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Storage of radioactive wastes

Technical manual for the management of low and intermediate level wastes generated at small nuclear research centres and by radioisotope users in medicine, research and industry

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

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FOREWORD

The International Atomic Energy Agency (IAEA) has published Technical Reports Series and Safety Series documents on radioactive waste management over nearly three decades. These documents have served Member States presenting basic reference material and comprehensive surveys of the 'state-of-the-art' technologies applied to radioactive waste management.

The need for assistance in specific waste management problems facing many countries has been demonstrated in IAEA activities including technical assistance projects and Waste Management Advisory Programme (WAMAP) missions. Technical Reports Series and Safety Series documents usually reflect:

- technological solutions based on experience and resources normally available in countries managing nuclear fuel cycle wastes;
- volumes and activities of radioactive wastes of orders of magnitude greater than those generated in countries without nuclear power.

A new series of technical documents is being undertaken especially to fully meet the needs of Member States for straightforward and low cost solutions to waste management problems. These documents will:

- give guidance on making maximum practicable use of indigenous resources;
- provide step-by-step procedures for effective application of technology;
- recommend technological procedures which can be integrated into an overall national waste management programme.

The series entitled 'Technical Manuals for the Management of Low and Intermediate Level Wastes Generated at Small Nuclear Research Centres and by Radioisotope Users in Medicine, Research and Industry' will serve as reference material to experts on technical assistance missions and provide 'direct know-how' for technical staff in Member States. Currently, the following manuals have been identified:

- Minimization and Segregation of Radioactive Wastes
- Storage of Radioactive Wastes
- Handling, Conditioning and Disposal of Spent Sealed Sources
- Handling and Treatment of Radioactive Aqueous Wastes
- Treatment and Conditioning of Radioactive Solid Wastes
- Treatment and Conditioning of Carcasses and Biological Material
- Treatment and Conditioning of Radioactive Organic Liquids

- Treatment and Conditioning of Spent Ion Exchange Resins from Research Reactors, Precipitation Sludges and Other Radioactive Concentrates

- Design of a Centralized Waste Processing and Storage Facility.

The order of preparation of the manuals is based on priority needs of Member States and it is recognized that additional areas of technical need may be identified as this programme is implemented. In this regard the programme is flexible, should other manuals or modifications prove necessary.

The objective of this manual is to provide essential guidance to Member States without a nuclear power programme on storage of radioactive wastes, the storage being essential for operating flexibility and as part of a waste management strategy. Segregated wastes should be stored safely and systematically for decay, where possible to exempt levels or otherwise to levels which are appropriate for a future management option including disposal.

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CONTENTS

1. INTRODUCTION

1.1. Background

Even if the best waste minimization measures are undertaken throughout radioisotope production or usage, significant radioactive wastes arise to make management measures essential. As shown in Figure 1, storage steps are an integrated part of the waste management system.

For developing countries with low isotope usage and little or no generation of nuclear materials, it may be possible to handle the generated waste by simply practising decay storage for several half-lives of the radionuclides involved, followed by discharge or disposal without further processing. For those countries with much larger facilities, longer lived isotopes are produced and used. In this situation, storage is used not only for decay storage but also for in-process retention steps and for the key stage of interim storage of conditioned wastes pending final disposal.

1.2. Objectives

In the sequence of radioactive waste management operations, storage is required specifically to provide the following:

- operational convenience (e.g. waste awaiting collection, transport or a treatment campaign);

- safe and secure retention during a period permitting radioactive decay prior to further radioactive waste management steps. (e.g. for shorter lived contamination in untreated wastes to permit disposal or discharge within exemption, de minimis or discharge limits authorized by the national regulatory organization);

- interim storage (e.g. retention of conditioned wastes contaminated with longer lived activity pending the eventual establishment of disposal facilities).

The above objectives must be part of an overall strategy for radioactive waste management based on minimizing the radiation exposures of workers and the public, including long term effects according to the guidelines of the International Commission on Radiological Protection (ICRP) and the IAEA [1-3].

1.3. Scope

The report will serve as a technical manual providing reference material and direct step-by-step know-how to staff in radioisotope user establishments and research centres in the developing Member States without nuclear power generation. Considerations are limited to the simpler storage facilities.

The restricted quantities and low activity associated with the relevant wastes will generally permit contact-handling and avoid the need for shielding requirements in the storage facilities or equipment used for handling. A small quantity of wastes from some radioisotope production cells and from reactor cooling water treatment may contain sufficient short lived activity from activated corrosion products to require some separate decay storage before contact-handling is suitable.

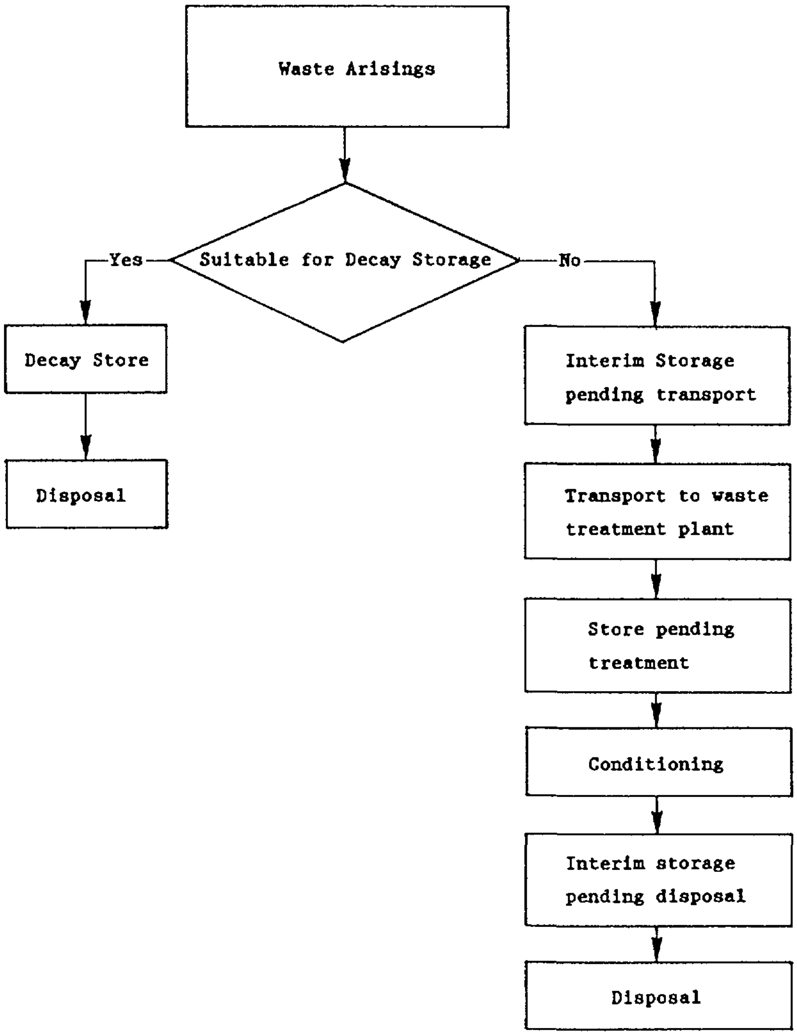


FIG. 1. Simplified flow chart showing the use of storage in the waste management system.

Spent sealed sources also arise within these countries but the immobilization and storage has specifically been covered in a previous manual [4]. Unconditioned sources need to be stored in a separate, if adjacent location, but conditioned sources may be placed with other solid conditioned radioactive wastes within an interim store. For unconditioned spent sources, temporary local shielding and simple handling-at-distance devices should suffice. Interim storage of the conditioned spent sealed sources must however take account of the exceptional nature of any spent radium or americium sources which, unlike all other wastes in the facility, cannot be consigned to eventual shallow land burial. The long-life and radiotoxicity of these heavy alpha active isotopes will require segregation for deep geological disposal.

2. WASTE ARISINGS AND CHARACTERISTICS

2.1. Sources, quantities and radioisotope contents

The types of radioactive waste generated in developing countries are presented in detail in the Technical Manual in this series entitled "Minimization and Segregation of Radioactive Wastes" [5]. That manual provides information on the types of radioactive waste generated in developing countries, quantities and activity levels generated from different types of facilities and radionuclides contained in the wastes.

Facilities that generate radioactive waste include:

Nuclear research centres

It is assumed that the developing Member State is likely to have a nuclear centre, probably with the facilities outlined below. It is generally considered that up to 0.5 m^3 low level solid waste is generated annually per employee.

Research reactors

The main wastes generated by the operation of a low power research reactor are the liquid wastes which are usually treated by decay storage or ion exchange and then discharged to the local system and the solid wastes which are generally around 1 m^3 per annum for treatment consisting of spent ion exchange resins, irradiated equipment and general trash.

Cyclotrons

These devices and other particle accelerators (which are built more cheaply than reactors and have an advantage of not requiring a supply of nuclear fuel) are likely to be included in the facilities. Bombardment of targets mainly by protons and electrons may be used to produce isotopes such as ^{11}C, ^{13}N, ^{18}F, ^{67}Ca, ^{81}Rb and ^{123}I. Wastes generated would be assumed to contain these radionuclides.

Radioisotope production laboratories

The capsules irradiated in the research reactors and the targets in the cyclotrons, producing the nuclides described previously, are chemically processed by dissolving or etching, thus giving rise to radioactive wastes of short lived activity, mostly aqueous solutions. Though initially some wastes may contain high levels of radioactivity, after decay storage no treatment is generally required.

Small users of radioisotopes

Hospitals, universities and manufacturing industries within the developing Member State are anticipated to be involved with handling radioactive materials and the likely main areas of application are:

- radioimmunoassay
- radiopharmaceuticals
- diagnostic techniques
- radiotherapy
- research.

Usage of the isotopes results in waste volumes of up to about 20 m^3 per annum. Wastes other than those containing long lived ^3H and ^{14}C generally do not require treatment beyond decay storage. Segregation should be carefully planned.

3. EXEMPTION OF WASTES

3.1. Exemption principles

Exemption of small amounts of very low level wastes from general regulatory controls on disposal of radioactive waste has been under consideration internationally for many years [6-8].

There has long been recognition that if every waste material that contains radionuclides had to be treated and disposed of as radioactive waste, the quantity of such materials would be large and the cost unnecessarily high. Many materials which contain small amounts of radionuclides can be shown to give rise to insignificant hazards. Regulation of such wastes achieves no benefit and it is usually considered to be more appropriate to exempt them from the requirements of regulatory controls.

Principles for exemption have been set out which specify radiological criteria for exemption but do not consider the translation into activity for exempt material.

Specification of exempt amounts of waste in terms of activity content is difficult because of the variability in the radiological significance of different radionuclides (see Table I) and because disposal may be to air, water or land when each offers different opportunities for the subsequent radiation exposure to man. Each individual disposal may be considered trivial but the overall impact may not. The large range of environmental conditions and human behaviour patterns arising in different countries change the exposure.

According to circumstances it may be appropriate to specify limits in terms of volume or mass concentration, e.g. for a large amount of slightly contaminated material. In other cases, surface contamination levels may be more relevant and in the case of small solid items, the total activity may be most relevant. Against this background, some indications are listed below for activity levels which may be a basis for deciding when activity levels in stored material have reached low levels that may be considered non-radioactive.

At one extreme, a very low exemption level may be adopted which can be applied to all circumstances. In the United Kingdom materials below 0.4 Bq g^{-1} (10^{-5} μCi g^{-1}) are exempt from the major requirements for control of radioactive materials. 0.37 MBq (10 μCi) in 0.1 m^3 and 37 kBq (1 μCi per item) excluding alpha emitters and ^{90}Sr are acceptable in local non-radioactive refuse sites. The value applies to all radionuclides, although higher limits are given for other radionuclides in particular circumstances.

Recommended clearance levels for recycling steel scrap and equipment have been suggested by the Commission of the European Communities (Table II) [9]. These values are broadly relevant to exemption of relatively large amounts of material. In Brazil (bulk) solid wastes contaminated by traces of short lived radionuclides not exceeding 74 Bq g^{-1} can be sent to a municipal refuse disposal plant [10]. This value is also given in Reference [11] but with additional requirements that the total activity (per disposal) is less than

- 3.7 kBq for radionuclides of very high toxicity
- 37 kBq for radionuclides of high toxicity

TABLE I.
BASIC RADIOLOGICAL CHARACTERISTICS OF SOME RELEVANT RADIONUCLIDES [8]

Radio-nuclide	Half-life year	Dose per unit intake, Sv Bq^{-1}		Mean Gamma Energy per Disintegration, MeV
		Inhalation	Ingestion	
H-3	1.2×10^{1}	1.7×10^{-11}	1.7×10^{-11}	0
C-14	5.7×10^{3}	5.6×10^{-10}	5.6×10^{-10}	0
P-32	3.9×10^{-2}	3.6×10^{-9}	2.1×10^{-9}	0
Cl-36	3.0×10^{5}	5.5×10^{-9}	8.2×10^{-10}	1.5×10^{-4}
Ca-45	4.5×10^{-1}	1.6×10^{-9}	8.1×10^{-10}	0
Co-60	5.3	4.1×10^{-8}	7.0×10^{-9}	2.5
Ni-63	9.6×10^{1}	8.4×10^{-10}	1.5×10^{-10}	0
Sr-90	2.9×10^{1}	3.4×10^{-7}	3.6×10^{-8}	0
Tc-99m	6.8×10^{-4}	8.7×10^{-12}	1.6×10^{-11}	1.3×10^{-1}
I-125	1.7×10^{-1}	5.8×10^{-9}	9.2×10^{-9}	0
I-131	2.2×10^{-2}	8.0×10^{-9}	1.3×10^{-8}	3.8×10^{-1}
Cs-137	3.0×10^{1}	7.7×10^{-9}	1.2×10^{-8}	5.6×10^{-1}
Ir-192	2.0×10^{-1}	6.3×10^{-9}	1.4×10^{-9}	8.1×10^{-1}
Ra-226	1.6×10^{3}	2.1×10^{-6}	3.0×10^{-7}	1.7
Th-232	1.4×10^{10}	4.4×10^{-4}	7.4×10^{-7}	1.8×10^{-4}
Pu-238	8.8×10^{1}	1.0×10^{-4}	8.6×10^{-7}	7.5×10^{-6}
Am-241	4.3×10^{2}	1.2×10^{-4}	9.8×10^{-7}	2.1×10^{-2}

Notes: Values of dose listed are committed effective dose equivalent for adults and include contributions from short lived radioactive daughter radionuclides where appropriate, and the chemical forms assumed on intake are those giving rise to the highest dose. Only gamma emissions above 50 keV are included since these are the main contributors to effective dose equivalent taking account of any short lived daughters.

- 370 kBq for radionuclides of moderate toxicity
- 3700 kBq for radionuclides of low toxicity.

An alternative method for calculating discharges for wastes is based on limiting exempt quantities to some multiple of that amount which on intake by man would give rise to the individual dose criterion for exemption. If national advice is not available a dose criterion of 10 μSv a^{-1} leads to the values given in Table III. These values may be used for guidance with the most restrictive of the inhalation and ingestion values taken, as appropriate. The values should not be applied without examining the local circumstances. For example, they may be too restrictive in the case of activity dispersed through a large volume of material (inhalation of the entire amount might be physically impossible, for example). On the other hand the values may be insufficiently restrictive for very small non-dispersible sources which could give rise to relatively large doses if held close to the skin.

TABLE II. THE RECOMMENDED CLEARANCE LEVELS FOR RECYCLING STEEL SCRAP AND EQUIPMENT [9]

Type of activity	Clearance level for the mass activity concentration	Clearance level for the surface activity concentration
Beta, gamma	1 Bq/g averaged over a maximum mass of 1000 kg [a]	0.4 Bq/cm^2 for non-fixed contamination on accessible surface [b]
Alpha	N/R [c]	0.04 Bq/cm^2 [b]

[a] no single item may exceed 10 Bq/g

[b] averaged over any area of 300 cm^2 of any part of the surface

[c] N/R: no value is recommended.

TABLE III. AMOUNTS OF RADIONUCLIDES WHICH ON INTAKE GIVE RISE TO A DOSE OF 10 μSv [8]

Radionuclide	Inhalation	Ingestion (Bq)
H-3	6×10^5	6×10^5
C-14	2×10^4	2×10^4
P-32	2×10^3	4×10^3
S-35	2×10^4	4×10^4
Cl-36	2×10^3	1×10^4
Co-60	2×10^2	1×10^3
Sr-90	2×10^1	2×10^2
Tc-99m	1×10^6	6×10^5
I-125	4×10^2	2×10^2
I-131	4×10^2	2×10^2
Ra-226	4	1×10^1
Th-232	8×10^{-3}	6
U-238	4×10^{-1}	1×10^2

In each case the chemical form giving rise to the highest dose has been assumed.

According to the nature or the types of waste arising and the availability of disposal routes, a choice can be made between storage for decay or storage prior to final disposal. Potentially the latter may involve storage for an unknown period and will affect the design requirements for the store. Decay for exemption might be expected to be carried out at user establishments. Long term storage is probably more reasonably carried out at any available centralised treatment facility, however, neither situation is exclusive.

4. STORAGE OF UNCONDITIONED WASTES

4.1. Overall requirements

4.1.1. Storage at radioisotope user establishments

Waste storage for untreated arisings of liquids and solids will be required utilizing a variety of facilities, particularly those engaged in research, to meet the objectives in Section 1.2.

The requirements are fulfilled normally in simple stores with direct-handling ranging from single secure cabinets to one or more dedicated rooms. However, it is particularly important in these small stores, that operation is not haphazard, with segregation, record keeping and easy retrieval permitting efficient despatch to treatment or disposal.

The efficiency of stores operation is vital to prevent accumulation of wastes in working areas through the planned system of collection and transfer. Small quantities of wastes in plastic bags, common bins, drawers or cupboards should be particularly restricted. Combustible wastes should generally not exceed about 100 litre batches and activity levels of 10 ALI (see Table IV) unless stored in a locked, fireproof enclosure, probably with containment in lidded metallic drums.

4.1.2. Storage at radioisotope production facilities

Generally, in the routine radioisotope production facilities, limited storage of liquid and solid wastes will be carefully designed as part of the facility arrangements. Quantities of wastes will arise up to the intermediate level requiring local decay storage of the predominantly short lived contaminants before handling and transfer to further storage, treatment or disposal. Larger radioisotope producers have installed special storage facilities adjacent to the hot cells with design features elaborated in the next section. The solid wastes arising from ^{99}Mo, ^{125}I, ^{131}I production, particularly spent cans and contents require some months of decay storage prior to release or further processing.

4.1.3. Storage at research reactors

In developing Member States most reactor facilities have some waste storage arrangements integrated into the original design. Cleanup of the primary circuit cooling water, removing activated corrosion products (e.g. ^{58}Co, ^{60}Co) and any fission product diffusing from the reactor fuel (e.g. ^{134}Cs, ^{137}Cs) and using normal ion exchange processing will give rise to a small proportion of wastes requiring segregation, treatment and conditioning.

If the reactor cooling water is treated by the ion exchange process without regeneration, then the spent ion exchange media is likely to be radioactive waste approaching the intermediate activity level, requiring *in situ* decay storage before handling. When the ion exchange media is regenerated, a small proportion of the liquid wastes should be segregated containing the majority of the activity and should be separately stored (considered in Section 4.2) for subsequent treatment.

4.2. Decay storage requirements

Advantage should be taken to avoid treatment of radioactive wastes, when possible by carefully organizing the decay storage of the shorter

TABLE IV. ALI_{min} [a] VALUES FOR SOME COMMON RADIONUCLIDES [13]

Nuclide	ALI_{min}(Bq)	Nuclide	ALI_{min}(Bq)
H-3 water	3×10^9	Sr-85m	8×10^9
C-14	3×10^8	Sr-85	6×10^7
F-18	2×10^9	Sr-87m	1×10^9
Na-22	2×10^7	Sr-89	5×10^0
Na-24	1×10^8	Sr-90	1×10^9
P-32	1×10^7	Y-90	2×10^7
P-33	1×10^8	Tc-99m	3×10^9
S-35	8×10^7	Mo-99	2×10^8
Cl-36	9×10^6	Cd-109	1×10^6
Cl-38	6×10^8	Cd-115	3×10^7
K-42	2×10^8	In-111	2×10^8
K-43	2×10^8	In-113m	2×10^9
Ca-45	3×10^7	Sb-124	1×10^8
Ca-47	3×10^7	I-123	1×10^8
Cr-51	7×10^8	I-125	1×10^6
Mn-52	3×10^7	I-129	2×10^5
Mn-52m	1×10^9	I-130	1×10^7
Mn-54	3×10^7	I-131	1×10^6
Mn-56	2×10^8	I-132	1×10^8
Fe-52	3×10^7	Cs-129	9×10^8
Fe-55	7×10^7	Cs-130	2×10^9
Fe-59	1×10^7	Cs-131	8×10^8
Co-56	7×10^6	Cs-134	3×10^6
Co-57	2×10^7	Cs-134m	4×10^9
Co-58	3×10^7	Cs-137	4×10^6
Co-60	1×10^6	Ba-131	1×10^8
Ni-63	1×10^8	Ba-133m	9×10^7
Cu-64	4×10^8	Ba-135m	1×10^8
Cu-67	2×10^8	La-140	2×10^7
Zn-62	5×10^7	Yb-169	2×10^7
Zn-65	1×10^7	Ir-192	8×10^6
Zn-69m	2×10^8	Au-198	4×10^7
Ga-67	3×10^7	Hg-197	2×10^8
Ga-68	6×10^8	Hg-203	2×10^7
As-73	8×10^8	Tl-201	6×10^8
As-74	8×10^7	Tl-204	7×10^7
Se-75	6×10^7	Pb-210	9×10^3
Br-76	1×10^8	Pb-212	1×10^6
Br-77	6×10^8	Po-210	2×10^4
Br-82	1×10^8	Ra-226	2×10^4
Rb-81m	9×10^9	Th-232	4×10^1
Rb-81	1×10^9	U-238	2×10^3
Rb-86	2×10^7	Am-241	2×10^2
Rb-88	7×10^8	Cm-244	4×10^2
Rb-89	1×10^9	Cf-252	1×10^3

[a] The ALI (Annual Limit on Intake) is a secondary limit for occupational internal exposure and is the smaller value of intake of a given radionuclide in a year by Reference Man [ICRP Publication 23] which would result in either a committed effective dose equivalent of 50 mSv or a committed dose equivalent in the lens of the eye of 150 mSv or in any other organ or tissue of 500 mSv.

lived contaminated wastes wherever permitted by the non-radioactive risks. More volatile or combustible wastes presenting hazard in the case of fire, biological instability or toxicity factors are the main risks to be taken into account.

Decay storage is normally applied to routinely segregated LLW from user hospitals, universities, research laboratories and other institutions for the common constituents, ^{99}Mo (66 h), ^{131}I (8 d), ^{125}I (60 d) and ^{192}Ir (74 d). At radioactivity concentrations 3.7 to 37 MBq/m^3 (0.1 to 1 mCi/m^3) decay storage of ten half lives potentially reduces the residual radioactivity content to below limits for disposal.

The advantageous option of decay storage requires the operation of protected, selective storage capacity with matching identification and other administrative procedures. Usual radiological protection requirements should apply regarding handling of active or potentially active materials even in the simplest facility.

Table V gives the times for reduction in activity by factors of 10 for the more short lived radionuclides listed in Table I. Large reduction factors are achieved within short periods for very short lived radionuclides, e.g. a factor of 10^6 in 5 days (1.4×10^{-2} a) for ^{99m}Tc. For such short lived radionuclides there are not likely to be problems with discharge limits of the exemption level. Very short storage periods will provide adequate decay even at the lower limits for exemption. The problem arises for radionuclides of half-lives between about 6 weeks to 1 year, and the answer also depends on the reduction required. Finally it may be appropriate to calculate the radiological impact of disposal, according for example to the straightforward suggestion in Reference [12]. For ^{45}Ca, of half-life 0.45 year, a period of 9 years is required for a 10^6 reduction. Storage over such a long period may not be judged appropriate because of some risk associated with the very long interim storage.

TABLE V. REDUCTION TIMES FOR EXAMPLE RADIONUCLIDES TO SPECIFIED LEVELS OF DECAY

Radio-nuclide	Decay Constant a^{-1}	Time,[a] a, for Reduction in Activity by a Factor of					
		10^1	10^2	10^3	10^4	10^5	10^6
P-32	1.8×10^1	1.3×10^{-1}	2.6×10^{-1}	3.9×10^{-1}	5.2×10^{-1}	6.5×10^{-1}	7.8×10^{-1}
Ca-45	1.5	1.5	3	4.5	6	7.5	9
Tc-99m	1.0×10^3	2.3×10^{-3}	4.6×10^{-3}	6.9×10^{-3}	9.2×10^{-3}	1.2×10^{-2}	1.4×10^{-2}
I-125	4.1	5.6×10^{-1}	1.1	1.7	2.3	2.8	3.4
I-131	3.2×10^1	1.7×10^{-1}	3.4×10^{-1}	5.0×10^{-1}	6.7×10^{-1}	8.4×10^{-1}	1.0

[a] The above table is calculated from the following formula:

$$T = \frac{\ln_e R}{\lambda}$$

where T is time in years
λ is the decay constant
R is the reduction factor in 10^n

TABLE VI. EXAMPLE DECAY STORE RECORD

Waste Item Number	Date Received	Radio-nuclide	Activity at Receipt	Description	Storage Location	Date for Disposal as Exempt Waste, or Authorised Waste, and Disposal Route	Disposal Completed
1.	1 July 90 Signature of Store Manager	P-32	1 MBq	Contaminated cotton swabs and plastic sealed in plastic container, mass 1 kg approx.	Bay 1	1st Sept. 90 to Muncipal Tip	Signature of Store Manager, date
2.	etc.						

Table VI illustrates the record which may need to be maintained for radionuclides placed in decay storage. Completion of the record will involve consideration of the special features of the waste. At the time of receipt the duration for decay storage should be evaluated. In using Table V, after 47.5 days (1.3×10^{-1} a) the waste will be below 100 kBq kg^{-1}, (with a mass of one kilogram the total activity is therefore 100 kBq) and thus have a total activity less than 370 kBq. Assuming ^{32}P is of moderate radiotoxicity, then after this time, the waste conforms to the exemption criteria given in Section 3.1. This is an example application of criteria and account would need to be taken of any national criteria.

4.3. Design features

4.3.1. General features

The design of waste storage space or facilities should meet the overall operational requirements outlined in Section 4.2 and should comply with the main common safety and housekeeping conditions below:

(i) Storage of solid unconditioned wastes should be separated from storage of inactive raw materials, intermediates or products and any maintenance materials.

(ii) Stores for radioactive substances should be sited away from working areas and designed so that all persons are adequately protected during both storage and transfer of substances to and from the stores.

(iii) 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 0.75 µSv h^{-1}. Data for shielding from gamma radiation by various materials is provided in Reference [1]. Shielding for radioactive substances should take account of scattered radiation and source distribution.

Advantage should be taken of self-shielding, e.g. by arranging spent radionuclide generators so that the highest activity is at the centre.

(iv) Storage of gas cylinders containing liquefied or compressed inflammable gases, inflammable or toxic liquids or solids should be in a separate building.

(v) Storage of the radioactive waste solids should be tidy and placed in drums or bins, racks, pallets or skids suitably planned for minimum handling.

(vi) Aisles should be at least one metre wider than the widest loaded device or vehicle accounting for the turning circles.

(vii) Maximum permissible floor loadings must be accounted for regarding storage heights with ordinary floors typically limited to loads of 650 kg/m^2 and reinforced concrete floors to 1000 kg/m^2.

(viii) Mechanical aids are normally necessary if lifts exceed 30 kg and movements exceed about 25 m.

(ix) Materials storage must be designed to ensure smoke detection, fire alarms, lights, switches, fuse boxes.

(x) Sprinklers and drains should not be obstructed and there should be fire fighting provisions including adequate clearance below sprinkler heads.

(xi) Appropriate ventilation and air conditioning should be included in the design (particularly if wastes are contaminated with the volatile radionuclides, ^{3}H, ^{14}C, ^{131}I) but not necessarily in fixed installation and permanent operation.

(xii) Air filters may be unnecessary for the amount of radioactivity stored and in hospitals should be assessed regarding maintenance and disposal problems.

(xiii) Storage capacity should be designed adequately to prevent aggravation of housekeeping problems and wastes in working areas.

(xiv) Store design should always provide security from unauthorised entry.

(xv) Store design should take adequate account of risks of accidents due to internal or external origin such as flooding or gales.

4.3.2. Liquid waste storage

The management of radioactive liquid wastes should involve the use of approved containers for small quantities of liquid wastes and for larger amounts will require storage tanks for:

- operational control
- collection and interim storage before treatment of a batch
- activity decay storage
- monitoring.

Liquid wastes requiring transfer from a container should not be poured for obvious safety reasons and the design of the installation should include suitable glandless pump and pipework.

Wastes in a particular store should be selected for chemical compatibility and suitability for retention in the longer term.

Before storage small quantities of liquid waste should be preferably absorbed in suitable material such as vermiculite. When more active liquid waste is stored it is often placed in a secondary container, or when small volumes are involved, on a tray large enough to contain the liquid if the primary container starts leaking during storage.

The design of bulk storage systems for a centralized waste treatment plant is being evaluated in detail in another document in this series (Design of a Centralized Waste Processing and Storage Facility) but the following factors have to be taken into account:

- volumetric and activity inventory and nature of liquids to be stored (corrosive, aqueous, organic),

- construction constraints, materials and fabrication standards,

- shielding safety requirements and containment requirements,

- accessibility for maintenance and remedial action, and

- sampling systems.

Storage tanks and associated equipment for larger quantities of liquid wastes may be constructed in horizontal or vertical form in a wide range of selected corrosion-resistant materials ranging in choice from glass, glass-lined, thermoplastic (polythene, PVC, SARAN), thermo-setting plastics with glass fibre (phenolic, polyester or epoxy resins) or stainless steels (commonly 304 L grade).

Agitation and homogenization of the contents are frequently arranged by recirculation using the discharge pump, although stirrers or other agitators may be required.

Primary containment is provided by the storage vessels and secondary containment by the cell lining and structure (for low level wastes epoxy lined cells may be adequate). Level gauges and alarms must be considered. For any alpha active liquids, a secondary containment may be provided by glove boxes constructed to high standards. The unlikely event of leakage from a storage tank needs to be detected and the leak retained by local containment. Sump tanks and transfer devices may be necessary.

Store buildings, internal surfaces and contents should be constructed of smooth and impervious finish to permit effective decontamination.

Under certain conditions, wastes may generate flammable gases owing to radiolysis or chemical action. Exceptionally, instrumentation systems to detect buildup and inert gas systems using a blanket of nitrogen or carbon dioxide may be required.

4.3.3. Waste storage in cabinets

If there are minimal arisings of low level waste for temporary storage at the smaller user establishments, a simple cabinet may be sufficient as a store. Under certain circumstances, it may be necessary to store wastes (e.g. carcasses) at reduced temperatures and chilled cabinets, refrigerators or deep freeze units may be used, provided that they are set

FIG 2 A storage cabinet for radioactive wastes

aside for the purpose. Solutions stored in refrigerators or cold-storage units should be in suitable containers which will not crack at low temperatures. Recommended design features in addition to those given in Section 4.3.1 are:

(i) Construction should be simple but stout and in corrosion protected metal.

(ii) Hinged doors should be secured by internal lock or padlock, keys being accessible to appointed persons only.

(iii) Segregation for each type of packaged waste should be arranged by internal divisions and shelving.

(iv) The cabinet should be labelled (Figure 2).

(v) Store contents should have surface finishes which will remain smooth and impervious throughout the design life, taking into account both operational and fault conditions and the need for effective decontamination. Corners, cavities and crevices in which radioactive materials may accumulate should be avoided.

4.3.4. Waste storage in rooms

At most user establishments in developing Member States and at some waste treatment plants, the store for low level untreated waste may be one or more rooms within the nuclear facility.

Particular additional recommended design features of the rooms are:

(i) Access must be designed to be secure with possible automatic restriction to authorized personnel.

(ii) Entrances to the store shall be designed to take account of the need for both personnel and waste package access into and out of the store. At facilities where larger volumes of waste are arising, bulk packages of waste may be made to reduce the number of individual waste movements. Separate access and receipt dispatch facilities may then be considered for the waste packages.

(iii) Separate areas within the store should be provided for storage of each packaged waste type. Industrial racking and storage shelf systems will be appropriate for smaller packages up to, say, 100 litre drums suitable for man-handling. For larger packages e.g. 200 L drums, access will be required for drum lifting and stacking machinery.

(iv) Account should be taken if there is a regular turnaround of particular types of waste packages with arrangements suitable for a first-in-first-out receipt/dispatch system to prevent the potential for inadvertently storing some packages for very long periods.

(v) Should the facility in which the store is located be fitted with a building ventilation system, then the store room should be connected direct to the extract side of the system. Air flow into the room should be from outside the facility, with filtered inlets, and heating or cooling and conditioning as appropriate to the local climatic conditions to avoid particularly cold or high humidity conditions.

(vi) If the facility is not equipped with a building ventilation system, then consideration should be given to installing a small system to serve the waste store independently, possibly switched on before and during entry.

4.3.5. Waste storage in shielded cells

Special designs of solid waste handling and storage systems for the intermediate level wastes associated with hot cells for radioisotope production are based on a variety of concepts. Appropriate minimization and segregation prior to the storage operations is extremely important in the efficiency for all designs.

Most production cells have a limited capacity for waste storage within or beneath the cells and early transfer is necessary from the production area to specific waste facilities. Usually there is insufficient in-cell decay for the bagged solid wastes to be contact handled without appreciable restrictions and in the larger radioisotope production plants some intermediate level wastes, initially up to 10 Sv/h or 10^3 rem/h are typical.

Carousel store

Isotope production hot cells may have shielded transfer of bagged wastes or containers to stores on the floor below. In one design, such wastes are chuted from cells to a selected drum on a carousel in the shielded store. The drums are later removed through a shield port as required with the system providing only contact handling after up to one year decay storage.

Compartment array store

In other designs, solid bagged wastes are taken from small shielded enclosures below the isotope process cells after a few days or weeks, typically using long-handled tongs and trolleys to adjacent larger shielded decay stores. Some of these stores are based on a steel compartmented array of ventilated rectangular or tubular units, often about one cubic meter capacity each, horizontal and equipped with a latched door of lead window glass.

Engineered, retrievable tube store

A sketch of a typical single tube waste store is shown in Figure 3. The tube store is designed to receive waste packed in cans. Typically two can sizes might be available allowing two methods of arranging the cans in the storage tube. Waste arising in the hot-cell would be placed in the can, and the can lid fitted. The can is then ported out of the cell via a gamma gate port into a shielded transport flask. This flask is used to transport the can to the tube store.

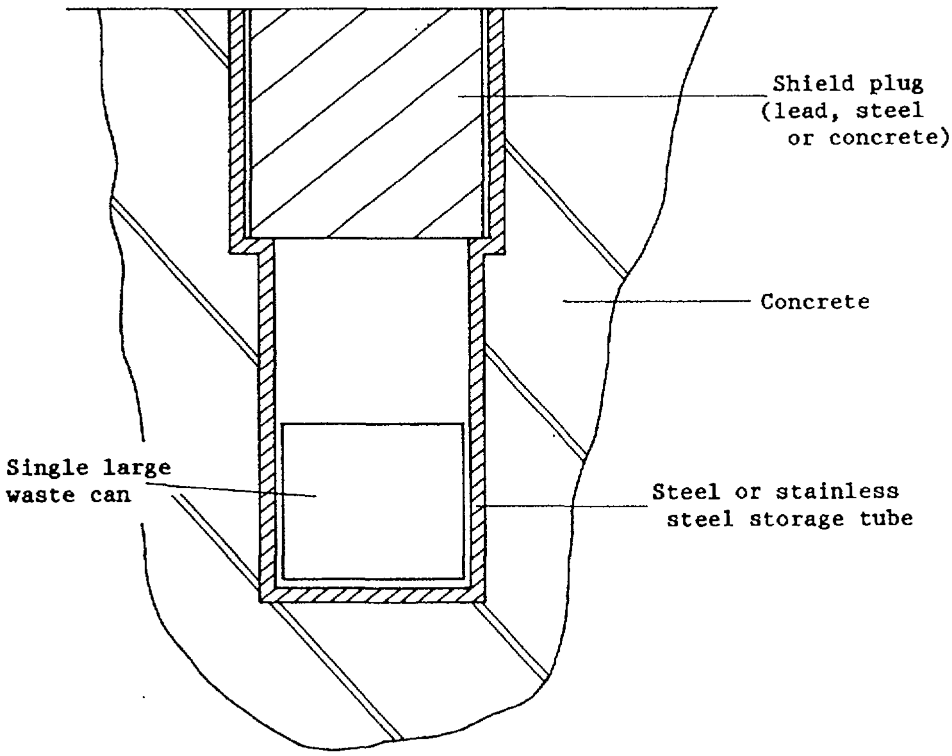
At the tube store, a gamma shield cover would be placed over the required storage area. This cover would be opened and the shielding plug removed when transport flasks arrive for unloading or loading. The shielded flask containing the waste can is placed on the floor next to the tube store. The can would be removed from the transportation flask and lowered into the tube. Once the waste is in place, the tube shield plug is then lifted into position, and the plug lowered into place in the storage tube. The gamma shield cover can then be replaced. A reverse procedure can be used for retrieving the waste.

4.3.6. Waste storage in buildings

Developing Member States will not usually require a substantial separate building as a store for untreated wastes. In the event of a backlog and no waste treatment plant is constructed, it may be necessary to provide for a separate storage facility.

Temporary storage of untreated/unconditioned wastes has on occasions been based on a compromise between the rooms in existing facilities and the construction of a separate building. The use of converted transport containers as a storage facility for untreated/unconditioned wastes has been found to offer a simple solution to such storage requirements. Reference has been made to this system in an earlier technical manual [4] of this series. Figure 4 provides an illustration of a converted transport container used for storage of untreated/unconditioned wastes.

Recently a large national laboratory in the USA described the installation of many modular steel storage units for low level hazardous waste storage. The units (costing US $6,000 to US $16,000 each, including site preparation) could be moved with a forklift truck. They are



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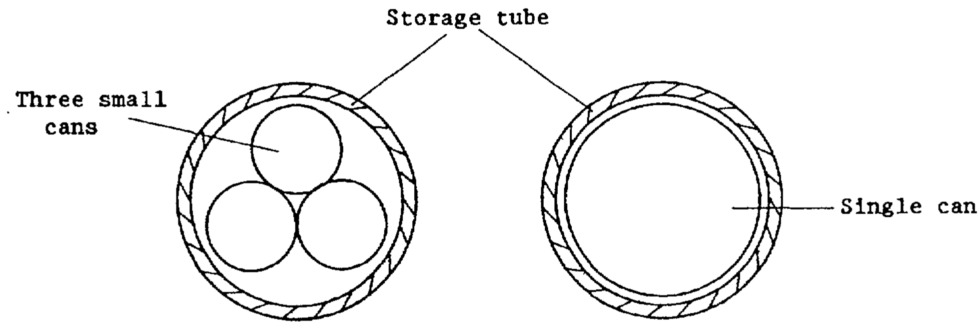

Alternative arrangement of cans

FIG. 3. Retrievable tube store.

constructed of corrosion resistant fibre-glass with raised grid floors containing separated, non-reactive polypropylene, lined sumps. Sprinklers and explosive proof lights are installed as part of the storage unit.

If a treatment and conditioning process cannot be installed to avoid the need for storage capacity in a separate building (typically, see Figure 5), the design features would be extended beyond the list for the room given in Section 4.3.4 to include the following:

(i) The normal radiological protection and safety features that are part of the nuclear installation, (e.g. change rooms, barrier procedures, contamination control areas, etc.) should be provided for in the storage building.

(ii) Separate divisions within the building should be provided for storage of each of the different types of packaged waste.

FIG. 4. Large scale container.

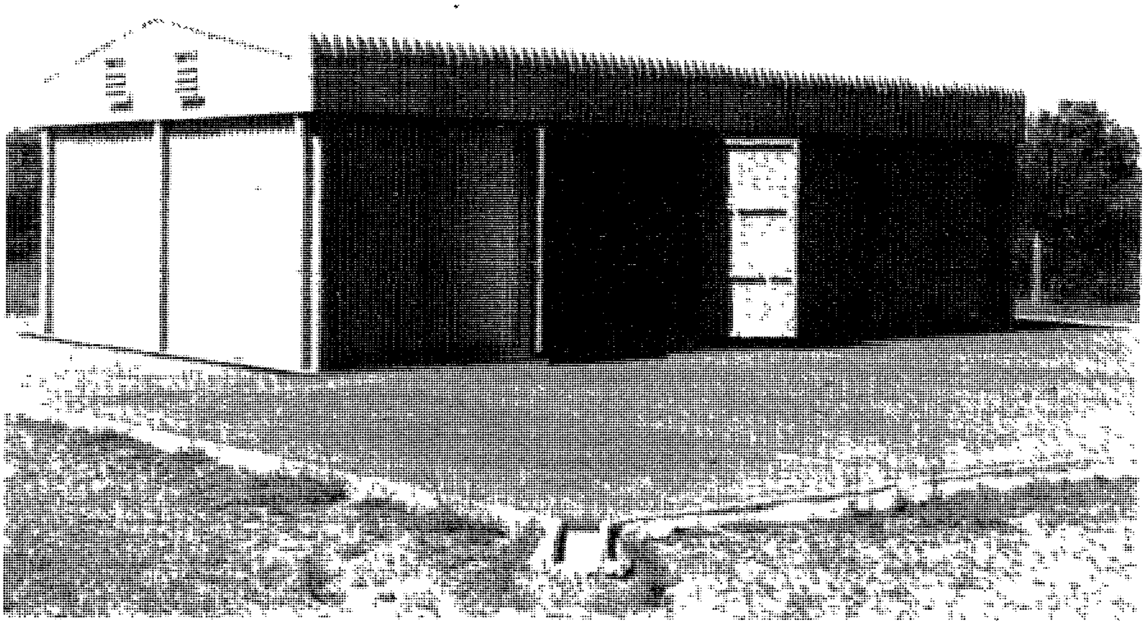

FIG. 5. Interim storage hall.

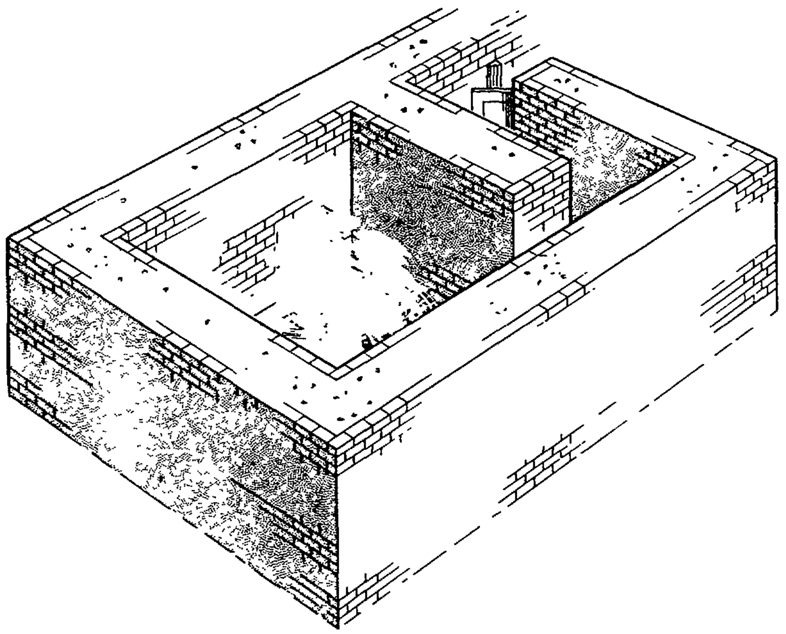

FIG. 6. Labyrinth entrance for a walled enclosure used for shielded storage.

Industrial racking and storage shelf systems will be appropriate for smaller packages up to, say, 100 litres suitable for man-handling. For larger packages, 200 L drums, access will be required for drum lifting and stacking equipment.

(iii) In a purpose built room it will be appropriate to provide a separate shielded store within the main store for the storage of higher radiation level wastes or alternatively providing sufficient portable shielding for each of these packages. The layout of a typical labyrinth store which would be suitable for this purpose is shown in Figure 6.

(iv) Consideration should be given to the provision of a ventilation system for the storage building which will be necessary together with air monitoring when wastes are contaminated with ^{3}H, ^{14}C, ^{125}I and ^{131}I. If local climatic conditions are severe this may need to include forced circulation with heating or cooling and conditioning of the inlet air as appropriate to avoid particularly cold or high humidity conditions.

4.4. Materials handling

In earlier sections it was pointed out that untreated waste stores will necessarily receive a variety of package types and sizes. For the majority of manually handled packages, industrial type racking and a shelving system will provide adequate facilities to store and segregate wastes in an ordered manner. Typical examples of shelf and rack systems are illustrated in Figure 7. For larger packages mechanical handling equipment is required, as the package will probably be too heavy or too bulky to allow ready manual handling. It is expected that the largest package to be handled routinely will be the 200 L drum. Simple single drum trolleys are available (Figure 8) which allow one man to handle a drum over reasonable ground condition for some distance. These are ideal in the untreated waste store for quickly handling drums into position, whilst requiring little room for access and use.

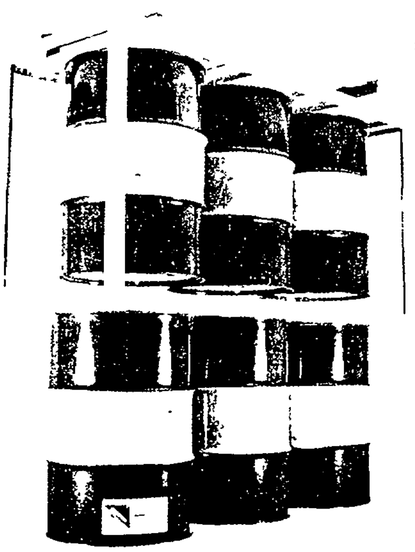

FIG. 7. Shelf and rack systems for storage of drums.

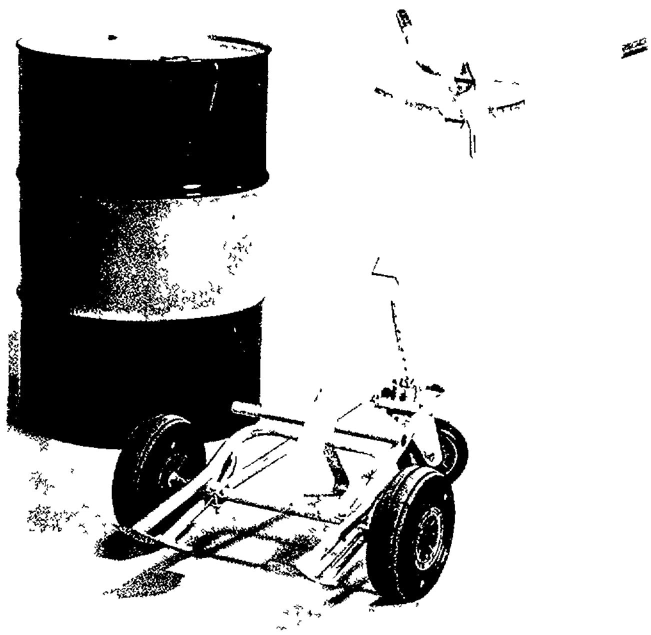

FIG. 8. Simple drum trolley.

However, drum trolleys do not permit drum stacking. If space is restricted such that vertical stacking of drums is necessary, then drum lifting devices are also necessary (see Figures 9 and 10). Manually operated mechanical drum lifters are available which will allow 2 tier stacking of drums. Direct stacking of drums is the most space efficient, but could incur additional handling penalties in order to access any one particular drum. For that reason, simple racking systems are also available for drums, which can be accessed by simple manual stackers, and which permit direct access to any, single drum instantly.

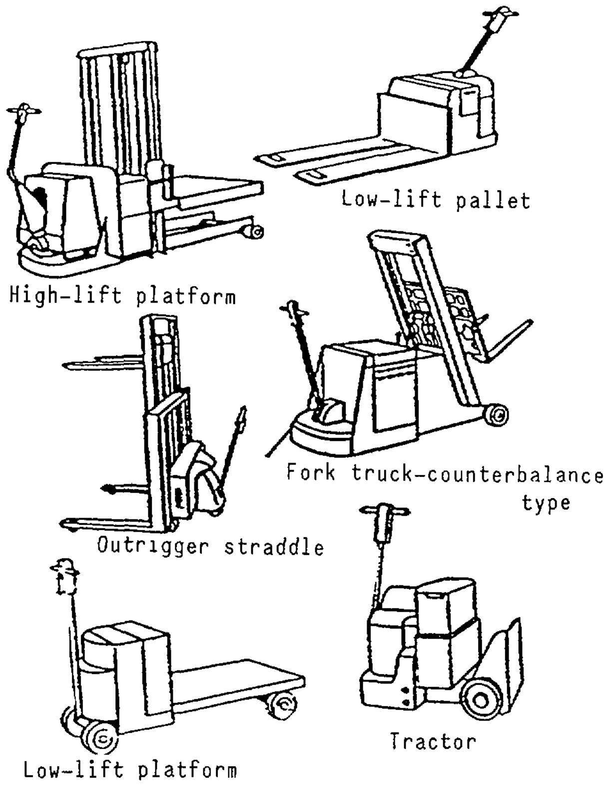

FIG 9 Mechanical drum lifters

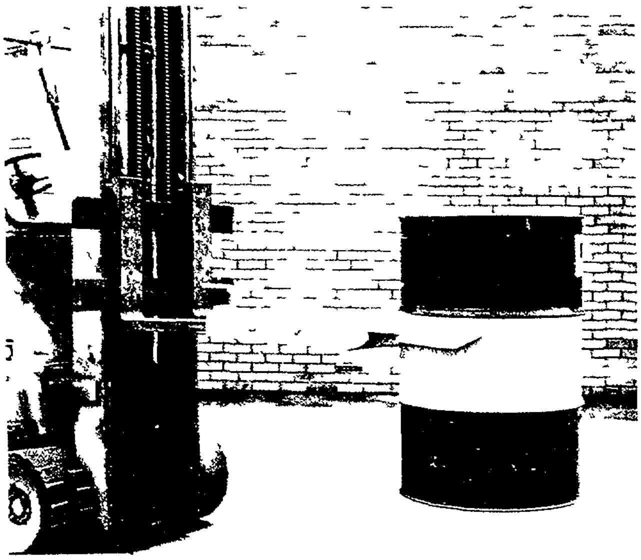

FIG 10 Fork lift for drums

If there is a high frequency of waste drum movements or larger distances for transporting, consideration should be given to the use of electric hoists and monorails in receiving and despatching of drums and powered trucks in the storage facility. However, powered trucks are considerably more expensive than the manual devices, but they may be available on loan from elsewhere for suitable periods on the nuclear site.

The storage of conditioned waste is much more likely to involve the powered trucks in the larger interim store since the cemented drums would weigh some 450 kg and may require stacking.

Vehicles may have pneumatic or cushion tyres according to ground and gradients. There are walkie type trucks (Figure 9) which are intermediate between manual and more complex mechanical devices. Walkie type trucks are economic, compact and offer easy maneuverability. Electric driven trucks require heavy batteries and bring some risks in battery charging (acid spills and hydrogen evolution) but offer clean operation in terms of air pollution. LPG and petrol trucks have fire risk in usage (they should carry an extinguisher) and together with diesel trucks give atmospheric pollution in working areas.

In handling unconditioned intermediate level wastes associated with storage, the radiation dose to the immediate operator and others in the vicinity must be kept as low as possible within dose limits. Therefore, as in all other handling operations, the following principles should be observed:

- the time of exposure to the handler and others should be maintained as short as possible;

- the distance between radiation source and operations should be maintained as high as possible;

- shielding materials should be interposed at sufficient thickness between the source and handler.

Engineered controls incorporated into design relating to the above are preferred to administrative controls. Shielding and shielded enclosures should enable stores to be operated conveniently without large exclusion zones.

4.5. Operating procedures

The operation of a waste storage facility is an important process in waste management. Any waste storage should be operated under the management of a responsible officer. This officer should be responsible for ensuring that all operations concerned with storage are carried out within the written authorised procedures. The operation of the store is considered in three sections: receipt, storage and despatch. The process within each of these sections are summarised as:

Receipt
- transport/collection
- placement in store
- production of records of waste details

Storage
- maintenance of records
- periodic checking of packages
- maintenance of adequate conditions for continued storage

Despatch
- retrieval of package storage
- transport/collection
- recording of waste transfers

Each of these sections is considered in more detail as follows.

Receipt phase

Appendix 1 identifies the information that the store manager should expect the form to contain to permit acceptance of a waste package into the store. Once completed by the waste consignor, the store manager would examine the information to confirm that the waste was acceptable for storage, e.g. correct packaging standard, radiation levels within limits. If unacceptable, the details are to be recorded and the documents returned to the consignor with an explanation, or request for further information.

On acceptance, the equipment required for transport of the waste to the store is selected and the store operator then proceeds with this equipment and prepares the appropriate documentation to store the waste. The operator is trained in the appropriate methods of radiological protection and monitoring, in the use of safety equipment as necessary for handling any 'special precaution' waste packages. At the store a suitable location for the waste is identified and the location details recorded. The waste would be placed in the chosen location.

The information provided by the consignor and the storage location of the package is filed in the central stores records.

Storage phase

The store manager will be responsible for the waste in the facility together with the maintenance of adequate conditions to allow satisfactory continued storage including:

- adequate environmental conditions to avoid deterioration of waste packages;

- sufficient storage space for future arisings of waste as anticipated by waste consignors;

- correct radiological protection procedures to ensure exposure to workers and the public are kept as low as reasonably achievable, and there is no contamination of the store or the waste packages.

The records of the store contents should be maintained up to date, and there should be periodic checking of the store contents against the records. For decay stored wastes these records will include the period of storage required, and the date on which the waste may be despatched from the store for disposal.

An audit should be carried out at suitable intervals or quarterly, by the person responsible for the store to account for each waste package which should be present. Monitoring should be undertaken in stores to ensure that contamination has not occurred. The frequency of the monitoring will depend upon the use, quantity and form of the substances; monthly monitoring should suffice for a typical store. It is especially important to ensure that appropriate monitoring instruments are used. Some of the commonly used radionuclides emit only low energy radiations not detected efficiently by the more robust Geiger Müller tube equipment. Thin window instruments may be required or scintillator detectors.

Waste despatch phase

Following receipt of the request to retrieve a package from storage, the store manager obtains the details of the particular waste package from the stores records and passes them to the appropriate party. If the details are in order the package is accepted for removal from storage. Once the store manager has authorised the release of the waste package, the package is retrieved from the store and taken to the despatch area. Here, the package is monitored for radiation levels before it is released. If the waste package is due for transport from the facility site, the details of the package are transferred to the transport records and the waste packaged for transport as appropriate under established standards [14]. The package storage records are amended to record the date of despatch and the receiving party.

5. STORAGE OF CONDITIONED WASTES

5.1. Overall requirements

The interim storage of conditioned waste is likely in most developing countries to be long term of some ten years or even up to 50 years during the interval between processing and the establishment of a disposal repository. Only conditioned solids in selected containers are suitable for such lengthy storage; liquids which are potentially more mobile and hence more difficult to isolate from the environment should first be immobilized.

The recommended containers for the storage of conditioned solid wastes are 200 L drums (Type A package). A picture of such a drum is shown in Figure 11. Such drums are commercially available from a number of suppliers. Depending on the level of activity other containers are also commonly used and their characteristics are given in Table VII. It is likely that there will be only a few of the alternate containers, possibly for some of the larger spent sealed sources or some larger contaminated metallic or other scrap. Ad hoc arrangements should be made for the larger shielded containers.

Cementation is envisaged for conditioning of wastes containing long lived nuclides primarily, precipitation sludges and spent ion exchange media. In-drum compaction is envisaged for the solid compressible wastes and in some cases cement grouting may embed the compacts. Bituminization and organic resins used for immobilization of low and intermediate level fuel cycle wastes are not regarded as suitable processes for developing countries.

On the supposition that the generation of radioactive waste in a small nuclear research centre will be approximately constant during 10 years, the estimated volumes of conditioned wastes after this period are in the range of 150-300 m^3 corresponding to 750-1500 (200 litre) drums.

5.2. Design features

A variety of conditioned waste storage concepts are used in waste management programmes depending on a number of factors including:

- nature of active conditioned waste
- package size and shape
- package handling requirements
- volume of waste for storage

FIG. 11. Type A 200 litre drum for storage of solid waste.

- period of storage
- need for future store expansion
- local site factors (i.e. weather, land conditions)
- national factors.

Designs can be divided into two categories: area storage or engineered storage.

Area storage involves the standing of waste packages on the ground, in the open or with simple covering. Area storage is not generally suitable for the lengthy storage period required for developing countries.

Many engineered storage designs are based on nuclear fuel cycle facilities with the need to handle large volumes of drummed or boxed encapsulated waste packages with high surface dose rates, and as such are unnecessarily elaborate for the low active wastes arising from the institutional activities in developing countries.

Simple engineered storage designs matched with economic mechanical handling by a fork lift truck with storage capacity for at least ten years should be considered. The need for retrievability should be restricted to the single occasion in the long term when disposal facilities are available. Therefore, some of the design features considered in Sections 4.3.1. to 4.3.4. are unnecessary. It is envisaged that waste containers would be arranged by stacking in rows up to three high as shown in Figure 12.

Interim storage of unconditioned and conditioned waste, especially for Member States having a small Nuclear Research Centre, has been proposed

TABLE VII. CHARACTERISTICS OF SOME COMMON CONTAINERS IN USE [15]

Property	Type of container			
	200 L drum	200 L drum inside 400 L drum with concrete between	Concrete cont. with 200 L drum inside	Cubical concrete container
Inner volume	200 L	200 L	200 L	1000 L
Outer volume	200 L	400 L	1000 L	1740 L
Dimensions (outside)	Dia. 57 cm height 88 cm	Dia. 77 cm height 110 cm	Dia. 100 cm, height 125 cm	Side length 1200 cm
Loaded weight	200-500 kg		2,3 t	
Wall thickness	1 mm	10 cm	20 cm	10.25 cm
Material	Mild steel –	Mild steel concrete	Normal concrete & mild steel	Reinforced normal concrete
Coating	Paint	Paint	No	No
Closure	None	Ring	Concrete cap	Concrete
Biol. Shield	None	Concrete	Concrete	Concrete
Strengthenings	Iron bars	Iron hoops	Iron bars	Iron bars
Mech. propert.	Good	Very good	Very good	Very good
Easiness of handling	Good	Good	Good	Good
Easiness of decont.	Good	Good	Poor	Poor
Corrosion resistant in				
air	> 10 a	> 100 a	> 100 a	> 100 a
fresh wat.	> 10 a	> 100 a	> 100 a	> 100 a
saline wat.	> 10 a	> 100 a	> 100 a	> 100 a

through the erection of a simple hall on the ground surface with a steel construction and corrugated transit sheets covering the walls and the roof (see Figure 5) [4]. The storage hall should be built above ground water level and not be reached by a potential flood or ground water. Where this is not possible, the building must be constructed with appropriate protective systems to prevent the inleakage of ground water. The capacity for the waste storage facility should be designed for a period of 10 years.

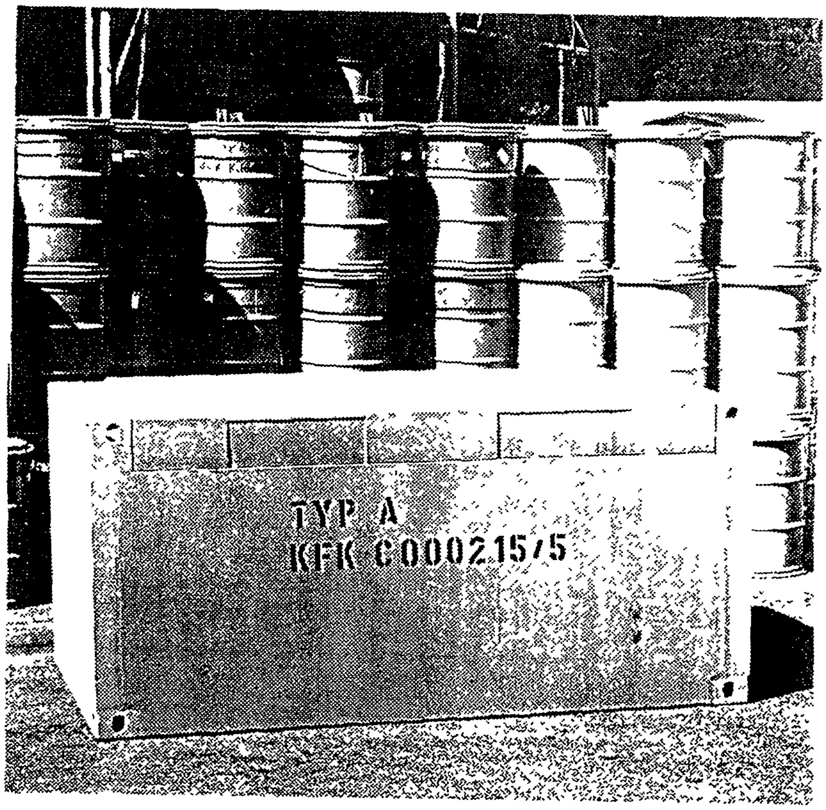

FIG. 12. Stacking of waste drums.

In the reference design of the IAEA Waste Processing and Storage Facility a simple separate store is prepared for conditioned wastes [16].

The store is a single storey rectangular building with overall plan dimensions of approximately 39 m x 26 m, rising to an eaves height of approximately 4-5 m. The roof is of symmetrical double pitch form. The building size and form is designed to facilitate the storage of 3000 waste drums and to ensure that it may be extended in the future, to increase its drum storage capacity, without the need for structural modifications to the original building. Similarly, if a smaller store was required the design could be modified by building one or more fewer bays.

The building is of steel framed construction. Unbraced, three bay, portal frames are provided at approximately 4.3 m centres along the length of the building. These portals provide support to the roof structure and lateral stability to the building in the transverse direction. Stability to the building in the longitudinal direction is provided by a system of roof bracing and bracing to the longitudinal external building elevations which will ensure that all lateral loads at roof level are transmitted to the foundations.

The roof comprises proprietary uninsulated metal cladding on steel purlins which span between the portal beams. Roof draining is achieved by pressed metal gutters to the eaves which discharge into downspouts to the exterior of the building envelope.

The exterior walls comprise proprietary uninsulated metal cladding on steel sheeting rails which span horizontally between the perimeter stanchions. Although not required at present, consideration has been given to the possible future option of providing an inner shield wall. This has been assumed to be of concrete block or reinforced concrete construction and to be located between the perimeter stanchions to which it would be mechanically tied. The overall building width has taken account of the space requirements for the construction of such a wall, assuming the waste drums are in place and adequate wall foundations have been provided. Internal partitions are not provided.

The stanchions are founded on individual mass concrete bases which are taken down to a suitable soil bearing station.

The ground floor comprises a reinforced concrete ground bearing slab. This slab is thickened locally all around the building perimeter, (to support the future shield wall) and locally around all internal stanchions. Resistance to water penetration from the ground is provided by a polythene damp proof membrane to the underside of the slab.

Structural steelwork will generally be grit blast cleaned and treated with a zinc rich primer followed by an alkyd undercoat and gloss finish paint system. All sheeting rails and purlins will be hot dip galvanised.

The ground floor slab will be finished with an epoxy paint.

Future extension of the building may be achieved by the addition of further pantal bay frames, thus increasing the length of the building in 4.3 m modules. The only modifications to the existing building made necessary by such an extension will be the removal of sheeting, sheeting rails and sheeting posts to the end gable to enable access between the existing and extension areas.

The design features for general safety in storage of unconditioned wastes for buildings, Section 4.3.6., are all generally applicable to the storage of conditioned waste.

In Section 4.3.6. the use of converted transport containers (see Figure 4) was examined for unconditioned wastes. Such large containers were also proposed for interim storage of conditioned wastes [4]. Service using transport containers is plainly possible as an expedient storage mode. Depending upon size, some 40 to 70 drums could be held stored in this manner. Transport of the container and waste drums would always be possible directly as a whole unit to a disposal facility once such a facility is operational.

5.3. Materials handling

Solid wastes accepted for the conditioned waste store will have previously passed through some type of waste treatment plant where the opportunity existed to standardize on a single waste package type whenever possible.

Handling equipment will need to be compatible with the store design and the waste package characteristics, in particular the radiation levels.

As noted earlier it is expected that developing Member States will choose the 200 L drum as the standard package owing to:

- ready availability at low cost,
- ready availability of matching handling equipment,
- acceptability as a Type A package for the purposes of transport.

Further, it is anticipated that in the majority of circumstances,

- the waste package will not require shielding,
- the waste package surfaces will be clean and uncontaminated,
- individual waste packages could weigh up to 500 kg.

Devices which could be used in unconditioned wastes were examined in Section 4.3. It is expected that the industrial fork lift truck with drum grab attachment will be the most suitable method for handling this type of waste package and placing it into the interim storage (see Figure 10).

Building cranes are used in many intermediate level waste stores in developed Member States particularly when there is a need for remote handling of waste packages. These overhead cranes are expensive to install and usually require a more complex facility construction to support the crane structure. Because of high costs, and because it is expected that remote handling of conditioned wastes will not be necessary for developing Member States, building cranes will not be justifiable for use in conditioned waste storage facilities.

5.4. Operating procedures

The control of operations in the interim storage facility for conditioned wastes is likely to be less complicated than in the facilities described for the variety of unconditioned wastes in the corresponding Section 4.4.

After treatment the liquid and solid wastes are conditioned by the irreversible immobilization method in an accepted solidification matrix which is almost certainly cement-based and contained in a standard certified packaging (220 L or 400 L drums for example).

The waste receipts can be programmed and they are nearly uniform, well packed, robust intrinsically safe containers, characterized by the waste management-oriented treatment staff. The interim storage objective is essentially passive for the long period pending removal (probably in bulk) when the disposal repository is established. The large single store is especially designed and almost certainly separately located.

The operating details for the receipt, storage and despatch phases considered earlier for the unconditioned waste stores, generally apply, but the protracted period of operations makes necessary near permanence of markings and records of contents and location of containers. Segregation of waste types is desirable to aid in any unplanned retrieval, revealed necessary by periodic inspections for degradation of waste containers, and in case there are categories of waste to be placed eventually in particular disposal repository locations.

The radionuclide content in the conditioned waste must comply with the local regulatory limits (for example lower than 400 Bq/g of conditioned waste). The radiation dose rate emitted by the conditioned waste packages imposes severe limitations according to the admissible radiation exposure to the personnel. Typically a dose rate at 1 m $\leq$ 0.5 mSv/h direct contact handling is accepted; otherwise, radiation protection features are mandatory.

A maximum allowable dose rate at the surface of each waste package should be defined for specific interim storage buildings or parts of buildings:

- a low level storage with access by manual system;

- a shielded intermediate level storage with access by remote and automatic device handling.

Usually, no drum having an average contact dose rate above 300 mSv/h is accepted in a management system for low or intermediate level conditioned waste.

Package acceptance qualification conditions will include:

- maximum allowable weight per package;

- mechanical resistance for the stacking of packages (3 without pallet and 4 with pallet is usually suggested);

- satisfactory corrosion resistance of the package metal;

- no loss of integrity after a drop test from a height related to the package transport condition;

- sufficient resistance to a standard fire test.

The above tests are designed to confirm the adequacy of the standard packaging design and performed occasionally on the waste package production.

The on-line measurements may be performed on each completed package to determine the radiological characteristics of the package and are likely to include:

- total activity content (GBq);
- gamma radiation dose rate (mSv/h);
- - average value over the lateral surface at surface contact and at 1 m from the package;

  - peak value and location of hot spot areas, important for the package transport and location in the storage building;

- outer surface contamination (Bq/cm^2);
- weight of the package.

In the case of external contamination, the package has to be cleaned and rechecked before the authorization for interim storage.

Waste packages identification should ensure that each of the completed waste packages is uniquely identified from the time of production. Marking and labelling should be performed according to local regulations and adequate traceability of waste packages established.

6. SAFETY ASSESSMENT

Formal safety case reporting is generally briefly carried out at the late stage of design for low level waste treatment plant due to low activity inventories and low ranking for risks. The very rigorous safety analyses as carried out for some nuclear fuel cycle facilities are unlikely to be required in significant depth.

Whilst stores contain the largest plant inventories of activity, the operations undertaken do not pose high hazard regarding difficulties in containment or isolation of radioactivity from working or external environment during normal or abnormal conditions. Rapid changes from safe to harmful conditions are unlikely in storage except in the event of fire or explosion giving airborne releases.

Pre-disposal storage is an option available to any waste management strategy. Any facility chosen as part of a strategy should have acceptable radiological implications. The designs proposed should follow the general principles of keeping dose levels as low as reasonably achievable and reducing the probability of accidents to as small as practicable. In addition the design should be capable of maintaining the 'as-received' integrity of the waste package until it is retrieved for disposal. These principles when incorporated into a sound and well engineered design, which can be constructed and operated to accepted standards, are the basis for limiting the radiological impact of a storage facility.

Here, radiological safety is addressed qualitatively and the assessment as such is a preliminary overview of the concepts.

From this assessment sensitive areas of the facility design, package design and/or operating system could be identified. It is these areas which would have a priority for quantitative assessment.

The assessed safety of the facility should be a reflection of its inherent susceptibility to hazards as well as the degree to which such hazards are avoided or contained. In this context hazard refers to a situation whereby persons may become exposed to radiation or to airborne contamination, either inside or outside the facility. The assessment approach thus includes:

(a) Identification of hazards

Hazard potential relates to the presence of radioactive substances in the waste packages being stored or handled. Specific hazards are identified by examination of the various operational or fault situations whereby exposure to radiation or to airborne contamination may occur.

(b) Examination of protection or mitigation features

Significant hazards should be avoided by the provision of design features or administrative measures. The extent to which this objective has been achieved needs to be determined. Design features of interest may include radiation shielding, remote handling or monitoring devices, maintenance aids, ventilation/filtration systems, containment barriers etc. Administrative measures may include operating, maintenance and health physics procedures.

In a rigorous assessment such as may be used in the approval process, hazards may be quantified in terms of their frequency of occurrence and the magnitude of their consequences. The effectiveness of protection or mitigating features may then be similarly quantified in terms of reduction of the risk associated with each hazard.

6.1. Storage of unconditioned wastes

Larger receipt and storage facilities attached to any centralized treatment plant will cater for wastes arising from on-site and off-site isotope producers and users in solid and liquid forms as examined previously. The wastes will require buffer storage prior to treatment and conditioning or decay storage prior to disposal.

Excepting for liquids received in larger quantities by pipeline or purpose-built tanker, transport and storage hazards will be satisfactorily addressed mainly through a simple measure i.e. ensuring the solid and liquid wastes are packed or overpacked in substantial metal drums, commonly 200 L capacity.

The main hazards are considered to arise from:

- receipt of packages with higher than anticipated levels of radiation or surface contamination;

- dropping of drums, carboys or spillages in transfer;

- fire associated with uncontrolled reactive waste contents or external events.

The examination of chemical composition and stability vital to safety control through segregation was presented in detail in Section 2.2. The important design features and operational procedures influencing the safety of the storage of the unconditioned wastes were listed in Sections 4.2. to 4.4.

6.2. Interim waste storage

Immobilized waste in 200 L drums or other substantial containers will be transferred to the simple store for long term storage pending the development of disposal facilities. This store may accumulate a substantial inventory of long lived radioisotopes but the risks are low because of the conditioned waste form. Typically it has been envisaged that the store will be a rectangular shaped, single storey building, capacity 3000 drums per ten years arisings. Drums will be stacked by fork-lift truck in pyramid fashion up to 3 high with each drum on the upper two levels supported by two drums beneath. It is necessary to consider both normal and abnormal operating circumstances.

6.2.1. Normal operation

Hazard situations arise in connection with the radiation environment which may affect:

- operating and maintenance staff performing their usual duties,
- other persons in the vicinity of the storage facility.

Both direct radiation and airborne contamination are of concern, and the assessment must take account of the normal situation both inside and outside of the facility. The outline procedure may be summarised as follows:

(1) Identify all potential radiation or contamination sources and the expected accumulation of these during the operational lifetime of the facility,

(2) Identify operating personnel movements within the facility,

(3) Identify routine maintenance activities,

(4) Assess the radiological hazard to operating and maintenance staff,

(5) Identify the radiation field external to the facility,

(6) Identify any routine releases of radioactive substance to the environment,

(7) Assess the radiological hazard to external persons,

(8) Identify and assess those protection or mitigation features which affect the radiological hazards.

Hazards during normal operation of a store are discussed in Table VIII.

6.2.2. Abnormal operation

Abnormal operation results from events which may lead to faults within the facility. Depending upon the extent of the fault, its influence may be limited in safety terms to the operating and maintenance staff or may extend to the environment.

For each event it is necessary to determine the resulting hazard. This depends on:

- faults result from initiating events which may arise internally or may be of external origin;

- internal events may include malfunctions or maloperations during the handling of waste packages, fires or floods from internal causes, etc.;

- external events may include earthquake, impact (e.g. airplane crash), fires or floods from external causes, etc.;

- the extent to which radiological barriers (shielding or containment) are degraded; such barriers may be part of the waste packages themselves or be part of the facility;

- any resulting change in the radiation field and/or the dispersion of radioactive substances inside or outside the facility;

- any consequential deviation from normal operating or maintenance practice which causes abnormal exposure of personnel.

The outline assessment procedure may be summarised as follows:

(1) Identify initiating events to be considered.

TABLE VIII. HAZARDS DURING NORMAL OPERATION OF A STORAGE FACILITY

Hazard	Protection	Notes
Radiation	Normal Operation The drums containing the conditioned wastes are unshielded.	
	Radiation protection of site personnel who are external to the facility is by controlled access into the facility. Radiation protection of operating personnel within the facility could be provided by self shielding by other drums and by distance. Radiological protection during transport to and from the facility could be by shielded overpack if required.	Facility would be required to be designed to give the required ALARA radiation attenuation.
	The facility will need to be sectioned into radiological zones defined as: - normally accessible - restricted access - non-accessible Personnel access to these areas would have to be controlled by administrative procedures and physical barriers.	
	Maintenance No maintenance operations are envisaged with the simple store design.	
Criticality	The concentration of fissile material in the wastes is so low that any criticality risk can be excluded.	
Radio-nuclide Release	The containment barriers which prevent radio-nuclide release in particulate form are: - the encapsulation matrix - the steel drum and grout cap Generated gases can permeate the clean grout cap and enter the storage volume.	Failure of the steel and grout cap could allow particulates to circulate within the storage volume.
	The air environment surrounding the drums has direct access to the environs. The facility structure therefore does not provide any additional barriers to those incorporated into the drum.	This has direct access to the environs and also can spread within the store.
	The waste drum will need to be inspected prior to storing to ensure that it is free from surface contamination and damage.	
	The steel drum has a corrosion allowance to cater for at least 10 years of storage and subsequent handling operations. The air within the store is ventilated by natural circulation. This prevents gas buildup but provides a direct release path to the surrounding environment.	The environment within the store is not conditioned. This environment may be aggressive to the steel drums.

(2) For each event characterize the resulting fault, i.e. identify the effects of the fault and the response of the facility, the stored waste, and the operating/maintenance personnel.

(3) Determine the severity of each fault and categorize as incidents or accidents.

(4) Group incidents and accidents as appropriate and assess the radiological hazards to operating and maintenance staff and to external persons.

(5) Identify and assess those protection or mitigation features which affect the radiological hazards.

Faults which could give rise to hazards in the store include:

(i) dispatch of an externally contaminated drum to the store

(ii) dropped drum during movement in the store

(iii) failure of containment during storage.

Following immobilization and curing, each drum will have been checked for contamination prior to dispatch to the store. Failure of this operation will result in the spread of contamination both in the facility and the store; this may result in an increased risk to the workforce handling the drums and require extensive decontamination of the store before operations can re-commence. Contamination of the drum can result from failure of a seal or sealing mechanism, overfilling of the drum or failure of the inspection system.

The main requirements of transport regulations for radiological protection relate to the surface dose rate from the package and contamination of the package. The material handled will be mainly low level waste and is likely to be classified as Low Specific Activity (LSA) material. Off-site transport requirements which are in line with international standards state that the surface dose rate of the package must not exceed 2 mSv/h, and that contamination levels must not exceed 0.4 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters or 0.04 Bq/cm^2 for all other alpha emitters. Containment of immobilized waste transported on-site from a conditioning plant to the interim store is likely to be similarly standard.

In the case of dropped drums of immobilized waste, the levitation of activity into the working areas will be low, since the activity in immobilized waste will be only dispersible with difficulty. In addition the heights that loads can fall will be restricted because the building is single storey and the drums will be only stacked 3 high.

Another hazard for the storage facility would arise from degradation or failure of the drum containment. This could occur due to the use of sub-standard drums, (i.e. with a manufacturing fault), damage to a drum after filling or corrosion or erosion in long-term storage (either internally or from external condensation). The risk from this hazard would be very low since the low mobility of the activity would minimize any airborne contamination problems.

Appendix

RADWASTE SERVICE WORKSHEET

Request for the Receipt of Radioactive Waste
(One form per package)

WASTE STORE

LC No.________________

Date received________________

Storage location________________

Waste arising from:

Bldg. ________________

Room/Lab.No.________ Tel.No.________

Confirm that the following have been excluded (Yes/No):

Materials capable of explosive decomposition ________________

Free liquid ________________

Waste capable of generating toxic gases etc. ________________

Complete the following:

Service required ________________
(disposal/storage/transport)

Package identity number ________________

Outer package type ________________

Volume (litres) ________________

Gross weight (kg) ________________

Inner package type ________________
(e.g. plastic bag)

Total α activity (MBq) ________________

Total βγ activity (MBq) ________________

Maximum radiation level from waste (mSv/h) ________________

Maximum contamination level

($Bqcm^{-2}$ α) ________________

($Bqcm^{-2}$ βγ)________________

Consigned by ________________

Signature________________Date________

Weight percentages of waste contents:

Paper ________________ Cardboard________________

Wood ________________ Plastic________________

Other ________________
(specify)

Special wastes ________________

DECAY STORAGE (Yes/No) ________________

DATE ________________

ACTIVITY B MBq ________________

HALF LIFE ________________

DATE REACHING EXEMPTION LIMIT ________________

βγ-Isotopes	Activity (MBq)
C-14	
Co-60	
I-129	
H-3	
Other βγ-Isotopes (specify)	
α-Isotopes/species Ra-226	
Other α-Isotopes (specify)	

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