Commission of the European Communities

radiation protection - 65

Principles and Methods for Establishing Concentrations and Quantities (Exemption values) Below which Reporting is not Required in the European Directive

Doc. XI-028/93

Commission of the European Communities

Principles and Methods for Establishing Concentrations and Quantities (Exemption values) Below which Reporting is not Required in the European Directive

Report prepared by

M. Harvey, S. Mobbs, J. Cooper (1)
A.M. Chapuis, A. Sugier (2)
T. Schneider, J. Lochard (3)
A. Janssens (4)

(1) National Radiological Protection Board (United-Kingdom)

(2) Institut de protection et de Sûreté Nucléaire (France)

(3) Centre d'Etudes sur l'Evaluation de la Protection dans le Domaine Nucléaire (France)

(4) Commission of the European Communities, DG XI

1993 XI-028/93

Foreword

The Basic Safety Standards for the health protection of the general public and workers against the dangers of ionising radiation[1] incorporate values of activities not to be exceeded so that the requirements for reporting and obtaining prior authorisation of activities involving a hazard arising from ionising radiation need not be applied (article 4 of Council Directive 80/836). For this purpose all relevant nuclides have been classified in four groups, according to their relative toxicity. Also radioactive substances of a concentration of less than 100 Bq g^{-1} are exempted from this requirement, this limit being increased to 500 Bq g^{-1} for solid natural radioactive substances. These exemptions, while allowing competent authorities in Member States to disregard a multitude of trivial practices, have so far not given rise to any situations where the health of the general public or of workers were put at risk. However, the opportunity of a major revision of the Basic Safety Standards, to bring these in line with the recommendations of ICRP (publication 60), was taken to introduce a more transparent and consistent methodology for establishing exemption levels on a nuclide-specific basis. The Group of Experts set up under Article 31 of the Euratom Treaty advised the Commission on these matters and the Commission entrusted the task of establishing an adequate rationale and of calculating the corresponding levels to two European organisations, the National Radiological Protection Board (Chilton, UK) and the Institut de Protection et de Sécurité Nucléaire (Fontenay-aux-Roses, France). The excellent interaction of both organisations with each other and with a Working Group of Art. 31, chaired by Professor R Clarke, ultimately led to the present joint report. This report was discussed thoroughly at the plenary Art. 31 meeting of 22 June 1993 and the proposed methodology and resulting values were finally endorsed. The Commission of the European Communities acknowledges this advice and the efforts spent by all those involved in this work, and is pleased to use this report as the basis for the exemption levels laid down in its proposal for revised Basic Safety Standards

S. FINZI, Director.

---

[1]Council Directive 84/467 EURATOM (OJ no L265/4)

Contents

Figures

Introduction

In the European Community, and in the context of the EURATOM Treaty[1], the Basic Safety Standards Directive[2] addresses Member States and its provisions are incorporated into national radiation protection legislation and regulatory measures.

National legislation may lay down specific measures, eg, constraints, rules, codes of practices, for different categories of practices or sources. The competent authorities may specify independently a number of criteria or type specifications applicable to sources, instruments, containers, etc... Further, administrative procedures may vary from one country to another because of different regulatory frameworks.

In addition to the general legislation, there is a discretionary power of competent authorities at the level of the individual practice or undertaking. This power is exercised most clearly with practices requiring prior authorisation. A third major component of regulatory control is that of verification. This applies both to on-site inspections and to the examination of information provided. Such information is, for example, provided to the competent authorities on the basis of the general requirement of reporting.

An essential requirement of any sound regulatory structure is to present a clear definition of its scope: certain sources or practices may be excluded from regulatory requirements or exempted from regulatory supervision.

One reason for such exemption is when the radiological risk or detriment associated with the practice is so small as not to warrant the imposition of the system of reporting or prior authorisation. The basis for calculating exemption levels is to establish a series of exposure scenarios covering use, misuse and disposal of materials in the relevant practices, and then to compare the resulting exposures with the appropriate dose criteria.

In the context of revising the European Directive laying down the basic standards for the protection of the health of the workers and the general public against the dangers arising from ionising radiation, CEC-Directorate General XI has awarded the Institute for Nuclear Safety and Protection (IPSN-France) and the National Radiological Protection Board (NRPB-UK) the task of establishing numerical values for setting up exemption levels for reporting (Annex 1 of the Directive).

The objective of this document is to present the concepts and methods for establishing concentrations and quantities (exemption values) below which reporting is not required. This is based on work undertaken by IPSN, NRPB and CEPN to clarify the methodological principles of the exemption procedure and to establish the numerical values for the European Directive.

1 Principles of Regulatory supervision in the field of ionising radiation

The following paragraphs present a short overview of these regulatory procedures with emphasis on the role of the reporting and prior authorisation systems.

1.1 Reporting

Reporting is a procedure enabling surveillance of sources and practices by obliging source owners to notify the authorities of the possession of such sources or of the initiation of practices. This means that, as soon as the conditions defined by the regulations have been satisfied, the authorities must issue the corresponding formal acknowledgement. Reporting proceedings are generally straightforward. With such a procedure, practices benefit from unrestrained freedom at the outset and are only subsequently subjected to control. Since the practice theoretically should involve only slight drawbacks and minimum risks, the observance of a few general precautionary measures would normally suffice to ensure that it remains completely harmless. This may or may not be supplemented with relevant instructions of a general nature for specific practices or categories of sources.

1.2 Prior authorisation

Prior authorisation only allows the practice to be carried out providing an authorisation is granted. It is mandatory in the event of serious dangers or drawbacks whereby the authorities can exercise particularly rigorous surveillance. It requires that implementation of each practice shall be individually examined and submitted to formal acceptance by the authorities. With such a procedure practices are subjected to prior control by the authorities who can oppose their initiation or, if they are accepted, can impose various requirements on them concerning radiation and safety, depending on circumstances. The fulfilment of these requirements will be continued to be verified by the authorities. Moreover, in all cases where the requirements have not been respected or where the conditions of prior authorisation have changed, it can be withdrawn or modified.

1.3 Prohibition

Prohibition constitutes an exceptional regulatory system since its purpose is to forbid one or several practices. In the field of radiological protection, prohibitions may be justified in two types of circumstances: practices are forbidden because they do not conform with the principle of justification recommended in the ICRP radiological protection system, or because they give rise to doses leading to risk levels which are deemed unacceptable.

1.4 Exemption

Exemption can be defined as relief from the obligation to comply with a condition imposed by law or by the public authorities. Consequently, the word "exemption" should never stand alone and one should always specify from which requirements or provisions there is exemption. Law tends to exempt all that is worth less than its intervention. Its implementation requires time and money and if the advantages to be obtained are too slight, the benefit is nullified by the cost of carrying it into effect.

The exemption principle associates the idea of negligibility and control efficiency with the scope of the regulatory provisions. Below a certain level of risk, the pursuance of regulatory supervision proves inefficient or even harmful from the social standpoint. In this perspective, exemption should be envisaged as the limit of what is to be considered as warranting supervision on the part of the competent authority. Such an approach contributes to efficient management, helping to avoid drawing the attention of the competent authorities to situations of no interest from the legal standpoint and, on the contrary, to focus attention on situations involving a manageable potential risk.

1.5 Exclusion

Exclusion of a subject or situation from the scope of the regulatory provisions may be defined as acknowledgement of limits beyond which the law cannot apply and consequently cannot regulate. It can also be defined as a social decision to refrain from including within the scope of the regulations subjects and situations where regulatory control would prove difficult or even unrealistic.

2 Scope of the exemption system in the European Directive

2.1 The reporting system in the Directive

Basically, the Directive applies to any practices or intervention situations which involve a hazard from ionising radiation. It governs the production, processing, handling, use, holding, storage, placing on the market, exportation and disposal of radioactive substances. The Directive stipulates that each person who, or undertaking which, carries out the practices listed above shall report them. However, the Directive extends this with, on the one hand, exceptions via the exemption system and, on the other hand, provisions for prohibition and compulsory prior authorisation for activities particularly liable to endanger public health.

With a view to simplifying the administrative procedures, the Directive stipulates that authorisations may be granted for a continuous practice and for the use of several sources over a predetermined period. The principles covering reporting and prior authorisation are set out in Articles 3 and 4 of the Directive: Article 3 states the general requirement of reporting and rules for exemption from the same requirement, Article 4 specifies the cases where prior authorisation shall be required. The strictest regulatory requirements are associated with the practices covered by Article 4, and therefore only these practices are listed clearly (as are those of Article 5 corresponding to prohibitions).

2.2 Practices to which reporting is not required

Article 3, paragraph 2 sets out *"practices for which no reporting is required"*. Its purpose is to avoid imposing inefficient requirements in particular on users of *small quantities* of radioactive substances (cases a and b). The Directive does not provide an exhaustive list of practices but merely specifies that the practices involved are "the use of radiaoctive substances or their subsequent disposal". Annex 1 of the Directive provides numerical values for exemption levels in terms of total activities or activity concentrations of radioactive substances.

It is important to distinguish these exemption levels from levels which may be applied to radioactive substances already under the system of regulatory control but that are eg, cleared for release. The term clearance levels is proposed for the latter situation. Practices related to

Article 4 are subject to the prior authorisation requirement owing mainly to - but not exclusively - the *large amounts* of radioactive substances involved. In particular, this is the case with both the disposal of radioactive substances and the recycling of material arising from the nuclear industry. Competent authorities could specify clearance levels in terms of activity concentrations, below which materials may be recycled or disposed of from nuclear plants. Clearance levels should be derived on the same radiological basis as that established for exemption. The derivation of these clearance levels should take into account the larger quantities of materials involved and the specific processes concerned. Consequently, it would be incorrect to refer to the values in Annex 1 to define clearance levels for disposal of radioactive substances or for the recycling of materials from nuclear plants.

In view of the earlier considerations, Annex 1 refers to practices involving small scale usage of radioactivity where the radiological risks incurred from the use, misuse and subsequent disposal are too small to warrant regulatory concern. Such practices may include the following uses of radioactivity:

- surface density gauges (β emitters)
- testing the integrity of semiconductors and leak testing generally (eg, ^{85}Kr)
- in education (eg, sealed sources for demonstrating properties of radiation)
- technological application (eg, ^{63}Ni in gas chromography)
- smoke detectors (eg, ^{241}Am)
- research laboratories (eg, ^{14}C and ^{32}P as tracers in biochemical research)
- hospital laboratories (eg, radio-immunoassay techniques).

This list is not exhaustive and some other practices may be relevant for the application of the Annex I.

2.3 The particular case of natural radioactivity

In the Directive, exposure to natural radiation sources is dealt with in general as an intervention situation and not as a practice. The scope of the Directive however extends to natural radiation sources at work in uranium mines and other workplaces as specified in Title VII (to the extent that the competent authority has declared that exposure to these natural radiation sources is subject to control).

The occupancy of dwellings is exempted from reporting, as are any other exposures to natural sources (Article 3), except uranium mines and without prejudice to Title VII. There are very few other situations where exemption from reporting could aply to natural radiation sources. It does not immediately apply to exposures at the workplace (discretionary power of the authorities), nor to the exposure of members of the public through the disposal of natural radioactive substances (prior authorisation is required under Article 4). The scope of application of exemption under article 3a and b is therefore merely the incorporation of naturally occurring radionuclides in consumer products (to the extent that this is not regarded as "deliberate addition" in terms of Article 4C) or their use as a radiaoctive source (eg, Ra-226, Po-210) or for their elemental properties (Thorium, Uranium). The latter imply extraction and purification of the substances to an extend that they would no longer be regarded as "natural" radiation sources.

2.4 Apparatus containing sealed sources and electrical equipment

The exemption of radioactive substances from the requirement of reporting is based solely on its radioactivity content (in terms of total activity or activity concentration) with disregard of the physico-chemical form of the substance or of its mode of fixation. Apparatus containing radioactive substances exceeding the quantities or concentration values specified in Annex 1 as well as electrical equipment can be exempted from reporting provided they are of a type approved by the competent authority. Thus a regulatory control has preceded the placing on the market of such apparatus containing radioactive substances; the approval must ensure that the structure of the source guarantees effective protection against any contact with the radioactive substances and against their leakage or dispersion into the environment (cf. definition of "sealed source"). Even though it is understood that this protection should be guaranteed under "normal conditions of use", the authorities will surely take into account the possibility of misuse of the apparatus and corresponding accidental dispersion. Accidental external exposure may occur if contact with the source is possible upon dismantling. The definition of "accessible surface" should therefore be interpreted in the sense that access to internal parts of the source is very difficult or impossible and even then would not cause harmful exposure. The same applies to electrical equipment (X-ray generators, electron microscopes) for which access to the direct radiation beam is precluded.

In view of these potential hazards, the authorities may associate the approval of the type of apparatus with conditions guaranteeing their safe use, eg, adequate labelling, prescriptions or warnings in an accompanying leaflet, etc... Some form of documentation must accompany the source so that the purchaser may know that it is of an approved type. In the absence of such documentation the user should assume that the source needs to be reported.

In general, disposal of the source following its normal use will be prohibited. There may be exceptions such as short-lived sources or sources incorporating a modest amount of radioactive substances. Indeed, the protection against leakage or dispersion will not be secured indefinitely in case of disposal. The type approval of the source may indicate e.g. whether the source may be disposed of without precautions or rather will need to be returned to the producer. Sources with very high content of radioactivity of course need to be of an approved type, but the authorities may require in addition that their use, transport, etc... be reported or even be subject to prior authorisation. Special rules may apply to mobile sources.

3 Methodology for deriving exemption levels

3.1 Principles for deriving exemption levels

According to ICRP 60[3] (section 287 to 290):

"There are two grounds for exempting a source or an environmental situation from regulatory control. One is that the source gives rise to small individual doses and small collective doses in both normal and accident conditions. The other is that no reasonable control procedures can achieve significant reductions in individual and collective doses. The basis for exemption on the grounds of trivial dose is much sought after, but very difficult to establish.... The second basis for exemption calls for a study similar to that needed in the optimisation of protection. It provides a logical basis for exemption of sources that cannot be exempted solely on the grounds of trivial doses, but for which regulation on any reasonable scale will produce little or no improvement."

Regarding the first approach to exemption, a 'trivial' dose could only be determined by comparison with social activities involving a risk**. On this basis, a trivial "additional" risk would be in the region of 10^{-5}, or even 10^{-6} if the vast array of potential sources of risk is taken into account.

The second approach proposed by ICRP for the determination of reporting levels is based on the fact that beyond a certain level of exposure, no significant improvement is possible. The suggestion of ICRP is to determine, by means of an optimisation-type approach, the protection level beyond which any action would produce only negligible benefits in terms of exposure mitigation.

3.2 Dose criteria

Generally, as in this report, exemption is expressed in terms of derived quantities such as activity concentrations or activities (quantities) of radionuclides which are related to the dose criteria by a set of defined models representing the practices being considered.

The radiological basis for exemption from regulatory control has been reviewed by the IAEA[4] who concluded that an annual individual dose*** of a "few tens of microSieverts" or less provided a basis for exemption. Furthermore, in order to take account of exposures of individuals from more than one exempt practice, it was recommended the critical group exposure from one such practice should be of the order of 10 $\mu Sv\ y^{-1}$. This recommendation has been followed.

The IAEA also require the collective dose commitment to be ALARA and suggest that it may be assumed to be so if it is below 1 manSv per year of the practice. For most radionuclides the collective dose is dominated by the dose to the most exposed individual. Hence, exempt levels based on the individual dose criterion and the scenarios considered here will ensure that the collective dose commitment is well below one manSv. Collective dose commitments calculated in a preliminary study[6] for the exempt levels based on the individual dose criterion ranged from 10^{-6} manSv to 3 10^{-4} manSv.

Additional radiological protection criteria may, however, be required. In some circumstances it is possible for selective localised exposure of the skin to occur from, say, handling a radioactive source. In order to exclude the possibility of any deterministic effects, a limit on the annual dose to skin of 50 mSv has been adopted. This limit is applied to the area of skin in contact with the source, ie, a few tens of square centimetres.

When accidents or misuse are being considered then the probability that the exposure will occur is taken into account. In other words, the probability weighted dose is compared with the dose criteria. This approach is consistent with that recommended in the most recent recommendations of ICRP[3]. Moreover, the accompanying exempt levels are set such that even in pessimistic situations the dose limit for members of the public, 1 $mSv\ y^{-1}$, would not be exceeded. The dose criteria used in the study are given in Table 1.

** In this context risk means the annual attributable risk of death.

***Unless otherwise stated, in this paper the term dose refers to effective dose as defined in ICRP Publication 60[3]. The only exception is skin dose which refers to the equivalent dose to areas of the skin. Effective doses from intakes are estimated from dose per unit intake data published by the UK National Radiological Protection Board[5].

3.3 Choice of radionuclides and physical form

About 300 radionuclides were considered in this study. Their possible uses and their related physical forms were reviewed in consultation with European experts involved in advising small-scale users of radioactivity materials.

About 100 of the radionuclides considered in the study were identified as currently having actual or potential uses. Each of these radionuclides was identified as being used in one or more of the following physical forms: gas/vapour, liquid/solution, dispersible solid (eg, powder), non-dispersible solid, thin film/foil and sealed source/capsule. The likely physical forms of those radionuclides for which no current use was identified were determined by consideration of the physical and chemical properties of the element in question.

The types of situations and applications in which the various physical forms are encountered include the following:

(i) Gaseous radionuclides such as ^{85}Kr are supplied in sealed glass or metal containers. These may either be used as beta sources (for example, in surface density gauges) or the gas may be used in the unsealed form, for example, in testing the integrity of some semiconductor devices. Both routine disposal and accidental releases will give rise to dispersion of the radionuclide in the atmosphere.

(ii) Many radionuclides are used in the form of liquid solutions, in a wide range of applications. Examples include the use of ^{99m}Tc in diagnostic nuclear medicine and ^{32}P in biochemical research. Occupational exposure may occur as a result of handling containers of liquid (external exposure) and inadvertent intakes of spilt material (contamination). Liquid wastes arise inevitably from the use of these materials.

(iii) Radionuclides can exist in the form of dispersible solids in a variety of ways such as, for example, finely divided process materials containing isotopes of the natural radioactive elements uranium and thorium. Almost all the radionuclides considered in the study could potentially be present in the form of dispersible solid low level wastes. In the case of natural radionuclides, exposure pathways arising from non-dispersible solid forms were also considered.

(iv) Sealed radioactive sources are commonly prepared in two forms: either a thin film, usually fixed on a carrier substrate, examples include ^{241}Am sources used in ionisation chamber smoke detectors and ^{63}Ni sources in some gas chromatographs; or as an encapsulated pellet or similar. The latter method of construction is very commonly used for gamma emitting radionuclides such as ^{137}Cs and ^{60}Co.

Some of the radionuclides considered have decay products (daughters) which are themselves radioactive and need to be taken into account when assessing exposure. Table 2 shows a list of all the decay sequences considered in the calculations. The daughters considered have half-lives sufficiently short, relative to their parents that secular equilibrium would be likely to be established within the timescales considered in the exposure scenarios.

Two special decay sequences have also been included consisting of ^{238}U and ^{232}Th each in secular equilibrium with all their decay produces (these sequences occur in nature). These are referred to in this report as $^{238}U_N$ and $^{232}Th_N$.

3.4 Scenarios and models

The scope of this study was to consider the doses arising from the use, misuse and disposal of radioactive materials and then to compare the resulting doses with the appropriate dose criteria. The first step was, therefore, to establish a set of exposure scenarios and pathways that covered the range of possible exposures. A total of 3 scenarios and 24 exposure pathways were identified as the most relevant following consultation with European experts and a review of existing calculations[6,7,8]. The three scenarios are normal use (workplace), accidental (workplace) and disposal to landfill (public). Each of these scenarios gives rise to doses via one or more pathways and therefore the doses from the relevant pathways are summed to give a total dose from the scenario before comparing with the dose criteria. The scenarios are listed in Table 3 and briefly described below. The associated formulae and radionuclide dependent data are listed in Appendices A and B.

(a) The Normal Use (workplace) scenario represents the use of small amounts of radionuclides in industry etc, in the manner for which they are intended, and involves external exposure and inadvertent intakes of radioactive materials.

    Exposures to the pubic arising from normal releases of activity are adequately covered by this workplace scenario.

(b) The Accidental (workplace) scenario represents abnormal procedures or incidents that might occur during the routine use of small amounts of radionuclides. These situations may lead to exposures via a range of external, inhalation and ingestion pathways.

(c) The Disposal (public) scenario represents a member of the public becoming exposed after subsequent disposal of the source. This situation may lead to external, inhalation and ingestion pathways. Both normal and accidental situations are considered.

The scenarios were used to calculate both exempt concentrations and quantities but the exposure pathways and parameter values used in the calculation of exempt concentrations differ from those used for exempt quantities. The difference arises because it is assumed that users may hold as much activity as they wish provided that the calculated activity concentration limits are not exceeded. As a result, the activity concentration pathways are generally more pessimistic. For example, it is assumed that the working environment is uniformly contaminated throughout the year and that intakes normally occur via inhalation and ingestion; external exposure is also assumed. In contrast the total activity scenarios represent small sources of higher activity concentration and in such circumstances exposures via dispersion during accidents and skin contact exposures become important.

3.5 Calculation of exemption levels

Doses arising in the scenarios were calculated using the formulae and parameters listed in Appendices A and B. These doses were then used to establish exemption activities and activity concentrations for the radionuclides, as listed in Tables 4 and 5, using the methodology outlined below and in Figure 1.

3.5.1 Dose calculations

Figure 1 illustrates the general methodology for the calculation of exemption levels. Doses to individuals in the workplace and to members of the public are obtained for an activity concentration of 1 Bq g^{-1} and an activity of 1 Bq. It is assumed that the total inventory of radioactive substances in the considered entity at any time remains 1 Bq g^{-1} or 1 Bq. This is a conservative assumption since in the case of short-lived nuclides, the average inventory will be much smaller. The two sets of scenarios used to calculate doses from unit activity levels and unit activity concentration levels are illustrated in more detail in Figures 2 and 3.

Figure 2 shows that an activity of 1 Bq is represented by a single source of a form described in section 3.3. This source remains undiluted for exposures from Normal Use and Accident (workplace) situations. Used sources are assumed to be disposed of on a landfill site, where exposures may occur following a decay period taken to be 24 hours; a member of the public may accidentally tamper with the source which is assumed to be diluted for the external pathway and undiluted for the ingestion, inhalation and skin exposure pathways.

In the unit activity concentration calculations (Figure 3), the source is assumed to remain undiluted for Normal Use (workplace) and for one of the Disposal (public) pathways (ingestion), and to be diluted for the other Disposal (public) pathways (external and inhalation).

The generic formula used to calculate doses is as follows:

$$D = (A \text{ or } C)\, f\, T\, R\, U\, s \quad \text{Sv y}^{-1}$$

The term D is the equivalent dose for skin doses, the effective dose for whole body doses or committed effective dose for intakes of radionuclides.

The terms A and C are the activity (1 Bq) or activity concentration (1 Bq g^{-1}) respectively.

The terms f, T, U and s are all scenario dependent parameters whose values are given in Appendix A.

The term R is the radionuclide dependent parameter, for which values are given in Appendix B.

The term f is the fraction of A or C which contributes to the dose, D. This may be expressed, for example, as a fraction which contaminates the individual, eg, Accidental-spillage or Accidental-ingestion from contaminated hands. The dose is likely to be very sensitive to this parameter but it will vary with each situation, and may be difficult to predict.

The term T is the time for which an individual is exposed to the source, (h y^{-1}). The exposure time taken is generally realistic, for example, in the Accident (workplace) scenario, it is assumed that an individual is exposed for 10 minutes before decontamination takes place.

The factor U is intended to convert A or C into units consistent with those of the dose factor, R. This conversion depends on the physical properties of the source, eg, mass, surface area and the form of the source at the time of exposure.

The term s represents the probability of an exposure occurring in a year. This is used in situations where it is not certain that a dose will occur in a year, ie, Accident (workplace) scenario and some Disposal (public) pathways. The probability chosen for all these situations was $1\ 10^{-2}$ per year; this assumption is discussed in more detail in Appendix C. Briefly, it ensures that, even if the event occurs, the effective dose to the individual would not exceed 1 mSv, the ICRP dose limit for members of the public. The doses calculated for these accident situations are termed average annual doses and are the product of the dose if it occurs and the annual probability that it will occur.

The term R is the radionuclide dependent dose factor, for a given pathway and the values are given in Appendix B. This factor may be modified by a geometry factor if the size of the source is smaller than the geometry assumed when deriving the dose factors; for example, when calculting the external dose from a 0.1 m^3 gas bottle the dose factor for an infinite slab is modified to account for the size of the gas bottle by multiplying by a geometric factor.

The values of f, T, U and s are necessarily arbitrary to some degree, as there is considerable uncertainty surrounding the 'real' values; in general, realistic assumptions were made. The radionuclide dependent data are largely standard dosimetric data from the literature.

3.5.2 Exemption level calculations

The exemption levels were calculated using the dose criteria in Table 1 and dividing these by the maximum doses obtained for each scenario and radionuclide, as follows:

$$\text{Exempt level for each scenario} = \frac{\text{Annual individual dose criteria}}{\text{Dose per unit activity (Bq) or activity concentration (Bq g}^{-1}\text{)}}$$

These were calculated for both skin doses and effective doses. For the Normal Use (workplace) and Disposal (public) scenarios the dose for each scenario was the sum of the effective doses from all the pathways considered. For the Accidental (workplace) scenario, the two basic types of accident (spillage and fire) were treated separately.

The smallest (most restrictive) exempt level for each radionuclide and waste form was determined from the two workplace scenarios and the public scenario, as shown in Figure 1. These values are presented in Table 4 together with the corresponding dominant pathway. It should be remembered that the exempt level for each scenario is based on the sum of doses from several exposure pathways.

These values were rounded up or down as follows: if the calculated value lies between $3\ 10^{X}$ and $3\ 10^{x+1}$, then the rounded exemption level is 10^{x+1}. For example, $6\ 10^7$ would be rounded up to 10^8 whereas $2\ 10^5$ would be rounded down to 10^5. The rounded values are given in Table 5, together with the corresponding dominant pathway.

4 Results and Discussion

4.1 Exemption activities

From Table 5 it can be seen that rounded activity values range between $1\ 10^3$ Bq for most α-emitting actinides, $1\ 10^9$ Bq for ^3H and ^{53}Mn, which are low energy β-emitters and even up to $1\ 10^{12}$ Bq for Kr 83 m, which is a short lived noble gas.

The exemption activity for α-emitting actinides is usually determined by the exposure from inhalation to a member of the public on a landfill site (a pathway which dominates for the actinides). The exemption activities for ^3H and ^{53}Mn are based on ingestion by a member of the public on a landfill site.

As a general rule the exemption values for gamma and beta emitters tend to be based on skin doses to a worker handling a source, or external effective doses. However, some of them have exemption activities based on internal doses to a worker accidentally inhaling smoke from a fire, or to a member of the public ingesting material from a landfill site.

4.2 Exemption activity concentrations

From Table 5 it can be seen that the rounded exemption activity concentration values range from 1 Bq g^{-1} for most α-emitting actinides to 1 10^6 Bq g^{-1} for ^3H and ^{37}Ar.

For the majority of radionuclides the exemption concentrations are based on external exposures arising in the workplace from standing near a source such as a store cupboard (see Appendix A). The exemption activity concentrations for radionuclides which are used in a gas form (including ^{37}Ar) are due to external doses from standing close to a gas bottle. For the remaining radionuclides (notably some of the actinides) the exemption activity concentrations are a result of doses from inhalation in the workplace or ingestion by a member of the public on a landfill site.

4.3 Discussion

In calculating exemption concentrations and quantities it has been assumed that there is no limit on the quantity of radioactivity that can be held provided it is below the exemption concentration; similarly, there is no limit to the activity concentration provided that the total activity limit is not exceeded.

These exemption values should be distinguished from clearance levels. The latter apply to radioactive substances already under reporting, registration or licensing that are for instance cleared for release.

Application of the rounded levels is expected to result in effective doses to the critical group of no more than around 10 μSv per year with doses of no more than 50 mSv per year to irradiated areas of the skin. Furthermore, these exposures are calculated for realistic exposure situations but even if unlikely, or pessimistic, exposure situations prevailed the dose limits for members of the public of 1 mSv per year (effective) and 50 mSv per year (skin) would not be exceeded. This is self evident for the Accident (workplace) scenario for exempt total activities but is not immediately obvious for the Accident (workplace) scenario for exempt activity concentrations as these were not explicitly calculated. However, it can be demonstrated by considering the parameter values used in the normal use scenario as follows: for the external pathway an exposure time of 100 hours was assumed for the normal use scenario. Therefore the maximum annual dose that could occur via this pathway is around 0.7 mSv, assuming continual occupancy. Furthermore, a dust loading of 40 μg m^{-3} over the working year (2000 hours) was used to calculate inhalation doses for the normal use scenario. In order to incur a dose of 1 mSv the dust loading would have to reach 4 mg m^{-3} which is verging on an intolerably dusty atmosphere. Similar considerations apply to the ingestion pathway.

5 Conclusion

Exemption concentrations and quantities for around 300 radionuclides have been calculated using defined exposure scenarios and pathways. The calculated values (Tables 4 and 5) apply to practices involving small scale usage of activity where the quantities involved are at most of the order of a tonne. The values take into account use, misuse and subsequent disposal.

6 References

1 Treaties establishing the European Communities. Office for Official Publications of the EC, Luxembourg, 1973.

2 Council Directive 80/836 Euratom amending the "Directives laying down the Basic Safety Standards for Health Protection of the General Public and Workers against the dangers of ionising radiations", O.J.L 246 of 17 September 1980. Completed by modification of 3 September, 1984, O.J.L 265 of 5 October 1984.

3 ICRP. Recommendations of the International Commission on Radiological Protection. ICRP Publication 60, Pergamon Press, Oxford (1990).

4 IAEA. Principles for exemption of radiation sources and practices from regulatory control. Vienna, IAEA Safety Series No. 89 (1988).

5 Phipps, A W, Kendall, G M, Stather, J W, and Fell, T P. Committed Equivalent Organ Dose and Committed Effective Doses from Intakes of Radionuclides. Chilton, NRPB-R245 (1991) (London, HMSO).

6 Harvey, M P, Mobbs, S F, Titley, J and McDonnell, C. Calculation of doses associated with suggested exemption quantities and concentrations and the derivation of proposed exemption levels. To be published.

7 Asselineau, J M, Chapuis, A M, Guetat, Ph, and Renaud, Ph. Determination of radioactivity levels and recommendations for the exemption of radioactive waste arising outside the nuclear fuel cycle. Commissariat à l'Energie Atomique. Final report, 1991.

8 Guetat, P, Renaud, P, Santucci, P. Eléments techniques pour la définition des seuils de déclaration et d'autorisation de la Directive Européenne, Rapport final - Contrat No. 92-PR-001, IPSN, Nov 1992.

TABLE 1 Radiological protection criteria for choosing exempt activities and activity concentrations

Annual dose criteria (mSv)		
	Effective	Skin
normal situations	0.01	50
pessimistic situations	1	50

TABLE 2 List of radionuclides with short-lived daughters assumed to be in secular equilibrium

Parent	Daughters included in secular equilibrium
Sr-80+	Rb-80
Sr-90+	Y-90
Zr-93+	Nb-93m
Zr-97+	Nb-97
Ru-106+	Rh-106
Ag-108m+	Ag-108
Cs-137+	Ba-137m
Ce-134+	La-134
Ce-144+	Pr-144
Ba-140+	La-140
Bi-212+	Tl-208 (.36), Po-212 (.64)
Pb-210+	Bi-210, Po-210
Pb-212+	Bi-212, Tl-208 (.36), Po-212 (.64)
Rn-220+	Po-216
Rn-222+	Po-218, Pb-214, Bi-214, Po-214
Ra-223+	Rn-219, Po-215, Pb-211, Bi-211, Tl-207
Ra-224+	Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (.36), Po-212 (.64)
Ra-226+	Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210
Ra-228+	Ac-228
Th-226+	Ra-222, Rn-218, Po-214
Th-228+	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (.36), Po-212 (.64)
Th-229+	Ra-225, Ac-225, Fr-221, At-217, Bi-213, Po-213, Pb-209
Th-232 N	Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (.36), Po-212 (.64)
Th-234+	Pa-234m
U-230+	Th-226, Ra-222, Rn-218, Po-214
U-232+	Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (.36), Po-212 (.64)
U-235+	Th-231
U-238+	Th-234, Pa-234m
U-238 N	Th-234, Pa-234m, U-234, Th-230, Ra-226, Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210
U-240+	Np-240m
Np-237+	Pa-233
Am-242m+	Am-242
Am-243+	Np-239

TABLE 3 List of exposure scenarios and pathways considered in calculations of doses

A	**ACTIVITY CONCENTRATION**	
A1	**Normal use (workplace) scenario:**	
	A1.1	External exposure from handling a source
	A1.2	External exposure from a 1 m^3 source
	A1.3	External exposure from a gas bottle
	A1.4	Inhalation of dusts
	A1.5	Ingestion from contaminated hands
A2	**Accidental (workplace) scenario: this is covered by Normal use (workplace) scenario**	
A3	**Disposal (public) scenario:**	
	A3.1	External exposure from a landfill site
	A3.2	Inhalation of dust from a landfill site
	A3.3	Ingestion of an object from a landfill site
B	**ACTIVITIES/QUANTITIES**	
B1	**Normal use (workplace) scenario:**	
	B1.1	External exposure from a point source
	B1.2	External exposure from handling a source
B2	**Accidental (workplace) scenario:**	
	B2.1	Spillage: External exposure from contaminated hands
	B2.2	Spillage: External exposure from contaminated face
	B2.3	Spillage: External exposure from contaminated surface
	B2.4	Spillage: Ingestion from hands
	B2.5	Spillage: Inhalation of resuspended activity
	B2.6	Spillage: External dose from aerosol or dust cloud
	B2.7	Fire: Contamination of skin
	B2.8	Fire: Inhalation of dust or volatiles
	B2.9	Fire: External from combustion products
B3	**Disposal (public) scenario:**	
	B3.1	External exposure from a landfill site
	B3.2	Inhalation from a landfill site
	B3.3	External exposure to skin from handling an object from a landfill site
	B3.4	Ingestion of an object from a landfill site

TABLE 4 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (UNROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
H-3	5.56E+05	ING ACC(P)	5.50E+08	ING ACC(P)
Be-7	3.37E+02	EXT(W)	1.91E+07	EXT(W)
C-14	1.79E+04	ING ACC(P)	1.77E+07	ING ACC(P)
O-15	1.09E+02	EXTG(W)	1.07E+09	EXT ACCF(W)
F-18	1.63E+01	EXT(W)	6.20E+05	EXT(W)
Na-22	7.61E+00	EXT(W)	3.42E+05	EXT(W)
Na-24	4.04E+00	EXT(W)	2.11E+05	EXT(W)
*Si-31	1.35E+03	EXT(W)	3.92E+05	SKIN(W)
P-32	9.29E+02	EXT(W)	2.51E+05	SKIN(W)
*P33	4.00E+04	ING ACC(P)	4.03E+07	ING ACC(P)
S-35	3.33E+04	ING ACC(P)	3.29E+07	ING ACC(P)
Cl-36	8.26E+03	EXT(W)	1.68E+06	SKIN(W)
*Cl-38	1.01E+01	EXT(W)	6.12E+04	SKIN(W)
Ar-37	4.89E+05	EXTG(W)	1.18E+08	SKIN(W)
Ar-41	8.68E+01	EXTG(W)	8.58E+08	EXT ACCF(W)
*K-40	1.01E+02	EXT(W)	7.54E+05	EXT(W)
K-42	4.12E+01	EXT(W)	3.17E+05	EXT(W)
*K-43	1.72E+01	EXT(W)	5.86E+05	EXT(W)
Ca-45	1.12E+04	ING ACC(P)	1.11E+07	ING ACC(P)
Ca-47	1.57E+01	EXT(W)	5.15E+05	EXT(W)
Sc-46	8.29E+00	EXT(W)	4.56E+05	EXT(W)
*Sc-47	1.54E+02	EXT(W)	2.29E+06	EXT(W)
*Sc-48	4.97E+00	EXT(W)	2.51E+05	EXT(W)
*V-48	1.63E+01	EXT(W)	1.78E+05	SKIN(W)
Cr-51	5.29E+02	EXT(W)	6.67E+06	SKIN(W)
*Mn-51	1.81E+01	EXT(W)	1.36E+05	SKIN(W)
*Mn-52	4.84E+00	EXT(W)	2.85E+05	EXT(W)
*Mn-52m	6.73E+00	EXT(W)	9.17E+04	SKIN(W)
*Mn-53	1.19E+04	EXT(W)	3.81E+08	ING ACC(P)
Mn-54	1.99E+01	EXT(W)	1.11E+06	EXT(W)
Mn-56	9.70E+00	EXT(W)	1.56E+05	SKIN(W)
Fe-52	2.25E+01	EXT(W)	1.27E+06	EXT(W)
Fe-55	2.50E+04	ING ACC(P)	6.25E+05	SKIN(W)
Fe-59	1.40E+01	EXT(W)	7.39E+05	EXT(W)
*Co-55	8.35E+00	EXT(W)	3.19E+05	EXT(W)

TABLE 4 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (UNROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
Co-56	4.88E+00	EXT(W)	2.68E+05	EXT(W)
Co-57	1.33E+02	EXT(W)	2.50E+06	SKIN(W)
Co-58	1.70E+01	EXT(W)	8.19E+05	EXT(W)
*Co-58m	8.16E+03	EXT(W)	6.67E+06	SKIN(W)
Co-60	6.64E+00	EXT(W)	6.31E+04	SKIN(W)
*Co-60m	2.34E+03	EXT(W)	1.43E+06	SKIN(W)
*Co-61	1.72E+02	EXT(W)	6.07E+05	SKIN(W)
*Co-62m	6.05E+00	EXT(W)	1.02E+05	SKIN(W)
*Ni-59	6.89E+03	EXT(W)	1.33E+08	ING ACC(P)
Ni-63	5.26E+04	ING ACC(P)	4.83E+07	ING ACC(P)
*Ni-65	2.96E+01	EXT(W)	3.05E+05	SKIN(W)
Cu-64	8.71E+01	EXT(W)	2.19E+06	EXT(W)
Zn-65	2.87E+01	EXT(W)	1.58E+06	EXT(W)
*Zn-69	7.63E+03	EXT(W)	1.30E+06	EXT(W)
Zn-69m	4.01E+01	EXT(W)	2.27E+06	EXT(W)
Ga-72	6.20E+00	EXT(W)	2.50E+05	EXT(W)
*Ge-71	3.98E+03	EXT(W)	2.26E+08	EXT(W)
*As-73	1.02E+03	EXT(W)	7.24E+06	EXT(W)
As-74	2.19E+01	EXT(W)	7.41E+05	EXT(W)
*As-76	3.45E+01	EXT(W)	1.08E+05	SKIN(W)
*As-77	1.74E+03	EXT(W)	1.96E+06	SKIN(W)
Se-75	4.29E+01	EXT(W)	2.31E+06	EXT(W)
Br-82	6.34E+00	EXT(W)	3.27E+05	EXT(W)
*Kr-74	9.66E+01	EXTG(W)	9.52E+08	EXT ACCF(W)
*Kr-76	2.58E+02	EXTG(W)	2.56E+09	EXT ACCF(W)
*Kr-77	1.10E+02	EXTG(W)	1.08E+09	EXT ACCF(W)
*Kr-79	4.34E+02	EXTG(W)	1.82E+05	SKIN(W)
*Kr-81	9.42E+03	EXTG(W)	3.53E+06	SKIN(W)
*Kr-83m	4.15E+04	EXTG(W)	3.49E+11	EXT ACCF(W)
Kr-85	5.24E+04	EXTG(W)	5.00E+03	SKIN(W)
*Kr-85m	7.03E+02	EXTG(W)	6.85E+09	EXT ACCF(W)
*Kr-87	1.41E+02	EXTG(W)	1.37E+09	EXT ACCF(W)
*Kr-88	5.79E+01	EXTG(W)	5.74E+08	EXT ACCF(W)
Rb-86	1.51E+02	EXT(W)	2.74E+05	SKIN(W)
Sr-85	3.26E+01	EXT(W)	1.77E+06	EXT(W)

TABLE 4 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (UNROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
Sr-85m	7.61E+01	EXT(W)	4.31E+06	EXT(W)
Sr-87m	5.21E+01	EXT(W)	2.95E+06	EXT(W)
Sr-89	1.34E+03	EXT(W)	3.44E+05	SKIN(W)
Sr-90+	1.58E+02	EXT(W)	5.68E+03	SKIN(W)
*Sr-91	2.35E+01	EXT(W)	2.67E+05	SKIN(W)
*Sr-92	1.24E+01	EXT(W)	5.29E+05	EXT(W)
Y-90	4.24E+02	EXT(W)	1.80E+05	SKIN(W)
*Y-91	9.71E+02	EXT(W)	3.24E+05	SKIN(W)
*Y-91m	3.14E+01	EXT(W)	1.78E+06	EXT(W)
*Y-92	4.36E+01	EXT(W)	6.95E+04	SKIN(W)
*Y-93	1.03E+02	EXT(W)	9.77E+04	SKIN(W)
*Zr-93+	2.20E+03	INH(W)	3.96E+06	INH ACCF(W)
Zr-95	2.25E+01	EXT(W)	1.16E+06	EXT(W)
*Zr-97+	1.96E+01	EXT(W)	2.36E+05	SKIN(W)
*Nb-93m	5.98E+03	EXT(W)	2.55E+07	INH ACCF(W)
*Nb-94	1.05E+01	EXT(W)	5.41E+05	EXT(W)
Nb-95	2.18E+01	EXT(W)	1.23E+06	EXT(W)
*Nb-97	2.53E+01	EXT(W)	4.71E+05	SKIN(W)
*Nb-98	6.76E+00	EXT(W)	1.32E+05	SKIN(W)
*Mo-90	2.02E+01	EXT(W)	7.74E+05	EXT(W)
*Mo-93	1.55E+03	EXT(W)	3.79E+07	ING ACC(P)
Mo-99	1.07E+02	EXT(W)	8.88E+05	EXT(W)
*Mo-101	1.25E+01	EXT(W)	3.11E+05	SKIN(W)
*Tc-96	6.89E+00	EXT(W)	3.79E+05	EXT(W)
*Tc-96m	3.26E+02	EXT(W)	1.85E+07	EXT(W)
*Tc-97	1.46E+03	EXT(W)	8.28E+07	EXT(W)
*Tc-97m	1.67E+03	EXT(W)	5.13E+06	SKIN(W)
*Tc-99	1.49E+04	ING ACC(P)	1.44E+07	ING ACC(P)
Tc-99m	1.32E+02	EXT(W)	7.37E+06	EXT(W)
*Ru-97	6.97E+01	EXT(W)	3.95E+06	EXT(W)
Ru-103	3.54E+01	EXT(W)	2.02E+06	EXT(W)
*Ru-105	2.13E+01	EXT(W)	5.41E+05	EXT(W)
Ru-106+	4.94E+01	EXT(W)	1.01E+05	SKIN(W)
*Rh-103m	9.51E+03	EXT(W)	6.25E+07	SKIN(W)
*Rh-105	2.14E+02	EXT(W)	3.10E+06	EXT(W)

TABLE 4 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (UNROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
*Pd-103	1.15E+03	EXT(W)	3.31E+07	ING ACC(P)
*Pd-109	9.77E+02	EXT(W)	7.41E+05	SKIN(W)
*Ag-105	3.19E+01	EXT(W)	1.80E+06	EXT(W)
*Ag108m+	1.02E+01	EXT(W)	5.45E+05	EXT(W)
Ag-110m	6.08E+00	EXT(W)	3.36E+05	EXT(W)
Ag-111	5.58E+02	EXT(W)	1.14E+06	EXT(W)
Cd-109	3.34E+03	EXT(W)	5.88E+05	SKIN(W)
*Cd-115	7.13E+01	EXT(W)	1.03E+06	EXT(W)
*Cd-115m	4.70E+02	EXT(W)	3.20E+05	SKIN(W)
In-111	4.32E+01	EXT(W)	2.00E+06	EXT(W)
In-113m	6.47E+01	EXT(W)	1.48E+06	EXT(W)
*In-114m	1.72E+02	EXT(W)	1.53E+06	ING ACC(P)
*In-115m	1.03E+02	EXT(W)	1.94E+06	EXT(W)
*Sn-113	7.20E+02	EXT(W)	8.17E+06	ING ACC(P)
*Sn-125	4.93E+01	EXT(W)	1.86E+05	SKIN(W)
Sb-122	3.70E+01	EXT(W)	1.08E+04	SKIN(W)
Sb-124	9.20E+00	EXT(W)	3.74E+05	EXT(W)
Sb-125	3.99E+01	EXT(W)	1.88E+06	EXT(W)
*Te-123m	1.12E+02	EXT(W)	6.25E+06	EXT(W)
*Te-125m	1.46E+03	EXT(W)	5.56E+06	SKIN(W)
*Te-127	2.98E+03	EXT(W)	1.95E+06	SKIN(W)
*Te-127m	1.41E+03	EXT(W)	4.09E+06	ING ACC(P)
*Te-129	2.44E+02	EXT(W)	4.09E+05	SKIN(W)
*Te-129m	4.26E+02	EXT(W)	2.22E+06	SKIN(W)
*Te-131	3.84E+01	EXT(W)	2.40E+05	SKIN(W)
*Te-131m	1.22E+01	EXT(W)	6.07E+05	EXT(W)
Te-132	7.23E+01	EXT(W)	3.50E+06	ING ACC(P)
*Te-133	1.75E+01	EXT(W)	1.73E+05	SKIN(W)
*Te-133m	7.26E+00	EXT(W)	2.01E+05	SKIN(W)
*Te-134	1.86E+01	EXT(W)	6.50E+05	EXT(W)
I-123	1.13E+02	EXT(W)	4.57E+06	EXT(W)
I-125	3.86E+02	EXT(W)	6.70E+05	ING ACC(P)
*I-126	3.65E+01	EXT(W)	3.44E+05	ING ACC(P)
*I-129	9.09E+01	ING ACC(P)	9.04E+04	ING ACC(P)
*I-130	7.82E+00	EXT(W)	3.50E+05	EXT(W)

TABLE 4 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (UNROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
I-131	5.38E+01	EXT(W)	4.92E+05	ING ACC(P)
I-132	7.42E+00	EXT(W)	2.86E+05	EXT(W)
*I-133	2.75E+01	EXT(W)	5.99E+05	EXT(W)
*I-134	6.45E+00	EXT(W)	2.14E+05	SKIN(W)
*I-135	1.07E+01	EXT(W)	3.95E+05	EXT(W)
*Xe-131m	5.55E+03	EXTG(W)	8.64E+03	SKIN(W)
Xe-133	2.41E+03	EXTG(W)	9.16E+03	SKIN(W)
*Xe-135	4.48E+02	EXTG(W)	4.38E+09	EXT ACCF(W)
*Cs-129	5.93E+01	EXT(W)	1.91E+05	SKIN(W)
Cs-131	7.30E+02	EXT(W)	4.33E+05	SKIN(W)
*Cs-132	2.37E+01	EXT(W)	1.42E+05	SKIN(W)
*Cs-134m	6.17E+02	EXT(W)	4.29E+04	SKIN(W)
Cs-134	1.07E+01	EXT(W)	2.52E+04	SKIN(W)
*Cs-135	5.26E+03	ING ACC(P)	5.23E+06	ING ACC(P)
*Cs-136	7.75E+00	EXT(W)	5.09E+04	SKIN(W)
Cs-137+	2.95E+01	EXT(W)	2.36E+04	SKIN(W)
*Cs-138	6.98E+00	EXT(W)	3.94E+03	SKIN(W)
*Ba-131	3.67E+01	EXT(W)	2.08E+06	EXT(W)
Ba-140+	6.62E+00	EXT(W)	1.31E+05	SKIN(W)
La-140	7.19E+00	EXT(W)	2.71E+05	EXT(W)
Ce-139	1.05E+02	EXT(W)	1.11E+06	SKIN(W)
Ce141	2.17E+02	EXT(W)	3.78E+06	EXT(W)
*Ce143	5.86E+01	EXT(W)	6.85E+05	SKIN(W)
Ce-144+	1.18E+02	EXT(W)	1.19E+05	SKIN(W)
*Pr-142	1.97E+02	EXT(W)	1.95E+05	SKIN(W)
Pr-143	5.26E+03	ING ACC(P)	1.20E+06	SKIN(W)
*Nd-147	1.18E+02	EXT(W)	1.57E+06	EXT(W)
*Nd-149	4.34E+01	EXT(W)	4.62E+05	SKIN(W)
Pm-147	1.49E+04	INH(W)	1.85E+07	ING ACC(P)
*Pm-149	1.14E+03	EXT(W)	1.13E+06	EXT(W)
*Sm-151	2.93E+04	INH(W)	4.03E+07	INH ACCF(W)
*Sm-153	2.86E+02	EXT(W)	1.62E+06	EXT(W)
Eu-152	1.44E+01	EXT(W)	7.19E+05	EXT(W)
*Eu-152m	5.57E+01	EXT(W)	5.48E+05	SKIN(W)
Eu-154	1.34E+01	EXT(W)	5.88E+05	EXT(W)

TABLE 4 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (UNROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
Eu-155	2.84E+02	EXT(W)	1.62E+07	EXT(W)
*Gd-153	1.58E+02	EXT(W)	8.98E+06	EXT(W)
*Gd-159	3.23E+02	EXT(W)	1.29E+06	EXT(W)
*Tb-160	1.49E+01	EXT(W)	6.17E+05	EXT(W)
*Dy-165	5.31E+02	EXT(W)	6.91E+05	SKIN(W)
*Dy-166	4.07E+02	EXT(W)	2.77E+06	EXT(W)
*Ho-166	3.59E+02	EXT(W)	2.71E+05	SKIN(W)
Er-169	1.61E+04	ING ACC(P)	1.71E+07	ING ACC(P)
*Er-171	4.35E+01	EXT(W)	7.14E+05	EXT(W)
Tm-170	1.96E+03	EXT(W)	1.25E+06	EXT(W)
*Tm-171	2.01E+04	EXT(W)	5.10E+07	ING ACC(P)
*Yb-175	4.17E+02	EXT(W)	3.33E+06	EXT(W)
*Lu-177	5.21E+02	EXT(W)	3.02E+06	SKIN(W)
*Hf-181	3.00E+01	EXT(W)	1.00E+06	EXT(W)
Ta-182	1.29E+01	EXT(W)	1.99E+04	SKIN(W)
*W-181	4.12E+02	EXT(W)	2.34E+07	EXT(W)
W-185	1.20E+04	ING ACC(P)	3.52E+06	SKIN(W)
*W-187	3.47E+01	EXT(W)	8.04E+05	EXT(W)
Re-186	7.08E+02	EXT(W)	1.84E+06	SKIN(W)
*Re-188	2.06E+02	EXT(W)	2.10E+05	SKIN(W)
*Os-185	2.32E+01	EXT(W)	1.29E+06	EXT(W)
*Os-191	2.09E+02	EXT(W)	1.13E+07	ING ACC(P)
*Os-191m	1.79E+03	EXT(W)	6.84E+06	SKIN(W)
*Os-193	2.17E+02	EXT(W)	1.04E+06	EXT(W)
*Ir-190	1.16E+01	EXT(W)	5.84E+05	EXT(W)
Ir-192	2.03E+01	EXT(W)	2.29E+04	SKIN(W)
*Ir-194	1.44E+02	EXT(W)	1.94E+05	SKIN(W)
*Pt-191	5.53E+01	EXT(W)	2.25E+06	EXT(W)
*Pt-193m	1.26E+03	EXT(W)	3.25E+06	SKIN(W)
*Pt-197	6.39E+02	EXT(W)	1.76E+06	SKIN(W)
*Pt-197m	1.96E+02	EXT(W)	1.16E+06	EXT(W)
Au-198	4.10E+01	EXT(W)	7.74E+05	EXT(W)
*Au-199	1.87E+02	EXT(W)	2.63E+06	EXT(W)
Hg-197	2.38E+02	EXT(W)	4.44E+06	EXT(W)
*Hg-197m	1.76E+02	EXT(W)	1.86E+06	EXT(W)

TABLE 4 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (UNROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
Hg-203	7.02E+01	EXT(W)	1.75E+05	SKIN(W)
*Tl-200	1.29E+01	EXT(W)	7.31E+05	EXT(W)
Tl-201	1.88E+02	EXT(W)	5.00E+05	SKIN(W)
*Tl-202	3.57E+01	EXT(W)	2.02E+06	EXT(W)
Tl-204	8.09E+03	EXT(W)	1.75E+04	SKIN(W)
*Pb-203	5.34E+01	EXT(W)	2.30E+06	EXT(W)
Pb-210+	5.21E+00	ING ACC(P)	5.10E+03	ING ACC(P)
*Pb-212+	1.05E+01	EXT(W)	1.86E+05	SKIN(W)
Bi-206	5.13E+00	EXT(W)	2.93E+05	EXT(W)
*Bi-207	1.08E+01	EXT(W)	5.36E+05	EXT(W)
*Bi-210	1.42E+03	INH(W)	9.51E+05	SKIN(W)
*Bi-212+	1.18E+01	EXT(W)	2.21E+05	SKIN(W)
*Po-203	1.02E+01	EXT(W)	4.86E+05	EXT(W)
*Po-205	1.08E+01	EXT(W)	5.69E+05	EXT(W)
*Po-207	1.26E+01	EXT(W)	6.67E+05	EXT(W)
Po-210	1.61E+01	ING ACC(P)	1.57E+04	ING ACC(P)
*At-211	3.95E+02	EXT(W)	7.46E+06	INH ACCF(W)
*Rn-220+	3.44E+03	INH(W)	5.04E+06	INH ACCF(W)
Rn-222+	9.52E+00	EXT(W)	3.53E+07	INH ACCF(W)
*Ra-223+	3.99E+01	INH(W)	6.64E+04	ING ACC(P)
*Ra-224+	9.88E+00	EXT(W)	1.20E+05	ING ACC(P)
*Ra-225	7.05E+01	INH(W)	1.01E+05	INH ACCF(W)
Ra-226+	4.67E+00	ING ACC(P)	4.54E+03	ING ACC(P)
*Ra-227	9.74E+01	EXT(W)	7.37E+05	SKIN(W)
*Ra-228+	1.52E+01	EXT(W)	3.55E+04	ING ACC(P)
*Ac-228	1.77E+01	EXT(W)	5.27E+05	EXT(W)
*Th-226+	8.39E+02	EXT(W)	1.57E+07	EXT(W)
*Th-227	4.18E+00	INH(W)	5.78E+03	INH ACCF(W)
Th-228+	1.50E+00	INH(W)	8.78E+03	INH ACC(P)
*Th-229+	4.21E-01	INH(W)	5.69E+02	INH ACCF(W)
Th-230	2.94E+00	INH(W)	1.18E+04	INH ACC(P)
*Th-231	6.52E+02	INH(W)	2.83E+07	EXT(W)
Th-232N	8.49E-01	INH(W)	1.55E+03	ING ACC(P)
*Th-234+	3.11E+02	EXT(W)	1.85E+05	SKIN(W)
*Pa-230	2.42E+01	EXT(W)	5.17E+05	INH ACCF(W)

TABLE 4 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (UNROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
*Pa-231	8.81E-01	INH(W)	1.19E+03	INH ACCF(W)
*Pa-233	8.19E+01	EXT(W)	3.18E+06	EXT(W)
*U-230+	2.78E+01	INH(W)	3.88E+04	INH ACCF(W)
*U-231	2.03E+02	EXT(W)	4.38E+06	EXT(W)
*U-232+	5.54E-01	INH(W)	7.85E+02	INH ACCF(W)
*U-233	4.17E+00	INH(W)	5.60E+03	INH ACCF(W)
U-234	4.29E+00	INH(W)	2.57E+04	INH ACC(P)
*U-235+	4.34E+00	INH(W)	6.11E+03	INH ACCF(W)
*U-236	4.55E+00	INH(W)	6.11E+03	INH ACCF(W)
*U-237	1.17E+02	EXT(W)	1.86E+06	EXT(W)
U-238+	4.76E+00	INH(W)	2.84E+04	INH ACC(P)
U-238N	1.83E+00	INH(W)	2.57E+03	SKIN(W)
*U-239	3.00E+02	EXT(W)	9.03E+05	EXT(W)
*U-240	2.13E+03	EXT(W)	7.08E+06	SKIN(W)
*U-240+	1.25E+01	EXT(W)	3.41E+05	SKIN(W)
*Np-237+	1.87E+00	INH(W)	2.58E+03	INH ACCF(W)
*Np-239	9.65E+01	EXT(W)	3.04E+06	EXT(W)
*Np-240	1.26E+01	EXT(W)	4.62E+05	EXT(W)
*Pu-234	2.41E+02	EXT(W)	1.38E+07	EXT(W)
*Pu-235	1.77E+02	EXT(W)	1.00E+07	EXT(W)
*Pu-236	5.17E+00	INH(W)	6.95E+03	INH ACCF(W)
*Pu-237	3.18E+02	EXT(W)	1.80E+07	EXT(W)
Pu-238	2.42E+00	INH(W)	6.85E+03	INH ACC(P)
Pu-239	2.21E+00	INH(W)	8.08E+03	INH ACC(P)
*Pu-240	2.21E+00	INH(W)	2.96E+03	INH ACCF(W)
*Pu-241	1.15E+02	INH(W)	1.55E+05	INH ACCF(W)
*Pu-242	2.31E+00	INH(W)	3.10E+03	INH ACCF(W)
*Pu-243	6.45E+02	EXT(W)	3.53E+06	EXT(W)
*Pu-244	2.34E+00	INH(W)	3.15E+03	INH ACCF(W)
Am-241	2.14E+00	INH(W)	7.87E+03	INH ACC(P)
*Am-242	8.31E+02	EXT(W)	3.00E+06	SKIN(W)
*Am-242m+	2.23E+00	INH(W)	3.01E+03	INH ACCF(W)
*Am-243+	2.08E+00	INH(W)	2.88E+03	INH ACCF(W)
*Cm-242	4.27E+01	INH(W)	5.76E+04	INH ACCF(W)
*Cm-243	2.99E+00	INH(W)	4.11E+03	INH ACCF(W)

TABLE 4 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (UNROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
Cm-244	3.75E+00	INH(W)	1.39E+04	INH ACC(P)
*Cm-245	2.06E+00	INH(W)	2.80E+03	INH ACCF(W)
*Cm-246	2.08E+00	INH(W)	2.80E+03	INH ACCF(W)
*Cm-247	2.18E+00	INH(W)	3.05E+03	INH ACCF(W)
*Cm-248	5.77E-01	INH(W)	7.75E+02	INH ACCF(W)
Bk-249	7.50E+02	INH(W)	1.01E+06	INH ACCF(W)
*Cf-246	8.72E+02	INH(W)	1.26E+06	INH ACCF(W)
*Cf-248	1.15E+01	INH(W)	1.55E+04	INH ACCF(W)
*Cf-249	1.71E+00	INH(W)	2.37E+03	INH ACCF(W)
*Cf-250	3.41E+00	INH(W)	4.58E+03	INH ACCF(W)
*Cf-251	1.70E+00	INH(W)	2.32E+03	INH ACCF(W)
Cf-252	3.84E+00	INH(W)	1.79E+04	INH ACC(P)
*Cf-253	1.83E+02	INH(W)	2.46E+05	INH ACCF(W)
*Cf-254	1.92E+00	INH(W)	2.58E+03	INH ACCF(W)
*Es-253	1.61E+02	INH(W)	2.19E+05	INH ACCF(W)
Es-254	2.09E+01	INH(W)	2.88E+04	INH ACCF(W)
*Es-254m	3.45E+01	EXT(W)	9.86E+05	EXT(W)
*Fm-254	5.92E+03	INH(W)	1.44E+07	INH ACCF(W)
*Fm-255	7.82E+02	EXT(W)	2.96E+06	INH ACCF(W)

TABLE 5 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (ROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
H-3	1.00E+06	ING ACC(P)	1.00E+09	ING ACC(P)
Be-7	1.00E+03	EXT(W)	1.00E+07	EXT(W)
C-14	1.00E+04	ING ACC(P)	1.00E+07	ING ACC(P)
O-15	1.00E+02	EXTG(W)	1.00E+09	EXT ACCF(W)
F-18	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Na-22	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Na-24	1.00E+01	EXT(W)	1.00E+05	EXT(W)
*Si-31	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
P-32	1.00E+03	EXT(W)	1.00E+05	SKIN(W)
*P33	1.00E+05	ING ACC(P)	1.00E+08	ING ACC(P)
S-35	1.00E+05	ING ACC(P)	1.00E+08	ING ACC(P)
Cl-36	1.00E+04	EXT(W)	1.00E+06	SKIN(W)
*Cl-38	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
Ar-37	1.00E+06	EXTG(W)	1.00E+08	SKIN(W)
Ar-41	1.00E+02	EXTG(W)	1.00E+09	EXT ACCF(W)
*K-40	1.00E+02	EXT(W)	1.00E+06	EXT(W)
K-42	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*K-43	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Ca-45	1.00E+04	ING ACC(P)	1.00E+07	ING ACC(P)
Ca-47	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Sc-46	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Sc-47	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Sc-48	1.00E+01	EXT(W)	1.00E+05	EXT(W)
*V-48	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
Cr-51	1.00E+03	EXT(W)	1.00E+07	SKIN(W)
*Mn-51	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
*Mn-52	1.00E+01	EXT(W)	1.00E+05	EXT(W)
*Mn-52m	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
*Mn-53	1.00E+04	EXT(W)	1.00E+09	ING ACC(P)
Mn-54	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Mn-56	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
Fe-52	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Fe-55	1.00E+04	ING ACC(P)	1.00E+06	SKIN(W)
Fe-59	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Co-55	1.00E+01	EXT(W)	1.00E+06	EXT(W)

TABLE 5 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (ROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
Co-56	1.00E+01	EXT(W)	1.00E+05	EXT(W)
Co-57	1.00E+02	EXT(W)	1.00E+06	SKIN(W)
Co-58	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Co-58m	1.00E+04	EXT(W)	1.00E+07	SKIN(W)
Co-60	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
*Co-60m	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
*Co-61	1.00E+02	EXT(W)	1.00E+06	SKIN(W)
*Co-62m	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
*Ni-59	1.00E+04	EXT(W)	1.00E+08	ING ACC(P)
Ni-63	1.00E+05	ING ACC(P)	1.00E+08	ING ACC(P)
*Ni-65	1.00E+01	EXT(W)	1.00E+06	SKIN(W)
Cu-64	1.00E+02	EXT(W)	1.00E+06	EXT(W)
Zn-65	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Zn-69	1.00E+04	EXT(W)	1.00E+06	EXT(W)
Zn-69m	1.00E+02	EXT(W)	1.00E+06	EXT(W)
Ga-72	1.00E+01	EXT(W)	1.00E+05	EXT(W)
*Ge-71	1.00E+04	EXT(W)	1.00E+08	EXT(W)
*As-73	1.00E+03	EXT(W)	1.00E+07	EXT(W)
As-74	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*As-76	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
*As-77	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
Se-75	1.00E+02	EXT(W)	1.00E+06	EXT(W)
Br-82	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Kr-74	1.00E+02	EXTG(W)	1.00E+09	EXT ACCF(W)
*Kr-76	1.00E+02	EXTG(W)	1.00E+09	EXT ACCF(W)
*Kr-77	1.00E+02	EXTG(W)	1.00E+09	EXT ACCF(W)
*Kr-79	1.00E+03	EXTG(W)	1.00E+05	SKIN(W)
*Kr-81	1.00E+04	EXTG(W)	1.00E+07	SKIN(W)
*Kr-83m	1.00E+05	EXTG(W)	1.00E+12	EXT ACCF(W)
Kr-85	1.00E+05	EXTG(W)	1.00E+04	SKIN(W)
*Kr-85m	1.00E+03	EXTG(W)	1.00E+10	EXT ACCF(W)
*Kr-87	1.00E+02	EXTG(W)	1.00E+09	EXT ACCF(W)
*Kr-88	1.00E+02	EXTG(W)	1.00E+09	EXT ACCF(W)
Rb-86	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
Sr-85	1.00E+02	EXT(W)	1.00E+06	EXT(W)

TABLE 5 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (ROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
Sr-85m	1.00E+02	EXT(W)	1.00E+07	EXT(W)
Sr-87m	1.00E+02	EXT(W)	1.00E+06	EXT(W)
Sr-89	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
Sr-90+	1.00E+02	EXT(W)	1.00E+04	SKIN(W)
*Sr-91	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
*Sr-92	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Y-90	1.00E+03	EXT(W)	1.00E+05	SKIN(W)
*Y-91	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
*Y-91m	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Y-92	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
*Y-93	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
*Zr-93+	1.00E+03	INH(W)	1.00E+07	INH ACCF(W)
Zr-95	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Zr-97+	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
*Nb-93m	1.00E+04	EXT(W)	1.00E+07	INH ACCF(W)
*Nb-94	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Nb-95	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Nb-97	1.00E+01	EXT(W)	1.00E+06	SKIN(W)
*Nb-98	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
*Mo-90	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Mo-93	1.00E+03	EXT(W)	1.00E+08	ING ACC(P)
Mo-99	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Mo-101	1.00E+01	EXT(W)	1.00E+06	SKIN(W)
*Tc-96	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Tc-96m	1.00E+03	EXT(W)	1.00E+07	EXT(W)
*Tc-97	1.00E+03	EXT(W)	1.00E+08	EXT(W)
*Tc-97m	1.00E+03	EXT(W)	1.00E+07	SKIN(W)
*Tc-99	1.00E+04	ING ACC(P)	1.00E+07	ING ACC(P)
Tc-99m	1.00E+02	EXT(W)	1.00E+07	EXT(W)
*Ru-97	1.00E+02	EXT(W)	1.00E+07	EXT(W)
Ru-103	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Ru-105	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Ru-106+	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
*Rh-103m	1.00E+04	EXT(W)	1.00E+08	SKIN(W)
*Rh-105	1.00E+02	EXT(W)	1.00E+07	EXT(W)

TABLE 5 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (ROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
*Pd-103	1.00E+03	EXT(W)	1.00E+08	ING ACC(P)
*Pd-109	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
*Ag-105	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Ag-108m+	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Ag-110m	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Ag-111	1.00E+03	EXT(W)	1.00E+06	EXT(W)
Cd-109	1.00E+04	EXT(W)	1.00E+06	SKIN(W)
*Cd-115	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Cd-115m	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
In-111	1.00E+02	EXT(W)	1.00E+06	EXT(W)
In-113m	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*In-114m	1.00E+02	EXT(W)	1.00E+06	ING ACC(P)
*In-115m	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Sn-113	1.00E+03	EXT(W)	1.00E+07	ING ACC(P)
*Sn-125	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
Sb-122	1.00E+02	EXT(W)	1.00E+04	SKIN(W)
Sb-124	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Sb-125	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Te-123m	1.00E+02	EXT(W)	1.00E+07	EXT(W)
*Te-125m	1.00E+03	EXT(W)	1.00E+07	SKIN(W)
*Te-127	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
*Te-127m	1.00E+03	EXT(W)	1.00E+07	ING ACC(P)
*Te-129	1.00E+02	EXT(W)	1.00E+06	SKIN(W)
*Te-129m	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
*Te-131	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
*Te-131m	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Te-132	1.00E+02	EXT(W)	1.00E+07	ING ACC(P)
*Te-133	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
*Te-133m	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
*Te-134	1.00E+01	EXT(W)	1.00E+06	EXT(W)
I-123	1.00E+02	EXT(W)	1.00E+07	EXT(W)
I-125	1.00E+03	EXT(W)	1.00E+06	ING ACC(P)
*I-126	1.00E+02	EXT(W)	1.00E+06	ING ACC(P)
*I-129	1.00E+02	ING ACC(P)	1.00E+05	ING ACC(P)
*I-130	1.00E+01	EXT(W)	1.00E+06	EXT(W)

TABLE 5 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (ROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
I-131	1.00E+02	EXT(W)	1.00E+06	ING ACC(P)
I-132	1.00E+01	EXT(W)	1.00E+05	EXT(W)
*I-133	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*I-134	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
*I-135	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Xe-131m	1.00E+04	EXTG(W)	1.00E+04	SKIN(W)
Xe-133	1.00E+03	EXTG(W)	1.00E+04	SKIN(W)
*Xe-135	1.00E+03	EXTG(W)	1.00E+10	EXT ACCF(W)
*Cs-129	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
Cs-131	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
*Cs-132	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
*Cs-134m	1.00E+03	EXT(W)	1.00E+05	SKIN(W)
Cs-134	1.00E+01	EXT(W)	1.00E+04	SKIN(W)
*Cs-135	1.00E+04	ING ACC(P)	1.00E+07	ING ACC(P)
*Cs-136	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
Cs-137+	1.00E+01	EXT(W)	1.00E+04	SKIN(W)
*Cs-138	1.00E+01	EXT(W)	1.00E+04	SKIN(W)
*Ba-131	1.00E+02	EXT(W)	1.00E+06	EXT(W)
Ba-140+	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
La-140	1.00E+01	EXT(W)	1.00E+05	EXT(W)
Ce-139	1.00E+02	EXT(W)	1.00E+06	SKIN(W)
Ce141	1.00E+02	EXT(W)	1.00E+07	EXT(W)
*Ce143	1.00E+02	EXT(W)	1.00E+06	SKIN(W)
Ce-144+	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
*Pr-142	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
Pr-143	1.00E+04	ING ACC(P)	1.00E+06	SKIN(W)
*Nd-147	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Nd-149	1.00E+02	EXT(W)	1.00E+06	SKIN(W)
Pm-147	1.00E+04	INH(W)	1.00E+07	ING ACC(P)
*Pm-149	1.00E+03	EXT(W)	1.00E+06	EXT(W)
*Sm-151	1.00E+04	INH(W)	1.00E+08	INH ACCF(W)
*Sm-153	1.00E+02	EXT(W)	1.00E+06	EXT(W)
Eu-152	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Eu-152m	1.00E+02	EXT(W)	1.00E+06	SKIN(W)
Eu-154	1.00E+01	EXT(W)	1.00E+06	EXT(W)

TABLE 5 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (ROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
Eu-155	1.00E+02	EXT(W)	1.00E+07	EXT(W)
*Gd-153	1.00E+02	EXT(W)	1.00E+07	EXT(W)
*Gd-159	1.00E+03	EXT(W)	1.00E+06	EXT(W)
*Tb-160	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Dy-165	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
*Dy-166	1.00E+03	EXT(W)	1.00E+06	EXT(W)
*Ho-166	1.00E+03	EXT(W)	1.00E+05	SKIN(W)
Er-169	1.00E+04	ING ACC(P)	1.00E+07	ING ACC(P)
*Er-171	1.00E+02	EXT(W)	1.00E+06	EXT(W)
Tm-170	1.00E+03	EXT(W)	1.00E+06	EXT(W)
*Tm-171	1.00E+04	EXT(W)	1.00E+08	ING ACC(P)
*Yb-175	1.00E+03	EXT(W)	1.00E+07	EXT(W)
*Lu-177	1.00E+03	EXT(W)	1.00E+07	SKIN(W)
*Hf-181	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Ta-182	1.00E+01	EXT(W)	1.00E+04	SKIN(W)
*W-181	1.00E+03	EXT(W)	1.00E+07	EXT(W)
W-185	1.00E+04	ING ACC(P)	1.00E+07	SKIN(W)
*W-187	1.00E+02	EXT(W)	1.00E+06	EXT(W)
Re-186	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
*Re-188	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
*Os-185	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Os-191	1.00E+02	EXT(W)	1.00E+07	ING ACC(P)
*Os-191m	1.00E+03	EXT(W)	1.00E+07	SKIN(W)
*Os-193	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Ir-190	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Ir-192	1.00E+01	EXT(W)	1.00E+04	SKIN(W)
*Ir-194	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
*Pt-191	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Pt-193m	1.00E+03	EXT(W)	1.00E+07	SKIN(W)
*Pt-197	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
*Pt-197m	1.00E+02	EXT(W)	1.00E+06	EXT(W)
Au-198	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Au-199	1.00E+02	EXT(W)	1.00E+06	EXT(W)
Hg-197	1.00E+02	EXT(W)	1.00E+07	EXT(W)
*Hg-197m	1.00E+02	EXT(W)	1.00E+06	EXT(W)

TABLE 5 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (ROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
Hg-203	1.00E+02	EXT(W)	1.00E+05	SKIN(W)
*Tl-200	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Tl-201	1.00E+02	EXT(W)	1.00E+06	SKIN(W)
*Tl-202	1.00E+02	EXT(W)	1.00E+06	EXT(W)
Tl-204	1.00E+04	EXT(W)	1.00E+04	SKIN(W)
*Pb-203	1.00E+02	EXT(W)	1.00E+06	EXT(W)
Pb-210+	1.00E+01	ING ACC(P)	1.00E+04	ING ACC(P)
*Pb-212+	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
Bi-206	1.00E+01	EXT(W)	1.00E+05	EXT(W)
*Bi-207	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Bi-210	1.00E+03	INH(W)	1.00E+06	SKIN(W)
*Bi-212+	1.00E+01	EXT(W)	1.00E+05	SKIN(W)
*Po-203	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Po-205	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Po-207	1.00E+01	EXT(W)	1.00E+06	EXT(W)
Po-210	1.00E+01	ING ACC(P)	1.00E+04	ING ACC(P)
*At-211	1.00E+03	EXT(W)	1.00E+07	INH ACCF(W)
*Rn-220+	1.00E+04	INH(W)	1.00E+07	INH ACCF(W)
Rn-222+	1.00E+01	EXT(W)	1.00E+08	INH ACCF(W)
*Ra-223+	1.00E+02	INH(W)	1.00E+05	ING ACC(P)
*Ra-224+	1.00E+01	EXT(W)	1.00E+05	ING ACC(P)
*Ra-225	1.00E+02	INH(W)	1.00E+05	INH ACCF(W)
Ra-226+	1.00E+01	ING ACC(P)	1.00E+04	ING ACC(P)
*Ra-227	1.00E+02	EXT(W)	1.00E+06	SKIN(W)
*Ra-228+	1.00E+01	EXT(W)	1.00E+05	ING ACC(P)
*Ac-228	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Th-226+	1.00E+03	EXT(W)	1.00E+07	EXT(W)
*Th-227	1.00E+01	INH(W)	1.00E+04	INH ACCF(W)
Th-228+	1.00E+00	INH(W)	1.00E+04	INH ACC(P)
*Th-229+	1.00E+00	INH(W)	1.00E+03	INH ACCF(W)
Th-230	1.00E+00	INH(W)	1.00E+04	INH ACC(P)
*Th-231	1.00E+03	INH(W)	1.00E+07	EXT(W)
Th-232N	1.00E+00	INH(W)	1.00E+03	ING ACC(P)
*Th-234+	1.00E+03	EXT(W)	1.00E+05	SKIN(W)
*Pa-230	1.00E+01	EXT(W)	1.00E+06	INH ACCF(W)

TABLE 5 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (ROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
*Pa-231	1.00E+00	INH(W)	1.00E+03	INH ACCF(W)
*Pa-233	1.00E+02	EXT(W)	1.00E+07	EXT(W)
*U-230+	1.00E+01	INH(W)	1.00E+05	INH ACCF(W)
*U-231	1.00E+02	EXT(W)	1.00E+07	EXT(W)
*U-232+	1.00E+00	INH(W)	1.00E+03	INH ACCF(W)
*U-233	1.00E+01	INH(W)	1.00E+04	INH ACCF(W)
U-234	1.00E+01	INH(W)	1.00E+04	INH ACC(P)
*U-235+	1.00E+01	INH(W)	1.00E+04	INH ACCF(W)
*U-236	1.00E+01	INH(W)	1.00E+04	INH ACCF(W)
*U-237	1.00E+02	EXT(W)	1.00E+06	EXT(W)
U-238+	1.00E+01	INH(W)	1.00E+04	INH ACC(P)
U-238N	1.00E+00	INH(W)	1.00E+03	SKIN(W)
*U-239	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*U-240	1.00E+03	EXT(W)	1.00E+07	SKIN(W)
*U-240+	1.00E+01	EXT(W)	1.00E+06	SKIN(W)
*Np-237+	1.00E+00	INH(W)	1.00E+03	INH ACCF(W)
*Np-239	1.00E+02	EXT(W)	1.00E+07	EXT(W)
*Np-240	1.00E+01	EXT(W)	1.00E+06	EXT(W)
*Pu-234	1.00E+02	EXT(W)	1.00E+07	EXT(W)
*Pu-235	1.00E+02	EXT(W)	1.00E+07	EXT(W)
*Pu-236	1.00E+01	INH(W)	1.00E+04	INH ACCF(W)
*Pu-237	1.00E+03	EXT(W)	1.00E+07	EXT(W)
Pu-238	1.00E+00	INH(W)	1.00E+04	INH ACC(P)
Pu-239	1.00E+00	INH(W)	1.00E+04	INH ACC(P)
*Pu-240	1.00E+00	INH(W)	1.00E+03	INH ACCF(W)
*Pu-241	1.00E+02	INH(W)	1.00E+05	INH ACCF(W)
*Pu-242	1.00E+00	INH(W)	1.00E+04	INH ACCF(W)
*Pu-243	1.00E+03	EXT(W)	1.00E+07	EXT(W)
*Pu-244	1.00E+00	INH(W)	1.00E+04	INH ACCF(W)
Am-241	1.00E+00	INH(W)	1.00E+04	INH ACC(P)
*Am-242	1.00E+03	EXT(W)	1.00E+06	SKIN(W)
*Am-242m+	1.00E+00	INH(W)	1.00E+04	INH ACCF(W)
*Am-243+	1.00E+00	INH(W)	1.00E+03	INH ACCF(W)
*Cm-242	1.00E+02	INH(W)	1.00E+05	INH ACCF(W)
*Cm-243	1.00E+00	INH(W)	1.00E+04	INH ACCF(W)

TABLE 5 SUMMARY OF EXEMPTION ACTIVITIES AND ACTIVITY CONCENTRATIONS (ROUNDED)

NUCLIDE	ACTIVITY CONCENTRATION BQ/G	CRITICAL PATHWAY FOR EXEMPT ACTIVITY CONCENTRATION	ACTIVITY BQ	CRITICAL PATHWAY FOR EXEMPT ACTIVITY
Cm-244	1.00E+01	INH(W)	1.00E+04	INH ACC(P)
*Cm-245	1.00E+00	INH(W)	1.00E+03	INH ACCF(W)
*Cm-246	1.00E+00	INH(W)	1.00E+03	INH ACCF(W)
*Cm-247	1.00E+00	INH(W)	1.00E+04	INH ACCF(W)
*Cm-248	1.00E+00	INH(W)	1.00E+03	INH ACCF(W)
Bk-249	1.00E+03	INH(W)	1.00E+06	INH ACCF(W)
*Cf-246	1.00E+03	INH(W)	1.00E+06	INH ACCF(W)
*Cf-248	1.00E+01	INH(W)	1.00E+04	INH ACCF(W)
*Cf-249	1.00E+00	INH(W)	1.00E+03	INH ACCF(W)
*Cf-250	1.00E+01	INH(W)	1.00E+04	INH ACCF(W)
*Cf-251	1.00E+00	INH(W)	1.00E+03	INH ACCF(W)
Cf-252	1.00E+01	INH(W)	1.00E+04	INH ACC(P)
*Cf-253	1.00E+02	INH(W)	1.00E+05	INH ACCF(W)
*Cf-254	1.00E+00	INH(W)	1.00E+03	INH ACCF(W)
*Es-253	1.00E+02	INH(W)	1.00E+05	INH ACCF(W)
Es-254	1.00E+01	INH(W)	1.00E+04	INH ACCF(W)
*Es-254m	1.00E+02	EXT(W)	1.00E+06	EXT(W)
*Fm-254	1.00E+04	INH(W)	1.00E+07	INH ACCF(W)
*Fm-255	1.00E+03	EXT(W)	1.00E+06	INH ACCF(W)

LEGEND FOR TABLES 4 AND 5

PREFIX (*) REFERS TO RADIONUCLIDE OF UNKNOWN USE AND WASTE FORM.

SUFFIX (+), (N) REFERS TO DAUGHTERS WHICH ARE LISTED IN TABLE 2.

ACTIVITY CONCENTRATIONS

EXT(W) EXTERNAL IN WORKPLACE FROM 1M CUBED SOURCE

EXTG(W) EXTERNAL IN WORKPLACE FROM GAS BOTTLE

INH(W) INHALATION IN WORKPLACE

ING ACC(P) ACCIDENTAL INGESTION TO PUBLIC FROM LANDFILL

ACTIVITIES

SKIN(W) SKIN DOSE IN WORKPLACE

EXT(W) EXTERNAL IN WORKPLACE (EFFECTIVE SKIN + POINT SOURCE)

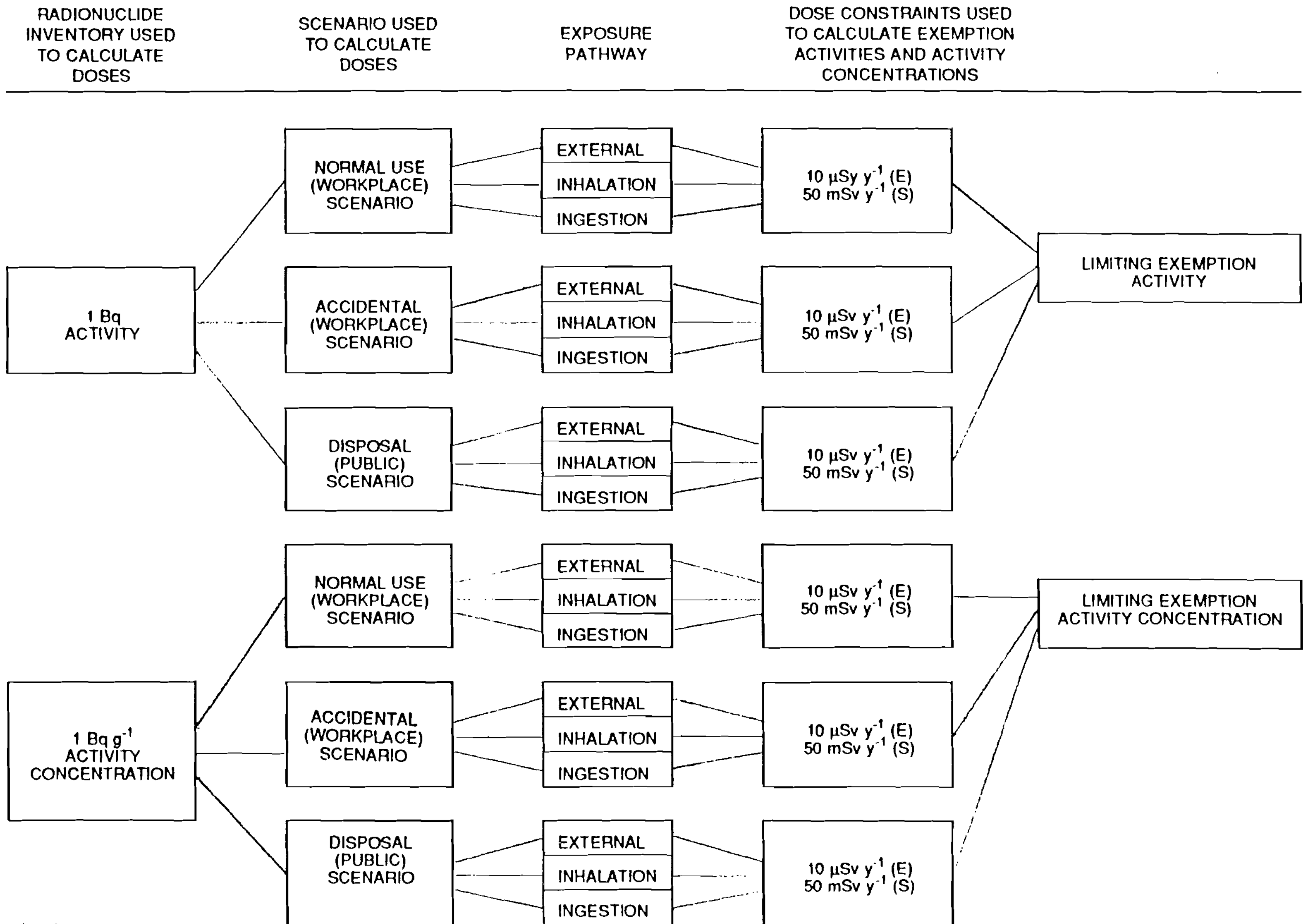
INH ACCF(W) INHALATION IN WORKPLACE FROM FIRE

EXT ACCF(W) EXTERNAL IN WORKPLACE FROM FIRE

INH ACC(P) ACCIDENTIAL INHALATION TO PUBLIC FROM LANDFILL

ING ACC(P) ACCIDENTAL INGESTION TO PUBLIC FROM LANDFILL

FIGURE 1 Block diagram illustrating methodology for calculating exempt activities and activity concentrations



E = Effective dose.
S = Skin equivalent dose.

FIGURE 2 Block diagram showing workplace and public scenarios used to calculate doses for unit activity of 1 Bq

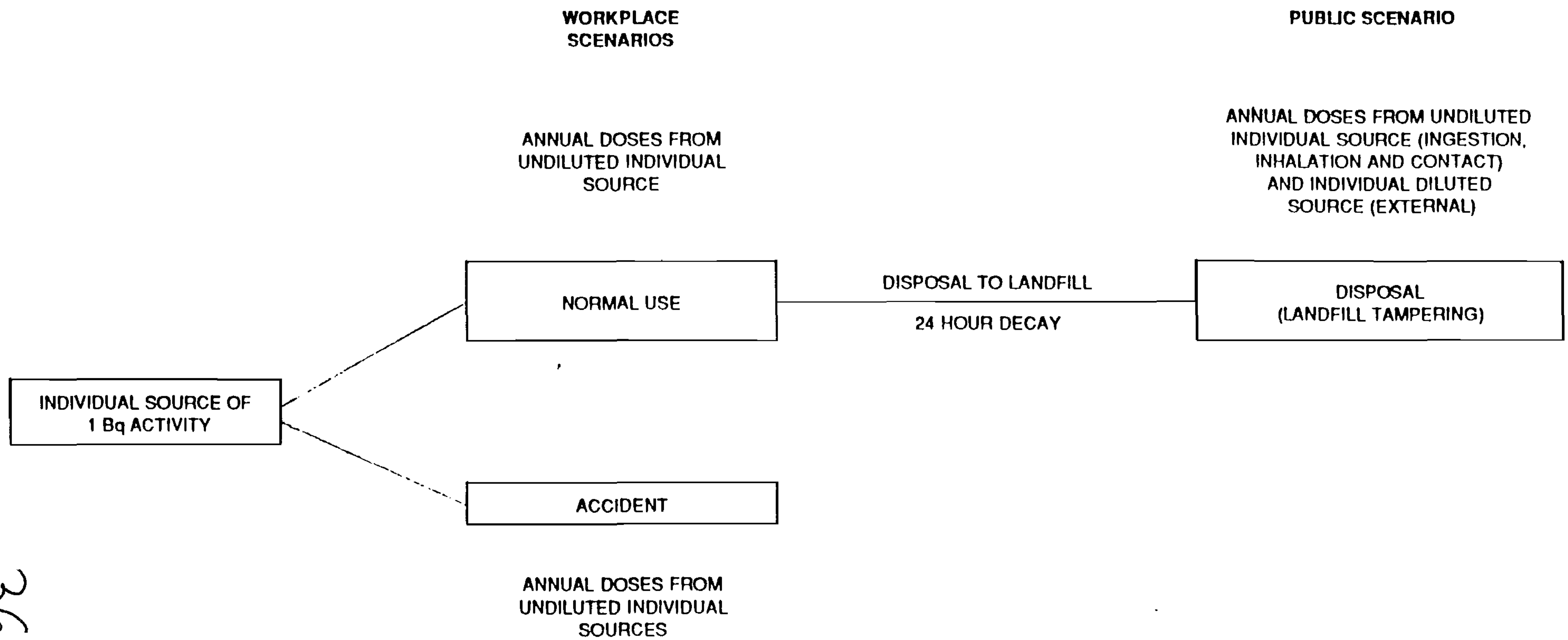
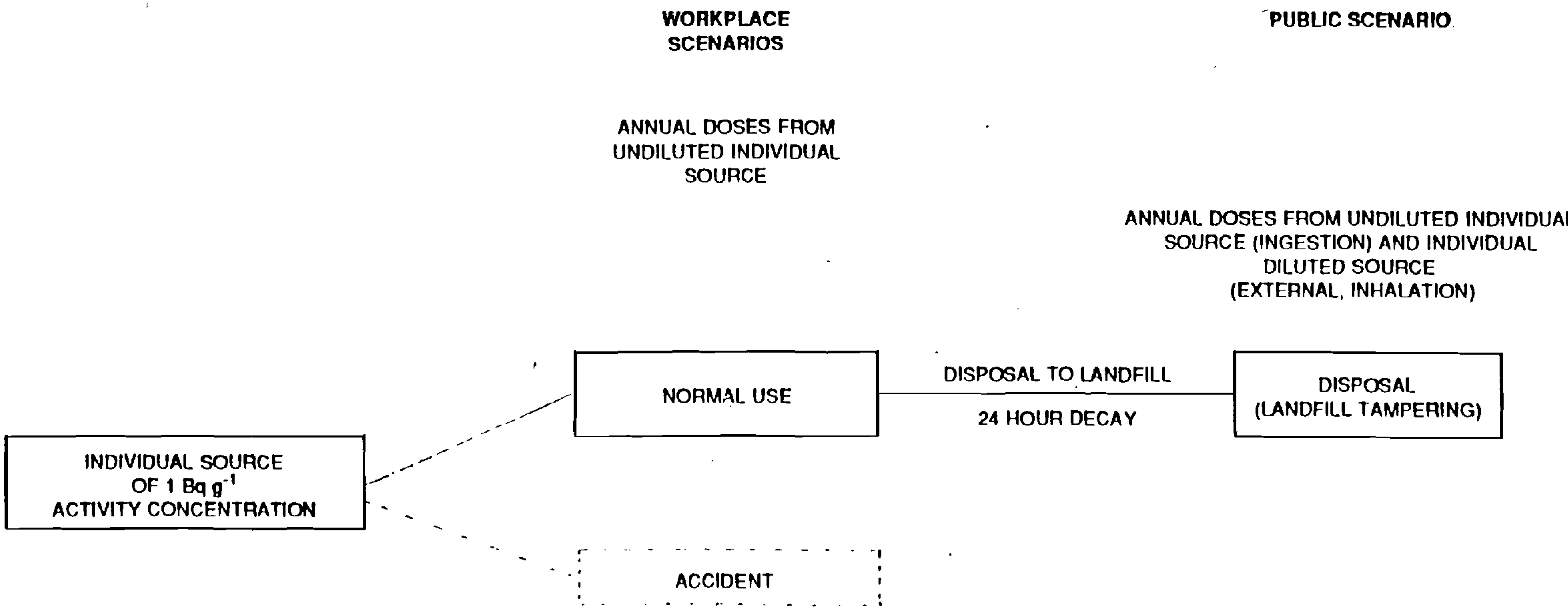


FIGURE 3 Block diagram showing workplace and public scenarios used to calculate doses for unit activity concentrations 1 Bq g^{-1}



APPENDIX A

Descriptions of scenarios, pathways, and formulae used for the dose calculations

Contents

APPENDIX A

Descriptions of scenarios, pathways and formulae used for the dose calculations

This section gives details of the scenarios and pathways considered, together with associated formulae, parameters and references. Doses are calculated for unit activity concentration (1 Bq g^{-1}) and unit activity (Bq) of the radionuclide in question.

Three types of exposure scenario are considered: exposure in the workplace in the course of normal use of the source, exposure of workers as a result of an accident, and normal and accidental exposure to members of the public from a landfill site. Each scenario gives rise to doses from one or more of the following exposure pathways: external exposure, ingestion or inhalation. Taking each scenario in turn, the doses from the relevant pathways are calculated and then summed to give a total dose for that scenario. These total doses are then compared with the dose criteria.

In cases where exposures are not certain to occur (accidental exposures), an 'annual average dose' was calculated, equal to the product of the dose if it occurs and the annual probability that it will occur.

A Activity concentration

A1 Normal use scenario

This scenario represents normal use of the source by an operator in the course of his or her work. Only doses to the person(s) using the source are assessed and it is assumed that the individual receives exposures via both external and internal (inhalation and ingestion) pathways.

A1.1 External exposure from handling a source

The individual is assumed to pick up and handle a source for a limited proportion of the working day (approximately 1% to 5%). Typical situations, which involve handling sources, may include the following:

(a) Manipulation of small sources, eg, the fitting of sources into jigs for calibrating instruments. This scenario also applies to long lived noble gases with a half life greater than 24 hours.

(b) Packaging of radioactive sources or materials.

(c) Machining of small radioactive components, eg, items manufactured from uranium.

It was assumed that the source is held by the fingers or within the palm of the hand, where the skin thickness is 400 µm[1]. For beta radiations the dose rate factor for 400 µm[2] was used and for gamma radiation the dose rate factor for 70 µm[3] was used, since no other data were available.

The exposure times and geometry considered here are such that an accidental situation, whereby a member of the public handles a source at a landfill site is covered by this scenario.

The skin equivalent dose from external radiation from a source in contact is given by:

$$H_{skin} = A_s\, T\, (R_7 + R_{24})$$

where: H_{skin} = Skin equivalent dose (Sv y^{-1})

As	=	Activity per unit area (Bq cm^{-2})
T	=	Exposure time (h y^{-1}) (= 2.5 10^1 h y^{-1} for all sources)
R_7	=	Skin equivalent dose rate to the basal layer of skin epidermis, for gamma irradiation (7 mg cm^{-2})* (Sv h^{-1} per Bq cm^{-2})[3].
R_{24}	=	Skin equivalent dose rate to the basal layer of skin epidermis, for beta irradiation (40 mg cm^{-2}) (Sv h^{-1} per Bq cm^{-2})[2].

The two halves are considered to be in contact with the skin and the activity per unit area, As, is calculated from the activity concentration per unit mass using the following method:

$$As = C \frac{M}{CONTACT} = C\ U$$

where C = Activity concentration per unit mass of source (1 Bq g^{-1})

CONTACT is calculated by dividing the mass of the source by the mass per unit area, assuming that opposite halves of the source are both in contact with skin.

$$CONTACT = \frac{M}{(\rho \frac{t}{2})} = \frac{M}{U}$$

where: M = Mass of source (g)

ρ = Density of source (g cm^{-3})

$\frac{t}{2}$ = Half thickness of source (cm)

For sealed gaseous sources, CONTACT is taken to be 0.5 cm^2 (the typical dimension of a source) and M is 6.15 10^{-4} g.

Values of M, ρ, $\frac{t}{2}$ and U used for the dose calculations are given in the table below:

These values are typical for the sources considered.

Source type	M (g)	ρ (g cm^{-3})	t/2 (cm)	U (g cm^{-2})
Dispersable solids	3.00 10^1	1.12 (resin) (4)	1.50 10^{-1}	1.68 10^{-1}
Gaseous	6.15 10^{-4}	-	-	1.23 10^{-3}

The effective dose from external radiation from a source is given by:

$$E = H_{skin}\ w_{skin} \frac{CONTACT}{BODY}$$

*Assume density of skin is approximately equivalent to that of water (1 g cm^{-3}).

where: E = Effective dose ($Sv\ y^{-1}$)

w_{skin} = Tissue weighting factor = 1 10^{-2}[5]

BODY = Total skin area = 1 10^4 cm^2

A1.2 External exposure from a 1 m^3 source

The operator is assumed to be exposed from a source of approximately 1 m^3 for 100 hours per year. Examples of this are exposure from small stock piles of ores containing natural radionuclides, process materials, or a store of small sources of waste, such as a cabinet.

The doses from a 1 m^3 source were calculated from semi-infinite/infinite slab geometry dose factors for beta[6] and gamma energies[7]. A geometry factor was applied to the gamma dose rate factor to represent a 1 m^3 source[7] and a shielding factor was applied to the beta dose rate to represent shielding by a cabinet. Both dose factors took account of self attenuation within the source.

The effective dose from external radiation from a 1 m^3 source is given by:

$$E = C\ T\ ((GAM\ R_1\ GEOM) + (BETA\ SHIELD))$$

where: E = Effective dose ($Sv\ y^{-1}$)

C = Activity concentration per unit mass (1 $Bq\ g^{-1}$)

T = Exposure time ($h\ y^{-1}$)
(1 10^2 $h\ y^{-1}$)

GAM = Effective dose rate 1 m above an infinite thick slab of 1 $Bq\ g^{-1}$ per MeV of gamma energy
(($Sv\ h^{-1}$) per ($Bq\ g^{-1}$ MeV))
(= 3 10^{-7} (($Sv\ h^{-1}$) per ($Bq\ g^{-1}$ MeV)))[7]

R_1 = The average photon energy per disintegration (MeV)[8]

BETA = Effective dose rate from beta particles 1 m above a semi-infinite† slab of 1 $Bq\ g^{-1}$ ($Sv\ h^{-1}$ per $Bq\ g^{-1}$)[6]

SHIELD = Shielding factor for beta particles
(= 1 10^{-1})

GEOM = Geometry reduction factor from infinite slab to finite source size
(= 2 10^{-2})[8]

For radionuclides for which BETA was not listed in reference 6, BETA was obtained by interpolation, using a graph of BETA against average energy based on the nuclides in reference 6, thus:

For energies	< 0.1 MeV	BETA	= 0
For energies	≥ 0.1 MeV < 0.4 MeV	$\log_e$ BETA	= 6 $\log_e R_2$ - 16.4
For energies	≥ 0.4 MeV	$\log_e$ BETA	= 2.86 $\log_e R_2$ - 19.7

where: R_2 = The average beta energy per disintegration (MeV)[8].

†A semi-infinite slab is assumed to be approximately the same as an infinite slab for beta energies.

A1.3 External exposure from a gas bottle

The operator is assumed to work at a distance of 1 m from a single gas bottle containing the radionuclide in question for 100 hours per year. This exposure geometry can be adequately represented by a 0.1 m^3 solid source[7], which approximates to 3 10^{-3} of the exposure from an infinite slab. This exposure pathway may occur in a number of situations, such as hospitals or research laboratories, where the person may be unaware of the potential dose from the gamma radiation emitted by the gas. It is unlikely that the beta particles will have any effect as they will be absorbed within the gas cylinder walls and hence these have been ignored. It is assumed that the 0.5 cm steel gas bottle walls provide negligible shielding from gamma energies.

The effective dose from external radiation from a 0.1 m^3 gas bottle is given by:

$$E = C\ T\ (GAM\ R_1)\ GEOM$$

where:

- E = Effective dose (Sv y^{-1})
- C = Activity concentration per unit mass (1 Bq g^{-1})
- T = Exposure time (h y^{-1}) (= 1 10^2 h y^{-1} (noble gases))
- GAM = Effective dose rate at 1 m above an infinite thick slab of 1 Bq g^{-1} per MeV of gamma energy ((Sv h^{-1}) per (Bq g^{-1} MeV)) (= 3 10^{-7} ((Sv h^{-1}) per (Bq g^{-1} MeV)))[7]
- R_1 = The average photon energy per disintegration (MeV)[8]
- GEOM = Geometric reduction factor from infinite thick slab source to 0.1 m^3 solid source. (= 3 10^{-3})[7]

A1.4 Inhalation of dust

The operator is assumed to be exposed for a normal working year (2000 h y^{-1}) to an atmosphere with a dust concentration of 0.04 mg m^{-3}, assuming that adequate engineering controls are employed for ventilation. This level is similar to the average air concentrations allowed for industrial processes, for some elements, as a result of their chemical toxicity limits. For example, silicon and cobalt are restricted to 0.1 mg m^{-3} [9] and beryllium is restricted to 0.002 mg m^{-3} [10].

Examples of situations where a user may be exposed to radioactively contaminated dust include exposure to natural radionuclides in the processing of mineral ores (eg Monazite sands for the production of thorium gas mantles) and during the manufacture of specialist refractories. Future exposure may occur where radioactively contaminated metals may be sawed or milled to produce a usable product.

The committed effective dose from inhalation of dust and volatiles is given by:

$$E = C\ T\ INH\ R_{10}\ Dust$$

where:

- E = Committed effective dose (Sv y^{-1})
- C = Activity concentration (1 Bq g^{-1})
- T = Exposure time (h y^{-1}) (= 2 10^3 h y^{-1})

INH = Breathing rate ($m^3\ h^{-1}$)
($= 1\ m^3\ h^{-1}$)[11]

R_{10} = Committed effective dose per unit intake for inhalation ($Sv\ Bq^{-1}$)[12]

Dust = Concentration of airborne dust ($g\ m^{-3}$)
($= 4\ 10^{-5}\ g\ m^{-3}$)

A1.5 Ingestion from contaminated hands

This pathway assumes an individual works for a normal working year (250 days per year) in an environment in which dust (contaminated with radionuclides) at an air concentration of 0.04 mg m^{-3} settles on work surfaces. The size of the room is assumed to be 32 m^3 and it is assumed that all the dust settles in a working day, giving a total of 1.28 10^{-3} g of deposited dust per day. It is assumed that the individual will inadvertently pick up and ingest 10% of the deposited dust each day, ie, an ingestion rate of 1.28 10^{-4} g per day. The total ingested mass of contaminated dust is therefore 32 mg per year.

The committed effective dose from ingestion of dust is given by:

$$E = C\ ING\ R_9$$

where: E = Committed effective dose ($Sv\ y^{-1}$)

C = Activity concentration ($1\ Bq\ g^{-1}$)

ING = Annual ingestion rate of contaminated material ($g\ y^{-1}$) ($= 32\ mg\ y^{-1}$)

R_9 = Committed effective dose per unit intake for ingestion ($Sv\ Bq^{-1}$)[12]

A2 Accidental (workplace) scenario

This scenario represents exposure arising from accidents and misuse in the workplace. The exposure pathways are external and internal (ingestion and inhalation). However, all these pathways have been considered in the normal use (workplace) scenario and the combination of dose rate, exposure time and probability of occurrence for the accidental pathways gives rise to average annual doses that are lower than those from the corresponding normal use (workplace) pathway. Therefore the Accidental (workplace) scenario is considered to be adequately covered by the Normal use (workplace) scenario and is not treated explicitly.

It can also be shown that the dose to the individual, should the accident occur, would be below the 1 mSv per year effective dose limit and the 50 mSv skin dose limit, as follows:

(a) For skin dose: the contact time assumed for normal use (workplace) is 25 h per year. If an accident occurred, the exposure time is likely to be much shorter (10 mins would appear to be a more reasonable estimate). Therefore, if normal use gives doses below the 50 mSv skin dose limit, then so will an accident, if it occurs.

(b) For external dose: an exposure time of 100 hours per year was used in the normal use (workplace) scenario. Assuming continual occupancy, the maximum individual dose is around 0.7 mSv.

(c) For inhalation: a dust loading of 40 μg m^{-3} over the working year was used in the normal use (workplace) scenario. In order to incur a dose of 1 mSv the dust loading throughout the year would have to reach 4 mg m^{-3}, which is verging on an intolerably dusty atmosphere.

(d) For ingestion: an ingestion rate of 32 mg per year is used in the normal use (workplace) scenario. In order to incur a dose of 1 mSv, over 3 g of material would have to be ingested in an accident.

A3 Disposal (public) scenario

The disposal scenario for activity concentrations considers the exposure of a member of the public who is visiting a landfill site in which a radioactive source has been disposed. Most sites are accessible to the public, especially if they are those which allow individual members of the public to dump their own rubbish, such as Local Authority tips in the UK. The landfill site is assumed to be a generic small site with a capacity of domestic waste of $1.5\ 10^4$ tonnes[6], over an area of $1\ 10^{-2}$ km^2. A delay of 24 hours is assumed to occur between use of the source and its subsequent disposal at the landfill site. The source is assumed to decay over this period. Radioactive decay over the exposure time of the individual is not included. This is a conservative assumption and also allows for the possibility of sequential disposal of sources. Accidental exposure of a member of the public is considered via two pathways, external and inhalation exposures. The ingestion pathway is considered as a normal exposure pathway.

For both accidental pathways, the chance of an exposure occurring in a year is assumed to be 1 in 100, or a probability of $1\ 10^{-2}$.

A3.1 External exposure from a landfill site

This pathway considers a member of the public walking over the landfill site for an annual time considered to be typical of outdoor recreational activities (300 h y^{-1}). When the source is disposed of on the landfill site it may either become diluted by the remaining waste, or remain an isolated source. In both cases the external dose to the individual will be the same.

The doses are calculated from external gamma radiation assuming that the landfill site can be represented by an infinite thick slab geometry as described in section A1.2.

The average annual effective dose from external radiation from a landfill site is given by:

$$E = C_D\ T\ (GAM\ R_1)\ s$$

where:

E	=	Average annual effective dose (Sv y^{-1})
C_D	=	Diluted activity concentration (Bq g^{-1})
T	=	Exposure time (h y^{-1}) (= 300 hours y^{-1})
GAM	=	Effective dose rate 1 m above an infinite thick slab of 1 Bq g^{-1}, per MeV of gamma energy ((Sv h^{-1}) per (Bq g^{-1} MeV)) (= $3\ 10^{-7}$ ((Sv h^{-1}) per (Bq g^{-1} MeV)))[7]
R_1	=	The average photon energy per disintegration (MeV)[8]
s	=	Probability of exposure occurring in a year (= 1.10^{-2} y^{-1})

The diluted activity concentration is calculated from source activity concentration in the following manner:

$$C_D = C \frac{M1}{M2} DECAY$$

where: C = Source activity concentration (1 Bq g^{-1})
M1 = Mass of source (g)
(= 1 10^2 g) (typical mass and used for all waste forms except gases)
M2 = Mass of waste tip (g)
(= 1.5 10^{10} g)[6]
DECAY = Fraction of parent radionuclide remaining after 24 hours of radioactive decay (daughters are not considered)

A3.2 Inhalation of dust from a landfill site

This pathway considers a member of the public walking over a landfill site as in A3.1 and inhaling dust from the exposed contaminated soil from a single source for 1 hour per year. The concentration of airborne dust is assumed to be 1 mg m^{-3}[(7)] and contaminated in the same proportion as the soil in A3.1.

The average annual committed effective dose from inhalation of dust from a landfill site is given by:

$$E = C_D \; T \; INH \; R_{10} \; Dust \; s$$

where: E = Average annual committed effective dose (Sv y^{-1})
C_D = Diluted activity concentration (Bq g^{-1})
T = Exposure time (h) if exposure occurs
(= 1 h)
INH = Breathing rate (m^3 h^{-1})
(= 1 m^3 h^{-1})[11]
R_{10} = Committed effective dose per unit intake for inhalation (Sv Bq^{-1})[12]
Dust = Concentration of airborne dust (g m^{-3})
(= 1 10^{-3} g m^{-3})[7]
s = Probability of exposure occurring in a year
(= 1 10^{-2} y^{-1})

The diluted activity concentration is calculated from the source activity per unit mass in the following manner:

$$C_D = C \frac{M1}{M2}$$

where: C = Source activity concentration (1 Bq g^{-1})
M1 = Mass of source (g)
(= 1 10^2 g) (typical mass and used for all waste forms except gases)
M2 = Mass of waste tip (g)
(= 1.5 10^{10} g)[6]

A3.3 Ingestion of an object from a landfill site

A member of the public is assumed to be walking over a landfill site and inadvertently ingests a small quantity of activity from the source. This scenario represents several different situations, for example, a person finding a radioactive source or an object contaminated with radioactivity which has seeped from a source, a person ingesting contaminated soil from their hands or a child accidentally swallowing a contaminated object.

It is assumed that an individual member of the public ingests 1 g of the source per year. (This is based on an ingestion rate of 2 g y^{-1} typically used for inadvertent ingestion of soil while gardening, and allowing for the fact that some of the ingested material would not be contaminated.)

The average annual committed effective dose for ingestion of an object found on a landfill site is given by:

$$E = C\ M1\ f\ R_9\ DECAY$$

where:

E	=	Average annual committed effective dose (Sv y^{-1})
C	=	Activity concentration of source (1 Bq g^{-1})
R_9	=	Committed effective dose per unit intake for ingestion (Sv Bq^{-1})[12]
f	=	Fraction of source ingested in a year (= 1 10^{-2})
M1	=	Mass of source (g) (= 1 10^{2} g)
DECAY	=	fraction of parent nuclide remaining after 24 hours of radioactive decay (daughters are not considered).

B Activities (Quantities)

B1 Normal use (workplace) scenario

The normal use (workplace) scenario for quantities or activities of radionuclides considers external exposure to the operator in the course of his or her work. Again, as with Activity Concentrations, only doses to the person(s) using the source are assessed.

B1.1 External exposure from a point source

The operator is assumed to be working near a small source, represented by a point source at 1 m.

Typical situations where this scenario may occur are as follows:

(a) Where repetitive use is required from a small sealed source to test equipment;

(b) During fitting of small sealed sources into devices (eg a device such as a smoke detector or scientific instrument);

(c) Where small sealed sources or small quantities of unsealed radioactive solutions (vials) may be packaged into containers;

(d) Use of radioactive sources in industry for tracer studies.

The effective dose from external radiation from a point source is given by:

$$E = A\ T\ (R_{19} + R_{20})$$

where: E = Effective dose ($Sv\ y^{-1}$)

A = Activity of source (1 Bq)

T = Exposure time ($h\ y^{-1}$)

(= $1\ 10^2\ h\ y^{-1}$ for liquids and dispersable solids.

$2\ 10^2\ h\ y^{-1}$ for non-dispersable solids, capsule and foil).

R_{19} = Effective dose rate for 1 Bq point source at 1 m (gamma) ($Sv\ h^{-1}$ per Bq)[6]

R_{20} = Effective dose rate for 1 Bq point source at 1 m (beta) ($Sv\ h^{-1}$ per Bq)[6]

B1.2 External exposure from handling a source

The individual is assumed to pick up and handle a source for a limited proportion of the working day (approximately 2-3 minutes). Typical situations, which involve handling sources, may include the following:

(a) Manipulation of small sources, eg, the fitting of sources into jigs for calibrating instruments. This scenario also applies to long lived noble gases with a half life greater than 24 hours.

(b) Packaging of radioactive sources or materials.

(c) Machining of small radioactive components, eg, items manufactured from uranium.

It was assumed that the source is held by the fingers or within the palm of the hand, where the skin thickness is 400 µm[1]. For beta radiations the dose rate factor for 400 µm[2] was used and for gamma radiation the dose rate factor for 70 µm[3] was used, since no other data were available.

It is assumed that the glass vial containing liquids, attenuates beta emitters through a glass wall thickness of 150 mg cm^{-2}.

The skin equivalent dose from external radiation from a source in contact is given by:

$$H_{skin} = As\ T\ (R_7 + R_{24}) \text{ for dispersable solids, sealed gaseous sources, capsule and foil}$$

$$H_{skin} = As\ T\ \left(R_7 + \left(\frac{R_{24}}{SF}\right)\right) \text{ for liquids}$$

where: H_{skin} = Skin equivalent dose ($Sv\ y^{-1}$)

As = Activity per unit area ($Bq\ cm^{-2}$)

T = Exposure time ($h\ y^{-1}$)

(= $1\ 10^1\ h\ y^{-1}$ for all sources).

R_7 = Skin equivalent dose rate to the basal layer of skin epidermis, for gamma irradiation (7 mg cm^{-2})‡ ($Sv\ h^{-1}$ per Bq cm^{-2})[3].

R_{24} = Skin equivalent dose rate to the basal layer of skin epidermis, for beta irradiation (40 mg cm^{-2}) ($Sv\ h^{-1}$ per Bq cm^{-2})[2].

SF = Shielding factor for liquid sources held in glass vials[13].

‡Assume density of skin is approximately equivalent to that of water (1 g cm^{-3}).

where: $SF = e^{\mu d}$

and $\mu = 0.017 \times E_{\beta max}^{-1.14}$

$d = 150 \text{ mg cm}^{-2}$

The activity per unit area, As, is calculated from activity and activity concentrations using the following method.

$$As = \frac{A}{CONTACT}$$

where: A = Activity of source (1 Bq)

CONTACT = Area of skin in contact with source (cm^2)

For liquid and solid sources CONTACT is calculated by dividing the mass of the source by the mass per unit area, assuming that opposite halves of the source are both in contact with skin.

$$CONTACT = \frac{M}{(\rho \frac{t}{2})} = \frac{M}{U}$$

where: M = Mass of source (g)

ρ = Density of source (g cm^{-3})

$\frac{t}{2}$ = Half thickness of source (cm)
(to account for 1 Bq distributed over two halves of the source)

For sealed gaseous sources, CONTACT is taken to be 0.5 cm^2 (the typical dimension of a source) and M is 6.15 10^{-4} g.

Values of M, ρ, $\frac{t}{2}$ and U used for the dose calculations are given in the table below:

These values are typical for the sources considered

Source type	M (g)	ρ (g cm^{-3})	t/2 (cm)	U (g cm^{-2})
Liquids	1.00 10^{1}	1.00 (water)[4]	5.00 10^{-1}	5.00 10^{-1}
Dispersable solids	3.00 10^{1}	1.12 (resin)[4]	1.50 10^{-1}	1.68 10^{-1}
Capsule	8.00 10^{-4}	5.00 (iron mixed)[4]	8.00 10^{-5}	4.00 10^{-4}
Foil	4.00 10^{-4}	5.00 (iron mixed)[4]	5.00 10^{-5}	2.00 10^{-4}
Gaseous	6.15 10^{-4}	-	-	1.23 10^{-3}

The effective dose from external radiation from a source is given by:

$$E = H_{skin} \, w_{skin} \, \frac{CONTACT}{BODY}$$

where: E = Effective dose (Sv y^{-1})

w_{skin} = Tissue weighting factor = $1\ 10^{-2}$[5]

BODY = Total skin area = $1\ 10^{4}\ cm^{2}$

B2 Accidental (workplace) scenario

The accidental (workplace) scenario for activity calculations considers exposure arising from accidents or misuse in the workplace.

The worker is assumed to be exposed to external and internal dose pathways from two basic situations: accidental spillage of radionuclides and contaminated smoke from a fire. Note for most spillage pathways the mass of the source is assumed to be 10 g for liquids and 30 g for dispersable solids. The exception is for pathway B2.5, where a more pessimistic mass of 100 g is assumed.

When calculating exempt levels, the two basic situations were treated separately ie. exempt levels were obtained for Accidental (spillage) and Accidental (fire) by summing the doses from the appropriate pathways but the spillage and fire doses were not added together.

B2.1 Spillage: external exposure from contaminated hands

Calculation of exposures from this pathway assumes that an individual accidentally spills a radioactive solution (liquid) or powder (dispersable solid) over a working surface and 10% is assumed to contaminate the back of the individual's hands and part of their arms. The individual fails to recognise this for 10 minutes, when it is washed off. The skin thickness over this region is 40 µm[1] and skin doses were calculated for a thickness of 40 µm for beta particles (monoenergetic electrons and continuous energy beta spectra) and 70 µm for gamma radiation.

The average annual skin equivalent dose resulting from hand and arm contamination due to spillage is given by:

$$H_{skin} = As\ T\ (R_7+R_8)\ s$$

where: H_{skin} = Average annual skin equivalent dose (Sv y^{-1})

As = Activity per unit area if spillage occurs (Bq cm^{-2})

T = Exposure time (h) if spillage occurs (= 0.16 h)

R_7 = Skin equivalent dose rate to the basal layer of the skin epidermis, for gamma irradiation (7 mg cm^{-2})§ (Sv h^{-1} per Bq cm^{-2})[3]

R_8 = Skin equivalent dose rate to the basal layer of the skin epidermis, for beta irradiation (4 mg cm^{-2}) (Sv h^{-1} per Bq cm^{-2})[2]

s = Probability of exposure occurring in a year (= $1\ 10^{-2}\ y^{-1}$)

The activity per unit area, As, is calculated from the activity, using the following method.

It is assumed that an activity of 1 Bq of a radioactive material is being used in solution (liquid) or as a powder (dispersable solid). The mass of the solution is assumed to be $1\ 10^{1}$ g and

§Assume density of skin is approximately equivalent to that of water (1 g cm^{-3})

the powder $3\ 10^1$ g. During a procedure, an accident occurs and all of the solution or powder is assumed to be spilt onto a working surface. It is assumed that 10% of this material is transferred to the back of the hands and arms with a deposit thickness of $1\ 10^{-2}$ cm[6].

$$As = \frac{\text{Activity deposited on hands and arms}}{\text{Area of skin in contact with spilt source}}$$

$$= \frac{A\ f}{CONTACT}$$

where: A = Activity of source before spillage (1 Bq)

f = Fraction of spilt material transferred to hands (= $1\ 10^{-1}$)[6]

CONTACT = Area of skin in contact with spilt source

CONTACT is calculated by dividing the mass of deposit on the hands by the mass per unit area of the deposit.

$$CONTACT = \frac{M\ f}{\rho\ t} = \frac{m}{U}$$

where: M = Mass of source before spillage (g)
(= $1\ 10^1$ g for liquids; $3\ 10^1$ g for dispersable solids (typical source sizes))

f = Fraction of spilt material transferred to hands
(= $1\ 10^{-1}$)[6]

ρ = Density of deposit on hands (g cm^{-3})
(= 1 g cm^{-3} for liquids[6]; $5\ 10^{-1}$ g cm^{-3} for dispersable solids[6])

t = Thickness of deposit on hands (cm)
(= $1\ 10^{-2}$ cm)[6]

m = Mass of source on hands (g)
(= 1 g for liquids; 3 g for dispersable solids)

Therefore CONTACT = $1\ 10^2$ cm^2 for liquids; $6\ 10^2$ cm^2 for solids

The effective dose resulting from hand and arm contamination due to spillage is given by:

$$E = H_{skin}\ w_{skin}\ \frac{CONTACT}{BODY}$$

where: E = Effective dose (Sv y^{-1})

w_{skin} = Tissue weighting factor for skin = $1\ 10^{-2}$[5]

BODY = Total skin area = $1\ 10^4$ cm^2

B2.2 Spillage: external exposure from contaminated face

This pathway assumes the situation where a spillage has occurred as in B2.1, and 10% of the material which has contaminated the hands is transferred to the face where it remains for

10 minutes, before it is washed off. The skin thickness over the face is 40 μm[1] and doses are calculated using the same dose factors as described in B2.1.

The average annual skin equivalent dose resulting from face contamination due to spillage is given by:

$$H_{skin} = As\ T\ (R_7+R_8)\ s$$

where: H_{skin} = Average annual skin equivalent dose (Sv y^{-1})
As = Activity per unit area (Bq cm^{-2}) if spillage occurs

T = Exposure time (h) if spillage occurs
(= 0.16 h)
R_7 = Skin equivalent dose rate to the basal layer of skin epidermis for gamma irradiation (7 mg cm^{-2})‖ (Sv h^{-1} per Bq cm^{-2})[3]
R_8 = Skin equivalent dose rate to the basal layer of the epidermis for beta irradiation (4 mg cm^{-2}) (Sv h^{-1} per Bq cm^{-2})[2]
s = Probability of an exposure occurring in a year
(= 1 10^{-2} y^{-1})

The activity per unit area, As, is calculated from the activity using the following method.

It is assumed that a similar situation occurs to that described in B2.1. The solution or powder, of mass 1 10^1 g or 3 10^1 g respectively is spilt onto a working surface and 10% of this material is transferred to the hands. 10% of the material on the hands is later transferred to the face at a deposit thickness of 1 10^{-3} cm[6].

$$As = \frac{\text{Activity deposited on face}}{\text{Area of skin in contact with source}}$$

$$= \frac{A\ f}{CONTACT}$$

where: A = Activity
f = Fraction of spilt material transferred to hands and then to face
(= 10^{-1} x 10^{-1} = 1 10^{-2})[6]
CONTACT = Area of skin in contact with spilt source

CONTACT is calculated by dividing the mass of deposit on the face by the mass per unit area of the deposit.

$$CONTACT = \frac{M\ f}{\rho\ t} = \frac{m}{U}$$

where: M = Mass of source before spillage (g)
(= 1 10^1 g for liquids; 3 10^1 g for dispersable solids (typical source sizes)).

‖Assume density of skin is approximately equivalent to that of water (1 g cm^{-3})

f = Fraction of spilt material transferred to hands and then to face
(= 10^{-1} x 10^{-1} = 1 10^{-2})[6]

ρ = Density of deposit on face (g cm^{-3})
(= 1 g cm^{-3} for liquids[6]; 5 10^{-1} g cm^{-3} for solids[6])

t = Thickness of deposit on face (cm)
(= 1 10^{-3} cm)[6]

m = Mass of source on face (g)
(= 1 10^{-1} g for liquids; 3 10^{-1} g for solids)

Therefore CONTACT = 1 10^2 cm^2 for liquids; 6 10^2 for solids.

The effective dose resulting from face contamination is given by:

$$E = H_{skin} \, w_{skin} \frac{CONTACT}{BODY}$$

where: E = Effective dose (Sv y^{-1}) for skin

w_{skin} = Tissue weighting factor for skin = 1 10^{-2}[5]

BODY = Total skin area = 1 10^4 cm^2

B2.3 Spillage: external exposure from contaminated surface

This pathway represents the situation where a radioactive solution (liquid) or powder (dispersable solid) is spilt on a surface and is not immediately noticed. It is assumed that the total quantity of the solution or powder is spilt over a circular area of a working surface of 7 m^2 (radius of 1.5 m). The exposed individual is assumed to be working at a distance of 1 m from the spilt source, for a period of 10 minutes, before the accident is recognised. Doses were calculated assuming the contaminated area was of a finite extent. The infinite plane geometry effective dose equivalent factor[14] was multiplied by a geometry reduction factor[15] to account for the finite area of the spilt source.

The average annual effective dose from external radiation from a spilt source is given by:

$$E = As \; T \; (R_5+R_6) \; GEOM \; s$$

where: E = Average annual effective dose (Sv y^{-1})

As = Activity per unit area (Bq m^{-2}) if spillage occurs

T = Exposure time (h) if spillage occurs
(= 0.16 h)

R_5+R_6 = Effective dose rate 1 m above an infinite plane for gamma and beta radiation (Sv h^{-1} per Bq m^{-2})[14]

GEOM = Geometric reduction factor relating a contaminated area with radius 1.5 m to an infinite plane
(= 1 10^{-1})[15]

s = Probability of exposure occurring in a year
(= 1 10^{-2} y^{-1})

The activity per unit area, As, is calculated from the activity using the following method:

$$As = \frac{A}{AREA} = A\ U$$

where: A = Activity of source (1 Bq)

AREA = Area of contamination (m^2) (= 7 m^2)

B2.4 Spillage: ingestion from hands

This pathway assumes a situation where a radioactive solution (liquid) or powder (dispersable solid) is spilt and the individual inadvertently ingests from his or her hands 1 mg of spilt material, (ie, $1\ 10^{-5}$ of the total activity).

The average annual committed effective dose from ingestion from contaminated hands following a spillage is given by:

$$E = A\ f\ R_9\ s$$

where: E = Average annual committed effective dose ($Sv\ y^{-1}$)

A = Activity of source (1 Bq)

f = Fraction of total activity which is ingested if spillage occurs (= $1\ 10^{-5}$ (0.001%))

R_9 = Committed effective dose per unit intake for ingestion ($Sv\ Bq^{-1}$)[12]

s = Probability of exposure occurring in a year (= $1\ 10^{-2}\ y^{-1}$)

B2.5 Spillage: inhalation of resuspended activity

This pathway assumes a situation, where a radioactive solution (liquid) or powder (dispersable solid) is spilt and an individual inhales the dust or aerosols for 10 minutes, close to the source. The mass of the spilt source is assumed to 100 g and the dust arises from this at a concentration of 5 mg m^{-3}.

The average annual committed effective dose from inhalation of aerosols or dust from a spilt source is given by:

$$E_c = A\ T\ INH\ R_{10}\ Dust\ s\ \frac{1}{M}$$

where: E_c = Average annual committed effective dose ($Sv\ y^{-1}$)

A = Activity of source (1 Bq)

T = exposure time (h) if spillage occurs (= 0.16 h)

INH = Breathing rate ($m^3\ h^{-1}$) (= 1 $m^3\ h^{-1}$)[11]

R_{10} = Committed effective dose per unit intake for inhalation ($Sv\ Bq^{-1}$)[12].

s = Probability of exposure occurring in a year
(= 1 10^{-2} y^{-1})

M = Mass of spilt source (g)
(= 1 10^{2} g)

Dust = Concentration of airborne dust (g m^{-3})
(= 5 10^{-3} g m^{-3})

B2.6 Spillage: external dose from an aerosol or dust cloud

This pathway assumes that an aerosol or dust cloud is formed from spilling a solution (liquid) or powder (dispersable solid), it disperses uniformly in a working room of 32 m^3 and remains airborne for at least 10 minutes. The individual is assumed to remain in the room for a period of 10 minutes and be exposed externally to the cloud.

It is assumed that all the mass from the spilt liquid is dispersed into the room by evaporation as aerosols and the airborne fraction which is radioactive depends on the volatility of the particular radionuclides.

For the spilt solid it is assumed that an airborne dust concentration of 5 mg m^{-3} occurs throughout the room which, for a 30 g source, constitutes 0.53% of the total mass spilt.

The external dose to the individual is calculated using effective dose factors based on total immersion in a semi-infinite cloud.

The average annual effective dose from external exposure to gamma and beta emitters in a dust cloud from spillage is given by:

$$E = \frac{\chi \; T \left((R_1 \; CF1) + (R_2 \; CF2 \; w_{skin}) \right) s}{h}$$

where: E = Average annual effective dose (Sv y^{-1})

χ = Activity per unit volume of air (Bq m^{-3}) if spillage occurs

T = Exposure time (h) if spillage occurs
(= 0.16 h)

R_1 = The average gamma photon energy per disintegration (MeV)[8]

CF1 = Effective dose rate in a semi-infinite cloud for 1 Bq m^{-3} per MeV of gamma energy. ((Sv y^{-1}) per (Bq m^{-3} MeV))
(= 1.6 10^{-6} ((Sv y^{-1}) per (Bq m^{-3} MeV)))[16]

R_2 = The average beta energy per disintegration (MeV)[8]

CF2 = Skin equivalent dose rate in a semi-infinite cloud for 1 Bq m^{-3} per MeV of beta energy
((Sv y^{-1}) per (Bq m^{-3} MeV))
(= 2 10^{-6} ((Sv y^{-1}) per (Bq m^{-3} MeV)))[16]

w_{skin} = Tissue weighting factor = 1 10^{-2}[5]

s = Probability of exposure occurring in a year
(= 1 10^{-2} y^{-1})

h = Number of hours in a year (h y^{-1})
(= 8760 h y^{-1})

The activity per unit volume, χ, is calculated from the activity using the following method:

For liquids:

$$\chi = \frac{A\ f\ V}{VOL} = A\ U\ V$$

For dispersable solids:

$$\chi = \frac{A\ f}{VOL} = A\ U$$

where:
A = Activity of source (1 Bq)
f = Fraction of source dispersed into room
(= 1 for liquids; 5.3 10^{-3} for solids (Typical value for a small source))
V = Volatility of radionuclide
VOL = Volume of room source is dispersed in (m^3)
(= 32 m^3 (typical laboratory room))

B2.7 Fire: Contamination of skin

This pathway considers a laboratory fire in which the radioactive source is ignited. The fraction of the source which is combustible into ash is assumed to be 100% for liquids and 1% for all other waste forms. For skin contamination it is assumed that the ash is deposited over a large area of the workplace, to a thickness of 0.1 mm[6]. The skin dose was calculated assuming that a skin area of 100 cm^2 was exposed to the deposit for 10 minutes. This is likely to be the parts of the face or the back of the hands, where the skin thickness is only 40 μm[6]. Doses are calculated using the same dose factors as described in B2.1.

The average annual skin equivalent dose resulting from skin contamination from an accidental fire is given by:

$$H_{skin} = As\ T\ (R_7+R_8)\ s$$

where:
H_{skin} = Average annual skin equivalent dose (Sv y^{-1})
As = Activity per unit area (Bq cm^{-2}) if fire occurs
T = Exposure time (h) if fire occurs
(= 0.16 h)
R_7 = Skin equivalent dose rate to basal layer of skin epidermis for gamma irradiation
(7 mg cm^{-2})** (Sv h^{-1} per Bq cm^{-2})[3]
R_8 = Skin equivalent dose rate to basal layer of skin epidermis for beta irradiation
(4 mg cm^{-2}) (Sv h^{-1} per Bq cm^{-2})[2]
s = Probability of an exposure occurring in a year
(= 1 10^{-2} y^{-1})

**Assume density of skin is approximately equivalent to that of water, (1 g cm^{-3}).

The activity per unit area, As, is calculated from the activity using the following method.

It is assumed that the ignited source produces a smoke cloud in which ash is deposited over a large area at a uniform activity per unit area. However, only 100 cm^2 of this deposit results in a dose to the exposed skin of the individual. The form of the deposit is likely to be water droplets for liquids and ash for all other waste forms. Gases are assumed to give no deposit - external doses from this waste form are considered for the cloud gamma and beta pathway (section B2.9).

$$As = \frac{A\ c}{AREA}$$

where: A = Activity of source before ignition (1 Bq)

c = Fraction of source which is combusted into ash/water vapour (=1 for liquids; 1 10^{-2} for all other waste forms)

AREA = Area of surface contaminated with ash/water droplets (cm^2)

AREA is calculated by dividing the total mass of deposit by the mass per unit area of deposit, assuming that the thickness is 0.1 mm and has the same physical properties as a dust.

$$AREA = \frac{M\ c}{\rho\ t} = \frac{m}{U}$$

where: M = Mass of source before ignition (g) (= 1 10^2 for all waste form)

C = Fraction of source which is combusted (= 1 for liquids; 1 10^{-2} for all other waste forms)

ρ = Density of deposit on surface (g cm^{-3}) (= 5 10^{-1} g cm^{-3})[6]

t = Thickness of deposit (cm) (= 1 10^{-2} cm)[6]

m = Mass of combusted material forming deposit (g) (= 1 10^2 g for liquids; 1 g for all other waste forms)

The effective dose resulting from skin contamination of fire ash is given by:

$$E = H_{skin}\ w_{skin}\ \frac{CONTACT}{BODY}$$

where: E = Effective dose (Sv)

w_{skin} = Tissue weighting factor = 1 10^{-2}[5]

CONTACT = Area of skin contamination = 1 10^2 cm^2

BODY = Total skin area = 1 10^4 cm^2

B2.8 Fire: inhalation of dust or volatiles

This pathway considers the same laboratory fire as in B2.7, in which a person inhales the combustion products for 10 minutes. This could occur even after the fire is extinguished, if the air remains laden with combustion products. It is assumed that 100% of the combusted fraction (100% for gases and liquids, 1% for all other waste forms) fills a room of 32 m^3 and remains at the same air concentration for at least 10 minutes.

The average annual committed effective dose from inhalation of aerosols and ash from an accidental fire is given by:

$$E = \chi \; T \; INH \; R_{10} \; s$$

where:
- E = Average annual committed effective dose ($Sv\ y^{-1}$)
- χ = Activity per unit volume of air ($Bq\ m^{-3}$) if fire occurs
- T = Exposure time (h) if fire occurs (= 0.16 h)
- INH = Breathing rate ($m^3\ h^{-1}$) (= 1 $m^3\ h^{-1}$)[11]
- R_{10} = Committed effective dose per unit intake for inhalation ($Sv\ Bq^{-1}$)[12]
- s = Probability of exposure occurring in a year (= 1 $10^{-2}\ y^{-1}$)

The activity per unit volume, χ, is calculated from the activity using the following method:

$$\chi = \frac{A \; c}{VOL} = A \; U \; c$$

where:
- A = Activity of source before ignition (1 Bq)
- c = Fraction of source which is combusted into ash (= 1 for liquids; 1 10^{-2} for all other waste forms)
- VOL = Volume of room in which aerosol or ash is dispersed (m^3) (= 32 m^2)

B2.9 Fire: external dose from combustion products

In this scenario it is assumed that the fire in B2.7 forms a cloud which persists for at least 10 minutes, in which time an individual will be exposed to an external dose from the gamma and beta emitters, within the cloud (as in B2.6). It is assumed that 100% of the combustible fraction fills a room 32 m^3, with the same air concentration for 10 minutes.

The average annual effective dose from external cloud gamma and beta emitters in a smoke cloud from an accidental fire is given by:

$$E = \frac{\chi \; T \left((R_1 \; CF1) + (R_2 \; CF2 \; w_{skin}) \right) s}{h}$$

where: E = Average annual effective dose (Sv y^{-1})

χ = Activity per unit volume of air (Bq m^{-3}) if fire occurs

T = Exposure time (h) if fire occurs
(= 0.16 h)

R_1 = The average gamma photon energy per disintegration (MeV)[8]

CF1 = Effective dose rate in a semi-infinite cloud for 1 Bq m^{-3} per MeV of gamma energy.
((Sv y^{-1}) per (Bq m^{-3}.MeV))
(= 1.6 10^{-6} ((Sv y^{-1}) per (Bq m^{-3}.MeV)))[16]

R_2 = The average beta energy per disintegration (MeV)[8]

CF2 = Skin equivalent dose rate in a semi-infinite cloud for 1 Bq m^{-3} per MeV of beta energy.
((Sv y^{-1}) per (Bq m^{-3}.MeV))
(= 2 10^{-6} ((Sv y^{-1}) per (Bq m^{-3}.MeV)))[16]

w_{skin} = Tissue weighting factor = 1 10^{-2}[5]

s = Probability of exposure occurring in a year
(= 1 10^{-2} y^{-1})

h = Number of hours in a year (h y^{-1})
(= 8760 h y^{-1})

The activity per unit volume, χ, is calculated from the activity using the following method:

$$\chi = \frac{A\ c}{VOL} = A\ U\ c$$

where: A = Activity of source before ignition (1 Bq)

c = Fraction of source which is combusted into ash
(= 1 for liquids; 1 10^{-2} for all other waste forms)

VOL = Volume of room in which aerosol or ash is dispersed (m^3)
(= 32 m^3)

B3 Disposal (public) scenario

This scenario considers normal and accidental exposure of a member of the public visiting a landfill site. External, inhalation and ingestion pathways are considered. Radioactive decay over 24 hours, the delay between use and disposal, is also considered (see A3).

B3.1 External exposure from a landfill site

The pathway considers a member of the public walking over the landfill site for an annual time considered to be typical of outdoor recreational activities (300 hy^{-1}). When the source is disposed of on the landfill site it may either become diluted by the remaining waste, or remain an isolated source. In both cases the external dose to the individual will be the same.

The doses are calculated from external gamma radiation assuming that the landfill site can be represented by an infinite thick slab geometry.

The average annual effective dose from external radiation from a landfill site is given by:

$$E = C_D \, T \, (GAM \, R_1) \, s$$

where:
- E = Average annual effective dose ($Sv\ y^{-1}$)
- C_D = Diluted activity concentration ($Bq\ g^{-1}$)
- T = Exposure time ($h\ y^{-1}$) (= 300 $h\ y^{-1}$)
- GAM = Effective dose rate 1 m above an infinite thick slab of 1 $Bq\ g^{-1}$, per MeV of gamma energy (($Sv\ h^{-1}$) per ($Bq\ g^{-1}.MeV$)) (= $3\ 10^{-7}$ (($Sv\ h^{-1}$) per ($Bq\ g^{-1}.MeV$)))[7]
- R_1 = The average photon energy per disintegration (MeV)[8]
- s = Probability of exposure occurring in a year (= $1\ 10^{-2}\ y^{-1}$)

The diluted activity concentration is calculated from the source activity in the following manner:

For source activity:

$$C_D = \frac{A}{M} \, DECAY$$

where:
- A = Source activity (1 Bq)
- M = Mass of waste tip (g) (= $1.5\ 10^{10}$ g)[6]

- $DECAY$ = Fraction of radionuclide remaining after 24 hours of radioactive decay (daughters are not considered).

B3.2 Inhalation of dust from a landfill site

This exposure pathway considers two possible routes by which dust may become inhaled by a member of the public from radioactive contaminated material on a landfill site.

The first considers a member of the public walking over a landfill site and accidentally inhaling dust from an undiluted source of 1 g, for a period of 1 h/y.

The second considers a member of the public residing close to a landfill site, where they inhale dust, arising from radioactivity material diluted within 100 kg of soil, for a period of 5000 h/y.

In both cases the doses are the same.

For the first case, the annual committed effective dose is given by:

$$E = \frac{A}{M} \, T \, INH \, R_{10} \, Dust \, s \, DECAY$$

where: E = Average annual committed effective dose ($Sv\ y^{-1}$)
A = Source activity (1 Bq)
M = Mass of source (g)
(= 1 g)
T = Exposure time (h) if exposure occurs
(= 1 h)
INH = Breathing rate ($m^3\ h^{-1}$)
(= 1 $m^3\ h^{-1}$)[11]
R_{10} = Committed effective dose per unit intake for inhalation ($Sv\ Bq^{-1}$)[12]
Dust = Concentration of airborne dust ($g\ m^{-3}$)
(= 1 10^{-3} $g\ m^{-3}$)[7]
s = Probability of exposure occurring in a year
(= 1 10^{-2} y^{-1})
DECAY = Fraction of radionuclide remaining after 24 hours of radioactive decay (daughters not considered)

For the second case, which is not an accidental exposure, the committed effective dose is given by:

$$E = C_D\ T\ INH\ R_{10}\ Dust$$

where: E = Committed effective dose ($Sv\ y^{-1}$)
C_D = Diluted activity concentration ($Bq\ g^{-1}$)
T = Exposure time (h) if contamination occurs
(= 5 10^3 h)
INH = Breathing rate ($m^3\ h^{-1}$)
(= 1 $m^3\ h^{-1}$)[11]
R_{10} = Committed effective dose per unit intake for inhalation ($Sv\ Bq^{-1}$)[12]
Dust = Concentration of airborne dust ($g\ m^{-3}$)
(= 2 10^{-4} $g\ m^{-3}$ (typical outside dust level))

The diluted activity concentration is calculated from the source activity in the following manner:

$$C_D = \frac{A}{M} DECAY$$

where: A = Source activity (1 Bq)
M = Mass of soil in which source is diluted
(= 1 10^5 g)
DECAY = Fraction of radionuclide remaining after 24 hours of radioactive decay (daughters are not considered)

B3.3 External exposure to skin from handling object from a landfill site

It is assumed that a person walking over the landfill site may find an object which may be of interest and pick it up (assumed to be 3 10^1 g for a radioactively contaminated object). The person is then assumed to hold the object or place it in his or her pocket for 8 hours. It is assumed that the source will only be in contact with the palm of the hand or be shielded by clothing and hence a skin thickness of 400 μm is assumed for dose calculations. The doses are calculated using a similar methodology to section B1.2 assuming a dispersable solid source 0.3 cm thick to represent radionuclides from all source forms (except gases). The sources are assumed to have been disposed of in this form, or become mixed with waste of similar properties (eg liquids contaminating soil or other waste objects).

The average annual skin equivalent dose resulting from skin contamination from a radioactive object found on a landfill site is given by:

$$H_{skin} = As\ T\ (R_7 + R_{24})\ s$$

where: H_{skin} = Average annual skin equivalent dose (Sv y^{-1})

As = Activity per unit area (Bq cm^2) if contamination occurs

T = Exposure time (h) if contamination occurs (= 8 h)

R_7 = Skin equivalent dose rate to the basal layer of skin epidermis for gamma irradiation (7 mg cm^{-2})†† (Sv h^{-1} per Bq $cm^{-2})^3$

R_{24} = Skin equivalent dose rate to the basal layer of skin epidermis for beta irradiation (40 mg cm^{-2}) (Sv h^{-1} per Bq $cm^{-2})^2$

s = Probability of exposure occurring in a year (= 1 10^{-2} y^{-1})

The activity per unit area, As, is calculated from the activity using the following method:

$$As = \frac{A}{CONTACT}\ DECAY$$

where: A = Activity of source (1 Bq)

DECAY = Fraction of radionuclide remaining after 24 hours decay (see section B3.2)

CONTACT = Area of skin in contact with source (cm^2)

CONTACT is calculated by dividing the mass of the source by the mass per unit area, assuming the two halves of the source are in contact with the skin.

$$CONTACT = \frac{M}{(\rho\ \frac{t}{2})} = \frac{M}{U}$$

††Assume density of skin is approximately equivalent to that of water, (1 g cm^{-3}).

where: M = Mass of source (g)
(= $3\ 10^{1}$ g for dispersable solids)

ρ = Density of source (g cm^{-3})
(= 1.12 g cm^{-3})[4]

$\frac{t}{2}$ = Half thickness of source (cm)
(= $1.5\ 10^{-1}$ cm)

The effective dose from external radiation from a source is given by:

$$E = H_{skin}\ w_{skin} \frac{CONTACT}{BODY}$$

where: E = Effective dose (Sv y^{-1})

w_{skin} = Tissue weighting factor for skin = $1\ 10^{-2}$[5]

BODY = Total skin area = $1\ 10^{4}\ cm^{2}$

B3.4 Ingestion of an object from a landfill site

A member of the public is assumed to be walking over a landfill site and finds a radioactive source or an object contaminated with radioactivity which has seeped from a source. The individual is then assumed to inadvertently ingest a small fraction, 0.1%, of the source. This scenario also represents the case of a child accidentally swallowing a contaminated object.

The average annual committed effective dose for ingestion of an object found on a landfill site is given by:

For unit activity: $E = A\ R_9\ f\ DECAY$

where: E = Average annual committed effective dose (Sv y^{-1})

A = Activity of source (1 Bq)

R_9 = Committed effective dose per unit intake for ingestion (Sv Bq^{-1})[12]

f = Fraction of source ingested
(= $1\ 10^{-3}$)

DECAY = Fraction of parent radionuclide remaining after 24 hours of radioactive decay (daughters are not considered).

References

1 Charles, M W. The biological bases of radiological protection criteria for superficial, low penetrating radiation exposure. Radiation Protection Dosimetry, 14, No. 2, 79-80 (1986).

2 Kocher, D C, and Eckermann, K F. Electron dose rate conversion factors for external exposure to the skin from uniformly deposited activity on the body surface. Health Physics, 53, No. 2, 135-141 (1987).

3 Chaptinel, Y, Durand, F, Piechowski, J, and Menoux, B. Dosimetry and therapy of skin contamination. Commissariat à l'Energie Atomique, CEA-R-5441 (1988).

4 Tennent, R M. Science Data Book. Edinburgh, Oliver and Boyd, (Tenth publication) (1986).

5 ICRP. Recommendations of the International Commission on Radiological Protection. ICRP Publication 60, Pergamon Press, Oxford (1990).

6 Asselineau, J M, Chapuis, A M, Guetat, Ph, and Renaud, Ph. Determination of radioactivity levels and recommendations for the exemption of radioactive waste arising outside the nuclear fuel cycle. Commissariat à l'Energie Atomique. Final report, 1991.

7 Sumerling, T J, and Sweeney, B J. A review of the justification for exemption orders, and for other low-level radioactive waste disposal practices. DoE/RW/87.069, 2 (1986/1987). (London, HMSO).

8 ICRP. Radionuclide transformations. Energy and intensity of emissions. ICRP Publication 38. Ann. ICRP, 11-13 (1983).

9 Van Den Oever, R, Roosels, D, Douwen, M, Vanderkeel, J, and Lahaye, D. Exposure of diamond polishers to Cobalt. Annals of Occupational Hygiene, 34, No. 6, 609-614 (1990).

10 Hoover, M D, Gregory, L, Finch, G L, Mewhinney, J A, and Eidson, A F. Release of aerosols during sawing and milling of Beryllium metal and Beryllium alloys. App. Occ. Environ. Hyg., 5, No. 11, 787-791 (1990).

11 ICRP - Report on the Task Group on Reference Man. ICRP Publication 23, Pergamon Press, Oxford (1974).

12 Phipps, A W, Kendall, G M, Stather, J W, and Fell, T P. Committed Equivalent Organ Dose and Committed Effective Doses from Intakes of Radionuclides. Chilton, NRPB-R245 (1991) (London, HMSO).

13 IAEA. Explanatory material for the safe transport of radioactive material (1985 Edition) Second Edition. Vienna, IAEA Safety Series No. 7 (1987).

14 Kocher, D C. Dose rate conversion factors for external exposure to photons and electrons. Health Physics, 45, No. 3, 665-686 (1983).

15 Handbook of Radiological Protection Part 1: Data; prepared by panel of the Radioactive Substances Advisory Committee (1971) (London, HMSO).

16 National Radiological Protection Board and the Commissariat à l'Energie Atomique, Methodology for evaluating the radiological consequences of radioactive effluents released in normal operation. Luxembourg, CEC, Doc. No. V/3865/79, (1979).

APPENDIX B

Radionuclide dependent data

This Appendix gives details of the radionuclide dependent data used in the formulae described in Appendix a to calculate doses in the main study.

CONTENTS

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
H-3	LIQUID	0.00E+00	5.68E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.80E-11	1.80E-11	0.00E+00	0.00E+00	1.00E+00
H-3	SOLID											
H-3	GAS VAPOUR											
H-3	FOIL											
Be-7	SOLID	4.94E-02	3.90E-08	1.30E-13	2.98E-09	0.00E+00	0.00E+00	3.30E-11	8.50E-11	4.94E-15	0.00E+00	
C-14	LIQUID	0.00E+00	4.95E-02	0.00E+00	0.00E+00	9.02E-07	0.00E+00	5.60E-10	5.60E-10	0.00E+00	0.00E+00	1.00E+00
C-14	SOLID											
C-14	GAS VAPOUR											
O-15	GAS VAPOUR	1.02E+00	7.34E-01	3.60E-12	5.90E-08			U	U	1.02E-13	2.94E-14	
F-18	LIQUIDS	1.02E+00	2.50E-01	3.20E-12	5.90E-08	2.63E-06	5.25E-07	4.70E-11	2.40E-11	1.02E-13	1.00E-15	
F-18	SOLIDS											
Na-22	LIQUIDS	2.19E+00	1.94E-01	6.54E-12	1.20E-07	2.40E-06	3.77E-07	3.00E-09	2.00E-09	2.42E-13	3.52E-16	
Na-22	SOLIDS											
Na-24	LIQUIDS	4.12E+00	5.53E-01	1.13E-11	1.80E-07	2.77E-06	8.85E-07	4.20E-10	3.20E-10	4.12E-13	2.21E-14	
*Si-31	LIQUIDS	8.86E-04	5.95E-01	2.46E-13	5.32E-11	2.98E-06	9.52E-07	1.30E-10	5.90E-11	8.86E-17	2.38E-14	
*Si-31	SOLIDS											
P-32	LIQUIDS	0.00E+00	6.95E-01	2.94E-13	0.00E+00	2.74E-06	1.20E-06	2.60E-09	4.30E-09	0.00E+00	2.70E-14	
P-32	SOLIDS											
*P33U	LIQUIDS	0.00E+00	7.66E-02	0.00E+00	0.00E+00	1.60E-06	2.85E-09	2.50E-10	5.00E-10	0.00E+00	7.66E-19	
*P33U	SOLIDS											
S-35	LIQUIDS	0.00E+00	4.88E-02	0.00E+00	0.00E+00	9.02E-07	0.00E+00	3.00E-10	6.80E-10	0.00E+00	0.00E+00	1.00E-03
S-35	SOLIDS											
Cl-36	LIQUIDS	1.52E-04	2.74E-01	2.55E-14	1.10E-11	2.51E-06	5.30E-07	8.40E-10	6.00E-09	1.73E-17	2.21E-15	1.00E+00
Cl-36	SOLIDS											
*Cl-38	LIQUIDS	1.49E+00	1.53E+00	4.58E-12	6.90E-08	7.65E-06	2.45E-06	1.20E-10	4.20E-11	1.49E-13	6.12E-14	1.00E+00
*Cl-38	SOLIDS											
Ar-37	GAS VAPOUR	2.27E-04	1.97E-03	2.72E-17	1.36E-11			0.00E+00	0.00E+00	2.27E-17	0.00E+00	
Ar-41	GAS VAPOUR	1.28E+00	4.64E-01	3.78E-12	7.68E-08			0.00E+00	0.00E+00	1.28E-13	1.86E-14	
*K-40	SOLID	1.56E-01	5.23E-01	6.00E-13	8.00E-09	2.40E-06	9.50E-07	5.00E-09	3.30E-09	1.56E-14	2.12E-14	
K-42	SOLIDS	2.76E-01	1.43E+00	1.25E-12	1.40E-08	7.15E-06	2.29E-06	4.00E-10	3.80E-10	2.76E-14	5.72E-14	
*K-43	LIQUIDS	9.69E-01	3.09E-01	3.21E-12	5.60E-08	2.30E-06	6.18E-07	2.30E-10	1.90E-10	9.69E-14	1.24E-14	
*K-43	SOLIDS											
Ca-45	SOLIDS	4.36E-06	7.72E-02	7.24E-22	2.10E-13	1.60E-06	3.65E-09	8.90E-10	1.80E-09	6.28E-21	0.00E+00	
Ca-47	LIQUIDS	1.06E+00	3.45E-01	3.09E-12	5.50E-08	2.30E-06	6.90E-07	2.20E-09	1.90E-09	1.06E-13	1.36E-14	
	SOLIDS											
Sc-46	LIQUIDS	2.01E+00	1.12E-01	8.05E-12	1.21E-07	1.94E-06	8.28E-06	2.00E-09	6.00E-09	2.01E-13	1.00E-17	
Sc-46	SOLIDS											
*Sc-47	LIQUIDS	1.08E-01	1.62E-01	3.94E-13	5.60E-09	1.62E-06	3.24E-07	8.60E-10	6.00E-10	1.08E-14	1.62E-18	
*Sc-47	SOLIDS											
*Sc-48	LIQUIDS	3.35E+00	2.29E-01	9.87E-12	1.68E-07	2.30E-06	4.58E-07	2.10E-09	1.20E-09	3.35E-13	2.29E-16	
*Sc-48	SOLIDS											

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
*V-48	LIQUIDS	9.94E-01	8.03E-01	6.66E-12	5.96E-08	4.00E-06	1.28E-06	2.60E-09	2.90E-09	9.94E-14	3.21E-14	
*V-48	SOLIDS											
Cr-51	LIQUIDS	3.15E-02	3.86E-03	1.07E-13	1.50E-08	0.00E+00	0.00E+00	5.30E-11	9.80E-11	3.57E-15	0.00E+00	
Cr-51	SOLIDS											
*Mn-51U	LIQUIDS	9.94E-01	9.34E-01	2.98E-12	5.96E-08	4.67E-06	1.49E-06	7.10E-11	2.50E-11	9.94E-14	3.74E-14	
*Mn-51U	SOLIDS											
*Mn-52	LIQUIDS	3.44E+00	7.46E-02	1.03E-11	1.90E-07	7.46E-07	1.49E-07	2.10E-09	1.60E-09	3.44E-13	7.46E-19	
*Mn-52	SOLIDS											
*Mn-52m	LIQUIDS	2.41E+00	1.13E+00	7.54E-12	1.30E-07	5.65E-06	1.81E-06	7.00E-11	2.00E-11	2.41E-13	4.52E-14	
*Mn-52m	SOLIDS											
*Mn-53U	LIQUIDS	1.39E-03	4.01E-03	5.46E-16	8.34E-11	0.00E+00	0.00E+00	2.50E-11	1.25E-10	1.39E-16	0.00E+00	
*Mn-53U	SOLIDS											
Mn-54	LIQUIDS	8.36E-01	4.22E-03	2.63E-12	6.10E-08	0.00E+00	0.00E+00	7.30E-10	1.70E-09	8.36E-14	0.00E+00	
Mn-56	LIQUIDS	1.69E+00	8.29E-01	5.31E-12	1.01E-07	4.15E-06	1.33E-06	2.30E-10	9.80E-11	1.69E-13	3.32E-14	
Mn-56	SOLIDS											
Fe-52	LIQUIDS	7.40E-01	1.93E-01	2.46E-12	4.44E-08	1.93E-06	3.86E-07	1.50E-09	3.20E-09	7.40E-14	1.00E-17	
Fe-55	FOIL	0.00E+00	4.20E-03	7.65E-16	1.60E-08	0.00E+00	0.00E+00	4.00E-10	6.40E-10	1.51E-16	0.00E+00	
Fe-59	LIQUIDS	1.19E+00	1.17E-01	3.44E-12	6.20E-08	1.17E-06	1.07E-07	3.10E-09	3.80E-09	1.29E-13	5.45E-17	
*Co-55U	LIQUIDS	1.99E+00	4.29E-01	5.97E-12	1.19E-07	2.30E-06	8.56E-07	1.25E-09	5.00E-10	1.99E-13	1.72E-14	
*Co-55U	SOLIDS											
Co-56	LIQUIDS	3.56E+00	1.24E-01	1.03E-11	1.70E-07	1.24E-06	2.48E-07	2.50E-08	1.90E-08	3.56E-13	1.00E-17	
Co-57	LIQUIDS	1.25E-01	1.86E-02	4.47E-13	4.00E-08	1.10E-07	0.00E+00	3.50E-09	2.60E-09	1.25E-14	0.00E+00	
Co-57	SOLIDS											
Co-58	LIQUIDS	9.75E-01	3.41E-02	3.06E-12	7.00E-08	4.11E-07	5.02E-08	6.80E-09	6.70E-08	1.10E-13	1.64E-17	
Co-58	SOLIDS											
*Co-58m	LIQUIDS	2.02E-03	2.28E-02	1.23E-15	1.50E-08	2.28E-07	0.00E+00	4.60E-11	3.30E-11	2.02E-16	0.00E+00	
*Co-58m	SOLIDS											
Co-60	LIQUID	2.50E+00	9.85E-02	7.10E-12	1.30E-07	1.83E-06	2.85E-08	9.20E-08	6.90E-08	2.71E-13	2.06E-17	
Co-60	CAPSULE											
*Co-60m	LIQUID	6.86E-03	5.78E-02	1.55E-14	7.00E-08	5.78E-07	1.20E-07	2.00E-12	6.80E-13	6.86E-16	5.78E-19	
*Co-60m	SOLIDS											
*Co-61U	LIQUID	9.06E-02	4.62E-01	4.86E-13	5.44E-09	2.30E-06	9.24E-07	7.10E-11	2.50E-11	9.06E-15	1.85E-14	
*Co-61U	SOLIDS											
*Co-62mU	LIQUID	2.70E+00	1.05E+00	8.10E-12	1.35E-07	5.25E-06	1.68E-06	5.00E-11	8.30E-12	2.70E-13	4.20E-14	
*Co-62mU	SOLIDS											
*Ni-59	LIQUID	2.41E-03	4.55E-03	1.44E-15	1.45E-10	0.00E+00	0.00E+00	6.80E-11	7.30E-10	2.41E-16	0.00E+00	
*Ni-59	SOLIDS											
Ni-63	FOIL	0.00E+00	1.71E-02	0.00E+00	0.00E+00	1.83E-08	0.00E+00	1.90E-10	1.70E-09	0.00E+00	0.00E+00	
*Ni-65	LIQUID	5.49E-01	6.32E-01	1.78E-12	3.29E-08	3.16E-08	1.01E-08	1.50E-10	9.20E-11	5.49E-14	2.53E 14	
*Ni-65	SOLIDS											

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Svh per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Svh per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
Cu-64	LIQUIDS	1.91E-01	1.23E-01	8.13E-13	1.90E-08	1.23E-06	2.46E-07	1.40E-10	8.00E-11	1.91E-14	1.00E-17	
Cu-64	SOLIDS											
Zn-65	LIQUIDS	5.81E-01	6.87E-03	1.71E-12	5.00E-08	3.77E-08	1.14E-09	3.80E-09	5.30E-09	5.81E-14	0.00E+00	
Zn-65	SOLIDS											
*Zn-69	LIQUIDS	6.00E-06	3.21E-01	7.13E-14	3.60E-13	2.30E-06	6.42E-07	3.00E-11	1.10E-11	6.00E-19	1.28E-14	
*Zn-69	SOLIDS											
Zn-69m	LIQUIDS	4.16E-01	2.23E-02	1.37E-12	2.50E-08	2.23E-07	4.46E-08	4.20E-10	2.40E-10	4.16E-14	0.00E+00	
Ga-72	LIQUIDS	2.68E+00	4.95E-01	8.09E-12	1.34E-07	2.30E-06	9.90E-07	1.30E-09	5.30E-10	2.68E-13	1.98E-14	
Ga-72	SOLIDS											
*Ge-71	LIQUIDS	4.18E-03	4.95E-03	4.04E-15	2.51E-10	0.00E+00	0.00E+00	2.70E-12	3.30E-11	4.18E-16	0.00E+00	
*Ge-71	SOLIDS											
*As-73	LIQUIDS	1.61E-02	8.03E-02	3.15E-14	9.66E-10	8.03E-07	1.21E-07	2.60E-10	9.60E-10	1.61E-15	8.03E-19	
*As-73	SOLIDS											
As-74	LIQUIDS	7.58E-01	2.68E-01	2.54E-12	4.55E-08	2.30E-06	5.36E-07	1.40E-09	2.30E-09	7.58E-14	1.00E-15	
As-74	SOLIDS											
*As-76	LIQUIDS	4.27E-01	1.06E+00	1.74E-12	7.00E-08	5.30E-06	1.70E-06	1.90E-09	1.10E-09	4.27E-14	4.24E-14	
*As-76	SOLIDS											
*As-77	LIQUIDS	8.77E-03	2.28E-01	4.83E-14	5.26E-10	2.30E-06	4.56E-07	4.80E-10	3.20E-10	8.77E-16	2.28E-16	
*As-77	SOLIDS											
Se-75	LIQUIDS	3.88E-01	1.44E-02	1.35E-12	4.20E-08	1.71E-07	3.31E-09	2.10E-09	2.00E-09	3.88E-14	0.00E+00	
Se-75	SOLIDS											
Br-82	LIQUIDS	2.63E+00	1.38E-01	8.12E-12	1.50E-07	1.38E-06	2.76E-07	4.80E-10	4.10E-10	2.63E-13	1.00E-17	
Br-82	SOLIDS											
*Kr-74	GAS VAPOUR	1.15E+00	7.85E-01	3.45E-12				0.00E+00	0.00E+00		7.85E-16	
*Kr-76	GAS VAPOUR	4.31E-01	1.50E-02	1.29E-12				0.00E+00	0.00E+00			
*Kr-77	GAS VAPOUR	1.01E+00	6.37E-01	3.03E-12				0.00E+00	0.00E+00			
*Kr-79	GAS VAPOUR	2.56E-01	2.42E-02	6.30E-13				0.00E+00	0.00E+00			
*Kr-81	GAS VAPOUR	1.18E-02	5.13E-03	4.30E-14				0.00E+00	0.00E+00			
*Kr-83m	GAS VAPOUR	2.68E-03	3.87E-02	3.84E-15				0.00E+00	0.00E+00			
Kr-85	GAS VAPOUR	2.12E-03	2.50E-01	3.64E-14				0.00E+00	0.00E+00		1.00E-15	
*Kr-85m	GAS VAPOUR	1.58E-01	2.55E-01	6.04E-13				0.00E+00	0.00E+00			
*Kr-87	GAS VAPOUR	7.90E-01	1.32E+00	2.77E-12				0.00E+00	0.00E+00			
*Kr-88	GAS VAPOUR	1.92E+00	3.81E-01	5.60E-12				0.00E+00	0.00E+00			
Rb-86	LIQUIDS	9.45E-02	6.68E-01	5.57E-13	5.10E-09	2.63E-06	1.14E-06	2.50E-09	1.70E-09	9.45E-15	2.67E-14	
Rb-86	SOLIDS											
*Sr-90+U	LIQUIDS	1.25E+00	2.01E+00	3.75E-12	7.50E-08	1.01E-05	3.22E-06	1.25E-12	6.30E-13	1.25E-13	8.04E-14	
*Sr-90+U	SOLIDS											
*Sr-91U	LIQUIDS	1.38E+00	9.98E-01	4.14E-12	8.28E-08	4.98E-06	1.59E-06	5.60E-11	1.70E-11	1.38E-13	3.98E-14	

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Svh per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Svh per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
*Sr-81U	SOLIDS											
*Sr-83U	LIQUIDS	7.79E-01	1.49E-01	2.34E-12	4.67E-08	1.49E-06	2.98E-07	8.30E-10	5.00E-10	7.79E-14	1.00E-17	
*Sr-83U	SOLIDS											
Sr-85	LIQUIDS	5.11E-01	8.97E-03	1.66E-12	4.70E-08	1.71E-08	8.33E-09	5.30E-10	1.30E-09	5.11E-14	0.00E+00	
Sr-85	SOLIDS											
Sr-85m	LIQUIDS	2.19E-01	1.22E-02	7.49E-13	1.31E-08	1.22E-07	2.44E-08	5.80E-12	2.20E-12	2.19E-14	0.00E+00	
Sr-87m	LIQUIDS	3.20E-01	6.69E-02	1.05E-12	1.92E-08	6.69E-07	1.34E-07	3.00E-11	1.10E-11	3.20E-14	1.00E-17	
Sr-89	LIQUIDS	8.45E-05	5.83E-01	2.43E-13	4.70E-12	2.63E-06	1.12E-06	3.80E-09	1.20E-08	9.60E-18	2.20E-14	
Sr-89	SOLIDS											
Sr-90+	LIQUIDS	1.69E-06	1.13E+00	3.88E-13	2.40E-12	5.14E-06	1.76E-06	2.80E-08	3.50E-07	3.95E-19	3.82E-14	
Sr-90+	SOLIDS											
Sr-90+	FOIL											
*Sr-91	LIQUIDS	6.93E-01	6.55E-01	2.36E-12	4.16E-08	2.63E-06	1.08E-06	9.10E-10	4.70E-10	6.93E-14	2.62E-14	
*Sr-91	SOLIDS											
*Sr-92	LIQUIDS	1.34E+00	1.96E-01	3.75E-12	6.04E-08	1.96E-08	3.92E-07	5.10E-10	2.10E-10	1.34E-13	7.84E-15	
*Sr-92	SOLIDS											
Y-90	LIQUIDS	1.69E-06	9.35E-01	3.83E-13	2.40E-12	2.74E-06	1.37E-06	4.20E-09	2.80E-09	1.69E-19	3.74E-14	
Y-90	SOLIDS											
*Y-91	LIQUIDS	3.61E-03	6.02E-01	2.63E-13	1.90E-10	2.63E-06	1.13E-06	4.00E-09	1.40E-08	3.61E-16	2.41E-14	
*Y-91	SOLIDS											
*Y-91m	LIQUIDS	5.30E-01	2.73E-02	1.72E-12	3.16E-08	2.73E-07	0.00E+00	1.20E-11	2.30E-09	5.30E-14	0.00E+00	
*Y-91m	SOLIDS											
*Y-92	LIQUIDS	2.51E-01	1.44E+00	1.25E-12	1.51E-08	7.20E-06	2.30E-06	4.70E-10	2.10E-10	2.51E-14	5.76E-14	
*Y-92	SOLIDS											
*Y-93	LIQUIDS	6.89E-02	1.17E+00	7.10E-13	5.33E-09	5.85E-06	1.87E-06	1.40E-09	6.20E-10	6.89E-15	4.68E-14	
*Y-93	SOLIDS											
*Zr-86U	LIQUIDS	2.88E-01	3.01E-02	9.68E-13	1.73E-08	3.01E-07	0.00E+00	1.00E-09	5.55E-10	2.88E-14	0.00E+00	
*Zr-86U	SOLIDS											
*Zr-88U	LIQUIDS	4.02E-01	1.62E-02	1.28E-12	2.41E-08	1.62E-07	0.00E+00	5.00E-10	6.30E-09	4.02E-14	0.00E+00	
*Zr-88U	SOLIDS											
*Zr-89U	LIQUIDS	1.16E+00	1.01E-01	3.65E-12	6.96E-08	1.01E-06	2.02E-07	8.30E-10	5.60E-10	1.16E-13	1.00E-17	
*Zr-89U	SOLIDS											
*Zr-93+	LIQUIDS	1.91E-03	4.80E-02	3.39E-15	1.15E-10	4.80E-07	0.00E+00	1.21E-09	5.09E-08	1.91E-16	0.00E+00	
*Zr-93+	SOLIDS											
Zr-95	LIQUIDS	7.39E-01	1.16E-01	2.34E-12	4.20E-08	1.94E-06	6.45E-06	1.30E-09	4.20E-09	7.39E-14	1.00E-17	
Zr-95	SOLIDS											
*Zr-97+	LIQUIDS	8.31E-01	6.99E-01	3.12E-12	4.99E-08	3.50E-06	1.12E-06	2.88E-09	1.32E-09	8.31E-14	2.80E-14	
*Zr-97+	SOLIDS											
*Nb-88U	LIQUIDS	4.12E+00	1.23E+00	1.24E-11	2.08E-07	6.15E-06	1.97E-06	2.50E-11	6.30E-12	4.12E-13	4.92E-14	
*Nb-88U	SOLIDS											
*Nb-89(66)U	LIQUIDS	1.92E+00	8.31E-01	5.76E-12	1.15E-07	4.16E-06	1.33E-06	1.25E-10	5.00E-11	1.92E-13	3.32E-14	
*Nb-89(66)U	SOLIDS											

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
*Nb-89(122)U	LIQUIDS	1.37E+00	1.11E+00	4.11E-12	8.22E-08	5.55E-06	1.78E-06	2.50E-10	8.30E-11	1.37E-13	4.44E-14	
*Nb-89(122)U	SOLIDS											
*Nb-90U	LIQUIDS	4.20E+00	4.02E-01	1.22E-11	2.10E-07	2.30E-06	8.04E-07	1.30E-09	5.60E-10	4.20E-13	1.61E-14	
*Nb-90U	SOLIDS											
*Nb-93m	LIQUIDS	1.91E-03	2.84E-02	3.39E-15	1.15E-10	0.00E+00	0.00E+00	2.10E-10	7.90E-09	1.91E-16	0.00E+00	
*Nb-93m	SOLIDS											
*Nb-94	LIQUIDS	1.57E+00	1.68E-01	4.97E-12	9.42E-08	2.17E-06	1.83E-07	2.30E-09	1.10E-07	1.57E-13	1.00E-17	
*Nb-94	SOLIDS											
*Nb-95mU	LIQUIDS	6.83E-02	1.66E-01	2.26E-13	4.10E-09	2.17E-06	1.83E-07	6.25E-10	6.25E-10	6.83E-15	1.00E-17	
*Nb-95mU	SOLIDS											
Nb-95	LIQUIDS	7.66E-01	4.44E-02	2.42E-12	4.30E-08	7.31E-07	2.05E-09	7.70E-10	1.60E-09	7.66E-14	0.00E+00	
Nb-95	SOLIDS											
*Nb-96U	LIQUIDS	2.74E+00	2.51E-01	7.68E-12	1.37E-07	2.30E-06	5.02E-07	1.25E-09	5.60E-10	2.74E-13	1.00E-15	
*Nb-96U	SOLIDS											
*Nb-97	LIQUIDS	6.52E-01	4.67E-01	2.29E-12	3.91E-08	2.63E-06	9.62E-07	6.40E-11	2.30E-11	6.52E-14	1.87E-14	
*Nb-97	SOLIDS											
*Nb-98	LIQUIDS	2.43E+00	8.84E-01	7.29E-12	1.46E-07	4.42E-06	1.41E-06	1.10E-10	3.30E-11	7.66E-14	3.54E-14	
*Nb-98	SOLIDS											
*Mo-90	LIQUIDS	8.26E-01	2.03E-01	2.48E-12	4.96E-08	2.30E-06	4.06E-07	7.60E-10	3.50E-10	6.26E-14	1.00E-15	
*Mo-90	SOLIDS											
*Mo-93	LIQUIDS	1.07E-02	5.54E-03	1.89E-14	8.42E-10	0.00E+00	0.00E+00	2.60E-10	3.50E-10	1.07E-15	0.00E+00	
*Mo-93	SOLIDS											
*Mo-93mU	LIQUIDS	2.25E+00	9.65E-02	6.75E-12	1.13E-07	9.65E-07	1.93E-07	2.50E-10	1.00E-10	2.25E-13	1.00E-17	
*Mo-93mU	SOLIDS											
Mo-99	LIQUIDS	1.50E-01	3.91E-01	6.26E-13	9.10E-09	2.63E-06	8.11E-07	1.90E-09	1.30E-09	1.50E-14	1.56E-14	
Mo-99	SOLIDS											
*Mo-101	LIQUIDS	1.32E+00	5.83E-01	4.62E-12	7.92E-08	2.92E-06	9.33E-07	4.30E-11	1.30E-11	1.32E-13	2.33E-14	
*Mo-101	SOLIDS											
*Tc-96	LIQUIDS	2.49E+00	6.75E-03	7.84E-12	1.49E-07	8.75E-08	0.00E+00	8.50E-10	6.90E-10	2.49E-13	0.00E+00	
*Tc-96	SOLIDS											
*Tc-96m	LIQUIDS	5.11E-02	2.72E-02	1.36E-13	3.07E-09	2.72E-07	0.00E+00	1.00E-11	6.80E-12	5.11E-15	0.00E+00	
*Tc-96m	SOLIDS											
*Tc-97	LIQUIDS	1.14E-02	5.57E-03	2.09E-14	6.84E-10	5.57E-08	0.00E+00	7.30E-11	2.80E-10	1.14E-15	0.00E+00	
*Tc-97	SOLIDS											
*Tc-97m	LIQUIDS	9.59E-03	8.68E-02	1.80E-14	5.75E-10	8.68E-07	1.74E-07	5.70E-10	1.50E-09	9.59E-16	1.00E-17	
*Tc-97m	SOLIDS											
*Tc-99	LIQUIDS	0.00E+00	1.01E-01	1.95E-16	0.00E+00	1.60E-06	1.37E-06	6.70E-10	2.40E-09	0.00E+00	1.00E-17	
*Tc-99	SOLIDS											
Tc-99m	LIQUIDS	1.26E-01	1.62E-02	4.61E-13	7.70E-09	3.31E-07	0.00E+00	2.10E-11	1.10E-11	1.26E-14	0.00E+00	
Tc-99m	SOLIDS											
*Ru-97	LIQUIDS	2.39E-01	1.33E-02	8.06E-13	1.43E-08	1.33E-07	0.00E+00	2.00E-10	1.30E-10	2.39E-14	0.00E+00	
*Ru-97	SOLIDS											

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
Ru-103	LIQUIDS	4.69E-01	7.45E-02	1.56E-12	2.70E-08	1.26E-06	2.40E-08	1.10E-09	1.90E-08	4.69E-14	1.00E-17	
*Ru-105	LIQUIDS	7.75E-01	3.97E-01	2.64E-12	4.65E-08	2.63E-06	8.68E-07	2.90E-10	1.30E-10	7.75E-14	1.59E-14	
*Ru-105	SOLIDS											
Ru-106+	SOLIDS	2.00E-01	1.41E+00	1.15E-12	1.20E-08	2.85E-06	1.80E-06	1.10E-08	1.30E-07	2.26E-14	9.62E-14	
Ru-106+	LIQUIDS											
*Rh-103m	LIQUIDS	1.75E-03	3.80E-02	3.69E-15	1.60E-09	0.00E+00	0.00E+00	3.70E-12	1.40E-12	1.75E-16	0.00E+00	
*Rh-103m	SOLIDS											
*Rh-105	LIQUIDS	7.76E-02	1.53E-01	2.64E-13	4.68E-09	2.05E-06	2.40E-07	5.40E-10	3.10E-10	7.76E-15	1.00E-17	
*Rh-105	SOLIDS											
*Pd-103	LIQUIDS	1.45E-02	5.87E-03	3.27E-14	8.70E-10	0.00E+00	0.00E+00	3.10E-10	4.70E-10	1.45E-15	0.00E+00	
*Pd-103	SOLIDS											
*Pd-109	LIQUIDS	1.17E-02	4.37E-01	1.03E-13	7.02E-10	2.30E-06	8.74E-07	7.20E-10	3.30E-10	1.17E-15	1.75E-14	
*Pd-109	SOLIDS											
*Ag-105	LIQUIDS	5.23E-01	1.89E-02	1.57E-12	3.14E-08	1.89E-07	0.00E+00	5.80E-10	1.20E-09	5.23E-14	0.00E+00	
*Ag-105	SOLIDS											
*Ag-108m+	LIQUIDS	1.62E+00	7.00E-02	5.21E-12	1.00E-07	2.76E-07	1.15E-07	2.10E-09	7.10E-08	1.62E-13	1.00E-17	
*Ag-108m+	SOLIDS											
Ag-110m	LIQUIDS	2.74E+00	7.13E-02	8.37E-12	1.50E-07	7.88E-07	8.22E-08	3.00E-09	2.10E-08	2.74E-13	1.00E-17	
Ag-110m	SOLIDS											
Ag-111	LIQUIDS	2.63E-02	3.54E-01	1.82E-13	1.50E-09	2.30E-06	7.08E-07	2.00E-09	1.90E-09	2.63E-15	1.42E-14	
Ag-111	SOLIDS											
Cd-109	FOIL	3.16E-03	8.27E-02	3.03E-14	1.70E-08	0.00E+00	0.00E+00	2.20E-09	1.60E-08	5.85E-15	0.00E+00	
*Cd-115	LIQUIDS	2.32E-01	3.02E-01	7.35E-13	1.39E-08	2.30E-06	6.04E-07	2.10E-09	1.40E-09	2.32E-14	1.21E-14	
*Cd-115	SOLIDS											
*Cd-115m	LIQUIDS	2.19E-02	6.08E-01	3.15E-13	1.31E-09	2.63E-06	1.13E-06	4.60E-09	1.20E-08	2.19E-15	2.42E-14	
*Cd-115m	SOLIDS											
In-111	LIQUIDS	3.86E-01	3.44E-02	1.38E-12	3.40E-08	4.80E-07	1.26E-06	3.90E-10	2.40E-10	4.54E-14	0.00E+00	
In-111	SOLIDS											
In-113m	LIQUIDS	2.57E-01	1.34E-01	6.52E-13	1.80E-08	9.59E-07	4.00E-07	2.60E-11	1.10E-11	2.57E-14	1.00E-17	
In-113m	SOLIDS											
*In-114m	LIQUIDS	9.42E-02	1.42E-01	3.07E-13	5.65E-09	1.42E-06	2.84E-07	6.40E-09	1.90E-08	9.42E-15	1.00E-17	
*In-114m	SOLIDS											
*In-115m	LIQUIDS	1.61E-01	1.72E-01	5.44E-13	9.66E-09	1.72E-06	3.44E-07	8.60E-11	3.40E-11	1.61E-14	1.00E-17	
*In-115m	SOLIDS											
*Sn-113	LIQUIDS	2.26E-02	6.35E-03	4.81E-14	1.20E-08	0.00E+00	0.00E+00	1.20E-09	3.00E-09	2.26E-15	0.00E+00	
*Sn-113	SOLIDS											
*Sn-125	LIQUIDS	3.11E-01	6.10E-01	1.23E-12	1.87E-08	4.05E-06	1.30E-06	5.00E-09	4.80E-09	3.11E-14	3.24E-14	
*Sn-125	SOLIDS											
Sb-122	LIQUIDS	4.40E-01	5.64E-01	1.64E-12	2.64E-08	2.82E-06	9.02E-07	2.80E-09	1.70E-09	4.40E-14	2.26E-14	
Sb-122	CAPSULE											
Sb-124	LIQUIDS	1.80E+00	3.64E-01	5.62E-12	9.50E-08	2.40E-06	6.28E-07	3.60E-09	5.10E-08	1.80E-13	1.54E-14	

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
Sb-124	SOLIDS											
Sb-125	LIQUIDS	4.17E-01	9.93E-02	1.38E-12	3.10E-06	1.37E-06	8.45E-06	9.80E-10	3.40E-09	4.17E-14	1.00E-17	
Sb-125	SOLIDS											
*Te-116U	LIQUIDS	7.30E-02	5.28E-02	2.19E-13	4.38E-09			1.87E-10	8.25E-11			
*Te-116U	SOLIDS											
*Te-121U	LIQUIDS	5.77E-01	9.95E-03	1.82E-12	3.46E-06			5.00E-10	5.00E-10			
*Te-121U	SOLIDS											
*Te-121mU	LIQUIDS	2.16E-01	7.95E-02	7.15E-13	1.30E-06			2.50E-09	7.10E-09		1.00E-17	
*Te-121mU	SOLIDS											
*Te-123U	LIQUIDS	1.98E-02	6.33E-03	2.26E-14	1.19E-09			2.50E-09	7.10E-09		0.00E+00	
*Te-123U	SOLIDS											
*Te-123m	LIQUIDS	1.48E-01	9.92E-02	5.08E-13	1.20E-06	2.28E-06	0.00E+00	1.20E-09	2.50E-09	1.48E-14	1.00E-17	
*Te-123m	SOLIDS											
*Te-125m	LIQUIDS	1.12E-02	8.21E-02	8.65E-14	1.80E-06	2.97E-06	0.00E+00	9.50E-10	1.80E-09	1.12E-15	1.00E-17	
*Te-125m	SOLIDS											
*Te-127	LIQUIDS	4.86E-03	2.23E-01	3.45E-14	2.90E-10	2.40E-06	4.57E-07	2.10E-10	9.10E-11	4.86E-16	1.00E-15	
*Te-127	SOLIDS											
*Te-127m	LIQUIDS	1.12E-02	8.21E-02	2.19E-14	6.72E-10	1.83E-06	1.07E-06	2.40E-09	5.70E-09	1.12E-15	1.00E-17	
*Te-127m	SOLIDS											
*Te-129	LIQUIDS	5.91E-02	5.43E-01	3.82E-13	3.55E-09	2.63E-06	1.04E-06	6.00E-11	2.50E-11	5.91E-15	2.17E-14	
*Te-129	SOLIDS											
*Te-129m	LIQUIDS	3.75E-02	2.60E-01	2.02E-13	2.25E-09	2.63E-06	4.00E-07	3.90E-09	6.80E-09	3.75E-15	1.00E-15	
*Te-129m	SOLIDS											
*Te-131	LIQUIDS	4.15E-01	7.15E-01	1.64E-12	2.40E-06	3.20E-06	1.14E-06	9.00E-11	4.30E-11	4.15E-14	2.86E-14	
*Te-131	SOLIDS											
*Te-131m	LIQUIDS	1.37E+00	1.95E-01	4.42E-12	8.22E-06	2.51E-06	1.94E-07	3.40E-09	2.40E-09	1.37E-13	1.00E-17	
*Te-131m	SOLIDS											
Te-132	LIQUIDS	2.30E-01	1.02E-01	7.73E-13	2.20E-06	1.48E-06	5.37E-09	3.50E-09	3.50E-09	2.30E-14	1.00E-17	
Te-132	SOLIDS											
*Te-133	LIQUIDS	9.26E-01	8.16E-01	3.19E-12	5.56E-06	4.06E-06	1.31E-06	7.40E-11	3.50E-11	9.26E-14	3.26E-14	
*Te-133	SOLIDS											
*Te-133m	LIQUIDS	2.28E+00	6.88E-01	7.13E-12	1.37E-07	3.44E-06	1.10E-06	3.00E-10	1.60E-10	2.28E-13	2.75E-14	
*Te-133m	SOLIDS											
*Te-134	LIQUIDS	8.64E-01	2.96E-01	2.84E-12	5.30E-06	1.48E-06	5.92E-07	8.70E-11	3.60E-11	8.64E-14	1.00E-15	
*Te-134	SOLIDS											
*I-120U	LIQUIDS	2.70E+00	1.42E+00	8.10E-12	1.35E-07			5.00E-10	1.70E-10			
*I-120U	SOLIDS											
*I-120mU	LIQUIDS	5.28E+00	1.24E+00	1.58E-11	2.64E-07			1.25E-10	6.30E-11			
*I-120mU	SOLIDS											
*I-121U	LIQUIDS	4.12E-01	8.20E-02	1.24E-12	2.47E-06			1.25E-10	7.10E-11			
*I-121U	SOLIDS											
I-123	LIQUIDS	1.47E-01	2.80E-02	5.73E-13	2.00E-06	4.91E-07	0.00E+00	2.10E-10	1.10E-10	1.99E-14	0.00E+00	1.00E-01

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
I-123	SOLIDS											
*I-124U	LIQUIDS	1.08E+00	1.93E-01	3.32E-12	6.48E-08			2.50E-08	1.67E-08			
*I-124U	SOLIDS											
I-125	LIQUIDS	4.20E-02	1.94E-02	7.83E-14	2.10E-08	0.00E+00	0.00E+00	1.50E-08	9.60E-09	8.08E-15	0.00E+00	1.00E-01
I-125	SOLIDS											
*I-126	LIQUIDS	4.54E-01	1.57E-01	1.52E-12	2.72E-08	1.57E-06	3.14E-07	2.90E-08	1.80E-08	4.54E-14	1.00E-17	1.00E-01
*I-126	SOLIDS											
*I-128U	LIQUIDS	8.49E-02	7.47E-01	5.60E-13	5.09E-09			2.50E-11	1.25E-11			
*I-128U	SOLIDS											
*I-129	LIQUIDS	2.46E-02	6.38E-02	6.93E-14	9.70E-09	6.51E-07	0.00E+00	1.10E-07	6.70E-08	2.46E-15	1.00E-17	1.00E-01
*I-129	SOLIDS											
*I-130	LIQUIDS	2.13E+00	2.95E-01	6.65E-12	1.28E-07	1.48E-06	5.90E-07	1.90E-09	1.00E-09	2.13E-13	1.00E-15	1.00E-01
*I-130	SOLIDS											
I-131	LIQUIDS	3.08E-01	1.90E-01	1.27E-12	2.20E-08	2.40E-06	3.42E-07	2.20E-08	1.30E-08	4.19E-14	8.44E-16	1.00E-01
I-131	SOLIDS											
I-132	LIQUIDS	2.24E+00	4.89E-01	7.32E-12	1.30E-07	2.63E-06	9.36E-07	2.70E-10	1.30E-10	2.24E-13	1.98E-14	1.00E-01
I-132	SOLIDS											
*I-132mU	LIQUIDS	3.21E-01	1.58E-01	9.63E-13	1.93E-08			5.00E-10	1.67E-10		1.00E-17	
*I-132mU	SOLIDS											
*I-133	LIQUIDS	6.02E-01	4.09E-01	2.08E-12	3.61E-08	2.63E-06	8.68E-07	4.20E-09	2.30E-09	6.02E-14	1.64E-14	1.00E-01
*I-133	SOLIDS											
*I-134	LIQUIDS	2.57E+00	6.18E-01	8.30E-12	1.54E-07	2.74E-06	1.11E-06	1.00E-10	4.30E-11	2.57E-13	2.46E-14	1.00E-01
*I-134	SOLIDS											
*I-135	LIQUIDS	1.55E+00	3.64E-01	4.63E-12	9.30E-08	2.51E-06	7.42E-07	9.00E-10	4.80E-10	1.55E-13	1.46E-14	1.00E-01
*I-135	SOLIDS											
*Xe-131mU	GAS VAPOUR	2.00E-02	1.44E-01	5.76E-14	1.20E-09			0.00E+00	0.00E+00		1.00E-17	
Xe-133U	GAS VAPOUR	4.60E-02	1.36E-01	1.60E-13	2.78E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.60E-15	1.00E-17	
*Xe-135U	GAS VAPOUR	2.48E-01	3.18E-01	9.10E-13	1.49E-08			0.00E+00	0.00E+00		1.26E-14	
*Cs-125U	LIQUIDS	6.77E-01	3.45E-01	2.03E-12	4.08E-08			2.50E-11	1.00E-11			
*Cs-125U	CAPSULE											
*Cs-127U	LIQUIDS	4.14E-01	2.91E-02	1.24E-12	2.48E-08			2.50E-11	1.25E-11			
*Cs-127U	CAPSULE											
*Cs-129	LIQUIDS	2.81E-01	1.77E-02	9.17E-13	1.69E-08	1.77E-07	3.54E-08	6.10E-11	4.20E-11	2.81E-14	0.00E+00	
*Cs-129	CAPSULE											
*Cs-130U	LIQUIDS	5.14E-01	4.01E-01	1.54E-12	3.08E-08			2.50E-11	7.14E-12	5.14E-14		
*Cs-130U	CAPSULE											
Cs-131	LIQUIDS	2.28E-02	6.60E-03	6.27E-14	9.90E-09	6.60E-08	1.32E-08	6.60E-11	4.40E-11	2.28E-15	0.00E+00	
Cs-131	CAPSULE											
*Cs-132	LIQUIDS	7.02E-01	1.42E-02	2.27E-12	4.21E-08	1.42E-07	2.84E-08	5.00E-10	3.30E-10	7.02E-14	0.00E+00	
*Cs-132	CAPSULE											
*Cs-134m	LIQUIDS	2.67E-02	1.11E-01	8.99E-14	1.10E-08	1.11E-06	2.22E-07	2.00E-11	1.30E-11	2.67E-15	1.00E-17	

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Svh per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Svh per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY 7(9-35)) OF LIQUIDS FRAC OF INVENTORY
*Cs-134m	CAPSULE											
Cs-134	SOLIDS	1.55E+00	1.63E-01	4.94E-12	8.80E-08	1.83E-06	3.08E-07	1.90E-08	1.20E-08	1.55E-13	1.00E-17	
Cs-134	FOIL											
*Cs-135	LIQUIDS	0.00E+00	6.30E-02	0.00E+00	0.00E+00	1.10E-06	5.71E-11	1.90E-09	1.20E-09	0.00E+00	1.00E-17	
*Cs-135	CAPSULE											
*Cs-135mU	LIQUIDS	1.58E+00	3.64E-02	4.74E-12	9.48E-08			1.25E-11	7.10E-12		0.00E+00	
*Cs-135mU	CAPSULE											
*Cs-136	LIQUIDS	2.15E+00	1.37E-01	8.70E-12	1.29E-07	2.28E-06	6.74E-08	3.00E-09	1.90E-09	2.15E-13	1.00E-17	
*Cs-136	CAPSULE											
Cs-137+	CAPSULE	5.63E-01	2.48E-01	1.85E-12	3.30E-08	2.54E-06	3.90E-07	1.30E-08	8.50E-09	6.54E-14	1.05E-15	
*Cs-138	LIQUIDS	2.31E+00	1.20E+00	7.17E-12	1.39E-07	6.00E-06	2.40E-06	9.20E-11	3.10E-11	2.31E-13	4.80E-14	
*Cs-138	CAPSULE											
*Ba-131	LIQUIDS	4.54E-01	4.50E-02	1.55E-12	2.72E-08	4.50E-07	0.00E+00	5.70E-10	1.80E-10	4.54E-14	0.00E+00	
*Ba-131	SOLIDS											
Ba-140+	LIQUIDS	2.49E+00	8.00E-01	7.55E-12	1.40E-07	5.48E-06	1.80E-06	3.70E-09	1.10E-09	2.49E-13	3.20E-14	
Ba-140+	SOLIDS											
La-140	LIQUIDS	2.31E+00	5.33E-01	6.84E-12	1.20E-07	2.74E-06	1.05E-06	2.80E-09	1.50E-09	2.31E-13	2.13E-14	
La-140	SOLIDS											
*Ce134+U	LIQUIDS	7.20E-01	7.36E-01					U	U			
*Ce134+U	SOLIDS											
*Ce135U	LIQUIDS	1.74E+00	2.39E-01					U	U			
*Ce135U	SOLIDS											
*Ce137U	LIQUIDS	3.54E-02	1.66E-02					U	U			
*Ce137U	SOLIDS											
*Ce137mU	LIQUIDS	5.28E-02	2.03E-01					U	U			
*Ce137mU	SOLIDS											
Ce-139	LIQUIDS	1.59E-01	3.56E-02	5.52E-13	1.90E-08	3.56E-07	7.12E-08	3.90E-10	2.40E-09	1.59E-14	0.00E+00	
Ce141	LIQUIDS	7.61E-02	1.70E-01	2.76E-13	5.90E-09	2.85E-06	1.83E-07	1.20E-09	2.60E-09	7.61E-15	1.00E-17	
Ce141	SOLIDS											
*Ce143	LIQUIDS	2.79E-01	4.28E-01	1.02E-12	1.67E-08	2.74E-06	8.79E-07	1.70E-09	1.10E-09	2.79E-14	1.71E-14	
*Ce143	SOLIDS											
Ce-144+	LIQUIDS	5.04E-02	1.21E+00	6.16E-13	4.10E-09	4.45E-06	1.50E-06	8.70E-09	1.00E-07	5.04E-15	4.84E-14	
Ce-144+	SOLIDS											
*Pr-142	LIQUIDS	5.84E-02	8.08E-01	4.97E-13	3.50E-09	4.04E-06	1.29E-06	1.80E-09	9.00E-10	5.84E-15	3.23E-14	
*Pr-142	SOLIDS											
Pr-143	SOLID	6.91E-09	3.14E-01	7.17E-14	5.00E-16	2.51E-06	7.08E-07	1.90E-09	2.50E-09	6.91E-22	1.26E-14	
*Nd-147	LIQUIDS	1.40E-01	2.68E-01	4.98E-13	8.40E-09	2.63E-06	4.79E-07	1.70E-09	2.10E-09	1.40E-14	1.00E-15	
*Nd-147	SOLIDS											
*Nd-149	LIQUIDS	3.77E-01	4.94E-01	1.44E-12	2.26E-08	2.30E-06	9.88E-07	1.30E-10	6.60E-11	3.77E-14	1.98E-14	
*Nd-149	SOLIDS											
Pm-147	FOIL	4.07E-06	6.20E-02	1.26E-17	4.90E-13	1.26E-06	4.11E-10	4.40E-10	1.00E-08	4.65E-19	0.00E+00	

74

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
*Pm-149	LIQUIDS	1.06E-02	3.65E-01	1.44E-13	6.36E-10	2.30E-06	7.30E-07	1.60E-09	9.80E-10	1.06E-15	1.48E-14	
*Pm-149	SOLIDS											
*Sm-151	LIQUIDS	1.34E-05	7.14E-05	1.69E-17	8.04E-13	2.85E-08	0.00E+00	1.70E-10	5.00E-09	1.34E-18	0.00E+00	
*Sm-151	SOLIDS											
*Sm-153	LIQUIDS	6.15E-02	2.71E-01	2.42E-13	3.69E-09	2.30E-06	5.42E-07	1.10E-09	6.30E-10	6.15E-15	1.00E-15	
*Sm-153	SOLIDS											
Eu-152	SOLID	1.15E+00	1.36E-01	3.50E-12	6.90E-08	1.60E-06	1.71E-07	2.00E-09	4.70E-08	1.15E-13	1.00E-17	
*Eu-152m	LIQUIDS	2.92E-01	5.05E-01	1.19E-12	1.75E-08	2.53E-06	8.08E-07	5.90E-10	2.30E-10	2.92E-14	2.02E-14	
*Eu-152m	SOLIDS											
Eu-154	SOLID	1.24E+00	2.88E-01	3.82E-12	7.44E-08	3.42E-06	3.77E-07	3.10E-09	5.90E-08	1.24E-13	1.00E-15	
Eu-155	SOLID	5.79E-02	6.26E-02	2.23E-13	3.47E-09	8.68E-07	3.20E-10	5.30E-10	7.60E-09	5.79E-15	1.00E-17	
*Gd-153	LIQUIDS	1.05E-01	4.37E-02	3.96E-13	6.30E-09	4.00E-07	0.00E+00	4.20E-10	4.10E-09	1.05E-14	0.00E+00	
*Gd-153	SOLIDS											
*Gd-159	LIQUIDS	4.98E-02	3.02E-01	2.06E-13	2.99E-09	2.30E-06	6.04E-07	6.80E-10	3.00E-10	4.98E-15	1.21E-14	
*Gd-159	SOLIDS											
*Tb-160	LIQUIDS	1.12E+00	2.54E-01	3.34E-12	6.72E-08	3.42E-06	4.22E-07	2.40E-09	6.40E-09	1.12E-13	1.00E-15	
*Tb-160	SOLIDS											
*Dy-165	LIQUIDS	2.58E-02	4.46E-01	2.41E-13	1.55E-09	2.30E-06	6.92E-07	6.70E-11	3.60E-11	2.58E-15	1.78E-14	
*Dy-165	SOLIDS											
*Dy-166	LIQUIDS	4.02E-02	1.59E-01	1.39E-13	2.41E-09	1.59E-06	3.16E-07	2.90E-09	2.40E-09	4.02E-15	1.00E-17	
*Dy-166	SOLIDS											
*Ho-166	LIQUIDS	2.90E-02	6.94E-01	3.72E-13	1.74E-09	3.47E-06	1.11E-06	2.00E-09	9.80E-10	2.90E-15	2.78E-14	
*Ho-166	SOLIDS											
Er-169	SOLID	9.46E-06	1.04E-01	1.65E-17	5.30E-11	1.85E-06	3.48E-06	6.20E-10	6.10E-10	1.29E-18	0.00E+00	
*Er-171	LIQUIDS	3.78E-01	4.17E-01	1.36E-12	2.27E-08	2.30E-06	6.34E-07	4.00E-10	1.50E-10	3.78E-14	1.67E-14	
*Er-171	SOLIDS											
Tm-170	SOLID	5.19E-03	3.31E-01	9.22E-14	3.11E-10	2.30E-06	6.62E-07	2.20E-09	7.20E-09	5.19E-16	1.32E-14	
*Tm-171	LIQUIDS	6.50E-04	2.56E-02	2.49E-15	3.90E-11	2.56E-07	0.00E+00	1.80E-10	1.60E-09	6.50E-17	0.00E+00	
*Tm-171	SOLIDS											
*Yb-175	LIQUIDS	3.96E-02	1.29E-01	1.33E-13	2.36E-09	1.29E-06	2.58E-07	7.00E-10	5.30E-10	3.96E-15	1.00E-17	
*Yb-175	SOLIDS											
*Lu-177	LIQUIDS	3.15E-02	1.47E-01	1.24E-13	1.89E-09	1.47E-06	2.94E-07	8.70E-10	7.90E-10	3.15E-15	1.00E-17	
*Lu-177	SOLIDS											
*Hf-181	LIQUIDS	5.55E-01	2.01E-01	1.80E-12	3.33E-08	2.30E-06	4.02E-07	1.70E-09	3.40E-09	5.55E-14	1.00E-15	
*Hf-181	SOLIDS											
Ta-182	SOLID	1.29E+00	2.12E-01	3.84E-12	7.74E-08	2.30E-06	4.24E-07	2.20E-09	1.20E-08	1.29E-13	1.00E-15	
Ta-182	CAPSULE											
Ta-182	FOIL											
*W-181	LIQUIDS	4.04E-02	1.09E-02	1.46E-13	2.42E-09	1.09E-07	0.00E+00	1.10E-10	3.30E-11	4.04E-15	0.00E+00	
*W-181	SOLIDS											

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
W-185	LIQUIDS	5.55E-05	1.27E-01	1.33E-16	3.33E-12	1.27E-06	2.54E-07	8.30E-10	1.70E-10	5.55E-18	1.00E-17	
W-185	SOLIDS							6.10E-10	1.70E-10			
*W-187	LIQUIDS	4.78E-01	3.07E-01	1.60E-12	2.87E-08	2.30E-06	8.14E-07	9.80E-10	2.10E-10	4.78E-14	1.23E-14	
*W-187	SOLIDS											
*Re-183Z	LIQUIDS			5.57E-13				7.60E-10	1.80E-09			
*Re-183Z	SOLIDS											
Re-186	LIQUIDS	2.05E-02	3.43E-01	1.64E-13	3.00E-09	2.30E-06	6.86E-07	1.30E-09	1.10E-09	2.05E-15	1.37E-14	
*Re-188	LIQUIDS	5.73E-02	7.78E-01	5.12E-13	3.44E-09	3.89E-06	1.24E-06	1.30E-09	8.00E-10	5.73E-15	3.11E-14	
*Re-188	SOLIDS											
*Os-185	LIQUIDS	7.17E-01	1.91E-02	2.28E-12	4.30E-08	6.05E-08	1.26E-08	8.40E-10	2.60E-09	7.17E-14	0.00E+00	
*Os-185	SOLIDS											
*Os-191	LIQUIDS	7.95E-02	1.35E-01	2.66E-13	4.77E-09	1.14E-06	0.00E+00	9.10E-10	1.30E-09	7.95E-15	0.00E+00	
*Os-191	SOLIDS											
*Os-191m	LIQUIDS	9.12E-03	8.50E-02	1.90E-14	5.47E-10	6.50E-07	1.30E-07	1.30E-10	9.00E-11	9.12E-16	0.00E+00	
*Os-191m	SOLIDS											
*Os-193	LIQUIDS	7.27E-02	3.68E-01	3.23E-13	4.36E-09	2.30E-06	7.36E-07	1.20E-09	6.50E-10	7.27E-15	1.47E-14	
*Os-193	SOLIDS											
*Ir-190	LIQUIDS	1.44E+00	1.23E-01	4.57E-12	8.64E-08	1.23E-06	2.46E-07	1.70E-09	1.90E-09	1.44E-13	0.00E+00	
*Ir-190	SOLIDS											
Ir-192	SOLIDS	8.20E-01	2.14E-01	2.72E-12	4.90E-08	2.63E-06	3.88E-07	2.00E-09	7.80E-09	8.20E-14	1.00E-15	
Ir-192	CAPSULE											
Ir-192	FOIL											
*Ir-194	LIQUIDS	8.92E-02	8.08E-01	6.24E-13	5.35E-09	4.04E-06	1.29E-06	1.80E-09	9.10E-10	8.92E-15	3.23E-14	
*Ir-194	SOLIDS											
*Pt-191	LIQUIDS	3.01E-01	6.28E-02	9.94E-13	1.81E-08	8.28E-07	1.26E-07	4.70E-10	1.50E-10	3.01E-14	1.00E-17	
*Pt-191	SOLIDS											
*Pt-193U	LIQUIDS	2.20E-03	8.72E-03	1.93E-15	1.32E-10	8.72E-08	0.00E+00	U	U		0.00E+00	
*Pt-193U	SOLIDS											
*Pt-193m	LIQUIDS	1.28E-02	1.37E-01	4.15E-14	7.68E-10	1.37E-06	2.74E-07	7.30E-10	2.20E-10	1.28E-15	1.00E-17	
*Pt-193m	SOLIDS											
*Pt-197	LIQUIDS	2.51E-02	2.53E-01	9.86E-14	1.51E-09	2.30E-06	5.06E-07	5.60E-10	1.50E-10	2.51E-15	1.00E-15	
*Pt-197	SOLIDS											
*Pt-197m	LIQUIDS	8.30E-02	3.22E-01	2.85E-13	4.98E-09	2.30E-06	6.44E-07	9.30E-11	3.30E-11	8.30E-15	1.29E-14	
*Pt-197m	SOLIDS											
*Au-196Z	LIQUID			1.60E-12				4.40E-10	3.70E-10			
*Au-196Z	SOLID											
Au-198	LIQUID	4.04E-01	3.28E-01	1.40E-12	2.40E-08	2.63E-06	7.30E-07	1.60E-09	1.10E-09	4.57E-14	8.04E-15	
Au-198	SOLID											
*Au-199	LIQUID	8.88E-02	1.43E-01	3.18E-13	5.33E-09	1.43E-06	2.86E-07	6.80E-10	4.90E-10	8.88E-15	1.00E-17	
*Au-199	SOLID											
Hg-197#	LIQUIDS	6.99E-02	6.64E-02	2.52E-13	2.20E-08	6.64E-07	1.33E-07	1.99E-10	1.02E-10	7.05E-15	0.00E+00	
Hg-197#	SOLIDS											

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCUDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
*Hg-197m	LIQUIDS	9.40E-02	2.14E-01	3.32E-13	5.64E-09	2.30E-06	4.28E-07	6.80E-10	3.50E-10	9.40E-15	1.00E-15	
*Hg-197m	SOLIDS											
Hg-203	SOLID	2.37E-01	9.87E-02	7.81E-13	1.50E-08	1.83E-06	4.22E-08	1.80E-09	1.80E-09	2.60E-14	0.00E+00	
Hg-203	CAPSULE											
*Tl-200	LIQUID	1.29E+00	3.86E-02	4.04E-12	7.74E-08	3.86E-07	0.00E+00	1.80E-10	1.20E-10	1.29E-13	0.00E+00	
*Tl-200	SOLID											
Tl-201	SOLID	8.87E-02	4.33E-02	3.36E-13	2.00E-08	6.05E-07	0.00E+00	7.40E-11	5.80E-11	9.49E-15	0.00E+00	
Tl-201	FOIL											
*Tl-202	LIQUID	4.67E-01	2.30E-02	1.55E-12	2.80E-08	2.30E-07	0.00E+00	3.70E-10	2.50E-10	4.67E-14	0.00E+00	
*Tl-202	SOLID											
Tl-204	FOIL	1.05E-03	2.38E-01	6.75E-14	3.20E-10	2.40E-06	5.71E-07	7.90E-10	5.70E-10	1.15E-16	3.28E-15	
*Pb-203U	LIQUID	3.12E-01	5.22E-02	1.05E-12	1.87E-08	5.22E-07	1.04E-07	2.50E-10	1.25E-10	3.12E-14	1.00E-17	
*Pb-203U	SOLID											
Pb-210+	SOLID	1.68E-03	4.27E-01	1.14E-13	8.30E-09	2.63E-06	8.45E-07	1.92E-06	4.15E-06	8.11E-16	1.44E-14	
*Pb-212+	LIQUID	1.55E+00	8.56E-01	4.74E-12	9.30E-08	5.82E-06	1.22E-06	1.23E-08	4.18E-08	1.55E-13	3.42E-14	
*Pb-212+	SOLID											
Bi-206	LIQUID	3.25E+00	1.32E-01	1.01E-11	1.63E-07	6.60E-07	2.64E-07	2.40E-09	1.80E-09	3.25E-13	1.00E-17	
*Bi-207	LIQUID	1.54E+00	1.16E-01	4.78E-12	9.24E-08	1.16E-06	2.32E-07	1.70E-09	5.50E-09	1.54E-13	1.00E-17	
*Bi-207	SOLID											
*Bi-210	LIQUID	0.00E+00	3.98E-01	1.22E-13	0.00E+00	2.63E-06	8.45E-07	2.10E-09	5.10E-08	0.00E+00	1.59E-14	
*Bi-210	SOLID											
*Bi-212+	LIQUID	1.40E+00	8.61E-01	4.23E-12	8.37E-08	2.74E-06	1.14E-06	2.50E-10	4.80E-09	1.40E-13	2.72E-14	
*Bi-212+	SOLID											
*Po-203U	LIQUID	1.64E+00	1.60E-01	4.92E-12	9.84E-08	1.60E-06	3.20E-07	5.56E-11	2.50E-11	1.64E-13	1.00E-17	
*Po-203U	SOLID											
*Po-205U	LIQUID	1.55E+00	5.75E-02	4.65E-12	9.30E-08	5.75E-07	1.15E-07	6.25E-11	5.00E-11	1.55E-13	1.00E-17	
*Po-205U	SOLID											
*Po-207U	LIQUID	1.32E+00	5.05E-02	3.96E-12	7.92E-08	5.05E-07	1.01E-07	1.67E-10	5.56E-11	1.32E-13	1.00E-17	
*Po-207U	SOLID											
Po-210	SOLID	8.51E-06	8.20E-06	2.69E-17	4.80E-13	0.00E+00	0.00E+00	6.20E-07	1.90E-06	9.61E-19	0.00E+00	
*At-211	LIQUID	3.91E-02	5.89E-03	1.41E-13	2.35E-09	5.89E-08	0.00E+00	1.10E-08	2.70E-08	3.91E-15	0.00E+00	
	SOLID											
*Rn-220+	GAS VAPOUR	4.02E-04	9.03E-06	1.72E-15	2.41E-11	9.03E-11	0.00E+00	U	4.00E-08	4.02E-17	0.00E+00	
Rn-222+	GAS VAPOUR	1.71E+00	9.40E-01	5.49E-12	1.03E-07	4.70E-06	1.50E-06	U	5.70E-09	1.71E-13	3.76E-14	
*Ra-223+	LIQUID	1.55E-01	9.47E-01	1.15E-12	9.29E-09	3.66E-06	9.89E-07	1.40E-07	2.00E-06	1.55E-14	3.79E-14	
*Ra-223+	SOLID											
*Ra-224+	LIQUID	1.56E+00	8.55E-01	4.78E-12	9.36E-08	5.86E-06	1.22E-06	9.23E-08	8.62E-07	1.56E-13	3.42E-14	
*Ra-224+	SOLID											
*Ra-225	LIQUID	1.37E-02	1.07E-01	4.74E-14	8.22E-10	1.07E-06	2.14E-07	7.30E-08	2.00E-06	1.37E-15	1.00E-17	
*Ra-225	SOLID											

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Svh per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Svh per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
Ra-226+	SOLID	1.78E+00	1.37E+00	5.59E-12	1.18E-07	8.53E-06	2.49E-06	2.14E-06	6.25E-06	1.84E-13	4.34E-14	
Ra-226+	SOLID MASSIVE											
*Ra-227U	LIQUID	1.66E-01	4.28E-01	4.98E-13	9.98E-09	2.30E-06	8.56E-07	8.30E-11	1.00E-10	1.66E-14	1.71E-14	
*Ra-227U	SOLID											
*Ra-228+	LIQUID	9.64E-01	4.78E-01	2.98E-12	5.78E-08	3.08E-06	7.19E-07	2.71E-07	1.15E-06	9.64E-14	1.91E-14	
*Ra-228+	SOLID											
*Th-226+U	LIQUID	1.87E-02	2.20E-02	6.28E-14	1.12E-09	2.20E-07	4.40E-08	2.50E-10	1.00E-08	1.87E-15	0.00E+00	
*Th-226+U	SOLID											
*Th-227	LIQUID	1.08E-01	4.57E-02	3.69E-13	6.38E-09	2.74E-07	8.22E-09	1.50E-08	3.50E-05	1.08E-14	0.00E+00	
*Th-227	SOLID											
Th-228+	SOLID	1.56E+00	8.80E-01	4.79E-12	1.00E-07	6.34E-06	1.22E-06	2.82E-07	8.60E-05	1.54E-13	1.35E-14	
Th-228+	SOLID MASSIVE											
*Th-229+	LIQUID	2.91E-01	4.70E-01	1.15E-12	7.30E-08	6.29E-06	9.87E-07	2.51E-08	3.54E-04	2.91E-14	1.88E-14	
*Th-229+	SOLID											
Th-230	SOLID	1.55E-03	1.46E-02	2.97E-15	3.80E-09	1.04E-07	0.00E+00	3.50E-07	5.10E-05	2.96E-16	0.00E+00	
Th-230	SOLID MASSIVE											
*Th-231	LIQUID	2.55E-02	1.63E-01	6.09E-14	1.53E-09	2.17E-06	1.08E-08	4.90E-10	2.70E-10	2.55E-15	1.00E-17	
*Th-231	SOLID											
Th-232N	SOLID	2.52E+00	1.37E+00	7.76E-12	1.65E-07	9.46E-06	1.94E-06	4.93E-06	1.53E-04	1.65E-13	1.35E-14	
Th-232N	SOLID MASSIVE											
Th-232N	CAPSULE(GEM)											
*Th-234+	LIQUID	1.96E-02	8.79E-01	4.08E-13	1.18E-09	3.82E-06	1.28E-08	5.70E-09	1.00E-08	1.96E-15	3.52E-14	
*Th-234+	SOLID											
*Ac-228	LIQUID	9.30E-01	4.60E-01	2.98E-12	6.30E-08	3.08E-06	7.19E-07	5.00E-10	5.00E-08	9.30E-14	1.84E-14	
*Ac-228	SOLID											
*Pa-230	LIQUID	6.46E-01	6.63E-02	2.09E-12	3.88E-08	6.63E-07	1.33E-07	1.50E-09	3.90E-07	6.46E-14	1.00E-17	
*Pa-230	SOLID											
*Pa-231	LIQUID	4.76E-02	6.28E-02	1.13E-13	2.88E-09	1.48E-07	5.14E-09	1.40E-06	1.70E-04	4.76E-15	1.00E-17	
*Pa-231	SOLID											
*Pa-233	LIQUID	2.03E-01	1.95E-01	7.38E-13	1.22E-08	2.97E-06	9.93E-08	1.40E-09	2.80E-09	2.03E-14	1.00E-17	
*Pa-233	SOLID											
*U-230+	LIQUID	2.17E-02	4.38E-02	6.91E-14	1.30E-09	4.38E-07	8.72E-08	1.40E-07	5.20E-06	2.17E-15	0.00E+00	
*U-230+	SOLID											
*U-231U	LIQUID	8.20E-02	7.08E-02	2.74E-13	4.92E-09	7.08E-07	1.41E-07	2.50E-10	2.50E-10	8.20E-15	1.00E-17	
*U-231U	SOLID											
*U-232+	LIQUID	1.56E+00	8.90E-01	4.79E-12	9.38E-08	6.38E-06	1.22E-06	5.32E-07	2.57E-04	1.56E-13	3.56E-14	
*U-232+	SOLID											
*U-233	LIQUID	1.31E-03	6.08E-03	1.62E-15	1.70E-09	5.25E-09	0.00E+00	4.00E-08	3.60E-05	1.31E-16	0.00E+00	
*U-233	SOLID											
U-234	SOLID	1.73E-03	1.32E-02	2.68E-15	2.70E-09	7.42E-09	0.00E+00	3.90E-08	3.50E-05	3.80E-16	0.00E+00	
U-234	SOLID MASSIVE											
*U-235+	LIQUID	1.80E-01	2.11E-01	6.25E-14	1.08E-08	2.52E-06	1.09E-08	3.60E-08	3.30E-05	1.80E-14	1.00E-15	
*U-235+	SOLID											

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
*U-236	LIQUID	1.57E-03	1.14E-02	2.44E-15	9.42E-11	4.57E-09	0.00E+00	3.70E-08	3.30E-05	1.57E-16	1.00E-17	
*U-236	SOLID											
*U-237U	LIQUID	1.42E-01	1.94E-01	5.05E-13	8.52E-09	1.94E-06	3.88E-07	8.30E-10	8.30E-10	1.42E-14	1.00E-17	
*U-237U	SOLID											
U-238+	SOLID	2.50E-02	8.89E-01	4.10E-13	9.70E-09	3.82E-06	1.26E-06	4.17E-08	3.10E-05	3.02E-15	4.08E-14	
U-238+	SOLID MASSIVE											
U-238N	SOLID	1.78E+00	2.29E+00	6.08E-12	1.35E-07	1.25E-05	3.75E-06	1.29E-06	6.16E-05	1.88E-13	8.42E-14	
U-238N	SOLID MASSIVE											
U-238N	CAPSULE(GEM)											
*U-239U	LIQUID	5.11E-02	4.08E-01	3.08E-13	3.07E-09	2.30E-06	8.16E-07	2.50E-11	8.30E-12	5.11E-15	1.63E-14	
*U-239U	SOLID											
*U-240U	LIQUID	7.61E-03	1.38E-01	1.32E-14	4.57E-10	2.05E-06	1.26E-07	1.00E-09	5.00E-10	7.61E-16	1.00E-17	
*U-240U	SOLID											
*U-240+U	LIQUID	1.32E+00	6.55E-01	3.71E-12	7.92E-08	8.22E-06	6.98E-07	1.00E-09	5.00E-10	1.32E-13	2.62E-14	
*U-240+U	SOLID											
*Np-237+	LIQUID	2.37E-01	2.64E-01	8.40E-13	5.50E-08	3.46E-06	9.93E-08	6.41E-07	7.80E-05	2.78E-14	1.00E-15	
*Np-237+	SOLID											
*Np-239	LIQUID	1.72E-01	2.57E-01	6.00E-13	1.03E-08	4.11E-06	1.37E-07	1.20E-09	7.50E-10	1.72E-14	1.00E-15	
*Np-239	SOLID											
*Np-240	LIQUID	1.31E+00	5.17E-01	3.89E-12	7.86E-08	6.16E-06	5.71E-07	7.80E-11	2.50E-11	1.31E-13	2.07E-14	
*Np-240	SOLID											
*Pu-234	LIQUID	6.84E-02	1.07E-02	2.05E-13	4.10E-09	1.07E-07	0.00E+00	1.70E-10	7.10E-09	6.84E-15	0.00E+00	
*Pu-234	SOLID											
*Pu-235	LIQUID	9.42E-02	2.13E-02	2.83E-13	5.65E-09	2.13E-07	0.00E+00	1.70E-12	5.60E-13	9.42E-15	0.00E+00	
*Pu-235	SOLID											
*Pu-236	LIQUID	2.09E-03	1.35E-02	3.31E-15	1.25E-10	0.00E+00	0.00E+00	1.90E-07	2.90E-05	2.09E-16	0.00E+00	
*Pu-236	SOLID											
*Pu-237U	LIQUID	5.23E-02	1.58E-02	1.86E-13	3.14E-09	1.58E-07	0.00E+00	1.00E-10	5.00E-10	5.23E-15	0.00E+00	
*Pu-237U	SOLID											
Pu-238	SOLID	2.08E-05	1.08E-02	1.25E-15	2.70E-09	1.08E-07	0.00E+00	5.10E-07	8.20E-05	2.08E-16	0.00E+00	
Pu-239	FOIL	5.19E-05	6.65E-03	1.34E-15	1.00E-09	4.34E-10	0.00E+00	5.60E-07	6.80E-05	1.63E-17	0.00E+00	
*Pu-240	LIQUID	1.73E-03	1.08E-02	2.75E-15	1.04E-10	0.00E+00	0.00E+00	5.60E-07	6.80E-05	1.73E-16	0.00E+00	
*Pu-240	SOLID											
*Pu-241	LIQUID	2.54E-06	5.24E-03	0.00E+00	1.60E-12	0.00E+00	0.00E+00	1.10E-08	1.30E-06	2.54E-19	0.00E+00	
*Pu-241	SOLID											
*Pu-242	LIQUID	1.44E-03	8.72E-03	2.28E-15	8.64E-11	0.00E+00	0.00E+00	5.30E-07	6.50E-05	1.44E-16	0.00E+00	
*Pu-242	SOLID											
*Pu-243	LIQUID	2.55E-02	1.71E-01	9.25E-14	1.53E-09	2.28E-06	2.51E-07	8.70E-11	4.20E-11	2.55E-15	1.00E-17	
*Pu-243	SOLID											
*Pu-244	LIQUID	1.22E-03	7.08E-03	1.94E-15	7.32E-11	0.00E+00	0.00E+00	5.30E-07	6.40E-05	1.22E-16	0.00E+00	
*Pu-244	SOLID											

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
*Pu-245U	LIQUID	4.08E-01	3.39E-01	1.40E-12				U	U	4.08E-14		
*Pu-245U	SOLID											
*Am-237U	LIQUID	3.68E-01	7.45E-02					U	U	3.68E-14		
*Am-237U	SOLID											
*Am-238U	LIQUID	8.79E-01	5.07E-02					U	U	8.79E-14		
*Am-238U	SOLID											
*Am-239U	LIQUID	2.38E-01	1.66E-01					U	U	2.38E-14		
*Am-239U	SOLID											
*Am-240U	LIQUID	1.02E+00	7.46E-02					U	U	1.02E-13		
*Am-240U	SOLID											
Am-241	CAPSULE	2.13E-02	5.19E-02	9.41E-14	1.70E-08	5.48E-08	0.00E+00	5.70E-07	7.00E-05	2.13E-15	1.00E-17	
Am-241	FOIL											
*Am-242	LIQUID	1.83E-02	1.79E-01	6.51E-14	1.10E-09	1.94E-06	2.97E-07	4.30E-10	1.20E-06	1.83E-15	1.00E-17	
*Am-242	SOLID											
*Am-242m+	LIQUID	2.34E-02	2.29E-01	7.42E-14	1.40E-09	1.94E-06	2.97E-07	5.50E-07	6.70E-05	2.34E-15	1.00E-15	
*Am-242m+	SOLID											
*Am-243+	LIQUID	2.30E-01	3.00E-01	8.06E-13	1.38E-08	4.24E-06	1.37E-07	5.70E-07	7.00E-05	2.30E-14	1.00E-15	
*Am-243+	SOLID											
*Am-244U	LIQUID	8.05E-01	3.41E-01	2.59E-12				U	U	8.05E-14		
*Am-244U	SOLID											
*Am-244mU	LIQUID	1.53E-03	9.23E-04					U	U	1.53E-16		
*Am-244mU	SOLID											
*Am-245U	LIQUID	3.23E-02	2.68E-01	1.55E-13				U	U	3.23E-15		
*Am-245U	SOLID											
*Am-246U	LIQUID	6.98E-01	6.51E-01	3.10E-12				U	U	6.98E-14		
*Am-246U	SOLID											
*Am-246mU	LIQUID	9.89E-01	4.68E-01					U	U	9.89E-14		
*Am-246mU	SOLID											
*Cm-238U	LIQUID	7.71E-02	9.66E-03					U	U	7.71E-15		
*Cm-238U	SOLID											
*Cm-240U	LIQUID	2.02E-03	1.08E-02					U	U	2.02E-16		
*Cm-240U	SOLID											
*Cm-241U	LIQUID	4.99E-01	1.30E-01					U	U	4.99E-14		
*Cm-241U	SOLID											
*Cm-242	LIQUID	1.83E-03	9.57E-03	3.10E-15	2.40E-09	0.00E+00	0.00E+00	2.40E-08	3.50E-06	1.83E-16	0.00E+00	
*Cm-242	SOLID											
*Cm-243	LIQUID	1.34E-01	1.37E-01	4.56E-13	8.04E-09	1.94E-06	3.42E-08	4.00E-07	4.90E-05	1.34E-14	1.00E-17	
*Cm-243	SOLID											
Cm-244	SOLID	1.88E-04	8.59E-03	2.76E-15	2.20E-09	0.00E+00	0.00E+00	3.20E-07	4.00E-05	1.88E-17	0.00E+00	
*Cm-245	LIQUID	9.55E-02	6.50E-02	2.68E-13	9.55E-08	9.82E-07	0.00E+00	5.90E-07	7.20E-05	9.55E-15	1.00E-17	
*Cm-245	SOLID											
*Cm-246	LIQUID	1.51E-03	8.00E-03	2.44E-15	1.51E-09	0.00E+00	0.00E+00	5.90E-07	7.20E-05	1.51E-16	0.00E+00	

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
*Cm-246	SOLID											
*Cm-247	LIQUID	3.14E-01	2.11E-02	1.05E-12	1.88E-08	1.60E-07	1.83E-08	5.40E-07	6.60E-05	3.14E-14	0.00E+00	
*Cm-247	SOLID											
*Cm-248	LIQUID	1.16E-03	8.04E-03	1.98E-15	6.98E-11	0.00E+00	0.00E+00	2.20E-06	2.60E-04	1.16E-16	0.00E+00	
*Cm-248	SOLID											
*Cm-249U	LIQUID	1.91E-02	2.83E-01	1.11E-13				U	U	1.91E-15		
*Cm-249U	SOLID											
Bk-249U	LIQUID	1.69E-07	3.29E-02					1.90E-09	2.00E-07	1.69E-20		
Bk-249U	SOLID											
*Bk-250	LIQUID	8.85E-01	2.91E-01	2.75E-12	5.31E-08	2.30E-06	5.82E-07	U	U	8.85E-14	1.00E-15	
*Bk-250	SOLID											
*Cf-244U	LIQUID	1.91E-03	8.51E-03					U	U	1.91E-16	0.00E+00	
*Cf-244U	SOLID											
*Cf-246	LIQUID	1.32E-03	5.93E-03		7.92E-11	5.93E-08	0.00E+00	5.00E-09	1.80E-07	1.32E-16	0.00E+00	
*Cf-246	SOLID											
*Cf-248	LIQUID	1.30E-03	5.98E-03	2.22E-15	7.80E-11	5.96E-08	0.00E+00	5.50E-06	1.30E-05	1.30E-16	0.00E+00	
*Cf-248	SOLID											
*Cf-249	LIQUID	3.33E-01	4.34E-02	1.10E-12	2.00E-08	3.20E-07	1.80E-08	7.00E-07	8.50E-05	3.33E-14	0.00E+00	
*Cf-249	SOLID											
*Cf-250	LIQUID	1.24E-03	5.65E-03	2.27E-15	7.44E-11	4.79E-09	0.00E+00	3.20E-07	4.40E-05	1.24E-16	0.00E+00	
*Cf-250	SOLID											
*Cf-251	LIQUID	1.31E-01	1.98E-01	4.25E-13	7.88E-09	1.96E-06	3.92E-07	3.80E-07	8.70E-05	1.31E-14	1.00E-17	
*Cf-251	SOLID											
Cf-252	SOLID	1.59E-02	1.30E-02	2.10E-15	1.30E-09	3.88E-09	0.00E+00	1.70E-07	3.90E-05	1.59E-15	0.00E+00	
Cf-252	CAPSULE											
Cf-252	FOIL											
*Cf-253	LIQUID	2.27E-05	7.92E-02	3.75E-17	1.36E-12	7.92E-07	1.58E-07	2.70E-09	8.20E-07	2.27E-18	1.00E-17	
*Cf-253	SOLID											
*Cf-254	LIQUID	1.74E+01	1.00E+01	7.36E-20	8.70E-07	5.00E-05	1.80E-05	6.40E-07	7.80E-05	1.74E-12	4.00E-13	
*Cf-254	SOLID											
*Es-253	LIQUIDS	1.10E-03	3.45E-03	2.30E-15	6.60E-11	3.45E-08	0.00E+00	1.00E-08	9.20E-07	1.10E-16	0.00E+00	
*Es-253	SOLIDS											
Es-254	LIQUIDS	1.91E-02	7.01E-02	3.78E-14	1.15E-09	7.01E-07	1.40E-07	5.40E-06	7.00E-06	1.91E-15	1.00E-17	
Es-254	SOLIDS											
*Es-254m	LIQUIDS	4.68E-01	2.54E-01	1.81E-12	2.81E-08	2.30E-06	5.08E-07	6.70E-09	1.30E-07	4.68E-14	1.00E-15	
*Es-254m	SOLIDS											
*Es-255U	LIQUIDS			1.64E-16				U	U			
*Es-255U	SOLIDS											
*Fm-254	LIQUIDS	1.28E-03	5.81E-03	2.41E-15	7.56E-11	5.81E-08	0.00E+00	4.20E-10	1.40E-08	1.28E-16	0.00E+00	
*Fm-254	SOLIDS											
*Fm-255	LIQUIDS	1.35E-02	9.79E-02	2.36E-14	8.10E-10	9.79E-07	1.96E-07	3.60E-09	6.80E-08	1.35E-15	1.00E-17	
*Fm-255	SOLIDS											

TABLE B1 RADIONUCLIDE DEPENDENT DATA

NUCLIDE	WASTE FORM	R1 (1) MEAN ENERGY PER DISINT'N GAMMA MEV	R2 (1) MEAN ENERGY PER DISINT'N BETA MEV	R5&R6 (2) GAMMA & BETA SEMI-INFINITE PLANE Sv/h per Bq/m2	R7 (3) GAMMA SKIN DOSE 7mg/cm2 Sv/h per Bq/cm2	R8 (4) BETA SKIN DOSE 4mg/cm2 Sv/h per Bq/cm2	R24 (4) BETA SKIN DOSE 40mg/cm2 Sv/h per Bq/cm2	R9 (5,8) INGESTION DPUI ICRP60 (max) Sv/Bq	R10 (5,8) INHALATION DPUI ICRP60 (max) Sv/Bq	R19 (6) POINT SOURCE GAMMA Sv/h per Bq	R20 (6) POINT SOURCE BETA Sv/h per Bq	VOLATILITY (7(S-35)) OF LIQUIDS FRAC OF INVENTORY
*Fm-256U	LIQUIDS	1.11E-01	1.20E-01					U	U	1.11E-14	1.00E-17	
*Fm-256U	SOLIDS											

Index to shorthand in tables

1 *Si-31- The '*' refers to radionuclides for which their use is unknown.

2 *P33 - The 'U' refers to a radionuclide for which the dose per unit intake for ingestion and/or inhalation is not given in reference 5.
Radionuclides with suffix U have inhalation and ingestion doses per unit intake calculated from ICRP Publication 30[(8)] or have been omitted.

3 Doses from inhalation of radon (^{222}Rn) and thoron (^{220}Rn) were estimated from reference 9 in the following way.

a) The dose from ^{222}Rn was estimated, by assuming that an average concentration of 20.5 Bq m^{-3} gives rise to a dose rate of 1 10^{-3} Sv y^{-1}. Assuming that an individual's inhalation rate is 1 m^3 h^{-1} then the 'dose per unit intake' (in Sv Bq^{-1}).

$$= \frac{1 10^{-3}\ \text{Sv y}^{-1}}{20.5\ \text{Bq m}^{-3} \times 1\ \text{m}^{3}\ \text{h}^{-1} \times 8760\ \text{h y}^{-1}} = 5.7\ 10^{-9}\ \text{Sv Bq}^{-1}.$$

b) The dose from ^{220}Rn was estimated, assuming a conversion factor of 40 10^{-9} Sv per Bq.h m^{-3}.
Assuming an inhalation rate 1 m^3 h^{-1}, the dose per unit intake in Sv Bq^{-1} = 4 10^{-8} Sv Bq^{-1}.

4 Zr-39+. The '+' means that the daughters referred to in Table 2 of the main text are included in the radionuclide dependent factors.

5 Re-182Z. The 'Z' refers to a radionuclide in which energy emission data is not available from ICRP Publication 38[1].

6 Hg-197#. The '#' means that inhalation and ingestion data was obtained from reference 6.

7 "Solid" is defined as a "dispersable solid".

8. "Solid Massive" is defined as a "non-dispersable solid".

References

1 ICRP. Radionuclide Transformations: Energy and intensity of emissions. ICRP Publication 38. Ann. ICRP, 11-13 (1983).

2 Kocher, D C. Dose rate conversion factor for external exposure to photons and electrons. Health Physics, 45, No. 3, 665-686 (1983).

3 Chaptinel, Y, Durand, F, Piechowski, J, and Monoux, B. Dosimetry and therapy of skin contamination. Commissariat à l'Energie Atomique, CEA-R-5441 (1988).

4 Kocher, D C, and Eckermann, K F. Electron dose rate conversion factors for external exposure to the skin from uniformly deposited activity on body surface. Health Physics, 53, No. 2, 135-141 (1987).

5 Phipps, A W, Kendall, G M, Stather, J W, and Fell, T P. Committed Equivalent Organ Dose and Committed Effective Doses from Intakes of Radionuclides. Chilton, NRPB-R245 (1991) (London, HMSO).

6 Asselineau, J M, Chapuis, A M, Guetat, Ph, and Renaud, Ph. Determination of radioactivity levels and recommendations for the exemption of radioactive waste arising outside the nuclear fuel cycle. Commissariat à l'Energic Atomique, final report, 1991.

7 Klein, R C, Party, E, and Gershey, E L. Volatility of S^{35}. Health Physics 58, No. 3, 355-358 (1990).

8 ICRP. Limits for intakes of radionuclides by workers. ICRP Publication 30, 3, Nos. 1-4, Supplement to Part 1 (1979; 5 Nos. 1-6, Supplement to Part 2 (1981); 7, Nos. 1-3 Supplement A to Part 3 (1982); 8 Nos. 1-3, Supplement B to Part 3, also addendum to Supplements Part 1 and Part 2 (1982).

9 Hughes, J S, Shaw, K B, and O'Riordan, M C. Radiation exposure of the UK population -1988 review. Chilton, NRPB-R227 (1991) (London, HMSO).

APPENDIX C

Basic assumptions for dose and risk criteria

The individual effective dose criteria (or dose constraint) adopted by the CEC for the determination of reporting levels is 10 µSv per year.

Two different situations are distinguished in the calculations: normal situations and low probability events (accidents). In ICRP 60, it is assumed that the risk of fatal cancer (over the lifetime) due to exposure to ionising radiation is $5\ 10^{-2}$ per sievert. This value is used here to relate the dose criteria to a risk criteria.

Risk criteria for normal situation:

The annual dose criteria for normal situations guarantees that the maximum individual risk per year related to the reporting level is:
$(10\ \mu Sv/year).(5\ 10^{-2}\ effect/Sv) = 5\ 10^{-7}$ fatal cancer per year of exposure

Risk criteria for low probability events:

As soon as low probability events are considered, it should be verified that the product of probability and consequence is lower or at least equal to the risk criteria defined for normal situations. Assuming an annual probability p for a misuse or a "low probability event", the individual dose criteria defined for the normal situation is no longer valid, but the individual dose D has to satisfy the following relationship:

$$p \times D \times \text{risk factor} \leq \text{Risk criteria for normal situation}$$

which means:

$$p \times D \times \text{risk factor} \leq 5\ 10^{-7}\ \text{fatal cancer/year}$$

The low probability events correspond to pessimistic situations and it can be reasonably assumed that the probability of occurrence per year for these situations is actually lower than 10^{-2}. Thus, according to the previous relationships, it is possible to derive the individual dose criteria per event for the public and workers (assuming $p \leq 10^{-2}$) as follows:

$$p \times D_{max} \times \text{risk factor} = (10^{-2}/\text{year}) \times D_{max} \times 5\ 10^{-2} = 5\ 10^{-7}\ \text{fatal cancer/year}$$

$$D_{max} = (5\ 10^{-7} / 5\ 10^{-2})\text{Sv}\ 10^{2}$$

$$D_{max} = 1\ \text{mSv/event}$$

Skin contamination:

The basic dose criteria for the normal situation is 50 mSv/year. This dose criteria is also applied to accidental situations. In other words, if the event occurs, a skin dose of 50 mSv is not exceeded.

R A D I O L O G I C A L P R O T E C T I O N

Publications of the Commission of the European Communities
Directorate-General Environment, Nuclear Safety and Civil Protection
Radiation Protection Division - Luxembourg

N° 1 Technical Recommendations for Monitoring the Exposure of Individuals to External Radiation,
Luxembourg, 1976 (EUR 5287 DE/FR/EN/IT/NL)

N° 2 Organization and Operation of Radioactivity Surveillance and Control in the Vicinity of Nuclear Plants,
Luxembourg, 1975 (EUR 5176 DA/DE/FR/EN/IT/NL) (out of print)

N° 3 Technical Recommendations for the Use of the Thermoluminescence for Dosimetry in Individual Monitoring for Photons and Electrons from External Sources,
Luxembourg, 1975 (EUR 5358 DE/FR/EN/IT/NL)

N° 4 Radiation Protection Measurement - Philosophy and Implementation. Selected papers of the International Symposium at Aviemore (2-6 June 1974),
Luxembourg, 1975 (EUR 5397 FR/EN)

N° 5 Studie über die Radioaktivität in Verbrauchsgütern
F. WACHSMANN,
Luxembourg, 1976 (EUR 5460 DE/EN)

N° 6 Radioactive Isotopes in Occupational Health
A. FAVINO,
Luxembourg, 1976 (EUR 5524 EN)

N° 7 Problems posed by the growing use of consumer goods containing radioactive substances. Conference papers of a seminar held at Luxembourg on 13-14 November 1975,
Luxembourg, 1976 (EUR 5601 multilingual)

N° 8 Legislation
Council Directive of 1 June 1976 laying down the revised basic safety standards for the health protection of the general public and workers against the dangers of ionizing radiation,
Luxembourg, 1977 (EUR 5563 DA/DE/FR/EN/IT/NL)

N° 9 Problèmes relatifs à l'évaluation de l'aptitude au travail comportant un risque d'irradiation E. STRAMBI,
Luxembourg, 1976 (EUR 5624 FR) (out of print)

N° 10 *Technical Recommendations for the Use of Radio-Photoluminescence for Dosimetry in Individual Monitoring,*
Luxembourg, 1976 (EUR 5655 EN)

N° 11 *Results of Environmental Radioactivity Measurements in the Member States of the European Community for Air - Deposition - Water 1973 - 1974, Milk1972 - 1973 - 1974,*
Luxembourg, 1976 (EUR 5630 DA/DE/FR/EN/IT/NL)

N° 12 *Radioactive contamination levels in the ambient medium and in the food chain - Quadriennal report 1972 - 1975,*
Luxembourg, 1976 (EUR 5441 FR/EN)

N° 13 *Seminar on the radiological protection.*
Problems presented by the preparation and use of pharmaceuticals containing radioactive substances.
Luxembourg, 27 and 28 september 1976,
Luxembourg, 1977 (EUR 5734 multilingual) (out of print)

N° 14 *Results of environmental radioactivity measurements in the Member States of the European Community for Air - Deposition - Water - Milk 1975-1976,*
Luxembourg, 1978 (EUR 5944 DA/DE/FR/EN/IT/NL)

N° 15 *Results of environmental radioactivity measurements in the Member States of the European Community for Air - Deposition - Water - Milk 1977,*
Luxembourg, 1979 (EUR 6212 DA/DE/FR/EN/IT/NL)

N° 16 *Information and training on radiation protection for trade union representatives from the nine Member States of the European Community - Papers presented at the third and fourth seminars on 10-11 October 1977 and 12-13 October 1978,*
Luxembourg, 1979 (EUR 6264 DE/EN/FR)
(The papers presented at the first and second seminar on information and training in radiation protection have been published by the Directorate General for Employment and Social Affairs in Luxembourg under the internal N° 1957/77 DE/FR/EN)

N° 17 *Results of environmental radioactivity measurements in the Member States of the European Community for Air - Deposition - Water - Milk 1978,*
Luxembourg, 1980 (EUR 6620 DA/DE/FR/EN/IT/NL)

N° 18 *A critical review of nuclear accident dosimeters*
B. MAJBORN
Luxembourg, 1980 (EUR 6838 EN)

N° 19 Development and testing of the dose equivalent rate meter tandem for beta and photon radiation to be used in radiation protection (Entwicklung und Erprobung des Äquivalentdosis-leistungsmessers Tandem für Beta- und Photonstrahlung zur Anwendung im Strahlenschutz)
J.BÖHM, K. HOHLFELD,
Luxembourg, 1980 (EUR 6845 DE/EN)

N° 20 Results of environmental radioactivity measurements in the Member States of the European Community for Air - Deposition - Water - Milk 1979
Luxembourg, 1980 (EUR 7032 DA/DE/FR/EN/IT/NL)

N° 21 Legislation Council Directive of 15 July 1980 amending the Directives laying down the basic safety standards for the health protection of the general public and workers against the dangers of ionizing radiation,
Luxembourg, 1981 (EUR 7330 DA/DE/FR/EN/IT/NL)

N°22 Results of environmental radioactivity measurements in the Member States of the European Community for Air - Deposition - Water - Milk 1980,
Luxembourg, 1982 (EUR 7639 DA/DE/FR/EN/IT/NL)

N° 23 Assessment of plutonium internal contamination in man
G.F. CLEMENTE - A. DELLE SITE,
Luxembourg, 1981 (EUR 7157 EN)

N°24 Third Information Seminar on the radiation protection dosemeter intercomparison programme
Beta Intercomparison - Grenoble - 6 October 1980,
Luxembourg, 1981 (EUR 7365 EN)

N°25 Information Seminar on the problems of applying the Directive laying down the Euratom basic safety standards for the health protection of the general public and workers against the dangers of ionizing radiation - Papers presented at the seminar on 4 and 5 June 1981 Luxembourg, 1982 (EUR 8287 EN/FR)

N° 26 Méthodes d'évaluation des conséquences de l'irradiation des populations
Rapport final 1976-1980,
Luxembourg, 1982 (EUR 8068 FR/EN)

N° 27 Operational quantities for use in external radiation protection measurements - An investigation of concepts and principles,
Luxembourg, 1982 (EUR 8346 EN)

N° 28 Results of environmental radioactivity measurements in the Member States of the European Community for Air - Deposition - Water - Milk 1981,
Luxembourg, 1983 (EUR 8308 DA/DE/FR/EN/IT/NL)

N° 29 *Environmental Monitoring – European Interlaboratory Test Programme for Integrating Dosemeter Systems*
E. PIESCH and B. BURGKHARDT,
Luxembourg, 1983 (EUR 8932 EN)

N° 30 *Photon dosimetry*
Fourth Information Seminar on the radiation protection dosemeter intercomparison programme
Bilthoven 25-27 October 1982,
Luxembourg, 1984 (EUR 9192 EN)

N° 31 *Radiological protection of the public in respect of consumer goods containing radioactive substances – A guide on the radiological protection criteria prepared by a group of experts convened by the Commission of the European Community,*
Luxembourg, 1984 (EUR 9290 DE/EN/FR)

N° 32 *Radiation protection optimization*
"As low As Reasonably Achievable",...
Proceedings of the second European scientific seminar held in Luxembourg, 8 and 9 November 1983,
Luxembourg, 1984 (EUR 9173 EN)

N° 33 *Legislation*
Council Directive of 3 September 1984 laying down basic measures for the radiation protection of persons undergoing medical examination or treatment.
Council Directive of 3 September 1984 amending Directive 80/836 Euratom as regards the basic safety standards for the health protection of the general public and workers against the dangers of ionizing radiation,
Luxembourg, 1985 (EUR 9728 DA/DE/EN/FR/GR/IT/NL)

N° 34 *Results of environmental radioactivity measurements in the Member States of the European Community for*
Air – Deposition – Water – Milk 1982-1983
Luxembourg, 1985 (EUR 10235 DA/DE/EN/FR/GR/IT/NL

N° 35 *Méthodes d'évaluation des conséquences de l'irradiation des populations*
Rapport final 1981-1984,
Luxembourg, 1986 (EUR 10289 FR, EN)

N° 36 *Occupational radiation dose statistics from Light Water power Reactors operating in Western Europe*
I.R. BROOKES, T. ENG,
Luxembourg, 1987 (EUR 10971 EN)

N° 37 *Radiological mass screening within the Member States of the European Community. Regulations, Practices, Effectiveness.*
Proceedings of a seminar held in Luxembourg, 3-4 December 1985,
Luxembourg, 1987 (EUR 11059 EN)

N° 38 Beta dosimetry
Fifth Information Seminar on the radiation protection dosemeter intercomparison programme, Bologna 25-27 May 1987,
Luxembourg, 1988 (EUR 11363 EN)

N° 39 Problèmes d'intervention médicale à mettre en oeuvre en cas de surexposition aux rayonnements ionisants;
Actes d'un séminaire, Luxembourg, 19-21 février 1986,
Luxembourg, 1987 (EUR 11 370 FR)

N° 40 Standing Conference on Health and Safety in the Nuclear Age. First meeting : Information of the public and the media on health protection and safety with regard to nuclear activities.
Proceedings of a conference held in Luxembourg, 5-7 October 1987,
Luxembourg 1988 (EUR 11 608 DE/FR/EN)

N° 41 Intercomparison of environmental gamma dose rate meters; a comprehensive study of calibration methods and field measurements. Part I : 1984 and 1985 experiments.
Luxembourg 1989 (EUR 11 665 EN)

N° 42 Methods used for fixing discharge limits for radioactive effluents from nuclear installations in the Member States; a review and analysis,
Luxembourg, 11/1988 (Doc. XI-3133/88 EN)

N° 43 Radiological protection criteria for the recycling of materials from the dismantling of nuclear installations : recommendations from the Group of Experts set up under the terms of Article 31 of the Euratom Treaty,
Luxembourg, 11/1988 (Doc. XI-3134/88 EN)

N° 44 Third European scientific seminar on radiation protection optimization - "Advances in practical implementation" -
Proceedings of a seminar held in Madrid, 12-14 September 1988,
Luxembourg 1989 (EUR 12 469 EN)

N° 45 Radiation Protection Training and Information for workers;
Proceedings of a seminar held in Luxembourg, 28-30 November 1988,
Luxembourg 1989 (EUR 12 177 EN/FR)

N° 46 Environmental radioactivity levels in the European Community - 1984 - 1985 - 1986
Luxembourg 1989 (EUR 12254 EN)

N° 47 The radiological exposure of the population of the european community from radioactivity in North european marine waters. Project "MARINA" A report by a group of experts convened by the Commission of the European Communities,
Luxembourg 1990 (EUR 12 483 EN)

N° 48 Intercomparison of environmental gama dose rate meters; a comprehensive study of calibration methods and field measurements. Part II : 1987 to 1989 experiments,
Luxembourg 1990 (EUR 12 731 EN)

N° 49 Standing Conference on Health and Safety in the Nuclear Age. Second meeting : Informing the public on improvements in emergency planning and nuclear accident management.
Proceedings of a conference held in Brussels, 5-6 December 1989,
Luxembourg 1990 (EUR 12 682 DE/FR/EN)

N° 50 Impact radioécologique de l'accident de Tchernobyl sur les écosystèmes aquatiques continentaux.
L. FOULQUIER
Luxembourg, 1990 (Doc. 3522/90 FR)

N° 51 Survey on Education and Training of Medical Physicists in the countries of the European Communities with reference to the Patient Directive (84/466/Euratom).
A. SCHMITT-HANNIG
Luxembourg, 1991 (EUR 13 298 EN)

N° 52 Transfer of Radioactivity through Food Chains following the Chernobyl Accident: a review of the Data and their Implications for Dose Assessment Methodology.
P.J. COUGHTREY, A. JACKSON, C.J. BEETHAM
Luxembourg, 1991 (EUR 13436)

N° 53 Comparative assessment of the environmental impact of radionuclides during three major nuclear accidents:
Kyshtym, Windscale, Chernobyl.
Proceedings of a seminar held in Luxembourg, 1-5 October 1990,
Luxembourg, 1991 (EUR 13574) - 2 volumes

N° 54 Intervention Levels and Countermeasures for Nuclear Accidents
Proceedings of a seminar held in Cadarache, 7-11 October 1991
Luxembourg, 1992 (EUR 14469)

N° 55 Radiocesium contamination of foodstuffs in Greece following the Chernobyl accident.
G. APOSTOLATOS, A.A. KATSANOS
Luxembourg, 1992 (Doc XI-4074)

N°56 Occupational radiation exposure in European light-water power reactors. 1981-1990.
I.R. BROOKES, K. SCHNUER
Luxembourg, 1992 (EUR 14685 EN)

N° 57 *Introduction to the Radioecology of forest ecosystems and Survey of radioactive contamination in food products from forests.*
A. FRAITURE
Luxembourg, 1992

N° 58 *Impact radiologique de l'accident de Tchernobyl sur les écosystèmes aquatiques*
L. FOULQUIER, Y. BAUDIN-JAULENT
Luxembourg, 1992

N° 59 *Development of a General Guideline for the Radiological Optimisation of the Restoration of Old Nuclear Sites*
Th. ZEEVAERT, P. GOVAERTS
Luxembourg, 1993

N° 60 *Off-site Emergency Response to Nuclear Accidents. Manual based on training courses organised in 1991 and 1992 at the SCK/CEN MOL, Belgium*
Editor: J. LAKEY
Luxembourg, 1993

N° 61 *Radiation Exposure of Civil Aircrew*
Proceedings of a workshop held in Luxembourg, 25-27 June 1991
(EUR 14964 EN)

N° 62 *PC COSYMA: An Accident Consequence Assessement Package For Use on a PC*
J.A. JONES, P.A MANSFIELD, S.M. HAYWOOD, A.F. NISBET, I. HASEMANN, C. STEINHAUER, J. EHRHARDT
(EUR 14916)

N° 63 *Radiation protection optimization "Achievements and opportunities"*
Proceedings of the Fourth European Scientific Seminar held in Luxembourg, 20-22.4.1993

N° 64 *Radiological Protection Principles for Relocation and Return of People in the Event of Accidental Releases of Radioactive Material.*
Recommendations from the Group of Experts set up under the terms of Article 31 of the Euratom Treaty.
(XI-027/93)

N° 65 *Principles and Methods for Establishing Concentrations and Quantities (Exemption values) Below which Reporting is not Required in the European Directive.*
M. HARVEY, S. MOBBS, J. COOPER, A.M. CHAPIUS, A. SUGIER, T. SCHNEIDER, J. LOCHARD, A. JANSSENS.
(XI-028/93)

Further information may be obtained from:

Commission of the European Communities
- Radiation Protection Division -
Mr. H. Leilig
Centre Wagner
Rue Alcide de Gasperi
L-2920 LUXEMBOURG

Tel: (352) 4301-36383, Fax.: (352) 4301-34646