SAFETY SERIES No. 111-G-1.1

SAFETY GUIDES

safety series

Classification of Radioactive Waste

A Safety Guide

A PUBLICATION WITHIN THE RADWASS PROGRAMME

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1994

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CLASSIFICATION OF RADIOACTIVE WASTE

A Safety Guide

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A Safety Guide

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FOREWORD

Radioactive waste is generated from the production of nuclear energy and from the use of radioactive materials in industrial applications, research and medicine. The importance of safe management of radioactive waste for the protection of human health and the environment has long been recognized and considerable experience has been gained in this field. The Radioactive Waste Safety Standards (RADWASS) programme is the IAEA's contribution to establishing and promoting, in a coherent and comprehensive manner, the basic safety philosophy for radioactive waste management and the steps necessary to ensure its implementation.

The RADWASS publications will: (a) reflect the existing international consensus in the approaches and methodologies for safe radioactive waste management, including disposal, and provide mechanisms to establish consensus where it does not yet exist; and (b) provide Member States with a comprehensive series of internationally agreed upon documents to assist in the derivation of new, or to complement existing, national criteria, standards and practices.

In keeping with the IAEA's Safety Series structure, the RADWASS publications are organized in four hierarchical levels. The leading publication in this series is the Safety Fundamentals. This publication lays down the basic objectives and fundamental principles for the management of radioactive waste.

In addition to the Safety Fundamentals, six Safety Standards cover the following subjects:

— Planning
— Predisposal
— Near surface disposal
— Geological disposal
— Uranium/thorium mining and milling
— Decommissioning/environmental restoration.

As the programme develops, other subjects may be added to this list.

The Safety Standards are supplemented by a number of Safety Guides and Safety Practices.

This Safety Guide addresses the subject of radioactive waste classification. It outlines various possibilities for the development of a classification system for radioactive waste, proposes a modified classification system with general quantitative boundaries, and gives guidance for the development of quantitative classification systems.

The Safety Guide has been prepared through two Consultants Meetings and a Technical Committee Meeting. The list of contributors to drafting and review of the Safety Guide along with their affiliations is given at the end of the report. The IAEA

wishes to acknowledge the contributions made by the experts in the preparation of the Safety Guide, especially E. Detilleux, who chaired the Technical Committee Meeting and G. Roles, who provided valuable comments and suggestions. D.J. Squires, M.J. Bell and E. Warnecke of the Division of Nuclear Fuel Cycle and Waste Management were the responsible officers at the IAEA.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

BACKGROUND

101. Radioactive wastes are generated in a number of different kinds of facilities and arise in a wide range of concentrations of radioactive materials and in a variety of physical and chemical forms. There is also a variety of alternatives for treatment and conditioning of the wastes prior to disposal. Likewise, there are a number of alternatives for safe disposal of these wastes, ranging from geological disposal to near surface disposal and direct discharge to the environment. To simplify their management, a number of schemes have evolved for classifying radioactive waste according to the physical, chemical and radiological properties of significance to those facilities managing this waste. These schemes have led to a variety of terminologies, differing from country to country and even between facilities in the same country. This situation makes it difficult for those concerned to communicate with one another regarding waste management practices, causes problems in comparing data published in the scientific literature, and causes confusion among members of the public trying to understand waste management programmes and practices of their country and of other Member States.

102. This document revises and updates earlier IAEA references on radioactive waste classification systems given in IAEA Technical Reports Series No. 101 [1] and Safety Series No. 54 [2]. Guidance regarding exemption of materials from regulatory control is consistent with IAEA Safety Series No. 89 [3] and the RADWASS documents published under IAEA Safety Series Nos 111-G-1.5 [4], 111-P-1.1 [5] and 111-P-1.2 [6].

OBJECTIVE

103. The objective of this Safety Guide is to recommend a method of deriving a classification system and to suggest a general system for classifying radioactive waste that will facilitate communication and information exchange among Member States, and eliminate some of the ambiguity that now exists in classification schemes for radioactive waste.

104. Furthermore, this Safety Guide is to specify boundaries in a general system for classifying radioactive waste, especially in the assignment of boundaries to radioactive waste classes. It describes how to deal with a classification system, points out approaches for further quantification of classes by setting limits for individual radionuclides and discusses methods by which boundaries can be derived.

SCOPE

105. This document provides guidance on classification of radioactive waste. It refers to those materials without a foreseen use that are considered appropriate for control as radioactive waste by the regulatory body. These materials contain or are contaminated with radionuclides at concentrations or radioactivity levels greater than the clearance levels for the exemption from nuclear regulatory control established by the regulatory body. It addresses classification of gaseous, liquid and solid radioactive waste, and identifies characteristics important to their management. It considers classification of a wide range of radioactive wastes: from high level waste including spent nuclear fuel when it is considered radioactive waste, to wastes having such low levels of radioactivity that they cannot be considered as 'radioactive' and consequently can be safely disposed of without further nuclear regulatory control.

STRUCTURE

106. The main text of the Safety Guide is organized as follows:

(a) Section 2 outlines the general approaches to radioactive waste classification, the different methods for the derivation of radioactive waste classes and the limitations of radioactive waste classification.
(b) In Section 3, a simple waste classification scheme based on international practices is proposed; boundary levels are given in terms of parameters most relevant for the safe handling and disposal of radioactive waste.

2. APPROACHES TO RADIOACTIVE WASTE CLASSIFICATION

PURPOSE OF CLASSIFICATION

201. Classification is an approach which is used, mainly when the quantity of elements considered (objects or ideas) is large, to ease management of the elements by reducing their number. Classification is realized by selecting the main features (criteria) and by structuring these criteria.

202. Classification may be more or less precise depending on the number of classes and the criteria considered. The degree of differentiation depends on the purpose of the classification. It is essential, however, that

— the definition of the classes and the derivation of the corresponding levels are clear and easily understood and developed on a sound technical basis;
— the restrictions of the applicability of the classification system are clearly known; and
— the number of classes is balanced between the desired differentiation and the ease of handling of the classification system.

203. Classification systems for radioactive waste may be derived from different points of view, such as safety related aspects, process engineering demands or regulatory issues. In this publication, emphasis is given to the safety related aspects, since these are in most cases of highest importance. This does not preclude the consideration of other aspects.

204. Classification of radioactive waste may be helpful at any stage between the arising of the raw waste and its conditioning, interim storage, transportation and disposal. Therefore, classification of radioactive waste will serve many purposes. It will help:

- at the conceptual level
  — in devising waste management strategies;
  — in planning and designing waste management facilities;
  — in designating radioactive waste to a particular conditioning technique or disposal facility;
- at the operational level
  — by defining operational activities and in organizing the work with waste;
  — by giving a broad indication of the potential hazards involved with the various types of radioactive waste;
  — by facilitating record keeping;
- for communication
  — by providing words or acronyms universally understood which improve communication among experts from different countries, and between experts, generators and managers of radioactive waste, regulators and the public.

205. To satisfy these purposes, an ideal radioactive waste classification system should meet a number of objectives, including the following:

— cover the full range of radioactive waste types;
— address all stages of radioactive waste management;
— relate radioactive waste classes to the associated potential hazard;
— be flexible to serve specific needs;
— change already accepted terminology as little as possible;
— be simple and easy to understand; and
— be as universally applicable as possible.

It should be clear from this list that an ideal classification system does not exist. For instance, a classification system cannot at the same time be universally applicable and still reflect the finer details of all the stages of radioactive waste management. Compromise is needed, and because a primary purpose of an international document is to facilitate communication, the compromise should be sought in the direction of simplicity and flexibility.

METHODS OF CLASSIFICATION

206. Depending on the purpose of a radioactive waste classification system there exist different approaches to its derivation [7]. One basic method of classification is a qualitative description of the individual classes. In this case, mostly general characteristics of the radioactive waste are used as criteria for the classification. Nonetheless, numerical values to characterize broad bands or orders of magnitude may also be helpful for classification by this approach. The other method is a quantitative approach, i.e. numerical values are given for the definition of most classes.

207. The methods described in the following sections have been derived mainly from the safety aspects of radioactive waste disposal, but can be developed into the other stages of radioactive waste management. It is reasonable to start classification from the point of disposal to keep consistency among the different stages of radioactive waste management.

208. A clear distinction has to be made between a classification system and a set of regulatory limits. The purpose of classification is to simplify language and to help planning, while the purpose of regulatory limits is to ensure safety. Therefore, the effort in developing precise limits has to be applied within the regulatory framework of licensing or authorizing specific radioactive waste management activities. Actual quantity or concentration limits for the classification of radioactive waste are to be established by the regulatory body of a Member State. While a radioactive waste classification system may be useful for generic safety considerations, it is not a substitute for specific safety assessments performed for an actual facility involving well-characterized types of radioactive waste.

Qualitative classification

209. There already exist 'natural' classification systems, e.g. grouping the radioactive wastes in terms of their origin. An example for such a qualitative classification system is given in the Annex. While this system is convenient for bookkeeping, notification and registration, it fails to meet many of the objectives listed in

para. 205. Moreover, even within a given type of radioactive waste, the characteristics related to safety may vary widely and necessitate different treatment of subtypes.

210. Another 'natural' classification system is the differentiation of radioactive wastes according to the physical state, i.e. solid, liquid, gaseous. This system stems from the process engineering needs for the treatment of the different radioactive waste streams and is often refined corresponding to individual radioactive waste treatment systems. A classification system of this type is mostly specific to individual facilities and follows their technical needs and possibilities. It may, however, incorporate safety considerations such as the radiation protection necessary for radioactive waste classes with higher radioactivity content.

211. A widely used qualitative classification system separates radioactive waste into three classes: low level waste (LLW), intermediate level waste (ILW) and high level waste (HLW). A further distinction is made between short lived and long lived waste [2]. These classes address activity content, radiotoxicity and thermal power. The differentiation between the long and short lived radionuclide content is made to assist in the choice of the appropriate type of repository (see also para. 302). This system mainly serves the purpose of facilitating international communication.

Derivation of quantitative criteria

212. Quantitative guidance with regard to radiological parameters such as dose rate or activity level has also been given [1]. The proposals originated from qualitative considerations of practical aspects related to processing and transportation of radioactive waste. Thus they are not based on quantitative assessments and justifications.

213. Classification of radioactive waste in many cases is related to safety aspects of their management. In this context it provides a link between the waste characteristics and safety objectives that have been set up by a regulatory body or the operator of a waste management facility. Since safety objectives are formulated in general in terms of numerical values, a quantitative approach to classification is necessary for this purpose. To derive a quantitative classification system a common procedure should be used which is outlined in the following paragraphs.

214. The first step is a definition of the purpose of the classification system, since any classification system can only address a particular aspect of radioactive waste management. This implies the decision on such aspects as

— the type of radioactive waste to be covered;
— the activity or installation considered;

— the corresponding level of application (planning, operation, post-operation); and
— the safety objectives to be met.

215. The next step requires the definition of the areas that are addressed by the system, for example

— exposure of personnel;
— exposure of members of the public;
— contamination of the environment;
— safety from criticality;
— normal operation, incidents or accidental conditions;
— heat generation of radioactive waste;
— process engineering aspects.

Communication is another important issue to be addressed.

216. For some of these areas regulatory or technical constraints may exist that have to be taken into account. These may be, for example,

— the radioactive waste itself, characterized by the annual arising, the spectrum of radionuclides and their concentrations;
— limits and requirements set by the authorities;
— pathways or scenarios prescribed for safety assessments;
— operational limits;
— site specific conditions (e.g. for radioactive waste disposal, geological, hydrogeological, and climatic characteristics may restrict the choice of a disposal site or of the type of radioactive waste that can be disposed of at the site);
— social or political aspects; and
— legal definitions and requirements.

These factors may restrict the degree of freedom for the choice and the development of a classification system and therefore have to be evaluated before the classification system can be derived.

217. Once the framework for classification has been set, the parameters to be used for classifying may be chosen in a third step. Starting from the radioactive waste itself, there are a number of properties that may be taken into account. Table I lists the more important ones that are used in one or the other case.

218. The possible scenarios, design options and site specific options have then to be evaluated in a fourth step to assess their suitability as classification parameters. Factors to be considered regarding disposal of radioactive waste in a repository are:

TABLE I. IMPORTANT PROPERTIES OF RADIOACTIVE WASTE USED AS CRITERIA FOR CLASSIFICATION

- Origin
- Criticality
- Radiological properties:
  - half-life
  - heat generation
  - intensity of penetrating radiation
  - activity and concentration of radionuclides
  - surface contamination
  - dose factors of relevant radionuclides
- Other physical properties:
  - physical state (solid, liquid or gaseous)
  - size and weight
  - compactability
  - dispersibility
  - volatility
  - solubility, miscibility
- Chemical properties:
  - potential chemical hazard
  - corrosion resistance/corrosiveness
  - organic content
  - combustibility
  - reactivity
  - gas generation
  - sorption of radionuclides
- Biological properties:
  - potential biological hazards

— interim storage for decay of radionuclides;
— selection of techniques for conditioning radioactive waste;
— engineering for handling of radioactive waste in the repository;
— administrative measures to be taken during handling of radioactive waste;
— engineered barriers to contain the radioactivity during handling and after emplacement (ventilation systems, backfill, dams, seals, covers);
— duration of institutional control as a factor in the design of a near surface disposal facility;
— improvements of some characteristics of the disposal site; and
— assignment of radioactive waste to a repository.

Interim storage may result in the subsequent attribution of a radioactive waste to a lower class and allow time to develop and implement a disposal strategy.

219. If a set of classification parameters has been chosen, intervals for numerical values or, as an alternative, qualitative characteristics are defined as limits for different classes. Assigning the considered types of radioactive waste to these classes will show whether or not a meaningful system has been established.

220. Normally, the classification system results from an iterative procedure in which the steps described in paras 214–219 are repeated until a satisfying result is reached.

221. A comparable procedure is in principle to be used in safety analyses for radioactive waste management facilities, especially for a repository. However, classification parameters, intervals for numerical values and resulting limits cannot be chosen as desired. They are derived from regulatory or legal requirements, e.g. by safety analyses, and will have to be mandatory with limits generally expressed as allowable values for the activity of individual radionuclides and for other properties of waste packages. At such an advanced level, an integrated, detailed classification system for radioactive waste can be established which covers all radioactive waste management steps from the generation of radioactive waste to its disposal [8]. Furthermore, it must be assured that all corresponding parameters are set up in such a way that they are amenable to being controlled or checked in individual waste packages.

3. PROPOSAL FOR A RADIOACTIVE WASTE CLASSIFICATION SYSTEM

INTRODUCTION

301. A classification system has previously been proposed by the IAEA [1, 2] placing radioactive waste into one of three classes: (1) high level waste (HLW), (2) intermediate level waste (ILW), or (3) low level waste (LLW), which are defined in Ref. [2] as:

High level waste. (i) The highly radioactive liquid, containing mainly fission products, as well as some actinides, which is separated during chemical reprocessing of irradiated fuel (aqueous waste from the first solvent extraction cycle and those waste streams combined with it). (ii) Any other waste with radioactivity levels intense enough to generate significant quantities of heat by the radioactive decay process. (iii) Spent reactor fuel, if it is declared a waste.

Intermediate level waste (medium level waste). Waste which, because of its radionuclide content requires shielding but needs little or no provision for heat dissipation during its handling and transportation.

Low level waste. Waste which, because of its low radionuclide content, does not require shielding during normal handling and transportation.

302. Within the ILW and LLW classification, the IAEA also differentiated between short and long lived waste, as well as alpha bearing waste [2]. Here the term short lived waste refers to radioactive waste which will decay to an activity level which is considered to be acceptably low from a radiological viewpoint, within a time period during which administrative controls can be expected to last. (Such waste can be determined by radiological performance assessment of the storage or disposal system chosen.) Long lived waste is radioactive waste that will not decay to an acceptable activity level during the time which administrative controls can be expected to last. Alpha bearing waste is radioactive waste containing one or more alpha emitting radionuclides, usually actinides, in quantities above acceptable limits established by the national regulatory body.

303. This classification system has proved to be useful for general purposes, although there are limitations. First, the classification system lacks a completely clear linkage to safety aspects in radioactive waste management, especially disposal. In addition, many countries use different definitions of radioactive waste consistent with their national programmes or mandates. Some countries classify radioactive waste according to the facilities in which this waste is generated, or by the processes that generate such waste. In addition, the current classification system lacks quantitative boundaries between classes and recognition of a class of waste that contains so little radioactive material that it cannot be considered as 'radioactive' and consequently may be exempted from control as radioactive waste. Finally, it lacks recognition of wastes such as those from mining and milling uranium ore, that contain small quantities of natural radionuclides dispersed through very large volumes of material.

SYSTEM OVERVIEW

304. To address these limitations and to improve communication, a modified classification system is proposed. An approach directed to that outlined in paras 212–221 has been adopted to develop this classification system. From this approach, three major classes of waste were identified and used as the basis for the system:

- Waste containing such a low concentration of radionuclides that it can be exempted from nuclear regulatory control in accordance with clearance levels, as the associated radiological hazards are negligible.

- Waste that contains such an amount of radioactive material that it requires actions to ensure the protection of workers and the public either for short or for long periods of time. This class covers a very wide range of radioactive wastes, ranging from radioactive waste just above exempt levels, e.g. not requiring shielding or particular confinement, to radioactive waste that contains such high levels of radioactivity that shielding and possibly cooling may be required. A range of disposal methods may be postulated for such waste.
- Waste that contains such high levels of radioactive material that a high degree of isolation, normally geological isolation, from the biosphere is required over long time periods. Such waste normally requires both shielding and cooling.

305. Although the principles of the existing classification system are retained, the revised classification system is organized to take into account matters considered of prime importance for disposal safety. Sufficient experience has been gained so that general quantitative boundaries between classes can be drawn. More detailed quantitative boundaries may be developed in accordance with national programmes and requirements.

306. The boundary levels addressed in this chapter are primarily applicable to solid radioactive waste, which is either generated as such or results from treatment and conditioning applied to liquid or gaseous radioactive waste, with a view to their further transportation, storage or disposal. See also paras 334–336.

WASTE CLASSES

307. The revised classification system is presented in Fig. 1. The principal waste classes include exempt waste, low and intermediate level waste, which may be subdivided into short lived and long lived waste, and high level waste.

308. Considering Fig. 1 vertically, radioactivity levels range from negligible to very high concentrations of radionuclides. As the level rises, there is an increased need to isolate the waste from the biosphere; suitable disposal options may range from simple and conventional methods to geological isolation. In addition, there is an increased need to consider shielding from radiation, and the generation of heat from radioactive decay.

309. Considering the figure horizontally, decay periods range from short (seconds) to very long time spans (millions of years) and similarly radioactive wastes range from those containing minor quantities of long lived radionuclides to those containing significant quantities thereof. As appropriate, radioactive waste may be (1) stored for decay and then exempted, (2) disposed of in near surface facilities, or (3) isolated

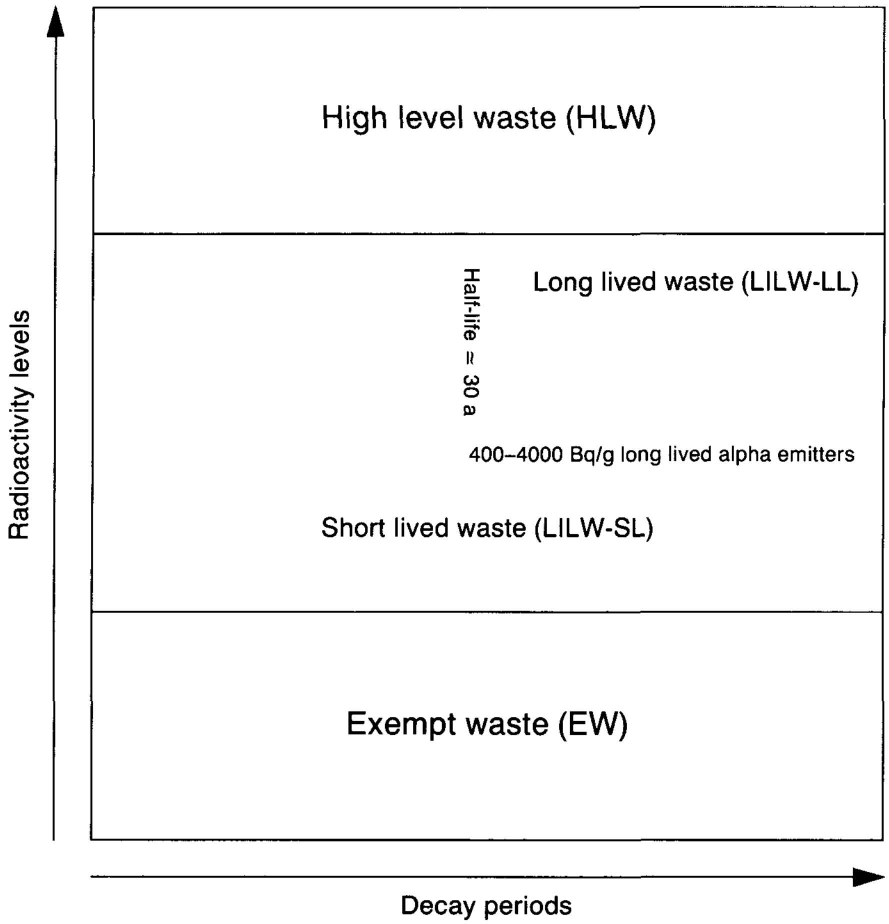

FIG. 1. Revised waste classification system.

from the biosphere in deep geological formations. This situation is reflected as two subclasses of radioactive waste distinguish short lived and long lived low and intermediate level waste.

310. Such a distinction between short lived and long lived low and intermediate level waste can be of substantial benefit because the radiological hazards associated with short lived radionuclides can be significantly reduced over a few hundred years by radioactive decay. Different time periods for the isolation of short lived and long lived low and intermediate level waste will be necessary. Activity limitations for a given disposal facility will in particular depend on the radiological, chemical, physical and biological properties of individual radionuclides. It can by no means be

implied that long lived radionuclides are inherently more hazardous than short lived radionuclides.

311. Additional considerations apply: (1) when the radioactive waste is characterized by long lived natural radionuclides, (2) when consideration should be given to the heat generated from radioactive decay, (3) when segregation of radioactive waste for near surface or geological disposal is applied, and (4) when liquid or gaseous radioactive waste is generated.

312. Below, a more detailed discussion is presented for each of the revised waste classes. Boundary levels between classes are presented as orders of magnitude and typical characteristics of waste classes are summarized in Table II. A more detailed classification of radioactive waste which provides a further subdivision of wastes within waste classes will depend on individual national programmes or requirements. Also addressed are suggestions for application of the modified classification system to actual disposal facilities.

313. Application of a classification system for the management of radioactive waste implies an adequate separation of wastes generated. A decision chart for the segregation of radioactive and exempt waste is presented in Fig. 2.

Exempt waste (EW)

314. Exempt waste (EW) contains so little radioactive material that it cannot be considered 'radioactive' and might be exempted from nuclear regulatory control. That is to say, although still radioactive from a physical point of view, this waste may be safely disposed of, applying conventional techniques and systems, without specifically considering its radioactive properties.

315. Many studies have been performed on the subject of waste exemption. The IAEA provides recommendations on exemption from regulatory control and specifies unconditional clearance levels for radionuclides in solid materials [4] based on limiting annual doses to members of the public to 0.01 mSv, consistent with the guidance outlined in Ref. [3]. The recommended activity concentrations are dependent on the individual radionuclide and range from about 0.1 Bq/g to about 10^4 Bq/g. Because possible individual radiation doses are trivial at these concentrations, no particular attention needs to be paid to the radioactive properties of such waste.

316. Levels of activity concentration for exempt waste higher than those suggested in Ref. [4] may be established by the national authority on a case by case basis if specific national peculiarities are considered or defined requirements or conditions

TABLE II. TYPICAL CHARACTERISTICS OF WASTE CLASSES

Waste classes	Typical characteristics	Disposal options
1. Exempt waste (EW)	Activity levels at or below clearance levels given in Ref. [4], which are based on an annual dose to members of the public of less than 0.01 mSv	No radiological restrictions
2. Low and intermediate level waste (LILW)	Activity levels above clearance levels given in Ref. [4] and thermal power below about $2 kW/m^3$	
2.1. Short lived waste (LILW-SL)	Restricted long lived radionuclide concentrations (limitation of long lived alpha emitting radionuclides to 4000 Bq/g in individual waste packages and to an overall average of 400 Bq/g per waste package); see paragraphs 324 and 325	Near surface or geological disposal facility
2.2. Long lived waste (LILW-LL)	Long lived radionuclide concentrations exceeding limitations for short lived waste	Geological disposal facility
3. High level waste (HLW)	Thermal power above about $2 kW/m^3$ and long lived radionuclide concentrations exceeding limitations for short lived waste	Geological disposal facility

are given for the exemption of waste. The levels of activity concentration appropriate for conditionally exempt waste are highly dependent on the conditions for exemption. Actual values can be derived for individual cases.

317. It is important to obtain a consensus on the boundary for unconditionally exempt material which may be transferred from one country to another (e.g. for recycle/reuse). It would be of great value if the same limits could be adopted by different countries. This would greatly simplify exemption procedures and would increase the confidence of the public in such practices.

Low and intermediate level waste (LILW)

318. Low level waste has been defined in the past to mean radioactive waste that does not require shielding during normal handling and transportation [2]. Radioactive waste which required shielding but needed little or no provision for heat dissipation was classified as intermediate level waste [2]. A contact dose rate of 2 mSv/h [9] was generally used to distinguish between the two classes.

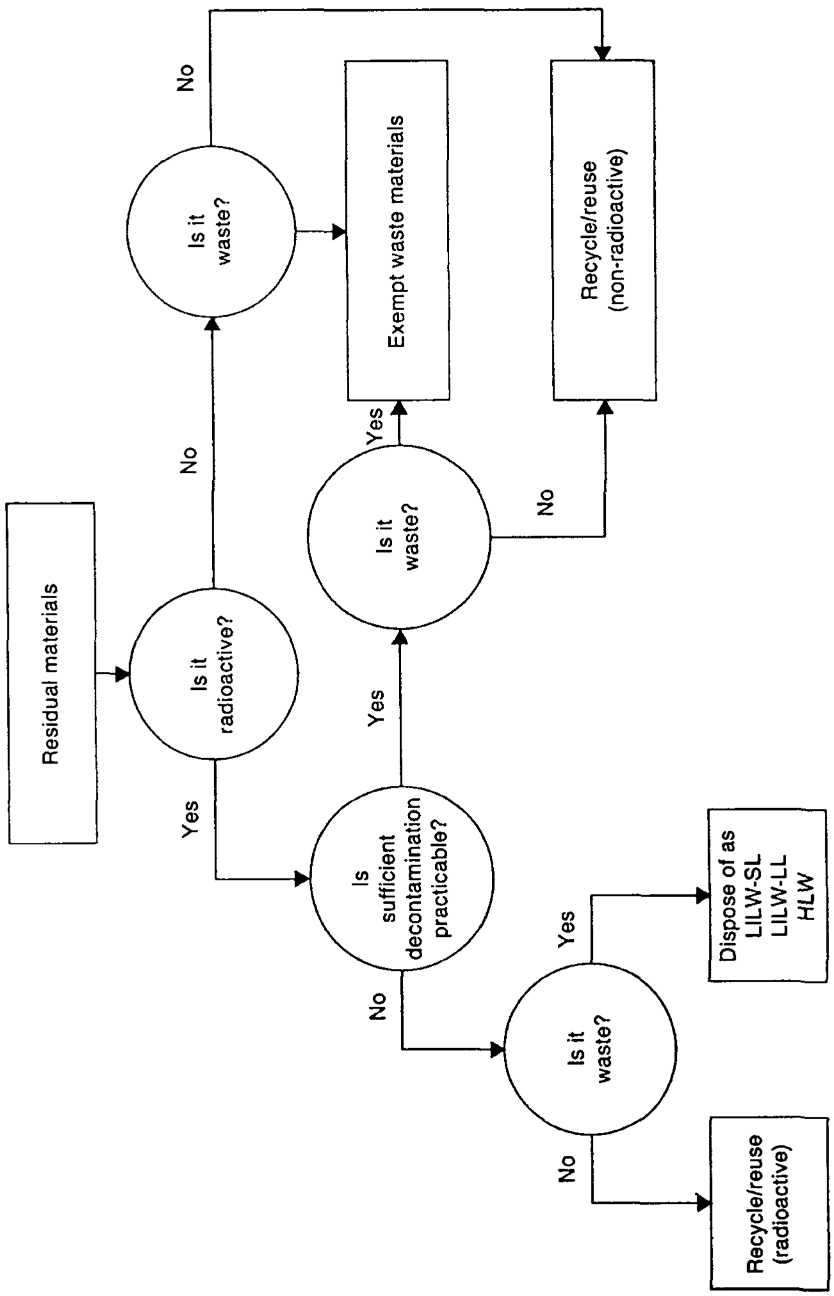

FIG. 2. Decision chart for segregation of radioactive and exempt waste.

319. This distinction appears of secondary importance in the present context. Classification should be related to individual radionuclides, taking the various exposures and exposure pathways into account, such as inhalation (e.g. in the case of an incident) and ingestion (e.g. in the case of long term releases in the post-operational period of a repository). Thus, low and intermediate level waste may be subdivided into short lived and long lived waste. Additional considerations which must be taken into account in managing low and intermediate level waste are presented subsequently under 'Additional Considerations'.

(a) Short lived waste (LILW-SL)

320. Short lived low and intermediate level waste (LILW-SL) contains low concentrations of long lived radionuclides. The possible hazard represented by the waste can often be significantly reduced by administratively controlling waste as part of storage or after disposal. Although the waste may contain high concentrations of short lived radionuclides, significant radioactive decay occurs during the period of institutional control. Concentrations of long lived radionuclides that will not decay significantly during the period of institutional control are controlled to low levels consistent with the radiotoxicity of the radionuclides and requirements set forth by national authorities.

321. Because LILW-SL may be generated in a wide range of concentrations, and may contain a wide range of radionuclides, there may be a range of acceptable disposal methods. The waste form or packaging may also be important for management of this waste. Depending upon safety analyses and national practices, these methods may range from simple surface landfills, to engineered surface facilities, and to disposal at varying depths, typically a few tens of metres, or in deep geological formations if a co-disposal of short and long lived waste is anticipated. National practices may impose varying levels of isolation depending upon the hazard represented by different classes of radioactive waste.

322. From existing criteria it appears that a general boundary between near surface and geological disposal of radioactive waste cannot be provided, as activity limitations will differ between individual radionuclides or radionuclide groups and will be dependent on the actual planning for a near surface disposal facility (e.g. engineered barriers, duration of institutional control, site specific factors).

(b) Long lived waste (LILW-LL)

323. Long lived low and intermediate level waste (LILW-LL) contains long lived radionuclides in quantities that need a high degree of isolation from the biosphere

(see para. 310). This is typically provided by disposal in geological formations at a depth of several hundred metres.

324. The boundary between short lived and long lived waste cannot be specified in a universal manner with respect to concentration levels for radioactive waste disposal, because allowable levels will depend on the actual radioactive waste management option and the properties of individual radionuclides. However, in current practice with near surface disposal in various countries, activity concentration is limited to 4000 Bq/g of long lived alpha emitters in individual radioactive waste packages [10], thus characterizing long lived waste which is planned to be disposed of in geological formations. This level has been determined based on analyses for which members of the public are assumed to access inadvertently a near surface repository after an active institutional control period, and perform typical construction activities (e.g. constructing a house or a road).

325. Applying this classification boundary, consideration should also be given to accumulation and distribution of long lived radionuclides within a near surface repository and to possible long term exposure pathways. Therefore, restrictions on activity concentrations for long lived radionuclides in individual waste packages may be complemented by restrictions on average activity levels or by simple operational techniques such as selective emplacement of higher activity waste packages within a disposal facility. An average limit of about 400 Bq/g for long lived alpha emitters in waste packages has been adopted by some countries for near surface disposal facilities [10].

326. In applying the classification system, attention should also be given to inventories of long lived radionuclides in a repository that emit beta or gamma radiation. For radionuclides such as ^{129}I or ^{99}Tc, allowable quantities or average concentrations within a repository depend strongly on site specific conditions. For this reason, national authorities may establish limits for long lived beta and gamma emitting radionuclides based on analyses of specific disposal facilities.

High level waste (HLW)

327. The high level waste (HLW) class largely retains the definition of the existing classification system. This waste contains large concentrations both of short and long lived radionuclides, so that a high degree of isolation from the biosphere, usually via geological disposal, is needed to ensure disposal safety. It generates significant quantities of heat from radioactive decay, and normally continues to generate heat for several centuries.

328. An exact boundary level is difficult to quantify without precise planning data for individual facilities. Specific activities for these waste forms are dependent on

many parameters, such as the type of radionuclide, the decay period and the conditioning techniques. Typical activity levels are in the range of 5×10^4 to 5×10^5 TBq/m^3, corresponding to a heat generation rate of about 2 to 20 kW/m^3 [11] for decay periods of up to about ten years after discharge of spent fuel from a reactor. From this range, the lower value of about 2 kW/m^3 is considered reasonable to distinguish HLW from other radioactive waste classes, based on the levels of decay heat emitted by HLW such as those from processing spent fuels.

329. The suggested boundary levels for high level waste need not be distinct because of the general consensus that a high degree of isolation is necessary for management of radioactive wastes having very high concentrations of short and long lived radionuclides. National programmes exist to manage such radioactive waste.

ADDITIONAL CONSIDERATIONS

330. A number of additional important factors should be considered when addressing specific types or properties of radioactive waste.

Waste containing long lived natural radionuclides

331. Many countries must address the disposal of very large quantities of waste containing long lived natural radionuclides. Such waste typically contains natural radionuclides like uranium, thorium, and radium and is frequently generated from uranium/thorium mining and milling or similar activities. It may also include waste from decommissioning of facilities, where other isotopes may also be present. The characteristics of these wastes are sufficiently different from other wastes that they may require an individual regulatory approach.

332. Although these wastes do contain long lived radionuclides, their concentrations are generally sufficiently low that either they can be exempted or disposal options similar to those for short lived waste may be considered, depending on safety analyses.

Heat generation

333. Although heat generation is a characteristic of high level radioactive waste, other radioactive wastes may also generate heat, albeit at lower levels. Heat generation is dependent upon the type and content of radionuclides (half-life, decay energy, etc.). Furthermore, the heat removal situation is highly important (thermal conductivity, storage geometry, ventilation, etc.). Therefore, heat generation cannot be

defined by a single value. The relevance of heat generation can vary by several orders of magnitude depending on the influencing parameters and the temperature limitations. Management of decay heat should be considered in a repository if the thermal power of waste packages reaches several W/m^3. Especially in the case of long lived waste, more restrictive values may apply.

Liquid and gaseous waste

334. The treatment of liquid waste (which may contain particulate solids) and gaseous waste (which may contain aerosols) aims at separating the radionuclides from the liquid or gaseous phase and concentrating them in a solid waste form. The separation is pursued until the residual concentration or total amount of radionuclides in the liquid or gaseous phase is below limits set by the regulatory body for the discharge of liquid or gaseous waste from a nuclear facility as an effluent. Treatment may include a storage period for radioactive decay.

335. Liquid and gaseous radioactive waste exceeding discharge limits set by national authorities should be conditioned for storage, transport and disposal. Only following sound safety analysis should radioactive waste in liquid or gaseous form be transported off the site or disposed of in terrestrial repositories in their original forms. Storage for decay at the facility of their origin may be considered as part of the conditioning process.

336. The classification of liquid and gaseous radioactive waste may be based on the different types of treatment that can be used, and on potential radiological, chemical and biological hazards. When solidified or conditioned for disposal these wastes fall under one of the solid radioactive waste classes.

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Annex

ORIGIN AND TYPES OF RADIOACTIVE WASTE

A-101. A great many activities involving the use of radionuclides and nuclear power generation result in generation of radioactive waste. Such activities include all steps in the nuclear fuel cycle (i.e. the activities associated with the generation of nuclear power) as well as other non-fuel-cycle activities. Radioactive waste may also be generated outside the nuclear activities by the (mostly large scale) processing of raw materials containing naturally occurring radionuclides which in some cases may be considered as being radioactive. Examples include phosphate ore processing and oil or gas exploration. The radionuclide content of radioactive waste from fuel cycle activities greatly exceeds the radionuclide content of materials from non-fuel cycle activities.

A-102. The radioactive waste that is generated is as varied in form, activity and type of contamination as it is in type of generating activity. It may be solid, liquid or gaseous. Within these groups are a variety of waste types such as trash, spent radioactive sources, pumps, pipes, ion exchange resins, sludges, and spent nuclear fuel. Activity levels range from extremely high levels associated with spent fuel and residues from fuel reprocessing to very low levels associated with radioisotope applications in laboratories, hospitals, etc. Equally broad is the spectrum of half-lives of the radionuclides contained in the radioactive waste. Which radionuclides are present will depend on the generating process; they may include uranium and other naturally occurring, transuranic and specific man-made radionuclides.

A-103. This annex briefly describes the major waste generating activities and the types of radioactive waste generated by each. The information contained in this annex is only qualitative, since quantities will be subject to variations.

NUCLEAR FUEL CYCLE

A-104. The nuclear fuel cycle refers to activities associated with the supply of fuel and the management of radioactive materials involved with the production of nuclear power. Although several nuclear fuel cycles are possible, the following description is limited to radioactive waste generated in the uranium fuel cycle. The major steps generating radioactive waste in the uranium fuel cycle are:

- *Mining and milling:* This waste results from the production of uranium. It contains low concentrations of uranium and is contaminated principally by its daughter products, e.g. thorium, radium and radon.

- *Fuel supply:* This waste may result from purification, conversion and enrichment of uranium and the fabrication of fuel elements. It includes contaminated trapping materials from off-gas systems, lightly contaminated trash, and residues from recycle or recovery operations. This radioactive waste generally contains uranium and, in the case of mixed oxide fuel, also plutonium.
- *Reactor operations/power generation:* This waste results from treatment of cooling water and storage ponds, equipment decontamination, and routine facility maintenance. Reactor waste is normally contaminated with fission products and activation products. Radioactive waste generated from routine operations includes contaminated clothing, floor sweepings, paper and concrete. Radioactive waste from treatment of the primary coolant systems and off-gas system includes spent resins and filters as well as some contaminated equipment. Radioactive waste may also be generated from replacement of activated core components such as control rods or neutron sources.
- *Management of spent fuel:* In addition to the radioactive waste described above, reactor operations generate spent nuclear fuel. This material contains uranium, fission products and actinides. It generates significant heat when freshly removed from the reactor. Spent fuel is either considered a waste or waste is generated from reprocessing operations. Reprocessing operations generate solid and liquid radioactive waste streams. Solid radioactive waste such as fuel element cladding hulls, hardware, and other insoluble residues are generated during fuel dissolution. They may contain activation products, as well as some undissolved fission products, uranium and plutonium. The principal liquid radioactive waste stream, however, is the nitric acid solution which contains both high activity fission products and actinides in high concentrations.

Transportation and storage of radioactive materials or radioactive waste and the disposal of radioactive waste are also essential parts of the nuclear fuel cycle.

PRODUCTION AND USE OF RADIONUCLIDES

A-105. The production and use of radionuclides are not directly related to nuclear power production. These activities generate smaller quantities of radioactive waste than do fuel cycle activities.

- *Research activities:* Research activities include a variety of activities and facilities such as research reactors, accelerators, and laboratory activities. All may generate radioactive waste, with the type and volume of waste dependent on the research conducted.
- *Radioisotope production:* The type and volume of radioactive waste produced depends on the radioisotope and its production method. Generally, the volume

of radioactive waste generated from these activities is small but, specific activities might be significant.

- *Radioisotope applications:* The use of radioisotopes may generate small volumes of radioactive waste. The type and volume of radioactive waste produced will depend on the application.

DECOMMISSIONING OF NUCLEAR FACILITIES

A-106. At the end of the useful life of a nuclear facility, adequate actions have to be taken to retire it from service, finally leading to unrestricted release or use of the site. The activities in decontamination and dismantling of a nuclear facility and the cleanup of the site will lead to radioactive waste which may vary greatly in type, activity, size and volume, and may be activated or contaminated. This waste may consist of solid materials such as process equipment, construction materials and tools. To reduce the amount of radioactive waste, decontamination of materials is widely applied. Radioactive liquid waste streams may originate from decontamination processes. Decommissioning waste may contain the radionuclide spectrum which has been used or generated in the respective nuclear facility.

WASTE NOT DERIVING FROM NUCLEAR ACTIVITIES

A-107. For several years, it has been recognized that industrial activities other than those mentioned above may also generate waste which in some cases may be considered as 'radioactive'. This is the case in industrial activities where raw materials containing naturally occurring radionuclides are processed on a large scale, for example the production of artificial fertilizers and the extraction of oil and gas.

A-108. In these cases, the natural radionuclides present at mostly low concentrations in the raw material (phosphate ore, oil, gas, etc.), are concentrated during the processing. They are found either in the products or in the different gaseous, liquid or solid waste streams. The concentration of the radionuclides in the waste streams may exceed the levels for exempt waste as recommended in Section 3. Because of their origin, these wastes contain only natural radionuclides.

GLOSSARY

The IAEA published a Radioactive Waste Management Glossary as TECDOC-264 (1982) and a second edition as TECDOC-447 (1988). Over the years, continuing developments in the field of radioactive waste management made it necessary to update or revise individual terms. New terms also needed to be defined or added to the Glossary. The IAEA recently published the third version of the Radioactive Waste Management Glossary, incorporating such updates, revisions and amendments. The Radioactive Waste Management Glossary serves as a source for the terms included in this Glossary.

activity. Of an amount of a radioactive nuclide in a particular energy state at a given time, the quotient of dN by dt, where dN is the expectation value of the number of spontaneous nuclear transitions from that energy state in the time interval dt:

$$A = \frac{dN}{dt}$$

The unit is s^{-1}.
The special name for the unit of activity is becquerel (Bq): 1 Bq = 1 s^{-1}.
(Although becquerel is a synonym for reciprocal second, it is to be used only as a unit for activity of a radionuclide.)
In practice, the former special unit curie (Ci) is still sometimes used:

1 Ci = $3.7 \times 10^{10}\,s^{-1}$ (exactly).

(See also **radioactivity**.)

analysis, safety. The evaluation of the potential hazards associated with the implementation of a proposed activity.

assessment, safety. An analysis to predict the performance of an overall system and its impact, where the performance measure is radiological impact or some other global measure of impact on safety.

clearance levels. A set of values, established by the regulatory body in a country or state, expressed in terms of activity concentrations and/or total activities, at or below which sources of radiation can be released from nuclear regulatory control. (See also **exemption**).

conditioning. Those operations that produce a waste package suitable for handling, transportation, storage and/or disposal. Conditioning may include the conversion of the radioactive waste to a solid waste form, enclosure of the radioactive waste in containers, and, if necessary, providing an overpack. (See also **packaging**.)

contamination. The presence of radioactive substances in or on a material or in the human body or other place where they are undesirable or could be harmful.

control, institutional. (See institutional control.)

criteria. Conditions on which a decision or judgement can be based. They may be qualitative or quantitative and should result from established principles and standards. In radioactive waste management, criteria and requirements are set by a regulatory body and may result from specific application of a more general principle. (See also **specifications.**)

decontamination. The removal or reduction of radioactive contamination e.g. by a physical and/or chemical process. (See also **contamination.**)

disposal. The emplacement of waste in an approved, specified facility (e.g. near surface or geological repository) without the intention of retrieval. Disposal also covers the approved direct discharge of effluents (e.g. liquid and gaseous wastes) into the environment, with subsequent dispersion.

disposal, geological. Isolation of waste, using a system of engineered and natural barriers at a depth up to several hundred metres in a geologically stable formation. Typical plans call for disposal of long lived and high level wastes in geological formations.

disposal, near surface. Disposal of waste, with or without engineered barriers, on or below the ground surface where the final protective covering is of the order of a few metres thick, or in caverns a few tens of metres below the Earth's surface. Typically, short lived, low and intermediate level wastes are disposed of in this manner. This term replaces 'shallow land/ground disposal'.

effluent. Gaseous or liquid radioactive materials which are discharged into the environment.

exemption or **exempt.** A designation, by the regulatory body in a country or state, for sources of radiation that *are not* subject to nuclear control because they present such a low radiological hazard (principles for exemption are presented in IAEA Safety Series 89). Under this designation, a distinction can be made between sources which never enter the regulatory control regime (control is not imposed) and sources which are released from regulatory control (control is removed), in both cases because the associated radiological hazards are negligible. The latter is especially pertinent to radioactive waste management, where sources of radiation are released from nuclear regulatory control in accordance with established clearance levels. (See also **clearance levels.**)

fuel, spent (used). Irradiated fuel not intended for further use in reactors.

fuel cycle (nuclear). Processes connected with nuclear power generation, including the mining and milling of fissile materials, enrichment, fabrication, utilization and storage of nuclear fuel, optional reprocessing of spent fuel, and processing and disposal of resulting radioactive wastes.

geological repository. (See repository, geological.)

institutional control. Control of a waste site (e.g. disposal site, decommissioning site, etc.) by an authority or institution designated under the laws of a country or state. This control may be active (monitoring, surveillance, remedial work) or passive (land use control) and may be a factor in the design of a nuclear facility (e.g. near surface disposal facility).

long term. In radioactive waste disposal, refers to periods of time which *exceed* the time during which active institutional control can be expected to last.

milling. The operation of processing ore to extract uranium or thorium for conversion into reactor fuel.

near surface disposal. (See disposal, near surface.)

non-nuclear industry wastes. (See waste, non-nuclear industry.)

packaging. The preparation of radioactive waste (e.g. spent fuel) for safe handling, transportation, storage and disposal by means of enclosing a conditioned waste form in a suitable container. (See also **conditioning**; **waste package**.)

radioactivity. Property of certain nuclides to undergo spontaneous disintegration in which energy is liberated, generally resulting in the formation of new nuclides. The process is accompanied by the emission of one or more types of radiation, such as alpha particles, beta particles and gamma rays.

radionuclide. A nucleus (of an atom) that possesses properties of spontaneous disintegration (radioactivity). Nuclei are distinguished by their mass and atomic number.

repository. A nuclear facility where radioactive waste is emplaced for disposal. Future retrieval of waste from the repository is not intended. (See also **disposal**.)

repository, geological. A nuclear facility for waste disposal located underground (usually more than several hundred metres below the surface) in a stable geological formation to provide long term isolation of radionuclides from the biosphere. Usually such a repository would be used for long lived and/or high level wastes. (See also **disposal, geological**.)

reprocessing. Recovery of fissile and fertile material for further use from spent fuel by chemical separation of uranium and plutonium from other transuranic elements and fission products. Selected fission products may also be recovered. This operation also results in the separation of wastes.

requirements. Conditions defined as necessary to be met by a product, material, or process. (See also **criteria; specifications.**)

segregation. An activity where waste or materials (radioactive and exempt) are separated or are kept separate according to radiological, chemical and/or physical properties which will facilitate waste handling and/or processing. It may be possible to segregate radioactive from exempt material and thus reduce the waste volume.

solidification. Immobilization of gaseous, liquid or liquid-like materials by conversion into a solid waste form, usually with the intent of producing a physically stable material that is easier to handle and less dispersable. Calcination, drying, cementation, bituminization and vitrification are some of the typical ways of solidifying liquid radioactive waste. (See also **conditioning**.)

specific activity. (1) The activity of a radioisotope per unit mass of a material in which the radioisotope occurs.
(2) The activity of a radioisotope per unit mass of a material consisting of only that isotope.

specifications. Detailed requirements to be satisfied by a product, a service, a material or process, indicating the procedure by means of which it may be determined whether the specified requirements are satisfied. (See also **criteria; requirements**).

spent (used) fuel. (See fuel, spent (used).)

spent fuel package. Conditioned spent fuel in a form suitable for transportation, storage and/or disposal.

storage (interim). The placement of waste in a nuclear facility where isolation, environmental protection and human control (e.g. monitoring) are provided and with the intent that the waste will be retrieved for exemption or processing and/or disposal at a later time.

transportation. Operations and conditions associated with and involved in the movement of radioactive material by any mode, on land, water or in the air. The terms 'transport' and 'shipping' are also used.

vitrification. The process of incorporating materials into a glass or glass-like form. Vitrification is commonly applied to the solidification of liquid high level **waste** from the reprocessing of spent fuel.

waste[1]. (See waste, radioactive.)

waste, alpha bearing. Radioactive waste containing one or more alpha emitting radionuclides, in quantities and/or concentrations above clearance levels. Alpha bearing waste can be short lived or long lived.

waste, cladding. Radioactive waste comprised of fragmented cladding hulls, end-caps, grid spacers and other hardware from spent fuel assemblies. It is generated in spent fuel reprocessing.

waste, exempt. In the context of radioactive waste management, waste (from a nuclear facility) that is released from nuclear regulatory control in accordance with clearance levels, because the associated radiological hazards are negligible. The designation should be in terms of activity concentration and/or total activity and may include a specification of the type, chemical/physical form, mass or volume of waste. (See also **clearance levels; exemption**.)

waste, gaseous. Airborne and gaseous waste streams containing radionuclides. Depending on the level of activity, gaseous waste is either discharged (e.g. after treatment) or is retained for further processing and disposal.

waste, heat generating. Waste which is sufficiently radioactive that the energy of its decay significantly increases its temperature and the temperature of its surroundings. For example, spent fuel and vitrified high level waste are heat generating, and thus require cooling for several years.

waste, high level (HLW). (1) The radioactive liquid containing most of the fission products and actinides originally present in spent fuel and forming the residue from the first solvent extraction cycle in reprocessing and some of the associated waste streams.
(2) Solidified high level waste from (1) above and spent fuel (if it is declared a waste).
(3) Any other waste with an activity level comparable to (1) or (2).

High level waste in practice is considered long lived. one of the characteristics which distinguishes HLW from less active waste is its level of thermal power.

waste, liquid. Radioactive waste in liquid form which may contain dissolved, colloidal or dispersed solids. Because liquids are mobile and dispersable, solidification is generally expected.

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[1] In the context of this Glossary, the term 'waste' refers to radioactive waste unless otherwise specified.

waste, long lived. Radioactive waste containing long lived radionuclides having sufficient radiotoxicity in quantities and/or concentrations requiring long term isolation from the biosphere. The term 'long lived radionuclide' usually refers to half-lives greater than 30 years. (See also **waste, alpha bearing**; **waste, high level**; **waste, short lived**.)

waste, low level (LLW). (See waste, low and intermediate level.)

waste, low and intermediate level. Radioactive wastes in which the concentration of or quantity of radionuclides is above clearance levels established by the regulatory body, but with a radionuclide content and thermal power below those of high level waste. Low and intermediate level waste is often separated into short lived and long lived wastes. Short lived waste may be disposed of in near surface disposal facilities. Plans call for the disposal of long lived waste in geological repositories.

waste, non-nuclear industry. Material arising from the use and handling of material containing naturally occurring radionuclides (e.g. from phosphate mining) and for which there is no use foreseen by the producer or handler — as opposed to waste produced in the nuclear fuel cycle.

waste, radioactive. For legal and regulatory purposes, radioactive waste may be defined as material that contains or is contaminated with radionuclides at concentrations or activities greater than clearance levels as established by the regulatory body, and for which no use is foreseen. (It should be recognized that this definition is purely for regulatory purposes, and that material with activity concentrations equal to or less than clearance levels is radioactive from a physical viewpoint, although the associated radiological hazards are negligible).

waste, short lived. Radioactive waste which will decay to a level which is considered to be insignificant, from a radiological viewpoint, in a time period during which institutional control can be expected to last. Radionuclides in short lived waste will generally have half-lives shorter than 30 years. (See also **waste, long lived**.)

waste acceptance criteria. Those criteria relevant to the acceptance of radioactive waste packages for handling, storage and disposal.

waste acceptance requirements. Those requirements relevant to the acceptance of radioactive waste packages for handling, storage and disposal. (See also **requirements**.)

waste form. The waste in its physical and chemical form after treatment and/or conditioning (resulting in a solid product) prior to packaging. The waste form is a component of the waste package.

waste management, radioactive. All activities, administrative and operational, that are involved in the handling, pretreatment, treatment, conditioning, transportation, storage and disposal of waste from a nuclear facility.

waste package. The product of conditioning that includes the waste form and any container(s) and internal barriers (e.g. absorbing materials and liner), as prepared in accordance with requirements for handling, transportation, storage and/or disposal.

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RADWASS PUBLICATION PLAN

SAFETY SERIES No. 111

SAFETY FUNDAMENTALS

111-F. The principles of radioactive waste management

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SAFETY GUIDES

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111-G-1.3 Licensing of radioactive waste management facilities	**111-G-2.3** Conditioning and storage of low and intermediate level waste from nuclear fuel cycle facilities	**111-G-3.3** Safety assessment for near surface disposal	**111-G-4.3** Safety assessment for geological disposal	**111-G-5.3** Safety assessment for the management of waste from mining and milling of U/Th ores	**111-G-6.3.** Decommissioning of nuclear fuel cycle facilities
111-G-1.4 Quality assurance for the safe management of radioactive waste	**111-G-2.4** Treatment, conditioning and storage of high level reprocessing waste				**111-G-6.4** Safety assessment for the decommissioning of nuclear facilities
111-G-1.5 **Clearance levels for radionuclides in solid materials: application of exemption principles**	**111-G-2.5** Preparation of spent fuel for disposal				**111-G-6.5** Environmental restoration of previously used or accidentally contaminated areas
111-G-1.6 Derivation of discharge limits for waste management facilities	**111-G-2.6** Safety assessment for predisposal waste management facilities				**111-G-6.6** Recommended cleanup levels for contaminated land areas
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Note: This is the RADWASS publication plan approved by the International Radioactive Waste Advisory Committee (INWAC) in March 1993. A review of the plan will be undertaken by INWAC in 1995.

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