EPR-
NPP-OILs
2017

EMERGENCY PREPAREDNESS
AND RESPONSE

Operational Intervention Levels for Reactor Emergencies

and Methodology for Their Derivation

DATE EFFECTIVE: MARCH 2017

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OPERATIONAL INTERVENTION LEVELS FOR REACTOR EMERGENCIES

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EPR-NPP-OILs (2017)

OPERATIONAL INTERVENTION LEVELS FOR REACTOR EMERGENCIES

AND METHODOLOGY FOR THEIR DERIVATION

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2017

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OPERATIONAL INTERVENTION LEVELS FOR REACTOR EMERGENCIES
AND METHODOLOGY FOR THEIR DERIVATION
IAEA, VIENNA, 2017
EPR-NPP-OILs (2017)
ISSN 2518–685X

Printed by the IAEA in Austria
March 2017

FOREWORD

The IAEA safety standards require the establishment of predetermined default operational criteria as part of the protection strategy for nuclear and radiological emergencies. The IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency, in para. 4.28(4) stipulates that: "Once the protection strategy has been justified and optimized and a set of national generic criteria has been developed, pre-established operational criteria (conditions on the site, emergency action levels (EALs) and operational intervention levels (OILs)) for initiating the different parts of an emergency plan and for taking protective actions and other response actions shall be derived from the generic criteria". This publication provides selected default OIL values for taking protective actions and other response actions to protect the public in an emergency involving a severe release of radioactive material from a light water reactor or its spent fuel, the methodological approach for their derivation, as well as practical tools and recommendations for their use, which will assist IAEA Member States in meeting the requirement of deriving pre-established OILs.

The default OIL values provided in this publication will contribute to the harmonization of national criteria for implementing protective actions and other response actions, a need that was emphasized by the 55th IAEA General Conference in resolution GC(55)/RES/9. It was again highlighted by the 56th IAEA General Conference in resolution GC(56)/RES/9, which stressed "the importance of the establishment and implementation of national emergency preparedness and response measures, based on the Agency's Safety Standards and relevant action plans, for improving preparedness and response, including communication in an emergency, and contributing to the harmonization of national criteria for protective and other actions".

The IAEA officers responsible for this publication were T. Mc Kenna and P. Vilar Welter of the Incident and Emergency Centre, Department of Nuclear Safety and Security.

CONTENTS

1. INTRODUCTION

This publication provides selected default OIL values, together with a detailed description of the methodology for their derivation, as well as practical tools and recommendations for their use. The tools and default OIL values provided here may be directly integrated into national emergency arrangements or reviewed and modified as necessary to meet the specific emergency preparedness and response arrangements of the country in which they will be applied.

1.1. BACKGROUND

The use of OILs as part of the protection strategy for nuclear and radiological emergencies is required by IAEA Safety Standards Series No. GSR Part 7 [1], and addressed by IAEA Safety Standards Series No. GSG-2 [2] (Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency) and No. GS-G-2.1 [3] (Arrangements for Preparedness for a Nuclear or Radiological Emergency), as well as by EPR Series publications (e.g. EPR-NPP Public Protective Actions 2013 [4]) and IAEA TECDOCs (e.g. IAEA-TECDOC-955 [5]).

OILs are operational criteria that allow the prompt implementation of protective actions and other response actions[1] on the basis of monitoring results that are readily available during a nuclear or radiological emergency. 'Operational' refers to the need for the OILs to be practical and reflect the realities of the response to an emergency, such as the need for the measured quantities to be representative, easily measurable and readily available during a nuclear or radiological emergency.

A default OIL value is a specific value of such a measured quantity that indicates the need to implement predetermined response actions (e.g. evacuation, relocation, food restrictions). The response actions implemented based on the default OIL values are intended to minimize radiation induced health effects that would reduce quality of life.[2] The default OIL values provided in this publication follow a reasonably conservative[3] approach; they are established below those levels at which radiation induced health effects will be observed, even in a very large exposed group of people composed of the most sensitive members of the public.

However, it is also important to consider non-radiological consequences of the response actions to ensure they do more good than harm. This is achieved by the justification and optimization of the overall protection strategy, as established in Requirement 5 of the IAEA Safety Standards Series No. GSR Part 7 [1]. The default OIL values and methodology provided in this publication are generically justified and optimized on radiation protection grounds, but further optimization and justification may be necessary in consideration of the specific protection strategy in which the OILs will be applied. For example, using much lower default OIL values than those provided here could result in more harm than good when considering: (a) the health hazard associated with the response action itself; and (b) the diversion of limited resources from the highest priority actions.

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[1] For ease of reading, 'protective actions and other response actions' will hereafter be referred to as 'response actions'.

[2] By avoiding severe deterministic effects or a discernible increase in the incidence of stochastic effects (e.g. cancers).

[3] Conservative meaning that it will result in a projected dose higher than the dose actually expected to be received under real conditions.

Default OIL values need to be developed during the preparedness stage, (a) to allow taking decisions on response actions quickly in the urgent and early phases of an emergency for the actions to be effective,[4] and (b) to account for the limited availability and reliability of information at these phases of the emergency. During past nuclear and radiological emergencies, failure to pre-establish default OIL values has resulted in unnecessarily postponing warranted response actions and in taking damaging actions that were not warranted based on the radiological health hazard [6, 7, 8, 9, 10].[5]

Once actions have been completed based on the default operational criteria, and once the greatest risk to the public has therefore been alleviated, there will be time for more deliberate assessments. As the emergency progresses, further information may become available. Arrangements need to be established in advance to consider prevailing conditions as they evolve and, if justified, to revise the OILs and explain those changes to the public in a plain and understandable form.[6]

1.2. SCOPE

This publication addresses OILs for a severe release of radioactive material from an LWR or its spent fuel[7], for the following monitoring results: (a) dose rate measurements above the ground; (b) dose rate measurements and beta count rates from the skin; (c) concentrations of marker radionuclides [8] in food, milk and drinking water samples; and (d) dose rate measurements from the thyroid.

The general methodology presented in this publication is generically applicable for deriving default OIL values for other reactor types or for radiological emergencies, but needs to be adapted. Additional publications addressing other reactor types and radiological emergencies may be issued by the IAEA.

1.3. OBJECTIVE

This publication seeks to assist IAEA Member States in meeting the requirement of para. 4.28(4) of the IAEA Safety Standards Series No. GSR Part 7 [1], and contribute to the harmonization of national criteria for response actions (a need emphasized by the 55th and 56th IAEA General Conferences in resolutions GC(55)/RES/9 and GC(56)/RES/9), by providing Member States with: (a) default OIL values that can be used immediately in the response to an emergency due to severe conditions at an LWR or its spent fuel; (b) a detailed explanation of the methodology for deriving the default OIL values; (c) practical tools and recommendations on how to use the OILs; and (d) considerations for revising the default OIL values.

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[4] Effective in keeping the dose below the pre-established generic criteria discussed in Section 3.2.

[5] Section 2.4 provides examples of damaging actions taken during past nuclear and radiological emergencies that were not warranted based on the radiological health hazard.

[6] Experience from past emergencies has shown that changing criteria for the implementation of response actions during an emergency may lead to confusion of decision makers and scepticism among the public [6].

[7] Only spent fuel that is sufficiently heated (either by its own decay heat or another heat source) to reach zirconium ignition temperatures is expected to result in a significant release of radioactive material warranting response actions. This is typically spent fuel in the spent fuel pool of an NPP.

[8] A marker radionuclide is easy to identify and is representative of all other radionuclides present, avoiding the need for costly and time intensive comprehensive isotopic analyses.

1.4. STRUCTURE

Following the introductory section (Section 1), this publication is structured into four main parts:

- Section 2 provides stand-alone 'OIL charts' (a practical tool for using the default OIL values during the response to an emergency), together with important practical information for using the OILs and making recommendations on warranted response actions.
- Section 3 provides a detailed explanation of the methodology for deriving the default OIL values given in Section 2, to support Member States in following the underlying calculations and assumptions.
- Section 4 provides a description of the two spreadsheets included on the attached CD, which were used to calculate the default OIL values (following the method given in Section 3); they are included here in order to facilitate the revision of the OILs to consider different underlying assumptions or another methodological approach than the one used by the IAEA.
- Section 5 provides (a) general considerations concerning the revision of the default OIL values to consider different underlying assumptions or another methodological approach and (b) instructions for adapting the default OIL value provided for the beta count rate from activity on the skin to a specific instrument.[9]

[9] Default OIL values are provided for the beta count rate from activity on the skin as requested by some Member States.

2. OIL CHARTS AND DEFAULT OIL VALUES FOR USE IN THE RESPONSE

This section provides stand-alone ‘OIL charts’ (a practical tool for using the OILs during the response to an emergency), together with important practical information that needs to be considered when using the OILs. The charts are structured as shown in Fig. 1. Before using the charts, it is important to understand the role of the OILs within the protection strategy, the evaluation of monitoring results and the communication with decision makers and public information officers (as explained in the following sections). Section 2.5 provides a step by step instruction on how to use the OIL charts, and Section 2.6 provides the actual charts.

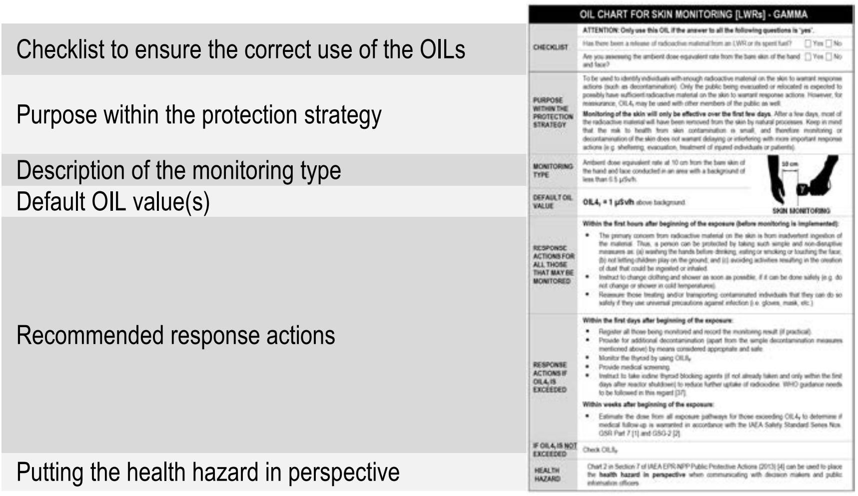

FIG. 1. General structure of the OIL charts.

2.1. ROLE OF THE OILS WITHIN THE PROTECTION STRATEGY

The role of the OILs provided in this publication (Table 1) is outlined in Fig. 2. As learned from past emergencies [6, 7, 8, 9, 10], for those response actions that in order to be effective[10] need to be taken before or shortly after a release of radioactive material, monitoring results will not be available in time to support decision making. Therefore, initial response actions need to be implemented within pre-established emergency planning zones and planning distances based on an emergency classification system (i.e. based on the detection of conditions that indicate the need for response actions, as described in Refs [1, 2, 4, 5, 11]).[11]

[10] Effective in keeping the dose below the pre-established generic criteria discussed in Section 3.2.

[11] For example, for a severe release of radioactive material from an NPP, the patterns of deposition are very complex and extensive and will change if there is an ongoing release, making it very difficult to promptly identify the areas warranting a restriction of food, milk and drinking water based on monitoring alone. Therefore, upon declaration of a General Emergency, provisions need to be in place within a pre-established emergency planning distance, i.e. the Ingestion and Commodities Planning Distance (ICPD) outlined in Refs [1, 4], to automatically restrict non-essential local produce (e.g. leafy vegetables) and wild-grown products (e.g. mushrooms) that may be directly contaminated by the release of radioactive material and consumed within weeks, milk from grazing animals, animal feed and directly collected rainwater (other sources of drinking water, e.g. wells, reservoirs or rivers, will only need to be restricted if the samples exceed OIL7). Failure to do so may result in significant doses to the public

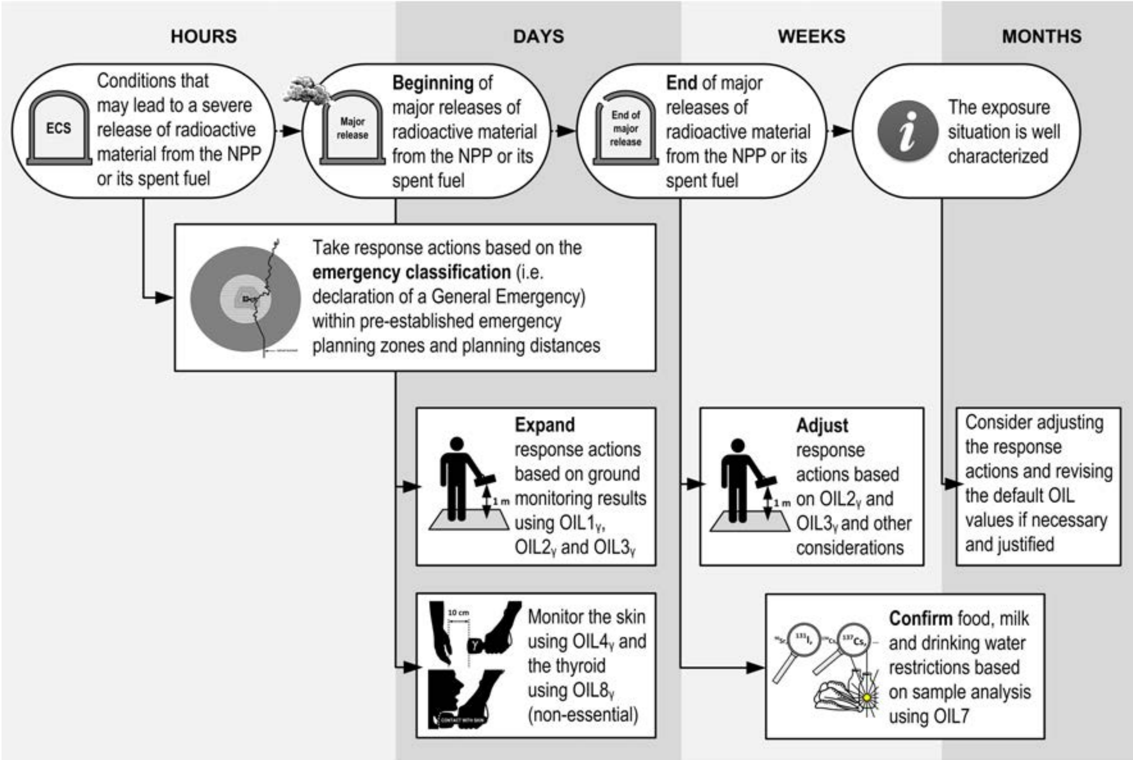

FIG. 2. Role of the OILs provided in this publication within the protection strategy.

Once monitoring results become available, OILs will be essential in first expanding and later adjusting the initial response actions. Owing to the lack of reliable information and the urgency of the response actions early in an emergency, default OIL values need to be pre-established to allow taking prompt and confident actions.[12]

Once actions have been completed based on these default operational criteria, and once the greatest risk to the public has therefore been alleviated, there is time for more deliberate assessments. As prevailing conditions evolve, OILs may be revised according to pre-established arrangements, as appropriate, ensuring that the response actions are optimized and justified and that the reasons for the revisions are explained to the public in a plain and understandable form.[13]

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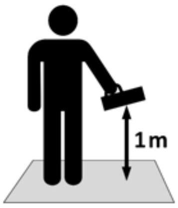
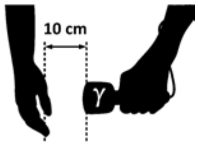
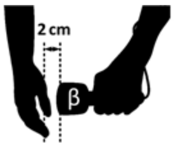
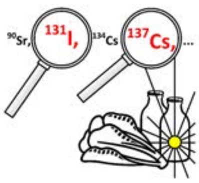
and in a discernible increase in the incidence of thyroid cancers as observed during past emergencies. Restrictions should only be implemented if alternative food, milk and drinking water are available.

[12] Following the previous example, restrictions on local produce, wild-grown products, milk from grazing animals, directly collected rainwater and animal feed would be extended based on ground monitoring results in areas exceeding $OIL1_{\gamma}$, $OIL2_{\gamma}$ or $OIL3_{\gamma}$. OIL7 would be used to confirm the adequacy of these restrictions based on food, milk and drinking water samples.

[13] Following the previous example, the food, milk and drinking water affected by the release and/or the consumption behaviour may be so well characterized late in the emergency that it may be justified to revise the default OIL7 values to reflect actual conditions. This revision will need to be based on a defensible basis, agreed with all relevant stakeholders and clearly communicated to the public.

TABLE 1. DEFAULT OIL VALUES PROVIDED IN THIS PUBLICATION

OIL	Default OIL value	Monitoring type		Charts in section
OIL1$_\gamma$	**1000 µSv/h**		GROUND MONITORING Ambient dose equivalent rate at 1 m above ground level	2.6.1
OIL2$_\gamma$	**100 µSv/h** (for the first 10 days after reactor shutdown[a])			
	25 µSv/h (later than 10 days after reactor shutdown[a] or for spent fuel)			
OIL3$_\gamma$[b]	**1 µSv/h**			
OIL4$_\gamma$[c]	**1 µSv/h**		SKIN MONITORING Ambient dose equivalent rate at 10 cm from the bare skin of the hand and face	2.6.2
OIL4$_\beta$[c]	**1000 cps**[d]		SKIN MONITORING Beta count rate at 2 cm from the bare skin of the hand and face (The use of OIL4$_\gamma$ is preferable over OIL4$_\beta$)	
OIL7	**1000 Bq/kg of I-131** and **200 Bq/kg of Cs-137**		MONITORING OF FOOD, MILK[e] AND DRINKING WATER SAMPLES Activity concentration of I-131[f] and Cs-137[f] in food, milk and drinking water samples	2.6.3
OIL8$_\gamma$	**0.5 µSv/h**		THYROID MONITORING Ambient dose equivalent rate in front of the thyroid in contact with the skin	2.6.4

[a] Time after the nuclear reaction in the core was stopped.

[b] The advantage of OIL3$_\gamma$ when compared with OIL7 is that, based on OIL3$_\gamma$, restrictions can be implemented early on in the emergency (i.e. when most needed) with readily available and easy to obtain ambient dose equivalent rates from deposition on the ground.

[c] The ambient dose equivalent rate OIL4$_\gamma$ is sufficient and preferable to assess the levels of radioactive material on the skin for a release of radioactive material from a nuclear power plant (NPP) or its spent fuel, because it is less dependent on the measurement technique and instrument characteristics. However, beta count rate OIL4$_\beta$ is also provided, since it may be used by some response organizations for skin monitoring.

[d] The default value is provided in cps and not in Bq/cm^2 because instruments natively provide cps. When providing Bq/cm^2, an implicit assumption is made on the radionuclides being monitored. However, the radionuclide mix released from an NPP will be complex and changing, making the use of Bq/cm^2 impractical.

[e] Milk is mentioned separately because of its key role in radiation induced thyroid cancers following the accident at the Chernobyl NPP.

[f] I-131 and Cs-137 serve as marker radionuclides. A marker radionuclide is easier to identify and is representative of all the other radionuclides present, avoiding the need for costly and time intensive comprehensive isotopic analyses. The contribution of the other radionuclides expected to be present after a release of radioactive material due to severe fuel damage was considered.

The default OIL values provided in this publication were developed for the concept of operations described in Ref. [4][14] and were generically justified and optimized on radiation protection grounds. Further justification and optimization within the overall protection strategy may be necessary during the preparedness stage to account for local and national conditions. The justification of the protection strategy requires risk informed decision making (as described in Refs [12, 13]), i.e. the participation of all those involved in the decision making process during the preparedness stage and late response phases. References [1, 2, 3] provide further details on the protection strategy for nuclear and radiological emergencies.

It needs to be highlighted that OILs indicate the need for promptly implementing response actions to protect the public during a nuclear or radiological emergency, and are not intended for the detection, classification or declaration of an emergency. Other operational criteria are intended for this purpose; namely observables/indicators and emergency action levels (EALs). In addition, it is inappropriate to use OILs for situations that are not emergency exposure situations (for example, during the regular transport of radioactive material or during medical exposure) since other criteria and assumptions apply.

2.2. EVALUATING MONITORING RESULTS

Early in an emergency, monitoring results will most likely be limited, confusing and possibly inconsistent (as observed during past emergencies [6, 7, 8, 9, 10]) due to:

- Complex and varying deposition patterns resulting from natural processes (e.g. variations in deposition due to meteorological or ground conditions);
- Considerable uncertainties in the monitoring results due to field and emergency conditions (even professional teams may provide significantly different results for the same area); and
- Complex and varying spatial radionuclide mix distributions resulting from changing fuel damage states and plant conditions (that result in different radionuclide mixes being released) combined with changing meteorological conditions (e.g. wind or precipitation).

This will be particularly problematic early on in the emergency, when decisions need to be made quickly in order to be effective. Arrangements need to be in place to initially enable prompt decision making, based on early monitoring results, taking into account the characteristics of the measurements, the natural and social environment of the area and the representativeness of the measurement, as described in Ref. [4]. Examples are: (a) the number of readings exceeding the OIL; (b) the magnitude of the reading and whether it slightly exceeds the OIL or is greatly in excess; (c) the reliability of the measurement (Have confirmatory measurements been performed? Does the instrument cover the ranges relevant for the OIL values?); (d) the population in the area; (e) the consequence of no action (or action); (f) the use of the land; (g) conditions that may make implementation of response actions hazardous (e.g. restricting essential food or water, movement of patients, evacuation or sheltering under hazardous conditions); (h) social conditions; (i) the ability to define the area in a way understandable to the public; and (j) administrative and jurisdictional boundaries.

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[14] Some minor modifications to the assumptions made in Ref. [4] were introduced here (as indicated in Section 3) in order to reflect more realistic emergency conditions and to improve clarity.

The OIL charts provide minimum requirements that need to be met by the monitoring results for the OILs to be applicable. For example, the monitoring result needs to be representative of the dose received by the public (e.g. a dose rate from a ditch or sewer is not representative of an area inhabited by people). Selecting representative monitoring results will be heavily based on expert judgement, and providing a detailed guidance lies outside the scope of this publication.

Monitoring needs to be integrated into decision making systems in such a way that its use will not impede the implementation of effective response actions, especially for those actions that need to be taken before or shortly after a release to be effective. Not every type of monitoring will allow the effective implementation of response actions during a nuclear or radiological emergency:

- The ambient dose equivalent rate is readily available, easy to obtain (with simple instruments and little training) and representative of the expected radionuclide mixes. For a release of radioactive material from an NPP or its spent fuel, the expected radionuclide mixes will emit sufficient gamma radiation for the ambient dose equivalent rate to be an appropriate and effective indicator under emergency conditions for the amount of radioactive material present on the ground ($OIL1_γ$, $OIL2_γ$ and $OIL3_γ$), on the skin ($OIL4_γ$) and in the thyroid ($OIL8_γ$[15,16]), making it unnecessary to measure beta or alpha radiation for this purpose. Although the use of the gamma dose rate is preferable over the beta count rate, an $OIL4_β$ for skin monitoring is provided because it may be used by some Member States.
- After the initial restrictions on food, milk and drinking water implemented on the basis of the declaration of a general emergency and on ground monitoring results (i.e. based on $OIL1_γ$, $OIL2_γ$ and $OIL3_γ$), food, milk and drinking water samples may be analysed to confirm these initial restrictions (as indicated in Fig. 2).[17] For this purpose, it is convenient to use marker radionuclides, which are representative of all the other radionuclides expected to be present and are easier to identify, avoiding the need for costly and time intensive comprehensive isotopic analyses. This publication provides OIL7 for the marker radionuclides I-131 and Cs-137. The use of OIL7 during a nuclear emergency is preferable over the use of OIL5 and OIL6 (given in Ref. [2]) because of the limited availability of time and resources early in an emergency. Once sufficient resources and time become available, OIL5 and OIL6 may be used, if considered necessary and justified, keeping in mind that the default OIL5 and OIL6 values provided in Ref. [2] (a) are applicable to any type of nuclear or radiological emergency; (b) are more conservative than OIL7; and (c) require determining the activity concentrations of all radionuclides present in food, milk and drinking water (and not only the activity concentration of a few radionuclides).

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[15] Only useful during the first week after intake of radioiodine.

[16] Skin activity levels greater than the $OIL4_γ$ or $OIL4_β$ values indicate that the individual may have inhaled or ingested sufficient radioactive iodine before the monitoring has taken place to warrant monitoring of the thyroid with $OIL8_γ$ and registration for later medical follow-up due to the risk of developing thyroid cancer and the need for early detection and effective treatment. It is early on (within the first few days) when valuable information can be easily obtained (e.g. the ambient dose equivalent rate from the thyroid, based on $OIL8_γ$).

[17] The analysis of samples will become relevant once sufficient samples have been collected, and time and resources are available for their analysis.

- OILs for rates or air concentrations in a plume[18] resulting from an ongoing release are not provided in this publication because, as indicated in Ref. [2]: (a) in many cases the significant release will be over by the time results of environmental measurements are available; (b) it is difficult to take and analyse air concentrations in a sample in a timely manner; and (c) there is a great variation in time and location of the plume concentrations at any location during a release. During the period of significant release, therefore, protective actions (e.g. evacuation) are best taken on the basis of the emergency classification system. Operating organizations of facilities at which there could be emergencies that might result in airborne releases of long duration need to develop EALs and possibly facility specific OILs for measurements taken in a plume, for possible airborne releases from the facilities.[19] Examples of OILs for dose rates in a release from an LWR resulting from core melt are provided in Ref. [5]. OILs for air concentrations arising from resuspension are not provided, because doses arising from resuspension have been considered in the OILs. Although not calculated for the purpose of in plume measurements, the default $OIL1_\gamma$ and $OIL2_\gamma$ values and associated response actions provided in this publication are consistent with the OILs for in plume measurements provided in Table B2 of Ref. [5]. There is no need to confirm that the measurement is not being taken in the plume for the default $OIL1_\gamma$ and $OIL2_\gamma$ values provided in this publication.
- Further OILs will need to be developed based on the new generic criteria given in Ref. [1] for enabling the transition to an existing exposure situation (para. II.15 of Ref. [1]), for vehicles, equipment and other items (Table II.4 of Ref. [1]) and for food and other commodities traded internationally (Table II.5 of Ref. [1]). International criteria for trade are established in Refs [1, 14, 15].

Once actions have been taken based on representative, readily available and practical measurement, and once the greatest risk to the public has thus been alleviated, there may be time and resources available to perform more detailed measurements, such as spectrometry or radiochemical analyses.

2.3. COMMUNICATING WITH DECISION MAKERS

Experience has shown that decision makers take actions best when they understand how the actions contribute to the safety of the public [16]. The information needs to be conveyed to decision makers in plain and simple language, indicating (a) what response actions need to be implemented when and where; (b) why they need to be implemented; and (c) how they will contribute to the safety of the public.[20] When communicating the assessment of the monitoring results to decision makers, the following points ought to be clearly addressed:

- The importance of avoiding unnecessary delays in decision making. Postponing response actions may result in radiation induced health effects that could have been avoided.

[18] Airborne radioactive material released from the NPP.

[19] In plume measurements are considered within the emergency classification system to detect a release of radioactive material (and classify the emergency accordingly), but are not considered suitable to determine specific locations warranting response actions.

[20] For example, a map showing monitoring results in combination with default OIL values does not explain to a layperson what response actions need to be implemented where, when, how and why.

- The need to implement the response actions safely and without causing more harm than good (e.g. avoiding dangerous travel conditions).
- The quality and reliability of the monitoring results being used and whether future refinements are expected.
- Using default OIL values above or below those agreed upon during the preparedness stage needs to be avoided unless there is a clear justification for it.[21] There is no need to add conservatism at the time of the emergency (like using half the default OIL value). Doing so may result in more harm than good. If changes are made to the default OIL values to account for prevailing conditions during an emergency, the reasons need to be based on defensible considerations and explained to the public in a plain and understandable form.
- The goal of the response actions is to protect all members of the public (including children and pregnant women) by minimizing radiation induced health effects.[22] Below the OIL values, no radiation induced health effects are expected to be observed, even in a very large exposed group composed of the most sensitive members of the public.
- Radiation induced health effects can only be assessed properly by experts (others, such as local physicians, may not have the necessary expertise).[23] This needs to be clearly conveyed to pregnant women of the affected areas to prevent actions that do more harm than good.
- Radiation induced thyroid cancers are the greatest concern among the possible radiation induced health effects following a release of radioactive material from a reactor core or spent fuel.[24] A discernible increase in the incidence of any other radiation induced cancers (e.g. leukaemia) among the public after such a release is considered very unlikely and would require that many people receive doses sufficient to result in severe deterministic effects [17, 18, 19]. There is no scientific evidence of an increase in the incidence of radiation induced cancers, other than thyroid cancers, among the public that could be related to radiation exposure from the Chernobyl accident [20, 21, 22, 23].[25]
- Emphasis has to be placed on the need to inform medical practitioners that universal precautions against infection (gloves, mask, etc.) will provide sufficient protection from the radioactive material (irrespective of the level of contamination).[26]

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[21] Section 5 addresses what needs to be considered before modifying the default OIL values.

[22] By avoiding severe deterministic effects or a discernible increase in the incidence of stochastic effects (e.g. cancers).

[23] There are only a limited number of experts in diagnosing and treating the health effects of radiation exposure in the world. Medical examinations, treatments and counselling need to be done only after consultation with those experts. Assistance can be obtained through the IAEA or WHO.

[24] This is because large amounts of radioactive iodine may be released which may be inhaled or ingested. Once inhaled or ingested, the radioactive iodine concentrates in the thyroid resulting in very high doses to the organ.

[25] To date, only a discernible increase in radiation induced thyroid cancers among the population group aged 0–18 years old (in 1986) living in the areas of Belarus, Russian Federation and Ukraine affected by the Chernobyl accident has been clearly established [23]. These cancers were due principally to doses received from drinking milk from cows grazing on pasture contaminated with radioactive iodine and were observed out to very long distances from the site (i.e. hundreds of kilometres). Radiation induced thyroid cancers started to appear in 1990, four years following the Chernobyl accident [22, 23]. These cancers are usually not life threatening if detected and treated early. For this reason, people who may have inhaled or ingested radioactive iodine need to be registered and have their dose estimated to determine whether a medical follow-up is warranted. $OIL8_{\gamma}$ was developed for this purpose.

[26] In several past emergencies [6, 8, 10], some medical staff refused to treat potentially contaminated patients, because they did not understand how to protect themselves from contamination.

2.4. COMMUNICATING WITH PUBLIC INFORMATION OFFICERS

The decisions taken by the decision maker need to be explained in plain and simple language to public information officers, who will be responsible for the direct communication with the public. The information provided to the public information officers needs to address the main concern of the public, i.e. **“Am I safe? And if not, what should I do to be safe?”** The system for putting the radiological health hazard in perspective in emergency situations provided in Refs [4, 24, 25] can be used for this purpose. The so called ‘perspective charts’ provided in Sections 7.2. and 7.3. of Ref. [4] (and displayed as thumbnails in Fig. 3 below) can be used to relate a measurement result with the associated health hazard. Further guidance regarding the communication with the public is available in Refs [26, 27].

The importance of public communication is highlighted when considering examples of actions taken by the public and decision makers during previous nuclear and radiological emergencies that were not warranted based on the radiological health hazard and resulted in unnecessary harm, such as [25]:

- Artificially terminating pregnancies [28];
- Performing unsafe evacuations [10];
- Medical staff being reluctant to treat possibly contaminated patients [29, 30, 31];
- Demanding unwarranted medical examinations that interfere with the treatment of those who are most at risk [29];
- Pregnant women worrying about their fetus [31, 32, 33, 34];
- Using inappropriate substitutes for iodine thyroid blocking (ITB) agents [31];
- Stigmatizing those from the affected area [7, 29, 32];
- Worrying about the possibility of radiation induced cancers [31];
- Rejecting products from the affected area [32];
- Limiting tourism and implementing restrictions on agriculture [29, 35];
- Cancelling necessary nuclear medical treatments due to fear of radiation [36].

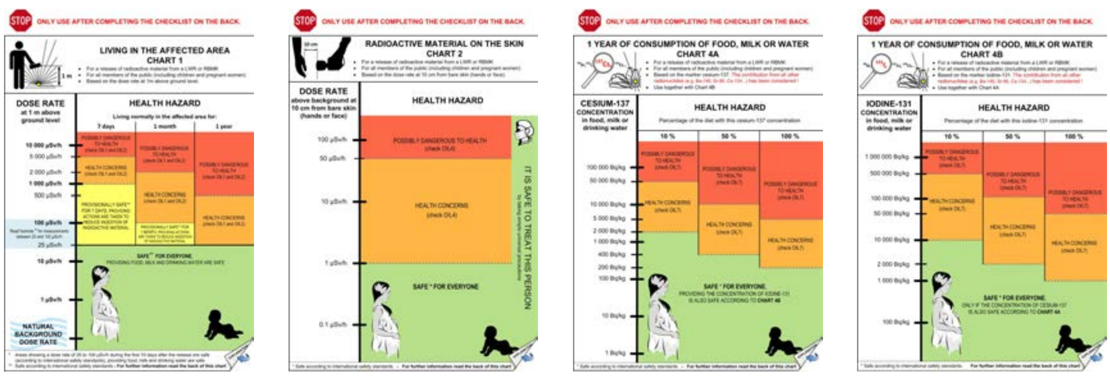


FIG. 3. Charts for placing the radiological health hazard in perspective (provided in Ref. [4]).

2.5. HOW TO USE THE OIL CHARTS

The charts can be used by following seven simple steps:

Step 1 Obtain monitoring results for one of the monitoring types listed in Table 1 and check their quality and reliability, as described in Section 2.2.

Step 2 Select the OIL chart applicable to the monitoring type, as indicated in Table 1.

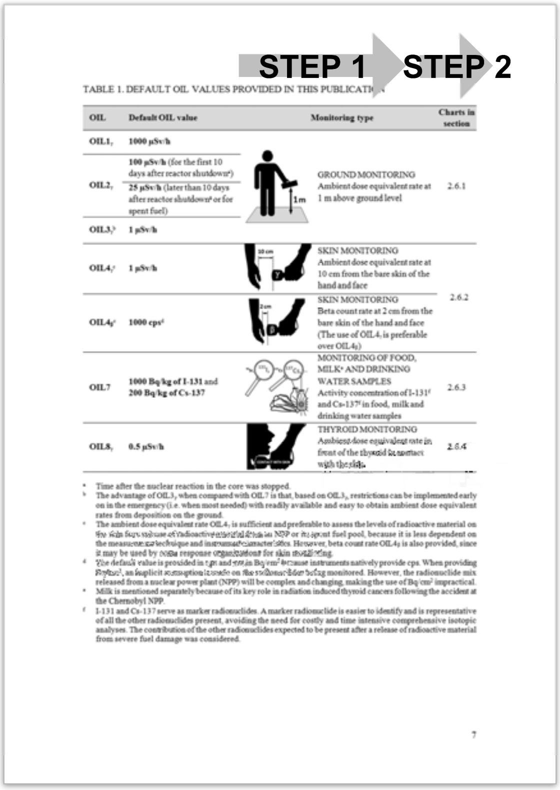
Step 3 Check if the chart is applicable to your situation by using the checklist at the beginning of the chart.

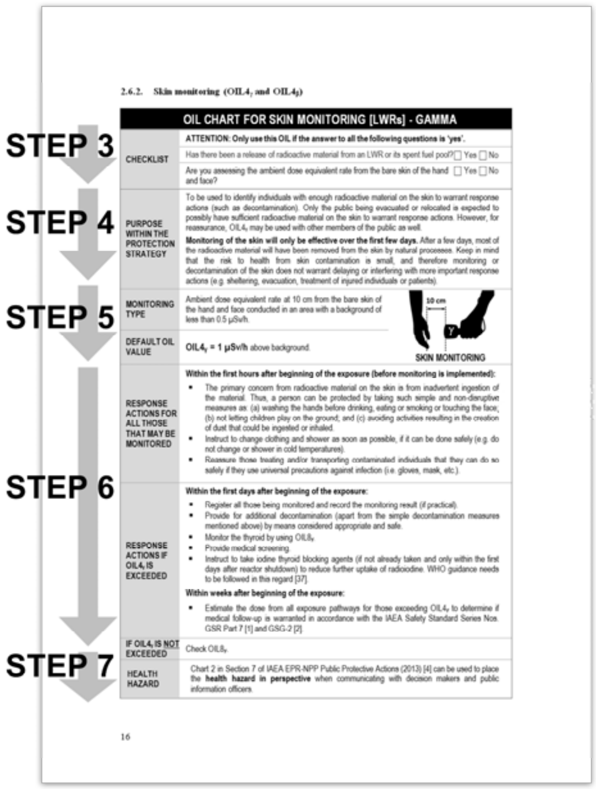
Step 4 Check the purpose within the protection strategy. Section 2.1 provides further advice in this regard.

Step 5 Compare your monitoring results with the default OIL value(s), ensuring they have the same units and prefixes as the default OIL value(s).

Step 6 Recommend taking the response actions indicated in the charts to the decision maker(s). When communicating with the decision maker(s), ensure that the information is clear, concise and goal oriented, as described in Section 2.3. Note that some actions are recommended to be taken whether or not the default OIL value is exceeded.

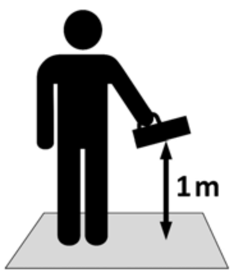
Step 7 Place the health hazard in perspective when communicating with decision makers and public information officers, as described in Section 2.4.





2.6. OIL CHARTS FOR USE IN THE RESPONSE

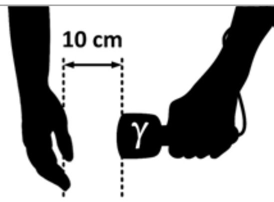
2.6.1. Ground monitoring (OIL1$_{\gamma}$, OIL2$_{\gamma}$ and OIL3$_{\gamma}$)

<table>
<tr><th colspan="4">OIL CHART FOR GROUND MONITORING (LWRs)</th></tr>
<tr><td rowspan="4">CHECKLIST</td><td colspan="3">ATTENTION: Only use this OIL if the answer to all the following questions is ‘yes’.</td></tr>
<tr><td colspan="2">Has there been a release of radioactive material from an LWR or its spent fuel?</td><td>☐ Yes ☐ No</td></tr>
<tr><td colspan="2">Are you assessing the ambient dose equivalent rate at 1 m above ground level?</td><td>☐ Yes ☐ No</td></tr>
<tr><td colspan="2">Is the measurement representative of an area inhabited or frequented by the public or of an area from where the public consumes or distributes local produce, wild-grown products (e.g. mushrooms or berries), milk from grazing animals, rainwater, local animals or animal feed?</td><td>☐ Yes ☐ No</td></tr>
<tr><td>PURPOSE WITHIN THE PROTECTION STRATEGY</td><td colspan="3">To be used to identify areas (beyond those for response actions have been taken based on the emergency classification) where the ground deposition of radioactive material warrants:
▪ Protection of the public frequenting or living in the area (by using OIL1$_{\gamma}$ for immediate urgent response actions and OIL2$_{\gamma}$ for early response actions);
▪ Restricting the consumption, distribution and sale of non-essential local produce, wild-grown products, milk from grazing animals, directly collected rainwater, local animals and animal feed (by using OIL3$_{\gamma}$ for immediate urgent response actions).
Avoid delays in decision making and implement response actions as soon as possible. Living in areas exceeding OIL1$_{\gamma}$ for more than 1 day may result in radiation induced health effects. Those living in areas exceeding OIL2$_{\gamma}$ will receive a large fraction of the annual dose in the first month. Consuming local produce, wild-grown products, milk from grazing animals, directly collected rainwater or local animals from an area exceeding OIL3$_{\gamma}$, may result in radiation induced health effects.</td></tr>
<tr><td>MONITORING TYPE</td><td colspan="2">Ambient dose equivalent rate at 1 m above ground level in a populated or frequented area or in an area used for farming or for grazing, ideally with low or no vegetation and away from roads, trees and buildings.</td><td rowspan="5">

GROUND MONITORING</td></tr>
<tr><td rowspan="4">DEFAULT OIL VALUE</td><td>OIL1$_{\gamma}$</td><td>= 1000 μSv/h</td></tr>
<tr><td rowspan="2">OIL2$_{\gamma}$</td><td>= 100 μSv/h — For the first 10 days after reactor shutdown (i.e. after the nuclear reaction in the core was stopped).</td></tr>
<tr><td>= 25 μSv/h — Later than 10 days after reactor shutdown or for spent fuel.</td></tr>
<tr><td>OIL3$_{\gamma}$</td><td>= 1 μSv/h above background.</td></tr>
<tr><td>RESPONSE ACTIONS BASED ON GENERAL EMERGENCY</td><td colspan="3">Response actions to be implemented upon declaration of a General Emergency and following a release (before monitoring is implemented):
▪ Within the Extended Planning Distance (EPD): Instruct the public to reduce inadvertent ingestion, by advising: (a) to wash hands before drinking, eating or smoking or touching the face; (b) not to let children play on the ground; and (c) to avoid activities resulting in the creation of dust that could be ingested or inhaled.
▪ Within the Ingestion and Commodities Planning Distance (ICPD): Instruct the public to stop consumption, distribution and sale of non-essential local produce, wild-grown products, milk from grazing animals, directly collected rainwater, local animals (unless fed with protected feed) and animal feed, until the activity concentrations have been assessed by using OIL7. If the restricted food, milk or drinking water is essential, replace it.
▪ Within the ICPD: Instruct the public to stop distribution of commodities that may have been contaminated until they have been assessed.</td></tr>
<tr><td colspan="4">THE CHART CONTINUES ON THE NEXT PAGE</td></tr>
</table>

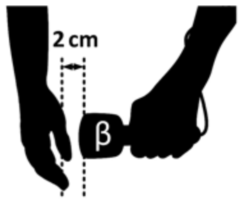
THE CHART BEGINS ON THE PREVIOUS PAGE	
RESPONSE ACTIONS IF $OIL1_\gamma$ IS EXCEEDED	**Within the first day after the beginning of the exposure:** ▪ Instruct the public to safely evacuate (only if it does not endanger those being evacuated; for example, patients in hospitals or care homes do not need to be immediately evacuated if this will put them at risk), if possible in combination with iodine thyroid blocking (only if it will not delay evacuation). If immediate evacuation is not possible or safe (e.g. for special facilities or owing to snow, floods or lack of transport), instruct the public to shelter preferably in large buildings in combination with iodine thyroid blocking, until safe evacuation is possible. ▪ Once evacuated, provide registration, skin and thyroid monitoring (by using $OIL4_\gamma$ and $OIL8_\gamma$), decontamination and medical screening for the evacuees. Instruct them to shower and change clothing, if it can be done safely (e.g. do not change or shower in cold temperatures). Skin and thyroid monitoring is not essential and does not warrant delaying other urgent response actions. **Within weeks after the beginning of the exposure:** ▪ Estimate the dose from all exposure pathways for those who were in the area to determine if medical follow-up is warranted in accordance with the IAEA Safety Standards Series Nos GSR Part 7 [1] and GSG-2 [2]. Also implement the response actions indicated for $OIL3_\gamma$.
RESPONSE ACTIONS IF $OIL2_\gamma$ IS EXCEEDED	**Within weeks after the beginning of the exposure:** ▪ Register those living in the area. ▪ Safely relocate those living in the area (i.e. do not endanger those being relocated). Prioritize those in the areas of highest potential exposure ensuring that those areas approaching $OIL1_\gamma$ will be relocated at least within the first days and those areas approaching $OIL2_\gamma$ will be relocated at least within the first month. ▪ Estimate the dose from all exposure pathways for those who were living in the area to determine if medical follow-up is warranted in accordance with the IAEA Safety Standards Series Nos. GSR Part 7 [1] and GSG-2 [2]. Also implement the response actions indicated for $OIL3_\gamma$.
RESPONSE ACTIONS IF $OIL3_\gamma$ IS EXCEEDED	**Within the first day after the beginning of the exposure:** ▪ If not already implemented based on the declaration of a General Emergency, implement the response actions indicated in the "RESPONSE ACTIONS BASED ON GENERAL EMERGENCY" section on the previous page regardless of the distance from the NPP. **Within weeks after the beginning of the exposure:** ▪ Estimate the dose from all exposure pathways for those who may have consumed local produce, wild-grown products milk from grazing animals, directly collected rainwater and local animals from the area where restrictions were implemented to determine if medical follow-up is warranted in accordance with the IAEA Safety Standards Series Nos. GSR Part 7 [1] and GSG-2 [2].
IF NONE OF THE OILs IS EXCEEDED	Adjust food, milk and drinking water restrictions by using OIL7 once food, milk and drinking water samples have been taken and analysed.
HEALTH HAZARD	Chart 1 in Section 7 of IAEA EPR-NPP Public Protective Actions (2013) [4] can be used to place the **health hazard in perspective** when communicating with decision makers and public information officers.

2.6.2. Skin monitoring (OIL4$_\gamma$ and OIL4$_\beta$)

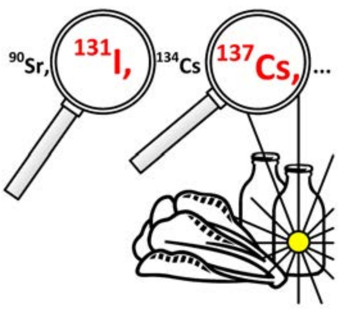
OIL CHART FOR SKIN MONITORING (LWRs) - GAMMA	
CHECKLIST	**ATTENTION: Only use this OIL if the answer to all the following questions is 'yes'.** Has there been a release of radioactive material from an LWR or its spent fuel? ☐ Yes ☐ No Are you assessing the ambient dose equivalent rate from the bare skin of the hand and face? ☐ Yes ☐ No
PURPOSE WITHIN THE PROTECTION STRATEGY	To be used to identify individuals with enough radioactive material on the skin to warrant response actions (such as decontamination). Only the public being evacuated or relocated is expected to possibly have sufficient radioactive material on the skin to warrant response actions. However, for reassurance, OIL4$_\gamma$ may be used with other members of the public as well. **Monitoring of the skin will only be effective over the first few days.** After a few days, most of the radioactive material will have been removed from the skin by natural processes. Keep in mind that the risk to health from skin contamination is small, and therefore monitoring or decontamination of the skin does not warrant delaying or interfering with more important response actions (e.g. sheltering, evacuation, treatment of injured individuals or patients).
MONITORING TYPE	Ambient dose equivalent rate at 10 cm from the bare skin of the hand and face conducted in an area with a background of less than 0.5 μSv/h.  **SKIN MONITORING**
DEFAULT OIL VALUE	**OIL4$_\gamma$ = 1 μSv/h** above background.
RESPONSE ACTIONS FOR ALL THOSE THAT MAY BE MONITORED	**Within the first hours after beginning of the exposure (before monitoring is implemented):** ▪ The primary concern from radioactive material on the skin is from inadvertent ingestion of the material. Thus, a person can be protected by taking such simple and non-disruptive measures as: (a) washing the hands before drinking, eating, smoking or touching the face; (b) not letting children play on the ground; and (c) avoiding activities resulting in the creation of dust that could be ingested or inhaled. ▪ Instruct to change clothing and shower as soon as possible, if it can be done safely (e.g. do not change or shower in cold temperatures). ▪ Reassure those treating and/or transporting contaminated individuals that they can do so safely if they use universal precautions against infection (i.e. gloves, mask, etc.).
RESPONSE ACTIONS IF OIL4$_\gamma$ IS EXCEEDED	**Within the first days after the beginning of the exposure:** ▪ Register all those being monitored and record the monitoring result (if practical). ▪ Provide for additional decontamination (apart from the simple decontamination measures mentioned above) by means considered appropriate and safe. ▪ Monitor the thyroid by using OIL8$_\gamma$. ▪ Provide medical screening. ▪ Instruct to take iodine thyroid blocking agents (if not already taken and only within the first days after reactor shutdown) to reduce further uptake of radioiodine. WHO guidance needs to be followed in this regard [37]. **Within weeks after the beginning of the exposure:** ▪ Estimate the dose from all exposure pathways for those exceeding OIL4$_\gamma$ to determine if medical follow-up is warranted in accordance with the IAEA Safety Standards Series Nos. GSR Part 7 [1] and GSG-2 [2].
IF OIL4$_\gamma$ IS NOT EXCEEDED	Check OIL8$_\gamma$.
HEALTH HAZARD	Chart 2 in Section 7 of IAEA EPR-NPP Public Protective Actions (2013) [4] can be used to place the **health hazard in perspective** when communicating with decision makers and public information officers.

OIL CHART FOR SKIN MONITORING (LWRs) - BETA

CAUTION: The ambient dose equivalent rate **OIL4$_{\gamma}$ is sufficient and preferable** to assess the levels of radioactive material on the skin for a release of radioactive material from an LWR or its spent fuel, because it is less dependent on the measurement technique and instrument characteristics. However, beta count rate OIL4$_{\beta}$ is also provided, since it may be used by some response organizations for skin monitoring.

CHECKLIST	**ATTENTION: Only use this OIL if the answer to all the following questions is 'yes'.**	
	Has there been a release of radioactive material from an LWR or its spent fuel?	☐ Yes ☐ No
	Are you assessing the beta count rate from the bare skin of the hand and face?	☐ Yes ☐ No
	Does the beta monitoring instrument meet **all** of the suitability criteria of Section 3.7.2.3 below (e.g. the effective window area of the instrument is less than or equal to 50 cm^2)?	☐ Yes ☐ No
PURPOSE WITHIN THE PROTECTION STRATEGY	The same as indicated in the gamma chart for skin monitoring.	
MONITORING TYPE	Beta count rate at 2 cm from the bare skin of the hand and face conducted in an area with a background of less than 0.5 µSv/h.	 **SKIN MONITORING**
DEFAULT OIL VALUE	**OIL4$_{\beta}$ = 1000 cps** The default OIL4$_{\beta}$ provided here can be used for a large variety of instruments. However, if the specific properties (e.g. efficiency and detector area) of the instrument are known, its suitability needs to be confirmed, or an instrument specific default OIL4$_{\beta}$ value needs to be calculated during the preparedness stage following Section 5.2 of this publication.	
RESPONSE ACTIONS FOR ALL THOSE BEING MONITORED	The same as indicated in the gamma chart for skin monitoring.	
RESPONSE ACTIONS IF OIL4$_{\beta}$ IS EXCEEDED	The same as indicated in the gamma chart for skin monitoring.	
IF OIL4$_{\beta}$ IS <u>NOT</u> EXCEEDED	The same as indicated in the gamma chart for skin monitoring.	
HEALTH HAZARD	The same as indicated in the gamma chart for skin monitoring.	

2.6.3. Food, milk and drinking water samples (OIL7)

OIL CHART FOR FOOD, MILK AND DRINKING WATER SAMPLES (LWRs)		
CHECKLIST	**ATTENTION: Only use this OIL if the answer to all the following questions is 'yes'.**	
	Has there been a release of radioactive material from an LWR or its spent fuel?	☐ Yes ☐ No
	Are you assessing the activity concentrations of radioactive material in food, milk or drinking water?	☐ Yes ☐ No
	Have you determined the activity concentration of <u>both</u> marker radionuclides I-131 and Cs-137 in Bq/kg?	☐ Yes ☐ No
	Is the measurement representative of the food, milk or drinking water that is being consumed?	☐ Yes ☐ No
	If you are analysing milk: Are you aware that the activity concentration of I-131 and Cs-137 in milk will not reach its maximum in the first day(s) after grazing on contaminated pasture (e.g. approximately two days for cows)?	☐ Yes ☐ No
PURPOSE WITHIN THE PROTECTION STRATEGY	To be used to confirm and adjust initial restrictions on food, milk and drinking water (i.e. those initial restrictions that were implemented based on the declaration of the emergency or on $OIL1_\gamma$, $OIL2_\gamma$ or $OIL3_\gamma$). The collection and analysis of samples will require much time and substantial resources. Comprehensive results are not expected within the first weeks (and even months) after the emergency; hence, there is time for a more detailed assessment. However, the sooner food, milk or water restrictions are implemented, the lower the dose received by the public will be.	
MONITORING TYPE	Activity concentration of I-131 and Cs-137 in food, milk and drinking water samples (these are marker radionuclides, i.e. the contribution of all other radionuclides expected to be present was considered in the calculation of OIL7).	 **MONITORING OF FOOD, MILK AND DRINKING WATER SAMPLES**
DEFAULT OIL VALUE	The activity concentration of **both** marker radionuclides I-131 and Cs-137 needs to be determined, and the OIL is exceeded if **either** the I-131 or Cs-137 value is exceeded. **OIL7 = 1000 Bq/kg of I-131 or 200 Bq/kg of Cs-137**	
RESPONSE ACTIONS IF OIL7 IS EXCEEDED	**Within days after obtaining the results:** ▪ Instruct the public to stop consumption, distribution and sale of the affected food, milk or drinking water (only if it can be implemented safely). If the restricted food, milk or drinking water is essential, replace it. **Within weeks after obtaining the results:** ▪ Estimate the dose from all exposure pathways for those who may have consumed food, milk or drinking water with activity concentrations greater than OIL7 to determine if medical follow-up is warranted in accordance with the IAEA Safety Standards Series Nos. GSR Part 7 [1] and GSG-2 [2].	
IF OIL7 IS <u>NOT</u> EXCEEDED	No need for further restrictions.	
HEALTH HAZARD	Charts 3A, 3B, 4A and 4B in Section 7 of IAEA EPR-NPP Public Protective Actions (2013) [4] can be used to place the **health hazard in perspective** when communicating with decision makers and public information officers.	

2.6.4. Thyroid monitoring ($OIL8_γ$)

OIL CHART FOR THYROID MONITORING (LWRs)		
CHECKLIST	**ATTENTION: Only use this OIL if the answer to all the following questions is 'yes'.**	
	Has there been a release of radioactive material from an LWR or its spent fuel?	☐ Yes ☐ No
	Are you assessing the ambient dose equivalent rate measured in front of the thyroid in contact with the skin?	☐ Yes ☐ No
	Was the person decontaminated and the contaminated outer clothing removed before monitoring?	☐ Yes ☐ No
	Was the measurement taken in the first week after the possible intake of I-131?	☐ Yes ☐ No
	Did you use an instrument with an effective window area of ≤ 15 cm^2 and a response of ≥ 0.1 μSv/h per kBq of I-131 activity in the thyroid? Further details are given in Section 3.7.1.3.	☐ Yes ☐ No
PURPOSE WITHIN THE PROTECTION STRATEGY	To be used to identify individuals warranting registration and medical follow-up due to the intake of radioiodine, i.e. evacuated public or those that have ingested local produce, wild-grown products, milk from grazing animals, directly collected rainwater or local animals from an area exceeding $OIL3_γ$. For reassurance, $OIL8_γ$ may be used with other members of the public as well. The thyroid needs to be monitored within the first week to detect if an individual has inhaled or ingested sufficient radioiodine to warrant medical follow-up. Identifying the individuals is difficult later on. The early identification of those with an increased risk of developing thyroid cancer is paramount in their later medical follow-up and treatment. However, keep in mind that monitoring of the thyroid does not warrant delaying or interfering with other urgent response actions.	
MONITORING TYPE	Ambient dose equivalent rate in front of the thyroid: ▪ In **contact with the skin**; ▪ Measured **within the first week** after the intake of radioiodine; ▪ Conducted in an area with a background of less than 0.25 μSv/h; ▪ Measured after the person has been decontaminated and contaminated outer clothing has been removed; and ▪ Measured with an instrument with an effective window area of ≤ 15 cm^2 and a response of ≥ 0.1 μSv/h (ambient dose equivalent rate in front of the thyroid in contact with the skin) per kBq of I-131 activity in the thyroid (as described in Section 3.7.1.3.).	 **THYROID MONITORING**
DEFAULT OIL VALUE	**$OIL8_γ$ = 0.5 μSv/h** above background.	
RESPONSE ACTIONS FOR ALL THOSE TO BE MONITORED	**Before monitoring:** ▪ Instruct those to be monitored to reduce inadvertent ingestion by: (a) washing their hands before drinking, eating or smoking or touching the face; (b) not letting children play on the ground; and (c) avoiding activities resulting in the creation of dust that could be ingested or inhaled. ▪ Instruct those to be monitored to change clothing and shower as soon as possible, if it can be done safely (e.g. do not change or shower in cold temperatures). ▪ Reassure those treating and/or transporting contaminated individuals that they can do so safely if they use universal precautions against infection (gloves, mask, etc.).	
RESPONSE ACTIONS IF $OIL8_γ$ IS EXCEEDED	**Immediately following the monitoring:** ▪ Register all those monitored and record the monitoring result. ▪ Instruct to take iodine thyroid blocking agents to reduce further uptake of radioiodine (if not already taken and only within the first days after reactor shutdown). WHO guidance needs to be followed in this regard [37]. ▪ Provide medical screening. **Within weeks after the beginning of the exposure:** Estimate the dose from all exposure pathways for those exceeding $OIL8_γ$ to determine if a medical follow-up is warranted in accordance with the IAEA Safety Standards Series Nos. GSR Part 7 [1] and GSG-2 [2].	
IF $OIL8_γ$ IS NOT EXCEEDED	Register all those monitored and record the monitoring result (if practical). No further actions are necessary.	

2.7. INTEGRATION OF THE CHARTS INTO NATIONAL ARRANGEMENTS

These charts need to be integrated in the overall protection strategy, incorporated into national emergency arrangements and adapted to local and site specific circumstances, ensuring that they remain practical for the response to an actual emergency (e.g. that the instructions are clear and unambiguous, and that the units are applicable to the monitoring results expected to be available during an emergency). Once revised, the charts need to be tested in drills and exercises and included in training programmes. Revisions of the default OIL values need to be considered with caution following the recommendations given in Section 5.

3. METHODOLOGY FOR DERIVING THE DEFAULT OIL VALUES

3.1. OVERVIEW

This section provides the methodology for deriving the default OIL values provided in this publication, giving a detailed explanation of the underlying assumptions, references and calculations. The default OIL values are intended to be used directly and confidently during the response. This requires making a series of considerations during the preparedness stage, as indicated in Fig. 4. The considered elements are shortly described below and discussed in detail in the sections indicated in Fig. 4:

- **Establish generic criteria at which to implement response actions:** The OILs provided in this publication are based on the generic criteria given in the IAEA Safety Standards Series No. GSR Part 7 [1] and described in Section 3.2. Generic criteria are projected or received doses at which response actions are to be taken in a nuclear or radiological emergency. Below the generic criteria, no radiation induced health effects are expected to be observed, even in a very large exposed group composed of the most sensitive members of the public. Being projected or received doses (i.e. calculated quantities), generic criteria cannot be used directly in the response, hence the need to develop operational criteria (such as OILs).
- **Consider all relevant radionuclide mixes:** The potential health effects from exposure to radioactive material, as well as the response of the monitoring instrument and the selection of marker radionuclides, depend on the radionuclides present. The OILs are therefore calculated for all the radionuclide mixes expected to be released from an LWR or its spent fuel during a severe emergency which may be significant contributors to the dose of the public or to the instrument response, as described in Section 3.3.
- **Consider all individuals being exposed:** Experience from past nuclear and radiological emergencies [6] has shown that assessments not considering all members of the public (especially those most sensitive, such as children and pregnant women), or not clearly stating that they have been considered, may result in unwarranted actions being taken by the public and/or decision makers that do more harm than good (examples of such actions are provided in Section 2.4). All members of the public have been considered in the calculation of the OILs by taking response actions based on the dose projected or received by the representative person, as described in Section 3.4.
- **Consider all relevant exposure scenarios and associated pathways:** The exposure scenario is a postulated set of conditions, circumstances, events and behaviour of the public that characterizes the exposure situation. It is the basis for determining the potentially exposed individuals, the relevant exposure pathways and the effectiveness of the response actions. Five exposure scenarios resulting from deposited radioactive material are considered for the OILs provided in this publication, i.e. the ‘ground’, ‘food pre-analysis’, ‘skin’, ‘food post-analysis’ and ‘thyroid’ scenarios, as described in Section 3.4. For each exposure scenario, different exposure pathways are considered. These pathways describe the routes by which radiation or radionuclides can reach humans and cause exposure.

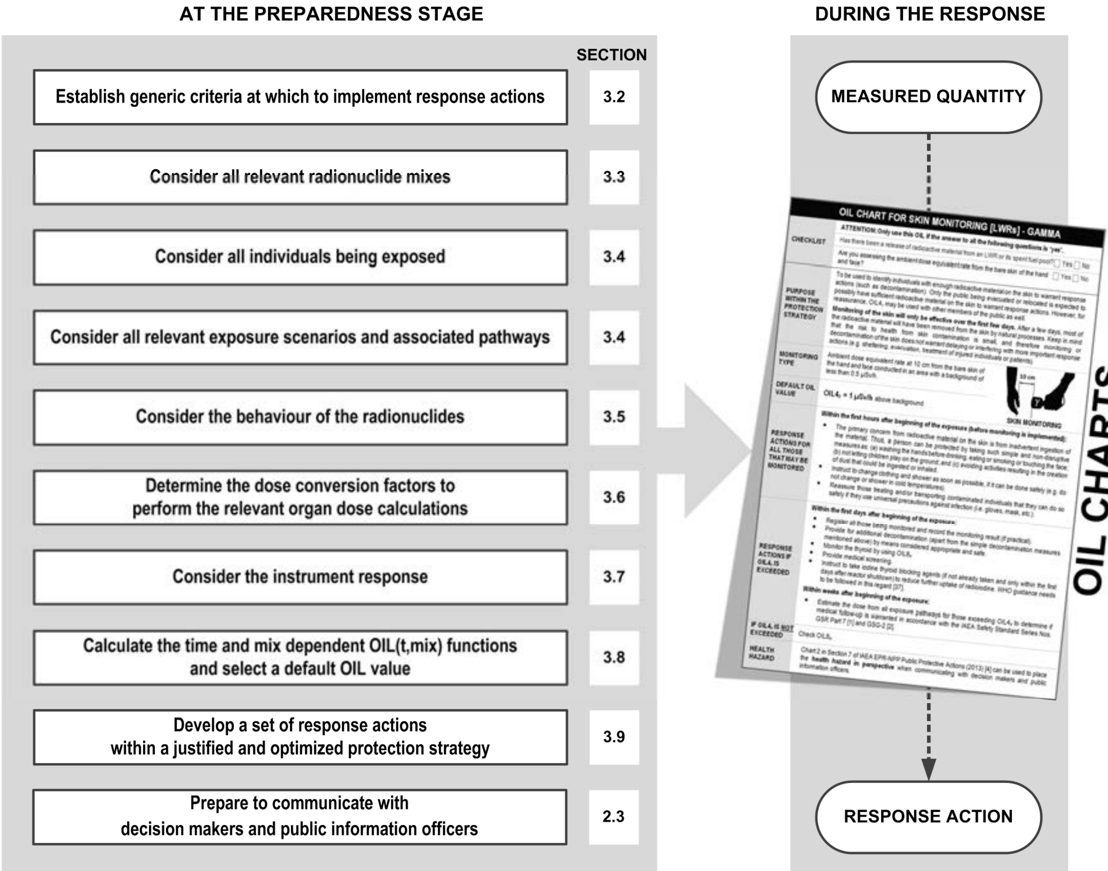


FIG. 4. Elements considered at the preparedness stage for developing the OILs and OIL charts.

- **Consider the behaviour of the radionuclides:** Any behaviour of the radionuclides that could have a significant impact on the dose or the OILs needs to be considered, such as the decrease in the dose rate due to decay and weathering, resuspension, transfer from the ground to milk or food or inadvertent ingestion. Section 3.5 considers the behaviour of the radionuclides (after being released into the environment)[27] and its impact on the dose by deriving a series of factors used in the OIL calculations.

- **Determine the dose conversion factors to perform the relevant organ dose calculations:** Dose conversion factors relate the activity of a certain radionuclide with the projected dose, which is needed to determine if the generic criteria may be exceeded. Section 3.6 provides the dose conversion factors for the exposure scenarios described in Section 3.4. The dose conversion factor will depend on the radionuclide, the dose quantity, the exposure pathways, the exposure scenario, the exposed individual and other considerations.

- **Consider the instrument response:** The instrument response will affect the default OIL values and needs to be considered in the calculations. Section 3.7 describes the basis for the instrument response assumed in the calculation of the different OILs.

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[27] The behaviour of the radionuclides within the NPP is addressed through the fuel damage scenarios given in Section 3.3.

- **Calculate the time and mix dependent OIL(t,mix) functions and select a default OIL value**: OIL values depend on the radionuclide mix that is considered, which will vary over time (due to processes such as decay). Therefore, for each OIL a set of time and mix dependent OIL(t,mix) functions is calculated, based on which a default OIL value is chosen, as described in Section 3.8. Choosing a default value over a time and/or mix dependant OIL is considered necessary because (a) the mix can vary considerably during an emergency with time and location [6, 7, 8, 9, 10]; and (b) not having a default criterion for the implementation of response actions has led to confusion of decision makers and scepticism among the public in past emergencies, delaying urgently required response actions [6, 16].
- **Develop a set of response actions within a justified and optimized protection strategy:** The charts in Section 2 provide the default OIL values, together with associated response actions. These response actions were developed by taking into consideration the overall protection strategy outlined in Ref. [1] and the concept of operations outlined in Ref. [4]. For a detailed description of the response actions, refer to Section 5 of Ref. [4].
- **Prepare to communicate with decision makers and public information officers:** During past nuclear and radiological emergencies, members of the public, those responsible for protecting the public and others (e.g. medical staff) have, on occasion, taken damaging actions that were not warranted based on the radiological health hazard. In some cases, these actions have resulted in avoidable deaths, injuries and an increased risk to health. In addition, these actions had adverse economic, social and psychological consequences. These adverse effects are also known as 'non-radiological' effects, which can be the most severe consequences of an emergency [6]. Experience has shown that decision makers take actions best when they understand how the actions contribute to the safety of the public [16]. Similarly, the public are more likely to follow instructions when they are clear and understandable in their own best interests. For this reason, the IAEA Safety Standards Series No. GSR Part 7 [1] requires in para. 5.71: "Arrangements shall be made so that in a nuclear or radiological emergency information is provided to the public in plain and understandable language." Further details can be found in Section 2.3. Providing detailed guidance on public communication lies outside of the scope of this publication.[28]

Due to the large number of assumptions and uncertainties taken into account in the derivation of the OILs (a) the results should not be considered as an exact value, but rather as a rough estimate, and (b) a reasonably conservative[29] approach is needed (as described in Section 3.10) to ensure that the response actions protect the public effectively from the radiological health hazard. However, using much lower default OIL values than those provided in this publication (e.g. one half of a default OIL value) may not be justified, since it could result in response actions that do more harm than good when considering: (a) the health hazard associated with the response action itself, and (b) the diversion of limited resources from the highest priority actions during an emergency.

[28] Further guidance regarding the communication with the public is available in Refs [26, 27].

[29] Conservative meaning that it will result in a projected dose higher than the dose actually expected to be received under real conditions. Section 3.10 discusses the considered conservatism.

3.2. GENERIC CRITERIA

The OILs provided in this publication are based on the generic criteria given in Tables II.1, II.2 and II.3 of the IAEA Safety Standards Series No. GSR Part 7 [1].[30] Only a subset of those generic criteria is needed for deriving the OILs given in this publication, as described in Table 2. Keeping the dose below the generic criteria given in Table 2 will ensure that none of the generic criteria listed in Tables II.1, II.2 and II.3 of Ref. [1] will be exceeded for a release from an LWR or its spent fuel.

Generic criteria are projected or received doses at which response actions are to be taken in a nuclear or radiological emergency. The generic criteria are established at doses below those at which radiation induced health effects would be expected to be observed, even in a very large exposed group composed of the most sensitive members of the public (e.g. children and pregnant women). Therefore, while implementing response actions above those generic criteria would almost always be justified on radiation protection grounds [38], below these generic criteria response actions may not be justified on radiation protection grounds, requiring a special and careful consideration before their implementation. In all cases, regardless whether the projected or received doses are above or below the generic criteria, the response actions need to be justified (i.e. do more good than harm) and optimized, taking the overall protection strategy into account.

Projected or received doses cannot be directly measured or easily calculated early in an emergency when information is limited and uncertainties significant, and decisions need to be made quickly in order for the actions to be effective. Hence the need to develop operational criteria, such as OILs, that can be used directly in the response. If a response action is implemented soon enough, the majority of the projected dose can be averted and the risk of suffering severe deterministic effects or incurring an increased risk of stochastic effects significantly reduced.

A detailed description of the basis for the generic criteria can be found in Ref. [19]. Member States may decide to adopt the IAEA's generic criteria directly or develop national generic criteria on the basis of the outcome of the justification and the optimization of their protection strategy.

[30] This publication does not contain OILs for the following generic criteria provided in Ref. [1]: (a) for vehicles, equipment and other items (table II.4 of Ref. [1]); (b) for food and other commodities traded internationally (Table II.5 of Ref. [1]); and (c) for enabling transition to an existing exposure situation (para. II.15 of Ref. [1]).

TABLE 2. GENERIC CRITERIA USED AS A BASIS FOR THE OILs

Actions[a]	Generic criterion (GC)	Used for	References
Take response actions **under any circumstance** to avoid or minimize severe deterministic effects	**GC(Acute,$AD_{skin-ext}$,10h) = 10 Gy** RBE weighted absorbed dose to 100 cm^2 of the skin dermis of the representative person[b] from acute external exposure in the first 10 hours	$OIL4_\gamma$ $OIL4_\beta$	Table II.1 of Ref. [1]
Take **urgent** response actions to reduce the risk of stochastic effects	**GC(Urgent,E,7d) = 0.1 Sv** total[c] effective[d] dose to the representative person[b] in the first 7 days	$OIL1_\gamma$ $OIL4_\gamma$ $OIL4_\beta$	Table II.2 of Ref. [1]
	GC(Urgent,H_{fetus},7d) = 0.1 Sv total[e] equivalent dose to the fetus[f] in the first 7 days	$OIL1_\gamma$ $OIL4_\gamma$ $OIL4_\beta$	Table II.2 of Ref. [1]
	GC(Urgent,$h_{thyroid,thy-burden}$) = 0.1 Sv[g] committed[h] equivalent dose to the thyroid from radioiodine in the thyroid (thyroid burden)	$OIL8_\gamma$	Ref. [1][i]
Take **early** response actions to reduce the risk of stochastic effects	**GC(Early,E,1a) = 0.1 Sv** total[c] effective[d] dose to the representative person[b] in the first year	$OIL2_\gamma$	Table II.2 of Ref. [1]
	GC(Early,H_{fetus},9mo) = 0.1 Sv total[e] equivalent dose to the fetus[f] in the full period of in utero development	$OIL2_\gamma$	Table II.2 of Ref. [1]
Take response actions to reduce the risk of stochastic effects due to the **ingestion** of food, milk or drinking water	**GC(Ingestion,e_{ing},1a) = 0.01 Sv[g]** committed[h] effective[d] dose to the representative person[b] from ingestion of food, milk and drinking water during the first year	$OIL3_\gamma$ OIL7	Table II.3. of Ref. [1]
	GC(Ingestion,$h_{fetus,ing}$,9mo) = 0.01 Sv[g] committed[h] equivalent dose to the fetus[f] from ingestion of food, milk and drinking water during the full period of in utero development	$OIL3_\gamma$ OIL7	Table II.3. of Ref. [1]

[a] Response actions are implemented based on projected doses. Received doses are used to identify those warranting medical actions to detect and effectively treat radiation induced health effects.

[b] The representative person is described in Section 3.4.

[c] The total effective dose includes the effective dose from external exposure and the committed effective dose from intake of radioactive material during the exposure period in accordance with Table II.2 of Ref. [1].

[d] Effective dose alone cannot be used to ensure that the doses to the specific organ may not exceed the threshold for severe deterministic effects resulting from intake (inhalation or ingestion) or radioactive material on the skin. However, keeping the projected equivalent dose to the fetus below 100 mSv for the exposure scenarios of interest will ensure that the RBE weighted dose from intake for any organ or tissue (including the fetus and the skin) will not exceed the generic criteria for severe deterministic effects, as listed in Table II.1 of Ref. [1].

[e] The total equivalent dose to the fetus includes: (a) the maximum committed equivalent dose to any organ from intake to the fetus for different chemical compounds and time relative to conception; and (b) the equivalent dose to the fetus from external exposure during the exposure period, in accordance with Table II.2 of Ref. [1].

[f] In this publication the term ‘fetus’ encompasses both the embryo and the fetus.

[g] For the notation of the dose, a lower case letter is used (i.e. e, h or ad) to indicate that only a single exposure pathway is considered, as opposed to the total dose from all relevant exposure pathways, for which an upper case letter is used (i.e. E, H or AD).

[h] For all committed doses addressed in this publication, the integration time given in the respective references is used, i.e. typically 50 a for the adult, 70 a for the infant and the period of in utero development for the fetus.

[i] The generic criterion of 50 mSv committed equivalent dose to the thyroid given in Table II.2 of Ref. [1] was not used because it is intended for implementation of ITB and not for the urgent identification of those that may need medical follow-up. The criterion of 100 mSv committed equivalent dose to the thyroid for medical follow-up was determined based on consideration of: (a) the equivalent dose to the fetus warranting medical follow-up as given in Ref. [1] (i.e. 100 mSv); (b) footnote e; (c) the controlling organ dose to the fetus for intake of iodine being the thyroid [39]; and (d) the assumption that the equivalent dose to the pregnant woman’s thyroid is approximately equal to the equivalent dose to the fetal thyroid [40].

3.3. RADIONUCLIDE MIX

Knowing the radionuclide mix is necessary to perform the dose calculations, determine the response of the monitoring instruments and select marker radionuclides. Releases of radioactive material from an NPP are composed of a large number of radionuclides. All the radionuclide mixes expected to be released which may be significant contributors to the dose of the public or to the instrument response need to be considered. Radionuclides expected not to be deposited in significant quantities to cause health effects off the site or not to have a significant impact on the OILs provided in this publication, such as noble gases, have not been included neither here nor in the attached spreadsheets. No exposure of the public is expected to occur before 30 minutes after reactor shutdown [41], eliminating the need to consider a broad range of short-lived radionuclides in the fuel that are of no consequence in a release of radioactive material.

Many factors influence the mix released from an NPP, including the amount of the radionuclides in the fuel, the type of damage to the reactor fuel, the time of the release and the conditions in the plant during the release. At the time of the emergency, it will be very difficult to associate the mix of radioactive material deposited at a given location with a specific fuel damage state. For example, during the early stage of the accident at the Fukushima Daiichi nuclear power plant, it was not clear whether the spent fuel was contributing to the release (as described in Technical Volume 2 of Ref. [8]). In order to ensure that the default OIL values provide adequate protection, the radionuclide mixes representative of the whole range of postulated or observed fuel damage scenarios and releases to the atmosphere resulting from severe conditions at an LWR or its spent fuel have been considered, including older sources of information such as Ref. [42] (i.e. postulated core to containment mixes), which seem to fit the releases of radioactive material from the Fukushima Daiichi accident better than the postulated core to atmosphere estimates. The considered mixes are described in Table 3 and are grouped as follows:

- **Postulated core to containment release scenarios:** The fuel undergoes different phases of damage resulting in the release of radionuclides from the core to the containment (Mix 1-11):
  - Gap release phase: The fuel cladding (fuel pins) holding the fuel pellets fails and releases gaseous fission products such as noble gases, iodine and caesium located in the gap between the fuel pellets.
  - Early in-vessel melt release phase: The fuel heats up resulting in melting and slumping of core materials to the bottom of the reactor vessel. During this phase, virtually all noble gases and significant fractions of the volatile radionuclides such as iodine and caesium are released from the fuel.
  - Ex-vessel melt release and late in-vessel release phases: The molten core debris (including reactor fuel) melts through the reactor vessel and falls onto the concrete structural materials of the cavity below the reactor vessel. As a result, the less volatile nuclides may be released due to the interaction with the concrete. It is also assumed that vaporization of radionuclides that have been deposited on surfaces within the reactor coolant system during the early in-vessel melt release phase and the ex-vessel melt release phase contribute to the release during this phase. Therefore, the ex-vessel melt release and late in-vessel release are added together.

- **Postulated core to atmosphere release scenarios:** The fuel undergoes different phases of damage resulting in the release of radionuclides from the core into the containment, which are then affected by conditions within the plant (e.g. by sprays or plate-out) (Mix 12-15).

- **Postulated spent fuel release scenario:** Spent fuel not being cooled, heating up and resulting in a self-sustained zirconium oxidation reaction (Mix 16).
- **Actual emergencies:** Estimated mix from the Chernobyl accident (Mix 17), estimated mix for the release of radioactive material from the Fukushima Daiichi accident (Mix 18) and mix considering the measured deposition resulting from the Fukushima Daiichi accident (Mix 19).

TABLE 3. DESCRIPTION OF THE CONSIDERED RADIONUCLIDE MIXES

Mix	Description	Reactor type	Fuel inventory
Postulated core to containment release scenarios			
1	Estimated release fractions from the core during the **gap release** phase of fuel damage for a pressurized water reactor (PWR) or boiling water reactor (BWR) with standard fuel, obtained from Tables 3.12 and 3.13 of Ref. [42].	PWR/ BWR	standard
2	Estimated release fractions from the core during the **early in-vessel melt release** phase of fuel damage for a BWR with standard fuel, obtained from Table 3.12 of Ref. [42].	BWR	
3	Sum of the estimated release fractions from the core during the **ex-vessel melt and late in-vessel release** phases of fuel damage for a BWR with standard fuel, obtained from Table 3.12 of Ref. [42]. The release fractions of these two phases were added together, because it is likely that both would be occurring at the time of a release from the containment to the atmosphere.		
4	Estimated release fractions from the core during the **early in-vessel melt release** phase of fuel damage for a PWR with standard fuel, obtained from Table 3.13 of Ref. [42].	PWR	
5	Sum of the estimated release fractions from the core during the **ex-vessel melt and late in-vessel release** phases of fuel damage for a PWR with standard fuel, obtained from Table 3.13 of Ref. [42]. The release fractions of these two phases were added together, because it is likely that both would be occurring at the time of a release from the containment to the atmosphere.		
6	Estimated release fractions from the core during the **gap release** phase of fuel damage for a BWR with high burnup fuel, obtained from Table 12 of Ref. [43].	BWR	high burnup
7	Estimated release fraction from the core during the **early in-vessel melt** release phase of fuel damage for a BWR with high burnup fuel, obtained from Table 12 of Ref. [43].		
8	Sum of the estimated release fractions from the core during the **ex-vessel melt and late in-vessel release** phases of fuel damage for a BWR with high burnup fuel, obtained from Table 12 of Ref. [43]. The release fractions of these two phases were added together, because it is likely that both would be occurring at the time of a release from the containment to the atmosphere.		
9	Estimated release fractions from the core during the **gap release** phase of fuel damage for a PWR with high burnup fuel, obtained from Table 13 of Ref. [43].	PWR	
10	Estimated release fractions from the core during the **early in-vessel melt** release phase of fuel damage for a PWR with high burnup fuel, obtained from Table 13 of Ref. [43].		
11	Sum of the estimated release fractions from the core during the **ex-vessel melt and late in-vessel release** phases of fuel damage for a PWR with high burnup fuel, obtained from Table 13 of Ref. [43]. The release fractions of these two phases were added together, because it is likely that both would be occurring at the time of a release from the containment to the atmosphere.		

Mix	Description	Reactor type	Fuel inventory
	Postulated core to atmosphere release scenarios		
12	Estimated atmospheric release fractions from a BWR following core melt and **melt through of the reactor vessel** resulting from long term station blackout. These are the total release fractions projected at about **22 hours** following start of the accident and about 2 hours after the containment fails resulting in the first phase of the major release. The values are obtained from Fig. 5-11 of Vol. 1 of Ref. [44] Ref. [44] does not provide a release fraction applicable to Sr. Therefore, the Sr release fraction used is based on the ratio of the Sr and Cs fractions for a BWR core melt from Mix 8 (Sr/Cs ≈ 0.5), and, consequently, the Sr release fraction was set at 0.5 times the release fraction for Cs.	BWR	standard and high burnup[a]
13	Estimated atmospheric release fractions from a BWR following core melt and **melt through of the reactor vessel** resulting from long term station blackout. These are total release fractions projected at about **24 hours** following the start of the accident and include the releases projected to occur during the second phase of the major release, which occurs when volatile radionuclides deposited on surfaces in the plant vaporize and are released. The values are obtained from Fig. 5-11 of Vol. 1 of Ref. [44]. Ref. [44] does not provide a release fraction applicable to Sr. Therefore, the Sr release fraction used is based on the ratio of the Sr and Cs fractions for a BWR core melt from Mix 8 (Sr/Cs ≈ 0.5), and, consequently, the Sr release fraction was set at 0.5 times the release fraction for Cs.		
14	Estimated atmospheric release fractions from a PWR following core melt and **melt through of the reactor vessel** resulting from long-term station blackout. These are total release fractions projected to occur by normal leakage at about **1.5 days** after the start of the accident. The values are obtained from Fig. 5-9 of Vol. 2 of Ref. [44]. Ref. [44] does not provide a release fraction applicable to Sr. Therefore, the Sr release fraction used is based on the ratio of the Sr and Cs fractions for a PWR core melt from Mix 11 (Sr/Cs ≈ 0.04), and, consequently, the Sr release fraction was set 0.04 times the release fraction for Cs.	PWR	
15	Estimated atmospheric release fractions from a PWR following core melt and **melt through of the reactor vessel** resulting from long term station blackout. These are the total release fractions projected at about **4 days** after the start of the accident and following containment failure. The values are obtained from Fig. 5-9 of Vol. 2 of Ref. [44]. Ref. [44] does not provide a release fraction applicable to Sr. Therefore, the Sr release fraction used is based on the ratio of the Sr and Cs fractions for a PWR core melt from Mix 11 (Sr/Cs ≈ 0.04), and, consequently, the Sr release fraction was set at 0.04 times the release fraction for Cs.		
	Postulated spent fuel release scenario		
16	Estimated release fractions from spent fuel. The radionuclide mix is assumed to be similar to the releases of the volatile fission products during core melt, except that it may result in higher releases of ruthenium during severe overheating of spent fuel as postulated in Ref. [45]. The mix was based on Mix 7 but with a Ru release faction that is the same as for Cs to account for the much higher releases of Ru. Only spent fuel that is sufficiently heated (either by its own decay heat or another heat source) to reach zirconium ignition temperatures is expected to result in a significant release of radioactive material warranting response actions. This is typically spent fuel in the spent fuel pool of an NPP.	-	standard and high burnup[a]

Mix	Description	Reactor type	Fuel inventory
	Actual emergencies		
17	Estimated release fractions from the Chernobyl accident based on the total release to the atmosphere estimated in Table 4 of Ref. [46]. For the radionuclides not mentioned in Ref. [46] the release fraction of the chemically similar radionuclides is used following Table 3.8 of Ref. [42].	-	standard and high burnup[a]
18	Estimated release amounts from the Fukushima Daiichi accident based on the average estimates of the total release to the atmosphere of Table 4.1–2 of Technical Volume 4 of Ref. [8]. The release amounts were normalized to the time of shutdown of the reactor (assuming 40 hours, since at this time the iodine ratios are similar). For the radionuclides not mentioned in Ref. [8], if available, the release fraction of an isotope is used, and, if not available, the release fractions for chemically similar radionuclide(s) are used following Table 3.8 of Ref. [42].	-	NA[b]
19	Mix 19 is used to examine the measured values of Sr-90, Te-129m, Te-132, Cs-134 and I-131 relative to Cs-137 on the ground following the atmospheric releases from the Fukushima Daiichi nuclear power plant, as provided in Refs [47, 48, 49, 50, 51]. These values, normalized to March 11, were: (a) Sr-90/Cs-137, in most cases at around 0.001 [47]; (b) Te-129m/Cs-137, in most cases around 0.5 [48, 49]; (c) Te-132/Cs-137, in most cases between 15–20 [50, 51]; (d) Cs-134/Cs-137, in most cases around 1.0 [47, 49]; and (e) I-131/Cs-137, in most cases between 15–25 [49, 50, 51]. Mix 19 was developed based on Mix 18, by modifying the release amounts of Sr-90, Te-129m, Te-132, Cs-134 and I-131 relative to Cs-137 according to the ratios given above.[c]	-	

[a] Both inventories (corresponding to standard and high burnup fuel) were considered in the calculations of the OILs. The results for both inventories only differ slightly and do not affect the final default OIL values; only the results for the standard fuel inventory are provided in Section 3.8. Providing both sets of results was considered to be of no added value.

[b] Not applicable. Table 4.1–2 of the Technical Volume 4 of Ref. [8] provides the estimated release in Bq and not the release fraction, making it unnecessary to choose between standard and high burnup fuel.

[c] The uncertainty for the estimates is greater for radionuclides other than iodine and caesium, reflecting the lack of direct measurements of these radionuclides immediately after the accident. Mix 19 needs to be treated with care and only considered as an approximation within orders of magnitude.

OIL values are calculated for each of the 19 radionuclide mixes described in Table 3 by using $RA_i(t,mix)$ [unitless], which is the relative activity of radionuclide i at time t after reactor shutdown (not the absolute activity in Bq). It is determined by Eq. (1):

$$RA_i(t, mix) = \frac{A_i(t, mix)}{\sum_{j=1}^{n} A_j(t, mix)} \quad (1)$$

where:

- n [unitless] is the number of considered radionuclides.
- t [s] is the time after shutdown of the reactor (i.e. after the fuel was last irradiated in a reactor).
- 'mix' refers to the mix number as provided in Table 3, Table 7, Table 8 and Table 9.
- $A_i(t,mix)$ [Bq] is the activity of radionuclide i at time t after reactor shutdown, for a specific radionuclide mix. It is determined by combining release fractions with core inventories for two operating conditions (standard and high burnup), as described in Eq. (2):

  $$A_i(t, mix) = I_{fuel-type,i}(t) \times RF_i(mix) \quad (2)$$

  where:

  - $I_{fuel\text{-}type,i}(t)$ [Bq] is the inventory of radionuclide i in the fuel at time t after reactor shutdown, which is calculated by Eq. (3):

    $$I_{fuel-type,i}(t) = I_{fuel-type,i}(t_0) \times e^{-\lambda_i \times (t-t_0)} \quad (3)$$

    where:

    - $I_{fuel\text{-}type,i}(t_0)$ [Bq] is the inventory of radionuclide i in the fuel at time t_0 = 30 min = 1800 s after reactor shutdown. As mentioned before, no exposure of the public is expected to occur before 30 minutes after reactor shutdown [41]. The values are given in Table 4 for a 3000 MW(th) power plant and are provided for two different fuel types: (a) standard fuel and (b) a high burnup fuel. Also mixed oxide fuel (MOX) was considered, but it did not have a significant impact for those radionuclides important in terms of health effects [43]; thus, it is not addressed in further detail. For those radionuclides marked with a '+' in Table 4, the progenies are assumed to be in equilibrium with the parent (Table 5 provides the ratio between the activity of the progeny and the parent radionuclide). Therefore, these particular radionuclides do not need to be considered separately.
      Both inventories (corresponding to standard and high burnup fuel) were considered in the calculations of the OILs. The results for both inventories only differ slightly and do not affect the final default OIL values.
    - λ_i [s^{-1}] is the decay constant for radionuclide i. The values are given in Table 6.

  - $RF_i(mix)$ [unitless] is the release fraction of radionuclide i from the fuel for a specific radionuclide mix. The values are given in Table 7, Table 8 and Table 9.

TABLE 4. INVENTORY OF RADIONUCLIDE i IN THE FUEL FOR A 3000 MW(th) LWR

Radionuclide	$I_{fuel-type,i}(t_0)$ [Bq]	
	Standard fuel[a]	**High burnup fuel**[b,c]
Rb-86	9.6E+14	3.7E+15
Sr-89	3.5E+18	3.2E+18
Sr-90+	1.4E+17	2.5E+17
Sr-91	4.1E+18	3.9E+18
Y-91	4.4E+18	4.1E+18
Zr-95+	5.6E+18	5.2E+18
Zr-97+	5.6E+18	5.1E+18
Mo-99+	5.9E+18	5.5E+18
Ru-103+	4.1E+18	4.1E+18
Ru-105	2.7E+18	2.4E+18
Ru-106+	9.3E+17	1.1E+18
Rh-105	1.8E+18	2.3E+18
Te-127m+	4.1E+16	3.7E+16
Te-127	2.2E+17	2.2E+17
Te-129m+	2.0E+17	1.3E+17
Te-131m	4.8E+17	5.1E+17
Te-132+	4.4E+18	4.1E+18
I-131	3.2E+18	2.9E+18
I-133	6.3E+18	6.0E+18
I-134	7.0E+18	4.7E+18
I-135	5.6E+18	5.5E+18
Cs-134	2.8E+17	3.1E+17
Cs-136	1.1E+17	1.2E+17
Cs-137+	1.7E+17	3.2E+17
Ba-140+	5.9E+18	5.3E+18
Ce-141	5.6E+18	5.0E+18
Ce-143	4.8E+18	4.8E+18
Ce-144+	3.2E+18	3.6E+18
Pr-143	4.8E+18	4.7E+18
Nd-147	2.2E+18	2.0E+18
Np-239	5.9E+19	4.8E+19
Pu-238	2.1E+15	5.8E+15
Pu-239	7.8E+14	1.2E+15
Pu-240	7.8E+14	9.6E+14
Pu-241	1.3E+17	3.3E+17
Am-241	6.3E+13	4.5E+14
Cm-242	1.9E+16	8.2E+16
Cm-244	8.5E+14	4.0E+15

[a] $I_{fuel-type,i}(t_0)$ for the standard fuel is obtained from Table ID of Ref. [5], which is based on Table VI-3-1 of Ref. [41].

[b] $I_{fuel-type,i}(t_0)$ for the high burnup fuel is obtained from the inventory in Tables A-3 to A-10 of Vol. 1 of Ref. [44], which was normalized to time t_0 = 30 min after reactor shutdown and to 3000 MW(th) to allow for a direct comparison. This was done in consideration of 3000 MW(th) being approximately equivalent to 1000 MW(e).

[c] The high burnup inventory shows reasonable agreement with the inventory for Unit 2 of the Fukushima Daiichi NPP at the time of the accident, as provided in Technical Volume 1 of Ref. [8].

\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

TABLE 5. PROGENIES CONSIDERED FOR THE RADIONUCLIDES MARKED WITH '+'
(The ratio between the activity of the progeny and the parent radionuclide is given in the parentheses and is obtained from Table 11 of Ref. [2].)

Parent radionuclide	Progenies considered to be in equilibrium with the parent radionuclide in the fuel
Sr-90	Y-90 (1.0)
Zr-95	Nb-95 (2.2)
Zr-97	Nb-97m (0.95), Nb-97 (1.0)
Mo-99	Tc-99m (0.96)
Ru-103	Rh-103m (1.0)
Ru-106	Rh-106 (1.0)
Te-127m [a]	Te-127 (1.0)
Te-129m	Te-129 (0.65)
Te-132	I-132 (1.0)
Cs-137	Ba-137m (1.0)
Ba-140	La-140 (1.2)
Ce-144	Pr-144m (0.018), Pr-144 (1.0)

[a] Te-127 is considered as being in equilibrium with Te-127m after its release. Te-127 is considered separately in the fuel inventory because it is not in equilibrium with the Te-127m in the fuel.

TABLE 6. HALF-LIFE AND DECAY CONSTANT

Radionuclide	Half-life ($T_{1/2}$)[a]		Decay constant (λ_i)[b]
	Value	Unit	[s^{-1}]
Rb-86	18.642	[d]	4.3E-07
Sr-89	50.53	[d]	1.6E-07
Sr-90	28.79	[a]	7.6E-10
Sr-91	9.63	[h]	2.0E-05
Y-91	58.51	[d]	1.4E-07
Zr-95	64.032	[d]	1.3E-07
Zr-97	16.744	[h]	1.1E-05
Mo-99	65.94	[h]	2.9E-06
Ru-103	39.26	[d]	2.0E-07
Ru-105	4.44	[h]	4.3E-05
Ru-106	373.59	[d]	2.1E-08
Rh-105	35.36	[h]	5.4E-06
Te-127m	109	[d]	7.4E-08
Te-127	9.35	[h]	2.1E-05
Te-129m	33.6	[d]	2.4E-07
Te-131m	30	[h]	6.4E-06
Te-132	3.204	[d]	2.5E-06
I-131	8.0207	[d]	1.0E-06
I-133	20.8	[h]	9.3E-06
I-134	52.5	[m]	2.2E-04
I-135	6.57	[h]	2.9E-05
Cs-134	2.0648	[a]	1.1E-08
Cs-136	13.16	[d]	6.1E-07
Cs-137	30.1671	[a]	7.3E-10
Ba-140	12.752	[d]	6.3E-07
Ce-141	32.508	[d]]	2.5E-07
Ce-143	33.039	[h]	5.8E-06
Ce-144	284.91	[d]	2.8E-08
Pr-143	13.57	[d]	5.9E-07
Nd-147	10.98	[d]	7.3E-07
Np-239	2.3565	[d]	3.4E-06
Pu-238	87.7	[a]	2.5E-10
Pu-239	24110	[a]	9.1E-13
Pu-240	6564	[a]	3.3E-12
Pu-241	14.35	[a]	1.5E-09
Am-241	432.2	[a]	5.1E-11
Cm-242	162.8	[d]	4.9E-08
Cm-244	18.1	[a]	1.2E-09

[a] The values are obtained from Table A.1. of Ref. [52].
[b] λ_i is calculated based on the half-life: $\lambda_i = \ln(2) / T_{1/2.}$

TABLE 7. RELEASE FRACTION OF RADIONUCLIDE i FROM THE FUEL FOR THE CONSIDERED RADIONUCLIDE MIXES (MIXES 1–7)
(The basis for these values are described in Table 3.)
(0.00E+00 means that only a negligible release is predicted to occur.)

Radionuclide	RF_i(mix1) [unitless]	RF_i(mix2) [unitless]	RF_i(mix3) [unitless]	RF_i(mix4) [unitless]	RF_i(mix5) [unitless]	RF_i(mix6) [unitless]	RF_i(mix7) [unitless]
Rb-86	5.0E-02	2.0E-01	3.6E-01	2.5E-01	4.5E-01	2.0E-03	1.3E-01
Sr-89	0.0E+00	2.0E-02	1.0E-01	2.0E-02	1.0E-01	0.0E+00	5.0E-03
Sr-90+	0.0E+00	2.0E-02	1.0E-01	2.0E-02	1.0E-01	0.0E+00	5.0E-03
Sr-91	0.0E+00	2.0E-02	1.0E-01	2.0E-02	1.0E-01	0.0E+00	5.0E-03
Y-91	0.0E+00	2.0E-04	5.0E-03	2.0E-04	5.0E-03	0.0E+00	1.4E-07
Zr-95+	0.0E+00	2.0E-04	5.0E-03	2.0E-04	5.0E-03	0.0E+00	1.3E-07
Zr-97+	0.0E+00	2.0E-04	5.0E-03	2.0E-04	5.0E-03	0.0E+00	1.3E-07
Mo-99+	0.0E+00	2.5E-03	2.5E-03	2.5E-03	2.5E-03	0.0E+00	2.0E-02
Ru-103+	0.0E+00	2.5E-03	2.5E-03	2.5E-03	2.5E-03	0.0E+00	2.7E-03
Ru-105	0.0E+00	2.5E-03	2.5E-03	2.5E-03	2.5E-03	0.0E+00	2.7E-03
Ru-106+	0.0E+00	2.5E-03	2.5E-03	2.5E-03	2.5E-03	0.0E+00	2.7E-03
Rh-105	0.0E+00	2.5E-03	2.5E-03	2.5E-03	2.5E-03	0.0E+00	2.7E-03
Te-127m+	0.0E+00	5.0E-02	2.6E-01	5.0E-02	2.6E-01	2.0E-03	3.9E-01
Te-127	0.0E+00	5.0E-02	2.6E-01	5.0E-02	2.6E-01	2.0E-03	3.9E-01
Te-129m+	0.0E+00	5.0E-02	2.6E-01	5.0E-02	2.6E-01	2.0E-03	3.9E-01
Te-131m	0.0E+00	5.0E-02	2.6E-01	5.0E-02	2.6E-01	2.0E-03	3.9E-01
Te-132+	0.0E+00	5.0E-02	2.6E-01	5.0E-02	2.6E-01	2.0E-03	3.9E-01
I-131	5.0E-02	2.5E-01	3.1E-01	3.5E-01	3.5E-01	2.0E-03	4.7E-01
I-133	5.0E-02	2.5E-01	3.1E-01	3.5E-01	3.5E-01	2.0E-03	4.7E-01
I-134	5.0E-02	2.5E-01	3.1E-01	3.5E-01	3.5E-01	2.0E-03	4.7E-01
I-135	5.0E-02	2.5E-01	3.1E-01	3.5E-01	3.5E-01	2.0E-03	4.7E-01
Cs-134	5.0E-02	2.0E-01	3.6E-01	2.5E-01	4.5E-01	2.0E-03	1.3E-01
Cs-136	5.0E-02	2.0E-01	3.6E-01	2.5E-01	4.5E-01	2.0E-03	1.3E-01
Cs-137+	5.0E-02	2.0E-01	3.6E-01	2.5E-01	4.5E-01	2.0E-03	1.3E-01
Ba-140+	0.0E+00	2.0E-02	1.0E-01	2.0E-02	1.0E-01	0.0E+00	5.0E-03
Ce-141	0.0E+00	5.0E-04	5.0E-03	5.0E-04	5.0E-03	0.0E+00	1.3E-07
Ce-143	0.0E+00	5.0E-04	5.0E-03	5.0E-04	5.0E-03	0.0E+00	1.3E-07
Ce-144+	0.0E+00	5.0E-04	5.0E-03	5.0E-04	5.0E-03	0.0E+00	1.3E-07
Pr-143	0.0E+00	2.0E-04	5.0E-03	2.0E-04	5.0E-03	0.0E+00	1.4E-07
Nd-147	0.0E+00	2.0E-04	5.0E-03	2.0E-04	5.0E-03	0.0E+00	1.4E-07
Np-239	0.0E+00	5.0E-04	5.0E-03	5.0E-04	5.0E-03	0.0E+00	1.3E-07
Pu-238	0.0E+00	5.0E-04	5.0E-03	5.0E-04	5.0E-03	0.0E+00	1.3E-07
Pu-239	0.0E+00	5.0E-04	5.0E-03	5.0E-04	5.0E-03	0.0E+00	1.3E-07
Pu-240	0.0E+00	5.0E-04	5.0E-03	5.0E-04	5.0E-03	0.0E+00	1.3E-07
Pu-241	0.0E+00	5.0E-04	5.0E-03	5.0E-04	5.0E-03	0.0E+00	1.3E-07
Am-241	0.0E+00	2.0E-04	5.0E-03	2.0E-04	5.0E-03	0.0E+00	1.4E-07
Cm-242	0.0E+00	2.0E-04	5.0E-03	2.0E-04	5.0E-03	0.0E+00	1.4E-07
Cm-244	0.0E+00	2.0E-04	5.0E-03	2.0E-04	5.0E-03	0.0E+00	1.4E-07

+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

TABLE 8. RELEASE FRACTION OF RADIONUCLIDE i FROM THE FUEL FOR THE CONSIDERED RADIONUCLIDE MIXES (MIXES 8–13)
(The basis for these values are described in Table 3.)
(0.00E+00 means that only a negligible release is predicted to occur.)

Radionuclide	RF_i(mix8) [unitless]	RF_i(mix9) [unitless]	RF_i(mix10) [unitless]	RF_i(mix11) [unitless]	RF_i(mix12) [unitless]	RF_i(mix13) [unitless]
Rb-86	6.0E-02	3.0E-03	2.3E-01	8.0E-02	3.0E-03	3.8E-03
Sr-89	3.4E-02	6.0E-04	4.0E-03	3.0E-03	1.5E-03	1.9E-03
Sr-90+	3.4E-02	6.0E-04	4.0E-03	3.0E-03	1.5E-03	1.9E-03
Sr-91	3.4E-02	6.0E-04	4.0E-03	3.0E-03	1.5E-03	1.9E-03
Y-91	5.0E-05	0.0E+00	1.5E-07	1.3E-05	5.0E-06	1.0E-05
Zr-95+	2.1E-03	0.0E+00	1.5E-07	2.4E-04	6.0E-05	7.5E-05
Zr-97+	2.1E-03	0.0E+00	1.5E-07	2.4E-04	6.0E-05	7.5E-05
Mo-99+	8.5E-03	0.0E+00	8.0E-02	4.0E-02	8.0E-04	8.5E-04
Ru-103+	2.6E-03	0.0E+00	6.0E-03	2.5E-03	2.0E-06	3.0E-06
Ru-105	2.6E-03	0.0E+00	6.0E-03	2.5E-03	2.0E-06	3.0E-06
Ru-106+	2.6E-03	0.0E+00	6.0E-03	2.5E-03	2.0E-06	3.0E-06
Rh-105	2.6E-03	0.0E+00	6.0E-03	2.5E-03	2.0E-06	3.0E-06
Te-127m+	3.3E-01	4.0E-03	3.0E-01	1.0E-01	2.2E-03	1.0E-02
Te-127	3.3E-01	4.0E-03	3.0E-01	1.0E-01	2.2E-03	1.0E-02
Te-129m+	3.3E-01	4.0E-03	3.0E-01	1.0E-01	2.2E-03	1.0E-02
Te-131m	3.3E-01	4.0E-03	3.0E-01	1.0E-01	2.2E-03	1.0E-02
Te-132+	3.3E-01	4.0E-03	3.0E-01	1.0E-01	2.2E-03	1.0E-02
I-131	4.0E-01	4.0E-03	3.7E-01	2.2E-01	4.0E-03	1.0E-02
I-133	4.0E-01	4.0E-03	3.7E-01	2.2E-01	4.0E-03	1.0E-02
I-134	4.0E-01	4.0E-03	3.7E-01	2.2E-01	4.0E-03	1.0E-02
I-135	4.0E-01	4.0E-03	3.7E-01	2.2E-01	4.0E-03	1.0E-02
Cs-134	6.0E-02	3.0E-03	2.3E-01	8.0E-02	3.0E-03	3.8E-03
Cs-136	6.0E-02	3.0E-03	2.3E-01	8.0E-02	3.0E-03	3.8E-03
Cs-137+	6.0E-02	3.0E-03	2.3E-01	8.0E-02	3.0E-03	3.8E-03
Ba-140+	3.4E-02	6.0E-04	4.0E-03	3.0E-03	4.5E-03	5.0E-03
Ce-141	2.1E-03	0.0E+00	1.5E-07	2.4E-04	6.0E-05	7.5E-05
Ce-143	2.1E-03	0.0E+00	1.5E-07	2.4E-04	6.0E-05	7.5E-05
Ce-144+	2.1E-03	0.0E+00	1.5E-07	2.4E-04	6.0E-05	7.5E-05
Pr-143	5.0E-05	0.0E+00	1.5E-07	1.3E-05	5.0E-06	1.0E-05
Nd-147	5.0E-05	0.0E+00	1.5E-07	1.3E-05	5.0E-06	1.0E-05
Np-239	2.1E-03	0.0E+00	1.5E-07	2.4E-04	6.0E-05	7.5E-05
Pu-238	2.1E-03	0.0E+00	1.5E-07	2.4E-04	6.0E-05	7.5E-05
Pu-239	2.1E-03	0.0E+00	1.5E-07	2.4E-04	6.0E-05	7.5E-05
Pu-240	2.1E-03	0.0E+00	1.5E-07	2.4E-04	6.0E-05	7.5E-05
Pu-241	2.1E-03	0.0E+00	1.5E-07	2.4E-04	6.0E-05	7.5E-05
Am-241	5.0E-05	0.0E+00	1.5E-07	1.3E-05	5.0E-06	1.0E-05
Cm-242	5.0E-05	0.0E+00	1.5E-07	1.3E-05	5.0E-06	1.0E-05
Cm-244	5.0E-05	0.0E+00	1.5E-07	1.3E-05	5.0E-06	1.0E-05

+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

TABLE 9. RELEASE FRACTION OF RADIONUCLIDE i FROM THE FUEL FOR THE CONSIDERED RADIONUCLIDE MIXES (MIX 14 TO 19)
(The basis for these values are described in Table 3.)
(0.00E+00 means that only a negligible release is predicted to occur.)

Radionuclide	RF_i(mix14) [unitless]	RF_i(mix15) [unitless]	RF_i(mix16) [unitless]	RF_i(mix17) [unitless]	RF_i(mix18)[a] [unitless]	RF_i(mix19)[a] [unitless]
Rb-86	4.0E-05	7.5E-04	1.3E-01	3.3E-01	5.7E+00	5.7E+00
Sr-89	1.6E-06	3.0E-05	5.0E-03	5.0E-02	2.1E-03	2.1E-03
Sr-90+	1.6E-06	3.0E-05	5.0E-03	5.0E-02	2.8E-04	5.3E-05
Sr-91	1.6E-06	3.0E-05	5.0E-03	5.0E-02	2.9E-03	2.9E-03
Y-91	0.0E+00	0.0E+00	1.4E-07	3.5E-02	4.2E-06	4.2E-06
Zr-95+	1.0E-06	2.0E-05	1.3E-07	3.5E-02	3.3E-06	3.3E-06
Zr-97+	1.0E-06	2.0E-05	1.3E-07	3.5E-02	3.4E-06	3.4E-06
Mo-99+	9.0E-06	1.0E-04	2.0E-02	3.5E-02	2.4E-11	2.4E-11
Ru-103+	0.0E+00	1.5E-05	1.3E-01	3.5E-02	9.8E-09	9.8E-09
Ru-105	0.0E+00	1.5E-05	1.3E-01	3.5E-02	8.9E-09	8.9E-09
Ru-106+	0.0E+00	1.5E-05	1.3E-01	3.5E-02	1.9E-09	1.9E-09
Rh-105	0.0E+00	1.5E-05	2.7E-03	3.5E-02	4.6E-09	4.6E-09
Te-127m+	4.0E-05	2.0E-02	3.9E-01	4.3E-01	2.2E-01	2.2E-01
Te-127	4.0E-05	2.0E-02	3.9E-01	4.3E-01	3.6E-02	3.6E-02
Te-129m+	4.0E-05	2.0E-02	3.9E-01	4.3E-01	6.1E-02	5.1E-02
Te-131m	4.0E-05	2.0E-02	3.9E-01	4.3E-01	1.6E-02	1.6E-02
Te-132+	4.0E-05	2.0E-02	3.9E-01	4.3E-01	2.8E-02	5.7E-02
I-131	6.0E-05	5.0E-03	4.7E-01	5.5E-01	1.0E-01	9.4E-02
I-133	6.0E-05	5.0E-03	4.7E-01	5.5E-01	9.5E-02	9.5E-02
I-134	6.0E-05	5.0E-03	4.7E-01	5.5E-01	9.2E-02	9.2E-02
I-135	6.0E-05	5.0E-03	4.7E-01	5.5E-01	7.8E-02	7.8E-02
Cs-134	4.0E-05	7.5E-04	1.3E-01	3.3E-01	9.5E-02	4.4E-02
Cs-136	4.0E-05	7.5E-04	1.3E-01	3.3E-01	1.8E-01	1.8E-01
Cs-137+	4.0E-05	7.5E-04	1.3E-01	3.3E-01	4.2E-02	4.2E-02
Ba-140+	3.0E-06	7.5E-04	5.0E-03	5.0E-02	2.2E-03	2.2E-03
Ce-141	1.0E-06	2.0E-05	1.3E-07	3.5E-02	3.7E-06	3.7E-06
Ce-143	1.0E-06	2.0E-05	1.3E-07	3.5E-02	3.1E-06	3.1E-06
Ce-144+	1.0E-06	2.0E-05	1.3E-07	3.5E-02	3.1E-06	3.1E-06
Pr-143	0.0E+00	0.0E+00	1.4E-07	3.5E-02	3.7E-06	3.7E-06
Nd-147	0.0E+00	0.0E+00	1.4E-07	3.5E-02	8.8E-06	8.8E-06
Np-239	1.0E-06	2.0E-05	1.3E-07	3.5E-02	2.6E-06	2.6E-06
Pu-238	1.0E-06	2.0E-05	1.3E-07	3.5E-02	1.8E-06	1.8E-06
Pu-239	1.0E-06	2.0E-05	1.3E-07	3.5E-02	1.5E-06	1.5E-06
Pu-240	1.0E-06	2.0E-05	1.3E-07	3.5E-02	1.9E-06	1.9E-06
Pu-241	1.0E-06	2.0E-05	1.3E-07	3.5E-02	1.8E-06	1.8E-06
Am-241	0.0E+00	0.0E+00	1.4E-07	3.5E-02	3.9E-02	3.9E-02
Cm-242	0.0E+00	0.0E+00	1.4E-07	3.5E-02	6.8E-07	6.8E-07
Cm-244	0.0E+00	0.0E+00	1.4E-07	3.5E-02	4.3E-03	4.3E-03

[a] The release fraction shown here is applicable for high burnup and is only provided for consistency. Technical Volume 4 of Ref. [8] provides the estimated release in Bq and not the release fraction, making it unnecessary to choose between standard and high burnup fuel.

\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

3.4. REPRESENTATIVE PERSON, EXPOSURE SCENARIOS AND PATHWAYS

All members of the public have been considered in the calculation of the OILs by taking response actions based on the dose projected or received by the representative person and its fetus, as recommended by the International Commission on Radiological Protection (ICRP) in Refs [38, 53], which gives reasonable assurance that the actions will also effectively protect any other member of the public. Using the representative person is a conservative approach: No member of the public is expected to receive a dose during an actual emergency close to that calculated for the representative person for the conditions described in the scenarios.

The representative person (which replaces the concept of 'critical group') does not represent any specific person from a particular age group; it is a theoretical construct defined by a combination of dosimetric and scenario factors (e.g. breathing and ingestion rates) that will result in the highest dose (effective or organ) reasonably expected to be received by any member of the public. It aggregates the dose models for the internal and external exposure of ICRP reference persons of different age groups, together with relevant exposure scenario, providing the highest dose estimate for particular pathways. Depending on the type of the exposure characteristic, e.g. effective dose or organ dose, the different sets of dose models have to be aggregated to assess the exposure of the representative person, as described in Table 10.

The scenarios used for the calculation of the OILs provided in this publication are described in Table 11. For a severe release of radioactive material from an LWR or its spent fuel the total effective dose to the representative person and the equivalent dose to its fetus[31] will be controlling for the 'ground', 'food pre-analysis', 'skin' and 'food post-analysis' scenarios. For the 'thyroid scenario', it will be the equivalent dose to the thyroid of the representative person. The exposure pathways for each exposure scenario and the associated parameters of the effective dose to the representative person and its fetus are described in Table 12 to Table 16. The figures shown in black represent the controlling member of the public for the corresponding exposure pathway and scenario, while the figures in grey indicate that the member of the public is not controlling for the exposure scenario (but was still considered).

For the 'ground', 'food pre-analysis', 'skin' and 'food post-analysis' scenarios, the exposure starts from deposition of radioactive material (on the ground or skin). The contribution from the plume (cloud shine and inhalation) is not considered in the OIL calculations, since the response actions to protect the public from these exposure pathways needs to be triggered by the emergency classification system to be effective and not by monitoring results (as discussed in Ref. [4]).

The 1-year-old infant, 10-year-old child and the adult (> 17 a) were used to represent the three age categories recommended in Ref. [53]. In this publication, the term 'fetus' encompasses both the embryo and the fetus.

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[31] Keeping the equivalent dose to the fetus from intake below the generic criteria will ensure that the dose to other organs will also stay below the generic criteria. The equivalent dose to the fetus is defined as the highest equivalent dose to any organ in the fetus during the period of in utero development.

TABLE 10. DOSIMETRIC CHARACTERISTICS OF THE REPRESENTATIVE PERSON FOR THE CONSIDERED EXPOSURE PATHWAYS

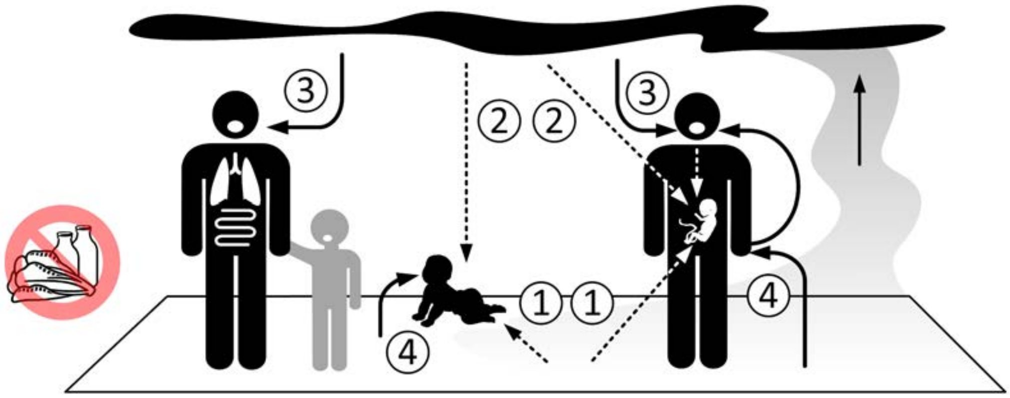
Dose to the representative person	Ingestion	Inadvertent ingestion	External exposure	Inhalation	Radioactive iodine in the thyroid
Effective dose	Infant or adult[a]	Infant	Infant	Adult	—
Equivalent dose to the fetus	Adult[b]	Adult[b]	Adult[b]	Adult[b]	—
Equivalent dose to the thyroid	Infant[c]	Infant[c]	—	Adult[c]	Infant
RBE weighted absorbed dose to the skin dermis	—	—	Age independent	—	—

[a] Depending on the radionuclide.
[b] Pregnant woman.
[c] Not directly considered in the calculation of the OILs given in this publication.

TABLE 11. DESCRIPTION OF THE EXPOSURE SCENARIOS CONSIDERED IN THE CALCULATION OF THE OILs

OIL	Exposure scenarios		Exposure pathways
	Name	Summary	
$OIL1_{\gamma}$ $OIL2_{\gamma}$	Ground	It is assumed that all members of the public live normally for 7 days (for the calculation of $OIL1_{\gamma}$) and for 1 year (for the calculation of $OIL2_{\gamma}$) in an area affected by a release of radioactive material, carrying out normal activities (such as children playing on the ground and people being inside normal structures part of the time). However, it is assumed that the public is not consuming food, milk or drinking water from the affected area, because restrictions have been implemented on the basis of the emergency classification (as described in Ref. [4]).	Table 12
$OIL3_{\gamma}$	Food pre-analysis	It is assumed that the public will consume local food and milk (e.g. from their garden or cow) that is directly affected by the deposition of radioactive material before entering the food distribution system and thus before it is sampled or controlled in any way. It is assumed that (a) there will be no reduction in the concentration of radioactive materials due to preparation of the food (e.g. peeling, washing) before consumption; (b) the affected food and milk is consumed over 1 year; and (c) 50% of the food and milk is affected.	Table 13
$OIL4_{\gamma}$ $OIL4_{\beta}$	Skin	It is assumed that the person has radioactive material on the skin (including the face and hands), and that no actions are taken to remove the material from the skin (e.g. washing) or to reduce inadvertent ingestion (e.g. keeping the hand away from the mouth).	Table 14
OIL7	Food post-analysis	It is assumed that the food, milk or drinking water in the food supply is affected, that samples are taken and that the activity concentrations of the marker radionuclides I-131 and Cs-137 in the food are known (e.g. by laboratory analysis). It is assumed that (a) 50% of the diet is affected; (b) it is consumed over 1 year; and (c) there is no reduction due to processing or preparation.	Table 15
$OIL8_{\gamma}$	Thyroid	It is assumed that the person has radioactive iodine in the thyroid resulting from inhalation or ingestion.	Table 16

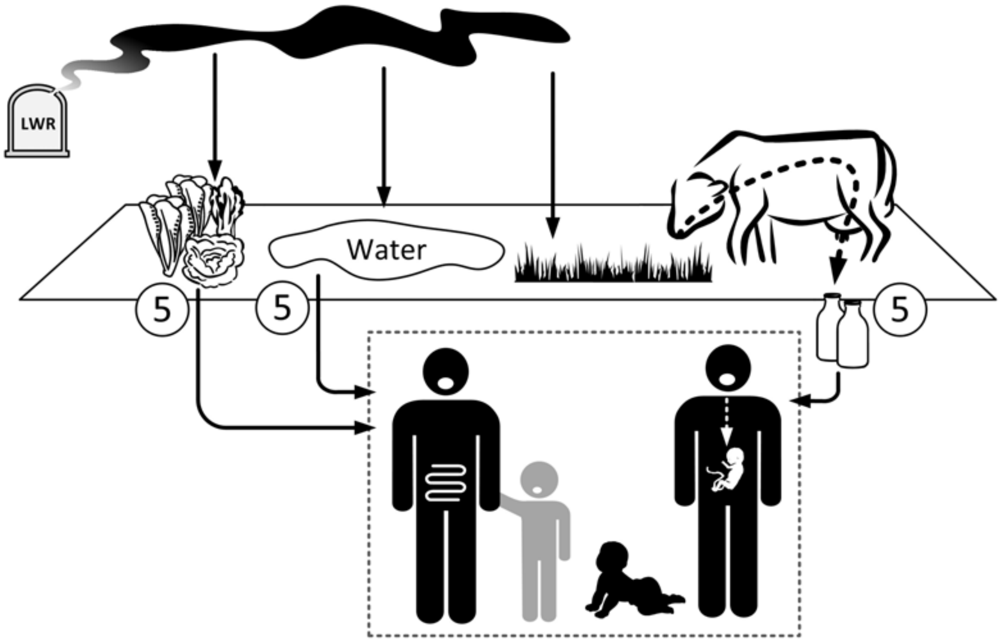
TABLE 12. EXPOSURE PATHWAYS AND PARAMETERS FOR THE ‘GROUND’ SCENARIO



	Exposure pathways	Effective dose to the representative person	Equivalent dose to the fetus
1	External exposure from radioactive material deposited on the ground (i.e. ground shine)	Effective dose to the infant	Equivalent dose to the fetus of the pregnant woman from external exposure to ground shine
2	External exposure from resuspended[a] radioactive material (i.e. air shine)	Effective dose to the infant	Equivalent dose to the fetus of the pregnant woman from external exposure to air shine
3	Inhalation of resuspended[a] radioactive material	Breathing rate for an adult performing light activity combined with the committed effective dose to the adult	Breathing rate for an adult (pregnant woman) performing light activity combined with the committed equivalent dose to the fetus from inhalation by the pregnant woman
4	Inadvertent ingestion of soil (e.g. from dirt on the hands)	Inadvertent ingestion rates by an infant during normal activity combined with the committed effective dose to the infant[b]	Inadvertent ingestion rates of dust and soil by an adult (pregnant woman) during normal activity combined with the committed equivalent dose to the fetus from ingestion by the pregnant woman

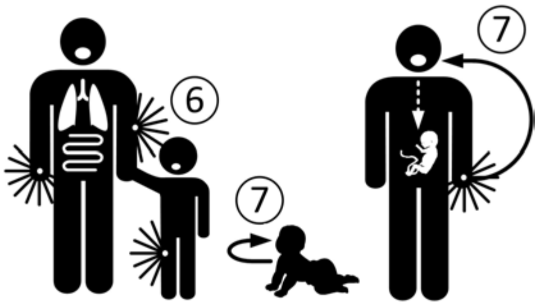
[a] Resuspended due to natural processes.
[b] For this scenario, the combination of infant ingestion rates and dose conversion factors is controlling for all radionuclides.

TABLE 13. EXPOSURE PATHWAYS AND PARAMETERS FOR THE 'FOOD PRE-ANALYSIS' SCENARIO



	Exposure pathways	Effective dose to the representative person	Equivalent dose to the fetus
5	Ingestion of radioactive material in local produce from the affected area (e.g. garden vegetables or milk from grazing animals) before it enters the distribution system	For each radionuclide, from the following combinations, the one resulting in the highest dose is used: ▪ Infant consumption rates combined with the committed effective dose to the infant; ▪ Adult consumption rates combined with the committed effective dose to the adult.	Adult (i.e. pregnant woman) consumption rates combined with the committed equivalent dose to the fetus from ingestion by the pregnant woman

TABLE 14. EXPOSURE PATHWAYS AND PARAMETERS FOR THE ‘SKIN’ SCENARIO

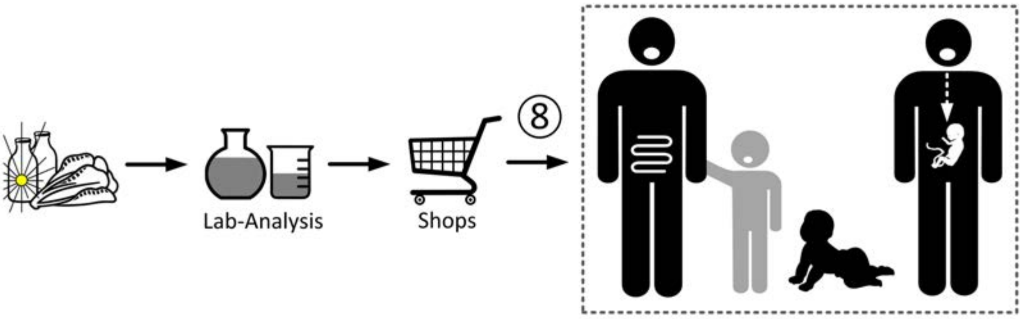


	Exposure pathways	Effective dose to the representative person	Equivalent dose to the fetus
6	External exposure to the dermis from radioactive material on the skin	RBE weighted absorbed dose to the skin[a]	Not applicable
7	Inadvertent ingestion of radioactive material on the skin	Inadvertent ingestion rates by an infant combined with the committed effective dose to the infant[b]	Inadvertent ingestion rates of material on the skin by an adult (pregnant woman) combined with the committed equivalent dose to the fetus from inadvertent ingestion by the pregnant woman

[a] The external exposure to the dermis from radioactive material deposited on the skin is considered to be age independent.

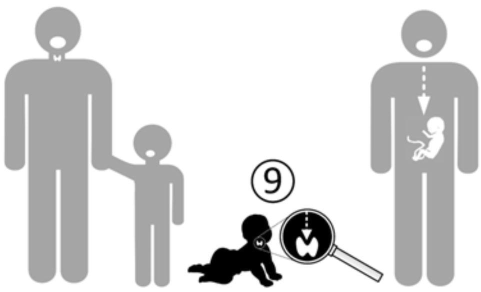
[b] For this scenario, the combination of infant ingestion rates and dose conversion factors is controlling for all radionuclides.

TABLE 15. EXPOSURE PATHWAYS AND PARAMETERS FOR THE 'FOOD POST-ANALYSIS' SCENARIO



	Exposure pathways	Effective dose to the representative person	Equivalent dose to the fetus
8	Ingestion of radioactive material in food, milk or drinking water from the distribution system	For each radionuclide, from the following combinations, the one resulting in the highest dose is used: ▪ Infant consumption rates combined with the committed effective dose to the infant; ▪ Adult consumption rates combined with the committed effective dose to the adult.	Adult (i.e. pregnant woman) consumption rates combined with the committed equivalent dose to the fetus from ingestion by the pregnant woman

TABLE 16. EXPOSURE PATHWAYS AND PARAMETERS FOR THE 'THYROID' SCENARIO



	Exposure pathways	Equivalent dose to the thyroid
9	Exposure of the thyroid from radioactive iodine in the thyroid	The committed equivalent dose to the thyroid of an infant is used

3.5. BEHAVIOUR OF THE RADIONUCLIDES

This section considers the behaviour of the radionuclides (after being released into the environment) by deriving a series of factors used in the OIL calculations. Only the most relevant factors (i.e. those that could have a significant impact on the final default OIL value) are provided. This section is not a comprehensive description of radionuclide behaviour. Depending on the specific circumstances, other behaviours may need to be considered.

3.5.1. Ground weathering and decay

The reduction in the external exposure rate from deposited radioactive material (ground shine) by ground weathering and decay is considered in the calculation of $OIL1_\gamma$ and $OIL2_\gamma$ by making use of $WI_{G,i}(\Delta)$ [s], which is the time integrated external ground dose rate weathering factor, for radionuclide i, integrated over the exposure period Δ (i.e. the period of time a person is living in the affected area). The values are given for the exposure periods of 7 d and 1 a in Table 17 and are determined by Eq. (4):

$$WI_{G,i}(\Delta) = \int_0^{\Delta} W_G(\tau) \times e^{-\lambda_i \times \tau} \times d\tau \qquad (4)$$

where:

- τ [s] is the time after the deposition.
- λ_i [s^{-1}] is the decay constant for radionuclide i. The values are given in Table 6.
- $W_G(\tau)$ [unitless] is the external ground dose rate weathering factor at time τ after deposition. It is displayed in Fig. 5, and determined by Eq. (5), which is obtained from Ref. [41]:
- The use of newer models, such as those provided in Section 4.5 of Ref. [54], have little impact considering the exposure periods discussed here (i.e. 7 days and 1 year).

$$W_G(\tau) = 0.63 \times e^{(-\beta_1 \times \tau)} + 0.37 \times e^{(-\beta_2 \times \tau)} \qquad (5)$$

where:

- β_1 = 1.13 a^{-1} = 3.59E-08 s^{-1} and β_2 = 7.48E-03 a^{-1} = 2.37E-10 s^{-1}

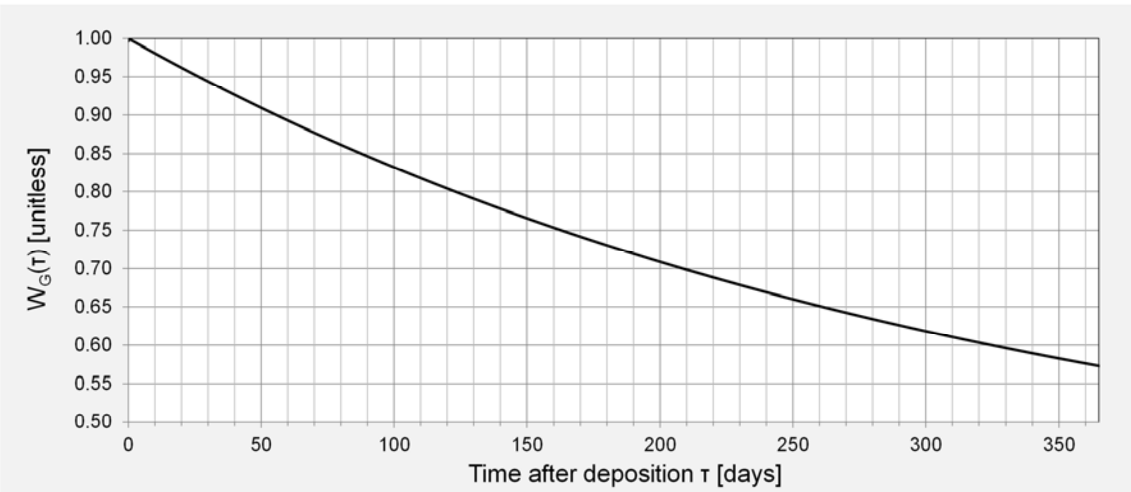


FIG. 5. External ground dose rate weathering factor $W_G(\tau)$ [unitless].

TABLE 17. TIME INTEGRATED EXTERNAL GROUND DOSE RATE WEATHERING FACTOR AND TIME INTEGRATED TRANSFER FACTORS FROM THE GROUND TO THE AIR BY NATURAL RESUSPENSION

Radionuclide	$WI_{G,i}(7d)$[a] [s]	$WI_{G,i}(1a)$[a] [s]	$TI_{grd\rightarrow air,i}(7d)$[b] [s/m]	$TI_{grd\rightarrow air,i}(1a)$[b] [s/m]
Rb-86	5.3E+05	2.2E+06	2.4E+00	3.2E+00
Sr-89	5.7E+05	5.5E+06	2.5E+00	4.1E+00
Sr-90+	6.0E+05	2.3E+07	2.5E+00	6.0E+00
Sr-91	5.0E+04	5.0E+04	4.7E-01	4.7E-01
Y-91	5.8E+05	6.3E+06	2.5E+00	4.2E+00
Zr-95+	5.8E+05	6.8E+06	2.5E+00	4.3E+00
Zr-97+	8.7E+04	8.7E+04	7.4E-01	7.4E-01
Mo-99+	2.8E+05	3.4E+05	1.6E+00	1.7E+00
Ru-103+	5.7E+05	4.4E+06	2.4E+00	3.9E+00
Ru-105	2.3E+04	2.3E+04	2.3E-01	2.3E-01
Ru-106+	6.0E+05	1.8E+07	2.5E+00	5.5E+00
Rh-105	1.8E+05	1.8E+05	1.2E+00	1.2E+00
Te-127m+	5.9E+05	1.0E+07	2.5E+00	4.7E+00
Te-127	4.9E+04	4.9E+04	4.6E-01	4.6E-01
Te-129m+	5.6E+05	3.8E+06	2.4E+00	3.7E+00
Te-131m	1.5E+05	1.6E+05	1.1E+00	1.1E+00
Te-132+	3.1E+05	4.0E+05	1.7E+00	1.8E+00
I-131	4.5E+05	9.8E+05	2.1E+00	2.5E+00
I-133	1.1E+05	1.1E+05	8.6E-01	8.6E-01
I-134	4.5E+03	4.5E+03	4.5E-02	4.5E-02
I-135	3.4E+04	3.4E+04	3.4E-01	3.4E-01
Cs-134	6.0E+05	2.0E+07	2.5E+00	5.7E+00
Cs-136	5.0E+05	1.6E+06	2.3E+00	2.9E+00
Cs-137+	6.0E+05	2.3E+07	2.5E+00	6.0E+00
Ba-140+	5.0E+05	1.5E+06	2.3E+00	2.9E+00
Ce-141	5.6E+05	3.7E+06	2.4E+00	3.7E+00
Ce-143	1.7E+05	1.7E+05	1.2E+00	1.2E+00
Ce-144+	6.0E+05	1.6E+07	2.5E+00	5.4E+00
Pr-143	5.1E+05	1.6E+06	2.3E+00	3.0E+00
Nd-147	4.9E+05	1.3E+06	2.2E+00	2.8E+00
Np-239	2.6E+05	2.9E+05	1.5E+00	1.5E+00
Pu-238	6.0E+05	2.3E+07	2.5E+00	6.0E+00
Pu-239	6.0E+05	2.4E+07	2.5E+00	6.0E+00
Pu-240	6.0E+05	2.4E+07	2.5E+00	6.0E+00
Pu-241	6.0E+05	2.3E+07	2.5E+00	6.0E+00
Am-241	6.0E+05	2.3E+07	2.5E+00	6.0E+00
Cm-242	5.9E+05	1.3E+07	2.5E+00	5.0E+00
Cm-244	6.0E+05	2.3E+07	2.5E+00	6.0E+00

[a] $WI_{G,i}(\Delta)$ is calculated based on Eq. (4).
[b] $TI_{grd\rightarrow air,i}(\Delta)$ is calculated based on Eq. (6).
\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

3.5.2. Resuspension and decay

The influence of decay and resuspension of radioactive material from the ground to the air (by wind or other natural processes) is considered in the calculation of $OIL1_\gamma$ and $OIL2_\gamma$ by making use of $TI_{grd\rightarrow air,i}(\Delta)$ [s/m], which is the time integrated transfer factor of radionuclide i from the ground to the air, integrated over the exposure period Δ (i.e. the period of time living in the affected area). The values are given for an exposure period of 7 d and 1 a in Table 17 and are determined by Eq. (6):

$$TI_{grd\rightarrow air,i}(\Delta) = \int_0^{\Delta} T_{grd\rightarrow air}(\tau) \times e^{-\lambda_i \times \tau} \times d\tau \qquad (6)^{32}$$

where:

- τ [s] is the time after deposition.
- λ_i [s^{-1}] is the decay constant for radionuclide i. The values are given in Table 6.
- $T_{grd\rightarrow air}(\tau)$ [m^{-1}] is the transfer factor from the ground to the air (by wind or other natural processes) at time τ after deposition, also called resuspension factor. It is displayed in Fig. 6, determined by Eq. (7) and is consistent with Refs [55, 57, 58]. The use of newer models like those from Ref. [56] has little impact on the OIL values for LWRs.[33,34]

$$T_{grd\rightarrow air}(\tau) = \begin{cases} T_{grd\rightarrow air}(\tau_0) & \text{for } 0 < \tau \leq \tau_0 \\ T_{grd\rightarrow air}(\tau_0) \times \dfrac{\tau_0}{\tau} + 10^{-9} & \text{for } \tau > \tau_0 \end{cases} \qquad (7)$$

where:

- τ_0 = 1 d = 86 400 s.
- $T_{grd\rightarrow air}(\tau_0) = 10^{-5}$ m^{-1} is the transfer factor from the ground to the air (by wind or other natural processes), at time τ_0. The default value was based on an examination of the results of Eq. (8) shown in Table 18 for different conditions. The default value was selected, because it would be conservative compared with most of those normally encountered by the public while living normally in an area. However, the inhalation and cloud shine doses from resuspended material are not significant contributors following a severe release of radioactive material from an LWR or its spent fuel.

$$T_{grd\rightarrow air}(\tau_0) \equiv \frac{\text{Concentration in the air}}{\text{Concentration on the ground}} \; \frac{[Bq/m^3]}{[Bq/m^2]} \qquad (8)$$

---

[32] The integral was solved numerically (by using a common mathematical computer program).
[33] For the exposure periods considered here (i.e. 7 days and 1 year).
[34] The model used here is initially conservative by around an order of magnitude when compared with those normally encountered by the public while living normally in an area.

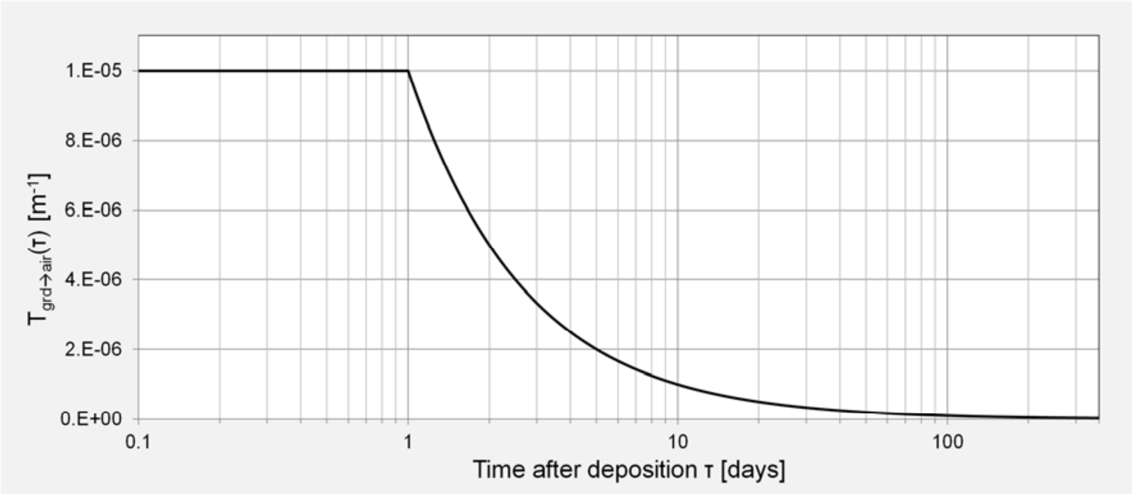


FIG. 6. Transfer factor from the ground to the air $T_{grd\to air}(\tau)$ $[m^{-1}]$, also called resuspension factor.

TABLE 18. TRANSFER FACTORS FROM THE GROUND TO THE AIR (ALSO CALLED RESUSPENSION FACTORS) FOR DIFFERENT REPRESENTATIVE CONDITIONS

Conditions	**$T_{grd\to air}(\tau_0)$[a] $[m^{-1}]$**
Wet — rain (minimum value)	1E-09
Normal conditions and rural conditions with light to moderate wind	1E-06
Arid and urban conditions (default value)	1E-05
Very dusty conditions (e.g. ploughing in dry conditions)	1E-04

[a] $T_{grd\to air}(\tau_0)$ is obtained from Refs [57, 58, 59].

3.5.3. Inadvertent ingestion from the ground and decay

The influence of decay and the transfer of radioactive material from the ground to the gastrointestinal (GI) tract by inadvertent ingestion is considered in the calculation of $OIL1_{\gamma}$ and $OIL2_{\gamma}$ by making use of $TI_{grd\to GI,i}(\Delta,g)$ $[m^2]$, which is the time integrated transfer factor of radionuclide i from the ground to the GI tract by inadvertent ingestion for an individual in age group g (i.e. infants for the representative person and adults for the fetal exposure), integrated over the exposure period Δ (i.e. period of time living in the affected area).

Since no model for the weathering effects on inadvertent ingestion was found, it was assumed that the material available for inadvertent ingestion is reduced in a similar way as for resuspension (as discussed in Eq. (7)), which is supported by the following considerations:

- As the material migrates into the soil, the transfer of radioactivity from the ground to the air or to the GI tract by inadvertent ingestion is reduced by the same factors: (a) dilution by unaffected soil; and (b) movement of the material beyond the depth that is likely to be resuspended or inadvertently ingested. The use of Eqs (9), (10) and (11) to model this

reduction with time is consistent with the traditional assumption that, on average, deposited material moves to a depth of about 1 cm within the first month [55][35] and thus below a depth available for resuspension or inadvertent ingestion of 1 mm (see Eq. (11)). It is also consistent with data from the Chernobyl accident indicating that, after a few weeks, it is not uncommon for downward migration of the activity in the soil to result in a relaxation length[36] of 1 cm, and, after a few months, to result in a relaxation length of 3 cm, before the downward migration begins to slow down [60].
- For material deposited on pavement, the material available for resuspension or inadvertent ingestion is reduced rapidly by either natural processes (e.g. wind or rain) or other processes (e.g. road traffic) or becomes fixed [61].

The values for $TI_{grd\rightarrow GI,i}(\Delta,g)$ [m^2] are given for an exposure period of 7 d and 1 a and for the infant and adult in Table 19 and are determined by Eq. (9):

$$TI_{grd\rightarrow GI,i}(\Delta,g) = \int_0^{\Delta} T_{grd\rightarrow GI}(\tau,g) \times e^{-\lambda_i \times \tau} \times d\tau \qquad (9)^{37}$$

where:

- τ [s] is the time after deposition.
- λ_i [s^{-1}] is the decay constant for radionuclide i. The values are given in Table 6.
- $T_{grd\rightarrow GI}(\tau,g)$ [m^2/s] is the transfer factor from the ground to the GI tract by inadvertent ingestion, for an individual in age group g (i.e. the infant for the representative person and the adult for the fetus), at time τ after deposition. It is displayed in Fig. 7 and determined by Eq. (10):

$$T_{grd\rightarrow GI}(\tau,g) = \begin{cases} T_{grd\rightarrow GI}(\tau_0,g) & \text{for } 0 < \tau \leq \tau_0 \\ T_{grd\rightarrow GI}(\tau_0,g) \times \dfrac{\tau_0}{\tau} & \text{for } \tau > \tau_0 \end{cases} \qquad (10)$$

where:

  - τ_0 = 1 d = 86 400 s (it is normally provided in days).
  - $T_{grd\rightarrow GI}(\tau_0,g)$ [m^2/s] is the transfer factor from the ground to the GI tract by inadvertent ingestion (i.e. the infant for the representative person and the adult for the fetus), for an individual in age group g, at time τ_0. The values are given below and determined by Eq. (11):
    - 7.2E-10 m^2/s for intake by the infant (considered for the representative person);
    - 3.6E-10 m^2/s for intake by adults (considered for the fetal exposure).

---

[35] Inadvertent ingestion of material at depths larger than those assumed would not greatly affect the $T_{grd\rightarrow GI}(\tau,g)$ value, because this would be offset by the lower activity concentration of the material ingested due to dilution (see Eq. (11)).

[36] The relaxation length is the thickness of a shielding material (e.g. soil) that will reduce the intensity of the radiation (e.g. ground shine) to 1/e (37%) of its original.

[37] The integral was solved numerically (by using a common mathematical computer program).

$$T_{grd \rightarrow GI}(\tau_0, g) = \frac{Q_{soil}(g)}{\rho_{dep} \times d_{inadv-ing} \times F_{soil,inadv-ing}(\tau_0)} \quad (11)$$

where:

- ρ_{dep} = 1600 mg/cm^3 = 1600 kg/m^3 is the density of the deposition. It is obtained from Ref. [62].
- $d_{inadv-ing}$ = 1 mm = 0.001 m is the depth available for inadvertent ingestion. It is obtained from Ref. [62].
- $F_{soil,inadv-ing}(\tau_0)$ = 1 [unitless] is the fraction of the deposited material available for ingestion (e.g. material that is within the $d_{inadv-ing}$ or not adhered to a surface) at time τ_0.
- $Q_{soil}(g)$ [kg/s] is the inadvertent ingestion rate of ground deposition for an individual in age group g living under normal conditions. The default values are given below, obtained from Ref. [63], and are consistent with findings of studies for dust and soil ingestion under normal circumstances, such as infants playing outside or being in camp grounds[38] [62]:
  - 100 mg/d = 1.2E-09 kg/s for intake by infants (considered for the representative person);
  - 50 mg/d = 5.8E-10 kg/s for intake by adults (considered for the fetal exposure).

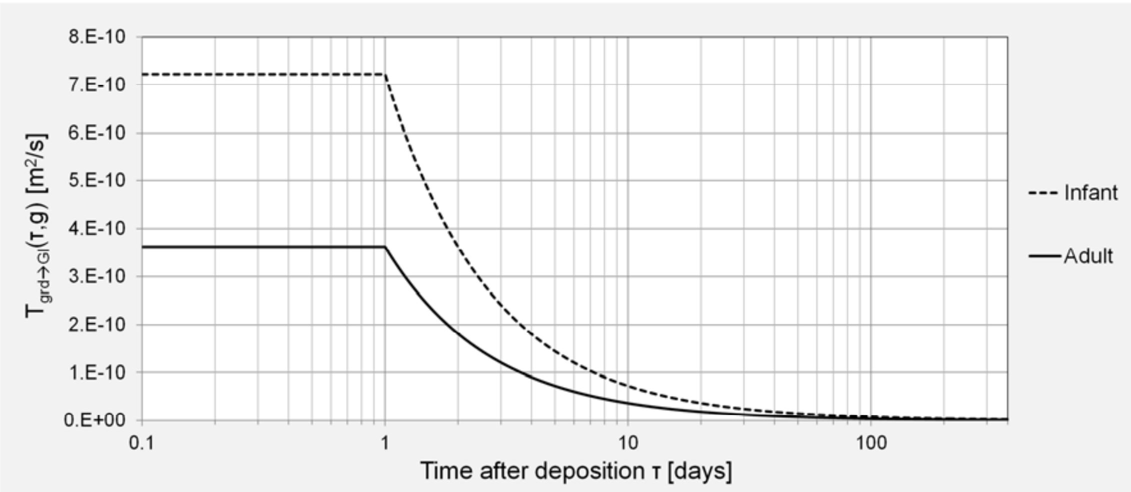


FIG. 7. Transfer factors from the ground to the GI tract by inadvertent ingestion, $T_{grd \rightarrow GI}(\tau,g)$ [m^2/s].

[38] Soil-pica, which is the recurrent ingestion of unusually high amounts of soil (i.e. around 1 to 5 g/day), and usually involves the consumption of the top 5 to 8 cm of surface soils [63], would not affect the default $T_{grd \rightarrow GI}(\tau_0,g)$ value, because the higher intake rates are offset by the larger inadvertent ingestion depth $d_{inadv-ing}$ of 5 to 8 cm.

TABLE 19. TIME INTEGRATED TRANSFER FACTORS FROM THE GROUND TO THE GI TRACT BY INADVERTENT INGESTION

Radionuclide	$TI_{grd \rightarrow GI,i}$(7d, infant) [a] [m²]	$TI_{grd \rightarrow GI,i}$(7d, adult) [a] [m²]	$TI_{grd \rightarrow GI,i}$(1a, infant) [a] [m²]	$TI_{grd \rightarrow GI,i}$(1a, adult) [a] [m²]
Rb-86	1.7E-04	8.5E-05	2.3E-04	1.2E-04
Sr-89	1.8E-04	8.9E-05	2.9E-04	1.5E-04
Sr-90+	1.8E-04	9.2E-05	4.3E-04	2.1E-04
Sr-91	3.4E-05	1.7E-05	3.4E-05	1.7E-05
Y-91	1.8E-04	9.0E-05	3.0E-04	1.5E-04
Zr-95+	1.8E-04	9.0E-05	3.1E-04	1.5E-04
Zr-97+	5.4E-05	2.7E-05	5.4E-05	2.7E-05
Mo-99+	1.2E-04	5.8E-05	1.2E-04	6.0E-05
Ru-103+	1.8E-04	8.9E-05	2.8E-04	1.4E-04
Ru-105	1.7E-05	8.3E-06	1.7E-05	8.3E-06
Ru-106+	1.8E-04	9.2E-05	3.9E-04	2.0E-04
Rh-105	8.7E-05	4.3E-05	8.7E-05	4.4E-05
Te-127m+	1.8E-04	9.1E-05	3.4E-04	1.7E-04
Te-127	3.3E-05	1.7E-05	3.3E-05	1.7E-05
Te-129m+	1.8E-04	8.8E-05	2.7E-04	1.3E-04
Te-131m	7.9E-05	3.9E-05	7.9E-05	4.0E-05
Te-132+	1.2E-04	6.2E-05	1.3E-04	6.5E-05
I-131	1.5E-04	7.7E-05	1.8E-04	9.1E-05
I-133	6.2E-05	3.1E-05	6.2E-05	3.1E-05
I-134	3.3E-06	1.6E-06	3.3E-06	1.6E-06
I-135	2.4E-05	1.2E-05	2.4E-05	1.2E-05
Cs-134	1.8E-04	9.2E-05	4.1E-04	2.1E-04
Cs-136	1.6E-04	8.2E-05	2.1E-04	1.1E-04
Cs-137+	1.8E-04	9.2E-05	4.3E-04	2.1E-04
Ba-140+	1.6E-04	8.2E-05	2.1E-04	1.1E-04
Ce-141	1.8E-04	8.8E-05	2.7E-04	1.3E-04
Ce-143	8.3E-05	4.2E-05	8.4E-05	4.2E-05
Ce-144+	1.8E-04	9.2E-05	3.9E-04	1.9E-04
Pr-143	1.7E-04	8.3E-05	2.1E-04	1.1E-04
Nd-147	1.6E-04	8.1E-05	2.0E-04	1.0E-04
Np-239	1.1E-04	5.4E-05	1.1E-04	5.6E-05
Pu-238	1.8E-04	9.2E-05	4.3E-04	2.2E-04
Pu-239	1.8E-04	9.2E-05	4.3E-04	2.2E-04
Pu-240	1.8E-04	9.2E-05	4.3E-04	2.2E-04
Pu-241	1.8E-04	9.2E-05	4.3E-04	2.1E-04
Am-241	1.8E-04	9.2E-05	4.3E-04	2.2E-04
Cm-242	1.8E-04	9.1E-05	3.6E-04	1.8E-04
Cm-244	1.8E-04	9.2E-05	4.3E-04	2.1E-04

[a] $TI_{grd \rightarrow GI,i}(\Delta,g)$ is calculated based on Eq. (9).

\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

3.5.4. Transfer from the ground to vegetables and pasture

The fraction of deposited activity intercepted by the edible portion of vegetation, per unit mass, as the result of deposition processes is considered in the calculation of $OIL3_{\gamma}$ by making use of mass interception factors. For pasture forage, conventionally the dry weight is used, while for fresh vegetables, the wet weight is used:

- Φ_1 = 3 m^2/kg is the mass interception factor for pasture grass in dry weight, i.e. the ratio between the activity concentration on the plant [Bq/kg] and the unit ground surface activity on the terrestrial surface [Bq/m^2] (soil plus vegetation). It is obtained from Table VII of Ref. [64].
- Φ_2 = 0.3 m^2/kg is the mass interception factor for leafy vegetables (fresh or wet weight), i.e. the ratio between the activity concentration on the plant [Bq/kg] and the unit ground surface activity on the terrestrial surface [Bq/m^2] (soil plus vegetation). It is obtained from Table VII of Ref. [64].

3.5.5. Removal from vegetation by weathering and decay

The reduction of the gross activity from vegetation due to natural processes (i.e. weathering, but not intentional washing) is considered in the calculation of $OIL3_{\gamma}$ by making use of $\Delta_{eff,OIL3,i}$ [s], which is the effective availability period for radionuclide i for ingestion in the 'food pre-analysis' scenario. The values are given in Table 20 and are determined by Eq. (12):

$$\Delta_{eff,OIL3,i} = \int_0^{\Delta_{available-ing}} e^{-(\lambda_{w-vegetation}+\lambda_i)\times t} dt = \frac{1 - e^{-(\lambda_{w-vegetation}+\lambda_i)\times\Delta_{available-ing}}}{\lambda_{w-vegetation} + \lambda_i} \quad (12)$$

where:

- $\Delta_{available-ing}$ = 365 d = 3.15E+07 s is the period of time that the affected food or forage is available for consumption. This is the exposure period of the GC(Ingestion,e_{ing},1a).
- λ_i [s^{-1}] is the decay constant for radionuclide i. The values are given in Table 6.
- $\lambda_{w-vegetation}$ [s^{-1}] is the removal constant from vegetation due to weathering. It is determined by Eq. (13):

$$\lambda_{w-vegetation} = \frac{\ln(2)}{T_{1/2,w-vegetation}} \quad (13)$$

  where:

  - $T_{1/2,w-vegetation}$ = 14 d = 1.2E+06 s is the half-life for removal of surface deposition from vegetation due to weathering. It is obtained from Ref. [64].

TABLE 20. EFFECTIVE AVAILABILITY PERIODS

Radionuclide	$\Delta_{eff,OIL3,i}$ [a] [s]	$\Delta_{eff,OIL4\text{-}Urgent,i}$ [b] [s]	$\Delta_{eff,OIL4\text{-}Acute,i}$ [c] [s]	$\Delta_{eff,OIL7,i}$ [d] [s]
Rb-86	1.0E+06	7.4E+04	2.8E+04	2.3E+06
Sr-89	1.4E+06	7.5E+04	2.9E+04	6.3E+06
Sr-90+	1.7E+06	7.6E+04	2.9E+04	3.1E+07
Sr-91	4.9E+04	3.0E+04	2.1E+04	5.0E+04
Y-91	1.4E+06	7.6E+04	2.9E+04	7.2E+06
Zr-95+	1.4E+06	7.6E+04	2.9E+04	7.8E+06
Zr-97+	8.3E+04	4.1E+04	2.4E+04	8.7E+04
Mo-99+	2.9E+05	6.2E+04	2.7E+04	3.4E+05
Ru-103+	1.3E+06	7.5E+04	2.9E+04	4.9E+06
Ru-105	2.3E+04	1.8E+04	1.5E+04	2.3E+04
Ru-106+	1.7E+06	7.6E+04	2.9E+04	2.3E+07
Rh-105	1.7E+05	5.4E+04	2.6E+04	1.8E+05
Te-127m+	1.5E+06	7.6E+04	2.9E+04	1.2E+07
Te-127	4.7E+04	3.0E+04	2.1E+04	4.9E+04
Te-129m+	1.2E+06	7.5E+04	2.9E+04	4.2E+06
Te-131m	1.4E+05	5.1E+04	2.6E+04	1.6E+05
Te-132+	3.2E+05	6.4E+04	2.8E+04	4.0E+05
I-131	6.4E+05	7.1E+04	2.8E+04	1.0E+06
I-133	1.0E+05	4.5E+04	2.5E+04	1.1E+05
I-134	4.5E+03	4.3E+03	4.3E+03	4.5E+03
I-135	3.3E+04	2.4E+04	1.8E+04	3.4E+04
Cs-134	1.7E+06	7.6E+04	2.9E+04	2.7E+07
Cs-136	8.5E+05	7.3E+04	2.8E+04	1.6E+06
Cs-137+	1.7E+06	7.6E+04	2.9E+04	3.1E+07
Ba-140+	8.3E+05	7.3E+04	2.8E+04	1.6E+06
Ce-141	1.2E+06	7.5E+04	2.9E+04	4.1E+06
Ce-143	1.6E+05	5.3E+04	2.6E+04	1.7E+05
Ce-144+	1.7E+06	7.6E+04	2.9E+04	2.1E+07
Pr-143	8.6E+05	7.3E+04	2.8E+04	1.7E+06
Nd-147	7.7E+05	7.2E+04	2.8E+04	1.4E+06
Np-239	2.5E+05	6.1E+04	2.7E+04	2.9E+05
Pu-238	1.7E+06	7.6E+04	2.9E+04	3.1E+07
Pu-239	1.7E+06	7.6E+04	2.9E+04	3.2E+07
Pu-240	1.7E+06	7.6E+04	2.9E+04	3.2E+07
Pu-241	1.7E+06	7.6E+04	2.9E+04	3.1E+07
Am-241	1.7E+06	7.6E+04	2.9E+04	3.2E+07
Cm-242	1.6E+06	7.6E+04	2.9E+04	1.6E+07
Cm-244	1.7E+06	7.6E+04	2.9E+04	3.1E+07

[a] $\Delta_{eff,OIL3,i}$ is calculated based on Eq. (12).
[b] $\Delta_{eff,OIL4\text{-}Urgent,i}$ is calculated based on Eq. (16).
[c] $\Delta_{eff,OIL4\text{-}Acute,i}$ is calculated based on Eq. (18).
[d] $\Delta_{eff,OIL7,i}$ is calculated based on Eq. (19).
\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

3.5.6. Transfer from cow's feed to cow's milk

The reduction in the gross activity from feed to cow's milk is considered in the calculation of $OIL3_\gamma$ by making use of the transfer factor $T_{feed\to cow\text{-}milk,i}$ [s/L] ([(Bq/L)/(Bq/s)] = [s/L]). The values are given in Table 21.

3.5.7. Reduction due to processing and delay before consumption

The reduction in the gross activity due to the period of time between deposition and consumption is considered in the calculation of $OIL3_\gamma$ by making use of $F_{consumption,i}$ [unitless], which is the fraction of the radionuclide i remaining at the time of human consumption. The values are given in Table 22 and determined by Eq. (14):

$$F_{consumption,i} = e^{-\lambda_i \times \Delta_{dep\to consumption}} \times F_{prep} \tag{14}$$

where:

- λ_i [s^{-1}] is the decay constant for radionuclide i. The values are given in Table 6.
- $\Delta_{dep\to consumption}$ = 1 d = 86 400 s is the period of time assumed between deposition and consumption.
- F_{prep} = 1 [unitless] is the fraction of the radioactive material remaining for ingestion after preparations. It assumes no reduction due to normal preparations/processing (e.g. washing and cooking), which, in some cases, substantially reduces the concentration of radionuclides in the food [65].

3.5.8. Transfer from the skin to the GI tract by inadvertent ingestion

The transfer of radioactive material from the skin to the GI tract is considered in the calculation of $OIL4_\gamma$ and $OIL4_\beta$ by making use of $T_{skin\to GI}(g)$ [m^2/s], which is the transfer factor from the skin to the GI tract due to inadvertent ingestion for an individual in age group g (i.e. the infant for the representative person and the adult for the fetus). It is considered a reasonable upper limit, because it assumes that no actions are taken to limit inadvertent ingestion (e.g. washing hands). The default values are given below and determined by Eq. (15):

- 3.2E-08 m^2/s for intake by adults (considered for the fetal exposure);
- 6.4E-08 m^2/s for intake by infants (considered for the representative person).

$$T_{skin\to GI}(g) = \frac{Q_{soil}(g)}{L_{hand}} \tag{15}$$

where:

- $Q_{soil}(g)$ [kg/s] is the inadvertent ingestion rate of ground deposition for an individual in age group g living under normal conditions. Its basis is described in Section 3.5.3., which also provides the default values.
- L_{hand} = 1.8 mg/cm^2 = 0.018 kg/m^2 is the amount of soil loaded on the hand of the maximally exposed individual (e.g. children playing outdoors). It is obtained from Ref. [62].

TABLE 21. TRANSFER FACTOR OF RADIONUCLIDE i FROM FEED TO THE MILK OF THE COW

Radionuclide	$T_{feed\rightarrow cow\text{-}milk,i}$ [a] [d/L]	$T_{feed\rightarrow cow\text{-}milk,i}$ [a] [s/L]	Reference[b]
Rb-86	1.0E-01	8.6E+03	[64]
Sr-89	1.3E-03	1.1E+02	[65]
Sr-90+	1.3E-03	1.1E+02	[65]
Sr-91	1.3E-03	1.1E+02	[65]
Y-91	6.0E-05	5.2E+00	[64]
Zr-95+	3.6E-06	3.1E-01	[65]
Zr-97+	3.6E-06	3.1E-01	[65]
Mo-99+	1.1E-03	9.5E+01	[65]
Ru-103+	9.4E-06	8.1E-01	[65]
Ru-105	9.4E-06	8.1E-01	[65]
Ru-106+	9.4E-06	8.1E-01	[65]
Rh-105	5.0E-04	4.3E+01	[64]
Te-127m+	3.4E-04	2.9E+01	[65]
Te-127	3.4E-04	2.9E+01	[65]
Te-129m+	3.4E-04	2.9E+01	[65]
Te-131m	3.4E-04	2.9E+01	[65]
Te-132+	3.4E-04	2.9E+01	[65]
I-131	5.4E-03	4.7E+02	[65]
I-133	5.4E-03	4.7E+02	[65]
I-134	5.4E-03	4.7E+02	[65]
I-135	5.4E-03	4.7E+02	[65]
Cs-134	4.6E-03	4.0E+02	[65]
Cs-136	4.6E-03	4.0E+02	[65]
Cs-137+	4.6E-03	4.0E+02	[65]
Ba-140+	1.6E-04	1.4E+01	[65]
Ce-141	2.0E-05	1.7E+00	[65]
Ce-143	2.0E-05	1.7E+00	[65]
Ce-144+	2.0E-05	1.7E+00	[65]
Pr-143	5.0E-06	4.3E-01	[66]
Nd-147	5.0E-06	4.3E-01	[66]
Np-239	5.0E-05	4.3E+00	[64]
Pu-238	1.0E-05	8.6E-01	[65]
Pu-239	1.0E-05	8.6E-01	[65]
Pu-240	1.0E-05	8.6E-01	[65]
Pu-241	1.0E-05	8.6E-01	[65]
Am-241	4.2E-07	3.6E-02	[65]
Cm-242	2.0E-06	1.7E-01	[64]
Cm-244	2.0E-06	1.7E-01	[64]

[a] The values for small grazing animals are assumed to be approximately 10 times higher [65].
[b] The mean values provided in Ref. [65] were used first, and, if not available in Ref. [65], the values were taken from Ref. [64]. If not available in Ref. [64] the values were taken from Ref. [66].
\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

TABLE 22. FRACTION OF THE RADIONUCLIDES REMAINING AT THE TIME OF HUMAN CONSUMPTION

Radionuclide	$F_{consumption,i}$ [a] [unitless]
Rb-86	9.6E-01
Sr-89	9.9E-01
Sr-90+	1.0E+00
Sr-91	1.8E-01
Y-91	9.9E-01
Zr-95+	9.9E-01
Zr-97+	3.7E-01
Mo-99+	7.8E-01
Ru-103+	9.8E-01
Ru-105	2.4E-02
Ru-106+	1.0E+00
Rh-105	6.2E-01
Te-127m+	9.9E-01
Te-127	1.7E-01
Te-129m+	9.8E-01
Te-131m	5.7E-01
Te-132+	8.1E-01
I-131	9.2E-01
I-133	4.5E-01
I-134	5.5E-09
I-135	7.9E-02
Cs-134	1.0E+00
Cs-136	9.5E-01
Cs-137+	1.0E+00
Ba-140+	9.5E-01
Ce-141	9.8E-01
Ce-143	6.0E-01
Ce-144+	1.0E+00
Pr-143	9.5E-01
Nd-147	9.4E-01
Np-239	7.5E-01
Pu-238	1.0E+00
Pu-239	1.0E+00
Pu-240	1.0E+00
Pu-241	1.0E+00
Am-241	1.0E+00
Cm-242	1.0E+00
Cm-244	1.0E+00

[a] $F_{consumption,i}$ is calculated based on Eq. (14).

\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

3.5.9. Removal from the skin by weathering and decay

The reduction of the gross activity on the skin surface due to natural processes (i.e. weathering, but not washing) is considered in the calculation of $OIL4_\gamma$ and $OIL4_\beta$ by making use of the effective availability period for inadvertent ingestion from the skin. Since two exposure periods for material on the skin (i.e. 7 d for urgent generic criteria and 10 h for acute generic criteria) are considered in the calculations, two corresponding effective availability periods for inadvertent ingestion of material on the skin are determined:

- $\Delta_{eff,OIL4\text{-}Urgent,i}$ [s] is the effective availability period for radionuclide i for inadvertent ingestion from the skin in the 'skin' scenario for the urgent generic criteria. The values are given in Table 20 and are determined by Eq. (16):

$$\Delta_{eff,OIL4-Urgent,i} = \\ = \int_0^{\Delta_{OIL4-Urgent}} e^{-(\lambda_i+\lambda_{w-skin})\times t} \times dt = \frac{1-e^{-(\lambda_i+\lambda_{w-skin})\times \Delta_{OIL4-Urgent}}}{\lambda_i+\lambda_{w-skin}} \quad (16)$$

where:

  - $\Delta_{OIL4\text{-}Urgent}$ = 7 d = 604 800 s is the exposure period considered for the urgent generic criteria (given in Table 2). It is obtained from Table II.2 of Ref. [1].
  - λ_i [s^{-1}] is the decay constant for radionuclide i. The values are given in Table 6.
  - $\lambda_{w\text{-}skin}$ [s^{-1}] is the removal constant from skin due to weathering. It is determined by Eq. (17):

$$\lambda_{w-skin} = \ln(2)/T_{1/2,w-skin} \quad (17)$$

  where:

    - $T_{1/2,w\text{-}skin}$ = 14.7 h = 52 920 s is the half-life for removal of surface deposition from the skin due to weathering. It is obtained from Ref. [67].

- $\Delta_{eff,OIL4\text{-}Acute,i}$ [s] is the effective availability period for radionuclide i for inadvertent ingestion from the skin in the 'skin' scenario for the acute generic criteria. The values are given in Table 20 and are determined by Eq. (18):

$$\Delta_{eff,OIL4-Acute,i} = \\ = \int_0^{\Delta_{OIL4-Acute}} e^{-(\lambda_i+\lambda_{w-skin})\times t} \times dt = \frac{1-e^{-(\lambda_i+\lambda_{w-skin})\times \Delta_{OIL4-Acute}}}{\lambda_i+\lambda_{w-skin}} \quad (18)$$

where:

  - $\Delta_{OIL4\text{-}Acute}$ = 10 h = 36 000 s is the exposure period considered for the acute generic criteria (Table 2).
  - λ_i [s^{-1}] is the decay constant for radionuclide i. The values are given in Table 6.
  - $\lambda_{w\text{-}skin}$ [s^{-1}] is the removal constant from skin due to weathering. It is determined by Eq. (17).

3.5.10. Reduction due to radioactive decay during the period of availability

The reduction of the gross activity in food, milk or drinking water due to decay is considered in the calculation of OIL7 by making use of $\Delta_{eff,OIL7,i}$ [s], which is the effective availability period for radionuclide i for ingestion in the 'food post-analysis' scenario. The values are given in Table 20 and are determined by Eq. (19):

$$\Delta_{eff,OIL7,i} = \int_0^{\Delta_{available-ing}} e^{-\lambda_i \times t} \times dt = \frac{1 - e^{-\lambda_i \times \Delta_{available-ing}}}{\lambda_i} \quad (19)$$

where:

- λ_i [s^{-1}] is the decay constant for radionuclide i. The values are given in Table 6.
- $\Delta_{available-ing}$ = 365 d = 3.15E+07 s is the period of time that the affected food or forage is available for consumption. This is the exposure period of the GC(Ingestion,e_{ing},1a).

3.5.11. Reduction of the measured dose rate due to the decay of I-131 in the thyroid

The reduction of the activity of I-131 in the thyroid due to decay and biological processes is considered in the calculation of $OIL8_\gamma$ by making use of $CorF_{I-131-thyroid-burden}(t_m)$ [unitless], which is displayed in Fig. 8 and determined by Eq. (20):

$$CorF_{I-131-thyroid-burden}(t_m) = e^{-(\lambda_{I-131} + \lambda_{bio-I-131}) \times t_m} \quad (20)$$

where:

- t_m [s] is the time between intake and measurement of the thyroid.
- λ_{I-131} = 1.0E-06 s^{-1} is the decay constant of I-131. The value is taken from Table 6.
- $\lambda_{bio-I-131}$ = 1.0E-07 s^{-1} is the biological removal constant of I-131 in the thyroid. It is determined by Eq. (21):

$$\lambda_{bio-I-131} = \ln(2)/T_{1/2,bio-I-131} \quad (21)$$

where:

  - $T_{1/2,bio-I-131}$ = 80 d = 6.9E+06 s is the biological half-life of I-131 provided in Ref. [68].

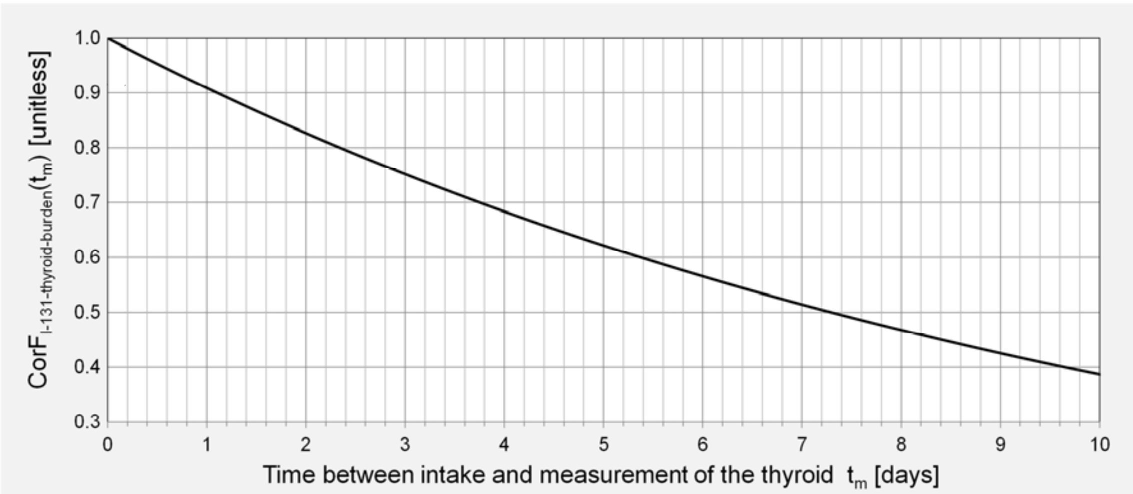


FIG. 8. Correction factor to account for the reduction in the dose rate from the thyroid due to the reduction of I-131, $CorF_{I-131-thyroid-burden}(t_m)$ [unitless].

3.6. DOSE CONVERSION FACTORS

This section provides the dose conversion factors used in the calculation of the OILs and their basis, following the exposure scenarios described in Section 3.4. Both effective and equivalent dose conversion factors are considered in the calculation of the OILs because the effective dose alone cannot be used as a basis for estimating the possible health hazard from radiation exposure [38], since it can greatly underestimate the possible radiation induced impact to individual organs following intake of radioactive material.[39] As mentioned in Section 3.4, the total effective dose to the representative person and the equivalent dose to its fetus[40] will be controlling for the 'ground', 'food pre-analysis', 'skin' and 'food post-analysis' scenarios, while for the 'thyroid scenario', it will be the equivalent dose to the thyroid of the representative person.

Sections 3.6.1 to 3.6.5 provide the dose conversion factors for the exposure scenarios described in Table 11 to Table 16. The most restrictive combinations of different factors such as age, public behaviour, exposure pathways, chemical forms of the radionuclides, radionuclide behaviour, times relative to conception, acute or chronic exposure and types of absorption are used. Section 3.10 discusses the considered conservatism in further detail.

In the notation of the dose conversion factors, the lower case letter is used to indicate that a single exposure pathway is considered when calculating the dose, as opposed to the total dose, for which an upper case letter is used (e.g. $E_{grd\text{-}scenario,i}$, $e_{grd\text{-}sh(grd\text{-}scenario),i}$).

3.6.1. Dose conversion factors for the 'ground' scenario

Table 23 provides the dose conversion factors for the total effective dose to the representative person and the total equivalent dose to the fetus for the 'ground' scenario (needed in the calculation of $OIL1_\gamma$ and $OIL2_\gamma$), over an exposure period Δ of 7 days and 1 year.[41] These dose conversion factors are determined as described in Sections 3.6.1.1 and 3.6.1.2.

3.6.1.1. Total effective dose to the representative person for the 'ground' scenario

Table 23 provides $E_{grd\text{-}scenario,i}(\Delta)$ [Sv/(Bq/m^2)], which is the total effective dose to the representative person over an exposure period Δ[41] for the 'ground' scenario, per unit ground surface activity of radionuclide i. It is determined by Eq. (22):

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[39] For example: The intake of radioiodine resulting in an effective dose below the generic criteria for urgent protective actions could result in an equivalent dose to the thyroid at which radiation induced health effects may occur.

[40] In this publication the term 'fetus' encompasses both the embryo and the fetus. Keeping the equivalent dose to the fetus from intake below the generic criteria will ensure that the dose to other organs will also stay below the generic criteria. The equivalent dose to the fetus is defined as the highest equivalent dose to any organ in the fetus during the period of in utero development.

[41] 7 days and 1 year are used, since those are the exposure periods provided for the corresponding generic criteria in the IAEA Safety Standards Series No. GSR Part 7 [1], as shown in Table 2. 7 days is used to calculate the early response action $OIL1_\gamma$, and 1 year is used to calculate the urgent response action $OIL2_\gamma$.

$$E_{grd-scenario,i}(\Delta) = e_{grd-sh(grd-scenario),i}(\Delta) + e_{air-sh(grd-scenario),i}(\Delta) + + e_{inh-resusp(grd-scenario),i}(\Delta) + e_{inadv-ing(grd-scenario),i}(\Delta) \quad (22)$$

where:

- $e_{grd\text{-}sh(grd\text{-}scenario),i}(\Delta)$ [Sv/(Bq/m^2)] is the external effective dose to the representative person (i.e. the infant for this exposure scenario and pathway), over an exposure period Δ, from ground shine resulting from ground deposition, for the 'ground' scenario, per unit ground surface activity of radionuclide i. It is determined by Eq. (23):

  $$e_{grd-sh(grd-scenario),i}(\Delta) = e_{plane-srf,i}(\text{adult}) \times CorF_{grd} \times \times SF_{e_{ext}(\text{adult}\rightarrow\text{infant})} \times WI_{G,i}(\Delta) \times \left(F_{sf} \times F_{of} + (1 - F_{of})\right) \quad (23)$$

  where:

  - $e_{plane\text{-}srf,i}(\text{adult})$ [(Sv/s)/(Bq/m^2)] is the effective dose rate to the adult from an infinite smooth plane source, per unit surface activity of radionuclide i. The values are given in Table 24 and are applicable to an exposed individual standing on an ideal plane, uniformly contaminated surface. This would overestimate the dose from a real (non-plane) surface of uniform concentration; therefore, a ground roughness correction factor is used, as described in the next bullet.
  - $CorF_{grd}$ = 0.7 [unitless] is the ground roughness correction factor to account for the dose rate reduction due to ground roughness, as described in Ref. [69].
  - $SF_{e_{ext}(\text{adult}\rightarrow\text{infant})}$ = 1.4 [unitless] is the scaling factor to convert the effective dose to the adult to the effective dose to the infant for external exposure, as discussed in Ref. [69].
  - $WI_{G,i}(\Delta)$ [s] is the time integrated external ground dose rate weathering factor, for radionuclide i, integrated over the exposure period Δ. The values are given for the exposure periods of 7 d and 1 a in Table 17.
  - F_{sf} = 0.4 [unitless] is the fraction of the dose rate received from ground deposition for a person located inside a building relative to the dose rate for that person located outside the building (shielding factor). It is obtained from Ref. [5] and is consistent with Ref. [70].[42]
  - F_{of} = 0.6 [unitless] is the fraction of the exposure period that the person is assumed to spend inside a building (occupancy fraction). It is obtained from Ref. [5].

- $e_{air\text{-}sh(grd\text{-}scenario),i}(\Delta)$ [Sv/(Bq/m^2)] is the external effective dose to the representative person (i.e. the infant for this exposure scenario and pathway), over an exposure period Δ, from air shine resulting from resuspended ground deposition, for the 'ground' scenario, per unit ground surface activity of radionuclide i. It is determined by Eq. (24):

  $$e_{air-sh(grd-scenario),i}(\Delta) = e_{air-sh,i}(\text{adult}) \times TI_{grd\rightarrow air,i}(\Delta) \times SF_{e_{ext}(\text{adult}\rightarrow\text{infant})} \quad (24)$$

  where:

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[42] The default of 0.4 is for a wooden framed house with the less effective shielding of the range of structures provided in Ref. [5]. The other structures have shielding factors between 0.2, for a one storey block house, to 0.01 for a large multi-storey structure. The default value is also higher than that estimated for most structures in Ref. [70].

- $e_{air\text{-}sh,i}$(adult) [(Sv/s)/(Bq/m^3)] is the external effective dose rate to the adult from air submersion, per unit volume activity of radionuclide i. The values are given in Table 24, and are applicable to an exposed individual standing at the centre of a semi-infinite, uniformly contaminated atmospheric cloud. This would overestimate the dose from a real (finite) plume of uniform concentration.
- $TI_{grd\rightarrow air,i}(\Delta)$ [s/m] is the time integrated transfer factor of radionuclide i from the ground to the air (resuspended into the air by wind or other natural processes), integrated over the exposure period Δ. The values are given for an exposure period of 7 d and 1 a in Table 17.
- $SF_{eext(adult\rightarrow infant)}$ = 1.4 [unitless] is the scaling factor to convert the effective dose to the adult to the effective dose to the infant for external exposure, as discussed in Ref. [69].

* $e_{inh\text{-}resusp(grd\text{-}scenario),i}(\Delta)$ [Sv/(Bq/m^2)] is the committed effective dose to the representative person (i.e. the adult for this exposure scenario and pathway), over an exposure period Δ, from inhalation of resuspended ground deposition, for the 'ground' scenario, per unit ground surface activity of radionuclide i. It is determined by Eq. (25):

$$e_{inh-resusp(grd-scenario),i}(\Delta) = e_{inh,i}(adult) \times TI_{grd\rightarrow air,i}(\Delta) \times F_{rf} \times Q_{air} \quad (25)$$

where:

- $e_{inh,i}$(adult) [Sv/Bq] is the committed effective dose to the adult from inhalation, per unit intake of radionuclide i. The values are given in Table 24.
- $TI_{grd\rightarrow air,i}(\Delta)$ [s/m] is the time integrated transfer factor of radionuclide i from the ground to the air (resuspended into the air by wind or other natural processes), integrated over the exposure period Δ. The values are given for an exposure period of 7 d and 1 a in Table 17.
- F_{rf} = 1 [unitless] is the fraction of the airborne radioactive material that is deposited in the pulmonary region of the lung (respirable fraction). In reality F_{rf} would be expected to be less than one tenth of this default value in most cases [71].
- Q_{air} = 1.2 m^3/h = 3.3E-04 m^3/s is the breathing rate of an adult performing light activity and is obtained from Ref. [72].

* $e_{inadv\text{-}ing(grd\text{-}scenario),i}(\Delta)$ [Sv/(Bq/m^2)] is the committed effective dose to the representative person (i.e. the infant for this exposure scenario and pathway), over an exposure period Δ, from inadvertent ingestion of ground deposition, for the 'ground' scenario, per unit ground surface activity of radionuclide i. It is determined by Eq. (26):

$$e_{inadv-ing(grd-scenario),i}(\Delta) = e_{ing,i}(infant) \times TI_{grd\rightarrow GI,i}(\Delta, infant) \quad (26)$$

where:

- $e_{ing,i}$(infant) [Sv/Bq] is the committed effective dose to the infant from ingestion, per unit intake of radionuclide i. The values are given in Table 24.
- $TI_{grd\rightarrow GI,i}(\Delta,infant)$ [m^2] is the time integrated transfer factor of radionuclide i from the ground to the GI tract by inadvertent ingestion for an infant (i.e. the representative person for this exposure scenario and pathway), integrated over the exposure period Δ. The values for an exposure period of 7 d and 1 a for the infant are given in Table 19.

3.6.1.2. Total equivalent dose to the fetus for the 'ground' scenario

Table 23 provides $H_{fetus,grd\text{-}scenario,i}(\Delta)$ [Sv/(Bq/m^2)], which is the total equivalent dose to the fetus over an exposure period Δ[43] for the 'ground' scenario, per unit ground surface activity of radionuclide i. It is determined by Eq. (27):

$$H_{fetus,grd-scenario,i}(\Delta) = \\ = h_{fetus,grd-sh(grd-scenario),i}(\Delta) + h_{fetus,air-sh(grd-scenario),i}(\Delta) + \\ + h_{fetus,inh-resusp(grd-scenario),i}(\Delta) + h_{fetus,inadv-ing(grd-scenario),i}(\Delta) \quad (27)$$

where:

- $h_{fetus,grd\text{-}sh(grd\text{-}scenario),i}(\Delta)$ [Sv/(Bq/m^2)] is the external equivalent dose to the fetus, over an exposure period Δ, from ground shine resulting from ground deposition, for the 'ground' scenario, per unit ground surface activity of radionuclide i. It is determined by Eq. (28):

$$h_{fetus,grd-sh(grd-scenario),i}(\Delta) = h_{red\ marrow,plane-srf,i}(adult) \times CorF_{grd} \times \\ \times WI_{G,i}(\Delta) \times SF_{(h_{red\ marrow} \rightarrow h_{fetus}),grd-sh} \times \left(F_{sf} \times F_{of} + (1 - F_{of})\right) \quad (28)$$

  where:

  - $h_{red\ marrow,plane\text{-}srf,i}(adult)$ [(Sv/s)/(Bq/m^2)] is the equivalent dose rate to the red marrow of the adult from an infinite smooth plane source, for radionuclide i.[44] The values are given in Table 25, and are applicable to an exposed individual standing on an ideal plane, uniformly contaminated surface. This would overestimate the dose from a real (non-plane) surface of uniform concentration; therefore, a ground roughness correction factor is used, as described in the next bullet.
  - $CorF_{grd}$ = 0.7 [unitless] is the ground roughness correction factor to account for the dose rate reduction due to ground roughness, as described in Ref. [69].
  - $SF_{(h_{redmarrow} \rightarrow h_{fetus}),grd\text{-}sh}$ = 0.9 [unitless] is the scaling factor to convert the dose conversion factor for the equivalent dose rate to the red marrow into equivalent dose rate to the fetus, for ground shine. It is based on the ratio between the dose to the uterus and the red marrow from Table II.6 of Ref. [69] for the photon energies of concern.
  - $WI_{G,i}(\Delta)$ [s] is the time integrated external ground dose rate weathering factor, for radionuclide i, integrated over the exposure period Δ. The values are given for the exposure periods of 7 d and 1 a in Table 17.
  - F_{sf} = 0.4 [unitless] is the fraction of the dose rate received from ground deposition for a person located inside a building relative to the dose rate for that person located outside

[43] 7 days and 1 year are used since those are the exposure periods provided for the corresponding generic criteria in the IAEA Safety Standards Series No. GSR Part 7 [1], as shown in Table 2. 7 days is used to calculate the early response action $OIL1_\gamma$, and 1 year is used to calculate the urgent response action $OIL2_\gamma$.

[44] Due to the lack of dose conversion factors for the equivalent dose to the fetus from ground shine, the dose conversion factor for the equivalent dose to the red marrow from an infinite smooth plane source from Table III.3 of Ref. [69] is used to estimate the dose conversion factors for the equivalent dose to the fetus by using a scaling factor which is representative of the ratio between the dose to the uterus and the red marrow from Table II.6 of Ref. [69] for the photon energies of concern.

the building (shielding factor). It is obtained from Ref. [5] and is consistent with Ref. [70].[45]

- F_{of} = 0.6 [unitless] is the fraction of the exposure period that the person is assumed to spend inside a building (occupancy fraction). It is obtained from Ref. [5].

- $h_{fetus,air\text{-}sh(grd\text{-}scenario),i}(\Delta)$ [Sv/(Bq/m^2)] is the external equivalent dose to the fetus, over an exposure period Δ, from air shine resulting from resuspended ground deposition, for the 'ground' scenario, per unit ground surface activity of radionuclide i. It is determined by Eq. (29):

$$h_{fetus,air-sh(grd-scenario),i}(\Delta) = \\ = h_{red\ marrow,air-sh,i}(adult) \times SF_{(h_{red\ marrow} \rightarrow h_{fetus}),air-sh} \times TI_{grd \rightarrow air,i}(\Delta) \quad (29)$$

where:

- $h_{red\ marrow,air\text{-}sh,i}(adult)$ [(Sv/s)/(Bq/m^3)] is the equivalent dose rate to the red marrow of the adult from submersion in a semi-infinite cloud of airborne radioactive material, per unit air activity concentration of radionuclide i.[46] The values are given in Table 25 and are applicable to an exposed individual standing at the centre of a semi-infinite, uniformly contaminated atmospheric cloud. This would overestimate the dose from a real (finite) plume of uniform concentration.
- $SF_{(h_{redmarrow} \rightarrow h_{fetus}),air\text{-}sh}$ = 0.9 [unitless] is the scaling factor to convert the dose conversion factor for the equivalent dose rate to the red marrow into the equivalent dose rate to the fetus, for air shine. It is based on the ratio between the dose to the uterus and the red marrow from Table II.4 of Ref. [69] for the photon energies of concern.
- $TI_{grd \rightarrow air,i}(\Delta)$ [s/m] is the time integrated transfer factor of radionuclide i from the ground to the air (resuspended into the air by wind or other natural processes), integrated over the exposure period Δ. The values are given for an exposure period of 7 d and 1 a in Table 17.

- $h_{fetus,inh\text{-}resusp(grd\text{-}scenario),i}(\Delta)$ [Sv/(Bq/m^2)] is the committed equivalent dose to the fetus, over an exposure period Δ, from inhalation of resuspended ground deposition by a pregnant woman, for the 'ground' scenario, per unit ground surface activity of radionuclide i. It is determined by Eq. (30):

$$h_{fetus,inh-resusp(grd-scenario),i}(\Delta) = h_{fetus,inh,i} \times TI_{grd \rightarrow air,i}(\Delta) \times F_{rf} \times Q_{air} \quad (30)$$

where:

[45] The default of 0.4 is for a wooden framed house with the less effective shielding of the range of structures provided in Ref. [5]. The other structures have shielding factors between 0.2, for a one storey block house, to 0.01 for a large multi-storey structure. The default value is also higher than that estimated for most structures in Ref. [70].

[46] Due to the lack of dose conversion factors for the equivalent dose to the fetus from air shine, the dose conversion factor for the equivalent dose to the red marrow from submersion in a semi-infinite cloud of airborne radioactive material from Table III.1. of Ref. [69] is used to estimate the dose conversion factors for the equivalent dose to the fetus by using a scaling factor which is representative of the ratio between the dose to the uterus and the red marrow from Table II.4 of Ref. [69] for the photon energies of concern.

- $h_{fetus,inh,i}$ [Sv/Bq] is the committed equivalent dose to the fetus from inhalation by an adult (i.e. pregnant woman), per unit intake of radionuclide i. The values are given in Table 25.
- $TI_{grd \rightarrow air,i}(\Delta)$ [s/m] is the time integrated transfer factor of radionuclide i from the ground to the air (resuspended into the air by wind or other natural processes), integrated over the exposure period Δ. The values are given for an exposure period of 7 d and 1 a in Table 17.
- F_{rf} = 1 [unitless] is the fraction of the airborne radioactive material that is deposited in the pulmonary region of the lung (respirable fraction). In reality, F_{rf} would be expected to be less than one tenth of this default value in most cases [71].
- Q_{air} = 1.2 m^3/h = 3.3E-04 m^3/s is the breathing rate of an adult performing light activity and is obtained from Ref. [72].

- $h_{fetus,inadv\text{-}ing(grd\text{-}scenario),i}(\Delta)$ [Sv/(Bq/m^2)] is the committed equivalent dose to the fetus, over an exposure period Δ, from inadvertent ingestion of ground deposition by an adult (i.e. pregnant woman), for the 'ground' scenario, per unit ground surface activity of radionuclide i. It is determined by Eq. (31):

$$h_{fetus,inadv-ing(grd-scenario),i}(\Delta) = h_{fetus,ing,i} \times TI_{grd \rightarrow GI,i}(\Delta, adult) \quad (31)$$

where:

- $h_{fetus,ing,i}$ [Sv/Bq] is the committed equivalent dose to the fetus from ingestion by an adult (i.e. pregnant woman), per unit intake of radionuclide i. The values are given in Table 25.
- $TI_{grd \rightarrow GI,i}(\Delta, adult)$ [m^2] is the time integrated transfer factor of radionuclide i from the ground to the GI tract by inadvertent ingestion for the adult (considered for fetal exposure), integrated over the exposure period Δ. The values for an exposure period of 7 d and 1 a for the adult are given in Table 19.

TABLE 23. DOSE CONVERSION FACTORS FOR THE TOTAL EFFECTIVE DOSE TO THE REPRESENTATIVE PERSON AND FOR THE TOTAL EQUIVALENT DOSE TO THE FETUS FOR THE ‘GROUND’ SCENARIO

Radionuclide	$E_{grd\text{-}scenario,i}(7d)$[a] [Sv/(Bq/m^2)]	$E_{grd\text{-}scenario,i}(1a)$[a] [Sv/(Bq/m^2)]	$H_{fetus,grd\text{-}scenario,i}(7d)$[b,c] [Sv/(Bq/m^2)]	$H_{fetus,grd\text{-}scenario,i}(1a)$[b,d] [Sv/(Bq/m^2)]
Rb-86	3.5E-11	1.3E-10	2.0E-11	8.3E-11
Sr-89	1.1E-11	2.4E-11	6.6E-11	1.1E-10
Sr-90+	1.6E-10	4.4E-10	1.8E-10	4.6E-10
Sr-91	2.1E-11	2.1E-11	1.3E-11	1.3E-11
Y-91	1.3E-11	4.1E-11	1.3E-12	1.3E-11
Zr-95+	8.7E-10	1.0E-08	5.4E-10	6.3E-09
Zr-97+	8.2E-11	8.2E-11	5.1E-11	5.1E-11
Mo-99+	4.8E-11	5.7E-11	2.9E-11	3.5E-11
Ru-103+	1.7E-10	1.3E-09	1.0E-10	8.0E-10
Ru-105	1.1E-11	1.1E-11	7.0E-12	7.0E-12
Ru-106+	1.4E-10	2.5E-09	5.4E-11	1.5E-09
Rh-105	8.8E-12	9.1E-12	5.2E-12	5.4E-12
Te-127m+	1.8E-11	1.3E-10	2.0E-11	7.2E-11
Te-127	2.2E-13	2.2E-13	9.8E-14	9.8E-14
Te-129m+	3.8E-11	2.0E-10	3.1E-11	1.3E-10
Te-131m	1.3E-10	1.3E-10	1.3E-10	1.3E-10
Te-132+	4.8E-10	6.1E-10	5.0E-10	5.9E-10
I-131	1.4E-10	2.7E-10	8.5E-10	1.1E-09
I-133	4.3E-11	4.4E-11	9.9E-11	9.9E-11
I-134	7.2E-12	7.2E-12	4.6E-12	4.6E-12
I-135	3.2E-11	3.2E-11	2.6E-11	2.6E-11
Cs-134	5.9E-10	1.9E-08	3.6E-10	1.2E-08
Cs-136	6.6E-10	2.1E-09	4.1E-10	1.3E-09
Cs-137+	2.6E-10	8.6E-09	1.4E-10	5.4E-09
Ba-140+	8.8E-10	2.7E-09	5.6E-10	1.7E-09
Ce-141	3.0E-11	1.8E-10	1.5E-11	9.8E-11
Ce-143	3.0E-11	3.1E-11	1.7E-11	1.8E-11
Ce-144+	7.4E-11	7.0E-10	1.8E-11	3.6E-10
Pr-143	3.5E-12	4.9E-12	1.1E-13	3.4E-13
Nd-147	4.5E-11	1.2E-10	2.4E-11	6.6E-11
Np-239	2.7E-11	3.1E-11	1.5E-11	1.7E-11
Pu-238	9.3E-08	2.2E-07	2.6E-09	6.2E-09
Pu-239	1.0E-07	2.4E-07	2.5E-09	5.8E-09
Pu-240	1.0E-07	2.4E-07	2.5E-09	5.8E-09
Pu-241	2.0E-09	4.6E-09	1.9E-12	4.4E-12
Am-241	8.2E-08	1.9E-07	1.4E-09	3.4E-09
Cm-242	5.0E-09	9.9E-09	9.3E-10	1.8E-09
Cm-244	4.8E-08	1.1E-07	1.4E-09	3.2E-09

[a] $E_{grd\text{-}scenario,i}(\Delta)$ calculated based on Eq. (22).
[b] $H_{fetus,grd\text{-}scenario,i}(\Delta)$ calculated based on Eq. (27).
[c] In this publication, the term ‘fetus’ encompasses both the embryo and the fetus.
[d] An exposure period of 1 year instead of the 9 months specified in Table 2 is used for simplicity.
\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

TABLE 24. DOSE CONVERSION FACTORS USED TO CALCULATE THE TOTAL EFFECTIVE DOSE TO THE REPRESENTATIVE PERSON FOR THE ‘GROUND’ SCENARIO

Radionuclide	$e_{plane\text{-}srf,i}$(adult)[a] [(Sv/s)/(Bq/m^2)]	$e_{air\text{-}sh,i}$(adult)[b] [(Sv/s)/(Bq/m^3)]	$e_{inh,i}$(adult)[c] [Sv/Bq]	$e_{ing,i}$(infant)[d] [Sv/Bq]
Rb-86	9.3E-17	4.8E-15	9.3E-10	2.0E-08
Sr-89	2.3E-18	7.7E-17	7.9E-09	1.8E-08
Sr-90+	5.6E-18	2.0E-16	1.6E-07	9.3E-08
Sr-91	6.8E-16	3.5E-14	4.1E-10	4.0E-09
Y-91	5.7E-18	2.6E-16	8.9E-09	1.8E-08
Zr-95+	2.4E-15	1.2E-13	9.9E-09	1.3E-08
Zr-97+	1.5E-15	7.5E-14	9.7E-10	1.4E-08
Mo-99+	2.6E-16	1.3E-14	1.0E-09	3.6E-09
Ru-103+	4.6E-16	2.3E-14	3.0E-09	4.6E-09
Ru-105	7.7E-16	3.8E-14	1.8E-10	1.8E-09
Ru-106+	2.1E-16	1.0E-14	6.6E-08	4.9E-08
Rh-105	7.6E-17	3.7E-15	3.5E-10	2.7E-09
Te-127m+	1.6E-17	3.9E-16	9.9E-09	1.9E-08
Te-127	5.2E-18	2.4E-16	1.4E-10	1.2E-09
Te-129m+	7.7E-17	3.3E-15	7.9E-09	2.4E-08
Te-131m	1.4E-15	7.0E-14	9.4E-10	1.4E-08
Te-132+	2.4E-15	1.2E-13	2.1E-09	3.2E-08
I-131	3.8E-16	1.8E-14	7.4E-09	1.8E-07
I-133	6.0E-16	2.9E-14	1.5E-09	4.4E-08
I-134	2.5E-15	1.3E-13	5.5E-11	7.5E-10
I-135	1.5E-15	8.0E-14	3.2E-10	8.9E-09
Cs-134	1.5E-15	7.6E-14	2.0E-08	1.6E-08
Cs-136	2.1E-15	1.1E-13	2.8E-09	9.5E-09
Cs-137+	5.9E-16	2.9E-14	3.9E-08	1.2E-08
Ba-140+	2.8E-15	1.5E-13	7.1E-09	3.4E-08
Ce-141	7.4E-17	3.4E-15	3.8E-09	5.1E-09
Ce-143	2.8E-16	1.3E-14	8.3E-10	8.0E-09
Ce-144+	5.8E-17	2.8E-15	5.3E-08	3.9E-08
Pr-143	7.0E-19	2.1E-17	2.4E-09	8.7E-09
Nd-147	1.4E-16	6.2E-15	2.4E-09	7.8E-09
Np-239	1.6E-16	7.7E-15	1.0E-09	5.7E-09
Pu-238	8.4E-19	4.9E-18	1.1E-04	4.0E-07
Pu-239	3.7E-19	4.2E-18	1.2E-04	4.2E-07
Pu-240	8.0E-19	4.8E-18	1.2E-04	4.2E-07
Pu-241	1.9E-21	7.3E-20	2.3E-06	5.7E-09
Am-241	2.8E-17	8.2E-16	9.6E-05	3.7E-07
Cm-242	9.6E-19	5.7E-18	5.9E-06	7.6E-08
Cm-244	8.8E-19	4.2E-18	5.7E-05	2.9E-07

[a] $e_{plane\text{-}srf,i}$(adult) is equal to the dose conversion factors for exposure to contaminated ground surface given in Table III.3 of Ref. [69]. The reference uses the legacy unit ‘effective dose equivalent’, which is equivalent to the effective dose from external exposure.

[b] $e_{air\text{-}sh,i}$(adult) is equal to the dose factors for air submersion given in Table III.1 of Ref. [69]. The reference uses the legacy unit ‘effective dose equivalent’, which is equivalent to the effective dose from external exposure.

[c] $e_{inh,i}$(adult) is the highest committed effective dose per unit intake for all absorption types and for members of the public older than 17 years from Table III.2E of Ref. [14].

[d] $e_{ing,i}$(infant) is the value for members of the public with an age between 1 and 2 a from Table III.2D of Ref. [14].

\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

TABLE 25. DOSE CONVERSION FACTORS USED TO CALCULATE THE TOTAL EQUIVALENT DOSE TO THE FETUS FOR THE 'GROUND' SCENARIO

Radionuclide	$h_{red\ marrow,plane\text{-}srf,i}$(adult)[a] [(Sv/s)/(Bq/m^2)]	$h_{red\ marrow,air\text{-}sh,i}$(adult)[b] [(Sv/s)/(Bq/m^3)]	$h_{fetus,inh,i}$[c,d] [Sv/Bq]	$h_{fetus,ing,i}$[e] [Sv/Bq]
Rb-86	9.2E-17	4.6E-15	7.5E-10	2.2E-09
Sr-89	1.9E-18	6.4E-17	6.6E-08	1.3E-07
Sr-90+	4.8E-18	1.7E-16	1.7E-07	3.4E-07
Sr-91	6.6E-16	3.3E-14	3.6E-11	1.3E-10
Y-91	5.3E-18	2.4E-16	5.9E-11	1.7E-12
Zr-95+	2.3E-15	1.1E-13	3.0E-09	1.5E-09
Zr-97+	1.5E-15	7.1E-14	9.7E-11	3.2E-10
Mo-99+	2.5E-16	1.2E-14	8.4E-10	2.5E-09
Ru-103+	4.5E-16	2.1E-14	9.9E-10	3.6E-10
Ru-105	7.5E-16	3.6E-14	5.3E-11	6.0E-11
Ru-106+	2.1E-16	9.8E-15	6.0E-09	6.9E-10
Rh-105	7.3E-17	3.4E-15	1.9E-11	2.7E-11
Te-127m+	9.2E-18	2.9E-16	2.1E-08	7.5E-09
Te-127	4.9E-18	2.2E-16	1.5E-11	4.9E-12
Te-129m+	6.8E-17	3.1E-15	1.9E-08	6.8E-09
Te-131m	1.3E-15	6.7E-14	1.2E-07	5.4E-08
Te-132+	2.4E-15	1.2E-13	3.4E-07	1.4E-07
I-131	3.6E-16	1.7E-14	9.9E-07	1.1E-06
I-133	5.8E-16	2.8E-14	2.3E-07	2.5E-07
I-134	2.5E-15	1.3E-13	1.9E-09	1.9E-09
I-135	1.5E-15	7.8E-14	4.8E-08	5.2E-08
Cs-134	1.5E-15	7.2E-14	3.9E-09	1.1E-08
Cs-136	2.0E-15	1.0E-13	1.2E-09	3.5E-09
Cs-137+	5.7E-16	2.7E-14	2.5E-09	7.2E-09
Ba-140+	2.7E-15	1.4E-13	8.1E-09	1.2E-08
Ce-141	6.5E-17	2.8E-15	3.8E-10	6.0E-11
Ce-143	2.6E-16	1.2E-14	3.7E-11	8.9E-11
Ce-144+	5.3E-17	2.5E-15	5.7E-09	4.7E-11
Pr-143	5.2E-19	1.6E-17	7.5E-13	1.1E-14
Nd-147	1.2E-16	5.4E-15	1.9E-11	7.3E-11
Np-239	1.5E-16	6.5E-15	5.9E-10	9.2E-11
Pu-238	1.9E-19	1.7E-18	3.1E-06	6.3E-09
Pu-239	1.2E-19	2.7E-18	2.9E-06	5.9E-09
Pu-240	1.9E-19	1.7E-18	2.9E-06	5.9E-09
Pu-241	1.4E-21	5.6E-20	2.2E-09	4.5E-12
Am-241	1.7E-17	5.2E-16	1.6E-06	3.2E-09
Cm-242	2.3E-19	1.9E-18	1.1E-06	2.2E-09
Cm-244	2.0E-19	1.5E-18	1.6E-06	3.3E-09

[a] $h_{red\ marrow,plane\text{-}srf,i}$(adult) is equal to the dose conversion factors for exposure to contaminated ground surface given in Table III.3 of Ref. [69]. The reference uses the legacy unit 'red marrow dose equivalent', which is the equivalent dose to the red marrow from external exposure.

[b] $h_{red\ marrow,air\text{-}sh,i}$(adult) is equal to the dose conversion factors for air submersion given in Table III.1 of Ref. [69].

[c] $h_{fetus,inh,i}$ is the value that gives the highest embryo or fetus organ dose for both acute and chronic inhalation, considering all absorption types and vapour (when applicable), for all times of inhalation (including inhalation prior to the pregnancy) for each radionuclide as given in Ref. [39]. For radionuclides for which dose conversion factors are not given in Ref. [39], the one year committed equivalent dose to the uterus of an adult from inhalation

of particulate aerosol (AMAD 1 micron) for all absorption types as given in Ref. [73] was considered as the committed equivalent dose to the fetus.

[d] In this publication, the term 'fetus' encompasses both the embryo and the fetus.

[e] $h_{fetus,ing,i}$ is the value that gives the highest embryo or fetus organ dose for both acute and chronic ingestion, for all times of ingestion (including ingestion prior to the pregnancy) for each radionuclide as given in Ref. [39]. For radionuclides for which dose conversion factors are not given in Ref. [39], the one year committed equivalent dose to the uterus of an adult due to ingestion given in Ref. [73] was considered as the committed equivalent dose to the fetus.

+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

3.6.2. Dose conversion factors for the 'food pre-analysis' scenario

Table 26 provides the dose conversion factors for the committed effective dose to the representative person and the committed equivalent dose to the fetus for the 'food pre-analysis' scenario (needed in the calculation of $OIL3_\gamma$), over an exposure period Δ of 1 year. These dose conversion factors are determined as described in Sections 3.6.2.1 and 3.6.2.2.

3.6.2.1. Committed effective dose to the representative person for the 'food pre-analysis' scenario

Table 26 provides $e_{ing,food\text{-}pre\text{-}analysis\text{-}scenario,i}$ [Sv/(Bq/m^2)], which is the committed effective dose to the representative person from ingestion over 1 year, for the 'food pre-analysis' scenario, per unit ground surface activity of radionuclide i. It is determined by Eq. (32). For ingestion, the representative person is defined by a combination of the adult and infant dose conversion factors and consumption rates resulting in the highest dose as described in Table 13.

$$e_{ing,food-pre-analysis-scenario,i} = [\phi_1 \times F_{milk} \times U_{cow} \times F_{cow-feed} \times T_{feed\rightarrow cow-milk,i} \times \times \mathrm{Max}\left\{\begin{matrix}\left(Q_{milk}(infant) \times e_{ing,i}(infant)\right), \\ ,\left(Q_{milk}(adult) \times e_{ing,i}(adult)\right)\end{matrix}\right\} + \mathrm{Max}\left\{\begin{matrix}\left(Q_{lv}(infant) \times e_{ing,i}(infant)\right), \\ ,\left(Q_{lv}(adult) \times e_{ing,i}(adult)\right)\end{matrix}\right\} \times \times \phi_2 \times F_{lv}] \times \Delta_{eff,OIL3,i} \times F_{consumption,i} \quad (32)$$

where:

- Φ_1 = 3 m^2/kg is the mass interception factor for pasture grass in dry weight, i.e. ratio between the activity concentration on the plant [Bq/kg] and the unit ground surface activity on the terrestrial surface [Bq/m^2] (soil plus vegetation). It is described in Section 3.5.4.
- Φ_2 = 0.3 m^2/kg is the mass interception factor for leafy vegetables (fresh or wet weight), i.e. ratio between the activity concentration on the plant [Bq/kg] and the unit ground surface activity on the terrestrial surface [Bq/m^2] (soil plus vegetation). It is described in Section 3.5.4.
- F_{milk} = 0.5 [unitless] is the fraction of the milk consumed assumed to be affected before actions are taken to control intake.
- F_{lv} = 0.5 [unitless] is the fraction of the leafy vegetables consumed assumed to be affected before actions are taken to control intake.
- U_{cow} = 16 kg/d = 1.9E-04 kg/s is the cow consumption rate of feed in dry weight. It is obtained from Table XII of Ref. [64].

- $F_{cow\text{-}feed}$ = 0.7 [unitless] is the fraction of the cow feed assumed to be affected. It is obtained from Ref. [74][47].
- $T_{feed\rightarrow cow\text{-}milk,i}$ [s/L] is the transfer factor of radionuclide i from feed to the milk of the cow. The values are given in Table 21.
- Q_{milk}(infant) = 120 L/a = 3.8E-06 L/s is the consumption rate of milk by infants (considered for the representative person). It is obtained from Table 13 in annex B of Ref. [20].
- Q_{milk}(adult) = 105 L/a = 3.3E-06 L/s is the consumption rate of milk by adults (considered for the fetal exposure). It is obtained from Table 13 in annex B of Ref. [20].
- Q_{lv}(infant) = 20 kg/a = 6.3E-07 kg/s is the consumption rate of leafy vegetables in fresh weight by infants (i.e. the representative person). It is obtained from Table 13 in annex B of Ref. [20].
- Q_{lv}(adult) = 60 kg/a= 1.9E-06 kg/s is the consumption rate of leafy vegetables in fresh weight by adults (considered for the fetus). It is obtained from Table 13 in annex B of Ref. [20].
- $e_{ing,i}$(infant) [Sv/Bq] is the committed effective dose to the infant from ingestion, per unit intake of radionuclide i. The values are given in Table 27.
- $e_{ing,i}$(adult) [Sv/Bq] is the committed effective dose to the adult from ingestion, per unit intake of radionuclide i. The values are given in Table 27.
- $\Delta_{eff,OIL3,i}$ [s] is the effective availability period for radionuclide i for ingestion in the 'food pre-analysis' scenario. The values are given in Table 20.
- $F_{consumption,i}$ [unitless] is the fraction of the radionuclide i remaining at the time of human consumption. The values are given in Table 22.

3.6.2.2. Committed equivalent dose to the fetus for the 'food pre-analysis' scenario

Table 26 provides $h_{fetus,ing,food\text{-}pre\text{-}analysis\text{-}scenario,i}$ [Sv/(Bq/m^2)], which is the committed equivalent dose to the fetus from ingestion of food, milk and drinking water by the pregnant woman, over the period of in utero development, for the 'food pre-analysis' scenario, per unit ground surface activity of radionuclide i. It is determined by Eq. (33):

$$\begin{aligned} &h_{fetus,ing,food-pre-analysis-scenario,i} = \\ &= [\phi_1 \times F_{milk} \times U_{cow} \times F_{cow-feed} \times T_{feed\rightarrow cow-milk,i} \times Q_{milk}(adult) \times h_{fetus,ing,i} + \\ &+\phi_2 \times F_{lv} \times Q_{lv}(adult) \times h_{fetus,ing,i}] \times \Delta_{eff,OIL3,i} \times F_{consumption,i} \end{aligned} \quad (33)$$

where:

- $h_{fetus,ing,i}$ [Sv/Bq], which is the committed equivalent dose to the fetus from ingestion by an adult (i.e. pregnant woman), per unit intake of radionuclide i. The values are given in Table 27.
- The other factors are described above.

The contribution to the dose from ingestion of affected drinking water is not included in these calculations, because it is very hard to make a reasonable estimation of the dose received. However, since it could be a significant contributor to the dose, whenever $OIL3_\gamma$ is exceeded, as a precaution, the consumption and distribution of directly collected rainwater is restricted as well.

[47] Ref. [74] assumes for the average backyard cow an average dry matter intake of 11 kg/d, from which the pasture intake is 8 kg/d (dry mass), i.e. approximately a fraction of 0.7.

TABLE 26. DOSE CONVERSION FACTORS FOR THE ‘FOOD PRE-ANALYSIS’ SCENARIO

Radionuclide	$e_{ing,food\text{-}pre\text{-}analysis\text{-}scenario,i}$ [a] [Sv/(Bq/m^2)]	$h_{fetus,ing,food\text{-}pre\text{-}analysis\text{-}scenario,i}$ [b,c,d] [Sv/(Bq/m^2)]
Rb-86	1.2E-07	1.2E-08
Sr-89	4.3E-09	6.3E-08
Sr-90+	2.9E-08	2.1E-07
Sr-91	6.2E-12	4.0E-13
Y-91	2.5E-09	6.8E-13
Zr-95+	1.7E-09	6.2E-10
Zr-97+	4.2E-11	2.8E-12
Mo-99+	1.3E-10	1.9E-10
Ru-103+	5.6E-10	1.3E-10
Ru-105	9.3E-14	9.2E-15
Ru-106+	7.9E-09	3.3E-10
Rh-105	3.6E-11	8.8E-13
Te-127m+	3.4E-09	3.5E-09
Te-127	1.1E-12	1.2E-14
Te-129m+	3.4E-09	2.5E-09
Te-131m	1.3E-10	1.4E-09
Te-132+	9.9E-10	1.1E-08
I-131	4.6E-08	3.8E-07
I-133	8.9E-10	6.7E-09
I-134	8.3E-21	2.8E-20
I-135	1.0E-11	8.1E-11
Cs-134	1.8E-08	1.0E-08
Cs-136	3.0E-09	1.5E-09
Cs-137+	1.3E-08	6.8E-09
Ba-140+	2.8E-09	2.7E-09
Ce-141	5.9E-10	2.1E-11
Ce-143	7.3E-11	2.4E-12
Ce-144+	6.3E-09	2.2E-11
Pr-143	6.8E-10	2.6E-15
Nd-147	5.4E-10	1.5E-11
Np-239	1.1E-10	5.0E-12
Pu-238	1.1E-07	3.1E-09
Pu-239	1.2E-07	2.9E-09
Pu-240	1.2E-07	2.9E-09
Pu-241	2.4E-09	2.2E-12
Am-241	1.0E-07	1.6E-09
Cm-242	1.2E-08	1.0E-09
Cm-244	6.0E-08	1.6E-09

[a] $e_{ing,food\text{-}pre\text{-}analysis\text{-}scenario,i}$ calculated based on Eq. (32).
[b] $h_{fetus,ing,food\text{-}pre\text{-}analysis\text{-}scenario,i}$ calculated based on Eq. (33).
[c] In this publication, the term ‘fetus’ encompasses both the embryo and the fetus.
[d] An exposure period of 1 year instead of the 9 months specified in Table 2 is used for simplicity.
\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately

TABLE 27. DOSE CONVERSION FACTORS USED TO CALCULATE THE DOSE CONVERSION FACTORS FOR THE 'FOOD PRE-ANALYSIS', 'FOOD POST-ANALYSIS' AND 'SKIN' SCENARIOS

Radionuclide	$e_{ing,i}$(infant)[a] [Sv/Bq]	$e_{ing,i}$(adult)[b] [Sv/Bq]	$h_{fetus,ing,i}$[c,d] [Sv/Bq]	$ad_{skin,skin-srf,i}$[e] [(Gy/s)/(Bq/m^2)]
Rb-86	2.0E-08	2.8E-09	2.2E-09	3.3E-14
Sr-89	1.8E-08	2.6E-09	1.3E-07	3.2E-14
Sr-90+	9.3E-08	3.1E-08	3.4E-07	5.0E-14
Sr-91	4.0E-09	6.5E-10	1.3E-10	3.2E-14
Y-91	1.8E-08	2.4E-09	1.7E-12	3.2E-14
Zr-95+	1.3E-08	2.2E-09	1.5E-09	5.9E-15
Zr-97+	1.4E-08	2.2E-09	3.2E-10	6.5E-14
Mo-99+	3.6E-09	6.2E-10	2.5E-09	2.4E-14
Ru-103+	4.6E-09	7.3E-10	3.6E-10	1.1E-15
Ru-105	1.8E-09	2.6E-10	6.0E-11	2.6E-14
Ru-106+	4.9E-08	7.0E-09	6.9E-10	4.5E-14
Rh-105	2.7E-09	3.7E-10	2.7E-11	7.3E-15
Te-127m+	1.9E-08	2.5E-09	7.5E-09	1.4E-14
Te-127	1.2E-09	1.7E-10	4.9E-12	1.4E-14
Te-129m+	2.4E-08	3.0E-09	6.8E-09	3.1E-14
Te-131m	1.4E-08	1.9E-09	5.4E-08	7.1E-15
Te-132+	3.2E-08	4.1E-09	1.4E-07	3.0E-14
I-131	1.8E-07	2.2E-08	1.1E-06	1.1E-14
I-133	4.4E-08	4.3E-09	2.5E-07	2.6E-14
I-134	7.5E-10	1.1E-10	1.9E-09	3.4E-14
I-135	8.9E-09	9.3E-10	5.2E-08	2.2E-14
Cs-134	1.6E-08	1.9E-08	1.1E-08	1.1E-14
Cs-136	9.5E-09	3.0E-09	3.5E-09	6.4E-15
Cs-137+	1.2E-08	1.3E-08	7.2E-09	1.5E-14
Ba-140+	3.4E-08	5.0E-09	1.2E-08	5.7E-14
Ce-141	5.1E-09	7.1E-10	6.0E-11	6.0E-15
Ce-143	8.0E-09	1.1E-09	8.9E-11	2.6E-14
Ce-144+	3.9E-08	5.3E-09	4.7E-11	4.3E-14
Pr-143	8.7E-09	1.2E-09	1.1E-14	2.0E-14
Nd-147	7.8E-09	1.1E-09	7.3E-11	1.4E-14
Np-239	5.7E-09	8.0E-10	9.2E-11	5.0E-15
Pu-238	4.0E-07	2.3E-07	6.3E-09	6.0E-17
Pu-239	4.2E-07	2.5E-07	5.9E-09	2.3E-17
Pu-240	4.2E-07	2.5E-07	5.9E-09	5.7E-17
Pu-241	5.7E-09	4.8E-09	4.5E-12	3.6E-20
Am-241	3.7E-07	2.0E-07	3.2E-09	3.7E-16
Cm-242	7.6E-08	1.2E-08	2.2E-09	5.4E-17
Cm-244	2.9E-07	1.2E-07	3.3E-09	5.1E-17

[a] $e_{ing,i}$(infant) is the value for members of the public with an age between 1 and 2 a from Table III.2D of Ref. [14].
[b] $e_{ing,i}$(adult) is the value for members of the public with an age > 17 a from Table III.2D of Ref. [14].
[c] $h_{fetus,ing,i}$ is the value that gives the highest embryo or fetus organ dose for both acute and chronic ingestion, for all times of ingestion (including ingestion prior to the pregnancy) for each radionuclide as given in Ref. [39]. For

radionuclides for which dose conversion factors are not given in Ref. [39], the one year committed equivalent dose to the uterus of an adult due to ingestion given in Ref. [73] was considered as the committed equivalent dose to the fetus.

d In this publication the term 'fetus' encompasses both the embryo and the fetus.

e $ad_{skin,skin\text{-}srf,i}$ is calculated following the method described in Appendix VI.2 of Ref. [75] (this method is used instead of the values given in Table 19 of Ref. [75], because inconsistencies were found in Table 19 of Ref. [75]) using the spectral data from the CD accompanying Ref. [52]. The dose is to 100 cm^2 of the dermis (skin structures at a depth 0.4 mm below the surface). Severe damage to the derma over this area results in severe deterministic effects [19, 75, 76].

+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

3.6.3. Dose conversion factors for the 'skin' scenario

Table 28 provides the dose conversion factors for the 'skin' scenario (needed in the calculation of $OIL4_\gamma$ and $OIL4_\beta$), for the committed effective dose to the representative person and the committed equivalent dose to the fetus from inadvertent ingestion, and the RBE weighted absorbed dose from external exposure to the skin derma of the representative person. These dose conversion factors are determined as described in Sections 3.6.3.1, 3.6.3.2 and 3.6.3.3.

3.6.3.1. Committed effective dose to the representative person for the 'skin' scenario

Table 28 provides $e_{ing,skin\text{-}scenario,i}$ [Sv/(Bq/m^2)], which is the committed effective dose to the representative person (i.e. the infant for this exposure scenario and pathway) from inadvertent ingestion, for the 'skin' scenario, per unit skin surface activity of radionuclide i. It is determined by Eq. (34):

$$e_{ing,skin-scenario,i} = e_{ing,i}(infant) \times T_{skin \to GI}(infant) \times \Delta_{eff,OIL4-Urgent,i} \quad (34)$$

where:

- $e_{ing,i}$(infant) [Sv/Bq] is the committed effective dose to the infant from ingestion, per unit intake of radionuclide i. The values are given in Table 27.
- $T_{skin \to GI}$(infant) = 6.4E-08 m^2/s is the transfer factor from the skin to the GI tract due to inadvertent ingestion for the representative person (i.e. the infant for this exposure scenario and pathway). It is described in Section 3.5.8.
- $\Delta_{eff,OIL4\text{-}Urgent,i}$ [s] is the effective availability period for radionuclide i for inadvertent ingestion from the skin in the 'skin' scenario for the urgent generic criteria. The values are given in Table 20.

3.6.3.2. Committed equivalent dose to the fetus for the 'skin' scenario

Table 28 provides $h_{fetus,ing,skin\text{-}scenario,i}$ [Sv/(Bq/m^2)], which is the committed equivalent dose to the fetus from inadvertent ingestion of radioactive material on the skin, for the 'skin' scenario, per unit skin surface activity of radionuclide i. It is determined by Eq. (35):

$$h_{fetus,ing,skin-scenario,i} = h_{fetus,ing,i} \times T_{skin \to GI}(adult) \times \Delta_{eff,OIL4-Urgent,i} \quad (35)$$

where:

- $h_{fetus,ing,i}$ [Sv/Bq] is the committed equivalent dose to the fetus from ingestion by an adult (i.e. pregnant woman), per unit intake of radionuclide i. The values are given in Table 27.

- $T_{skin \rightarrow GI}$(adult) = 3.2E-08 m^2/s is the transfer factor from the skin to the GI tract due to inadvertent ingestion by the pregnant woman for fetal exposure. It is described in Section 3.5.8.
- $\Delta_{eff,OIL4\text{-}Urgent,i}$ [s] is the effective availability period for radionuclide i for inadvertent ingestion from the skin in the 'skin' scenario for the urgent generic criteria. The values are given in Table 20.

3.6.3.3. RBE weighted absorbed dose to the skin derma of the representative person for the 'skin' scenario

Table 28 provides $ad_{skin,skin\text{-}scenario,i}$ [$Gy/(Bq/m^2)$], which is the RBE weighted absorbed dose to the skin derma of the representative person,[48] for the 'skin' scenario, per unit skin surface activity of radionuclide i. It is determined by Eq. (36):

$$ad_{skin,skin-scenario,i} = ad_{skin,skin-srf,i} \times \Delta_{eff,OIL4-Acute,i} \quad (36)$$

where:

- $ad_{skin,skin\text{-}srf,i}$ [$(Gy/s)/(Bq/m^2)$] is the RBE weighted absorbed dose rate to the skin derma of the representative person from activity on the skin, per unit skin surface activity of radionuclide i. The values are given in Table 27.
- $\Delta_{eff,OIL4\text{-}Acute,i}$ [s] is the effective availability period for radionuclide i for inadvertent ingestion from the skin in the 'skin' scenario for the acute generic criteria. The values are given in Table 20.

[48] The RBE weighted absorbed dose rate to the skin derma is considered to be age independent.

TABLE 28. DOSE CONVERSION FACTORS FOR THE 'SKIN' SCENARIO

Radionuclide	$e_{ing,skin\text{-}scenario,i}$ [a] [Sv/(Bq/m²)]	$h_{fetus,ing,skin\text{-}scenario,i}$ [b,c] [Sv/(Bq/m²)]	$ad_{skin,skin\text{-}scenario,i}$ [d] [Gy/(Bq/m²)]
Rb-86	9.5E-11	5.2E-12	9.5E-10
Sr-89	8.7E-11	3.2E-10	9.1E-10
Sr-90+	4.6E-10	8.3E-10	1.4E-09
Sr-91	7.8E-12	1.3E-13	6.8E-10
Y-91	8.7E-11	4.1E-15	9.2E-10
Zr-95+	6.1E-11	3.7E-12	1.7E-10
Zr-97+	3.8E-11	4.2E-13	1.6E-09
Mo-99+	1.5E-11	4.9E-12	6.5E-10
Ru-103+	2.2E-11	8.7E-13	3.1E-11
Ru-105	2.0E-12	3.4E-14	4.1E-10
Ru-106+	2.4E-10	1.7E-12	1.3E-09
Rh-105	9.4E-12	4.7E-14	1.9E-10
Te-127m+	9.4E-11	1.8E-11	4.1E-10
Te-127	2.3E-12	4.7E-15	2.8E-10
Te-129m+	1.2E-10	1.6E-11	8.8E-10
Te-131m	4.6E-11	8.9E-11	1.8E-10
Te-132+	1.3E-10	2.9E-10	8.4E-10
I-131	8.2E-10	2.5E-09	3.1E-10
I-133	1.3E-10	3.6E-10	6.4E-10
I-134	2.1E-13	2.6E-13	1.4E-10
I-135	1.3E-11	3.9E-11	4.0E-10
Cs-134	7.8E-11	2.7E-11	3.2E-10
Cs-136	4.5E-11	8.2E-12	1.8E-10
Cs-137+	5.9E-11	1.8E-11	4.3E-10
Ba-140+	1.6E-10	2.8E-11	1.6E-09
Ce-141	2.5E-11	1.4E-13	1.7E-10
Ce-143	2.7E-11	1.5E-13	6.7E-10
Ce-144+	1.9E-10	1.2E-13	1.2E-09
Pr-143	4.1E-11	2.6E-17	5.8E-10
Nd-147	3.6E-11	1.7E-13	4.1E-10
Np-239	2.2E-11	1.8E-13	1.3E-10
Pu-238	2.0E-09	1.5E-11	1.7E-12
Pu-239	2.1E-09	1.4E-11	6.7E-13
Pu-240	2.1E-09	1.4E-11	1.6E-12
Pu-241	2.8E-11	1.1E-14	1.0E-15
Am-241	1.8E-09	7.9E-12	1.1E-11
Cm-242	3.7E-10	5.4E-12	1.5E-12
Cm-244	1.4E-09	8.1E-12	1.5E-12

[a] $e_{ing,skin\text{-}scenario,i}$ calculated based on Eq. (34).
[b] $h_{fetus,ing,skin\text{-}scenario,i}$ calculated based on Eq. (35).
[c] In this publication the term 'fetus' encompasses both the embryo and the fetus.
[d] $ad_{skin,skin\text{-}scenario,i}$ calculated based on Eq. (36).
\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

3.6.4. Dose conversion factors for the 'food post-analysis' scenario

Table 29 provides the dose conversion factors for the committed effective dose to the representative person and the committed equivalent dose to the fetus for the 'food post-analysis' scenario (needed in the calculation of OIL7), over an exposure period Δ of 1 year. These dose conversion factors are determined as described in Sections 3.6.4.1 and 3.6.4.2.

3.6.4.1. Committed effective dose to the representative person for the 'food post-analysis' scenario

Table 29 provides $e_{ing,food\text{-}post\text{-}analysis\text{-}scenario,i}$ [Sv/(Bq/kg)], which is the committed effective dose to the representative person from ingestion of food, milk and drinking water over 1 year, for the 'food post-analysis' scenario, per unit activity concentration of radionuclide i in food, milk or drinking water. It is determined by Eq. (37). For ingestion, the representative person is defined by a combination of the adult and infant dose conversion factors and consumption rates, resulting in the highest dose as described in Table 15.

$$e_{ing,food-post-analysis-scenario,i} = \\ = Max\begin{Bmatrix} \left(Q_{diet}(infant) \times e_{ing,i}(infant)\right), \\ ,\left(Q_{diet}(adult) \times e_{ing,i}(adult)\right) \end{Bmatrix} \times \Delta_{eff,OIL7,i} \times F_{diet,OIL7} \times F_{prep} \quad (37)$$

where:

- $e_{ing,i}(infant)$ [Sv/Bq] is the committed effective dose to the infant from ingestion, per unit intake of radionuclide i. The values are given in Table 27.
- $e_{ing,i}(adult)$ [Sv/Bq] is the committed effective dose to the adult from ingestion, per unit intake of radionuclide i. The values are given in Table 27.
- $Q_{diet}(infant)$ = 415 kg/a = 1.6E-05 kg/s is the consumption rate of food, milk and drinking water (total diet) by infants (considered for the representative person). It is obtained from Table 13 of annex B of Ref. [20].
- $Q_{diet}(adult)$ = 1040 kg/a = 3.2E-05 kg/s is the consumption rate of food, milk and drinking water (total diet) by adults (considered for the fetal exposure). It is obtained from Table 13 of annex B of Ref. [20].
- $\Delta_{eff,OIL7,i}$ [s] is the effective availability period for radionuclide i for ingestion in the 'food post-analysis' scenario. The values are given in Table 20.
- $F_{diet,OIL7}$ = 0.5 [unitless] fraction of the total diet (i.e. all food, milk and drinking water consumed) assumed to be affected for the 'food post-analysis' scenario. In reality, it is expected to be smaller, considering the diverse components and sources of the diet.
- F_{prep} = 1 [unitless] is the fraction of the radioactive material remaining for ingestion after preparations. It assumes no reduction due to normal preparations/processing (e.g. washing and cooking), which, in some cases, substantially reduces the concentration of radionuclides in the food [65].

3.6.4.2. Committed equivalent dose to the fetus for the 'food post-analysis' scenario

Table 29 provides $h_{fetus,ing,food\text{-}post\text{-}analysis\text{-}scenario,i}$ [Sv/(Bq/kg)], which is the committed equivalent dose to the fetus from ingestion of food, milk and drinking water by the pregnant woman over 1 year, for the 'food post-analysis' scenario, per unit activity concentration of radionuclide i in food, milk or drinking water. It is determined by Eq. (38):

$$h_{fetus,ing,food-post-analysis-scenario,i} = \\ = [h_{fetus,ing,i} \times Q_{diet}(adult) \times \Delta_{eff,OIL7,i} \times F_{diet,OIL7} \times F_{prep} \quad (38)$$

where:

- $h_{fetus,ing,i}$ [Sv/Bq] is the committed equivalent dose to the fetus from ingestion by an adult (i.e. pregnant woman), per unit intake of radionuclide i. The values are given in Table 27.
- The other factors are described above.

3.6.5. Dose conversion factors for the 'thyroid' scenario

$h_{thyroid,I\text{-}131\text{-}thyroid\text{-}burden}$ = 1.2E-05 Sv/Bq is the committed equivalent dose to the thyroid of an infant from I-131 in the thyroid (thyroid burden)[49] (needed in the calculation of OIL8). No specific values for $h_{thyroid,I\text{-}131\text{-}thyroid\text{-}burden}$ could be found, and therefore it was estimated based on the assumption that approximately 1/3 of the I-131 intake is retained in the thyroid, as described in Eq. (39). Although the equivalent dose to the thyroid from ingestion was used in Eq. (39), using dose conversion factors for inhalation would lead to the same result.

$$h_{thyroid,I-131-thyroid-burden} = h_{thyroid,ing-I-131} / F_{I-131-retained-in-thyroid} \quad (39)$$

where:

- $F_{I\text{-}131\text{-}retained\text{-}in\text{-}thyroid}$ = 0.3 [unitless] is the fraction of I-131 that is retained in the thyroid following intake. The value is based on Table XII-C6-3 of Ref. [77], which provides similar values for different age groups and times after intake.
- $h_{thyroid,ing\text{-}I\text{-}131}$ = 3.6E-06 Sv/Bq is the committed equivalent dose to the thyroid from ingestion of I-131 by the infant, per unit intake of I-131. It is obtained from Ref. [73].

[49] The contribution to the thyroid dose from short lived iodine and Te-132 were not included in the calculations, because they are not major contributors to the thyroid dose relative to I-131. The resulting OIL will be conservative, because the measured ambient dose equivalent rate is assumed to only result from I-131 (which contributes a much higher dose to the thyroid relative to its ambient equivalent dose rate).

TABLE 29. DOSE CONVERSION FACTORS FOR THE 'FOOD POST-ANALYSIS' SCENARIO

Radionuclide	$e_{ing,food-post-analysis-scenario,i}$ [a] [Sv/(Bq/kg)]	$h_{fetus,ing,food-post-analysis-scenario,i}$ [b,c,d] [Sv/(Bq/kg)]
Rb-86	3.1E-07	8.4E-08
Sr-89	7.4E-07	1.3E-05
Sr-90+	1.9E-05	1.7E-04
Sr-91	1.3E-09	1.1E-10
Y-91	8.5E-07	2.0E-10
Zr-95+	6.5E-07	2.0E-07
Zr-97+	8.3E-09	4.6E-10
Mo-99+	8.2E-09	1.4E-08
Ru-103+	1.5E-07	2.9E-08
Ru-105	2.7E-10	2.3E-11
Ru-106+	7.4E-06	2.6E-07
Rh-105	3.3E-09	8.2E-11
Te-127m+	1.5E-06	1.5E-06
Te-127	3.8E-10	3.9E-12
Te-129m+	6.7E-07	4.7E-07
Te-131m	1.4E-08	1.4E-07
Te-132+	8.5E-08	9.4E-07
I-131	1.2E-06	1.8E-05
I-133	3.1E-08	4.5E-07
I-134	2.2E-11	1.4E-10
I-135	2.0E-09	2.9E-08
Cs-134	8.4E-06	4.9E-06
Cs-136	1.0E-07	9.5E-08
Cs-137+	6.7E-06	3.7E-06
Ba-140+	3.5E-07	3.1E-07
Ce-141	1.4E-07	4.0E-09
Ce-143	9.0E-09	2.5E-10
Ce-144+	5.4E-06	1.6E-08
Pr-143	9.7E-08	3.1E-13
Nd-147	7.0E-08	1.6E-09
Np-239	1.1E-08	4.5E-10
Pu-238	1.2E-04	3.3E-06
Pu-239	1.3E-04	3.1E-06
Pu-240	1.3E-04	3.1E-06
Pu-241	2.4E-06	2.3E-09
Am-241	1.0E-04	1.7E-06
Cm-242	8.0E-06	5.8E-07
Cm-244	6.1E-05	1.7E-06

[a] $e_{ing,food-post-analysis-scenario,i}$ is calculated based on Eq. (37).
[b] $h_{fetus,ing,food-post-analysis-scenario,i}$ is calculated based on Eq. (38).
[c] In this publication, the term 'fetus' encompasses both the embryo and the fetus.
[d] An exposure period of 1 year instead of the 9 months specified in Table 2 is used for simplicity.
\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

3.7. INSTRUMENT RESPONSE

OILs are operational criteria intended to be used with monitoring results provided by instruments. This section describes how the response of the instruments was considered in the OIL calculations.

3.7.1. Ambient dose equivalent rate

It is assumed that all ambient dose equivalent rate instruments respond similarly while measuring the ambient dose equivalent rate H*(10), with the response depending on the monitored surface or object, the monitoring procedures and the conditions encountered. OILs are provided for the ambient dose equivalent rate as measured by a field survey instrument for emissions from radioactive material deposited on the ground ($OIL1_\gamma$, $OIL2_\gamma$, $OIL3_\gamma$), radioactive material deposited on the skin ($OIL4_\gamma$) and radioactive material in the thyroid ($OIL8_\gamma$). The basis for the ambient dose equivalent rate for these OILs (as measured at the recommended distance) is described below.

3.7.1.1. Ground monitoring for $OIL1_\gamma$, $OIL2_\gamma$ and $OIL3_\gamma$

The ambient dose equivalent rate at 1 m above ground level, per unit ground surface activity of radionuclide i (i.e. $H^*_{grd\text{-}sh,i}$ [(Sv/s)/(Bq/m^2)]) is given in Table 30 and determined by Eq. (40):

$$H^*_{grd-sh,i} = e_{plane-srf,i}(adult) \times CorF_{grd} \times SF_{e\rightarrow H^*} \quad (40)$$

where:

- $e_{plane\text{-}srf,i}$(adult) [(Sv/s)/(Bq/m^2)] is the effective dose rate to the adult from an infinite smooth plane source, per unit surface activity of radionuclide i. The values are given in Table 24.
- $CorF_{grd}$ = 0.7 [unitless] is the ground roughness correction factor to account for the dose rate reduction due to ground roughness, as described in Ref. [69].
- $SF_{e\rightarrow H^*}$ = 1.4 [unitless] is the scaling factor to convert the effective dose into ambient dose equivalent for the photon energies of concern. It is obtained from Section 5.3.2 of Ref. [78].

3.7.1.2. Skin monitoring for $OIL4_\gamma$

The ambient dose equivalent rate at 10 cm from activity on 100 cm^2 of the skin surface, per unit surface activity of radionuclide i (i.e. $H^*_{skin\text{-}100cm^2\text{-}srf,i}$ [(Sv/s)/(Bq/m^2)]) is given in Table 30 and determined by Eq. (41):

$$H^*_{skin-100cm^2-srf,i} = \sum_j Y^\gamma_{E_{j,i}} \times ConF_{\phi\rightarrow H^*(10),E_j} \times GF_{srf} \times UC \quad (41)$$

where:

- $Y^\gamma_{E_{j,i}}$ [Bq^{-1} s^{-1}] is the absolute yield of discrete photons of energy E_j emitted per nuclear transformation of the radionuclide i. It is taken from the CD accompanying Ref. [52].
- $ConF_{\phi\rightarrow H^*(10),E_j}$ [pSv cm^2] is the conversion factor for the ambient dose equivalent H*(10) [pSv] per fluence [cm^{-2}] of photons with energy E_j. It is obtained from Table A.21 of Ref. [78]. For those energies not in Table A.21 of Ref. [78], the conversion factor was derived by interpolation.
- UC = 10^{-6} (Sv m^2)/(pSv cm^2) is a unit conversion factor.

- GF_{srf} [unitless] is the geometry factor to account for the measurement being taken at 10 cm from the skin with an instrument with a view of 100 cm^2. It is determined by Eq. (42), which was obtained based on Eq. 30 of Ref. [79]:

$$GF_{srf} = \frac{1}{4}\ln\left[1 + \left(\frac{R_{view-area}}{d_{monitoring}}\right)^2\right] \tag{42}$$

where:

- $d_{monitoring}$ = 0.1 m is the monitoring distance at which the measurements of the skin are recommend to be taken for the default $OIL4_\gamma$ value (as indicated in Section 2.6.2), and is considered a reasonable distance for skin surface monitoring under emergency conditions.
- $R_{view-area}$ = 0.0564 m is the radius of a circle with an area of 100 cm^2. This area was chosen because it is the typical surface area of a hand [80] and face. The skin of the hand and face are to be monitored in accordance with the procedures for the default $OIL4_\gamma$ indicated in Section 2.6.2.

TABLE 30. AMBIENT DOSE EQUIVALENT RATE CONVERSION FACTORS

Radionuclide	$H^*_{grd\text{-}sh,i}$ [a] [(Sv/s)/(Bq/m^2)]	$H^*_{skin\text{-}100cm^2\text{-}srf,i}$ [b] [(Sv/s)/(Bq/m^2)]
Rb-86	9.1E-17	3.3E-18
Sr-89	2.2E-18	3.2E-21
Sr-90+	5.5E-18	4.7E-22
Sr-91	6.6E-16	2.6E-17
Y-91	5.6E-18	1.1E-19
Zr-95+	2.3E-15	9.1E-17
Zr-97+	1.5E-15	5.9E-17
Mo-99+	2.6E-16	1.1E-17
Ru-103+	4.5E-16	2.1E-17
Ru-105	7.5E-16	3.0E-17
Ru-106+	2.1E-16	8.1E-18
Rh-105	7.5E-17	3.2E-18
Te-127m+	1.6E-17	2.5E-18
Te-127	5.1E-18	2.1E-19
Te-129m+	7.5E-17	5.0E-18
Te-131m	1.3E-15	5.4E-17
Te-132+	2.4E-15	9.8E-17
I-131	3.7E-16	1.6E-17
I-133	5.9E-16	2.4E-17
I-134	2.5E-15	9.4E-17
I-135	1.4E-15	5.3E-17
Cs-134	1.5E-15	6.0E-17
Cs-136	2.0E-15	7.8E-17
Cs-137+	5.7E-16	2.3E-17
Ba-140+	2.7E-15	1.0E-16
Ce-141	7.2E-17	3.7E-18
Ce-143	2.7E-16	1.3E-17
Ce-144+	5.7E-17	2.0E-18
Pr-143	6.9E-19	3.4E-25
Nd-147	1.4E-16	7.1E-18
Np-239	1.6E-16	1.1E-17
Pu-238	8.2E-19	6.5E-19
Pu-239	3.6E-19	2.8E-19
Pu-240	7.9E-19	6.1E-19
Pu-241	1.9E-21	1.4E-22
Am-241	2.7E-17	3.7E-18
Cm-242	9.4E-19	6.4E-19
Cm-244	8.6E-19	5.5E-19

[a] $H^*_{grd\text{-}sh,i}$ is calculated based on Eq. (40).
[b] $H^*_{skin\text{-}100cm^2\text{-}srf,i}$ is calculated based on Eq. (41).
\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

3.7.1.3. Thyroid monitoring for $OIL8_\gamma$

$OIL8_\gamma$ was initially calculated for a variety of instruments [81, 82, 83, 84], but it was found that not all instruments would result in a default $OIL8_\gamma$ value above 0.5 µSv/h, which is considered the lowest practical ambient dose equivalent rate for monitoring the thyroid under severe emergency conditions (lower values may not be feasible due to increased variation in the background radiation). Therefore, in order for $OIL8_\gamma$ to be operational, i.e. usable under field conditions, a baseline instrument for monitoring the thyroid is used in the calculation of the default $OIL8_\gamma$ value. This baseline instrument for monitoring the thyroid is defined by (a) a calibration factor ≤ 3.5E+13 Bq/(Sv/s) and (b) an effective area ≤ 15 cm^2 (due to the geometrical considerations). Instruments with higher calibration factors that will result in default $OIL8_\gamma$ values below 0.5 µSv/h may be used if the measurement is taken in a low background or the monitoring technique is improved in any other way.

The ambient dose equivalent rate ($H^*_{I\text{-}131\text{-thyroid-burden}}$(baseline-inst)) in front of the thyroid as measured with the baseline instrument for monitoring the thyroid (baseline-inst) against the neck of the infant, per unit activity of I-131 (burden) in the thyroid, is equal to 2.9E-14 (Sv/s)/Bq (i.e. 0.1 (µSv/h)/kBq, as used in the OIL chart for thyroid monitoring given in Section 2.6.4) and determined by Eq. (43):

$$\mathrm{H}^*_{\mathrm{I-131-thyroid-burden}}(\mathrm{baseline-inst}) = \frac{1}{\mathrm{CalF}_{\mathrm{R,I-131}}(\mathrm{baseline-inst})} \quad (43)$$

where:

- $CalF_{R,I\text{-}131}$(baseline-inst) = 3.5E+13 Bq/(Sv/s) is the calibration factor of the baseline monitoring instrument for the activity of I-131 in the thyroid relative to the ambient dose rate measured in front of the thyroid in contact with the skin of an infant.

Examples of possible methods for determining the calibration factor are described in Refs [81, 84]. Providing detailed guidance on how to derive the calibration factor for specific instruments lies beyond the scope of this publication.

3.7.2. Beta monitoring instrument response

The response of beta monitoring instruments (e.g. cps) is needed for the calculation of the default and instrument specific $OIL4_\beta$ values. Under emergency conditions, for the same surface activity, the response of different instruments can be considerably different depending on factors such as: (a) the efficiency of the instrument for the radionuclides being measured; (b) the window area of the instrument; (c) the area being monitored relative to the window area of the instrument; (d) surface conditions (e.g. irregular, presence of dirt); and (e) monitoring techniques (e.g. duration of measurement or distance of the detector from the surface). In addition, not all surface contamination monitors are suitable for monitoring skin contamination during an emergency (e.g. the window area may be too large to give representative results for monitoring the hands and face). These factors were accounted for in the default $OIL4_\beta$ value by:

- Using the response of a baseline monitoring instrument (for all the radionuclides of concern) in calculating the default $OIL4_\beta$ value, as described in Section 3.7.2.1. This baseline monitoring instrument has a detector area and an efficiency such that its response would be conservative or within a factor of two to the wide range of instruments for monitoring surface contamination typically used for monitoring beta activity on the skin during an emergency. This does not include instruments designed for detection (e.g. those used by first responders such as HAZMAT teams).

- Including correction factors that account for reductions in count rate due to the distance of the detector from the surface and surface conditions encountered during the emergency.
- Stating the measurement distance and providing a description of a suitable instrument in the beta chart for skin monitoring in Section 2.6.2.

This is done to allow for the use of the default $OIL4_{\beta}$ value without revision for most suitable instruments. However, if the specific properties (e.g. efficiency and detector area) of the beta monitoring instruments to be used in the response to the emergency are known, either (a) the suitability of the default $OIL4_{\beta}$ value needs to be confirmed or (b) the default $OIL4_{\beta}$ value needs to be calculated for this specific instrument, following the instructions provided in Section 5.2. This needs to be done in advance as part of the preparedness, since calculation and effective application of instrument specific OILs early during an emergency may be very difficult, if not impossible.

Section 3.7.2.1 describes the baseline beta monitoring instrument, Section 3.7.2.2 the impact of the field conditions and Section 3.7.2.3 the suitability criteria for beta monitoring instruments.

3.7.2.1. Baseline beta monitoring instrument

The baseline beta monitoring instrument is characterized by its effective window area and its ideal response factors, which will be required in calculating the default $OIL4_{\beta}$ value and determining the coefficients and calibration factors of the baseline beta monitoring instrument. These are needed in the calculation of an instrument specific $OIL4_{\beta}$ value (as discussed in Section 5.2).

3.7.2.1.1. Effective window area of the baseline beta monitoring instrument

For the baseline beta monitoring instrument (used in the calculation of the default $OIL4_{\beta}$ value provided in Section 2.6.2), an effective window area ($a_{eff,\beta}$(baseline-inst) [cm^2]) of 15 cm^2 is used, because it is at the low end of the effective window areas of the commonly available beta monitoring instruments.

3.7.2.1.2. Ideal response factor of the baseline beta monitoring instrument

The ‘ideal response factor’ is equivalent to the efficiency of the baseline monitoring instrument. The term ‘ideal response factor’ is used instead of ‘efficiency’ to avoid any confusion with efficiency values obtained based on empirical data (i.e. by using a reference source). This was necessary considering that the efficiencies of the baseline beta monitoring instrument had to be calculated for all radionuclides, since vendors typically only provide the efficiencies for a few radionuclides and not for all those of concern in a reactor emergency.

The ideal response factor of the baseline beta monitoring instrument ($R_{4\pi,\beta,i}$(baseline-inst) [cps/Bq]) reflects the response [cps] for each nuclear transformation per second [Bq] of radionuclide i on the surface, for 4π geometry[50], assuming ideal conditions (e.g. no self-absorption or air absorption) and the instrument window being very close to the surface. It is given in Table 32 and determined by Eq. (44):[51]

$$R_{4\pi,\beta,i}(\text{baseline} - \text{inst}) = Y_{\beta,E,i} \times F_{\text{ideal-surf-emission}} \times R_{\beta}(\text{baseline} - \text{inst}) \qquad (44)$$

where:

- $Y_{\beta,E,i}$ [Bq^{-1} s^{-1}] is the number of particles of interest emitted with energies equal to or above 75 keV (i.e. detectable by the baseline monitor) per nuclear transformation of radionuclide i (yield); the particles of interest include beta +, beta – and internal conversion electrons. The values are given in Table 32.
- $F_{\text{ideal-surf-emission}}$ = 0.5 [unitless] is the ideal surface emission factor, i.e. the ratio between (a) the number of particles that emerge from the front face of a surface and (b) the number of particles emitted from a radionuclide on the surface. This accounts for the fact that half of the emissions escape towards the detector under ideal conditions (e.g. no backscatter, self-absorption or air absorption).
- R_{β}(baseline-inst) = 0.3 [counts] is the ratio between (a) the number of counts by the baseline instrument and (b) the number of particles of interest with an energy above 75 keV (and thus assumed to be detected) that reach the outside face of the detector. This value is chosen to ensure that, for the relevant range of energies, the $R_{4\pi,\beta,i}$(baseline-inst) values are lower than (i.e. conservative)[52] the 4π instrument efficiencies stated by instrument manufacturers for most of the contamination monitoring instruments.

The $R_{4\pi,\beta,i}$(baseline-inst) values given in Table 32 were compared to the instrument efficiencies for medium and high energy beta emitters (e.g. C-14, Cl-36, C-60, Cs-137, I-129, Sr-90 and Tc-99) stated by instrument manufacturers for a range of beta surface contamination monitoring instruments that could be used in the field. This does not include instruments designed for detection (e.g. those used by first responders such as HAZMAT teams). It was found that the $R_{4\pi,\beta,i}$(baseline-inst) values were lower (i.e. more conservative) than the 4π instrument efficiencies stated by instrument manufacturers for most of the instruments, and within a factor of two of those stated by virtually all the instrument vendors.

3.7.2.1.3. Instrument coefficient and calibration factors of the baseline beta monitoring instrument

The calibration factors and instrument coefficients of the baseline beta monitoring instrument are only used for the calculation of an instrument specific $OIL4_{\beta}$ value (as discussed in Section 5.2), and therefore only calculated for a limited number of radionuclides, i.e. those often provided by vendors, as described in Table 31.

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[50] The numerical value of $R_{4\pi,\beta,i}$(baseline-inst) corresponds to (or is often referred to) the 4π efficiency stated by many manufacturers. It is assumed that the 2π efficiency is equal to 2 times the 4π efficiency.

[51] This approach does not consider backscatter; which is ‘conservative’, since the count rate with backscatter will be higher than calculated here.

[52] ‘Conservative’ meaning that using the default $OIL4_{\beta}$ value for the baseline monitor will result in actions being taken at projected dose below the generic criteria under real conditions with virtually all beta monitoring instruments. The conservatism considered in this publication are discussed in Section 3.10.

- The baseline beta monitoring instrument coefficient for radionuclide i (i.e. $C_{\beta,i}$(baseline-inst) [cps/(Bq/cm^2)]) is given in Table 31 and determined by Eq. (45):

$$C_{\beta,i}(\text{baseline} - \text{inst}) \cong a_{\text{eff},\beta}(\text{baseline} - \text{inst}) \times R_{4\pi,\beta,i}(\text{baseline} - \text{inst}) \quad (45)$$

where:

  - $a_{\text{eff},\beta}$(baseline-inst) = 15 cm^2 is the effective window area (e.g. sensitive or radiation inlet area) of the baseline beta monitoring instrument and is described in Section 3.7.2.1.1.
  - $R_{4\pi,\beta,i}$(baseline-inst) [cps/Bq] is the ideal response factor of the baseline beta monitoring instrument, which reflects the response [cps] for each nuclear transformation per second [Bq] of radionuclide i on the surface, for 4π geometry, assuming ideal conditions (e.g. no self-absorption or air absorption) and the instrument window being very close to the surface. It is given in Table 32.[53]

- The calibration factor of the baseline beta monitoring instrument for radionuclide i ($\text{CalF}_{\beta,i}$(baseline-inst) [(Bq/cm^2)/cps]) is given in Table 31 and determined by Eq. (46):

$$\text{CalF}_{\beta,i}(\text{baseline} - \text{inst}) = 1/C_{\beta,i}(\text{baseline} - \text{inst}) \quad (46)$$

3.7.2.2. Field beta correction factor

Field monitoring conditions may result in the beta monitoring instruments providing considerably different responses (in cps) to the same levels of deposition of radioactive material. To account for the reduction in the beta count rate for measurements made under field (i.e. non-ideal) conditions, the field beta correction factor of $\text{CorF}_{\text{field},\beta}$ = 0.25 [unitless] is used, which accounts for absorption by the air (OIL4_β was calculated for measurements at 2 cm from the bare skin) and reductions due to surface conditions. It is determined by Eq. (47):

$$\text{CorF}_{\text{field},\beta} = \text{CorF}_{\text{distance},\beta} \times \text{CorF}_{\text{surface},\beta} \quad (47)$$

where:

- $\text{CorF}_{\text{distance},\beta}$ = 0.5 [unitless] is the distance correction factor for the beta monitoring instrument that accounts for the reduction due to absorption in air at the recommended distance of 2 cm for skin monitoring. It is based on Table 4.5 of Ref. [85] for the medium or high energy beta emitters of concern during a reactor emergency.
- $\text{CorF}_{\text{surface},\beta}$ = 0.5 [unitless] is the surface correction factor for the beta monitoring instrument that accounts for the absorption due to non-ideal surface conditions encountered during an emergency. It is based on Table 5.15 of Ref. [85] for the medium or high energy beta emitters of concern during a reactor emergency.

[53] The numerical value of $R_{4\pi,\beta,i}$(baseline-inst) corresponds to (or is often referred to as) the 4π efficiency stated by many manufacturers. It is assumed that the 2π efficiency is equal to 2 times the 4π efficiency.

3.7.2.3. Suitability criteria for the beta monitoring instrument

This section provides criteria to determine if a beta monitoring instrument is suitable for the default $OIL4_\beta$ for monitoring the activity on the skin. The suitability criteria can be divided into (a) general criteria applicable to all beta monitoring instruments to be used for skin monitoring and (b) suitability criteria for use with the default $OIL4_\beta$ value provided in this publication.

3.7.2.3.1. General suitability criteria for all beta monitoring instruments

As a minimum criterion, a beta monitoring instrument is considered suitable to be used for monitoring the skin activity if:

- The instrument can display cps (or equivalent cpm) over the relevant ranges of the $OIL4_\beta$ values.
- The effective window area of the instrument is less than or equal to 50 cm^2. This maximum window area is specified to prevent significantly non-conservative responses in terms of counts per second relative to the actual level of surface activity on the hands and face. These non-conservative responses would result from (a) the detector area being significantly larger than the area of the face and hands being monitored (the $OIL4_\beta$ value assumes that the window is smaller or approximately equal to the hand or face area being monitored) and (b) significant portions of the monitor window being located at distances from hand and face greater than the 2 cm assumed in the calculation of $OIL4_\beta$.[54]

3.7.2.3.2. Suitability criteria for use with the default $OIL4_\beta$ value

A beta monitoring instrument is considered suitable to be used directly with the default $OIL4_\beta$ value provided in this publication, without having to adapt the value to the specific instrument, if:

- Either the calibration factors of the beta monitoring instrument ($CalF_{\beta,i}(inst)$ [(Bq/cm^2)/cps]), as determined by Eq. (48), are smaller than the calibration factor of the suitable instrument given in Table 31.

$$CalF_{\beta,i}(inst) \cong 1/a_{eff,\beta}(inst) \times R_{4\pi,\beta,i}(inst) \qquad (48)$$

where:

- $a_{eff,\beta}(inst)$ [cm^2] is the effective window area (e.g. sensitive or radiation inlet area) of the beta monitoring instrument (inst).
- $R_{4\pi,\beta,i}(inst)$ [cps/Bq] is the response factor of the beta monitoring instrument, which reflects the response [cps] for each nuclear transformation per second [Bq] of radionuclide i on the surface, for 4π geometry, assuming ideal conditions (e.g. no self-absorption or air absorption) and the instrument window being very close to the surface. It is often provided by the manufacturer as the 4π efficiency of the instrument. If the

[54] This is applicable to any other irregular (i.e. non-plane) surface because of the significant reduction due to absorption in air, as described in Section 3.7.2.2.

manufacturer only provides a 2π geometry efficiency, divide this by 2 to get the 4π efficiency.[55]

- Or the instrument coefficients of the beta monitoring instrument ($C_{\beta,i}$(inst) [cps/(Bq/cm^2)]), as determined by Eq. (49), are greater than the instrument coefficients of the suitable instrument given in Table 31.

$$C_{\beta,i}(\text{inst}) \cong a_{\text{eff},\beta}(\text{inst}) \times R_{4\pi,\beta,i}(\text{inst}) \tag{49}$$

These conditions ensure that the instrument has a response within a factor of 2 or higher (i.e. conservative) than that assumed in the development of the $OIL4_\beta$ value.

TABLE 31. CALIBRATION FACTORS AND INSTRUMENT COEFFICIENTS FOR THE BASELINE AND SUITABLE BETA MONITORING INSTRUMENTS

Emitter	Baseline instrument (baseline-inst)		Suitable instrument (suitable-inst)	
	$CalF_{\beta,i}$[a] [(Bq/cm^2)/cps]	**$C_{\beta,i}$**[b] [cps/(Bq/cm^2)]	**$CalF_{\beta,i}$**[c] [(Bq/cm^2)/cps]	**$C_{\beta,i}$**[d] [cps/(Bq/cm^2)]
P-32, Cl-36, Cs-137 or other medium or high energy beta emitters ($E_{\beta,max}$ > 400 keV)	0.5	2	< 1	> 1
Sr-90 / Y-90 (Sr-90 in equilibrium with progeny Y-90)	0.25	4	< 0.5	> 2

[a] $CalF_{\beta,i}$(baseline-inst) is determined by Eq. (46).
[b] $C_{\beta,i}$(baseline-inst) determined by Eq. (45).
[c] $CalF_{\beta,i}$(suitable-inst) is 2 times the $CalF_{\beta,i}$(baseline-inst).
[d] $C_{\beta,i}$(suitable-inst) is 1/2 of the $C_{\beta,i}$(baseline-inst).

[55] 4π efficiency applies to emissions in all directions, and 2π efficiency applies to emissions toward the detector.

TABLE 32. ENERGY RELATED YIELD AND IDEAL RESPONSE FACTOR OF THE BASELINE BETA MONITORING INSTRUMENT

Radionuclide	$Y_{\beta,E,i}$ [a] [Bq^{-1} s^{-1}]	$R_{4\pi,\beta,i}$(baseline-inst) [b] [cps/Bq]
P-32 [c]	9.7E-01	1.5E-01
Cl-36 [c]	8.6E-01	1.3E-01
Rb-86	9.5E-01	1.4E-01
Sr-89	9.4E-01	1.4E-01
Sr-90+	1.8E+00	2.6E-01
Sr-91	9.4E-01	1.4E-01
Y-91	9.5E-01	1.4E-01
Zr-95+	1.0E+00	1.5E-01
Zr-97+	1.9E+00	2.9E-01
Mo-99+	1.0E+00	1.5E-01
Ru-103+	3.5E-01	5.2E-02
Ru-105	1.1E+00	1.7E-01
Ru-106+	9.9E-01	1.5E-01
Rh-105	6.8E-01	1.0E-01
Te-127m+	1.4E+00	2.1E-01
Te-127	8.1E-01	1.2E-01
Te-129m+	1.3E+00	1.9E-01
Te-131m	8.0E-01	1.2E-01
Te-132+	1.4E+00	2.1E-01
I-131	7.8E-01	1.2E-01
I-133	9.1E-01	1.4E-01
I-134	9.7E-01	1.5E-01
I-135	8.5E-01	1.3E-01
Cs-134	5.9E-01	8.8E-02
Cs-136	7.3E-01	1.1E-01
Cs-137+	8.6E-01	1.3E-01
Ba-140+	2.0E+00	3.0E-01
Ce-141	9.1E-01	1.4E-01
Ce-143	9.3E-01	1.4E-01
Ce-144+	1.5E+00	2.3E-01
Pr-143	8.8E-01	1.3E-01
Nd-147	8.9E-01	1.3E-01
Np-239	1.3E+00	2.0E-01
Pu-238	1.0E-03	1.5E-04
Pu-239	3.9E-04	5.8E-05
Pu-240	8.0E-04	1.2E-04
Pu-241	7.9E-06	1.2E-06
Am-241	3.3E-03	5.0E-04
Cm-242	4.0E-04	6.1E-05
Cm-244	3.1E-04	4.6E-05

[a] $Y_{\beta,E,i}$ [Bq^{-1} s^{-1}] is obtained from the CD accompanying Ref. [52].
[b] $R_{4\pi,\beta,i}$(baseline-inst) is calculated based on Eq. (44).
[c] P-32 and Cl-36 are provided in this table (and not in the other tables) because they are often used for the calibration of instruments, but are not relevant to the dose received by the public following a severe release of radioactive material from an LWR or its spent fuel.
\+ The progenies that are in equilibrium with this parent radionuclide (as listed in Table 5) have been considered in the OIL calculations as being in equilibrium with the parent and do not need to be considered separately.

3.8. OIL(t,mix) FUNCTIONS AND DEFAULT OIL VALUES

This section provides the calculations to determine the time and mix dependent OIL(t,mix) functions, which are used as a basis for selecting the default OIL values. For each of the OILs, two sections are provided describing (a) the calculation of the OIL(t,mix) functions and (b) the analysis of the OIL(t,mix) functions to choose default OIL values.

Although the use of prefixed SI units and the use of non-SI units has been avoided as far as reasonable throughout this publication, due to the common use of μSv/h when monitoring, the OIL(t,mix) functions and default OIL values are given in μSv/h.

3.8.1. OIL1$_\gamma$

3.8.1.1. OIL1$_\gamma$(t,mix) calculation

Calculation of the default OIL1$_\gamma$ value is based on evaluation of the OIL1$_\gamma$(t,mix) functions for each mix given in Table 3. OIL1$_\gamma$(t,mix) [μSv/h] is the ambient dose equivalent rate measured at 1 m above ground level at time t after reactor shutdown, which, for the 'ground' scenario, results in any of the generic criteria specified for OIL1$_\gamma$ (in Table 2) being met, for a specific radionuclide mix. The values are given in Fig. 9 for all considered mixes and are determined by Eq. (50):

$$\mathrm{OIL1_\gamma(t,mix)} = \left(\sum_{\mathrm{i}} \left(\mathrm{RA_i(t,mix)} \times \mathrm{H^*_{grd-sh,i}}\right)\right) \times \mathrm{WF_{OIL1_\gamma}} \times \mathrm{UC} \times \mathrm{DA_{OIL1}(t,mix)} \quad (50)$$

where:

- t [s] is the time after shutdown of the reactor (i.e. after the fuel was last irradiated in a reactor).
- 'mix' refers to the mix number as provided in Table 3, Table 7, Table 8 and Table 9.
- RA_i(t,mix) [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).
- $H^*_{grd-sh,i}$ [(Sv/s)/(Bq/m^2)] is the ambient dose equivalent rate at 1 m above ground level, per unit ground surface activity of radionuclide i. The values are given in Table 30.
- $WF_{OIL1\gamma}$ = 3 [unitless] is a weighting factor used to avoid the implementation of unwarranted response actions based on the default OIL1$_\gamma$ value. It is described in Section 3.9.
- UC = 3.6E+09 (μSv/h)/(Sv/s) is the unit conversion factor from Sv/s to μSv/h.
- DA_{OIL1}(t,mix) [Bq/m^2] is the derived gross activity on the ground at time t after reactor shutdown, which, for the 'ground', scenario results in any of the generic criteria specified for OIL1$_\gamma$ (in Table 2) being met, for a specific radionuclide mix. It is determined by Eq. (51):

$$\mathrm{DA_{OIL1}(t,mix)} = \min\left\{\mathrm{A_{OIL1,E}(t,mix)},\ \mathrm{A_{OIL1,H_{fetus}}(t,mix)}\right\} \quad (51)$$

  where:

  - $A_{OIL1,E}$(t,mix) [Bq/m^2] is the gross activity on the ground at time t after reactor shutdown, which, for the 'ground' scenario, results in a total effective dose to the representative person meeting the GC(Urgent,E,7d), for a specific radionuclide mix. It is determined by Eq. (52).

$$A_{OIL1,E}(t,mix) = \frac{GC(Urgent,E,7d)}{\sum_i \left(E_{grd-scenario,i}(7d) \times RA_i(t,mix)\right)} \quad (52)$$

where:

- GC(Urgent,E,7d) = 0.1 Sv is the generic criterion used to take urgent response actions based on the total effective dose to the representative person in the first 7 days (given in Table 2).
- $E_{grd\text{-}scenario,i}$(7d) [Sv/(Bq/m^2)] is the total effective dose to the representative person over an exposure period Δ of 7 days for the 'ground' scenario, per unit ground surface activity of radionuclide i. The values are given in Table 23.
- RA_i(t,mix) [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).

- $A_{OIL1,H_{fetus}}$(t,mix) [Bq/m^2] is the gross activity on the ground at time t after reactor shutdown, which, for the 'ground' scenario results in a total equivalent dose to the fetus meeting the GC(Urgent,H_{fetus},7d), for a specific radionuclide mix. It is determined by Eq. (53):

$$A_{OIL1,H_{fetus}}(t,mix) = \frac{GC(Urgent,H_{fetus},7d)}{\sum_i \left(H_{fetus,grd-scenario,i}(7d) \times RA_i(t,mix)\right)} \quad (53)$$

where:

- GC(Urgent,H_{fetus},7d) = 0.1 Sv is the generic criterion used to take urgent response actions based on the total equivalent dose to the fetus in the first 7 days (given in Table 2).
- $H_{fetus,grd\text{-}scenario,i}$(7d) [Sv/(Bq/m^2)] is the total equivalent dose to the fetus over an exposure period Δ of 7 days for the 'ground' scenario, per unit ground surface activity of radionuclide i. The values are given in Table 23.
- RA_i(t,mix) [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).

3.8.1.2. Analysis

The $OIL1_\gamma$(t,mix) functions calculated in this way are displayed in Fig. 9.[56] The red line shows the chosen default $OIL1_\gamma$ value of 1000 μSv/h, which is lower than the $OIL1_\gamma$(t,mix) functions for almost all times after shutdown and mixes.

[56] The reason that some of the OIL(t,mix) functions are not smooth is the 'min' function used in the calculation of the DA(t,mix).

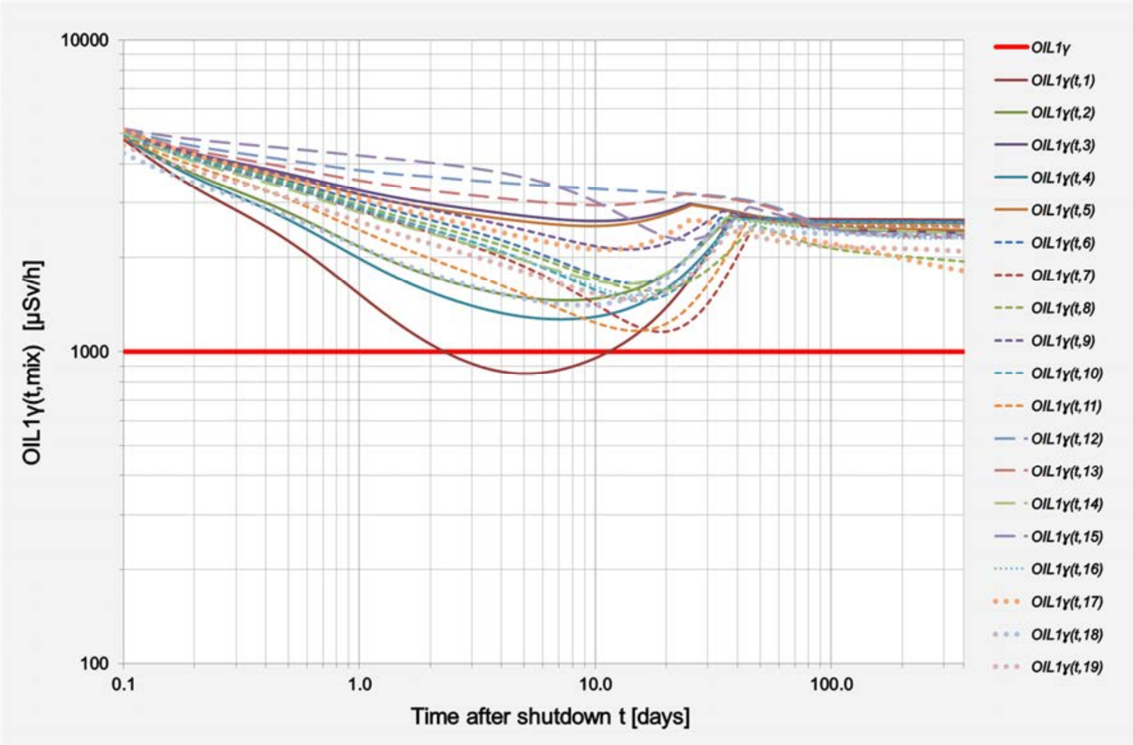

FIG. 9. $OIL1_{\gamma}$(t,mix) [µSv/h] functions and default $OIL1_{\gamma}$ value (in red).

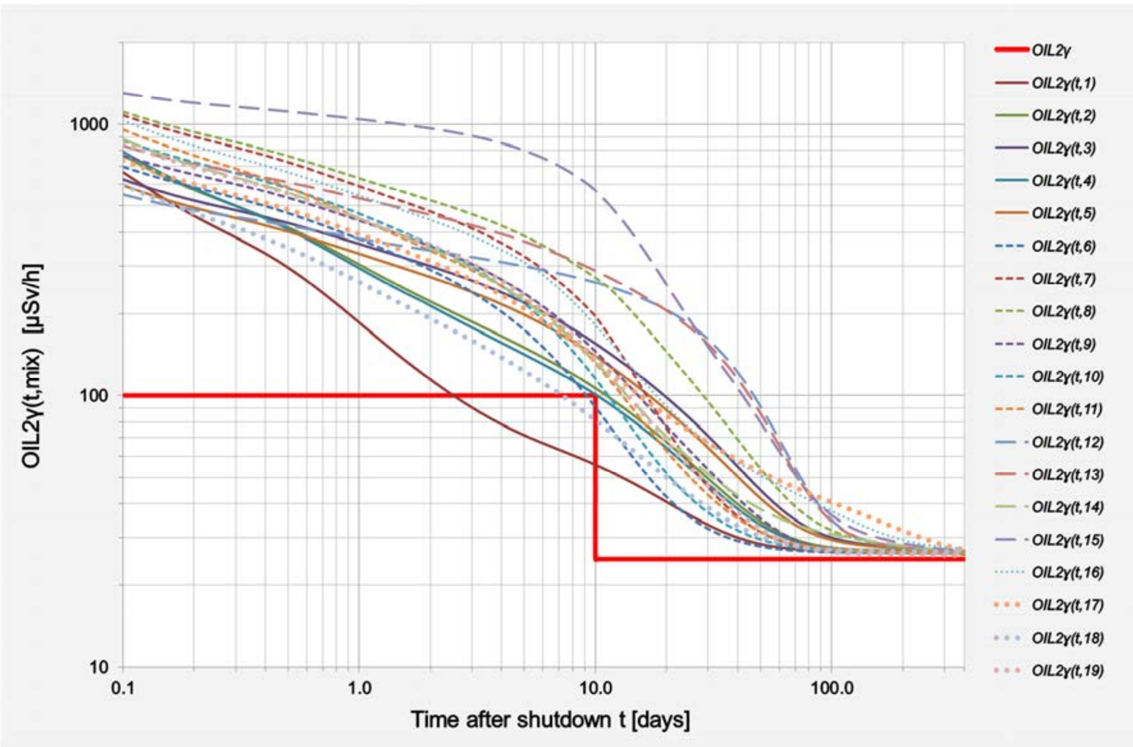

FIG. 10. $OIL2_{\gamma}$(t,mix) [µSv/h] functions and default $OIL2_{\gamma}$ value (in red).

3.8.2. OIL2$_\gamma$

3.8.2.1. OIL2$_\gamma$(t,mix) calculation

Calculation of the default OIL2$_\gamma$ value is based on evaluation of the OIL2$_\gamma$(t,mix) functions for each mix given in Table 3. OIL2$_\gamma$(t,mix) [µSv/h] is the ambient dose equivalent rate measured at 1 m above ground level at time t after reactor shutdown, that for the 'ground' scenario results in any of the generic criteria specified for OIL2$_\gamma$ (in Table 2) being met, for a specific radionuclide mix. The values are given in Fig. 10 for all considered mixes and determined by Eq. (54):

$$\mathrm{OIL2_\gamma(t,mix)} = \left(\sum_{\mathrm{i}} \left(\mathrm{RA_i(t,mix)} \times \mathrm{H^*_{grd-sh,i}}\right)\right) \times \mathrm{WF_{OIL2_\gamma}} \times \mathrm{UC} \times \mathrm{DA_{OIL2}(t,mix)} \quad (54)$$

where:

- t [s] is the time after shutdown of the reactor (i.e. after the fuel was last irradiated in a reactor).
- 'mix' refers to the mix number as provided in Table 3, Table 7, Table 8 and Table 9.
- RA_i(t,mix) [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).
- $H^*_{grd-sh,i}$ [(Sv/s)/(Bq/m^2)] is the ambient dose equivalent rate at 1 m above ground level, per unit ground surface activity of radionuclide i. The values are given in Table 30.
- $WF_{OIL2\gamma}$ = 1 [unitless] is a weighting factor used to avoid the implementation of unwarranted response actions based on the default OIL2$_\gamma$ value. It is described in Section 3.9.
- UC = 3.6E+09 (µSv/h)/(Sv/s) is the unit conversion factor from Sv/s to µSv/h.
- DA_{OIL2}(t,mix) [Bq/m^2] is the derived gross activity on the ground at time t after reactor shutdown, which, for the 'ground' scenario, results in any of the generic criteria specified for OIL2$_\gamma$ (in Table 2) being met, for a specific radionuclide mix. It is determined by Eq. (55):

$$\mathrm{DA_{OIL2}(t,mix)} = \min\left\{\mathrm{A_{OIL2,E}(t,mix)}\ ,\ \mathrm{A_{OIL2,H_{fetus}}(t,mix)}\right\} \quad (55)$$

where:

  - $A_{OIL2,E}$(t,mix) [Bq/m^2] is the gross activity on the ground at time t after reactor shutdown, which, for the 'ground' scenario, results in a total effective dose to the representative person meeting the GC(Early,E,1a), for a specific radionuclide mix. It is determined by Eq. (56):

$$\mathrm{A_{OIL2,E}(t,mix)} = \frac{\mathrm{GC(Early,E,1a)}}{\sum_{\mathrm{i}}\left(\mathrm{E_{grd-scenario,i}(1a)} \times \mathrm{RA_i(t,mix)}\right)} \quad (56)$$

  where:

    - GC(Early,E,1a) = 0.1 Sv is the generic criterion used to take early response actions based on the total effective dose to the representative person in the first year (given in Table 2).
    - $E_{grd-scenario,i}$(1a) [Sv/(Bq/m^2)] is the total effective dose to the representative person over an exposure period Δ of 1 year for the 'ground' scenario, per unit ground surface activity of radionuclide i. The values are given in Table 23.

- $RA_i(t,mix)$ [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).

- $A_{OIL2,H_{fetus}}(t,mix)$ [Bq/m^2] is the gross activity on the ground at time t after reactor shutdown, which, for the 'ground' scenario, results in a total equivalent dose to the fetus meeting the GC(Early,H_{fetus},9mo), for a specific radionuclide mix. It is determined by Eq. (57):

$$A_{OIL2,H_{fetus}}(t,mix) = \frac{GC(Early, H_{fetus}, 9mo)}{\sum_i \left(H_{fetus,grd-scenario,i}(1a) \times RA_i(t,mix)\right)} \quad (57)$$

where:

- GC (Early,H_{fetus},9mo) = 0.1 Sv is the generic criterion used to take early response actions based on the total equivalent dose to the fetus in the full period of in utero development (given in Table 2).
- $H_{fetus,grd-scenario,i}(1a)$ [Sv/(Bq/m^2)] is the total equivalent dose to the fetus over an exposure period Δ of 1 year for the 'ground' scenario, per unit ground surface activity of radionuclide i. The values are given in Table 23.
- $RA_i(t,mix)$ [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).

3.8.2.2. Analysis

The $OIL2_\gamma(t,mix)$ functions calculated in this way are displayed in Fig. 10. The red line shows the two chosen default values for $OIL2_\gamma$: (a) 100 µSv/h for measurements that are taken less than 10 days after the shutdown of a reactor and (b) 25 µSv/h for measurements that are taken later than 10 days after reactor shutdown. Two values are chosen to account for the high $OIL2_\gamma$ values during the first 10 days after reactor shutdown caused by the short lived radionuclides.

Despite being greater than the $OIL2_\gamma(t,mix)$ for two mixes during short times after shutdown, the default $OIL2_\gamma$ is acceptable, because this OIL triggers the implementation of early response actions in the first days after an emergency has been declared (as described in Ref. [4]), which is only a fraction of the exposure period of 1 year assumed in the calculations. Therefore, the resulting dose will be well below the generic criterion of 100 mSv in all cases.

3.8.3. $OIL3_\gamma$

3.8.3.1. $OIL3_\gamma(t,mix)$ calculation

Calculation of default $OIL3_\gamma$ is based on evaluation of the $OIL3_\gamma(t,mix)$ functions for each mix given in Table 3. $OIL3_\gamma(t,mix)$ [µSv/h] is the ambient dose equivalent rate measured at 1 m above ground level at time t after reactor shutdown, which, for the 'food pre-analysis' scenario, results in any of the generic criteria specified for $OIL3_\gamma$ (in Table 2) being met, for a specific radionuclide mix. The values are given in Fig. 11 for all considered mixes and determined by Eq. (58):

$$\mathrm{OIL3_{\gamma}(t,mix)} = \left(\sum_{i}\left(\mathrm{RA_i(t,mix)} \times \mathrm{H^{*}_{grd-sh,i}}\right)\right) \times \mathrm{WF_{OIL3_{\gamma}}} \times \mathrm{UC} \times \mathrm{DA_{OIL3}(t,mix)} \quad (58)$$

where:

- t [s] is the time after shutdown of the reactor (i.e. after the fuel was last irradiated in a reactor).
- ‘mix’ refers to the mix number as provided in Table 3, Table 7, Table 8 and Table 9.
- RA_i(t,mix) [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).
- $H^*_{grd-sh,i}$ [(Sv/s)/(Bq/m^2)] is the ambient dose equivalent rate at 1 m above ground level, per unit ground surface activity of radionuclide i. The values are given in Table 30.
- $WF_{OIL3\gamma}$ = 5 [unitless] is a weighting factor used to avoid the implementation of unwarranted response actions based on the default $OIL3_\gamma$ value. It is described in Section 3.9.
- UC = 3.6E+09 (μSv/h)/(Sv/s) is the unit conversion factor from Sv/s to μSv/h.
- DA_{OIL3}(t,mix) [Bq/m^2] is the derived gross activity on the ground at time t after reactor shutdown, which, for the ‘food pre-analysis’ scenario, results in any of the generic criteria specified for $OIL3_\gamma$ (in Table 2) being met, for a specific radionuclide mix. It is determined by Eq. (59):

$$\mathrm{DA_{OIL3}(t,mix)} = \min\left\{\mathrm{A_{OIL3,e_{ing}}(t,mix)},\ \mathrm{A_{OIL3,h_{fetus,ing}}(t,mix)}\right\} \quad (59)$$

where:

  - $A_{OIL3,e_{ing}}$(t,mix) [Bq/m^2] is the gross activity on the ground at time t after reactor shutdown, which, for the ‘food pre-analysis’ scenario, results in a committed effective dose from ingestion to the representative person meeting the GC(Ingestion,e_{ing},1a), for a specific radionuclide mix. It is determined by Eq. (60):

$$\mathrm{A_{OIL3,e_{ing}}(t,mix)} = \frac{\mathrm{GC(Ingestion,e_{ing},1a)}}{\sum_i\left(\mathrm{e_{ing,food-pre-analysis-scenario,i}} \times \mathrm{RA_i(t,mix)}\right)} \quad (60)$$

  where:

    - GC(Ingestion,e_{ing},1a) = 0.01 Sv is the generic criterion used to restrict the ingestion of non-essential food, milk and drinking water based on the committed effective dose from ingestion to the representative person over the first year (given in Table 2).
    - $e_{ing,food-pre-analysis-scenario,i}$ [Sv/(Bq/m^2)] is the committed effective dose to the representative person (defined by a combination of the adult and infant dose conversion factors and consumption rates) from ingestion over 1 year, for the ‘food pre-analysis’ scenario, per unit ground surface activity of radionuclide i. The values are given in Table 26.
    - RA_i(t,mix) [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).

  - $A_{OIL3,h_{fetus,ing}}$(t,mix) [Bq/m^2] is the gross activity on the ground at time t after reactor shutdown, which, for the ‘food pre-analysis’ scenario, results in a committed equivalent dose to the fetus from ingestion meeting the GC(Ingestion,$h_{fetus,ing}$,9mo), for a specific radionuclide mix. It is determined by Eq. (61):

$$A_{OIL3,h_{fetus,ing}}(t,mix) = \\ = \frac{GC(Ingestion, h_{fetus,ing}, 9mo)}{\sum_i \left(h_{fetus,ing,food-pre-analysis-scenario,i} \times RA_i(t,mix)\right)} \quad (61)$$

where:

- GC(Ingestion,$h_{fetus,ing}$,9mo) = 0.01 Sv is the generic criterion used to restrict the ingestion of non-essential food, milk and drinking water based on the committed equivalent dose to the fetus from ingestion over the full period of in utero development (given in Table 2).
- $h_{fetus,ing,food-pre-analysis-scenario,i}$ [Sv/(Bq/m^2)] is the committed equivalent dose to the fetus from ingestion of food, milk and drinking water by the pregnant woman, over the period of in utero development, or the 'food pre-analysis' scenario, per unit ground surface activity of radionuclide i. The values are given in Table 26.
- RA_i(t,mix) [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).

3.8.3.2. Analysis

The $OIL3_\gamma$(t,mix) functions calculated in this way are displayed in Fig. 11. The red line shows the chosen default $OIL3_\gamma$ value. As the default $OIL3_\gamma$ value, 1 µSv/h was chosen, despite the fact that it is greater than the $OIL3_\gamma$(t,mix) [µSv/h] by as much as a factor of 3 for certain mixes and times after shutdown. This is considered acceptable because of the very conservative assumption that as much as 50% of all the food, milk and water ingested is affected. In addition, 1µSv/h is considered the lowest practical ambient dose equivalent rate to be used for ground monitoring under severe emergency conditions (lower values may not be feasible owing to increased variation in the background radiation).

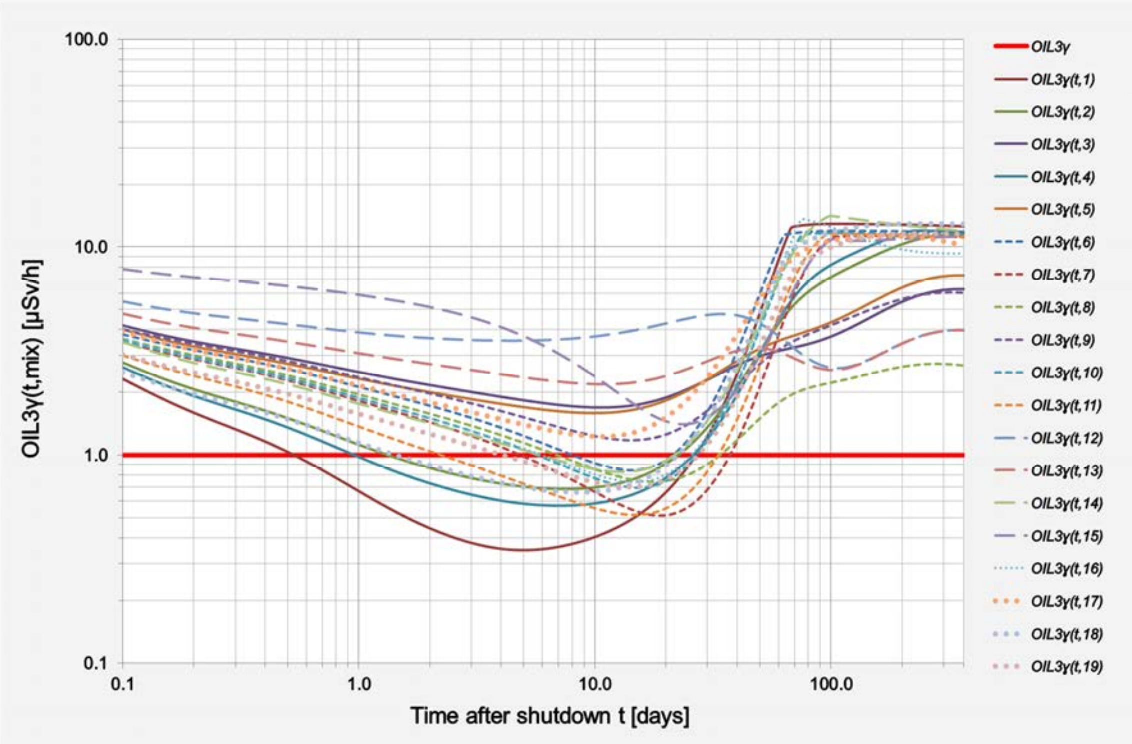

FIG. 11. $OIL3_{\gamma}$(t,mix) [µSv/h] functions and default $OIL3_{\gamma}$ value (in red).

3.8.4. $OIL4_{\gamma}$

3.8.4.1. $OIL4_{\gamma}$(t,mix) calculation

Calculation of default $OIL4_{\gamma}$ is based on evaluation of the $OIL4_{\gamma}$(t,mix) functions for each mix given in Table 3. $OIL4_{\gamma}$(t,mix) [µSv/h] is the ambient dose equivalent rate measured at 10 cm from bare skin at time t after reactor shutdown, which, for the ‘skin’ scenario, results in any of the generic criteria specified for $OIL4_{\gamma}$ (in Table 2) being met, for a specific radionuclide mix. The values are given in Fig. 12 for all considered mixes and determined by Eq. (62):

$$\mathrm{OIL4_{\gamma}(t,mix)} = \\ = \left(\sum_{i}\left(\mathrm{RA_i(t,mix)} \times \mathrm{H}^{*}_{\mathrm{skin-100cm^2-srf,i}}\right)\right) \times \mathrm{WF_{OIL4_{\gamma}}} \times \mathrm{UC} \times \mathrm{DA_{OIL4}(t,mix)} \qquad (62)$$

where:

- t [s] is the time after shutdown of the reactor (i.e. after the fuel was last irradiated in a reactor).
- ‘mix’ refers to the mix number as provided in Table 3, Table 7, Table 8 and Table 9.
- RA_i(t,mix) [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).
- $H^{*}_{skin\text{-}100cm^2\text{-}srf,i}$ [(Sv/s)/(Bq/m^2)] is the ambient dose equivalent rate at 10 cm from activity on 100 cm^2 of the skin surface, per unit surface activity of radionuclide i. The values are given in Table 30.

- $WF_{OIL4\gamma}$ = 0.5 [unitless] is a weighting factor used to avoid the implementation of unwarranted response actions based on the default $OIL4_{\gamma}$ value. It is described in Section 3.9.
- UC = 3.6E+09 (μSv/h)/(Sv/s) is the unit conversion factor from Sv/s to μSv/h.
- DA_{OIL4}(t,mix) [Bq/m^2] is the derived gross activity on the skin surface at time t after reactor shutdown, which, for the 'skin' scenario, results in any of the generic criteria specified for $OIL4_{\gamma}$ (in Table 2) being met, for a specific radionuclide mix. It is determined by Eq. (63):

$$DA_{OIL4}(t,mix) = \min\left\{A_{OIL4,e}(t,mix),\ A_{OIL4,h_{fetus}}(t,mix),\ A_{OIL4,AD_{skin}}(t,mix)\right\} \quad (63)$$

where:

- ○ $A_{OIL4,e}$(t,mix) [Bq/m^2] is the gross activity on the skin surface at time t after reactor shutdown, which, for the 'skin' scenario, results in an effective dose to the representative person from inadvertent ingestion meeting the GC(Urgent,E,7d), for a specific radionuclide mix. It is determined by Eq. (64):

$$A_{OIL4,e}(t,mix) = \frac{GC(Urgent, E, 7d)}{\sum_i \left(e_{ing,skin-scenario,i} \times RA_i(t,mix)\right)} \quad (64)$$

where:

  - ▪ GC(Urgent,E,7d) = 0.1 Sv is the generic criterion used to take urgent response actions based on the total effective dose to the representative person in the first 7 days (given in Table 2).
  - ▪ $e_{ing,skin\text{-}scenario,i}$ [Sv/(Bq/m^2)] is the committed effective dose to the representative person (i.e. the infant for this exposure scenario and pathway) from inadvertent ingestion, for the 'skin' scenario, per unit skin surface activity of radionuclide i. The values are given in Table 28.
  - ▪ RA_i(t,mix) [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).

- ○ $A_{OIL4,h_{fetus}}$(t,mix) [Bq/m^2] is the gross activity on the skin surface at time t after reactor shutdown, that for the 'skin' scenario results in an equivalent dose to the fetus from inadvertent ingestion meeting the GC(Urgent,H_{fetus},7d), for a specific radionuclide mix. It is determined by Eq. (65):

$$A_{OIL4,h_{fetus}}(t,mix) = \frac{GC(Urgent, H_{fetus}, 7d)}{\sum_i \left(h_{fetus,ing,skin-scenario,i} \times RA_i(t,mix)\right)} \quad (65)$$

where:

  - ▪ GC(Urgent,H_{fetus},7d) = 0.1 Sv is the generic criterion used to take urgent response actions based on the total equivalent dose to the fetus in the first 7 days (given in Table 2).
  - ▪ $h_{fetus,ing,skin\text{-}scenario,i}$ [Sv/(Bq/m^2)] is the committed equivalent dose to the fetus from inadvertent ingestion of radioactive material on the skin, for the 'skin' scenario, per unit skin surface activity of radionuclide i. The values are given in Table 28.

- $RA_i(t,mix)$ [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).

- $A_{OIL4,AD_{skin}}(t,mix)$ [Bq/m^2] is the gross activity on the skin surface at time t after reactor shutdown, which, for the 'skin' scenario, results in an RBE weighted absorbed dose to the skin meeting the GC(Acute,$AD_{skin-ext}$,10h), for a specific radionuclide mix. It is determined by Eq. (66):

$$A_{OIL4,AD_{skin}}(t,mix) = \frac{GC(Acute, AD_{skin-ext}, 10h)}{\sum_i \left(ad_{skin,skin-scenario,i} \times RA_i(t,mix)\right)} \quad (66)$$

where:

  - GC(Acute,$AD_{skin-ext}$,10h) = 10 Gy to 100 cm^2 is the generic criterion used to take response actions under any circumstance based on the RBE weighted absorbed dose to the skin over 10 hours (given in Table 2).
  - $ad_{skin,skin-scenario,i}$ [Gy/(Bq/m^2)] is the RBE weighted absorbed dose to the skin derma of the representative person,[57] for the 'skin' scenario, per unit skin surface activity of radionuclide i. The values are given in Table 28.
  - $RA_i(t,mix)$ [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).

3.8.4.2. Analysis

The $OIL4_\gamma(t,mix)$ functions calculated in this way are displayed in Fig. 12. The red line shows the chosen default $OIL4_\gamma$ value of 1 µSv/h, which is conservative for all times after shutdown and mixes. In fact, default $OIL4_\gamma$ values as high as 4 µSv/h would be conservative as described in Section 3.9.

[57] The RBE weighted absorbed dose rate to the skin derma is considered to be age independent.

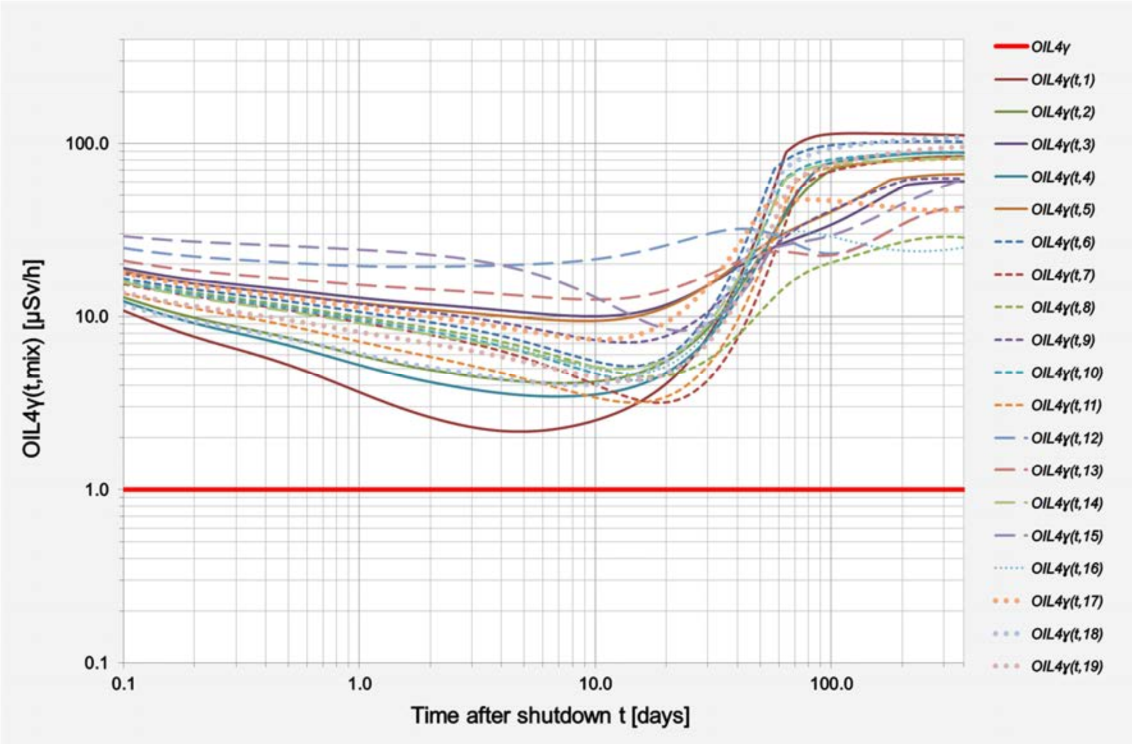

FIG. 12. OIL4$_{\gamma}$(t,mix) [µSv/h] functions and default OIL4$_{\gamma}$ value (in red).

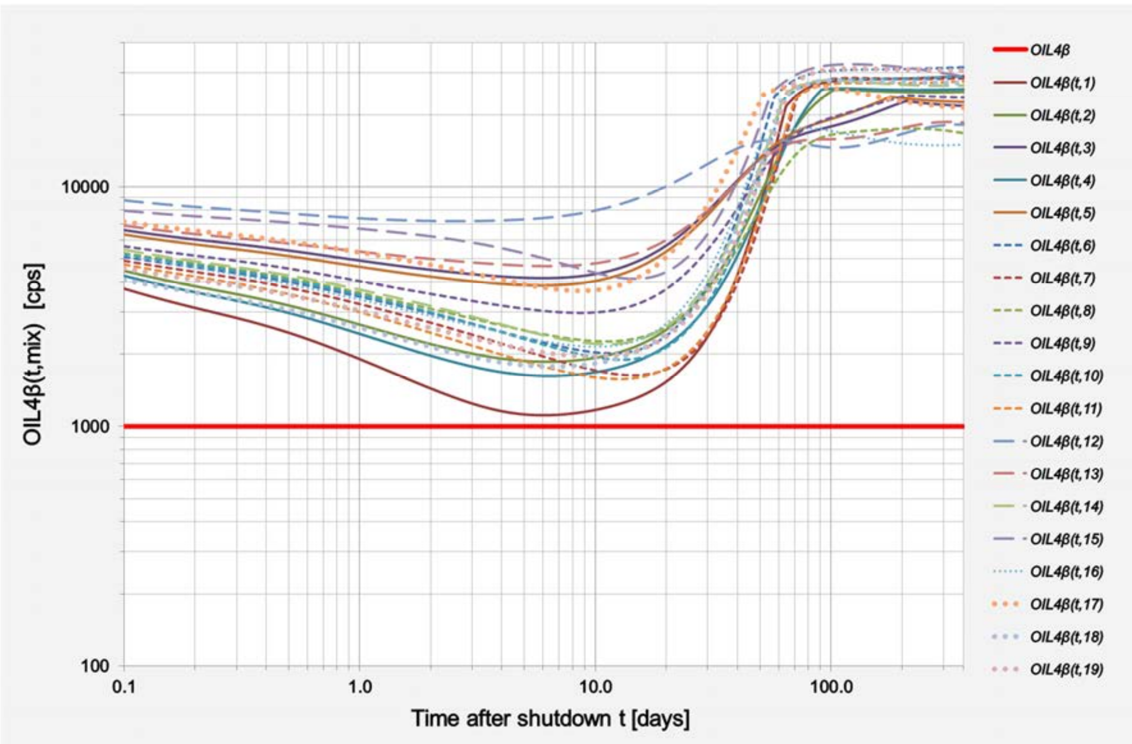

FIG. 13. OIL4$_{\beta}$(t,mix) [cps] functions and default OIL4$_{\beta}$ value (in red).

3.8.5. $OIL4_{\beta}$

3.8.5.1. $OIL4_{\beta}$(t,mix) calculation

Calculation of default $OIL4_{\beta}$ is based on evaluation of the $OIL4_{\beta}$(t,mix) functions for each mix given in Table 3. $OIL4_{\beta}$(t,mix) [cps] is the beta count rate measured with the baseline beta monitoring instrument at 2 cm from bare skin at time t after reactor shutdown, which, for the 'skin' scenario, results in any of the generic criteria specified for $OIL4_{\beta}$ (in Table 2) being met, for a specific radionuclide mix. The values are given in Fig. 13 for all considered mixes and determined by Eq. (67):

$$\mathrm{OIL4_{\beta}(t,mix)} = \left(\sum_{i}\left(\mathrm{RA_i(t,mix)} \times \mathrm{R_{4\pi,\beta,i}(baseline-inst)}\right)\right) \times \times \mathrm{WF_{OIL4_{\beta}}} \times \mathrm{DA_{OIL4}(t,mix)} \times \mathrm{a_{eff,\beta}(baseline-inst)} \times \mathrm{CorF_{field,\beta}} \quad (67)$$

where:

- t [s] is the time after shutdown of the reactor (i.e. after the fuel was last irradiated in a reactor).
- 'mix' refers to the mix number as provided in Table 3, Table 7, Table 8 and Table 9.
- $R_{4\pi,\beta,i}$(baseline-inst) [cps/Bq] is the ideal response factor of the baseline beta monitoring instrument, which reflects the response [cps] for each nuclear transformation per second [Bq] of radionuclide i on the surface, for 4π geometry, assuming ideal conditions (e.g. no self-absorption or air absorption) and the instrument window being very close to the surface.[58] It is given in Table 32.
- RA_i(t,mix) [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).
- $WF_{OIL4\beta}$ = 0.5 [unitless] is a weighting factor used to avoid the implementation of unwarranted response actions based on the default $OIL4_{\beta}$ value. It is described in Section 3.9.
- DA_{OIL4}(t,mix) [Bq/m^2] is the derived gross activity on the skin surface at time t after reactor shutdown, that for the 'skin' scenario results in any of the generic criteria specified for $OIL4_{\beta}$ (Table 2) being met, for a specific radionuclide mix. It is determined by Eq. (63).
- $a_{eff,\beta}$(baseline-inst) = 15 cm^2 = 1.5E-03 m^2 is the effective window area (e.g. sensitive or radiation inlet area) of the baseline beta monitoring instrument and is described in Section 3.7.2.1.1.
- $CorF_{field,\beta}$ = 0.25 [unitless] is the field beta correction factor for the beta monitoring instrument that accounts for the reduction in the beta count rate for measurements made under field (i.e. non-ideal) conditions. It is determined by Eq. (47).

3.8.5.2. Analysis

The $OIL4_{\beta}$(t,mix) functions calculated in this way are displayed in Fig. 13. The red line shows the default $OIL4_{\beta}$ value of 1000 cps, which is conservative for all times after shutdown and mixes. In fact, default $OIL4_{\beta}$ values as high as 2000 cps would be conservative as described in Section 3.9.

[58] The numerical value of $R_{4\pi,\beta,i}$(baseline-inst) corresponds to (or is often referred to) the 4π efficiency stated by many manufacturers. 2π efficiency is equal to 2 times the 4π efficiency.

3.8.6. OIL7

3.8.6.1. OIL7(t,mix) calculation

OIL7 values are expressed as activity concentrations [Bq/kg] of the two marker radionuclides I-131 ($OIL7_{I-131}$) and Cs-137 ($OIL7_{Cs-137}$) in food, milk or drinking water,[59] which, for the 'food post-analysis' scenario, result in any of the generic criteria specified for OIL7 (in Table 2) being met, thus indicating if the food, milk and water are safe for consumption.

Calculation of the default $OIL7_{I-131}$ and $OIL7_{Cs-137}$ values is based on evaluation of the $OIL7_{I-131}$(t,mix) and $OIL7_{Cs-137}$ (t,mix) functions for each mix given in Table 3, as described below:

- $OIL7_{I-131}$(t,mix) [Bq/kg] is the activity concentration of the marker radionuclide I-131 in food, milk or drinking water at time t after reactor shutdown, which, for the 'food post-analysis' scenario, results in any of the generic criteria specified for OIL7 (in Table 2) being met, for a specific radionuclide mix (it needs to be used together with $OIL7_{Cs-137}$). The values are given in Fig. 14 for all considered mixes and determined by Eq. (68):

$$\mathrm{OIL7}_{\mathrm{I-131}}(\mathrm{t,mix}) = \mathrm{RA}_{\mathrm{I-131}}(\mathrm{t,mix}) \times \mathrm{WF}_{\mathrm{OIL7}} \times \mathrm{DA}_{\mathrm{OIL7}}(\mathrm{t,mix}) \qquad (68)$$

  where:

  - t [s] is the time after shutdown of the reactor (i.e. after the fuel was last irradiated in a reactor).
  - 'mix' refers to the mix number as provided in Table 3, Table 7, Table 8 and Table 9.
  - RA_{I-131}(t,mix) [unitless] is the relative activity of I-131 at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).
  - WF_{OIL7} = 5 [unitless] is a weighting factor used to avoid the implementation of unwarranted response actions based on the default OIL7 value. It is described in Section 3.9.
  - DA_{OIL7}(t,mix) [Bq/kg] is the activity concentration in food, milk or drinking water at time t after reactor shutdown, which, for the 'food post-analysis' scenario, results in any of the generic criteria specified for OIL7 (in Table 2) being met, for a specific radionuclide mix. It is determined by Eq. (69):

$$\mathrm{DA}_{\mathrm{OIL7}}(\mathrm{t,mix}) = \min\left\{\mathrm{A}_{\mathrm{OIL7,e_{ing}}}(\mathrm{t,mix}),\ \mathrm{A}_{\mathrm{OIL7,h_{fetus,ing}}}(\mathrm{t,mix})\right\} \qquad (69)$$

    where:

    - $A_{OIL7,e_{ing}}$(t,mix) [Bq/kg] is the activity concentration in food, milk or drinking water, which, for the 'food post-analysis' scenario, results in a committed effective dose to the representative person from ingestion meeting the GC(Ingestion,e_{ing},1a), for a specific radionuclide mix. It is determined by Eq. (70):

[59] OIL7 applies to food, milk and water destined for human consumption (i.e. it is not applicable for 'not ready to eat' products such as dried food or concentrated food).

$$A_{OIL7,e_{ing}}(t,mix) = \\ = \frac{GC(Ingestion, e_{ing}, 1a)}{\sum_i \left(e_{ing,food-post-analysis-scenario,i} \times RA_i(t,mix)\right)} \quad (70)$$

where:

- $GC(Ingestion, e_{ing}, 1a)$ = 0.01 Sv is the generic criterion used to restrict the ingestion of non-essential food, milk and drinking water based on the committed effective dose from ingestion to the representative person over the first year (as given in Table 2).
- $e_{ing,food\text{-}post\text{-}analysis\text{-}scenario,i}$ [Sv/(Bq/kg)] is the committed effective dose to the representative person (defined by a combination of the adult and infant dose conversion factors) from ingestion of food, milk and drinking water over 1 year, for the 'food post-analysis' scenario, per unit activity concentration of radionuclide i in food, milk or drinking water. The values are given in Table 29.
- $RA_i(t,mix)$ [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).

- $A_{OIL7,h_{fetus,ing}}(t,mix)$ [Bq/kg] is the activity concentration in food, milk or drinking water, that for the 'food post-analysis' scenario results in a committed equivalent dose to the fetus from ingestion meeting the $GC(Ingestion, h_{fetus,ing}, 1a)$, for a specific radionuclide mix. It is determined by Eq. (71):

$$A_{OIL7,h_{fetus,ing}}(t,mix) = \\ = \frac{GC(Ingestion, h_{fetus,ing}, 9mo)}{\sum_i \left(h_{fetus,ing,food-post-analysis-scenario,i} \times RA_i(t,mix)\right)} \quad (71)$$

where:

- $GC(Ingestion, h_{fetus,ing}, 9mo)$ = 0.01 Sv is the generic criterion used to restrict the ingestion of non-essential food, milk and drinking water based on the committed equivalent dose to the fetus from ingestion over the full period of in utero development (as given in Table 2).
- $h_{fetus,ing,food\text{-}post\text{-}analysis\text{-}scenario,i}$ [Sv/(Bq/kg)] is the committed equivalent dose to the fetus from ingestion of food, milk and drinking water by the pregnant woman, over 1 year, for the 'food post-analysis' scenario, per unit activity concentration of radionuclide i in food, milk or drinking water. The values are given in Table 29.
- $RA_i(t,mix)$ [unitless] is the relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).

- $OIL7_{Cs\text{-}137}$ (t,mix) [Bq/kg] is the activity concentration of the marker radionuclide Cs-137 in food, milk or drinking water at time t after reactor shutdown, which, for the 'food post-analysis' scenario, results in any of the generic criteria specified for OIL7 (in Table 2) being met, for a specific radionuclide mix (it needs to be used together with $OIL7_{I\text{-}131}$). The values are given in Fig. 15 for all considered mixes and determined by Eq. (72):

$$\mathrm{OIL7_{Cs-137}(t,mix) = RA_{Cs-137}(t,mix) \times WF_{OIL7} \times DA_{OIL7}(t,mix)} \quad (72)$$

where:

- $RA_{Cs\text{-}137}$(t,mix) [unitless] is the relative activity of Cs-137 at time t after reactor shutdown for a specific radionuclide mix. It is determined by Eq. (1).
- The other factors are described above.

3.8.6.2. Analysis

The $OIL7_{I\text{-}131}$(t,mix) and $OIL7_{Cs\text{-}137}$ (t,mix) functions calculated in this way are displayed in Fig. 14 and Fig. 15. The red lines show the default $OIL7_{I\text{-}131}$ value of 1000 Bq/kg (in Fig. 14) and the default $OIL7_{Cs\text{-}137}$ value of 200 Bq/kg (in Fig. 15). As shown in Fig. 14, the $OIL7_{I\text{-}131}$(t,mix) functions fall drastically after the 10th day, due to the short half-life of I-131, hence the need to use Cs-137 as a second marker radionuclide representative of longer lived radionuclides (Fig. 15).

In combination, the default $OIL7_{I\text{-}131}$ and $OIL7_{Cs\text{-}137}$ values are conservative for nearly all times after shutdown and mixes. In order to examine the combined use of $OIL7_{I\text{-}131}$ and $OIL7_{Cs\text{-}137}$, Fig. 16 displays ROIL7(t,mix) [unitless], which is the maximum value of $OIL7_{I\text{-}131}$(t,mix) and $OIL7_{Cs\text{-}137}$(t,mix) relative to their corresponding default OIL value, as described in Eq. (73):

$$\mathrm{ROIL7(t,mix) = max\left\{\frac{OIL7_{I-131}(t,mix)}{OIL7_{I-131}}, \frac{OIL7_{Cs-137}(t,mix)}{OIL7_{Cs-137}}\right\}} \quad (73)$$

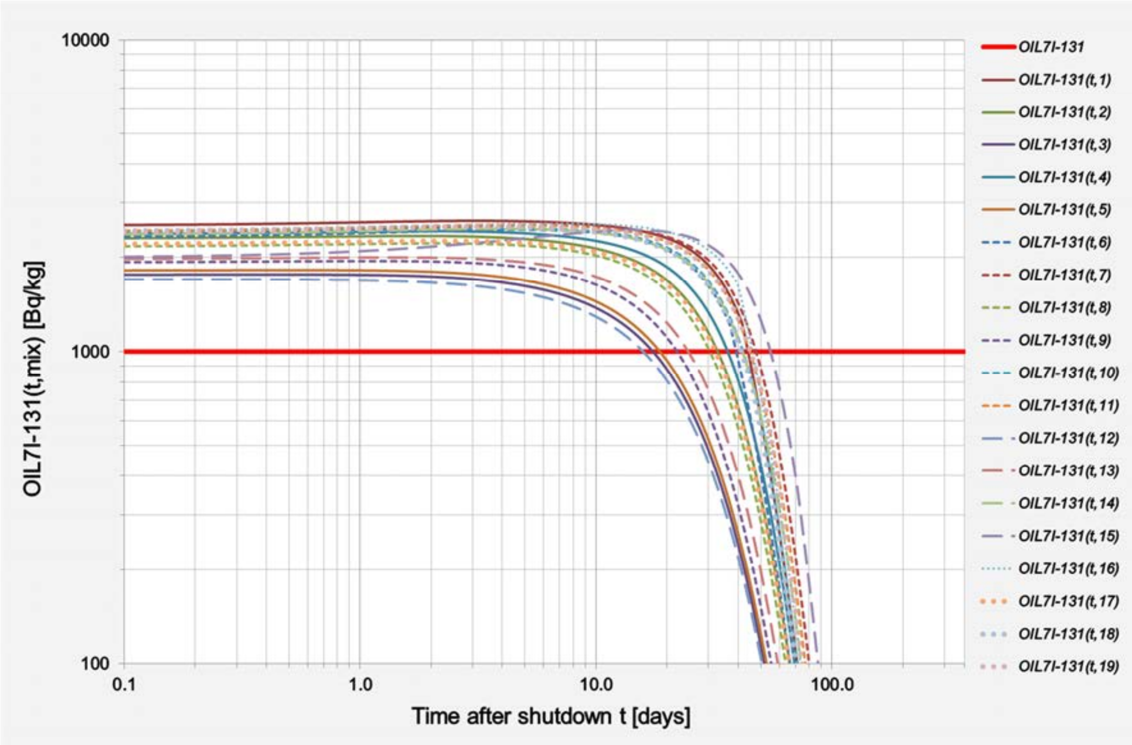

FIG. 14. OIL7$_{I-131}$(t,mix) [Bq/kg] functions and default OIL7$_{I-131}$ value (in red).

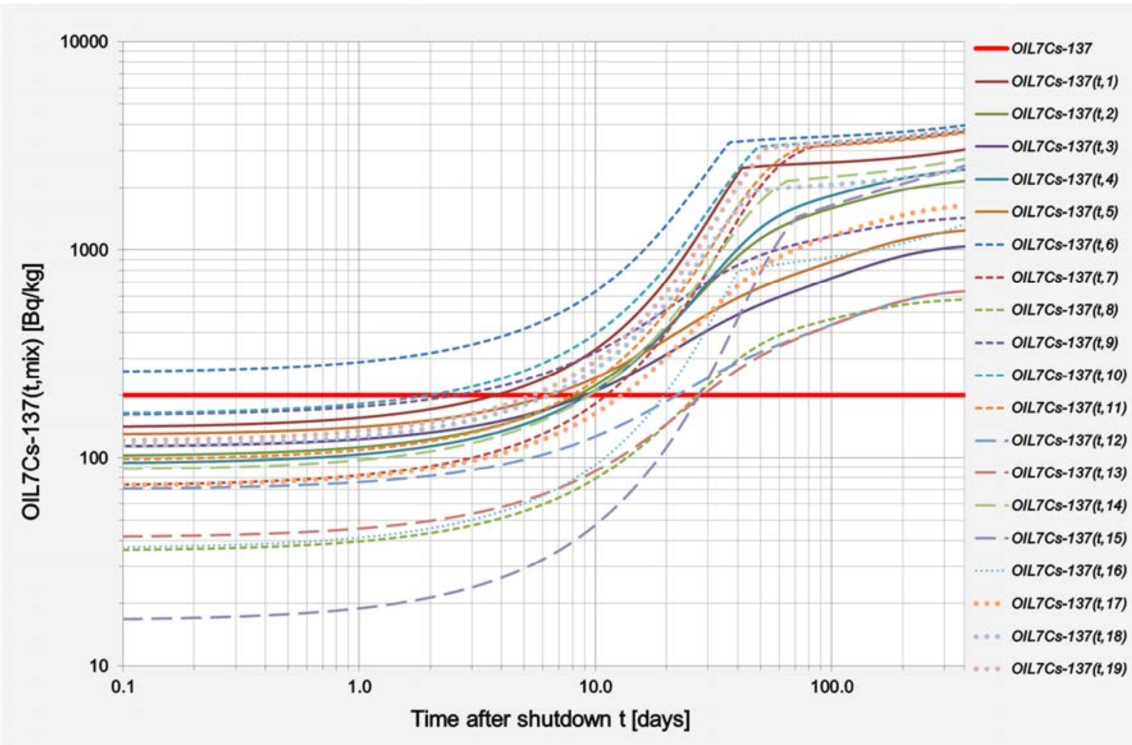

FIG. 15. OIL7 $_{Cs-137}$(t,mix) [Bq/kg] functions and default OIL7 $_{Cs-137}$ value (in red).

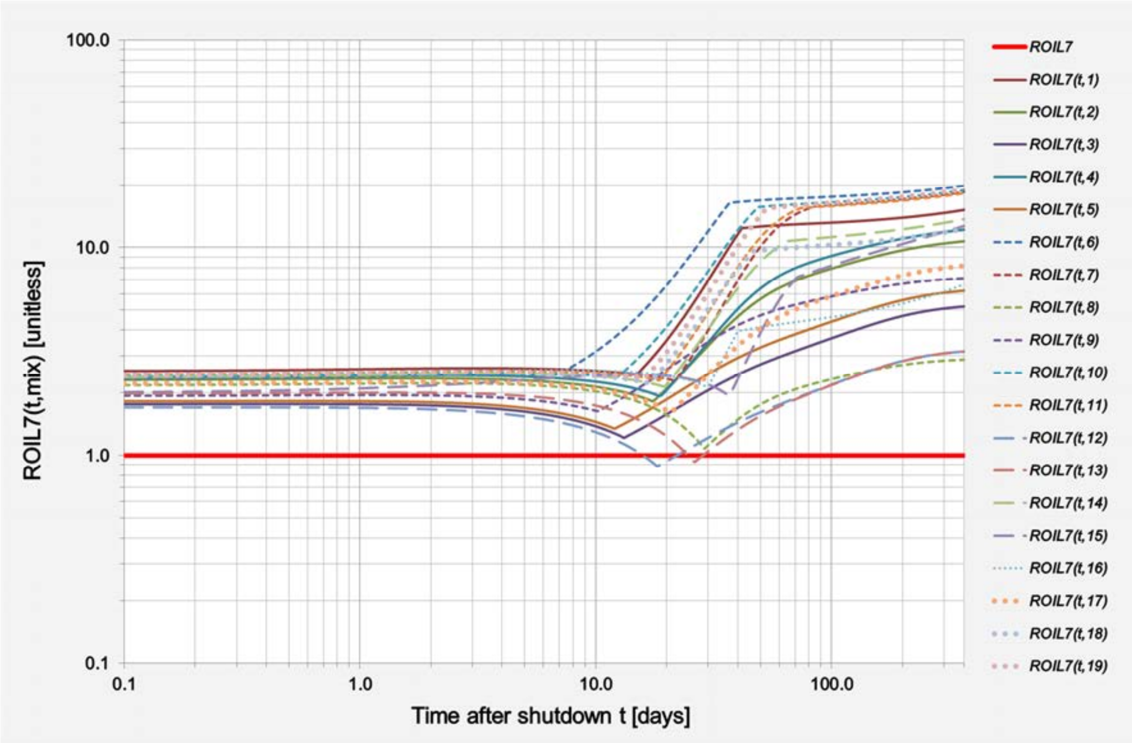

FIG. 16. ROIL7(t,mix) [unitless] function, displaying the combined use of $OIL7_{I\text{-}131}$ and $OIL7_{Cs\text{-}137}$.

3.8.7. $OIL8_\gamma$

3.8.7.1. $OIL8_\gamma(t_m$,baseline-inst) calculation

Calculation of the default $OIL8_\gamma$ value is based on evaluation of $OIL8_\gamma(t_m$,baseline-inst) [µSv/h], which is the ambient dose equivalent rate measured with the baseline monitoring instrument (baseline-inst) in front of the thyroid in contact with the skin of an infant, at time t_m after intake, for which the activity concentration of I-131 in the thyroid results in the generic criterion specified for $OIL8_\gamma$ (in Table 2) being met. The values are given in Fig. 17 and determined by Eq. (74):

$$\mathrm{OIL8_\gamma(t_m, baseline-inst)} = \mathrm{H^*_{I-131-thyroid-burden}(baseline-inst)} \times \\ \times \mathrm{CorF_{I-131-thyroid-burden}}(t_m) \times \mathrm{WF_{OIL8_\gamma}} \times \mathrm{UC} \times \mathrm{A_{OIL8,h_{thyroid,I-131-burden}}} \quad (74)$$

where:

- t_m [s] is the time between intake and measurement of the thyroid.
- $H^*_{I\text{-}131\text{-thyroid-burden}}$(baseline-inst) = 2.9E-14 (Sv/s)/Bq is the ambient dose equivalent rate in front of the thyroid as measured with the baseline instrument for monitoring the thyroid (baseline-inst) against the neck of an infant, per unit activity of I-131 (burden) in the thyroid.
- $CorF_{I\text{-}131\text{-thyroid-burden}}(t_m)$ [unitless] is the correction factor to account for the reduction of the activity in the thyroid due to the radioactive decay and biological removal of I-131. It is displayed in Fig. 8 and determined by Eq. (20).
- WF_{OIL8_γ} = 1 [unitless] is a weighting factor used to avoid the implementation of unwarranted response actions based on the default $OIL8_\gamma$ value. It is described in Section 3.9.

- UC = 3.6E+09 (µSv/h)/(Sv/s) is the unit conversion factor from Sv/s to µSv/h.
- $A_{OIL8,h_{thyroid,I\text{-}131\text{-}burden}}$ [Bq] is the activity of I-131 in the thyroid (thyroid burden), which, for the 'thyroid' scenario, results in a committed equivalent dose to the thyroid of an infant meeting the GC(Urgent,$h_{thyroid,thy\text{-}burden}$). It is determined by Eq. (75):

$$A_{OIL8,h_{thyroid,I-131-burden}} = \frac{GC(Urgent, h_{thyroid,thy-burden})}{h_{thyroid,I-131-thyroid-burden}} \quad (75)$$

where:

  - GC(Urgent,$h_{thyroid,thy\text{-}burden}$) = 0.1 Sv is the generic criterion used to take urgent response actions based on the committed equivalent dose to the thyroid from radioiodine in the thyroid (thyroid burden) (given in Table 2).
  - $h_{thyroid,I\text{-}131\text{-}thyroid\text{-}burden}$ = 1.2E-05 Sv/Bq is the committed equivalent dose to the thyroid of an infant from I-131 in the thyroid (thyroid burden). It is determined by Eq. (39).

3.8.7.2. Analysis

The OIL8$_\gamma$(t_m,baseline-inst) values calculated in this way are displayed as a dashed curve in Fig. 17. The bold continuous line shows the chosen default OIL8$_\gamma$ value of 0.5 µSv/h, which is conservative for the first week after intake of the radioiodine and is considered the lowest practical ambient dose equivalent rate for monitoring the thyroid under severe emergency conditions (lower values may not be feasible due to increased variation in the background radiation).

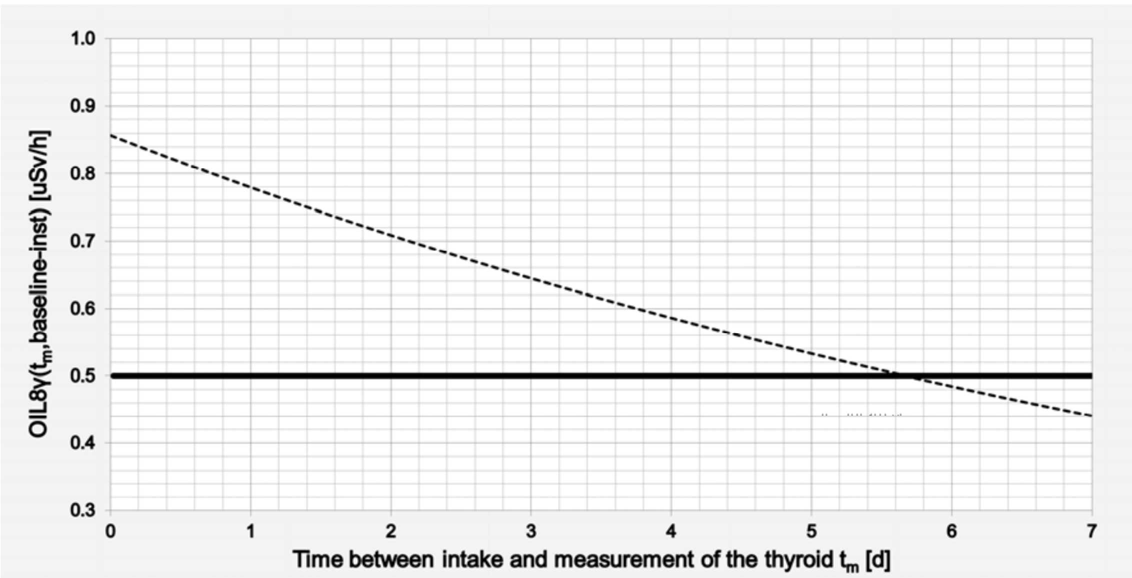

FIG. 17. OIL8$_\gamma$(t_m,baseline-inst) [µSv/h] function (dashed curve) and default OIL8$_\gamma$ [µSv/h]value (bold continuous line).

3.9. WEIGHTING FACTORS

The weighting factors used in the default OIL calculations (in Section 3.8) are intended to ensure that all members of the public are effectively protected and to avoid the implementation of unwarranted actions that will do more harm than good. The weighting factors may have to be reviewed and adapted to national arrangements, conditions and/or other considerations as deemed appropriate by specialists who are familiar with dose assessment as well as with emergency preparedness and response to nuclear and radiological emergencies.

- **$OIL1_\gamma$ and $OIL2_\gamma$:** As described in Ref. [4], $OIL1_\gamma$ is used in combination with $OIL2_\gamma$ to allow for the prioritization of response actions for those at highest risk (i.e. at risk of severe radiation induced health effects) and to avoid diverting limited resources from the highest priority actions during an emergency.[60] $OIL1_\gamma$ is intended to trigger the implementation of urgent response actions in the first hours after an emergency has been declared, and, therefore, the actual exposure period is expected to be a fraction of the 7 days assumed in the calculations. Since the dose actually received during the response, if the response actions are implemented within the first day, would be 1/3 of the dose projected for an exposure period of 7 days, a weighting factor $WF_{OIL1\gamma} = 3$ [unitless] is used in the calculation of $OIL1_\gamma$ to ensure the best use of limited resources to protect those at highest risk.

  For $OIL2_\gamma$ more time is available (i.e. weeks) to implement the response actions. The weighting factor is set to $WF_{OIL2\gamma} = 1$ [unitless], because the default $OIL2_\gamma$ value is considered a reasonable criterion for implementing effective response actions.

- **$OIL3_\gamma$ and OIL7:** The generic criteria for food, milk and drinking water restrictions provided in Table II.3 of Ref. [1] were established at 1/10 of the generic criteria for taking early response actions given in Table II.2 of Ref. [1], to ensure that the dose via all exposure pathways, including ingestion, will not exceed the generic criteria for early response actions mentioned above. Careful consideration needs to be given when selecting default OIL values, taking into account the concept of operations, which assumes that those areas where ingestion of food, milk or drinking water may contribute to exceeding the generic criteria for early response actions (from all exposure pathways, including ingestion) will be within the ICPD outlined in Refs [1, 4]. In the ICPD, restrictions are initially implemented on the basis of the emergency classification system and not on the basis of OILs. It is therefore assumed that, if the concept of operations outlined in Ref. [4] is followed, the doses within the ICPD will be mainly attributable to the exposure pathways covered in the 'ground' scenario, since the appropriate restrictions on food, milk and drinking water will have already been implemented based on the declaration of the emergency. In the areas beyond the ICPD, the contribution to the total dose by all exposure pathways except ingestion of food, milk and drinking water will be significantly smaller, allowing an increase in the contribution from ingestion of food, milk and drinking water to the total dose by making use of a weighting factor of $WF_{OIL3} = 5$ and $WF_{OIL7} = 5$

[60] While $OIL1_\gamma$ is intended to protect members of the public from severe radiation induced health effects, $OIL2_\gamma$ is intended to keep the doses to the members of the public below the international generic criteria given in Ref. [1] that call for taking response actions (to include medical screening) in order to further assess: (a) the small possible risk to pregnant women (i.e. the fetus); and (b) the small possible increase in the risk of radiation induced cancers.

[unitless]. The total dose received from all exposure pathways is still expected to be well below the generic criteria for early response actions, if the concept of operations outlined in Ref. [4] is implemented.

- **$OIL4_\gamma$ and $OIL4_\beta$:** Default $OIL4_\gamma$ values as high as 4 μSv/h (and default $OIL4_\beta$ values as high as 2000 cps) would be conservative (i.e. lead to a projected dose below the urgent generic criteria). However, a weighting factor of $WF_{OIL4\gamma} = 0.5$ (and $WF_{OIL4\beta} = 0.5$) is used to drive the value down to about 1 μSv/h (and 1000 cps) to account for the following:

    - Activity on the skin exceeding the default $OIL4_\gamma$ or $OIL4_\beta$ values may indicate that the individual has inhaled or ingested sufficient radioactive iodine prior to monitoring to result in doses to the thyroid that are 2 or more times above the generic criteria, calling for registration and later medical follow-up.[61]
    - Implementing response actions at the default $OIL4_\gamma$ and $OIL4_\beta$ values is only expected for a limited number of members of the public following a release of radioactive material due to severe conditions at the NPP (only few individuals are expected to have sufficient radioactive material on the skin that would warrant response actions).[62]
    - The default $OIL4_\gamma$ value (i.e. 1 μSv/h) is considered to be the lowest practical value usable under field conditions following a severe release of radioactive material from an LWR or its spent fuel.

- **OIL7:** See the bullet '$OIL3_\gamma$ and OIL7' above.

- **$OIL8_\gamma$:** For $OIL8_\gamma$ the weighting factor was set to $WF_{OIL8\gamma} = 1$ because the default $OIL8_\gamma$ value is considered a reasonable criterion for implementing effective response actions and is already as low as considered practical for field conditions.

3.10. CONSERVATISM

This section describes the conservatism considered in the calculation of the OILs. In this publication, 'conservative' is understood as the assumption of conditions that will result in a projected dose higher than the dose actually expected to be received under real conditions.

A variety of conservative assumptions are made whenever it is considered necessary, for example when: (a) there is insufficient information available (e.g. for the dose conversion factors for the fetus); (b) generalizations are required (e.g. for the baseline monitoring instrument or exposure scenarios); (c) required by operational considerations (e.g. limited availability of time and resources during the response); or (d) considered necessary based on the experience from past nuclear and radiological emergencies (e.g. OILs need to apply to all members of the public and not only to subgroups). The list below provides the main[63] conservatism considered in the calculation of the OILs with regard to their impact on the possible radiation induced health effects. The list follows the

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[61] This will most likely not be the case if urgent response actions are implemented on the basis of an emergency classification system as described in Refs [1, 2, 4, 5, 11].

[62] Assuming that urgent response actions are implemented on the basis of an emergency classification system as described in Refs [1, 2, 4, 5, 11].

[63] 'Main' regarding their impact on the possible radiation induced health effects. This list is not complete.

outline given in Section 3.1 and is intended to provide an overview (not a comprehensive description):

- **Generic criteria (Section 3.2):**
  - o The generic criteria are established at doses below those at which radiation induced health effects would be expected to be observed, even in a very large exposed group composed of the most sensitive members of the public (e.g. children and pregnant women).
  - o These health effects would probably not be seen at doses up to doses two or more times higher than the generic criteria of Ref. [1], in part due to the lower dose rates that will occur off the site of an NPP following a release of radioactive material [4, 19, 38, 86].
  - o At the generic criteria for which response actions are expected to be taken under any circumstances to avoid or minimize the severe deterministic effects of Ref. [1], severe deterministic effects will be seen in only 5% of exposed individuals [19].

- **Radionuclide mixes (Section 3.3):** From all radionuclide mixes expected during the exposure, those resulting in the highest dose to the public are driving the default OIL values.

- **Representative person (Section 3.4):** The OILs are developed based on the dose projected or received by the representative person. In a real event, no member of the public is expected to receive a dose during an emergency approaching the one calculated for the representative person for the conditions described in the scenarios.

- **Exposure scenarios and exposure pathways (Section 3.4):** The details of the exposure scenarios provided in Section 3.4 are generic, because conditions influencing the exposure among individual members of the public may vary significantly. To ensure the dose received by any member of the public will not exceed the dose calculated for the exposure scenarios (i.e. most of the projected dose will be averted under actual emergency conditions), the following conservative assumptions are made:
  - o For the 'ground' scenario, it is assumed that (a) apart from food restrictions, no protective actions of any type are taken and people live normally during the full period of exposure (which includes children playing on the ground and people working outside); and (b) the public is living in wooden framed houses with the least effective shielding of the range of structures provided in Ref. [70].
  - o For the food related scenarios, it is assumed that (a) the affected food, milk and drinking water is consumed over 1 year; (b) 50% of the total diet (i.e. all food, milk and drinking water consumed) is assumed to be affected; (c) the most restrictive age dependent dose conversion factors and consumption rates (i.e. those for infants) are used; and (d) there will be no reduction in the activity concentrations due to normal preparations/processing of the food (e.g. peeling, washing or cooking), which in some cases substantially reduces the concentration of radionuclides in the food [65].
  - o For the 'skin' scenario, it is assumed that no actions are taken to remove the material from the skin (e.g. washing) or to reduce inadvertent ingestion (e.g. keeping the hands away from the mouth).

- **Behaviour of the radionuclides (Section 3.5):** The radionuclide behaviour may vary significantly depending on specific circumstances. To ensure the factors provided in Section 3.5 cover a wide spectrum of possible cases the following conservative assumptions are made:

- The transfer factor from the ground to the air (i.e. resuspension factor) is initially conservative by around an order of magnitude when compared with those normally encountered by the public while living normally in an area.
- It is assumed that all the deposited material is available for inadvertent ingestion.
- It is assumed that all airborne radioactive material is deposited in the pulmonary region of the lung (i.e. the respirable fraction is 1, which, in reality, would be expected to be less than one tenth of this default value in most cases [71]).
- To estimate the amount of soil loaded on the hand for normal behaviour, the values for the maximally exposed individual from Ref. [62] is used, which is roughly twice as high as for the average.

- **Dose conversion factors (Section 3.6):** The most restrictive combinations of different factors such as age, public behaviour, exposure pathways, chemical forms of the radionuclides, radionuclide behaviour, times relative to conception, acute or chronic exposure and types of absorption are considered in the calculation of the dose conversion factors. Especially the dose conversion factors or intake were approached in a conservative way:

  - The equivalent dose to the fetus from intake (inhalation and ingestion) is established at the highest dose to any fetal organ. Furthermore, the dose conversion factors for the organs from intake were the highest in Ref. [39] for both acute and chronic inhalation, considering all absorption types and vapour (when applicable), for all times of intake (including intake prior to the pregnancy). For radionuclides for which dose conversion factors are not given in Ref. [39], the one year committed equivalent dose to the uterus of an adult from intake as given in Ref. [73] was considered as the committed equivalent dose to the fetus.
  - For the effective dose from inhalation, the highest committed effective dose per unit intake for all absorption types and for members of the public older than 17 years from Table III-2E of Ref. [14] are used. This, combined with the breathing rate for an adult performing light activity, ensured the dose from inhalation would be the highest among the public.
  - For the effective dose from ingestion for each radionuclide, the highest dose is used of either (a) infant consumption rates combined with the committed effective dose to the infant, or (b) adult consumption rates combined with the committed effective dose to the adult.

- **Monitoring instruments (Section 3.7):** The response of the baseline beta monitoring instrument was chosen so that it is lower than the 4π instrument efficiencies stated by instrument manufacturers for most of the surface contamination monitoring instruments, and within a factor of two of those stated by virtually all the instrument vendors. Notable exceptions are instruments designed for detection (e.g. those used by first responders or HAZMAT teams).

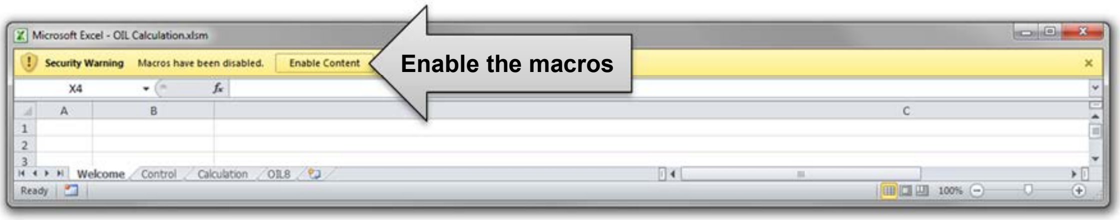
- **OIL(t,mix) functions and default OIL value (Section 3.8):** The default OIL values are below the OIL(t,mix) functions for most mixes and times after shutdown (Fig. 9 to Fig. 17).

4. SPREADSHEETS

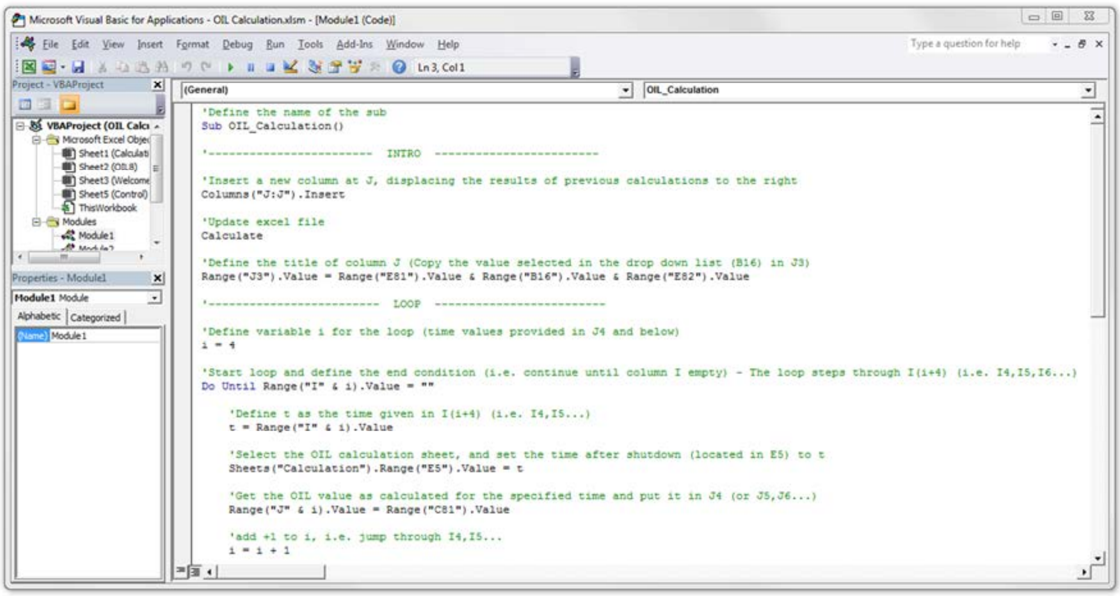
The calculations to derive the default OIL values described in Section 3 were performed with Microsoft Excel 2010 spreadsheets, available on the attached CD. These spreadsheets are provided to support Member States in adjusting the default OIL values to their specific needs. The spreadsheets follow the general structure of this publication. Most of the calculations are provided in the ‘OIL Calculation’ spreadsheet. Those calculations that would considerably slow down the execution of the macros have been included in the ‘Spectra’ spreadsheet and serve as input for the ‘OIL Calculation’ spreadsheet. For any details regarding the basis of the calculations, please refer to Section 3. Before revising the default OIL values, Sections 5 needs to be considered.

4.1. MACROS

The spreadsheets contain macros to automate the calculation process, and **these need to be enabled for the spreadsheet to work correctly.** Since macros pose a potential security concern, they are normally disabled by default and need to be enabled by the user.



The code of the macros was developed in Microsoft Visual Basic for Applications 2010 (VBA7) and is described step by step within the code itself.



4.2. ‘OIL CALCULATION’ SPREADSHEET

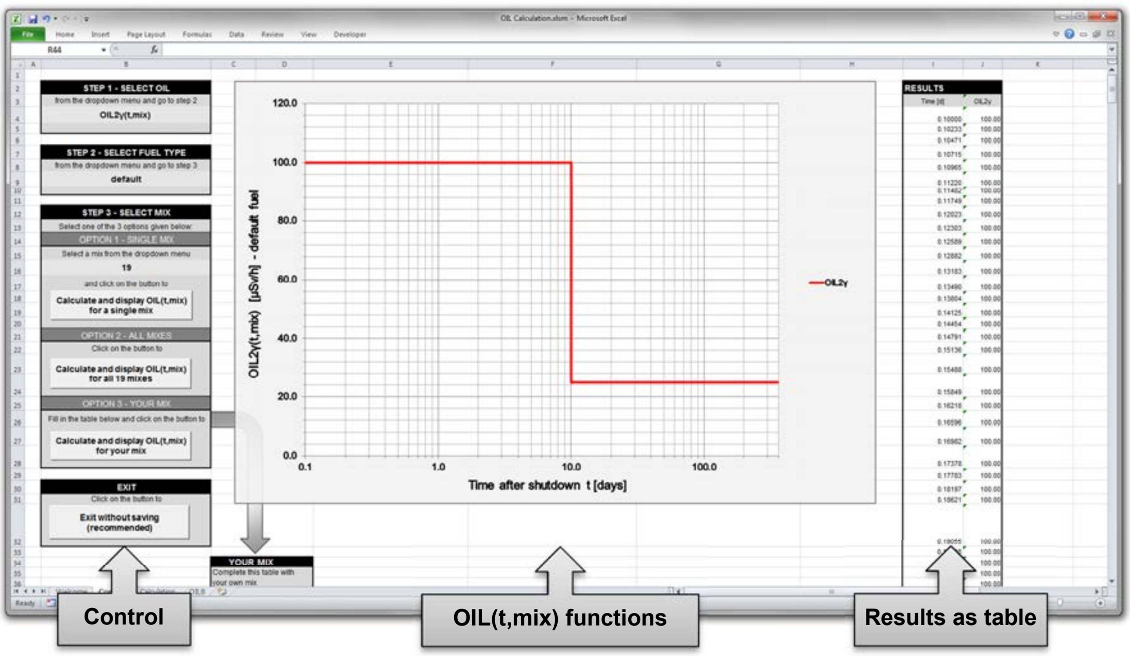
This spreadsheet contains all the calculations described in Section 3, except those related to energy spectra (which are provided in the ‘Spectra’ spreadsheet described in Section 4.3). It is divided into four tabs, each with a specific function as described in the following sections.

4.2.1. Welcome tab

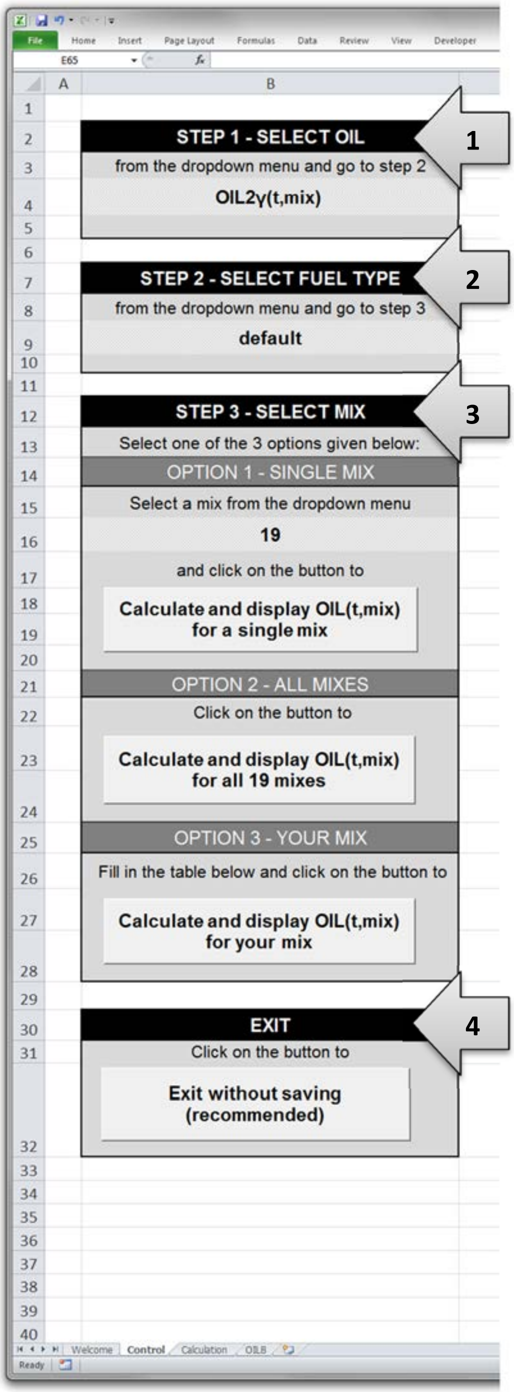
The ‘welcome’ tab provides a short description of the purpose and the scope of the spreadsheet.

4.2.2. Control tab

The ‘control’ tab allows the user to calculate and display the OILs. It is structured as follows: (a) on the left is the control area; (b) in the centre is the chart displaying the calculated OIL(t,mix) functions for $OIL1_\gamma$, $OIL2_\gamma$, $OIL3_\gamma$, $OIL4_\gamma$, $OIL4_\beta$ and OIL7 ($OIL8_\gamma$ is provided in the ‘OIL8’ tab); and (c) on the right are the results provided in tabular form.



To control the spreadsheet, perform the calculations and display the results, the user needs to follow four simple steps:



STEP 1 Select the OIL(t,mix) to be calculated from the dropdown menu, which provides $OIL1_\gamma$, $OIL2_\gamma$, $OIL3_\gamma$, $OIL4_\gamma$, $OIL4_\beta$ and OIL7 ($OIL8_\gamma$ is provided in the 'OIL8' tab).

STEP 2 Select the fuel type (further details on the fuel type are provided in Section 3.3). Three options are available in the dropdown menu:

Default: This option automatically selects the fuel type according to the mix as described in Table 3.

Standard: This option forces the use of the standard fuel irrespective of the selected mix.

High burnup: This option forces the use of the high burnup fuel irrespective of the selected mix.

STEP 3 Select the mix (further details on the mixes are provided in Table 3). Three options are available:

OPTION 1 - Single mix: This option allows the selections of a single mix from the dropdown menu. It is necessary to press the button to calculate and display the OIL(t,mix) function.

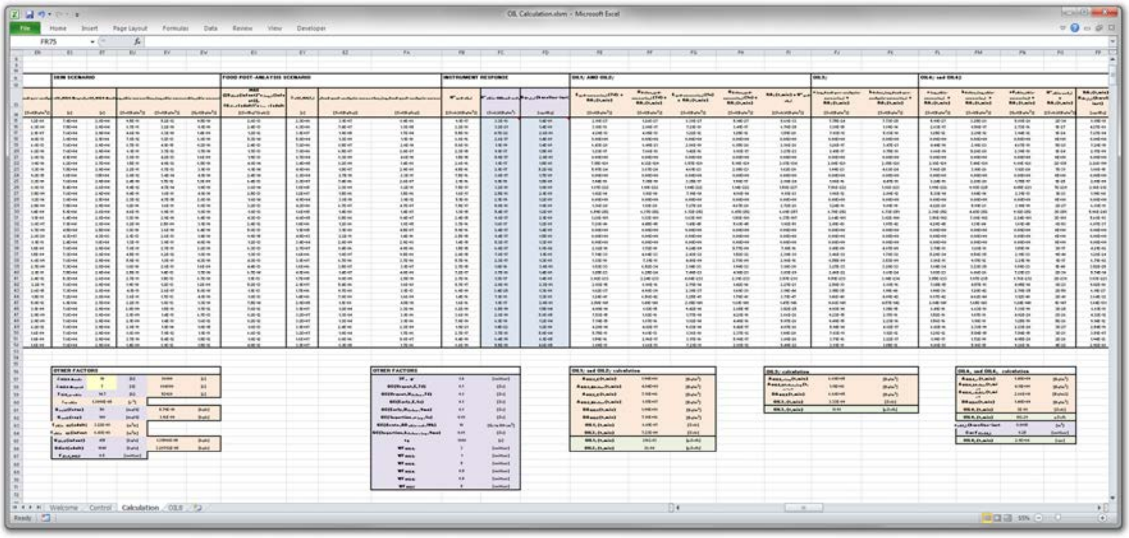
OPTION 2 - All mixes: This option calculates and displays the OIL(t,mix) functions for all the mixes provided in Table 3.

OPTION 3 - Your mix: This option allows calculating and displaying the OIL(t,mix) function for your own mix. It is necessary to introduce the release fraction for each radionuclide in the table indicated by the silver arrow and to press the button.

STEP 4 Consider saving the file with a different name and exiting without saving (to avoid modifying the master file).

4.2.3. Calculation tab

The ‘calculation’ tab contains most of the calculations described in this publication, except for the $OIL8_{\gamma}$ calculations (provided in the ‘OIL8’ tab) and spectra related calculations (provided in the ‘Spectra’ spreadsheet). The ‘calculation’ tab is organized following the general structure and order of Section 3, and its fields are colour coded as described in Table 33.



4.2.4. OIL8 tab

The $OIL8_{\gamma}$ calculation follows a different structure than that of the other OILs and is therefore provided in a separate tab. Since $OIL8_{\gamma}$ is mix independent, there is no need for the user to control this tab. The colour coding is described in Table 33.

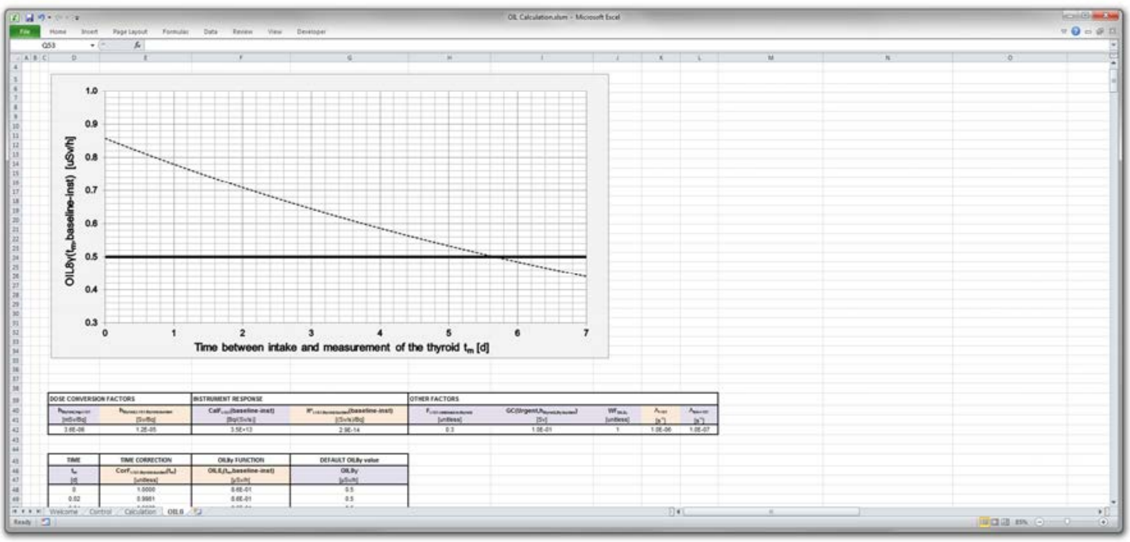


TABLE 33. COLOUR CODING

Colour of the field	Content of the field
Purple	Data as given in the original references (as indicated throughout this publication)
Orange	Calculations (as described throughout this publication)
Blue	Exceptions to general rules requiring special attention
Green	Results (i.e. the OIL(t,mix) values for a specific mix, fuel type and time, as applicable)
Red	Reserved for the operation of the macros (do not modify)
Yellow	Fields that cannot simply be modified (i.e. the modification will not be automatically considered in the calculations)[a]

[a] These fields are either associated with exposure periods (which are defined in the generic criteria) or with the calculation of $TI_{grd \to air,i}(\Delta)$and $TI_{grd \to GI,i}(\Delta,g)$, which, as described in Section 3.5.2 and 3.5.3, were not solved in the Excel file but obtained via numerical integration (by using a common mathematical computer program).

4.3. ‘SPECTRA’ SPREADSHEET

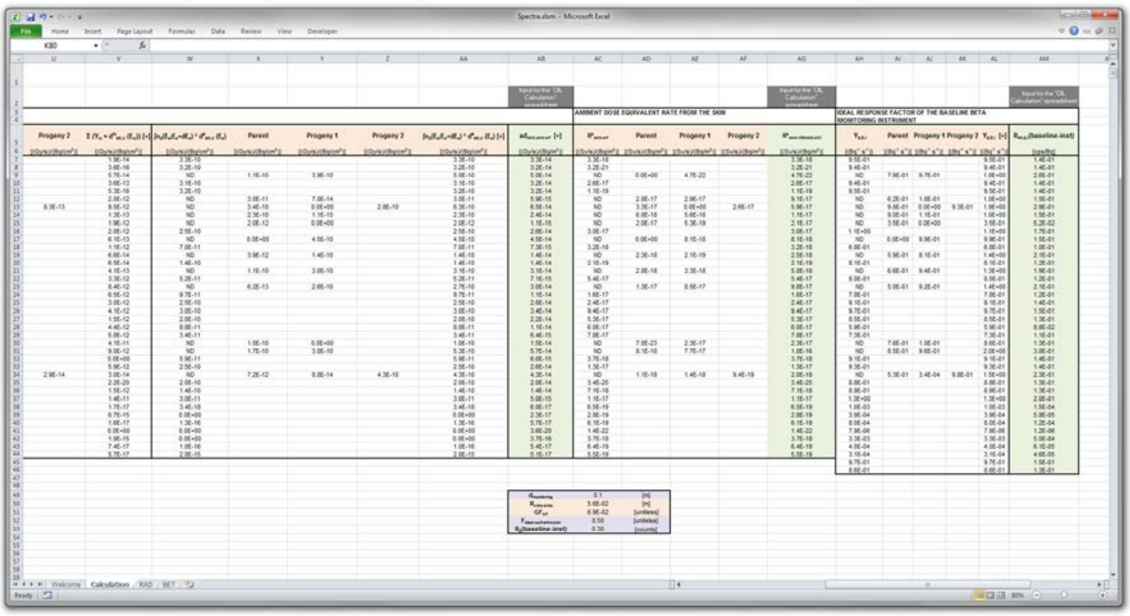
This spreadsheet serves as input for the ‘OIL Calculation’ spreadsheet by providing those calculations that would considerably slow down the execution of the macros of the ‘OIL Calculation’ spreadsheet. It is divided into four tabs, each with a specific function as described in the following sections. The colour coding is described in Table 33.

4.3.1. Welcome tab

The ‘welcome’ tab provides a short description of the purpose and scope of the spreadsheet.

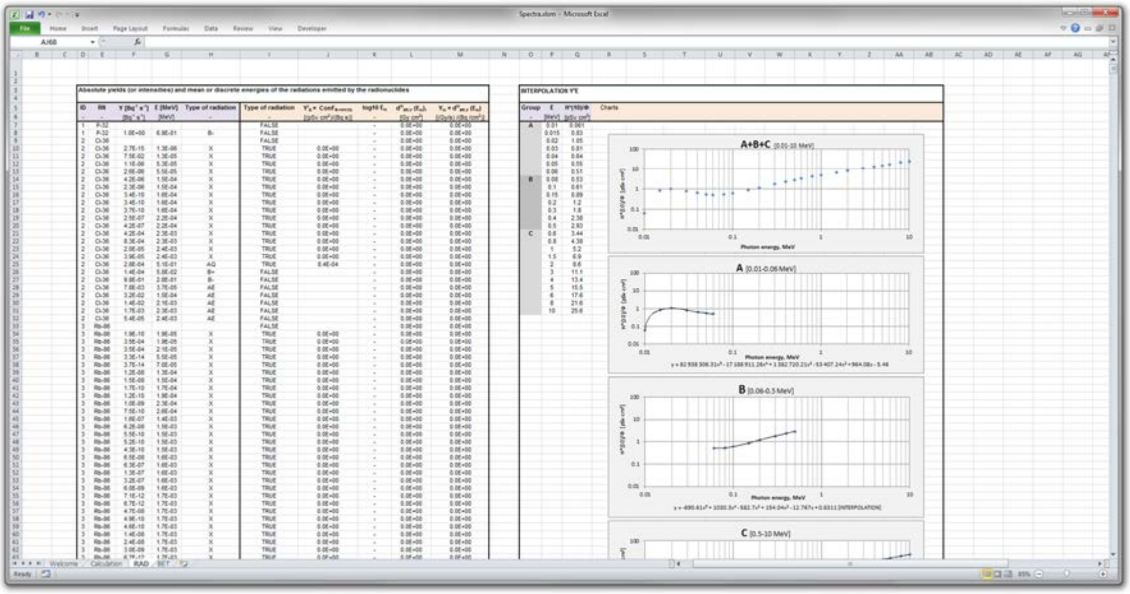
4.3.2. Calculation tab

The ‘calculation’ tab provides the calculation of the quantities to be used as input for the ‘OIL Calculation’ spreadsheet. The colour coding is described in Table 33.



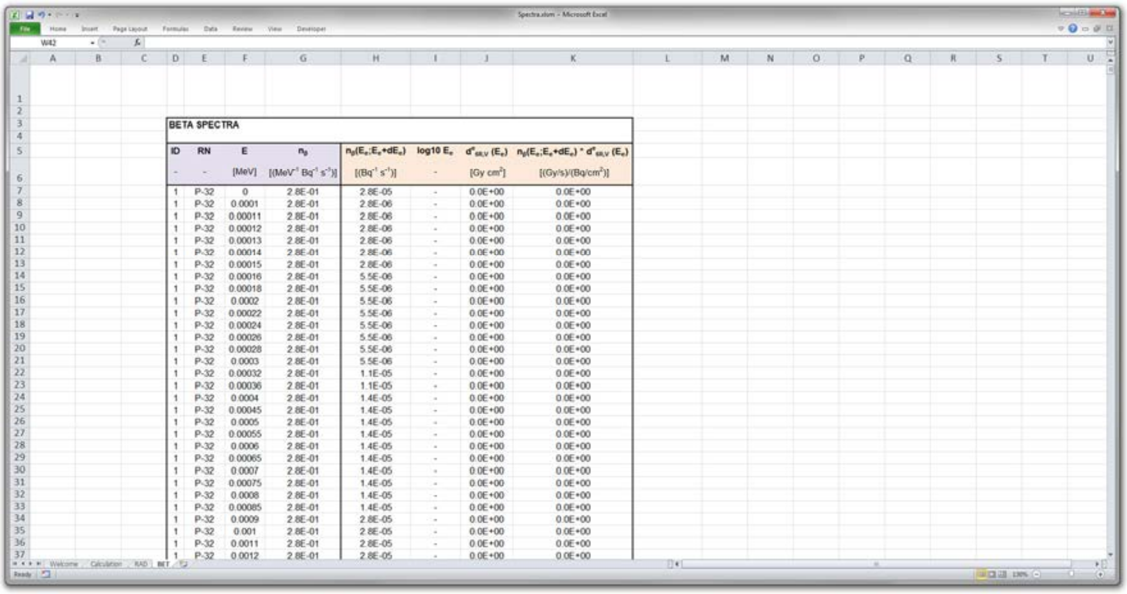
4.3.3. RAD tab

The ‘RAD’ tab provides the absolute yields (or intensities) and mean or discrete energies of the radiations emitted by the radionuclides as required in the calculation of the OILs. The interpolation of data (to evaluate $ConF_{\phi \rightarrow H^*(10),E_j}$ from Eq. (41)) was performed by a polynomial of fifth order as described in the charts.



4.3.4. BET tab

The ‘BET’ tab provides the beta spectra as required in the calculation of the OILs.



BETA SPECTRA

ID	RN	E	n_β	$n_\beta(E_e;E_e+dE_e)$	log10 E_e	$d^*_{skV}(E_e)$	$n_\beta(E_e;E_e+dE_e) \cdot d^*_{skV}(E_e)$
-	-	[MeV]	[(MeV^{-1} Bq^{-1} s^{-1})]	[(Bq^{-1} s^{-1})]	-	[Gy cm^2]	[(Gy/s)/(Bq/cm^2)]
1	P-32	0	2.8E-01	2.8E-05	-	0.0E+00	0.0E+00
1	P-32	0.0001	2.8E-01	2.8E-06	-	0.0E+00	0.0E+00
1	P-32	0.00011	2.8E-01	2.8E-06	-	0.0E+00	0.0E+00
1	P-32	0.00012	2.8E-01	2.8E-06	-	0.0E+00	0.0E+00
1	P-32	0.00013	2.8E-01	2.8E-06	-	0.0E+00	0.0E+00
1	P-32	0.00014	2.8E-01	2.8E-06	-	0.0E+00	0.0E+00
1	P-32	0.00015	2.8E-01	2.8E-06	-	0.0E+00	0.0E+00
1	P-32	0.00016	2.8E-01	5.5E-06	-	0.0E+00	0.0E+00
1	P-32	0.00018	2.8E-01	5.5E-06	-	0.0E+00	0.0E+00
1	P-32	0.0002	2.8E-01	5.5E-06	-	0.0E+00	0.0E+00
1	P-32	0.00022	2.8E-01	5.5E-06	-	0.0E+00	0.0E+00
1	P-32	0.00024	2.8E-01	5.5E-06	-	0.0E+00	0.0E+00
1	P-32	0.00026	2.8E-01	5.5E-06	-	0.0E+00	0.0E+00
1	P-32	0.00028	2.8E-01	5.5E-06	-	0.0E+00	0.0E+00
1	P-32	0.0003	2.8E-01	5.5E-06	-	0.0E+00	0.0E+00
1	P-32	0.00032	2.8E-01	1.1E-05	-	0.0E+00	0.0E+00
1	P-32	0.00036	2.8E-01	1.1E-05	-	0.0E+00	0.0E+00
1	P-32	0.0004	2.8E-01	1.4E-05	-	0.0E+00	0.0E+00
1	P-32	0.00045	2.8E-01	1.4E-05	-	0.0E+00	0.0E+00
1	P-32	0.0005	2.8E-01	1.4E-05	-	0.0E+00	0.0E+00
1	P-32	0.00055	2.8E-01	1.4E-05	-	0.0E+00	0.0E+00
1	P-32	0.0006	2.8E-01	1.4E-05	-	0.0E+00	0.0E+00
1	P-32	0.00065	2.8E-01	1.4E-05	-	0.0E+00	0.0E+00
1	P-32	0.0007	2.8E-01	1.4E-05	-	0.0E+00	0.0E+00
1	P-32	0.00075	2.8E-01	1.4E-05	-	0.0E+00	0.0E+00
1	P-32	0.0008	2.8E-01	1.4E-05	-	0.0E+00	0.0E+00
1	P-32	0.00085	2.8E-01	1.4E-05	-	0.0E+00	0.0E+00
1	P-32	0.0009	2.8E-01	2.8E-05	-	0.0E+00	0.0E+00
1	P-32	0.001	2.8E-01	2.8E-05	-	0.0E+00	0.0E+00
1	P-32	0.0011	2.8E-01	2.8E-05	-	0.0E+00	0.0E+00
1	P-32	0.0012	2.8E-01	2.8E-05	-	0.0E+00	0.0E+00

4.4. REVISING THE SPREADSHEETS

Before modifying the spreadsheets, it is strongly recommended to acquire a complete understanding of (a) the derivation of the OILs as described in Section 3; (b) the structure of the spreadsheet (including its content, its dependencies and the macros); and (c) the recommendations given in Section 5. **It is easy for users to introduce errors, and they may be difficult to audit.** The most frequent mistakes when revising the spreadsheet are:

- Not paying attention to fields with exceptions to general rules;
- Modifying fields needed by the macros or not updating the macros according to the changes in the spreadsheet;
- Introducing rows or columns, or modifying their order, without attention to the dependencies and macros;
- Not having a thorough understanding for the derivation of the OILs.

5. REVISING THE DEFAULT OIL VALUES

This section provides (a) general considerations concerning the revision of the default OIL values (in Section 5.1) and (b) instructions for adapting the default $OIL4_{\beta}$ value to a specific instrument (in Section 5.2).

5.1. GENERAL CONSIDERATIONS

Member States may want to revise the default OIL values to consider different underlying assumptions or another methodological approach than the ones used by the IAEA in this publication. These changes need to be built on a defensible basis and clearly explained to all relevant interested parties during the preparedness stage. Introducing changes to the default OIL values given in this publication requires experts with experience in dose assessment and emergency preparedness and response, as well as a clear understanding of the methodology for deriving the OILs. Section 3 provides the methodology used by the IAEA, which can be employed as a basis for revision.

Member States may also want to adapt the default OIL values to the specific conditions of the accident once sufficient information becomes available. In this case, arrangements need to be in place to explain these changes to the public in a plain and understandable form, as described in para. 5.69 and 5.70 of the IAEA Safety Standards Series No. GSR Part 7 [1]. Operational criteria (like the OILs) are only to be changed during the emergency if there is clear evidence that the revised criteria will do more good than harm, considering both radiological and non-radiological consequences, and when the situation is clearly understood (e.g. exposure scenarios, public behaviour and radionuclide mixes are well characterized). Failure to do so may lead to confusion and scepticism on the part of decision makers and the public, potentially resulting in unwarranted actions being taken.

In order to support Member States, the key elements that need to be considered to ensure that the revised OIL values are built on a defensible basis have been highlighted in Table 34 and Table 35. Table 34 addresses general considerations for increasing or decreasing the default OIL values, while Table 35 addresses generic considerations applicable to all or multiple OILs.

TABLE 34. GENERAL CONSIDERATIONS FOR INCREASING OR DECREASING THE DEFAULT OIL VALUES

OIL	Change	Considerations	Example when the revision may be justified
$OIL1_\gamma$	Increase	The use of higher default $OIL1_\gamma$ values (e.g. twice the $OIL1_\gamma$) needs to be considered with great care to ensure that all members of the public are effectively protected against severe radiation induced health effects. Living in an area above the current default $OIL1_\gamma$ value for more than a day could result in radiation induced health effects.	Evacuation is not possible for all areas exceeding the default value, and other response actions are effectively implemented that will protect the public.
	Decrease	The use of lower default $OIL1_\gamma$ values (e.g. one half of $OIL1_\gamma$) could result in the diversion of limited resources from the highest priority actions, which may cause more harm than good. However, it may be justified if sufficient resources are available to cope with the higher number of people affected by the response actions.	Lowering the default value does not result in a significant increase in the number of affected people.
$OIL2_\gamma$	Increase	The use of higher default $OIL2_\gamma$ values (e.g. twice the $OIL2_\gamma$) may be considered if the exposure conditions are well understood early in the emergency, and the generic criteria for reducing the risk for stochastic effects will not be exceeded during the anticipated exposure period (i.e. before response actions are fully implemented for all members of the public).	The behaviour of the public is well characterized and is estimated to result in lower doses than those estimated in this publication.
	Decrease	The use of lower default $OIL2_\gamma$ values (e.g. one half of $OIL2_\gamma$) may be considered if it is clearly demonstrated to be justified and optimized with account taken of non-radiological effects (e.g. social or economic effects). A reduction of the default $OIL2_\gamma$ value may be justified if actual conditions during the emergency would result in higher doses than those assumed in the calculation of the OILs.	The impacted area has a very low population density.
$OIL3_\gamma$	Increase	The use of higher default $OIL3_\gamma$ values (e.g. twice the $OIL3_\gamma$) may be justified to avoid other adverse effects caused by the restriction of food, milk or drinking water. The values may also be increased if the exposure conditions are well understood early in the emergency and the generic criteria for reducing the risk for stochastic effects will not be exceeded as a result of the consumption of these products, taking all exposure pathways into account.	If only certain crops (for example due to the time of the year) are affected, it may be justified to increase the default value.
	Decrease	The default $OIL3_\gamma$ value is as low as considered to be reasonably measurable and practical under field and emergency conditions.	The areas affected by the release of radioactive material are relatively small.

OIL	Change	Considerations	Example when the revision may be justified
$OIL4_\gamma$	Increase	The use of higher default $OIL4_\gamma$ values (e.g. twice the $OIL4_\gamma$) may be considered if it is difficult to apply the default OIL value under emergency conditions.	The resources available for monitoring are limited and there are higher priorities.
	Decrease	The default $OIL4_\gamma$ value is as low as considered to be reasonably measurable and practical under field and emergency conditions. Lower values may be used if demonstrated to be justified and feasible for the effective implementation of response actions, considering the diversion of limited resources and unwarranted anxiety among those being monitored.	The location where the monitoring is performed has a very low background.
$OIL4_\beta$	Increase	The use of higher default $OIL4_\beta$ values (e.g. twice the $OIL4_\beta$) may be considered if it is difficult to apply the default OIL value under emergency conditions.	The number of affected people exceeds the capabilities of the response.
	Decrease	Lower $OIL4_\beta$ values (e.g. one half of $OIL4_\beta$) may be used if demonstrated to be justified and feasible for the effective implementation of response actions, considering the diversion of limited resources and unwarranted anxiety among those being monitored.	The instrument response is higher than assumed in the calculations.
OIL7	Increase	The use of higher default OIL7 values (e.g. twice the OIL7) may be considered if the exposure conditions are well understood (e.g. if enough samples are taken and the behaviour of the public, exposure pathways and scenarios are well characterized) and the generic criteria for reducing the risk for stochastic effects will not be exceeded as a result of the consumption of these products, taking all exposure pathways into account.	The percentage of affected food, milk and drinking water and the consumption behaviour of the public is well characterized and results in lower doses than expected.
	Decrease	The use of lower default OIL7 values (e.g. one half of OIL7) may be considered if the exposure conditions are well understood (e.g. if enough samples have been taken and the behaviour of the public, exposure pathways and scenarios are well characterized). It needs to be considered with great care to ensure that it causes more good than harm, with account taken of non-radiological effects.	A specific affected product is consumed in larger quantities than expected.
$OIL8_\gamma$	Increase	The use of higher default $OIL8_\gamma$ values (e.g. twice the $OIL8_\gamma$) may be considered, especially if the properties (e.g. efficiency) of the monitoring instruments that will be used are known, but it needs to be ensured that these values allow for all members of the public to be effectively identified for registration and medical follow-up.	The instrument efficiency is higher than the one assumed in the calculations.
	Decrease	The default $OIL8_\gamma$ value is as low as considered to be reasonably measurable and practical under field and emergency conditions.	An improved monitoring technique allows using lower values.

TABLE 35. GENERAL CONSIDERATIONS FOR REVISING THE DEFAULT OIL VALUES
(The answer to all questions needs to be 'yes' for the revised OILs to be defensible)

Changes in the:	Considerations
Objective of the OILs	▪ Does the new objective allow the prompt and effective implementation of emergency response actions on the basis of monitoring results readily available during a nuclear or radiological emergency? ▪ Does the new objective allow avoiding a discernible increase in the incidence of radiation induced health effects? ▪ Does the new objective allow avoiding the delay of decision making due to limited availability of information (as expected early on in an emergency)? ▪ Does the new objective allow avoiding response actions that would result in more harm than good because of an overly conservative approach?
Generic criteria	▪ Have dosimetric criteria (as described in Ref. [1]) been used that provide a solid foundation for the implementation of response actions? ▪ Do the new dosimetric criteria ensure that there will be no discernible increase in radiation induced health effects? ▪ Are the new dosimetric criteria reasonable, i.e. do they provide a solid basis for a justified and optimized protection strategy? ▪ Do the new dosimetric criteria consider individual organ doses and resulting health effects, and not only the effective dose?
Radionuclide mix	▪ Have all radionuclide mixes which are expected to be released or have been released, and which may be of significant impact, been considered? ▪ Have all possible releases of radioactive material that may result from a severe emergency been considered, including those resulting from beyond design accidents? ▪ Have you considered the fact that, following a release of radioactive material, the measured radionuclide mix will change depending on the location and time (as described in Section 2.2)?
Individuals being exposed	▪ Have all members of the public that may be exposed (including those most sensitive to radiation) been considered? ▪ Has it been clearly stated that all members of the public (including those most sensitive to radiation) have been considered?
Exposure scenarios and pathways	▪ Have all relevant exposure scenarios been considered? ▪ Have all relevant exposure pathways been considered? ▪ Have the behaviour of the public and other factors affecting public exposure been considered for the different scenarios and pathways?
Behaviour of the radionuclides	▪ Have all relevant aspects of radionuclide behaviour been considered that may have a significant impact on the dose or the OILs?
Dose conversion factors	▪ Have dose conversion factors been developed (or considered) for each radionuclide, dose quantity, exposure pathway, exposure scenario and for all exposed individuals? ▪ Have both effective and equivalent dose conversion factors been considered?
Instrument response	▪ Are the OILs applicable to the instruments being used? ▪ Are the instruments appropriate for the intended measurement?

Changes in the:	Considerations
OIL(t,mix) functions and default OIL value	▪ Have time and mix dependent OIL(t,mix) functions been developed for all considered radionuclide mixes? ▪ Has a reasonably conservative and justified default OIL value been chosen considering the overall protection strategy and operational requirements?
Response actions	▪ Do the response actions take into account the overall protection strategy, the contribution from the different exposure pathways for the specific exposure scenario, how the response action would contribute to reducing the dose and whether the response action is feasible and justified?
Communicating the response actions to decision makers	▪ Have preparations been made for communicating the response actions to decision makers and public information officers?
Changes during the emergency	▪ Is there enough evidence that justifies changing the default OIL values?
Other	▪ Is the approach reasonably conservative, i.e. does it ensure that the response actions protect the public effectively from the radiological health hazard? ▪ Are the response actions justified and optimized within the overall protection strategy?

5.2. REVISING OIL4$_\beta$ FOR A SPECIFIC BETA MONITORING INSTRUMENT

Although the ambient dose equivalent rate OIL4$_\gamma$ is sufficient to assess the levels of radioactive material on the skin for a release of radioactive material from an LWR or its spent fuel, in some cases, beta monitoring instruments may be used instead of ambient dose equivalent rate instruments. Therefore, a default OIL4$_\beta$ value is also provided in this publication.

The default OIL4$_\beta$ value given in Section 2 can be used, without revision, with any instrument that meets the suitability criteria described in Section 3.7.2.3. However, beta monitoring instruments that are suitable could have considerably different responses, in cps, to the same levels of deposition, primarily due to differences in the efficiency and effective window area. The default OIL4$_\beta$ value needs to be adapted to specific beta monitoring instruments during the preparedness stage for the response teams' instruments by following two steps:

- **Step 1:** Calculate δ_β(inst) [unitless], which is the ratio factor of the beta monitoring instrument by using either (a) its calibration factor [(Bq/cm^2)/cps] (if provided for one of the radionuclides listed in Table 31); (b) its instrument coefficient [cps/(Bq/cm^2)]; or (c) the effective window area [cm^2] in combination with the response factor [cps/Bq], as described in Eq. (76):

$$\delta_\beta(\text{inst}) = \frac{\text{CalF}_{\beta,i}(\text{baseline} - \text{inst})}{\text{CalF}_{\beta,i}(\text{inst})} = \frac{C_{\beta,i}(\text{inst})}{C_{\beta,i}(\text{baseline} - \text{inst})} \cong \cong \frac{a_{\text{eff},\beta}(\text{inst}) \times R_{4\pi,\beta,i}(\text{inst})}{a_{\text{eff},\beta}(\text{baseline} - \text{inst}) \times R_{4\pi,\beta,i}(\text{baseline} - \text{inst})} \quad (76)$$

where:

  - $\text{CalF}_{\beta,i}$(baseline-inst) [(Bq/cm^2)/cps] is the calibration factor of the baseline beta monitoring instrument for radionuclide i. The values are given in Table 31.
  - $\text{CalF}_{\beta,i}$(inst) [(Bq/cm^2)/cps] is the calibration factor of the beta monitoring instrument (inst) for one of the radionuclides listed in Table 31.
  - $C_{\beta,i}$(baseline-inst) [cps/(Bq/cm^2)] is the beta baseline monitoring instrument coefficient for radionuclide i. It is given in Table 31.
  - $C_{\beta,i}$(inst) [cps/(Bq/cm^2)] beta monitoring instrument coefficient for radionuclide i.
  - $a_{\text{eff},\beta}$(baseline-inst) = 15 cm^2 is the effective window area (e.g. sensitive or radiation inlet area) of the baseline beta monitoring instrument and is described in Section 3.7.2.1.1.
  - $a_{\text{eff},\beta}$(inst) [cm^2] is the effective window area (e.g. sensitive or radiation inlet area) of the beta monitoring instrument (inst).
  - $R_{4\pi,\beta,i}$(baseline-inst) [cps/Bq] is the ideal response factor of the baseline beta monitoring instrument, which reflects the response [cps] for each nuclear transformation per second [Bq] of radionuclide i on the surface, for 4π geometry, assuming ideal conditions (e.g. no self-absorption or air absorption) and the instrument window being very close to the surface.[64] It is given in Table 32.

[64] The numerical value of $R_{4\pi,\beta,i}$(baseline-inst) corresponds to (or is often referred to) the 4π efficiency stated by many manufacturers. 2π efficiency is equal to 2 times the 4π efficiency.

- $R_{4\pi,\beta,i}$(inst) [cps/Bq] is the response factor of the beta monitoring instrument, which reflects the response [cps] for each nuclear transformation per second [Bq] of radionuclide i on the surface, for 4π geometry, assuming ideal conditions (e.g. no self-absorption or air absorption) and the instrument window being very close to the surface. It is often provided by the manufacturer as the 4π efficiency of the instrument. If the manufacturer only provides a 2π geometry efficiency, divide this by 2 to get the 4π efficiency.[65]

- **Step 2:** Calculate the $OIL4_{\beta}$(inst) [cps] for a specific beta monitoring instrument (inst) by using Eq. (77):

$$\mathrm{OIL4}_{\beta}(\mathrm{inst}) = \delta_{\beta}(\mathrm{inst}) \times \mathrm{OIL4}_{\beta} \quad (77)$$

where:

- δ_{β}(inst) [unitless] is the ratio factor of the beta monitoring instrument (inst), as determined in the previous step in Eq. (76).
- $OIL4_{\beta}$ = 1000 cps is the default $OIL4_{\beta}$ value for baseline instrument, as given in Section 2.6.2.

[65] 4π efficiency applies to emissions in all directions and 2π efficiency applies to emissions toward the detector.

APPENDIX

RELATIONSHIP WITH OTHER IAEA PUBLICATIONS

This publication (EPR-NPP-OILs) is part of the IAEA Emergency Preparedness and Response Series and is related to the following IAEA publications:

IAEA Safety Standards Series:

- **General Safety Requirements No. GSR Part 7 (2015)** [1] provides the requirements for establishing an adequate level of preparedness and response for a nuclear or radiological emergency. It is a revised and updated version of the IAEA Safety Standards Series No. GS-R-2 issued in 2002.[66] It establishes in para. 4.28(4) the requirement to develop operational criteria (including OILs) for initiating the different parts of an emergency plan and taking response actions as part of the overall protection strategy. It also provides in its Appendix II generic criteria in terms of projected or received dose at which response actions need to be taken. These generic criteria are the basis for the default OIL values derived in this (EPR-NPP-OILs) publication (as describe in Section 3.2).

- **General Safety Guide No. GSG-2 (2011)** [2] elaborates the framework of generic and operational criteria for taking effective response actions in a nuclear or radiological emergency, including numerical values of these criteria. The default operational criteria of GSG-2 are applicable to any radiological or nuclear emergency, i.e. they are not specific to any particular type of emergency. While the generic criteria and OILs provided in GSG-2 are consistent with GSR Part 7 [1], their scope has been broadened in GSR Part 7. The OILs for LWR emergencies and guidance provided in this (EPR-NPP-OILs) publication considers the latest guidance given in GSR Part 7 as well as the lessons learned since the publication of GSG-2 (e.g. from the accident at the Fukushima Daiichi nuclear power plant).

- **Safety Guide No. GS-G-2.1 (2007)** [3] provides additional guidance on meeting specific EPR safety requirements, describes appropriate responses to a range of nuclear and radiological emergencies, and gives background information on past experience. It also discusses the concept of OILs and provides further technical basis on their development.

IAEA EPR Series publications and IAEA TECDOCs:

- **IAEA EPR-NPP Public Protective Actions (2013)** [4] provides practical guidance on the actions necessary to be taken to protect the public in the event of an emergency involving actual or projected severe damage to the fuel or spent fuel of an LWR. It provides a basis for developing the tools that would be needed in taking actions in response to such an emergency. EPR-NPP Public Protective Actions can be used as a basis for developing

[66] The IAEA Safety Standards Series No. GS-R-2 (2002) was superseded by the IAEA Safety Standards Series No. GSR Part 7 [1]. GS-R-2 provided generic intervention levels and action levels for taking an intervention in a nuclear or radiological emergency. However, they have been superseded by the concept of generic and operational criteria and the protection strategy addressed in GSG-2 [2] and GSR Part 7 [1].

protection strategies for this type of emergency consistently with GSR Part 7 [1]. However, the OILs, associated response actions and methodology provided in this publication (EPR-NPP-OILs) update those in the EPR-NPP Public Protective Actions publication (in a minor way) in consideration of the latest safety requirements (GSR Part 7).

- **IAEA-TECDOC-955 (1997)** [5] provides technical procedures for determining response actions for the public and controlling doses to emergency workers for accidents at a nuclear reactor. These include: procedures for classifying an accident, projecting consequences, coordinating and interpreting environmental monitoring, determining public protective actions and controlling emergency worker doses. The technical guidance for response actions and OILs contained in IAEA-TECDOC-955 are superseded by Refs [2, 3, 4] and by this publication (EPR-NPP-OILs).

- **IAEA EPR-MEDICAL (2005)** [77] serves as a practical resource for planning the medical response to a nuclear or radiological emergency. It provides practical tools and generic procedures for use by emergency medical personnel and guidance for the development of medical response capabilities. The OILs it provides for skin contamination are consistent with the OIL4 provided in this publication; however, they are intended for any type of radiation emergency and are not specific to LWR emergencies.

Further details of the principles and arrangements to respond effectively to a severe nuclear or radiological emergency can be found in the IAEA Safety Fundamentals [87], Safety Requirements [1], Safety Guides [2, 3], EPR Series publications, TECDOCs and Accident Reports provided at http://www-pub.iaea.org/MTCD/publications/publications.asp. The IAEA Safety Glossary Ref. [88] defines and explains technical terms used in IAEA safety standards and other safety related IAEA publications, and provides information on their usage

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NOTATION

Notation	Unit	Definition	Value
$ad_{skin,skin\text{-}scenario,i}$	[Gy/ (Bq/m^2)]	RBE weighted absorbed dose to the skin derma of the representative person, for the 'skin' scenario, per unit skin surface activity of radionuclide i	Table 28
$ad_{skin,skin\text{-}srf,i}$	[(Gy/s)/ (Bq/m^2)]	RBE weighted absorbed dose rate to the skin derma of the representative person, from activity on the skin, per unit skin surface activity of radionuclide i	Table 27
$a_{eff,\beta}$(baseline-inst)	[cm^2]	Effective window area (e.g. sensitive or radiation inlet area) of the baseline beta monitoring instrument	15
$a_{eff,\beta}$(inst)	[cm^2]	Effective window area (e.g. sensitive or radiation inlet area) of the beta monitoring instrument (inst)	External input
A_i(t,mix)	[Bq]	Activity of radionuclide i at time t after reactor shutdown, for a specific radionuclide mix	Eq. (2)
$A_{OIL1,E}$(t,mix)	[Bq/m^2]	Gross activity on the ground at time t after reactor shutdown, that for the 'ground' scenario results in a total effective dose to the representative person meeting the GC(Urgent,E,7d), for a specific radionuclide mix	Eq. (52)
$A_{OIL1,Hfetus}$(t,mix)	[Bq/m^2]	Gross activity on the ground at time t after reactor shutdown, which, for the 'ground' scenario, results in a total equivalent dose to the fetus meeting the GC(Urgent,H_{fetus},7d), for a specific radionuclide mix	Eq. (53)
$A_{OIL2,E}$(t,mix)	[Bq/m^2]	Gross activity on the ground at time t after reactor shutdown, which, for the 'ground' scenario, results in a total effective dose to the representative person meeting the GC(Early,E,1a), for a specific radionuclide mix	Eq. (56)
$A_{OIL2,Hfetus}$(t,mix)	[Bq/m^2]	Gross activity on the ground at time t after reactor shutdown, which, for the 'ground' scenario, results in a total equivalent dose to the fetus meeting the GC(Early,H_{fetus},9mo), for a specific radionuclide mix	Eq. (57)
$A_{OIL3,eing}$(t,mix)	[Bq/m^2]	Gross activity on the ground at time t after reactor shutdown, which, for the 'food pre-analysis' scenario, results in a committed effective dose from ingestion to the representative person meeting the GC(Ingestion,e_{ing},1a), for a specific radionuclide mix	Eq. (60)
$A_{OIL3,hfetus,ing}$(t,mix)	[Bq/m^2]	Gross activity on the ground at time t after reactor shutdown, which, for the 'food pre-analysis' scenario, results in a committed equivalent dose to the fetus from ingestion meeting the GC(Ingestion,$h_{fetus,ing}$,9mo), for a specific radionuclide mix	Eq. (61)
$A_{OIL4,ADskin}$(t,mix)	[Bq/m^2]	Gross activity on the skin surface at time t after reactor shutdown, which, for the 'skin' scenario, results in an RBE weighted absorbed dose to the skin meeting the GC(Acute,$AD_{skin\text{-}ext}$,10h), for a specific radionuclide mix	Eq. (66)
$A_{OIL4,e}$(t,mix)	[Bq/m^2]	Gross activity on the skin surface at time t after reactor shutdown, which, for the 'skin' scenario, results in an effective dose to the representative person from inadvertent ingestion meeting the GC(Urgent,E,7d), for a specific radionuclide mix	Eq. (64)

Notation	Unit	Definition	Value
$A_{OIL4,hfetus}(t,mix)$	[Bq/m^2]	Gross activity on the skin surface at time t after reactor shutdown, which, for the 'skin' scenario, results in an equivalent dose to the fetus from inadvertent ingestion meeting the GC(Urgent,H_{fetus},7d), for a specific radionuclide mix	Eq. (65)
$A_{OIL7,eing}(t,mix)$	[Bq/kg]	Activity concentration in food, milk or drinking water, which, for the 'food post-analysis' scenario, results in a committed effective dose to the representative person from ingestion meeting the GC(Ingestion,e_{ing},1a), for a specific radionuclide mix	Eq. (70)
$A_{OIL7,hfetus,ing}(t,mix)$	[Bq/kg]	Activity concentration in food, milk or drinking water, which, for the 'food post-analysis' scenario, results in a committed equivalent dose to the fetus from ingestion meeting the GC(Ingestion,$h_{fetus,ing}$,1a), for a specific radionuclide mix	Eq. (71)
$A_{OIL8,hthyroid,I\text{-}131\text{-}burden}$	[Bq]	Activity of I-131 in the thyroid (thyroid burden), which, for the 'thyroid' scenario, results in a committed equivalent dose to an infant meeting the GC(Urgent,$h_{thyroid,thy\text{-}burden}$)	Eq. (75)
$CalF_{\beta,i}$(baseline-inst)	[(Bq/cm^2)/cps]	Calibration factor of the baseline beta monitoring instrument for radionuclide i	Table 31
$CalF_{\beta,i}$(inst)	[(Bq/cm^2)/cps]	Calibration factor of the beta monitoring instrument (inst) for one of the radionuclides listed in Table 31	Eq. (48)
$CalF_{\beta,i}$(suitable-inst)	[(Bq/cm^2)/cps]	Calibration factor of a suitable beta monitoring instrument for radionuclide i	Table 31
$CalF_{R,I\text{-}131}$(baseline-inst)	[Bq/(Sv/s)]	Calibration factor of the baseline monitoring instrument for the activity of I-131 in the thyroid relative to the ambient dose rate measured in front of the thyroid in contact with the skin of an infant	3.5E+13
$C_{\beta,i}$(baseline-inst)	[cps/(Bq/cm^2)]	Baseline beta monitoring instrument coefficient for radionuclide i	Table 31
$C_{\beta,i}$(inst)	[cps/(Bq/cm^2)]	Beta monitoring instrument coefficient for radionuclide i	Eq. (49)
$C_{\beta,i}$(suitable-inst)	[cps/(Bq/cm^2)]	Instrument coefficient of a suitable beta monitoring instrument for radionuclide i	Table 31
$ConF_{\phi\rightarrow H^*(10),Ej}$	[pSv cm^2]	Conversion factor for the ambient dose equivalent H*(10) [pSv] per fluence [cm^{-2}] of photons with energy E_j	Table A.21 of Ref. [78]
$CorF_{distance,\beta}$	[unitless]	Distance correction factor for the beta monitoring instrument that accounts for the reduction due to absorption in air at the recommended distance of 2 cm for skin monitoring	0.5
$CorF_{field,\beta}$	[unitless]	Field beta correction factor for the beta monitoring instrument that accounts for the reduction in the beta count rate for measurements made under field (i.e. non-ideal) conditions	0.25
$CorF_{grd}$	[unitless]	Ground roughness correction factor to account for the dose rate reduction due to ground roughness	0.7
$CorF_{I\text{-}131\text{-}thyroid\text{-}burden}(t_m)$	[unitless]	Correction factor to account for the reduction in the activity in the thyroid due to the radioactive decay and biological removal of I-131	Fig. 8

Notation	Unit	Definition	Value
$CorF_{surface,\beta}$	[unitless]	Surface correction factor for the beta monitoring instrument that accounts for the absorption due to non-ideal surface conditions encountered during an emergency	0.5
$DA_{OIL1}(t,mix)$	[Bq/m^2]	Derived gross activity on the ground at time t after reactor shutdown, which, for the 'ground' scenario, results in any of the generic criteria specified for $OIL1_\gamma$ (in Table 2) being met, for a specific radionuclide mix	Eq. (51)
$DA_{OIL2}(t,mix)$	[Bq/m^2]	Derived gross activity on the ground at time t after reactor shutdown, which, for the 'ground' scenario, results in any of the generic criteria specified for $OIL2_\gamma$ (in Table 2) being met, for a specific radionuclide mix	Eq. (55)
$DA_{OIL3}(t,mix)$	[Bq/m^2]	Derived gross activity on the ground at time t after reactor shutdown, which, for the 'food pre-analysis' scenario, results in any of the generic criteria specified for $OIL3_\gamma$ (in Table 2) being met, for a specific radionuclide mix	Eq. (59)
$DA_{OIL4}(t,mix)$	[Bq/m^2]	Derived gross activity on the skin surface at time t after reactor shutdown, which, for the 'skin' scenario, results in any of the generic criteria specified for $OIL4_\gamma$ and $OIL4_\beta$ (in Table 2) being met, for a specific radionuclide mix	Eq. (63)
$DA_{OIL7}(t,mix)$	[Bq/kg]	Activity concentration in food, milk or drinking water at time t after reactor shutdown, which. for the 'food post-analysis' scenario, results in any of the generic criteria specified for OIL7 (in Table 2) being met, for a specific radionuclide mix	Eq. (69)
Δ	[s]	Exposure period	Variable
$\Delta_{available\text{-}ing}$	[s]	Period of time that the affected food or forage is available for consumption	365 d = 3.15E+07 s
$\delta_\beta(inst)$	[unitless]	Ratio factor of the beta monitoring instrument (inst)	Eq. (76)
$\Delta_{dep\rightarrow consumption}$	[s]	Period of time between deposition and consumption	1 d = 86 400 s
$\Delta_{eff,OIL3,i}$	[s]	Effective availability period for radionuclide i for ingestion in the 'food pre-analysis' scenario	Table 20
$\Delta_{eff,OIL4\text{-}Acute,i}$	[s]	Effective availability period for radionuclide i for inadvertent ingestion from the skin in the 'skin' scenario for the acute generic criteria	Table 20
$\Delta_{eff,OIL4\text{-}Urgent,i}$	[s]	Effective availability period for radionuclide i for inadvertent ingestion from the skin in the 'skin' scenario for the urgent generic criteria	Table 20
$\Delta_{eff,OIL7,i}$	[s]	Effective availability period for radionuclide i for ingestion in the 'food post-analysis' scenario	Table 20
$d_{inadv\text{-}ing}$	[m]	Depth available for inadvertent ingestion	1 mm = 0.001 m
$d_{monitoring}$	[m]	Monitoring distance at which the measurements of the skin are recommend to be taken for the default $OIL4_\gamma$ value (as indicated in Section 2.6.2)	0.1
$\Delta_{OIL4\text{-}Acute}$	[s]	Exposure period considered for the acute generic criteria (given in Table 2)	10 h = 36 000 s

Notation	Unit	Definition	Value
$\Delta_{OIL4\text{-}Urgent}$	[s]	Exposure period considered for the urgent generic criteria (given in Table 2)	7 d = 604 800 s
$e_{air\text{-}sh,i}(adult)$	[(Sv/s)/ (Bq/m^3)]	External effective dose rate to the adult from air submersion, per unit volume activity of radionuclide i	Table 24
$e_{air\text{-}sh(grd\text{-}scenario),i}(\Delta)$	[Sv/ (Bq/m^2)]	External effective dose to the representative person, over an exposure period Δ, from air shine resulting from resuspended ground deposition, for the 'ground' scenario, per unit ground surface activity of radionuclide i	Eq. (24)
$e_{ing,food\text{-}pre\text{-}analysis\text{-}scenario,i}$	[Sv/ (Bq/m^2)]	Committed effective dose to the representative person from ingestion over 1 year, for the 'food pre-analysis' scenario, per unit ground surface activity of radionuclide i	Table 26
$e_{ing,skin\text{-}scenario,i}$	[Sv/ (Bq/m^2)]	Committed effective dose to the representative person from inadvertent ingestion, for the 'skin' scenario, per unit skin surface activity of radionuclide i	Table 28
$E_{grd\text{-}scenario,i}(\Delta)$	[Sv/ (Bq/m^2)]	Total effective dose to the representative person over an exposure period Δ, for the 'ground' scenario, per unit ground surface activity of radionuclide i	Table 23
$e_{grd\text{-}sh(grd\text{-}scenario),i}(\Delta)$	[Sv/ (Bq/m^2)]	External effective dose to the representative person, over an exposure period Δ, from ground shine resulting from ground deposition, for the 'ground' scenario, per unit ground surface activity of radionuclide i	Eq. (23)
$e_{inadv\text{-}ing(grd\text{-}scenario),i}(\Delta)$	[Sv/ (Bq/m^2)]	Committed effective dose to the representative person, over an exposure period Δ, from inadvertent ingestion of ground deposition, for the 'ground' scenario, per unit ground surface activity of radionuclide i	Eq. (26)
$e_{ing,food\text{-}post\text{-}analysis\text{-}scenario,i}$	[Sv/ (Bq/kg)]	Committed effective dose to the representative person from ingestion of food, milk and drinking water over 1 year, for the 'food post-analysis' scenario, per unit activity concentration of radionuclide i in food, milk or drinking water	Table 29
$e_{ing,i}(adult)$	[Sv/Bq]	Committed effective dose to the adult from ingestion, per unit intake of radionuclide i	Table 27
$e_{ing,i}(infant)$	[Sv/Bq]	Committed effective dose to the infant from ingestion, per unit intake of radionuclide i	Table 24 and Table 27
$e_{inh,i}(adult)$	[Sv/Bq]	Committed effective dose to the adult from inhalation, per unit intake of radionuclide i	Table 24
$e_{inh\text{-}resusp(grd\text{-}scenario),i}(\Delta)$	[Sv/ (Bq/m^2)]	Committed effective dose to the representative person, over an exposure period Δ, from inhalation of resuspended ground deposition, for the 'ground' scenario, per unit ground surface activity of radionuclide i	Eq. (25)
$e_{plane\text{-}srf,i}(adult)$	[(Sv/s)/ (Bq/m^2)]	Effective dose rate to the adult from an infinite smooth plane source, per unit surface activity of radionuclide i	Table 24
Φ_1	[m^2/kg]	Mass interception factor for pasture grass in dry weight, i.e. ratio between the activity concentration on the plant [Bq/kg] and the unit ground surface activity on the terrestrial surface [Bq/m^2] (soil plus vegetation)	3

Notation	Unit	Definition	Value
Φ_2	[m^2/kg]	Mass interception factor for leafy vegetables (fresh or wet weight), i.e. ratio between the activity concentration on the plant [Bq/kg] and the unit ground surface activity on the terrestrial surface [Bq/m^2] (soil plus vegetation)	0.3
$F_{consumption,i}$	[unitless]	Fraction of the radionuclide i remaining at the time of human consumption	Table 22
$F_{cow\text{-}feed}$	[unitless]	Fraction of the cow feed assumed to be affected	0.7
$F_{diet,OIL7}$	[unitless]	Fraction of the total diet (i.e. all food, milk and drinking water consumed) assumed to be affected for the 'food post-analysis' scenario	0.5
$F_{I\text{-}131\text{-}retained\text{-}in\text{-}thyroid}$	[unitless]	Fraction of I-131 that is retained in the thyroid following intake	0.3
$F_{ideal\text{-}surf\text{-}emission}$	[unitless]	Ideal surface emission factor, i.e. ratio between (a) the number of particles that emerge from the front face of a surface and (b) the number of particles emitted from a radionuclide on the surface	0.5
F_{lv}	[unitless]	Fraction of the leafy vegetables consumed assumed to be affected before actions are taken to control intake	0.5
F_{milk}	[unitless]	Fraction of the milk consumed assumed to be affected before actions are taken to control intake	0.5
F_{of}	[unitless]	Fraction of the exposure period that the person is assumed to spend inside a building (occupancy fraction)	0.6
F_{prep}	[unitless]	Fraction of the radioactive material remaining for ingestion after preparations	1
F_{rf}	[unitless]	Fraction of the airborne radioactive material that is deposited in the pulmonary region of the lung (respirable fraction)	1
F_{sf}	[unitless]	Fraction of the dose rate received from ground deposition for a person located inside a building relative to the dose rate for that person located outside the building (shielding factor)	0.4
$F_{soil,inadv\text{-}ing}(\tau_0)$	[unitless]	Fraction of the deposited material available for ingestion (e.g. material that is within the $d_{inadv\text{-}ing}$ or not adhered to a surface) at time τ_0	1
GC(Acute, $AD_{skin\text{-}ext}$,10h)	[Gy]	Generic criterion used to take response actions under any circumstance based on the RBE weighted absorbed dose to 100 cm^2 of the skin dermis of the representative person from acute external exposure in the first 10 hours	10 Gy to 100 cm^2
GC(Early,E,1a)	[Sv]	Generic criterion used to take early response actions based on the total effective dose to the representative person in the first year	0.1
GC (Early,H_{fetus},9mo)	[Sv]	Generic criterion used to take early response actions based on the total equivalent dose to the fetus in the full period of in utero development	0.1
GC (Ingestion,e_{ing},1a)	[Sv]	Generic criterion used to restrict the ingestion of non-essential food, milk and drinking water based on the committed effective dose from ingestion to the representative person over the first year	0.01

Notation	Unit	Definition	Value
GC(Ingestion, $h_{fetus,ing}$,9mo)	[Sv]	Generic criterion used to restrict the ingestion of non-essential food, milk and drinking water based on the committed equivalent dose to the fetus from ingestion over the full period of in utero development	0.01
GC(Urgent,E,7d)	[Sv]	Generic criterion used to take urgent response actions based on the total effective dose to the representative person in the first 7 days	0.1
GC (Urgent,H_{fetus},7d)	[Sv]	Generic criterion used to take urgent response actions based on the total equivalent dose to the fetus in the first 7 days	0.1
GC(Urgent, $h_{thyroid,thy\text{-}burden}$)	[Sv]	Generic criterion used to take urgent response actions based on the committed equivalent dose to the thyroid from radioiodine in the thyroid (thyroid burden)	0.1
GF_{srf}	[unitless]	Geometry factor to account for the measurement being taken at 10 cm from the skin with an instrument with a view of 100 cm^2	Eq. (42)
$H^*_{grd\text{-}sh,i}$	[(Sv/s)/ (Bq/m^2)]	Ambient dose equivalent rate at 1 m above ground level, per unit ground surface activity of radionuclide i	Table 30
$H^*_{I\text{-}131\text{-}thyroid\text{-}burden}$ (baseline-inst)	[(Sv/s) /Bq]	Ambient dose equivalent rate in front of the thyroid as measured with the baseline instrument for monitoring the thyroid (baseline-inst) against the neck of an infant, per unit activity of I-131 (burden) in the thyroid	2.9E-14
$H^*_{skin\text{-}100cm^2\text{-}srf,i}$	[(Sv/s)/ (Bq/m^2)]	Ambient dose equivalent rate at 10 cm from activity on 100 cm^2 of the skin surface, per unit surface activity of radionuclide i	Table 30
$h_{fetus,air\text{-}sh(grd\text{-}scenario),i}(\Delta)$	[Sv/ (Bq/m^2)]	External equivalent dose to the fetus, over an exposure period Δ, from air shine resulting from resuspended ground deposition, for the 'ground' scenario, per unit ground surface activity of radionuclide i	Eq. (29)
$h_{fetus,ing,food\text{-}pre\text{-}analysis\text{-}scenario,i}$	[Sv/ (Bq/m^2)]	Committed equivalent dose to the fetus from ingestion of food, milk and drinking water by the pregnant woman, over the period of in utero development, for the 'food pre-analysis' scenario, per unit ground surface activity of radionuclide i	Table 26
$H_{fetus,grd\text{-}scenario,i}(\Delta)$	[Sv/ (Bq/m^2)]	Total equivalent dose to the fetus over an exposure period Δ, for the 'ground' scenario, per unit ground surface activity of radionuclide i	Table 23
$h_{fetus,grd\text{-}sh(grd\text{-}scenario),i}(\Delta)$	[Sv/ (Bq/m^2)]	External equivalent dose to the fetus, over an exposure period Δ, from ground shine resulting from ground deposition, for the 'ground' scenario, per unit ground surface activity of radionuclide i	Eq. (28)
$h_{fetus,inadv\text{-}ing(grd\text{-}scenario),i}(\Delta)$	[Sv/ (Bq/m^2)]	Committed equivalent dose to the fetus, over an exposure period Δ, from inadvertent ingestion of ground deposition by an adult (i.e. pregnant woman), for the 'ground' scenario, per unit ground surface activity of radionuclide i	Eq. (31)
$h_{fetus,ing,food\text{-}post\text{-}analysis\text{-}scenario,i}$	[Sv/ (Bq/kg)]	Committed equivalent dose to the fetus from ingestion of food, milk and drinking water by the pregnant woman, over 1 year, for the 'food post-analysis' scenario, per unit activity concentration of radionuclide i in food, milk or drinking water	Table 29

Notation	Unit	Definition	Value
$h_{fetus,ing,i}$	[Sv/Bq]	Committed equivalent dose to the fetus from ingestion by an adult (i.e. pregnant woman), per unit intake of radionuclide i	Table 25 and Table 27
$h_{fetus,ing,skin\text{-}scenario,i}$	[Sv/ (Bq/m^2)]	Committed equivalent dose to the fetus from inadvertent ingestion of radioactive material on the skin, for the 'skin' scenario, per unit skin surface activity of radionuclide i	Table 28
$h_{fetus,inh,i}$	[Sv/Bq]	Committed equivalent dose to the fetus from inhalation by an adult (i.e. pregnant woman), per unit intake of radionuclide i	Table 25
$h_{fetus,inh\text{-}resusp(grd\text{-}scenario),i}(\Delta)$	[Sv/ (Bq/m^2)]	Committed equivalent dose to the fetus, over an exposure period Δ, from inhalation of resuspended ground deposition by a pregnant woman, for the 'ground' scenario, per unit ground surface activity of radionuclide i	Eq. (30)
$h_{red\ marrow,air\text{-}sh,i}(adult)$	[(Sv/s)/ (Bq/m^3)]	Equivalent dose rate to the red marrow of the adult from submersion in a semi-infinite cloud of airborne radioactive material, per unit air activity concentration of radionuclide i	Table 25
$h_{red\ marrow,plane\text{-}srf,i}(adult)$	[(Sv/s)/ (Bq/m^2)]	Equivalent dose rate to the red marrow of the adult from an infinite smooth plane source, for radionuclide i	Table 25
$h_{thyroid,I\text{-}131\text{-}thyroid\text{-}burden}$	[Sv/Bq]	Committed equivalent dose to the thyroid of an infant from I-131 in the thyroid (thyroid burden)	1.2E-05
$h_{thyroid,ing\text{-}I\text{-}131}$	[Sv/Bq]	Committed equivalent dose to the thyroid from ingestion of I-131 by the infant, per unit intake of I-131	3.6E-06
$I_{fuel\text{-}type,i}(t)$	[Bq]	Inventory of radionuclide i in the fuel at time t after reactor shutdown	Eq. (3)
$I_{fuel\text{-}type,i}(t_0)$	[Bq]	Inventory of radionuclide i in the fuel at time t_0	Table 4
$\lambda_{bio\text{-}I\text{-}131}$	[s^{-1}]	Biological removal constant of I-131 in the thyroid	1.0E-07
λ_i	[s^{-1}]	Decay constant for radionuclide i	Table 6
L_{hand}	[kg/m^2]	Amount of soil loaded on the hand of the maximally exposed individual (e.g. children playing outdoors)	1.8 mg/cm^2 = 0.018 kg/m^2
$\lambda_{w\text{-}skin}$	[s^{-1}]	Removal constant from skin due to weathering	Eq. (17)
$\lambda_{w\text{-}vegetation}$	[s^{-1}]	Removal constant from vegetation due to weathering	Eq. (13)
$OIL1_\gamma$	[µSv/h]	Default $OIL1_\gamma$ value, i.e. the ambient dose equivalent rate value measured at 1 m above ground level at which to implement the response actions specified in the OIL chart in Section 2.6.1	1000
$OIL1_\gamma(t,mix)$	[µSv/h]	Ambient dose equivalent rate measured at 1 m above ground level at time t after reactor shutdown, which, for the 'ground' scenario, results in any of the generic criteria specified for $OIL1_\gamma$ (in Table 2) being met, for a specific radionuclide mix	Fig. 9
$OIL2_\gamma$	[µSv/h]	Default $OIL2_\gamma$ value, i.e. the ambient dose equivalent rate value measured at 1 m above ground level at which to implement the response actions specified in the OIL chart in Section 2.6.1	100 (t ≤ 10 d) 25 (t > 10 d)

Notation	Unit	Definition	Value
$OIL2_{\gamma}(t,mix)$	[µSv/h]	Ambient dose equivalent rate measured at 1 m above ground level at time t after reactor shutdown, which, for the ‘ground’ scenario, results in any of the generic criteria specified for $OIL2_{\gamma}$ (in Table 2) being met, for a specific radionuclide mix	Fig. 10
$OIL3_{\gamma}$	[µSv/h]	Default $OIL3_{\gamma}$ value, i.e. the ambient dose equivalent rate value measured at 1 m above ground level at which to implement the response actions specified in the OIL chart in Section 2.6.1	1
$OIL3_{\gamma}(t,mix)$	[µSv/h]	Ambient dose equivalent rate measured at 1 m above ground level at time t after reactor shutdown, which, for the ‘food pre-analysis’ scenario, results in any of the generic criteria specified for $OIL3_{\gamma}$ (in Table 2) being met, for a specific radionuclide mix	Fig. 11
$OIL4_{\beta}$	[cps]	Default $OIL4_{\beta}$ value, i.e. the beta count rate value measured with the baseline beta monitoring instrument at 2 cm from bare skin, at which to implement the response actions specified in the OIL chart in Section 2.6.2	1000
$OIL4_{\beta}(inst)$	[cps]	Default $OIL4_{\beta}$ value for a specific instrument, i.e. the beta count rate value measured with the instrument (inst) at 2 cm from bare skin, at which to implement the response actions specified in the OIL chart in Section 2.6.2	Eq. (77)
$OIL4_{\beta}(t,mix)$	[cps]	Beta count rate measured with the baseline beta monitoring instrument at 2 cm from bare skin at time t after reactor shutdown, which, for the ‘skin’ scenario, results in any of the generic criteria specified for $OIL4_{\beta}$ (in Table 2) being met, for a specific radionuclide mix	Fig. 13
$OIL4_{\gamma}$	[µSv/h]	Default $OIL4_{\gamma}$ value, i.e. the ambient dose equivalent rate value measured at 10 cm from the bare skin, at which to implement the response actions specified in the OIL chart in Section 2.6.2	1
$OIL4_{\gamma}(t,mix)$	[µSv/h]	Ambient dose equivalent rate measured at 10 cm from bare skin at time t after reactor shutdown, which, for the ‘skin’ scenario results in any of the generic criteria specified for $OIL4_{\gamma}$ (in Table 2) being met, for a specific radionuclide mix	Fig. 12
OIL5	[Bq/kg]	Gross beta or alpha concentrations in food, milk or drinking water at which to implement the response actions specified in para. II.21 of Ref. [2] (i.e. stop consumption)	Table 9 of Ref. [2]
OIL6	[Bq/kg]	Activity concentration of a specific radionuclide in food, milk or drinking water at which to implement the response actions specified in para. II.21 of Ref. [2] (i.e. stop consumption)	Para. II.24 of Ref. [2]
OIL7	[Bq/kg]	Combination of the default $OIL7_{I\text{-}131}$ and $OIL7_{Cs\text{-}137}$ values	1000 for I-131 200 for Cs-137
$OIL7_{Cs\text{-}137}$	[Bq/kg]	Default OIL7 value for the activity concentration of the marker radionuclide Cs-137 in food, milk or drinking water, i.e. the activity concentration value of Cs-137 at which to implement the response actions specified in the OIL chart in Section 2.6.3 (needs to be checked in combination with $OIL7_{I\text{-}131}$)	200

Notation	Unit	Definition	Value
$OIL7_{Cs-137}$ (t,mix)	[Bq/kg]	Activity concentration of the marker radionuclide Cs-137 in food, milk or drinking water at time t after reactor shutdown, which, for the 'food post-analysis' scenario, results in any of the generic criteria specified for OIL7 (in Table 2) being met, for a specific radionuclide mix (needs to be used together with $OIL7_{I-131}$)	Fig. 15
$OIL7_{I-131}$	[Bq/kg]	Default OIL7 value for the activity concentration of the marker radionuclide I-131 in food, milk or drinking water, i.e. the activity concentration value of I-131 at which to implement the response actions specified in the OIL chart in Section 2.6.3 (needs to be checked in combination of $OIL7_{Cs-137}$)	1000
$OIL7_{I-131}$(t,mix)	[Bq/kg]	Activity concentration of the marker radionuclide I-131 in food, milk or drinking water at time t after reactor shutdown, which, for the 'food post-analysis' scenario, results in any of the generic criteria specified for OIL7 (in Table 2) being met, for a specific radionuclide mix (needs to be used together with $OIL7_{Cs-137}$)	Fig. 14
$OIL8_{\gamma}$	[µSv/h]	Default $OIL8_{\gamma}$ value, i.e. the ambient dose equivalent rate value measured in front of the thyroid in contact with the skin at which to implement the response actions specified in the OIL chart in Section 2.6.4	0.5
$OIL8_{\gamma}$(t_m, baseline-inst)	[µSv/h]	Ambient dose equivalent rate measured with the baseline monitoring instrument (baseline-inst) in front of the thyroid in contact with the skin of an infant, at time t_m after intake, for which the activity concentration of I-131 in the thyroid results in the generic criterion specified for $OIL8_{\gamma}$ (in Table 2) being met	Fig. 17
Q_{air}	[m^3/s]	Breathing rate of the adult performing light activity	1.2 m^3/h = 3.3E-04 m^3/s
Q_{diet}(g)	[kg/s]	Consumption rate of food, milk and drinking water (total diet) for an individual in age group g	415 kg/a= 1.6E-05 kg/s for infants 1040 kg/a = 3.2E-05 kg/s for adults
Q_{lv}(g)	[kg/s]	Consumption rate of leafy vegetables in fresh weight by an individual in age group g	20 kg/a = 6.3E-07 kg/s for infants 60 kg/a = 1.9E-06 kg/s for adults
Q_{milk}(g)	[L/s]	Consumption rate of milk by an individual in age group g	120 L/a = 3.8E-06 L/s for infants 105 L/a = 3.3E-06 L/s for adults

Notation	Unit	Definition	Value
$Q_{soil}(g)$	[kg/s]	Inadvertent ingestion rate of ground deposition for an individual in age group g living under normal conditions	100 mg/d = 1.2E-09 kg/s for infants 50 mg/d = 5.8E-10 kg/s for adults
$R_{4\pi,\beta,i}$(baseline-inst)	[cps/Bq]	Ideal response factor of the baseline beta monitoring instrument, which reflects the response [cps] for each nuclear transformation per second [Bq] of radionuclide i on the surface, for 4π geometry, assuming ideal conditions (e.g. no self-absorption or air absorption) and the instrument window being very close to the surface	Table 32
$R_{4\pi,\beta,i}$(inst)	[cps/Bq]	Response factor of the beta monitoring instrument, which reflects the response [cps] for each nuclear transformation per second [Bq] of radionuclide i on the surface, for 4π geometry, assuming ideal conditions (e.g. no self-absorption or air absorption) and the instrument window being very close to the surface.	External input
R_{β}(baseline-inst)	[counts]	Ratio between (a) the number of counts by the baseline instrument and (b) the number of particles of interest with an energy above 75 keV (and thus assumed to be detected) that reach the outside face of the detector	0.3
ρ_{dep}	[kg/m^3]	Density of the deposition	1600 mg/cm^3 = 1600 kg/m^3
RA_i(t,mix)	[unitless]	Relative activity of radionuclide i at time t after reactor shutdown for a specific radionuclide mix	Eq. (1)
RF_i(mix)	[unitless]	Release fraction of radionuclide i from the fuel for a specific radionuclide mix	Table 7, Table 8 and Table 9
ROIL7(t,mix)	[unitless]	Maximum value of $OIL7_{I-131}$(t,mix) and $OIL7_{Cs-137}$(t,mix) relative to their corresponding default OIL value	Fig. 16
$R_{view-area}$	[m]	Radius of a circle with an area of 100 cm^2	0.0564
$SF_{e\rightarrow H^*}$	[unitless]	Scaling factor to convert the effective dose into ambient dose equivalent	1.4
$SF_{eext(adult\rightarrow infant)}$	[unitless]	Scaling factor to convert the effective dose to the adult to the effective dose to the infant for external exposure	1.4
$SF_{(h_{redmarrow}\rightarrow h_{fetus}),air-sh}$	[unitless]	Scaling factor to convert the dose conversion factor for the equivalent dose rate to the red marrow into equivalent dose rate to the fetus, for air shine	0.9
$SF_{(h_{redmarrow}\rightarrow h_{fetus}),grd-sh}$	[unitless]	Scaling factor to convert the dose conversion factor for the equivalent dose rate to the red marrow into equivalent dose rate to the fetus, for ground shine	0.8
τ	[s]	Time after deposition	Variable
t	[s]	Time after shutdown of the reactor (i.e. after the fuel was last irradiated in a reactor)	Variable
τ_0	[s]	One day	1 d = 86 400 s

Notation	Unit	Definition	Value
t_0	[s]	Time after reactor shutdown before which no exposure of the public is expected to occur	30 min = 1800 s
$T_{1/2,bio-I-131}$	[s]	Biological half-life of I-131 in the thyroid	80 d = 6.9E+06 s
$T_{1/2,w-skin}$	[s]	Half-life for removal of surface deposition from the skin due to weathering	14.7 h = 5.2E+04 s
$T_{1/2,w-vegetation}$	[s]	Half-life for removal of surface deposition from vegetation due to weathering	14 d = 1.2E+06 s
t_m	[s]	Time between intake and measurement of the thyroid	Variable
$TI_{grd\rightarrow air,i}(\Delta)$	[s/m]	Time integrated transfer factor of radionuclide i from the ground to the air (resuspended into the air by wind or other natural processes), integrated over the exposure period Δ	Table 17
$TI_{grd\rightarrow GI,i}(\Delta,g)$	[m^2]	Time integrated transfer factor of radionuclide i from the ground to the GI tract by inadvertent ingestion for an individual in age group g, integrated over the exposure period Δ	Table 19
$T_{feed\rightarrow cow-milk,i}$	[s/L]	Transfer factor of radionuclide i from feed to the milk of the cow	Table 21
$T_{grd\rightarrow air}(\tau)$	[m^{-1}]	Transfer factor from the ground to the air (by wind or other natural processes) at time τ after deposition, also called resuspension factor	Fig. 6
$T_{grd\rightarrow air}(\tau_0)$	[m^{-1}]	Transfer factor from the ground to the air (by wind or other natural processes), at time τ_0	10E-05
$T_{grd\rightarrow GI}(\tau,g)$	[m^2/s]	Transfer factor from the ground to the GI tract by inadvertent ingestion, for an individual in age group g (i.e. the infant for the representative person and the adult for the fetus), at time τ after deposition	Fig. 7
$T_{grd\rightarrow GI}(\tau_0,g)$	[m^2/s]	Transfer factor from the ground to the GI tract by inadvertent ingestion, for an individual in age group g (i.e. the infant for the representative person and the adult for the fetus), at time τ_0	3.6E-10 m^2/s for adults 7.2E-10 m^2/s for infant
$T_{skin\rightarrow GI}(g)$	[m^2/s]	Transfer factor from the skin to the GI tract due to inadvertent ingestion for an individual in age group g (i.e. the infant for the representative person and the adult for the fetus)	6.4E-08 m^2/s for infants 3.2E-08 m^2/s for adults
UC	as applicable	Unit conversion factor	as applicable
U_{cow}	[kg/s]	Cow consumption rate of feed in dry weight	16 kg/d = 1.9E-04 kg/s
$WI_{G,i}(\Delta)$	[s]	Time integrated external ground dose rate weathering factor, for radionuclide i, integrated over the exposure period Δ	Table 17
$WF_{OIL1\gamma}$	[unitless]	Weighting factor used to avoid the implementation of unwarranted response actions based on the default $OIL1_\gamma$ value	3

Notation	Unit	Definition	Value
$WF_{OIL2\gamma}$	[unitless]	Weighting factor used to avoid the implementation of unwarranted response actions based on the default $OIL2_{\gamma}$ value	1
$WF_{OIL3\gamma}$	[unitless]	Weighting factor used to avoid the implementation of unwarranted response actions based on the default $OIL3_{\gamma}$ value	5
$WF_{OIL4\gamma}$	[unitless]	Weighting factor used to avoid the implementation of unwarranted response actions based on the default $OIL4_{\gamma}$ value	0.5
$WF_{OIL4\beta}$	[unitless]	Weighting factor used to avoid the implementation of unwarranted response actions based on the default $OIL4_{\beta}$ value	0.5
WF_{OIL7}	[unitless]	Weighting factor used to avoid the implementation of unwarranted response actions based on the default OIL7 value	5
$WF_{OIL8\gamma}$	[unitless]	Weighting factor used to avoid the implementation of unwarranted response actions based on the default $OIL8_{\gamma}$ value	1
$W_G(\tau)$	[unitless]	External ground dose rate weathering factor at time τ after deposition	Fig. 5
$Y_{\beta,E,i}$	[Bq^{-1} s^{-1}] [unitless]	Number of particles of interest emitted with energies equal to or above 75 keV (i.e. detectable by the baseline monitor) per nuclear transformation of radionuclide i (yield); the particles of interest include beta +, beta – and internal conversion electrons.	Table 32
$Y^{\gamma}_{E_{j,i}}$	[Bq^{-1} s^{-1}] [unitless]	Absolute yield of discrete photons of energy E_j emitted in nuclear transformation of the radionuclide i	'Spectra' spreadsheet on the attached CD.

ABBREVIATIONS

BWR	boiling water reactor
E	effective dose
EAL	emergency action level
EPD	extended planning distance
EPR	emergency preparedness and response
GC	generic criteria
GI	gastrointestinal
HAZMAT	hazardous materials
ICPD	ingestion and commodities planning distance
ICRP	International Commission on Radiological Protection
ITB	iodine thyroid blocking
LWR	light water reactor
MW(e)	megawatt electric
MW(th)	megawatt thermal
NPP	nuclear power plant
OIL	operational intervention level
PAZ	precautionary action zone
PWR	pressurized water reactor
RBE	relative biological effectiveness
WHO	World Health Organization

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