pu-240	9.0E-01
Pu-241	9.0E-01
Pu-242	9.0E-01
Am-241	5.0E-01
Am-242	2.6E-01
Am-243	5.0E-01
Cm-242	1.0E-01
Cm-243	1.0E-01
Cm-244	1.0E-01

Table 14. Partitioning and decay factor for sludge to be incinerated per unit release rate into sewage treatment works

The factors in this table should be used to refine the source term to take account of losses during transit through a sewage treatment works when assessing the doses to local resident family and dose rates to terrestrial wildlife living close to an incinerator of sewage sludge. Q_{slu} factors are not considered for radionuclides with a half-life of less than 3 hours as the radionuclide would have decayed before the sludge is incinerated.

Radionuclide	Partitioning and decay factor, (Q_{slu}) (Bq/y in sludge for incineration per Bq/y of discharge into STW)
H-3	1.5E-01
H-3 organic	1.5E-01
C-14	1.5E-01
Na-22	1.0E-01
Na-24	1.2E-03
P-32	6.6E-01
P-33	7.2E-01
S-35	9.7E-02
Cl-36	1.0E-01
Ca-45	3.9E-01
Ca-47	2.2E-01
V-48	7.6E-01
Cr-51	8.1E-01
Mn-52	5.8E-01
Mn-54	9.4E-01
Fe-55	9.0E-01
Fe-59	8.5E-01
Co-56	8.7E-01
Co-57	8.9E-01
Co-58	8.7E-01
Co-60	9.0E-01
Ni-63	9.0E-01
Cu-61	2.5E-09
Cu-64	5.0E-03
Zn-62	7.6E-05
Zn-65	9.9E-02
Ga-67	3.8E-01
Se-75	4.9E-01
Br-76	1.6E-03
Br-77	3.0E-02
Br-82	1.5E-02
Rb-81	4.9E-08
Rb-83	9.7E-02
Sr-83	5.1E-02
Sr-85	3.8E-01
Sr-89	3.8E-01
Sr-90	4.0E-01
Y-90	3.4E-01
Zr-89	2.1E-01
Zr-95	4.8E-01

Radionuclide	Partitioning and decay factor, (Q_{slu}) (Bq/y in sludge for incineration per Bq/y of discharge into STW)
Nb-95	4.6E-01
Mo-99	3.6E-02
Tc-99	1.0E-01
Tc-99m	1.5E-06
Ru-103	9.3E-02
Ru-106	9.9E-02
Ag-110m	8.9E-01
In-111	3.3E-01
Sb-125	1.0E-01
I-123	1.3E-03
I-124	1.0E-01
I-125	1.9E-01
I-129	2.0E-01
I-131	1.4E-01
I-133	8.2E-03
I-135	8.5E-06
Cs-134	1.0E-01
Cs-136	8.1E-02
Cs-137	1.0E-01
Ba-140	3.2E-01
La-140	1.3E-01
Ce-141	4.6E-01
Ce-144	5.0E-01
Pm-147	5.0E-01
Sm-153	1.2E-01
Eu-152	5.0E-01
Eu-154	5.0E-01
Eu-155	5.0E-01
Er-169	3.7E-01
Lu-177	3.3E-01
Re-188	2.0E-03
Au-198	1.8E-01
Tl-201	2.0E-01
Pb-210	9.0E-01
Pb-212	1.7E-03
Po-210	8.8E-01
At-211	2.0E-05
Ra-223	3.9E-01
Ra-226	5.0E-01
Ac-225	6.8E-01
Th-227	7.8E-01
Th-230	9.0E-01
Th-232	9.0E-01
Th-234	8.3E-01
U-234	1.0E-01
U-235	1.0E-01
U-238	1.0E-01
Np-237	1.0E-01

Radionuclide	Partitioning and decay factor, (Q_{slu}) (Bq/y in sludge for incineration per Bq/y of discharge into STW)
Pu-238	1.0E-01
Pu-239	1.0E-01
Pu-240	1.0E-01
Pu-241	1.0E-01
Pu-242	1.0E-01
Am-241	5.0E-01
Am-242	7.8E-03
Am-243	5.0E-01
Cm-242	8.8E-01
Cm-243	9.0E-01
Cm-244	9.0E-01

Table 15. Incinerator partitioning factors to flue gas: proportion of radionuclide released to atmosphere with flue gas

Radionuclide*	Dry gas cleaned incinerator	Wet gas cleaned incinerator
H-3	1	0.001
H-3 organic	1	0.001
C-14	0.99	0.98
Na-22	0.001	0.001
Na-24	0.001	0.001
P-32	0.1	0.1
P-33	0.1	0.1
S-35	0.2	0.2
Cl-36	0.3	0.3
Ca-45	0.001	0.001
Ca-47	0.001	0.001
V-48	0.06	0.06
Cr-51	0.005	0.005
Mn-52	0.001	0.001
Mn-54	0.001	0.001
Fe-55	0.001	0.001
Fe-59	0.001	0.001
Co-56	0.001	0.001
Co-57	0.001	0.001
Co-58	0.001	0.001
Co-60	0.001	0.001
Ni-63	0.001	0.001
Cu-61	0.01	0.01
Cu-64	0.01	0.01
Zn-62	0.02	0.02
Zn-65	0.02	0.02
Ga-67	0.001	0.001
Se-75	0.001	0.001
Br-76	0.001	0.001
Br-77	0.001	0.001
Br-82	0.001	0.001
Rb-81	0.3	0.3
Rb-83	0.3	0.3
Sr-83	0.01	0.01
Sr-85	0.01	0.01
Sr-89	0.01	0.01
Sr-90	0.01	0.01
Y-90	0.07	0.07
Zr-89	0.06	0.06
Zr-95	0.06	0.06
Nb-95	0.06	0.06
Mo-99	0.01	0.01
Tc-99	0.001	0.001
Tc-99m	0.001	0.001
Ru-103	0.01	0.01
Ru-106	0.01	0.01
Ag-110m	0.1	0.1
In-111	0.001	0.001

Radionuclide*	Dry gas cleaned incinerator	Wet gas cleaned incinerator
Sb-125	0.01	0.01
I-123	0.01	0.01
I-124	0.01	0.01
I-125	0.01	0.01
I-129	0.01	0.01
I-131	0.01	0.01
I-133	0.01	0.01
I-135	0.01	0.01
Cs-134	0.01	0.01
Cs-136	0.01	0.01
Cs-137	0.01	0.01
Ba-140	0.01	0.01
La-140	0.07	0.07
Ce-141	0.07	0.07
Ce-144	0.07	0.07
Pm-147	0.07	0.07
Sm-153	0.07	0.07
Eu-152	0.07	0.07
Eu-154	0.07	0.07
Eu-155	0.07	0.07
Er-169	0.07	0.07
Lu-177	0.07	0.07
Re-188	0.001	0.001
Au-198	0.24	0.24
Tl-201	0.98	0.98
Pb-210	0.01	0.01
Pb-212	0.01	0.01
Po-210	0.001	0.001
At-211	0.01	0.01
Ra-223	0.01	0.01
Ra-226	0.01	0.01
Ac-225	0.001	0.001
Th-227	0.001	0.001
Th-230	0.001	0.001
Th-232	0.001	0.001
Th-234	0.001	0.001
U-234	0.001	0.001
U-235	0.001	0.001
U-238	0.001	0.001
Np-237	0.001	0.001
Pu-238	0.001	0.001
Pu-239	0.001	0.001
Pu-240	0.001	0.001
Pu-241	0.001	0.001
Pu-242	0.001	0.001
Am-241	0.001	0.001
Am-242	0.001	0.001
Am-243	0.001	0.001
Cm-242	0.001	0.001
Cm-243	0.001	0.001

Radionuclide*	Dry gas cleaned incinerator	Wet gas cleaned incinerator
Cm-244	0.001	0.001

*radionuclides with a half-life of less than 3 hours not considered as these will have decayed before the sludge leaves the sewage treatment works. Radionuclides which are gases not considered as these would not be released to sewer.

Table 16. Recommended default radionuclides for other alpha and other beta/gamma categories

In the first instance, you should try to find out exactly which radionuclides are likely to be present in the other alpha or other beta/gamma categories which may help to refine the assessment. If this information is not available, suggested radionuclides for each release scenario are listed below. The radionuclides suggested are those which lead to the highest dose or dose rate for each category and discharge scenario.

Category	Default radionuclide for each discharge scenario: doses to public			
	Atmosphere	Estuary / coastal water	River	Sewage
Other alpha	Pu-239	Th-232	Pu-239	Po-210
Other beta/gamma (half-life < 1 day)	Pb-212	Pb-212	Pb-212	Na-24
Other beta/gamma (half-life < 10 days)	I-131	Mn-52	Mn-52	Mn-52
Other beta/gamma (half-life > 10 days)	Pb-210	Pb-210	P-32	Pb-210
Category	**Default radionuclide for each discharge scenario: dose rates to wildlife**			
	Atmosphere	**Estuary / coastal water**	**River**	**Sewage**
Other alpha	Ra-226	Ac-225	Ac-225	Ra-226
Other beta/gamma (half-life < 1 day)	C-11	Pb-212	Pb-212	Pb-212
Other beta/gamma (half-life < 10 days)	Ca-47	Mn-52	Mn-52	La-140
Other beta/gamma (half-life > 10 days)	Cl-36	Co-56	P-32	C-14

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List of abbreviations

Bq	Becquerel
BSS	Basic Safety Standards
DPUR	dose per unit release for people; dose rate per unit release for wildlife
EPR 16	Environmental Permitting Regulations 2016
GDC	Generalised Derived Constraints
Gy	Gray – unit of absorbed radiation dose
HPA	Health Protection Agency
NIEA	Northern Ireland Environment Agency
NRPB	National Radiological Protection Board
NRW	Natural Resources Wales
SEPA	Scottish Environment Protection Agency
STW	sewage treatment works
Sv	Sievert – unit of effective radiation dose and radiation dose equivalent
UKHSA	UK Health Security Agency

5 Appendix A: How to use dose per unit release (DPUR) factors - worked examples

This appendix shows how the DPUR factors can be used to perform an initial radiological assessment without the use of the spreadsheet tools. It shows the calculations which are performed by the spreadsheet tools when the user selects or enters different data.

The data within the IRAT2 spreadsheets are recorded to more significant figures than the values listed in the tables of this report and the IRAT2 Part 2 report [A.1]. Therefore, outputs from the worked examples in this Appendix, which rely on data from this report, will differ slightly from outputs generated using the IRAT2 spreadsheets. This is due to rounding differences in the data used in the calculations.

The examples are for illustrative purposes only and are not based on real case studies. All data referring to site-specific and discharge data is fictitious. For the examples below we have applied the Environment Agencies screening thresholds to determine when refinement of the assessment is needed, i.e. we have followed the process shown in Figure 1.

For each example, the calculations needed for each stage of the assessment are shown in the tables below which reference which data table in the report the relevant data is taken from. In the tables below, each value is given an alphabetical reference ([A], [B], [C] etc.) to help the user follow the calculations. The alphabetical references are used in the text throughout these examples to help the user follow the calculations shown in the tables.

5.1 Example 1: A hospital in the Thames Valley

A hospital in the Thames Valley has an incinerator permitted to discharge 420 MBq/month (5.04 GBq/y) of carbon-14 to air and 120 GBq/month (1.44 TBq/y) of iodine-131 to sewer.

The Figures which show how this example can be worked through using the spreadsheet tools are as follows:

- Figure 3. IRAT2 release to air stage 1 assessment with the assessment details tab completed for Example 1
- Figure 6. IRAT 2 release to sewer stage 1 assessment with assessment details tab partially completed for Example 1
- Figure 7. IRAT2 release to sewer stage 1 assessment with assessment details tab completed for Example 1
- Figure 15. IRAT2 release to sewer stage 1 assessment results for Example 1
- Figure 19. IRAT2 release to air stage 2 refined assessment with assessment details tab completed for Example 1 applying partitioning factors and selecting an effective release height

- Figure 23. IRAT2 release to sewer stage 2 refined assessment with assessment details tab completed for Example 1 with a user defined sewage flow rate entered

Stage 1 – Initial radiological assessment using default data

For a stage 1 assessment the DPUR [B] is simply multiplied by the annual discharge limits [A].

For exposure pathways which involve exposure to treated effluent from the sewage treatment works, the DPUR must also be multiplied by an effluent partitioning & decay factor (Q_{eff}) [C] to account for the decay and partitioning of the radionuclide within the Sewage Treatment Works (STW). The DPUR factors for coastal and river wildlife exposed via effluent from a sewage treatment works also need to be scaled by the factor effluent partitioning & decay (Qeff) [C].

For the release to estuary/coast scenario, DPURs are calculated using a coastal exchange rate of 100 m^3/s. For a stage 1 assessment the default coastal exchange rate is set as 30 m^3/s therefore a scaling factor of 3.3 is applied when calculating dose in this stage.

Releases to air

Releases to air Exposure group – Local resident family			
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 2 (μSv/y per Bq/y) [B]	Dose (μSv/y) [C] = [A] x [B]
C-14	5.04E+09	7.0E-11	3.5E-01
Total dose (μSv/y) Sum of [C]			3.5E-01

Releases to air Exposure group – Terrestrial wildlife			
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 3 (μGy/h per Bq/y) [B]	Dose Rate (μGy/h) [C] = [A] x [B]
C-14	5.04E+09	1.1E-13	5.5E-04
Total dose rate (μGy/h) Sum of [C]			5.5E-04

Releases to sewer

Releases to sewer Exposure group – Sewage treatment workers			
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 9 (μSv/y per Bq/y) [B]	Dose (μSv/y) [C] = [A] x [B]
I-131	1.44E+12	1.9E-08	2.7E+04
Total dose (μSv/y) Sum of [C]			2.7E+04

Releases to sewer Exposure group – Farming family on sludge conditioned land			
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 11 (μSv/y per Bq/y) [B]	Dose (μSv/y) [C] = [A] x [B]
I-131	1.44E+12	1.3E-09	1.9E+03
Total dose (μSv/y) Sum of [C]			1.9E+03

Releases to sewer Exposure group – Children playing in brook				
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 10 (μSv/y per Bq/y) [B]	Effluent Partitioning & Decay Factor (Q_{eff}) Table 13 [C]	Dose (μSv/y) [D] = [A] x [B] x [C]
I-131	1.44E+12	2.0E-09	7.6E-01	2.2E+03
Total dose (μSv/y) Sum of [C]				2.2E+03

Releases to sewer Exposure group – Coastal fishing family				
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 4 (μSv/y per Bq/y) [B]	Effluent Partitioning & Decay Factor (Q_{eff}) Table 13 [C]	Dose (μSv/y) [D] = [A] x [B] x [C] x 3.3#
I-131	1.44E+12	2.6E-12	7.6E-01	9.4E+00
Total dose (μSv/y) Sum of [D]				9.4E+00

Coastal release DPURs are calculated using a coastal exchange rate of 100 m^3/s. For an initial screening assessment the default coastal exchange rate is 30 m^3/s therefore a scaling factor of 3.3 is applied when calculating dose.

Releases to sewer Exposure group – River angler family				
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 6 (μSv/y per Bq/y) [B]	Effluent Partitioning & Decay Factor (Q_{eff}) Table 13 [C]	Dose (μSv/y) [D] = [A] x [B] x [C]
I-131	1.44E+12	1.4E-09	7.6E-01	1.5E+03
Total dose (μSv/y) Sum of [D]				1.5E+03

Releases to sewer Exposure group – Irrigated food consumer family				
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 7 (μSv/y per Bq/y) [B]	Effluent Partitioning & Decay Factor (Q_{eff}) Table 13 [C]	Dose (μSv/y) [D] = [A] x [B] x [C]
I-131	1.44E+12	1.4E-09	7.6E-01	1.5E+03
Total dose (μSv/y) Sum of [D]				1.5E+03

Releases to sewer Exposure group – Terrestrial wildlife sludge to land			
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 12 (μGy/h per Bq/y) [B]	Dose Rate (μGy/h) [C] = [A] x [B]
I-131	1.44E+12	2.9E-14	4.2E-02
Total dose rate (μGy/h) Sum of [C]			4.2E-02

Releases to sewer Exposure group – Coastal wildlife				
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 5 (μGy/h per Bq/y) [B]	Effluent Partitioning & Decay Factor (Q_{eff}) Table 13 [C]	Dose Rate (μGy/h) [D] = [A] x [B] x [C] x 3.3#
I-131	1.44E+12	1.7E-13	7.6E-01	6.1E-01

Total dose rate (µGy/h) Sum of [D]	6.1E-01

Coastal release DPURs are calculated using a coastal exchange rate of 100 m^3/s. For an initial screening assessment the default coastal exchange rate is 30 m^3/s therefore a scaling factor of 3.3 is applied when calculating dose.

Releases to sewer Exposure group –River wildlife				
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 8 (µGy/h per Bq/y) [B]	Effluent Partitioning & Decay Factor (Q_{eff}) Table 13 [C]	Dose Rate (µGy/h) [D] = [A] x [B] x [C]
I-131	1.44E+12	2.9E-11	7.6E-01	3.2E+01
Total dose rate (µGy/h) Sum of [D]				3.2E+01

Summary total dose

Release route	Exposure group	Total dose Human (µSv/y) Wildlife (µGy/h)	Worst total dose Human (µSv/y) Wildlife (µGy/h)	
Air	Local resident family	3.5E-01	3.5E-01	
	Terrestrial wildlife	5.5E-04	5.5E-04	
Sewer	Sewage treatment workers	2.7E+04	Maximum = 2.7E+04	
	Farming family on sludge conditioned land	1.9E+03		
	Children playing in brook	2.2E+03		
	Coastal fishing family	9.4E+00		
	River angler family	1.5E+03		
	Irrigated food consumer family	1.5E+03		
	Terrestrial wildlife- sludge conditioned soil	4.2E-02	Terrestrial + coastal = 6.5E-01	Maximum = 3.2E+01
	Coastal wildlife	6.1E-01	Terrestrial + river = 3.2E+01	
	River wildlife	3.2E+01		
Total critical group dose (µSv/y)				2.7E+04
Total wildlife dose rate (µGy/h)				3.2E+01

For the release to air the dose is 0.35 μSv/y. For release to sewer, the highest dose of 27000 μSv/y is predicted for workers at the sewage treatment works. The resultant total dose of 27000 μSv/y is dominated by the dose to the worker at the sewage treatment works which is much greater than 20 μSv/y. As a result, refined data should be used for the release to sewer assessment (Stage 2).

For wildlife, the total dose rate (the sum of the release to air dose rate to terrestrial wildlife and the release to sewer dose rate to terrestrial and aquatic wildlife) is 32 μGy/h. This is greater than 1 μGy/h meaning that refined data should be used for the release to sewer assessment (Stage 2).

Stage 2 – Initial radiological assessment using refined data

It has been established that the treated effluent from the sewage treatment works flows to a brook, which then enters the lower reaches of the freshwater Thames river and then goes into the mid-section of the Thames Estuary. After periods of dry weather the brook flow is maintained by the treated effluent from the sewage treatment works. Downstream of where the brook joins the freshwater Thames, the Thames is a source of drinking water and is used by a large number of anglers for coarse fishing. The coarse fish are mostly thrown back.

The main refinements which can be undertaken are to:

- determine which sewage treatment works receives the releases to sewer and establish the average annual raw sewage flow.
- determine the flow rate in the brook
- determine the flow rate in the River Thames
- determine the net tidal exchange rate in the Thames

Refined data have been established are as follows:

Raw throughput of sewage to sewage treatment works:	30000 m^3/d
Average volumetric flow rate in the brook:	0.3 m^3/s
Average volumetric flow rate in River Thames:	30 m^3/s
Long-term net tidal exchange rate Thames estuary (mid)	231 m^3/s

The flow through the works is 5000 times higher than the default for the initial assessment of 60 m^3/d. The greater dilution means that the estimated doses will be much reduced.

The impact on freshwater wildlife is only considered in the river and not the brook.

Releases to sewer

For a stage 2 assessment, the resulting dose can be scaled using site-specific flow rate data for the sewage treatment works, brook and river. Higher volumetric flow will reduce the assessed dose. The resulting doses can also be scaled using the volumetric exchange rate of the estuary/coastal water.

To refine the assessment using the flow rates or exchange rate data provided, the DPURs [B] are multiplied by the discharge limits [A] as in stage 1. They are then scaled by multiplying by the default flow rate or exchange rate given in the IRAT2 methodology and dividing by the known actual flow rate or exchange rate [C] or [D].

The default flow and exchange rates used in the methodology are as follows:

- Sewage treatment works flow rate, 60 m^3/d
- Brook flow rate, 0.1m^3/s
- River flow rate, 1m^3/s
- Coastal exchange rate, 100 m^3/d

Releases to sewer Exposure group – Sewage treatment workers		Raw sewage flow rate (m^3/d) [C]	30000
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 9 (µSv/y per Bq/y) [B]	Dose (µSv/y) [D] = [A] x [B] x 60 m^3/d / [C]
I-131	1.44E+12	1.9E-08	5.5E+01
Total dose (µSv/y) Sum of [D]			5.5E+01

Releases to sewer Exposure group – Farming family on sludge conditioned land		Raw sewage flow rate (m^3/d) [C]	30000
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 11 (µSv/y per Bq/y) [B]	Dose (µSv/y) [D] = [A] x [B] x 60 m^3/d / [C]
I-131	1.44E+12	1.3E-09	3.7E+00
Total dose (µSv/y) Sum of [D]			3.7E+00

Releases to sewer Exposure group – Children playing in brook	Brook flow rate (m^3/s) [D]	0.3

Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 10 (μSv/y per Bq/y) [B]	Effluent Partitioning & Decay Factor (Q_{eff}) Table 13 [C]	Dose (μSv/y) [E] = [A] x [B] x [C] x 0.1 m^3/s /[D]
I-131	1.44E+12	2.0E-09	7.6E-01	7.3E+02
Total dose (μSv/y) Sum of [D]				7.3E+02

Releases to sewer Exposure group – Coastal fishing family			Exchange rate (m^3/s) [D]	231
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 4 (μSv/y per Bq/y) [B]	Effluent Partitioning & Decay Factor (Q_{eff}) Table 13 [C]	Dose (μSv/y) [E] = [A] x [B] x [C] x 100 m^3/s / [D]
I-131	1.44E+12	2.6E-12	7.6E-01	1.2E+00
Total dose (μSv/y) Sum of [E]				1.2E+00

Releases to sewer Exposure group – River angler family			River flow rate (m^3/s) [D]	30
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 6 (μSv/y per Bq/y) [B]	Effluent Partitioning & Decay Factor (Q_{eff}) Table 13 [C]	Dose (μSv/y) [E] = [A] x [B] x [C] x 1 m^3/s / [D]
I-131	1.44E+12	1.4E-09	7.6E-01	5.1E+01
Total dose (μSv/y) Sum of [E]				5.1E+01

Releases to sewer Exposure group – Irrigated food consumer family			River flow rate (m^3/s) [D]	30
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 7 (μSv/y per Bq/y) [B]	Effluent Partitioning & Decay Factor (Q_{eff}) Table 13 [C]	Dose (μSv/y) [E] = [A] x [B] x [C] x 1 m^3/s / [D]
I-131	1.44E+12	1.4E-09	7.6E-01	5.1E+01

Total dose (μSv/y) Sum of [E]	5.1E+01

Releases to sewer Exposure group – Terrestrial wildlife: sludge conditioned land		Raw sewage flow rate (m^3/d) [C]	30000
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 12 (μGy/h per Bq/y) [B]	Dose rate (μGy/h) [D] = [A] x [B] x 60 m^3/d / [C]
I-131	1.44E+12	2.9E-14	8.4E-05
Total dose rate (μGy/h) Sum of [D]			8.4E-05

Releases to sewer Exposure group – Coastal wildlife		Exchange rate (m^3/s) [D]		231
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 5 (μGy/h per Bq/y) [B]	Effluent partitioning & decay factor (Q_{eff}) Table 13 [C]	Dose rate (μGy/h) [E] = [A] x [B] x [C] x 100 m^3/s / [D]
I-131	1.44E+12	1.7E-13	7.6E-01	8.1E-02
Total dose rate (μGy/h) Sum of [E]				8.1E-02

Releases to sewer Exposure group – River wildlife		River flow rate (m^3/s) [D]		30
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 8 (μGy/h per Bq/y) [B]	Effluent partitioning & decay factor (Q_{eff}) Table 13 [C]	Dose rate (μGy/h) [E] = [A] x [B] x [C] x 1 m^3/s /[D]
I-131	1.44E+12	2.9E-11	7.6E-01	1.1E+00
Total dose rate (μGy/h) Sum of [D]				1.1E+00

Stage 2 – Summary total dose or dose rate

Release route	Exposure group	Total dose Human (μSv/y) Wildlife (μGy/h)	Worst total dose Human (μSv/y) Wildlife (μGy/h)

<table>
<tr><td rowspan="2">Air</td><td>Local resident family</td><td>3.5E-01</td><td colspan="2">3.5E-01</td></tr>
<tr><td>Terrestrial wildlife</td><td>5.5E-04</td><td colspan="2">5.5E-04</td></tr>
<tr><td rowspan="9">Sewer</td><td>Sewage treatment workers</td><td>5.5E+01</td><td colspan="2" rowspan="6">Maximum = 7.3E+02</td></tr>
<tr><td>Farming family on sludge conditioned land</td><td>3.9E+00</td></tr>
<tr><td>Children playing in brook</td><td>7.3E+02</td></tr>
<tr><td>Coastal fishing family</td><td>1.2E+00</td></tr>
<tr><td>River angler family</td><td>5.1E+01</td></tr>
<tr><td>Irrigated food consumer family</td><td>5.1E+01</td></tr>
<tr><td>Terrestrial wildlife- sludge conditioned soil</td><td>8.4E-05</td><td>Terrestrial + coastal = 8.1E-02</td><td rowspan="3">Maximum = 1.1E+00</td></tr>
<tr><td>Coastal wildlife</td><td>8.1E-02</td><td rowspan="2">Terrestrial + river = 1.1E+00</td></tr>
<tr><td>River wildlife</td><td>1.1E+00</td></tr>
<tr><td colspan="4">Total critical group dose (µSv/y)</td><td>7.3E+02</td></tr>
<tr><td colspan="4">Total wildlife dose rate (µGy/h)</td><td>1.1E+00</td></tr>
</table>

The highest dose is now for children playing in the brook at 730 µSv/y. The second highest dose is 55 µSv/y the sewage treatment worker and the third highest is 51 µSv/y to the irrigated food consumer family and the river angler family. As these are still greater than 20 µSv/y, it is necessary to consider whether a separate detailed site-specific assessment is required (Stage 3).

For wildlife, the total dose rate (the sum of the release to air the dose rate to terrestrial wildlife and the release to sewer dose rate to terrestrial and aquatic wildlife) is 1.1 µGy/h. This is greater than 1 µGy/h meaning that it is necessary to undertake a multiple releases assessment for wildlife (Stage 3).

Stage 3 – Determine need for a separate site-specific radiological assessment

A Stage 3 review will help determine a number of key facts such as:

- what the actual disposal routes are for sewage sludge
- whether there is access to the brook such that children can play in the stream
- what proportion of the fish caught by anglers is kept for consumption,
- whether there is any drinking water abstraction downstream of the discharge
- whether any treatment is applied to the drinking water which could have an effect on radionuclide concentrations

- whether there are any other exposure pathways, such as the production and consumption of watercress.

The doses to children playing in a brook may be ignored if there is no physical access to the brook. The drinking water consumption doses may be excluded for the river angler and irrigated food family groups if there is no drinking water abstraction downstream of the discharge point or modified if the water is subject to water treatment processes. The dose to the angler family from the consumption of freshwater fish may be scaled by lower consumption rates.

If it is established that the sewage sludge is disposed of via incineration, an additional initial radiological assessment of releases to air may be undertaken. An initial assessment of sludge incineration must be undertaken in two parts.

Firstly, the release to sewer discharge data [A] should be multiplied by a sludge partitioning & decay factor [B] (Q_{slu}) (Table 14) to generate a new source term. Q_{slu} is applied to take into account the partitioning and radioactive decay of the radionuclides in the sludge during transit through the sewage treatment works. The new source term can then be multiplied by the DPURs [C] for the release to air discharge scenario to assess the impact following release to air via incineration, following the steps already described above.

Stage 1 – initial assessment sludge incineration

Releases to air – incineration of sewage sludge Exposure group – Local resident family				
Radionuclide	Discharge to sewer (Bq/y) [A]	Sludge partitioning & decay factor (Q_{slu}) Table 14 [B]	Total DPUR from Table 2 (μSv/y per Bq/y) [C]	Dose (μSv/y) [D] = [A] x [B] x [C]
I-131	1.44E+12	1.4E-01	4.4E-09	8.9E+02
Total dose (μSv/y) Sum of [D]				8.9E+02

Releases to air – incineration of sewage sludge Exposure group – Terrestrial wildlife				
Radionuclide	Discharge to sewer (Bq/y) [A]	Sludge partitioning & decay factor (Q_{slu}) Table 14 [B]	Total DPUR from Table 3 (μGy/h per Bq/y) [C]	Dose rate (μGy/h) [D] = [A] x [B] x [C]
I-131	1.44E+12	1.4E-01	1.4E-14	2.8E-03
Total dose rate (μGy/h) Sum of [D]				2.8E-03

For the release to air following incineration of sewage sludge the dose to the local resident is 890 µSv/y. This is higher than 20 µSv/y so a refined assessment should be undertaken.

For the release to air following incineration of sewage sludge the dose rate to terrestrial wildlife is 0.0028 µGy/h. This is lower than 1 µGy/h so a refined assessment for wildlife is not needed.

Stage 2 – refined assessment for sludge incineration

When assessing the impact of sludge incineration, the assessment can be refined by to applying incineration partitioning factors [D] to account for the behaviour of the I-131 within the incinerator. To refine the assessment in this way, the DPUR [C] is multiplied by the sludge partitioning and decay factor (Q_{slu}) [B] and the discharge to sewer [A] as above, and then multiplied by the incineration partitioning factor [D].

Releases to air – incineration of sewage sludge Exposure group – Local resident family					
Radionuclide	Discharge to sewer (Bq/y) [A]	Sludge partitioning & decay factor (Q_{slu}) Table 14 [B]	Total DPUR from Table 2 (µSv/y per Bq/y) [C]	Incineration partitioning factor Table 15 [D]	Dose (µSv/y) [E] = [A] x [B] x [C] X [D]
I-131	1.44E+12	1.4E-01	4.4E-09	0.01	8.9E+00
Total dose (µSv/y) Sum of [E]					8.9E+00

The dose to the local resident is 8.9 µSv/y. This is below 20 µSv/y, so no further refinement is needed. If the resulting dose was higher than 20 µSv/y then a further refinement could be made by adjusting the effective stack height, this process is shown in example 3.

5.2 Example 2: A university research department

A research department in a large university is seeking a permit to discharge radionuclides to air and to river.

The following discharge limits for air are proposed: 2 MBq/month (24 MBq/y) of tritium, 4.2 MBq/month (50.4 MBq/y) of carbon-14, 4.2 MBq/month (50.4 MBq/y) of sulphur-35, 1.5 MBq/month (18 MBq/y) of iodine-125 and 260 MBq/month (3.12 GBq/y) of iodine-131.

The discharges to river will made from two release points from the university, the flow rate at the second discharge point is greater than at the first. The proposed discharge limits are: 3.33 MBq/month (40 MBq/y) of carbon-14 from discharge point 1, 2.5 MBq/month (30 MBq/y) of carbon-14 from discharge point 2 and 2.5 MBq/month (30 MBq/y) of iodine-131 from discharge point 2.

The Figures which show how this example can be worked through using the spreadsheet tools are as follows:

- Figure 5. IRAT2 release to river stage 1 assessment with the assessment details tab completed for Example 2
- Figure 10. IRAT2 release to river stage 1 assessment release to river tab with discharges entered for Example 2
- Figure 14. IRAT2 release to river stage 1 assessment results for Example 2
- Figure 22. IRAT2 release to river stage 2 assessment with assessment details tab completed for Example 2 with average river flow rate data entered for two discharge points

Stage 1 – Initial radiological assessment using default data

For a stage 1 assessment the DPUR [B] is simply multiplied by the annual discharge limits [A].

Releases to air

Releases to air Exposure group – Local resident family			
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 2 (µSv/y per Bq/y) [B]	Dose (µSv/y) [C] = [A] x [B]
H-3	2.40E+07	9.8E-13	2.4E-05
C-14	5.04E+07	7.0E-11	3.5E-03
S-35	5.04E+07	5.7E-11	2.9E-03
I-125	1.80E+07	3.3E-09	5.9E-02
I-131	3.12E+09	4.4E-09	1.4E+01
Total dose (µSv/y) Sum of [C]			**1.4E+01**

Releases to air Exposure group – Terrestrial wildlife			
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 3 (μGy/h per Bq/y) [B]	Dose rate (μGy/h) [C] = [A] x [B]
H-3	2.40E+07	3.5E-15	8.4E-08
C-14	5.04E+07	1.1E-13	5.5E-06
S-35	5.04E+07	1.2E-14	6.0E-07
I-125	1.80E+07	9.6E-15	1.7E-07
I-131	3.12E+09	1.4E-14	4.4E-05
Total dose rate (μGy/h) Sum of [C]			**5.0E-05**

Where there are multiple releases to river, the dose at each discharge point can be calculated. For an initial assessment, where it is known that the flow at discharge point 2 (down river) is greater than at discharge point 1, a flow rate of $2m^3/s$ is assumed at discharge point 2. To calculate the dose at discharge point 1 [C], the release at discharge point 1 [A] is simply multiplied by the DPUR [B]. To calculate the dose at discharge point 2 [C'], the discharges from discharge point 1 [A] and 2 [A'] are summed, multiplied by the DPUR [B] and then divided by the flow rate of $2m^3/s$ to scale the result according to the increased flow rate down river.

Release to river

Releases to river Exposure group – River angler family					
Radionuclide	Discharge 1 (Bq/y) [A]	Discharge 2 (Bq/y **[A']**	Total DPUR from Table 6 (μSv/y per Bq/y) [B]	Dose at discharge point 1 (μSv/y) [C] = [A] x [B]	Dose at discharge point 2# (μSv/y) [C'] = [A]+[A'] x [B]/$2m^3/s$
C-14	4.00E+07	3.00E+07	1.9E-07	7.6E+00	6.7E+00
I-131	0.00E+00	3.00E+07	1.4E-09	0.0E+00	2.1E-02
Worst total dose (μSv/y) Maximum of Sum of [C] and Sum of [C']				**7.6E+00**	

Releases to river Exposure group – Irrigated food consumer family					
Radionuclide	Discharge 1 (Bq/y) [A]	Discharge 2 (Bq/y	Total DPUR from Table 7 (μSv/y per Bq/y)	Dose at discharge Point 1 (μSv/y)	Dose at discharge Point 2# (μSv/y)

		[A']	[B]	[C] = [A] x [B]	[C'] = [A]+[A'] x [B]/2 m^3/s
C-14	4.00E+07	3.00E+07	1.6E-10	6.4E-03	5.6E-03
I-131	0.00E+00	3.00E+07	1.4E-09	0.0E+00	2.1E-02
Worst total dose (μSv/y) Maximum of Sum of [C] and Sum of [C']				**2.7E-02**	

Releases to river Exposure group – River wildlife					
Radionuclide	Discharge 1 (Bq/y) [A]	Discharge 2 (Bq/y [A']	Total DPUR from Table 8 (μGy/h per Bq/y) [B]	Dose rate at discharge point 1 (μGy/h) [C] = [A] x [B]	Dose rate at discharge point 2# (μGy/h) [C'] = [A]+[A'] x [B]/2 m^3/s
C-14	4.00E+07	3.00E+07	1.6E-10	6.4E-03	5.6E-03
I-131	0.00E+00	3.00E+07	2.9E-11	0.0E+00	4.4E-04
Worst total dose rate (μGy/h) Maximum of Sum of [C] and Sum of [C']				**6.4E-03**	

#For an initial assessment where it is known that the flow at discharge point 2 is greater than 1, a flow rate of $2m^3$ is assumed at discharge point 2.

Stage 1 - Summary total dose

Release route	Exposure group	Total dose Human (μSv/y) Wildlife (μGy/h)	Worst total dose Human (μSv/y) Wildlife (μGy/h)
Air	Local resident family	1.4E+01	1.4E+01
	Terrestrial wildlife	5.0E-05	5.0E-05
River	River angler	7.6E+00	Maximum = 7.6E+00
	Irrigated food consumer	2.7E-02	
	River wildlife	6.4E-03	6.4E-03
Total critical group dose (μSv/y)			2.2E+01
Total wildlife dose rate (μGy/h)			6.5E-03

In this exposure scenario it is established that the release points to river are very far from the release point to air, therefore it is not appropriate to assume that members of the public or wildlife would be exposure to both releases to air and river. In this situation the doses from each exposure pathway can be considered separately.

For releases to air the total dose for the local resident family from releases to air is 14 µSv/y, which is below 20 µSv/y. The total dose rate for terrestrial wildlife is 0.00005 µGy/h, which is below 1 µGy/h. For releases to river the worst dose is to the river angler exposure group, 7.4 µSv/y, which is below 20 µSv/y. The worst dose rate for wildlife is for river wildlife, 0.0064 µGy/h, which is below 1 µGy/h. As a result, no further assessments should be warranted.

5.3 Example 3: A nuclear power station

A nuclear power station is permitted to discharge radionuclides to air and to sea. The following rolling 12-month limits for discharges to air are included in the permit: 6 TBq of tritium, 5 TBq of carbon-14, 160 GBq of sulphur-35, 60 TBq of argon-41, 5 GBq of iodine-131 and 1 GBq of ‘beta particulates’, here represented by cobalt-60.

The following rolling 12-month limits for discharges to sea are included: 1.2 PBq of tritium, 3 TBq of sulphur-35, 30 GBq of cobalt-60 and 300 GBq of ‘other beta-gamma’, here represented by caesium-137.

Information about direct radiation has also been provided by the operator of the power station which states that there is annual dose to the local resident family from direct radiation of 19 µSv/y. This should be included when assessing total critical group dose.

The Figures which show how this example can be worked through using the spreadsheet tools are as follows:

- Figure 2. IRAT2 release to air stage 1 assessment with the assessment details tab completed for Example 3
- Figure 4. IRAT2 release to estuary/coast stage 1 assessment with assessment details tab completed for Example 3
- Figure 9. IRAT2 release to air stage 1 assessment release to air tab with discharges entered for Example 3
- Figure 12. IRAT2 release to estuary/coast stage 1 assessment results for Example 3
- Figure 13. IRAT2 release to air spreadsheet tool stage 1 assessment results for Example 3
- Figure 17. IRAT2 release to air stage 2 refined assessment with assessment details completed for Example 3, with an effective release height selected
- Figure 18. IRAT 2 release to air stage 2 refined assessment with assessment details completed for Example 3, selecting user defined scaling factors
- Figure 20. IRAT2 release to estuary/coast stage 2 assessment with assessment details tab completed for Example 3 selecting a user defined average coastal exchange rate
- Figure 21. IRAT2 release to estuary/coast stage 2 assessment with assessment details tab completed for Example 3, selecting a coastal location

Stage 1 – Initial radiological assessment using default data

For a stage 1 assessment the DPUR [B] is simply multiplied by the annual discharge limits [A].

For the release to estuary/coast scenario, DPURs are calculated using a coastal exchange rate of 100 m^3/s. For a stage 1 assessment the default coastal exchange rate is set as 30 m^3/s therefore a scaling factor of 3.3 is applied when calculating dose in this stage.

Releases to air

Releases to air Exposure group – Local resident family			
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 2 (μSv/y per Bq/y) [B]	Dose (μSv/y) [C] = [A] x [B]
H-3	6.0E+12	9.8E-13	5.9E+00
C-14	5.0E+12	7.0E-11	3.5E+02
S-35	1.6E+11	5.7E-11	9.1E+00
Ar-41	6.0E+13	3.3E-12	2.0E+02
I-131	5.0E+09	4.4E-09	2.2E+01
Co-60	1.0E+09	1.2E-08	1.2E+01
Total dose (μSv/y) Sum of [C]			6.0E+02

Releases to air Exposure group – Terrestrial wildlife			
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 3 (μGy/h per Bq/y) [B]	Dose rate (μGy/h) [C] = [A] x [B]
H-3	6.0E+12	3.5E-15	2.1E-02
C-14	5.0E+12	1.1E-13	5.5E-01
S-35	1.6E+11	1.2E-14	1.9E-03
Ar-41	6.0E+13	1.8E-15	1.1E-01
I-131	5.0E+09	1.4E-14	7.0E-05
Co-60	1.0E+09	2.0E-12	2.0E-03
Total dose rate (μGy/h) Sum of [C]			6.8E-01

Releases to estuary/coastal water

Releases to estuary/coastal water Exposure group – Coastal fishing family			
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 4 (μSv/y per Bq/y) [B]	Dose (μSv/y) [C] = [A] x [B]*3.3#
H-3	1.2E+15	9.0E-16	3.6E+00

S-35	3.0E+12	7.6E-15	7.5E-02
Co-60	3.0E+10	3.7E-09	3.7E+02
Cs-137	3.0E+11	2.0E-10	2.0E+02
Total dose (μSv/y) Sum of [C]			5.7E+02

Releases to estuary/coastal water Exposure group – Coastal wildlife			
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 5 (μGy/h per Bq/y) [B]	Dose rate (μGy/h) [C] = [A] x [B]*3.3#
H-3	1.2E+15	2.60E-18	1.0E-02
S-35	3.0E+12	2.70E-17	2.7E-04
Co-60	3.0E+10	1.30E-11	1.3E+00
Cs-137	3.0E+11	3.80E-13	3.8E-01
Total dose rate (μGy/h) Sum of [C]			1.7E+00

Coastal release DPURs are calculated using a coastal exchange rate of 100 m^3/s. For an initial screening assessment the default coastal exchange rate is 30 m^3/s therefore a scaling factor of 3.3 is applied when calculating dose.

Stage 1 – Summary total dose or dose rate

Release route	Exposure group	Total dose Human (μSv/y) Wildlife (μGy/h)	Worst total dose Human (μSv/y) Wildlife (μGy/h)
Air	Local resident family	6.0E+02	6.0E+02
	Terrestrial wildlife	6.8E-01	6.8E-01
Estuary/coastal water	Fishing family	5.7E+02	5.7E+02
	Coastal wildlife	1.7E+00	1.7E+00
Direct radiation	Local resident family	1.9E+01	1.9E+01
Total critical group dose (μSv/y)			1.2E+03
Total wildlife dose rate (μGy/h)			2.4E+00

For releases to air the dose is 600 μSv/y and for releases to sea it is 570 μSv/y. There is an additional contribution from direct radiation of 19 μSv/y. The resultant total dose of 1189 μSv/y is greater than 20 μSv/y. As a result, refined data should be used for both the releases to atmosphere and the coastal environment (Stage 2).

The total dose rate for wildlife (the sum of the dose rate to terrestrial wildlife via release to air and the dose rate to coastal wildlife via release to estuary/coast is 2.4 μGy/h. This is greater than the screening threshold of 1 μGy/h therefore refined data should be used in this assessment (Stage 2).

Stage 2 – Initial radiological assessment using refined data

The main refinement for the releases to atmosphere assessment is to determine what effective stack height the releases are made from.

At this site the effective stack height is 20 m. This will have the effect of reducing air concentrations and deposition rates at the receptor locations and, in turn, doses to the local resident family and dose rates to terrestrial wildlife.

For the liquid discharges the main refinement is to determine the characteristics of the releases and the receiving environment.

At this site releases are via pipeline directly to the sea. Local beaches are used for bait digging and recreational use. Some fish and seafood are caught locally and sold on regionally. The water exchange rate of the receiving water is 130 m^3/s, which is higher than the 30 m^3/s assumed in Stage 1. The resulting greater dilution will result in a reduction in estimated doses.

The coastal fishing family do not live close to the site so it is not appropriate to sum the doses for the coastal fishing family and the local resident family.

Releases to air

To refine the assessment using the known effective site stack height, pre-calculated scaling factors for different release heights can be applied. These can be taken from Figure 16. There are different scaling factors for food exposure and inhalation and external exposures so the calculation must be performed in a few steps. To calculate the dose the DPURs for External [C] and Inhalation [D] exposures are multiplied by the inhalation and external dose scaling factor [F] taken from Figure 16 for the specified stack height and multiplied by the annual discharge [A]. The DPURs for Food exposure [B] are multiplied by the food dose scaling factor [E], taken from Figure 16 for the specified stack height, and multiplied by the annual discharge [A]. The resulting values can then be summed [G].

Releases to air Exposure group – Local resident family			Food dose scaling factor from Figure 16 [E]		0.34
			Inhalation and external dose scaling factor from Figure 16 [F]		0.021
Radionuclide	Discharge (Bq/y) [A]	Food DPUR from Table 2 (μSv/y per Bq/y) [B]	External DPUR from Table 2 (μSv/y per Bq/y) [C]	Inhalation DPUR from Table 2 (μSv/y per Bq/y) [D]	Dose (μSv/y) [G] = [A] x [B] x [E] + [A] x [C] x [F] + [A] x [D] x [F]
H-3	6.0E+12	2.8E-13	0.0E+00	7.1E-13	6.6E-01
C-14	5.0E+12	3.4E-11	6.5E-17	3.6E-11	6.2E+01
S-35	1.6E+11	3.3E-11	7.7E-17	2.4E-11	1.9E+00
Ar-41	6.0E+13	0.0E+00	3.3E-12	0.0E+00	4.2E+00
I-131	5.0E+09	4.1E-09	3.9E-11	3.5E-10	7.0E+00
Co-60	1.0E+09	5.0E-11	1.1E-08	2.3E-10	2.5E-01
Total dose (μSv/y) Sum of [G]					7.6E+01

Releases to air Exposure group – Terrestrial wildlife		Food dose scaling factor from Figure 16 [D]	0.34
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 3 (μGy/h per Bq/y) [B]	Dose rate (μGy/h) [C] = [A] x [B] x [D]
H-3	6.0E+12	3.5E-15	7.1E-03
C-14	5.0E+12	1.1E-13	1.9E-01
S-35	1.6E+11	1.2E-14	6.5E-04
Ar-41	6.0E+13	1.8E-15	3.7E-02
I-131	5.0E+09	1.4E-14	2.4E-05
Co-60	1.0E+09	2.0E-12	6.8E-04

Total dose rate (μGy/h) Sum of [C]	**2.4E-01**

Releases to estuary/coastal water

To refine the assessment using the known coastal exchange rate for the site, the DPURs [B] should be multiplied by the annual discharge limit [A] then multiplied by the coastal exchange rate assumed in the IRAT2 methodology (100 m^3/s) and divided by the known coastal exchange rate [C].

Releases to estuary/coastal water Exposure group – Coastal fishing family		Exchange rate (m^3/s) [C]	130
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 4 (μSv/y per Bq/y) [B]	Dose (μSv/y) [D] = [A] x [B] x 100 m^3/s / [C]
H-3	1.2E+15	9.0E-16	8.3E-01
S-35	3.0E+12	7.6E-15	1.8E-02
Co-60	3.0E+10	3.7E-09	8.5E+01
Cs-137	3.0E+11	2.0E-10	4.6E+01
Total dose (μSv/y) Sum of [D]			1.3E+02

Releases to estuary/coastal water Exposure group – Coastal wildlife		Exchange rate (m^3/s) [C]	130
Radionuclide	Discharge (Bq/y) [A]	Total DPUR from Table 5 (μGy/h per Bq/y) [B]	Dose rate (μGy/h) [D] = [A] x [B] x 100/ [C]
H-3	1.2E+15	2.60E-18	2.4E-03
S-35	3.0E+12	2.70E-17	6.2E-05
Co-60	3.0E+10	1.30E-11	3.0E-01
Cs-137	3.0E+11	3.80E-13	8.8E-02
Total dose rate (μGy/h) Sum of [D]			3.9E-01

Stage 2 – Summary total dose

Release route	Exposure group	Total dose Human (μSv/y) Wildlife (μGy/h)	Worst total dose Human (μSv/y) Wildlife (μGy/h)
Air	Local resident family	7.6E+01	7.6E+01
	Terrestrial wildlife	2.4E-01	2.4E-01

Direct radiation	Local resident family	1.9E+01	1.9E+01
Total dose (μSv/y)			9.5E+01
Estuary/coastal water	Fishing family	1.3E+02	1.3E+02
	Coastal wildlife	3.9E-01	3.9E-01
Maximum critical group dose (μSv/y)			1.3E+02
Total wildlife dose (μGy/h)			6.3E-01

The maximum dose to the exposure groups is now 130 μSv/y, and the dose to local resident family is now 76 μSv/y. As these are both still greater than 20 μSv/y, it is necessary to consider if a separate detailed site-specific assessment is required (Stage 3).

The total wildlife dose rate (sum of dose rate to terrestrial wildlife via release to air and dose rate to coastal wildlife via release to estuary/coast) is 0.63 μGy/h. This is below the screening threshold of 1 μGy/h. No further assessment is required

Stage 3 – Determine need for a site-specific radiological assessment

For both the atmospheric and coastal assessments, ‘surrogate’ radionuclides were selected to represent ‘other’ discharges. As part of any detailed assessment, it should be ascertained which radionuclides are most likely to be present in the discharge which are the most appropriate radionuclides to use in the assessment.

Most of the dose from the atmospheric discharges results from the consumption of terrestrial foods. Important factors which should be reviewed are which of the foods included in the DPUR data are actually produced locally and at what distances from the release point. Other factors that are likely to have a large influence on the food consumption doses are the consumption rates of local produce. In the initial assessment it is assumed that all foodstuffs are consumed at statistically critical rates. Actual consumption rates, such as determined by a local habit survey, could be much lower.

External irradiation from argon-41 in the effluent cloud results in the second highest dose to the atmospheric exposure group. The greatest factors influencing this are the distance of the exposure group from the discharge point and the total occupancy time of members of the group at that location, so these should be considered when making a further assessment.

There could be the need for site-specific air dispersion modelling to take account of building, coastal and terrain effects.

For the liquid discharges most of the dose arises from external irradiation from sediments deposited on local beaches. Any further assessment should consider the actual occupancy time of the exposure group on beaches within a few kilometres of the site. The second highest dose arises from caesium-137 in seafood. This should be reviewed bearing in mind actual consumption rates of locally caught fish and seafood.

Appendix A References

A.1 Cailes C R, Dean R, Dowds C, Limer L, Murdoch A, Penfold J, Paul L, Rowe J and Titley J. (2022). Initial Radiological Assessment Tool 2 – Part 2 methods and input data. Environment Agency report EBPRI 13097/R2 October 2022.

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