IAEA-TECDOC-1041

Management of small quantities of radioactive waste

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

The originating Section of this publication in the IAEA was:

Waste Technology Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

MANAGEMENT OF SMALL QUANTITIES OF
RADIOACTIVE WASTE
IAEA, VIENNA, 1998
IAEA-TECDOC-1041
ISSN 1011-4289

Printed by the IAEA in Austria
September 1998

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FOREWORD

The purpose of this publication is to provide practical guidance, primarily to developing Member States, on the predisposal management of small quantities of radioactive waste arising from hospitals, laboratories, industries, institutions, research reactors and research centres. Predisposal management of radioactive wastes includes handling, treatment, conditioning, storage and transportation. The report covers the management of liquid (aqueous and organic), solid (including spent sealed sources) and gaseous radioactive wastes at the users' premises and also give general guidance on procedures at centralized waste management facilities.

The report is intended for use by Member States who require information on the management of small quantities of radioactive waste, and by organizations or individuals which provide advice to Member States on this matter. It should be used in conjunction with other IAEA publications dealing with radiation protection and specific safety and technology aspects of waste management, such as those listed in the references section of this publication.

The IAEA wishes to express its gratitude to all the contributors to the drafting and review of this publication. The IAEA staff members responsible for this publication were S. Miaw and M. Al-Mughrabi of the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Radioactive wastes may be generated from the use of radioactive materials and other sources of ionizing radiation. The amount and type of waste generated vary depending on the radionuclides involved and their application.

When use of radioactive material is planned, it is important to also define a system for the predisposal management of waste arising. Predisposal management includes all steps or activities involved with management of radioactive waste from its generation to ultimate discharge or disposal. Characteristics of selected predisposal waste management systems strongly depend on the type as well as on the quantity of waste generated. So far the IAEA has provided guidance on management of relatively large amounts of waste generated in countries with extensive use of radiation sources in a large number of different institutions. The overall goal of predisposal management of radioactive waste is to minimize the hazards posed by the waste prior to discharge/disposal [1].

1.2. OBJECTIVE

The main objective of this publication is to provide practical guidance primarily to developing Member States on the predisposal management of small quantities of radioactive waste arising from hospitals, laboratories, industries, institutions, research reactors and research centres.

1.3. SCOPE

The publication covers the management of small quantities of liquid (aqueous and organic), solid (including spent sealed sources) and gaseous radioactive wastes at the users' premises and gives general guidance on procedures at a centralized waste management facility. Details on techniques and procedures of centralized facilities can be found in References [2] and [3]. The publication is directed primarily to developing Member States that:

(A) utilize individual radionuclides at a few hospital locations, universities and industries;

(B) have multi-use of radionuclides in hospitals and other institutional areas;

(C) have multi-use of radionuclides and nuclear research centres which are capable of indigenous production of several radionuclides.

For the purpose of this publication these Member States are classified as class A, B and C countries according to the above-mentioned usage of radionuclides.

Predisposal management of radioactive waste includes handling, treatment, conditioning, storage and transportation. The reuse of radioactive material and spent sealed sources is specifically excluded from this publication, as this material is not regarded as waste. It is, however, worth noting that special arrangements would be required to control the reuse of radioactive materials and the possible transfer of ownership.

1.4. STRUCTURE

The main text of this publication is organized as follows:

- Section 2 presents the topics related to the national waste management framework;
- Section 3 deals with the origin and characteristics of radioactive waste arising from users generating small quantities of waste;
- Section 4 provides radioactive waste management concepts appropriate for small quantities;
- Section 5 provides practical guidance on local waste management;
- Section 6 presents information about the documentation and approval necessary for the consignment of waste to a centralized waste management facility;
- Section 7 provides practical guidance on centralized waste management;
- Section 8 deals with exemption of radionuclides from the regulatory body;
- Section 9 deals with transportation;
- Section 10 provides guidance on environmental monitoring;
- Section 11 provides information about quality assurance for the whole predisposal process;
- Section 12 deals with regional co-operation aspects.

2. NATIONAL RADIOACTIVE WASTE MANAGEMENT FRAMEWORK

While this publication is intended to provide information for Member States that have small users, as it is laid down in Sections 1.2 and 1.3, it is important to provide some background material on the main elements for establishing a national system that provides for the safe management of the radioactive waste in question. The following material is provided to make of this publication a self contained document on the subject and it is partly quoted from IAEA Safety Series No. 111-S-1 [1]. More details on the subject can be obtained from the said publication.

2.1. PURPOSE AND DESCRIPTION

The radioactive waste management policy should be in accordance with the national objectives for radioactive waste management and with internationally agreed upon principles on waste management, and should define goals of waste management. A national radioactive waste management framework is one component required in order to protect human health and the environment both now and in the future without imposing undue burdens on future generations [4]. The national framework for radioactive waste management should include the following components [1]: policy, strategies, systems.

The radioactive waste management strategy should be developed to implement the national policies and should take into account both current and future requirements. National radioactive waste strategies will vary from country to country and will depend on administrative, legal and governmental control; circumstances and priorities; and the amount and type of waste generated. In the context of this publication there are essentially three different waste management strategies, depending on the extent of use of radionuclides within a country:

- local waste management (at the users' premises);
- centralized waste management (at a centralized facility serving more users);
- a combination of local and centralized waste management.

In all cases it will be required to apply some local waste management operations. These should be consistent with the national waste management strategy and, if applicable, with the requirements of the centralized waste management facility.

The waste management system should be based on laws and regulations and enforced by a regulatory body. The organization and role of the regulatory body should be clearly defined. The basic requirements of a radioactive waste management system should be adequately provided in accordance with the scope of the national programme.

Legislation should be formulated in accordance with international recommendations.

The national radioactive waste management system should include legislation for the management of wastes which may contain a combination of radioactive and other hazardous materials.

2.2. RESPONSIBILITIES

The responsibilities within a national waste management framework are distributed among the State, the regulatory body, the waste generators and the operators of waste management facilities. For more details refer to Reference [1].

The State should be responsible for:

- Establishing and implementing a legal framework;
- Establishing a regulatory body;
- Defining responsibilities of waste generators and operators of radioactive waste management facilities;
- Providing for adequate resources.

The regulatory body should be responsible for:

- Enforcing compliance with legal requirements;
- Implementing the licensing process;
- Advising the government.

The waste generators and operators of radioactive waste management facilities should be responsible for:

- Managing radioactive waste safety;
- Identifying an acceptable destination for the radioactive waste;
- Complying with legal requirements.

The Member State should inform the public about radioactive waste management matters.

3. ORIGIN AND CHARACTERISTICS OF RADIOACTIVE WASTE

As a result of the application of radionuclides in medicine, research and industry, radioactive waste is generated in varying quantities with a wide range of characteristics.

3.1. APPLICATIONS OF RADIONUCLIDES

The main applications of radionuclides in medicine, research, industry, consumer products and military applications are listed below.

Medicine (including veterinary medicine)

The use of radioactive materials may include [5, 6]:

- "In vitro" radio-assay for clinical diagnosis, therapy and follow-up;
- "In vivo" use of radio pharmaceuticals for clinical diagnosis, therapy and follow-up;
- Radiotherapy using sealed radiation sources.

Research

- Uses of radionuclides may include:
- Calibration sources;
- Development and labelling of radio-labelled compounds;
- Study of metabolic, toxicological or environmental pathways associated with a large range of compounds such as drugs, pesticides, fertilizers and other chemicals. The use of animals may be involved resulting in radioactive excreta, carcasses and bedding;
- Development of clinical processes and applications of prepared compounds (e.g. pharmaceuticals);
- Basic research in the field of physics, chemistry, engineering and biology in universities and laboratories; and

- Research in small nuclear research centres or in research reactor centres.

Industry

Uses of radionuclides may include:

- Production and labelling of compounds;
- Manufacture of radioactive sealed sources, luminous devices, electronic valves;
- Use of radioactive material (mainly sealed sources) for scientific measurements/ calibration, oil exploration and well logging, process and plant control, non- destructive testing and quality control;
- Water treatment;
- Sterilization; and
- Food irradiation.

Consumer products

Uses of radionuclides may include:

- Smoke detectors;
- Luminous devices; and
- Lightening rods.

Defence uses

Uses of radionuclides may include:

- Equipment and instruments with luminous paint or gaseous tritium lights; and
- Test sources.

3.2. WASTE CHARACTERISTICS

Examples of radioactive waste arising from clinical, medical and biological research activities are reported in Table I. The wastes contain mainly short-lived radionuclides. Notable exceptions are wastes containing ^{14}C and ^{36}Cl.

Examples of sealed sources used in medicine, industry and research are given in Tables II, III and IV, respectively, and described in Reference [7]. There is a potential for a wide range of spent sealed sources to arise.

Typical radioactive waste streams arising from small users worldwide are described in Reference [8]. Tables V and VI contain estimates of the aqueous and organic liquid wastes generated in class A, B and C Member States. It can be concluded from Table I that the waste arising from small users will be primarily liquid and solid. Comparison of Tables V and VI indicates that organic wastes usually represent less than 1% of the total liquid waste generated. Liquid radioactive waste is mainly composed of contaminated effluent, chemical process and decontamination solutions, solvents, blood specimens, wound or oral discharges and urine, and small quantities of contaminated oils and scintillation fluids.

Solid radioactive waste consists mainly of general trash, which includes protective clothing, plastic sheets and bags, rubber gloves, mats, overshoes, paper wipes, towels, metal and glass, infectious waste, carcasses, hand tools and discarded equipment. Solid waste may also contain various process wastes from nuclear research centres, such as spent filter cartridges, spent resins and sludge from effluent treatment plants. Sealed radiation sources are a special form that is used in almost all fields and that are usually characterized and handled in a special way. The principal types of solid waste generated or handled in research centres are reported in Table VII.

As an example, a typical composition by volume of low-activity solid radioactive waste generated by research centres is shown below [8].

70% compactable or combustible materials, subdivided into:

Plastic fragments	25%
Paper and cloth	25%
Small metallic or glass objects	15%
Miscellaneous (animal carcasses, wood, etc.)	5%

20% heavy/hard materials (non-compactable):

Metal components
Building materials
Large items

10% debris

Resulting from plant conversions and operational incidents (concrete, soil, etc.)

The characteristics of typical biological radioactive waste (waste containing a mixture of radioactive and pathogenic materials) are presented in Table VIII.

4. RADIOACTIVE WASTE MANAGEMENT

4.1. GENERAL CONSIDERATIONS

Radioactive waste management will generally involve a number of basic steps. Selection of particular processes and the overall approach will depend on the waste management strategy of the Member State. In order to ensure safe and efficient waste management practice it is necessary to consider the operations involved in the particular processes both in isolation, and as a part of an integrated waste management system. For example, it may be necessary to transport the waste between particular waste management processes. In this case it is necessary to take into account the transport requirements (package design, activity limits, etc.) in the previous waste management process, in order to permit transportation.

TABLE I. PRINCIPAL RADIONUCLIDES USED IN MEDICINE AND BIOLOGICAL RESEARCH[a]

Radionuclide	Half-life	Principal application	Typical quantity per application	Waste characteristics
^{3}H	12 3 a	Clinical measurements Biological research Labelling on site	Up to 5 MBq Up to 50 GBq	Solid, liquid, organic Organics Solvents
^{14}C	5730 a	Medical Biological research Labelling	Less than 1 GBq Up to 10 MBq	Solid, liquid solvent Exhaled CO_2
^{18}F	1 8 h	Positron emission Tomography	Up to 500 MBq	Solid, liquid
^{22}Na ^{24}Na	2 6 a 15 0 h	Clinical measurements Biological research	Up to 50 kBq Up to 5 GBq	Liquid effluent
^{32}P ^{33}P	14 3 d 25 4 d	Clinical therapy Biological research	Up to 200 MBq Up to 50 MBq	Solid, liquid effluent
^{35}S	87 4 d	Clinical measurements Medical and biological research	Up to 5 GBq	Solid, liquid effluent
^{36}Cl	3 01 x 10^{5} a	Biological research	Up to 5 MBq	Gaseous, solid, liquid
^{45}Ca ^{47}Ca	163 d 4 5 d	Biological research Clinical measurements	Up to 100 MBq Up to 1 GBq	Mainly solid Some liquid
^{46}Sc	83 8 d	Medical and biological research	Up to 500 MBq	Solid, liquid
^{51}Cr	27 7 d	Clinical measurements Biological research	Up to 5 MBq Up to 100 kBq	Solid Mainly liquid effluent
^{57}Co ^{58}Co	271 7 d 70 8 d	Clinical measurements Biological research	Up to 50 kBq —	Solid, liquid effluent
^{59}Fe	44 5 d	Clinical measurements Biological research	Up to 50 MBq	Solid Mainly liquid effluent
^{67}Ga	3 3 d	Clinical measurements	Up to 200 MBq	Solid, liquid effluent
^{81m}Kr	13 3 s	Lung ventilation studies	Up to 2 GBq	Gaseous
^{85}Sr	64 8 d	Clinical measurements Biological research	Up to 50 MBq	Solid, liquid
^{86}Rb	18 7 d	Medical and biological research	Up to 500 MBq	Solid, liquid
^{89}Sr	50 5 d	Clinical therapy	Up to 300 MBq	Solid, liquid
^{90}Y	2 7 d	Clinical therapy and measurements Medical and biological research	Up to 300 MBq	Solid, organic, liquid
^{95}Nb	35 0 d	Medical and biological research	Up to 500 MBq	Solid, liquid

TABLE I. (CONT.)

Radionuclide	Half-life	Principal application	Typical quantity per application	Waste characteristics
^{99m}Tc	6 0 h	Clinical measurements Biological research Nuclide generators	Up to 1 GBq	Solid, liquid
^{111}In	2 8 d	Clinical measurements Biological research	Up to 500 MBq	Solid, liquid
^{123}I ^{125}I ^{131}I	13 2 h 60 1 d 8 0 d	Medical and biological research Clinical measurements Clinical therapy	Up to 500 MBq Up to 500 MBq Up to 500 MBq Up to 10 GBq Up to 50 MBq	Solid, liquid Occasionally vapour
^{113}Sn	155 0 d	Medical and biological research	Up to 500 MBq	Solid, liquid
^{133}Xe	5 3 d	Clinical measurements	Up to 400 MBq	Gaseous
^{153}Sm	1 9 d	Clinical therapy	Up to 8 GBq	Solid, liquid
^{198}Au	2 7 d	Clinical measurements	Up to 500 MBq	Solid, liquid
^{201}Tl	3 0 d	Clinical Measurements	200 MBq	Solid, liquid
^{197}Hg ^{203}Hg	2 6 d 46 6 d	Clinical measurements Biological research	Up to 50 MBq	Solid, liquid

[a] See also Reference [5].

TABLE II. SEALED SOURCES USED IN MEDICINE [a]

Application	Radionuclide	Half-life	Source activity	Comments
Bone densitometry	^{241}Am ^{153}Gd ^{125}I	433 0 a 244 0 d 60 1 d	1–10 GBq 1–40 GBq 1–10 GBq	Mobile units
Manual brachytherapy	^{137}Cs ^{226}Ra ^{60}Co ^{90}Sr ^{103}Pd ^{125}I ^{192}Ir ^{252}Cf	30 0 a 1600 a 5 3 a 29 1 a 17 0 d 60 1 d 74 0 d 2 6 a	50–500 MBq 30–300 MBq 50–500 MBq 50–1500 MBq 50–1500 MBq 50–1500 MBq 200–1500 MBq 50–1500 kBq	Small portable sources
Remote after loading brachytherapy	^{60}Co ^{137}Cs ^{192}Ir	5 3 a 30 0 a 74 0 d	approx 10 GBq 0 03–10 MBq approx 400 GBq	Mobile units
Teletherapy	^{60}Co ^{137}Cs	5 3 a 30 0 a	50–1000 TBq 500 TBq	Fixed installations
Whole blood irradiation	^{137}Cs	30 0 a	2–100 TBq	Fixed installations

[a] See also Reference [7].

TABLE III. SEALED SOURCES IN INDUSTRY [a]

Application	Radionuclide	Half life	Source activity	Comments
Industrial radiography	^{192}Ir ^{60}Co (^{137}Cs, ^{170}Tm)	74 0 d 5 3 a	0 1–5 TBq 0 1–5 TBq	Usually portable units
Well logging	^{241}Am/Be ^{137}Cs (^{252}Cf)	433 0 a 30 0 a	1–800 GBq 1–100 GBq	Portable units
Moisture detector	^{241}Am/Be ^{137}Cs (^{252}Cf, ^{226}Ra/Be) ^{239}Pu	433 0 a 30 0 a	0 1–2 GBq 400 MBq 3GBq	Portable units to measure moisture content/density normally contain both a neutron and gamma emitter
Conveyor gauge	^{137}Cs	30 0 a	0 1–40 GBq	Fixed installations to measure density of coal, silt or ores
Density gauge	^{137}Cs ^{241}Am	30 0 a 433 0 a	0 1–20 GBq 0 1–10 GBq	Fixed installations to measure density of materials in a constant volume
Level gauge	^{137}Cs ^{60}Co (^{241}Am)	30 0 a 5 3 a	0 1–2- GBq 0 1–10 GBq	Fixed installations to measure level of materials in tanks, silos or packages
Thickness gauge	^{85} Kr ^{60} Sr (^{14}C, ^{147}Pm, ^{241}Am)	10 8 a 29 1 a	0 1–50 GBq 0 1–4 GBq	Fixed installations to measure thickness of papers, plastic or similar materials
Static electricity eliminator	^{241} Am ^{210}Po (^{226}Ra) ^{60}Co	433 0 a 128 0 d	1–4 GBq 1–4 GBq	Fixed installations and portable units
Lightning preventer	^{241}Am (^{226}Ra) ^{60}Co	433 0 a 1600 a 5 3 a	50–500 MBq 3–7 GBq	Fixed installations
Electron capture detector	^{63}Ni ^{3}H	96 0 a 12 3 a	200–500 MBq 1–7 4 GBq	Fixed or portable equipment
X ray fluorescence analyser	^{55}Fe ^{109}Cd (^{238}Pu, ^{241}Am, ^{57}Co)	2 7 a 463 0 d	0 1–5 GBq 1–8 GBq	Often portable units to analyse alloys by stimulating fluorescence X rays
Sterilization and food preservation	^{60}Co ^{137}Cs	5 3 a 30 0 a	0 1–400 PBq 0 1–400 PBq	Fixed installations (individual source activity up to 600 TBq)
Calibration facility	^{60}Co ^{137}Cs	5 3 a 30 0 a	1–100 TBq	Fixed installations
Smoke detector	^{241}Am ^{226}Ra (^{239} Pu)	433 0 a	0 02–3 MBq	Fixed (easily removed)
Dredger	^{60}Co ^{137}Cs	5 3 a 30 0 a	1–100 GBq 1–100 GBq	Fixed installations for silt density measurements
Blast furnace control	^{60}Co	5 3 a	2 GBq	Fixed

[a] See also Reference [7]

TABLE IV. SEALED SOURCES IN RESEARCH[a]

Application	Radionuclide	Half life	Source activity	Comments
Calibration source	Many different	Variable	< 0.1 GBq	Small portable sources
Electron capture detector	^{3}H ^{63}Ni	12.3 a 96.0 a	1–50 GBq 200–500 MBq	Can be used in portable units and in gas chromatography detectors
Irradiator	^{60}Co ^{137}Cs	5.3 a	1–1000 TBq	Fixed installations
Calibration facility	^{137}Cs ^{60}Co ^{252}Cf ($^{241}Am/Be$ $^{238}Pu/Be$) $^{226}Ra/Be$	30.0 a 5.3 a 2.6 a	<100 TBq <100 TBq <10 GBq	Fixed installations
Tritium target	^{3}H	12.3 a	1–10 TBq	Fixed installations for neutron production

[a] See also Reference [7].

TABLE V. ESTIMATED ANNUAL VOLUMES AND ACTIVITIES OF AQUEOUS LIQUID RADIOACTIVE WASTE GENERATED IN COUNTRIES BELONGING TO CLASSES A, B, AND C[a]

	Liquid Effluent for					
	Decay, Dilution, Discharge		Treatment		Conditioning without treatment	
Member States	**Volume (m^3/a)**	**Activity (GBq/a)**	**Volume (m^3/a)**	**Activity (GBq/a)**	**Volume (m^3/a)**	**Activity (GBq/a)**
Class A	5–10	40	–	–	–	–
Class B	10–50	200	1–5	4	0.1	0.4
Class C	100–400	400–2000	100–200	200–400	0.5	4

[a] See also Reference [13].

TABLE VI. TYPES AND ESTIMATED ANNUAL VOLUMES AND SPECIFIC ACTIVITIES OF RADIOACTIVE ORGANIC LIQUIDS GENERATED IN COUNTRIES BELONGING TO CLASSES A, B AND C[a]

Organic liquids	Member States		
	Class A	Class B	Class C
Oil, lubricants m^3/a MBq/m^3 Radionuclides	– – –	0.005 30 ^3H, ^{14}C	0.1 300 Fission and activation products, ^3H, ^{14}C
Scintillation liquids m^3/a MBq/m^3 Radionuclides	0.01 30 ^3H, ^{14}C	0.01–0.02 30–50 ^3H, ^{14}C	0.05 300 ^3H, ^{14}C, ^{125}I, ^{32}P, ^{35}S
Organic and extraction agents m^3/a MBq/m^3 Radionuclides	0.01 30 U, Th, + daughters	0.01 30 U, Th, + daughters	0.05–0.2 < 10 000 U, Th, + daughters Fission products, TRU

[a] See also Reference [16].

TABLE VII. THE PRINCIPAL TYPES OF SOLID RADIOACTIVE WASTE[a]

Type		Composition
Combustible	*Compactable* (low and high-force)	Tissues, swabs, paper, cardboard, plastics (PE, etc.), rubber, gloves, protective clothes, filters
	Non-compactable	Carcasses, excreta Ion exchange resins (research reactor)
Non-combustible	*Compactable* (high-force)	Glassware, metallic items, scrap, brickwork, plastics (PVC, etc.)
	Non-compactable	Sealed sources

[a] See also Reference [10].

TABLE VIII. TYPES OF BIOLOGICAL RADIOACTIVE WASTE [a]

Type of Waste	Physical Property	Composition
1. Solid	wet	Absorbent materials, tubes/vials with liquids, dressings
	dry	Tissues, gloves, disposable plastics, animal bedding, sharps, metallic items, glassware
	damp	Human or animal tissues, organs, limbs; animal carcasses, cultures, faeces
2. Liquid	aqueous	Common solutions
	organic	Scintillation fluids, solvents
	physiological	Blood specimens, wound or oral discharges, urine
3. Gaseous	exhausts to the atmosphere	^{133}Xe, ^{81m}Kr
	exhausts collected on filters	From iodisations or handling of other volatile radionuclides

[a] See also Reference [5].

4.2. WASTE MANAGEMENT STRATEGY

For effective radioactive waste management it is necessary to consider the waste management strategy of the Member State. Radioactive waste management may be implemented at the user's facility (waste generator), at a centralized facility or at both facilities. An example of a waste management strategy is shown schematically in Figure 1. In this example, the various waste management processes are divided between the users' facility (local waste management) and a centralized waste management facility (centralized waste management). In practice, there may be considerable overlap between localized and centralized waste management operations, depending on individual circumstances. For example, in some countries it might be considered appropriate that decay storage and disposal of solid waste containing radionuclides with half-lives longer than 100 days and shorter than one year should be carried out centrally. In this case, it would be necessary for the centralized waste management facility to be equipped with a decay store, and able to dispose of decayed waste.

5. LOCAL WASTE MANAGEMENT

Local waste management is defined as "waste management operations carried out at source" (i.e. at the waste generator's premises). Approval from the regulatory body should be obtained before proceeding with local waste management operations. This will ensure consistency with the national waste management strategy, compliance with State laws and regulations, and that adequate resources are available.

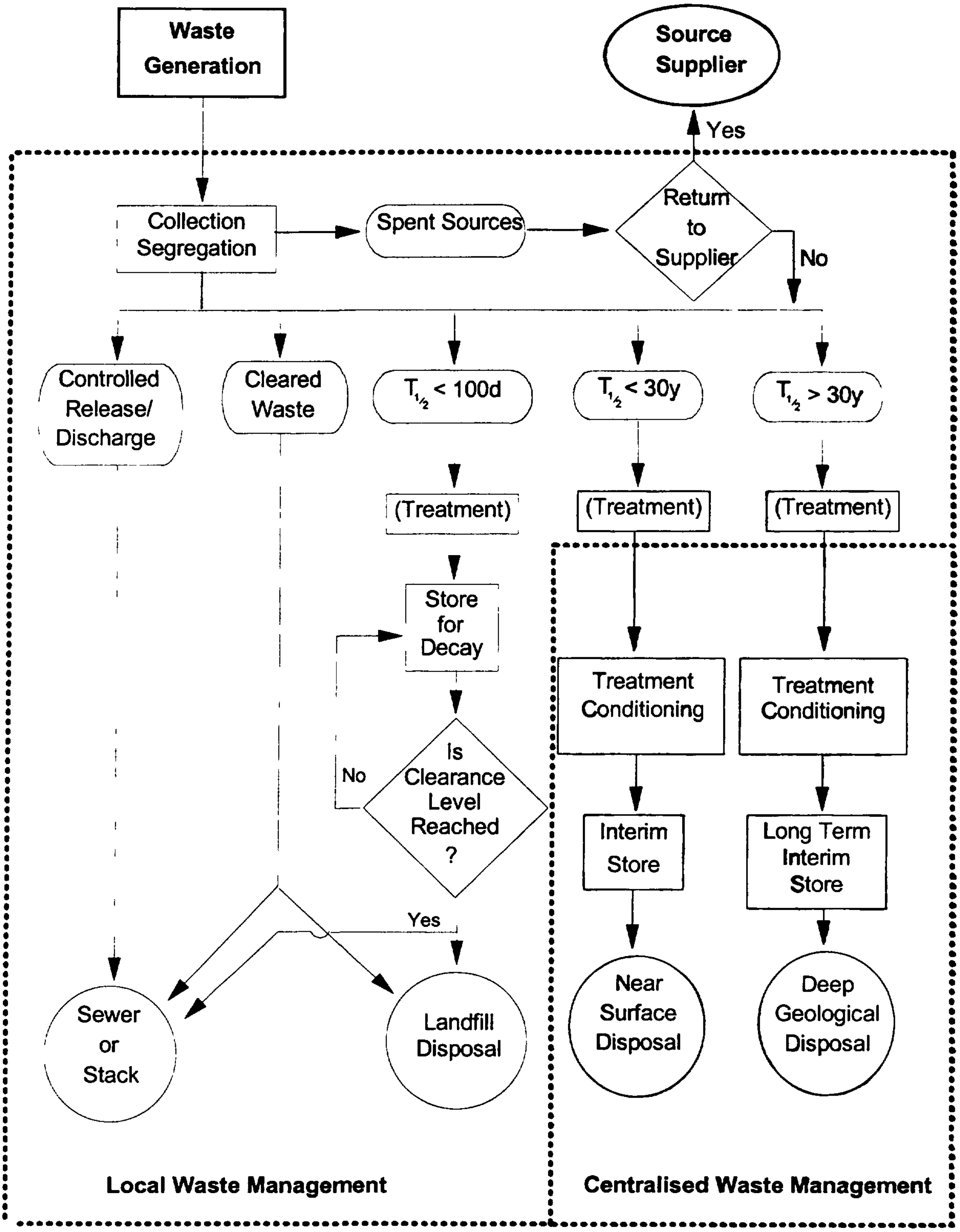

Fig. 1. Example of waste management strategy.

5.1. GENERAL CONSIDERATIONS

Local waste management operations should only be implemented after adequate training of personnel has been carried out, and once the operators and managers of the waste management facility are fully acquainted with their responsibilities to the State, to one another and to the general public. The extent of local waste management will depend on the national waste management strategy and on the particular application of radioactive material. It is important that the scope of local waste management is established for each waste generator. Local waste management can include a full range of operations, such as waste minimization, segregation, characterization, treatment, conditioning, storage and disposal. However, as a minimum, waste segregation, basic characterization, minimization and storage should be applied. It is essential that at all stages of local waste management full documentation is produced and retained (waste characteristics, origin, treatment and conditioning methods, etc.), and that adequate safety precautions are applied.

5.1.1. Training

At all stages of local waste management, it is essential that all operators are aware of the nature of the waste, and understand relevant operating procedures and associated safety precautions. It is also important that waste management staff have an adequate understanding of the overall waste management system and associated hazards, as well as the local and national radioactive waste management strategies.

A systematic training programme should be provided to new staff. Refresher training should be available to existing staff. The scope of the training programme should be commensurate with the size and complexity of the proposed operation. Training should include, but not be limited to: fundamental and practical aspects of occupational health; safety and radiation protection; regulatory requirements; waste characterization, including radiological, physical and chemical properties; pre-treatment; treatment and conditioning; storage; monitoring and transport. It is also important to include any site-specific and license requirements, as well as the operating procedures for implementing the regulations. Wherever possible, advantage should be taken of national and international training programmes.

5.1.2. Responsibilities

The main responsibility of local waste management is to comply with requirements of State laws, regulations and the national waste management strategy. Responsibilities of the waste generator include:

- Operational planning for local waste management;
- Waste minimization;
- Justification for the use of radioactive materials;
- Waste characterization, segregation, treatment and conditioning, and storage;
- Waste documentation (clarity, accessibility and compliance with legislation);

- If necessary, arranging transport of the radioactive waste to another facility which has been approved by the regulatory body for processing, storage and disposal operations;

- Identifying waste disposal routes (as appropriate); and

- Training (handling procedures, radiological protection, etc.).

5.1.3. Waste minimization and segregation

An essential component of radioactive waste management is to ensure that the activity and the volume of radioactive waste arising from any nuclear application are kept to the minimum practicable level. Waste minimization and segregation should be employed to achieve this objective.

Waste minimization is essential to reduce waste volumes, environmental impact and cost. For these reasons, unnecessary equipment, devices, packaging, etc. should not be brought into controlled and restricted areas.

Preferably, dedicated equipment should be used in controlled/restricted areas. Where possible, reuse of equipment should be considered. Decontamination of equipment should be considered carefully because, although the equipment could potentially be reused, a decontamination waste stream will be produced, which will also require management.

Shorter lived radionuclides should be used whenever possible in preference to longer-lived radionuclides, in order to minimize waste generated and to simplify radioactive waste management. The minimum quantity of radioactive material should be procured and used for each application. Unnecessary duplication of radionuclide procurement should be avoided. Guidelines for the procurement, handling and control of radioactive materials should be developed by the regulatory authority, and should be supported by written procedures.

If possible, spent sealed sources should be returned to the supplier. This strategy can be applied either for centralized or for local waste management systems.

Waste should be segregated at source into separate waste streams, in accordance with the established waste management strategy. Segregation should be based on:

- Non-radioactive and radioactive;

- Suitability for decay storage (for example half-lives less than 100 days);

- Activity and radionuclide content;

- Physical and chemical form;
  - Liquid (aqueous and organic);
  - Solid (combustible/non-combustible, compactable/non-compactable (if applicable);

- Spent sealed sources;

- Mixed waste containing special hazardous materials such as toxic, pathogenic, etc.

If applicable, waste should be segregated in accordance with the requirements of the centralized waste management facility.

5.1.4. Characterization

Waste characterization is essential for efficient and cost-effective waste management.

Prior to any operation involving radioactive waste it is necessary to determine activity, radionuclide content, physical and chemical form (liquid, solid, etc.) and associated hazards. This can be achieved by a combination of quality assurance (records of radionuclide inventory, activity balance, composition of materials used, etc.) and by direct measurement techniques. Segregation of waste arisings at source will help to easily characterize waste streams. Waste of unknown origin and composition will require detailed characterization. This may be complex and expensive.

5.1.5. Storage

The following reasons for storing radioactive material or sources may be applicable depending on the extent of local waste management [9]:

- Storage for decay (prior to discharge or disposal);
- Storage of unconditioned radioactive waste (prior to conditioning);
- Storage of conditioned radioactive waste (prior to disposal).

Decay and storage are discussed in detail in Sections 5.2.4 for liquid waste, 5.3.4 and 5.3.5 for solid waste and Section 5.7 discusses operational storage facility aspects.

5.1.6. Documentation

Comprehensive documentation (records and procedures) is required for all stages involving the handling, segregation, treatment and conditioning, packaging, storage, transportation and discharge/disposal of radioactive waste.

5.1.7. General safety considerations

The following general points should be applied when handling radioactive wastes:

- Exposure to ionizing radiation should be kept as low as reasonably achievable (ALARA);

- Handling of radioactive materials should be carried out in suitably ventilated and access controlled areas;

- Surfaces in radiologically controlled areas should be easy to decontaminate;

- Personal protection should be worn as appropriate (usually contact clothing, overshoes, gloves, face-shield, safety glasses, respiratory protection and foot protection);
- An appropriate level of personal dosimetry and monitoring should be implemented;
- In order to minimize radiation exposure, radioactive sealed sources used in the workplace should have suitable protection (device or apparatus, source-holder, etc.) and should be shielded if necessary;
- Precautions should be taken to avoid: contamination of personnel and equipment, unnecessary dispersal of radioactive material, inhalation of radioactive material by personnel;
- Clearly defined and documented working procedures should be established.

5.2. LIQUID WASTE

5.2.1. Assessment of radionuclide inventory

As a result of the use of radioactive materials by small users, part of the initial inventory is converted to liquid waste (see Table I). Examples of waste arising from these kinds of installations are shown in Tables IX and X. During each stage of operation leading to the generation of radioactive waste, semi-quantitative assessment should be carried out to estimate the activity of each waste stream produced. This approach can be used as a primary method of estimating the radioactive content of waste generated. For example, when a radioactive liquid is stored in and subsequently emptied from a glass vial, a small proportion (possibly a few per cent) will remain associated with the vial depending on the viscosity of the liquid. On disposal of the vial, this associated radioactivity will be consigned as solid waste, whereas the majority of the initial activity will still be associated with the original liquid.

TABLE IX. TYPICAL LOW LEVEL RADIOACTIVE WASTE VOLUME CATEGORIZED BY PHYSICAL FORM [a] [24]

Physical form	**Volume (m^3)**	**Per cent of total**
Solid	51.2	67
Liquid	5.4	7
Scintillation vials	5.9	8
Biological	13.3	18
Total	**75.8**	**100**

[a] Waste collected during 1990 from a 560 bed teaching hospital and generated by 88 non-clinical research.

TABLE X. LOW-LEVEL RADIOACTIVE WASTE VOLUME CLASSIFIED BY ISOTOPES [a] [24]

Isotope	Volume (m^3)	Per cent of total
^{125}I	19.3	25.5
^{32}P	14.5	19.1
^{3}H	11.0	14.5
^{14}C	6.6	8.7
^{35}S	4.7	6.2
^{131}I	0.8	1.1
^{51}Cr	0.6	0.8
^{45}Ca	0.3	0.4
Microspheres[b]	13.4	17.6
Other isotopes[c]	4.6	6.1

[a] Waste collected during 1990 from a 560 bed teaching hospital and generated by 88 non- clinical researches.
[b] Microsphere isotopes included ^{153}Gd, ^{141}Ce, ^{113}Sn, ^{103}Ru, ^{95}Nb, and ^{46}Sc with each waste package containing five simultaneously.
[c] Other isotopes included < 1 % by volume of the following: ^{89}Sr, ^{90}Sr, ^{99m}Tc, ^{111m}In, ^{67}Ga, ^{22}Na, ^{36}Cl, ^{60}Co, ^{59}Fe, ^{65}Zn, and ^{201}Tl.

5.2.2. Segregation

Liquid waste should be collected, segregated and characterized as far as possible at the point of origin according to its physical, chemical, biological and radiological properties in order to facilitate treatment, conditioning and transportation operations and to minimize the volume requiring subsequent storage and disposal.

It is necessary to segregate liquid wastes into the following main categories according to their properties:

- Activity and radionuclide content;
- Short-lived radionuclides suitable for decay storage;
- Long-lived liquid waste requiring conditioning, subsequent storage and final disposal;
- Organic liquids;
- Aqueous liquids;
- Non-homogeneous waste (sludges);
- Infectious liquids;
- Chemically hazardous liquids.

Segregation is required in order to minimize waste hazards and to facilitate subsequent operations. The segregation of waste at the origin is more efficient than to perform segregation after mixing. For small volumes of immiscible liquids segregation can be done by using simple laboratory equipment (e.g. separating funnel).

Chemically incompatible wastes should be collected separately in order to avoid uncontrolled chemical reactions.

5.2.3. Characterization

Waste can be characterized by means of quality assurance techniques (records) using information on the material used and radionuclide inventory for each operation, and estimates of the distribution of the initial inventory amongst associated waste arisings. In addition, a range of direct measurement techniques can be used to further characterize the radioactivity of waste streams.

It is important to characterize wastes adequately in order to ascertain whether the waste can be exempted from regulatory control (see Section 8) and discharged within authorized limits.

Characterization techniques include:

- *Simple monitoring techniques* — Simple trials can be carried out to provide a correlation between count-rate of beta, gamma and X ray probes (as appropriate) and the activity content of waste solutions.

- *Sophisticated measurement techniques* — If necessary, waste solutions can be sampled and analysed by either gamma spectrometry, liquid scintillation counting, alpha spectrometry, or a combination of these techniques.

Information obtained from the characterization stage should be entered on the appropriate record card, data sheet or computer spreadsheet and the most important one should be recorded on the storage vessel by using the existing label or by affixing an additional label.

5.2.4. Operational storage

Operational storage may be required:

- Prior to and during characterization;
- For decay, prior to discharge;
- Prior to dilution and discharge;
- Prior to transportation to a centralized waste management facility;
- Prior to conditioning;
- Prior to disposal.

5.2.4.1 Storage containers

Liquid waste should be collected in suitable containers or tanks selected according to the chemical and radiological characteristics and volume of the waste, and the handling and storage requirements. In general, high-density polyethylene (HD-PE) containers should be used in preference to glass, as they are more robust and can be easily and safely volume-reduced when they become waste. Organic solvents should be stored in chemically compatible containers, constructed either from HD-PE or other suitably inert material and unplastisized material. Tritiated wastes should be stored in glass or chemically compatible metal containers (e.g. stainless steel). If plastic containers are required, polycarbonate can be used. In all cases, care should be taken to avoid pressurization of the containers due to the expansion of liquids and the evolution of gases and vapours. It is usual that an additional containment that is able to hold the contents of the primary storage vessel is used. Colour coding of containers can be used for segregated waste stream, and the colour reference should be well documented.

Storage containers should be marked to indicate the maximum filling level, generally around 80%, and labelled with a radiation trefoil and permanently marked with a unique identification number. Special care should be taken with identification when containers are to be reused. The following information should be recorded for each storage vessel:

- Identification number;
- Radionuclides;
- Activity (if measured or estimated)/date of measurement;
- Origin (room, laboratory, individual, etc. if applicable);
- Potential/actual hazards (chemical, infectious, etc.);
- Surface dose rate/date of measurement;
- Quantity (weight or volume) of liquid;
- pH value (if necessary); and
- Responsible person.

Preferably, this and other detailed information concerning the waste should be recorded on a record card, information sheet or computer spreadsheet.

Waste packages should be inspected on a regular basis (at least weekly) to ensure that they are intact and still present in the store.

5.2.4.2. Practical safety considerations for storage

A dedicated facility should be provided for the storage of radioactive waste. The design, layout and equipment should be commensurate with the volume and hazards of the waste. In the context of this publication, "waste stores" may be metal cupboards, rooms and buildings.

In general, storage facilities should have the following characteristics [9]:

- Sufficient capacity to buffer the waste arisings before discharge, local treatment and transportation to the centralized waste management facility;

- Simple construction provided with non-combustible and easily decontaminable walls and floors;
- Impermeable floor covering with a containment edge and slight slope to a central collection area;
- Adequate ventilation;
- Air sampling and radiation alarms (as required);
- Fire detection/protection (as appropriate);
- Fire resistant door that can be locked;
- Compartments in order to separate different kinds of waste;
- Demarcation as radiologically classified areas;
- Utilise a log book system, listing the number of containers, entry date, waste type, activity, etc. The log book should be kept outside but near the storage room or area;
- Provide protection from the environment (weather) including temperature extremes;
- Provide protection from intrusion (by man, animals, insects, etc.);
- If necessary, be suitable for the safe storage of volatile organic liquids (venting, cooling,, etc.);
- Utilise movable radiation shielding (as appropriate).

5.2.4.3. Decay storage prior to discharge

Practical experience shows that storage for decay is often suitable when waste is contaminated with radionuclides with relatively short half-lives, usually less than 100 days but potentially as long as one year. A decay storage period of ten half-lives will reduce the activity of the waste by a factor of approximately 1000. Decay storage of waste to achieve an activity below the authorized discharge level or clearance level is the preferred management option, both technically and economically.

The optimum decay storage period of the waste should be evaluated prior to storage. If storage space allows, the store can be divided into areas according to half-life and decay storage period. Segregation of waste in this way can simplify waste discharge operations and administration. Storage for decay of liquid wastes containing longer-lived radionuclides (i.e. with half lives longer than 100 d) may not be judged to be appropriate because of the long storage times involved and associated safety considerations (especially with unconditioned radioactive wastes).

Table XI provides an example of a record which should be used for radioactive wastes placed in decay storage. Completion of the record will involve consideration of any special features of the radioactive waste. At the time of receipt the duration for decay storage should be evaluated.

5.2.5. Effluent discharges

Approval should be obtained from the regulatory body before radioactive effluent is discharged to the environment (trade waste and sewage system, etc.). It is important to ensure that discharged effluent is homogeneous, readily dispersible in water and the activity levels are within authorized limits. Effluent containing suspended solids or sediments, should be filtered and fully characterized prior to discharge. Non-aqueous and mixed (hazardous) wastes should not be discharged to the sewage or trade waste systems unless they have been appropriately treated and the discharge has been approved by the regulatory body.

The discharge of liquid effluent should be strictly controlled by a combination of quality assurance techniques (records, procedures, etc.) and direct measurement. All the information concerning individual discharges should be recorded. An example of a record card for effluent discharge is shown in Table XII.

TABLE XI. EXAMPLE OF DECAY STORE RECORD

Waste Item No.	Date Received	Radio-nuclide	Activity on Receipt	Description and Special Hazards	Storage Location and Container Code No.	Date for Disposal [a] as Exempt Waste, or Authorized Waste, and Disposal Route	Disposal Completed
1	1 July 1990 Signature of Store Manager	^{32}P	1 MBq	500 mL of saline solution from medical experiments	Bay 1	1 Sep 90 to Municipal dump site	Signature of Store Manager/ date
2	etc						

[a] To be calculated and/or approved by the store manager.

TABLE XII. EXAMPLE OF EFFLUENT DISCHARGE RECORD

Batch No.	Generator	Date of discharge	Radio-nuclides	Activities at discharge	Volume (s)m^3	Concentration Bq/L	Discharged to:	Description and special hazards	Discharge completed
1	Lab. 1	1 July 1994	^{3}H	100 MBq	1	100 kBq/L	River	Saline solution medical experiments	Signature of authorized individual/ date
2	etc								

5.2.6. Treatment and conditioning methods

A wide range of methods exists for the treatment and conditioning of liquid radioactive wastes arising from small users (see Section 7). In some cases, effluent treatment processes can be very beneficial prior to discharge of effluents to the environment. A good example of this is in the treatment of thorium gas mantle production effluents. It is possible to significantly reduce the thorium content of effluents by a combination of precipitation (with ammonia) and sedimentation/filtration. After clarification, the resulting waste stream could potentially be discharged to the trade waste system, provided the total activity and chemical composition are within authorized limits (i.e. those given by the regulatory body during the licensing stage). The precipitated thorium (sludge) can be collected in a suitable container (polythene bottle/carboy or heavy gauge plastic bag) and transferred to the operational storage facility. Where possible the sludge should be appropriately packaged and transported to a centralized waste management facility for further treatment and conditioning.

With short-lived aqueous waste, decay storage followed by disposal as exempt waste is the preferred disposal option. With mixed (hazardous) and many long-lived radioactive wastes, long-term storage is the only option, until a suitable disposal facility is available.

Treatment and conditioning of radioactive effluents will be required before interim (long-term) storage, in order to achieve a physically stable waste form.

5.3. SOLID WASTES

5.3.1. Assessment of radionuclide inventory

For small users in developing Members States, solid waste generally contains relatively low levels of radioactivity compared to liquid wastes. It should be noted that higher concentration of radionuclides might be found in sludges, sediments, ion exchange resins, air filters, and other absorbers. Operational solid waste generally consists of trash, and is therefore likely to contain only a relatively small proportion of the initial radionuclide inventory associated with a particular operation. Solid waste also includes decommissioning waste (refurbishment) arisings.

During each stage of operation leading to the generation of radioactive solid waste, semi-quantitative assessment should be carried out to estimate the activity and radionuclide content of the solid waste arisings. This approach can be used as the primary method of estimating the radioactivity of waste generated.

5.3.2. Segregation

Solid waste should be characterized, collected and segregated as far as possible at the point of origin according to its physical, chemical, special hazard and radiological properties. This is to facilitate treatment, conditioning and transportation operations and to minimize the volume requiring subsequent storage and conditioning. Segregation of solid waste should be carried out in accordance with the waste management strategy. In general, solid waste should be segregated into the following main categories:

- Activity and radionuclide content suitable for decay;
- Pathogenic;
- Toxic (heavy metals, cyanide, etc.);
- Dangerous (explosive, pyrophoric, etc.);
- Sharp (broken glass, hypodermic needles, etc.);
- Damp solids;
- Presence of absorbed liquid waste (flash points >60°C);
- Combustible/non-combustible (if applicable);
- Compactable/non-compactable (if applicable).

A detailed description of the segregation of solid wastes is given in Reference [10]. Segregation of waste is required in order to minimize potential hazards and to facilitate subsequent operations. Segregation at the point of origin is more efficient than performing segregation after mixing. Chemically incompatible wastes (e.g. tissues and pyrophoric metals) should be collected separately in order to avoid uncontrolled chemical reactions.

Where compaction systems are available either locally or at a centralized waste management facility, waste should be segregated into compactable and non-compactable. Where incineration is available and activity levels of the waste permit, waste should be segregated into combustible and non-combustible.

Waste containing radionuclides with relatively short half-lives (e.g. <100 days) should be segregated at source to facilitate decay storage and disposal.

Solid wastes can be collected in simple containers lined inside with a durable plastic bag (about 0.5 mm thickness) which can be sealed (using a radio-frequency (RF) welder or tied with adhesive tape) and transferred to a larger container (also lined) when necessary.

Sharp wastes should be collected separately and stored in rigid, puncture-resistant containers (preferably metal) which have been clearly labelled "sharps".

Potentially pathogenic waste, such as animal carcasses, should be segregated, stored separately and appropriately and, whenever possible, incinerated. If prompt disposal is not possible, deep-freezing is often an acceptable option for storage [5]. Pathogenic waste should be sterilized and checked by an authorized doctor before conditioning.

Damp solid waste should be collected in such a way as to avoid leakage of the contaminated liquids. Normally double packaging is used.

Waste to be sent to a centralized waste management facility should be clearly identified and packed in small (~20 l) transparent plastic bags to facilitate characterization and sorting. Standardized and approved containers should be used, where possible, for transportation.

Solid waste sent to a centralized facility for compaction should not contain the following kind of waste:

- Sealed sources;
- Absorbed liquids (unless in an approved form);
- Flasks containing free liquids;
- Heavy objects;
- Wood (in some cases);
- Putrescible materials;
- Toxic, pathogenic and dangerous materials;
- Powders;
- Aerosol or pressurized containers; and
- Un-contained (loose) sharps.

Storage containers should be appropriately labelled with a radiation trefoil and a unique identification code. The following information on the waste should be retained:

- Identification number;
- Radionuclides;
- Activity (if measured or estimated)/date;
- Origin (room, laboratory, installation, etc. if applicable);
- Potential/actual hazards (chemical, infectious, etc.);
- Surface dose rate/date of measurement; and
- Quantity (weight or volume).

Preferably, this and other detailed information concerning the waste should also be recorded on a suitable record card, information sheet or computer spreadsheet.

5.3.3. Characterization

It is important to characterize wastes adequately in order to ascertain whether the waste can be exempted from regulatory control (see Section 8) or disposed of within authorized limits.

Waste can be characterized by using quality assurance techniques (records). Characterization can be accomplished by using information on the radionuclide inventory associated with each operation leading to the generation of waste, and estimates of the distribution of the initial inventory amongst associated waste arisings. In addition, a range of physical measurement techniques can be used to further characterize the radioactivity of waste streams.

Physical characterization techniques include:

- *Simple monitoring techniques* - Simple trials can be carried out to provide a correlation between the count-rate of alpha, beta, gamma and X ray probes (as applicable) and the activity content of the waste.

- *Sophisticated measurement techniques* - When possible, portable gamma spectrometry can be used to characterize solid waste packages. Consideration should be given to the possibility of sharing a portable gamma spectrometer among a number of users.

Information obtained from the characterization stage should be recorded on an appropriate record card, data sheet or computer spreadsheet.

5.3.4. Operational storage

Operational storage (prior to treatment, disposal or transportation to a centralized waste management facility) may be required:

- Prior to, during and after characterization.
- For decay prior to disposal;
- Prior to transfer to a centralized waste management facility;
- Prior to conditioning/disposal.

Similar safety storage considerations are required for solids as for liquids (see Section 5.2). The solid and liquid wastes should be physically separated during storage. As far as possible, different solid waste streams (e.g. operational wastes, spent sealed sources, potentially pathogenic wastes, long- and short-lived, different activity ranges, etc.) should be stored separately. Special radiological and security protection precautions are required for the storage of spent sealed sources [11]. In general, storage facilities for solids are similar to those for liquids, except that there is no need for a sloping floor (to collect spillages). The duration of operational storage should be kept as short as possible.

Waste containers should be inspected on a regular basis (at least weekly) to ensure that they are intact and are still present in the store.

5.3.5. Decay storage prior to disposal

Decay storage of solid waste containing radionuclides with shorter half-lives (e.g. <100 days) is a practical option for reducing the activity of the waste to levels which may be below clearance levels. The optimum decay storage period of the waste should be evaluated prior to storage. If storage space allows, the store can be divided into areas according to half-life and decay storage period. Segregation of waste in this way can simplify waste disposal operations and administration. Storage for decay of waste containing longer-lived (i.e. half-life more than or equal to 100 d) radionuclides may not be judged to be appropriate because of the long storage times involved and associated safety considerations (especially with unconditioned radioactive wastes). An example of a record form for decay storage is given in Table XI. Hazardous properties of the waste should also be recorded.

Decayed mixed wastes should not be disposed of to landfill sites unless specific approval has been obtained from the regulatory body.

5.3.6. Landfill disposal of cleared or approved waste

Approval should be obtained from the regulatory body before radioactive waste is disposed of to a landfill site. All radiation labels (trefoils) should be removed before disposal. All the information concerning individual disposals should be recorded. Hazardous, infectious and biological waste should be treated before or excluded from landfill disposal.

5.3.7. Treatment and conditioning methods

A wide range of methods exists for the treatment and conditioning of solid radioactive wastes from small users (see Section 7). With short-lived solid waste, decay storage followed by disposal as cleared waste is the preferred disposal option. With mixed and long-lived radioactive waste, long term storage may be the only option, until a suitable disposal route has been identified.

Waste treatment and conditioning operations should take into account the requirements of subsequent waste management steps, and the overall waste management strategy. In particular, the requirements for transportation and centralized waste management (if applicable) should be taken into account.

It may be necessary to treat or condition waste prior to long-term storage in order to achieve a physically stable or more compact waste form, or to remove specific hazards (e.g. pathogenic). The most common treatment and conditioning methods applicable to small users include:

- Low-force (in-drum) compaction;
- Direct immobilization;
- Incineration of combustible waste followed by direct disposal of the ash if within authorized levels or immobilization of the ash in a cement grout.

Low-force compaction and direct immobilization are potential options for local radioactive waste management. However, in many cases these techniques are more suited for use at a centralized waste management facility.

In the context of this publication, incineration is only really applicable for small quantities of waste (usually 1–5 m^3), containing small quantities of radionuclides. Approval from the regulatory body should be obtained before radioactive waste is incinerated. In many cases an environmental impact assessment will be required by the regulatory body before incineration operations will be authorized. Special consideration should be given to the environmental impact of incinerating waste containing potentially volatile radionuclides (e.g. $^{125/131}I$, ^{14}C and ^{3}H).

A relevant example of the applicability of incineration is the incineration of potentially pathogenic waste containing volatile radionuclides such as ^{14}C or ^{3}H. In this case the pathogenic hazard of the waste is removed, and the resultant ash is virtually free from radioactive contamination.

5.4. MIXED WASTES

Mixed wastes pose both a radiological and a toxicological hazard (e.g. chemical, pathogenic, etc.). Special consideration should be given to the management of mixed wastes as additional safety precautions will be required. Such wastes should not be disposed of to landfill sites or discharged to the sewage or trade waste systems unless specific approval has been obtained from the regulatory body. It is important to recognize that the non-radiological hazards could in some cases outweigh the radiological hazards.

5.4.1. Special considerations for potentially pathogenic wastes

Potentially pathogenic waste should be segregated from other radioactive waste streams and stored in appropriate, clearly labelled containers. These wastes will require special treatment in order to avoid hazards to operators of the waste management facility and the public.

If possible, potentially pathogenic wastes should be incinerated [5]. Alternatively, pathogenic waste should be sterilized by autoclaving or chemical disinfection [5] and checked by an authorized doctor before conditioning or discharge/disposal. Incineration is the preferred method of treatment.

Approval should be obtained from the relevant regulatory bodies before discharge and disposal of potentially pathogenic radioactive wastes.

5.4.2. Special considerations for organic liquid wastes

Wastes containing immiscible organic liquids should not be discharged to the sewage or radioactive waste systems unless they have been appropriately treated and the discharge has been approved by the regulatory authority. For small quantities of organic waste, consideration should be given (within the national waste management strategy) to absorption on a suitable absorber.

Provided that an adequate excess of an appropriate absorber is used, and the flash point of the organic waste is >60°C, the product could under most circumstances be regarded as solid waste. The loaded absorber should be contained in a suitable outer container (polyethylene bag or bottle, stainless steel drum). Potentially suitable absorbers are described in Table XIII.

Organic liquid waste can also be incinerated, if radionuclides, activity levels and chemical composition permit. If long storage periods are likely to occur between the generation of the waste and its incineration, consideration should be given to the possibility of absorbing the organic liquid on an organic absorber such as "Imbiber Beads" which can be incinerated.

The liquid scintillation solution used for tritium and ^{14}C counting normally has such a low activity concentration that it can be treated only as a chemically toxic organic solvent.

TABLE XIII. PERFORMANCE OF ABSORBENTS FOR ORGANIC LIQUIDS [14]

Product	Absorbency waste/ sorbent (ratio by volume)	Organic waste by volume (%)	Volume increase (%)
Natural fibre	0.9	47	111
Synthetic fibre	0.8	44	125
Clays	0.6	33	167
Diatomaceous earth	0.65	40	154
Vermiculite	0.35	26	286
Imbiber beads	4.0	80	25

5.4.3. Special considerations for chemically hazardous and toxic wastes

Special precautions are required for the management of chemically hazardous and toxic radioactive wastes. These wastes should be segregated from other radioactive waste streams and stored in appropriate, clearly labelled containers. Disposal of chemically hazardous and toxic radioactive wastes should be in accordance with relevant waste management strategies, and should be approved by the appropriate regulatory bodies.

5.5. GASEOUS WASTES

The amount of gaseous waste generated by small users is usually very small and often contains radionuclides with relatively shorter half lives (i.e. <100 days). Dilution by air after atmospheric dispersal will often be sufficient to maintain exposures to the public at acceptable levels. Additional treatment of radioactive gases generated by small users is therefore unlikely to be necessary or justifiable. All discharges of radioactive gases or vapour should be authorized by the regulatory body, following submission of a safety assessment by the user/disposer.

Air streams containing air-borne particles may have to be cleaned by air filter prior to release to the atmosphere. Unless only contaminated with short-lived radionuclides, the filter should be treated as solid waste (if only short-lived radionuclides are contaminating the filter it can be left for decay to clearance level and treated as non-radioactive waste).

5.6. SPENT SEALED SOURCES

Whenever possible, spent sealed sources should be returned to the supplier. As a general principle, sealed sources should not be removed from their holders, or the holders physically modified.

Spent sealed sources can be categorized as follows:

– *Sources with half-lives <100 days, with high activity content.* Radionuclides like ^{192}Ir are widely used in medical applications and in gamma-radiography (200–1500 MBq in medical applications and up to 5 TBq for radiography). For this type of sealed source, decay storage at a centralized waste management facility is the preferred option.

- *Sources with half-lives >100 days, with low or high activity.* The source-holder with the source inside should be kept intact during operational storage. Adequate security and radiological precautions should be taken during the handling and storage of these sources (e.g. additional shielding, strict access control, radiation monitoring, etc.). For neutron sources, it is usually necessary to use shielding, such as polyethylene, borated solid waxes, containing elements of low atomic weight.

- *Sources with a potential emanation and contamination hazard.* Adequate security and radiological precautions should also be taken during the handling and storage of spent radium sources [11] and sources known to be leaking. Special attention should be given to the monitoring of surface and airborne contamination. These sources should be stored in a dedicated area with appropriate ventilation.

Consideration should be given to the possibility that sources containing primarily short-lived radionuclides, may also contain smaller quantities of long-lived radionuclides. This may be the case for example, for ^{60}Co sources, where plates or beads of ^{59}Co are coated with a thin layer of nickel during the manufacturing process. During activation in a reactor, the coating will be activated to ^{59}Ni and ^{63}Ni which are long-lived radionuclides. Similarly, activated platinum/iridium wires containing primarily ^{192}Ir also contain a long-lived isotope of platinum, ^{193}Pt, with a half-life of approximately 50 years.

Detailed records should be maintained for all spent sealed sources in storage. Records should include as a minimum:

- Identity code (if known);
- Radionuclides present;
- Original activity/date;
- Physical and chemical form;
- Source dimensions, geometry;
- Details of shielding (e.g. gross weight - including shielding containers);
- Results and date of a previous leak test;
- Measured dose rate and details of measurement equipment used (type, model, serial number);
- Supplier of the source;
- Owner, last user of the source (details and persons responsible).

The regulatory body should be informed when a sealed source is taken out of use, and becomes a spent source in storage.

Spent sealed sources should be segregated and collected separately because of their potentially high radiological hazard. Spent sealed sources should not be removed from their associated shielding or source holders unless adequate precautions are taken to avoid exposure to radiation and contamination. Peripheral components of large irradiation equipment (i.e. those not directly associated with the source) should be removed, monitored and disposed of appropriately. Sealed sources should not be subjected to compaction, shredding or incineration.

5.7. OPERATIONAL STORAGE FACILITIES

Operational storage facilities for liquid or solid wastes may consist of metal cabinets, rooms or entire buildings. Storage cabinets and rooms are most likely be to used for local waste management applications. The essential design features of storage cabinets and rooms are therefore discussed in detail in the following sections.

5.7.1. Waste storage in cabinets

Storage cabinets are primarily applicable to the temporary storage of small quantities of low-activity, low-hazard radioactive waste. Design features for storage cabinets (besides general features mentioned above) may include:

- Simple but stout construction from corrosion-protected metal;
- Provision for low atomic weight material (if applicable) for the shielding of neutron sources and high energy beta emitters such as ^{32}P (to prevent bremsstrahlung production);
- Internal surfaces finished and without crevices so as to permit effective decontamination;
- Hinged doors secured by internal lock or padlock, keys being accessible to appointed persons only;
- Internal divisions/compartments to permit segregation of wastes;
- Discrete, suitably shielded and labelled compartments for spent sealed sources;
- Monitoring and access control;
- Chilling/cooling for biological radioactive waste (carcasses) in a locked freezer;
- Appropriate radiation labelling.

5.7.2. Waste storage in rooms

Storage rooms are applicable to larger volumes of low activity unconditioned radioactive waste. The salient design features of storage rooms are listed below:

- Entrances should be suitable both for personnel and radioactive waste packages, doors should be secured by a lock and access should be restricted to authorized persons;

- Separate areas should be provided for each packaged waste type, for different types of radionuclides (e.g. short-lived for decay), and for spent sealed sources;

- For the storage of unconditioned radioactive waste, rooms should include adequate ventilation and a fire protection system. If a ventilation/filtration system is unavailable, natural ventilation should be considered.

Modular corrosion-resistant steel storage units (e.g. ISO freight containers) could be considered as a potential alternative to a storage room.

5.8. PACKAGING AND TRANSPORTATION

Packaging will be required for the transportation of radioactive waste from the point of origin to the centralized waste management facility, from the centralized waste management facility to the final disposal facility, or directly to the disposal facility. Packaging and transportation should be carried out in accordance with IAEA Transport Regulations [12] and national regulations (see Section 9). The package design should take into account subsequent transportation and storage requirements.

In the case of sealed sources, shielding is usually an integral part of the original storage/transport package. The dimensions and type of shielding depend on activity and radionuclides to be shipped. If possible the original manufacturer's packaging should be used when transporting the source. However, consideration should be given to whether the design of the original packaging is in accordance with the current IAEA Transport Regulations. If the original package is not available, the spent source should be repackaged in accordance with the Transportation Regulations. The position of the on/off knob of the source holder should be verified and sealed (by welding) in the locked-off position.

6. ACCEPTANCE DOCUMENTATION

Prior to the transportation of a waste package from the user's premises to a centralized waste management facility, it will be necessary to obtain the necessary acceptance approval from the operator of the centralized waste management facility. This is normally achieved by completing and submitting a questionnaire which is supplied by the operator of the centralized waste management facility. It should be noted that copies of all relevant information relating to the radioactive waste consignment (i.e. that recorded by the consignor) should be submitted to the centralized waste management facility and to the regulatory body.

Such a questionnaire should contain, as a minimum, the following information for each individual package:

- Comprehensive identification of the waste generator; name and signature of the person responsible for waste management at the user's premises;

- Identification of the package;

- Type and design details of the package;

- Weight of package;
- External size and/or volume of the package;
- Maximum dose rate at contact and 1 m (transport index)/date of measurement;
- Result of surface contamination measurement;
- Radionuclide and activity content;
- Fissile material content;
- Physical nature;
- Origin of waste;
- Other associated hazards (potentially pathogenic, chemical, etc.);
- Total number of drums or containers in the consignment;
- Total weight of the consignment.

Copies of the records and documentation relating to waste packages should be attached to the questionnaire. All documentation corresponding to a waste package should be checked by a designated person at the user's premises before transportation, in order to ensure compliance with the acceptance criteria of the centralized waste management facility and the Transport Regulations.

7. CENTRALIZED WASTE MANAGEMENT

The centralized waste management facility should be constructed and operated in accordance with the State laws and regulations, and should be subject to regular inspections by the regulatory body.

The operator of the centralized waste management facility should inform waste generators of requirements for waste segregation, treatment and packaging. Operations carried out by the centralized waste management facility will potentially include:

- Operational storage;
- Treatment and conditioning;
- Interim storage of conditioned waste.

This section gives only an overview of the storage and processing options at a centralized facility, the technical details are presented in a technical report [3].

7.1. OPERATIONAL STORAGE

Waste packages should be inspected immediately on receipt at the centralized waste management facility. Inspection should include verification of:

- Physical integrity of the package;
- Surface contamination and external dose rate of the package;
- Completeness of documentation;
- Verifications of content.

Immediately after inspection, radioactive waste packages should be transferred to the operational waste store. Comprehensive radiological protection controls and physical security should be available in the store area, as unconditioned waste will be present. The capability to handle and store spent sealed sources including spent radium sources should be available at the centralized facility. Spent sealed sources should not be removed from their associated shielding during operational storage. The general considerations discussed in Sections 5.2.4, 5.3.4 and 5.7 are also relevant for an operational store at a centralized waste management facility.

The operational store should provide, as a minimum, the following services:

- Comprehensive radiation protection;
- Access control to radiologically classified areas;
- Adequate shielded areas;
- Quality control (record systems);
- Physical security;
- Fire protection system;
- Handling equipment (hoists, forklift trucks, etc.); and
- Maintenance services.

7.2. TREATMENT AND CONDITIONING

It is possible that the treatment of liquid wastes can give rise to an increase in the specific activity, potentially resulting in a significant increase of the dose rate. This should be taken into consideration in the design of treatment and conditioning facilities.

7.2.1. Treatment of aqueous liquid wastes

The selection of a suitable treatment process depends on a number of factors such as volume and type of the waste to be treated, technical capabilities, the discharge requirements for the liquid effluent and subsequent conditioning requirements. The treatment process usually results in a decontaminated effluent stream which incorporates most of the original waste volume and is intended for discharge, and a concentrate which contains most of the radionuclides and will require further conditioning. Typical treatment methods include chemical precipitation, evaporation, ion exchange, absorption.

Chemical precipitation processes involve separation of the active components of the waste stream by coagulation-flocculation. Most radionuclides and chemical contaminants can be precipitated, co-precipitated and/or adsorbed by insoluble compounds, e.g. hydroxides, oxides, carbonates, phosphates and ferrocyanides, and so removed from the liquid waste stream. Precipitation is performed in three stages:

- Addition of reagents during agitation;
- Flocculation;
- Solid–liquid separation (sedimentation/filtration).

After separation, the effluent may be suitable for discharge if sufficiently decontaminated. The sludge (concentrate) will require conditioning prior to interim storage and disposal. The extent of decontamination of the effluent will depend on the radionuclides involved and the precipitation process.

Chemical precipitation is potentially suitable for the treatment of a wide variety of different aqueous liquid waste streams, including those containing large amounts of particulate and high concentrations of inactive salts [13]. Adequate development will be required in order to optimize the operating conditions and performance of the precipitation process for individual waste streams. Special consideration should be given to the precipitation of hazardous and chemically and biologically toxic waste streams. Chemical precipitation is a simple, low-cost liquid waste treatment option.

Evaporation is a well established process [13] for large-volume, well-characterized waste streams. However, it is unlikely to be suitable for waste streams generated by small users of Member States of classes A and B. Also the use of ion exchange resins as a primary method for decontamination of aqueous liquid radioactive waste streams generated by small users is quite common today.

The use of absorbers, in particular locally available minerals such as bentonite and zeolite, in the treatment of liquid radioactive wastes is described in Reference [14].

Other liquid waste treatment techniques include membrane filtration and electrodialysis [15]. These techniques are usually selected for specific applications, and are not generally suitable for a wide range of liquid waste streams.

7.2.2. Treatment of organic liquids

Organic liquid waste is mainly comprised of scintillation cocktails, organic extractants, contaminated oils and miscellaneous solvents. A number of options are available for the treatment of organic liquid wastes. Incineration is potentially the most attractive option for the complete destruction of organic material, and provides a large waste volume reduction [16]. However, because of the significant investment costs, it may not be justified to install an incinerator for the management of small volumes of organic liquid wastes. In this case, absorption and cementation may be more applicable. Absorption on an inert absorbent material followed, if necessary, by cementation is the preferred option (see Section 5).

7.2.3. Conditioning of liquid wastes

Concentrates arising from the treatment of liquid wastes should be immobilized to produce a physically stable solid waste form which is acceptable for interim storage (and potentially for transport and disposal). Development work will normally be required to optimize the immobilization conditions and performance. Matrix selection should be based on the following factors:

- Volume, activity content, chemical composition, homogeneity and matrix compatibility;
- Potential hazards of the waste (radiation level);
- Available waste management infrastructure (availability of matrix materials, equipment, solidification processes);
- Volume minimization;
- Acceptance criteria for interim storage, transport and disposal;
- Cost of disposal; and
- Compatibility with the national waste management strategy.

The package resulting from the conditioning of wastes should be permanently labelled. Packaging should be carried out in accordance with the IAEA Transport Regulations [12] and the national regulations. All information related to the content of the conditioned waste should be collected and stored in a structured way, to facilitate retrieval when needed. The most frequently used are cementation and bitumenization.

Cements are potentially suitable matrices for the immobilization of liquid wastes as they satisfy a number of process and product requirements, including:

- Potentially acceptable properties for the retention of contaminants both in the short term and in the disposal environment;
- Excellent thermal stability due to their high specific heat;
- Fire resistance (non-flammable);
- Simple, ambient temperature process;
- Long-term stability (extensive civil engineering experience); and
- Shielding properties.

The most common inorganic cements are those based on calcium silicate (Portland cements) and those based on calcium aluminates (high alumina cements). Other inorganic materials based on calcium sulfate or gypsum cements have also been in use. The addition of certain clays to the cement matrix can also improve the retention of contaminants in the matrix.

A cement mixture of 3:1 blast furnace slag to ordinary Portland cement (BFS/OPC) can be used as a general purpose matrix material for the immobilization of radioactive waste. Mixtures of pulverized fly ash (PFA) and OPC are also commonly used and exhibit particularly good mechanical properties. An example of cement mixture used successfully to immobilize specific concentrates into 200 L drums is shown below:

Cement Portland (CPA50):	170 kg
Silica sand (ø < 5 mm):	64 kg
Plasticizer (sobracite):	16 kg
Concentrates (800 g/L):	110 kg

The main disadvantage of using cement as a matrix is that relatively low waste loadings are achievable, leading to large increases in waste volume. The compatibility of the liquid waste with the cement matrix material should be confirmed, if possible, by laboratory trials.

Bituminization is a potential option for the immobilization of liquid wastes, and is often used for the immobilization of liquid concentrates. It is a high investment process, and extensive experimental trials would be required to develop a suitable process to accept the variety of liquid wastes arising from small users.

7.2.4. Treatment of solid wastes

Checking and sorting of the contents of waste packages is usually necessary before the waste is treated and/or conditioned. This is necessary to confirm that the waste is as described in the supporting documentation, and to ensure that hazardous and/or prohibited wastes are excluded. In practice, waste should arrive from small users in packages, e.g. drums, containing small transparent plastic packages. In this case, checking and sorting is relatively straightforward. The degree of integrity of the sorting area will depend on the activity and composition of radioactive material likely to be present in the waste. Sorting facilities such as fume cupboards, glove boxes and contained areas (modular containment or pressurized suit areas) can be used.

There are a variety of potentially suitable options applicable to the treatment of solid radioactive waste. These include:

- Compaction (low- and high-force);
- Incineration;
- Size reduction for non-compactable wastes; and
- Decontamination.

Compaction is a useful technique for reducing the volume of solid waste and for producing a waste form with improved physical properties. Compaction can be divided into two main techniques, low-force (in-drum) compaction and high-force compaction.

Before compaction is carried out it is essential to characterize the waste to ensure that hazardous and prohibited wastes are excluded. After checking, the compactable waste should be placed in a suitable drum (100 L or 200 L). Special attention should be given to the updating and retention of information relating to the waste (identification, location, associated documentation, etc.).

All compaction operations should be carried out in a suitable ventilated area. If necessary (depending on the activity level and radionuclide content of the waste), the ventilation extract from this area could be provided with a filtration system containing a high efficiency particulate (HEPA) filter. In some cases the filtration unit could be an integrated part of the compactor. Airborne contamination monitoring should be provided and respiratory protection equipment should be available.

Low-force (in-drum) compaction can provide a significant volume reduction for soft waste (tissue, plastic and rubber). Usually a volume reduction factor of up to 5:1 can be achieved.

High-force compaction (super-compaction) is normally used only for the large quantities of solid waste generated at nuclear power plants.

Incineration of combustible waste usually results in large volume and weight reduction factors. The investment cost is high and it requires very skilled operational staff. Therefore, incineration is normally only used for nuclear power plant waste. There are, however, hospitals at research institutions which have installed a small incinerator for biological and pathological waste. Such incinerators may also be used for some low-level solid radioactive waste provided that it is approved by the regulatory body.

In most cases non-compactable waste is directly immobilized without treatment. However, volume reduction should be carried out where possible to segregate radioactive and non-radioactive material prior to conditioning and interim storage. Simple dismantling of equipment can be carried out in order to reduce the volume of waste to be conditioned. Special attention should be given to the dismantling hydraulic equipment which could give rise to significant quantities of liquids (oils). The dismantled items should be monitored and segregated. Dismantling operations should be carried out in a suitably ventilated area, which if necessary is fitted with HEPA filtration. Source-holders and devices containing spent sealed sources should not be dismantled. However, where possible associated electronic and mechanical components should be dismantled and removed to minimize waste volumes.

In some circumstances it may be appropriate to decontaminate items, to permit reuse (e.g. personal protective equipment), or to simplify subsequent disposal. The applicability of decontamination techniques depends on:

- Availability of suitable decontamination agents;
- Disposability of the decontamination agent;
- Availability of infrastructure to treat the secondary waste generated;
- Safety of operation;
- Economic benefits.

7.2.5. Conditioning of solid wastes

Solid waste can be conditioned to improve mechanical stability and improve the retention of the radioactive components. Solid radioactive wastes can be immobilized in a solid matrix to produce a more physically stable waste form for storage, transport and disposal. The choice of matrix will depend on the composition of the waste to be immobilized, and interim storage requirements.

Cement is frequently used for immobilization and for the conditioning of primary and secondary solid waste arisings (see Section 5). However, cement immobilization of biological waste which has been treated with lime can present problems with respect to long-term stability, and acceptability for disposal. Incineration or chemical oxidation and subsequent immobilization of ash or residue may, therefore, prove to be a more satisfactory option.

The package resulting from the conditioning process should be permanently labelled, with an identity code and a radiation trefoil. Packaging should be in accordance with interim storage and transport requirements. Information related to the content of the conditioned waste should be collected and stored in a structured way, to facilitate retrieval when needed.

7.2.6. Special considerations concerning spent sealed sources

In the case of spent sealed sources containing radionuclides with half-lives greater than 30 years, it is essential to maintain physical retrievability until a final disposal route has been identified. Spent sealed sources and source holders, in this case, should not be irretrievably immobilized in cement or in any other matrix.

Special conditioning techniques are required for spent radium sources. These are described in detail in Reference [11]. Spent radium sources should be stored in an appropriate interim storage area with strict access control and radiation monitoring.

In some countries with inadequate radioactive waste management infrastructure, it may be necessary to apply simple but effective methods of increasing the security of spent sealed sources. A potentially suitable method of securing spent sources from random or organized pilfering, is to contain the spent sources or source holders in a suitable size metal drum (200 L). A convenient way to embed the source in concrete would be to place it in the centre of the 200 L drum and to fill the drum with concrete.

When immobilizing spent sealed sources the need for security and possible long-term retrievability of the drum should always be considered. Some countries place more emphasis on security whilst others place more emphasis on retrievability.

7.3. INTERIM STORAGE

Interim storage is the storage, after treatment and conditioning, of waste prior to transfer to a disposal facility.

Design of an interim storage facility should take into account:

- Type, volume and weight of conditioned waste to be stored;
- Type of waste packages;
- Quantities of radioactivity to be stored;
- External radiation levels;
- Duration of storage;
- Risks of accidents due to internal or external factors such as flooding, hurricanes or tornados;
- Retrieval of waste.

It is essential that the interim storage facility is designed to ensure safe and secure storage of conditioned radioactive waste. The radiological protection and safety objectives of the interim storage facility are to:

- Keep radiation exposures to workers and the population as low as reasonably achievable (ALARA);
- Reduce the probability of severe accidents (e.g. fire) to acceptable levels;
- Provide physical protection to the waste packages.

Waste packages transferred to the interim storage facility should have acceptable physical stability and should be designed for safe handling. Drums and containers to be used as primary packages for transportation should comply with the IAEA Transport Regulations [12] and local transport regulations.

7.3.1. General features of an interim storage facility

Stores for radioactive wastes should be sited away from working areas, and designed to provide security from unauthorized entry and the protection of operators during both storage and transfer operations. The storage capacity should be adequate for current and future needs. A modular design would facilitate expansion as required. Treated and conditioned waste should be stored separately from unconditioned waste, inactive raw materials and maintenance materials. It may be appropriate to store the packages in bins, racks, pallets or skids to improve storage efficiency. Storage locations should be planned to minimize handling. General information on storage can be found in Reference [9].

Cylinders containing liquefied or compressed inflammable gases, inflammable or toxic liquids or solids should be stored in a separate building or rooms.

Shielding should be provided so that the radiation dose rate at any accessible position outside the store does not exceed locally prescribed levels, typically of the order of 2.5 μSv/h. Shielding for radioactive substances should take account of scattered radiation and source distribution. For spent neutron sources, appropriate neutron shielding (polyethylene, borated wax, etc.) should be used. Advantage should be taken of the additional shielding provided by the waste packages themselves, for example, by arranging the waste packages so that the highest activity packages are shielded by the lowest activity packages.

The interim storage facility should provide the following:

- Aisles at least one metre wider than the widest load device or vehicle accounting for the turning circles;

- Maximum permissible floor loadings according to the storage requirements: ordinary concrete floors typically limited to loads of 650 kg/m^2 and reinforced concrete floors to 1000 kg/m^2;

- Mechanical lifting aids such as forklifts, cranes to lift loads in excess of 250 kg;

- Appropriate ventilation but not necessarily as a fixed installation or in permanent operation. The requirement for air filtration will depend on the amount and type of radioactive waste being stored;

- Built-in smoke detection, fire alarms and fire prevention systems, lights, switches, fuse boxes, etc. (as required); and

- A comprehensive radiological surveillance programme.

Further information concerning the requirements for a safe storage can be found in References [2, 12].

7.3.2. Inspection and maintenance of the facility

Regular inspection of equipment and facilities should be carried out in order to ensure that:

- Waste packages are still present;
- Physical integrity of the waste packages is adequate;
- Equipment and monitoring systems are in good operating condition;
- Operations are carried out in accordance with current written procedures, safety requirements and licenses;
- Waste discharges and disposal are within authorized limits;
- Comprehensive documentation is available and maintained;
- Operators receive adequate training.

8. CLEARANCE OF RADIOACTIVE WASTE FROM FURTHER REGULATORY CONTROL

Under certain circumstances small quantities of radioactive materials might be cleared by the regulatory body from further regulatory control.

8.1 CLEARANCE GUIDELINES

The following guidelines should be considered when defining clearance levels:

- The disposal and discharge of radioactive materials should be as low as reasonably achievable. In practical terms, the disposals and discharge of radioactive waste should be limited to quantities which will not expose the individual members of the public to doses in excess of the limit set by the national regulatory authority.

- Setting clearance levels for the discharge of radionuclides is an extremely difficult process. Full consideration should be given to References [17–20].

- The radiation risks to individuals caused by the discharge of exempted quantities of radionuclides should be sufficiently low so as to be of no regulatory concern.

- Many countries have defined exemption limits for radionuclides which are based on annual limits of intake (ALI) or fractions of ALI. It is the responsibility of the regulatory body to define exemption levels and site specific discharge authorizations.

8.2. EXAMPLES

Examples of very conservative exemption levels of selected radionuclides are included in Table XIV. In practice, levels will usually differ depending on specific site authorizations. The European Commission has set minimum requirements for conditions where reporting, licensing, and prior authorization are not needed. These conditions are listed below:

(a) The quantities involved do not exceed:

- 5×10^3 Bq for nuclides of *very high radiotoxicity* (e.g. ^{226}Ra, ^{238}Pu, ^{239} Pu, ^{241}Am, ^{242}Cm, ^{244}Cm, ^{252}Cf);

- 5×10^4 Bq for nuclides of *high radiotoxicity* (e.g. ^{60}Co, ^{90}Sr, ^{91}Y, ^{93}Zr, ^{94}Nb, ^{106}Ru, ^{110m}Ag, ^{109}Cd, ^{115m}Cd, ^{114m}In, ^{125}I, ^{126}Sn, ^{131}I, ^{192}Ir);

- 5×10^5 Bq for nuclides of *moderate radiotoxicity* (e.g. ^{14}C, ^{22}Na, ^{24}Na, ^{32}P, ^{35}S, ^{36}Cl, ^{42}K, ^{45}Ca, ^{47}Ca, ^{51}Cr, ^{57}Co, ^{58}Co, ^{59}Fe, ^{75}Se, ^{82}Br, ^{85}Sr, ^{89}Sr, ^{90}Y, ^{123}I, ^{137}Cs, ^{147}Pm, ^{169}Er, ^{186}Re, ^{197}Hg, ^{198}Au, ^{201}Tl);

- 5×10^6 Bq for nuclides of *low radiotoxicity* (e.g. ^{3}H, ^{99m}Tc, ^{113m}In, ^{133}Xe). The nuclides ^{67}Ga, ^{81m}Kr, ^{111}In, ^{127}Xe are not included; their group should be chosen by the regulatory body;

- For radioluminescent paint: 2×10^9 Bq of ^{3}H, 1×10^8 Bq of ^{147}Pm;

(b) Radioactive substances with a specific activity less than 100 Bq/g;

(c) For solid naturally occurring radioactive substances with a specific activity less than 500 Bq/g;

(d) Navigation instruments and timepieces.

It is emphasized that these values should *not* be considered as allowable amounts for unrestricted release. More detailed information on existing practices on exemption in the European Community countries can be found in Reference [18].

TABLE XIV. EXAMPLES OF EXEMPTION LEVELS FOR DISCHARGE [19]

Radionuclide	Specific activity (Bq/g)	Total activity (Bq/a)
^{3}H	1×10^{6}	1×10^{9}
^{14}C	1×10^{4}	1×10^{7}
^{32}P	1×10^{3}	1×10^{5}
^{125}I	1×10^{3}	1×10^{6}
^{226}Ra	1×10^{1}	1×10^{4}

9. TRANSPORTATION

Off-site transportation of radioactive waste should be in accordance with any relevant national transport regulations and with the IAEA Regulations for the Safe Transport of Radioactive Material [12]. The IAEA Regulations include general safety principles, activity limits and the testing requirements for packages, storage in transit, and the test and inspection procedures. Documentation accompanying radioactive waste to be transported should contain sufficient information for its recipient to handle the packages safely and in accordance with the requirements of the relevant regulatory body.

10. ENVIRONMENTAL MONITORING

Environmental monitoring is likely to be required for large centralized waste management facilities, and in many cases for smaller facilities. The environmental monitoring programme should be carried out to assess:

- The adequacy of the controls implemented during the predisposal waste management system regarding the release of radioactivity to the environment;
- That radiation exposures to the general public are kept as low as reasonably achievable and within acceptable levels;
- That radiological impact resulting from any discharges is as low as reasonably achievable and within legal levels;
- Compliance with national regulations, environmental standards, and waste discharge authorized limits; and
- Interpretation of operational records to carry out trend analysis.

Environmental monitoring programmes should be planned in accordance with the potential hazards of the facility and the environmental condition of the site. The programme may consist of the collection of different environmental samples (ground water, air, dust, etc.) and measurement of radiation and contamination levels. Whenever possible, real-time mode radiation monitors should be located in different areas within and around the site, preferably in downwind positions.

11. QUALITY ASSURANCE

Quality assurance means all planned and systematic actions necessary to provide adequate confidence that an item, process or service will satisfy the given requirements for quality.

Quality assurance programmes relevant to waste management operations should include:

- Handling, segregation, characterization, treatment, packaging, storage, discharge and disposal of radioactive waste at the user's premises;
- Transportation operations;
- Handling, segregation, characterization, treatment and conditioning, packaging, storage and disposal of radioactive waste at the centralized radioactive waste management facility;
- Record keeping.

Quality assurance programmes aim to ensure confidence that all operations are optimally managed, waste disposals and discharges are within authorized limits, and conditioned waste packages are produced in accordance with the specifications for storage, transportation and for possible disposal. Training of personnel is an integral part of quality assurance. Procedures are required for all operations involving the management of waste at the user's premises and at the centralized radioactive waste management facility.

A quality assurance programme is usually developed as part of the license application by the operator and reviewed and approved by the regulatory body. The programme should define and describe the organization, responsibilities, relevant quality assurance steps and organizational interfaces involved in predisposal waste management. A system for document control and records should provide evidence that the required quality has been achieved. Guidance on the development and implementation of a quality assurance programme may be found in IAEA quality assurance code and safety guides [21, 22].

General guidelines for quality assurance concerning conditioning and storage are given in the IAEA publication Characterization of Radioactive Waste Forms and Packages [23]. The details of the quality assurance programme should be commensurate with the extent and complexity of the activities giving rise to the waste and the quantities and potential hazards of that waste.

12. REGIONAL CO-OPERATION

Regional co-operation in waste management should be seriously considered. Since the benefits in terms of shared costs, greater safety and better technology are obvious, it would make good sense. Such co-operation among countries could involve development of techniques and procedures for collection and conditioning of liquid and solid waste, and spent sealed sources; transport; interim storage and disposal. Co-operation may also include the use of common resources especially for extended storage and eventual disposal. This option should be implemented taking into account existing international safety and environmental standards and conventions. Some countries may, in the future, rely on regional co-operation when it comes to disposal options.

The present public opinion and most national policies are not in favour of receiving radioactive waste, including spent sealed sources from other countries. Careful and sensitive efforts should, however, be started and continued. This may not be achieved in the near future and may take many years. It is therefore prudent that concerned waste managers promote the idea.

Clear, understandable, quantitative evidence of the benefits of regional cooperation should be presented at relevant international conferences. Discussions with national authorities, organizations and eventually with the public of the countries concerned, should be initiated.

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Consultants Meetings

Vienna, Austria: 13–17 June 1994, 25–29 September 1995,
30 September – 4 October 1996

Advisory Group Meeting

Vienna, Austria: 19–23 February 1996