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Minimization and segregation 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

July 1992

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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 minimization and segregation of radioactive wastes, which are logically the first steps and the foundation for an efficient waste management system. The prevention of unnecessary amounts and radioactivity content of wastes is of universal benefit and must be followed by efficient sorting to take advantage of the most favourable treatment, conditioning, storage and disposal options.

The IAEA wishes to express its gratitude to the consultants for the project, namely, D. O. Dumas (E.I. Du Pont de Nemours (E.I.) and Co., Massachussetts, USA) and M. W. Wakerley (ANS Consultants Ltd, Epsom, United Kingdom), who participated in the preparation of this document. The IAEA staff members responsible were G. R. Plumb and V. S. Tsyplenkov of the Division of Nuclear Fuel Cycle and Waste Management.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. Background

Radioactive wastes are generated by virtually all activities which utilize radioactive materials as part of their operating process. Generally, such activities include all steps in the nuclear fuel cycle (for power generation) and non-fuel cycle activities. The increasing production and utilization of radioisotopes within a Member State without nuclear power must be accompanied by a corresponding development of a waste management system. At the very beginning of waste management planning, a number of actions have to be undertaken to bring the wastes into a form that complies with specifications or acceptance criteria for subsequent management steps. An overall waste management scheme generally includes several, or all, of the following steps: segregation, treatment, conditioning, storage, transport and disposal. There are a variety of alternatives for each step in waste management including safe waste disposal, e.g. ranging from disposal to landfills and direct discharge to the environment, to deep geological disposal.

To achieve a satisfactory overall waste management strategy, component steps must be complementary and compatible with each other. A diagram of a typical waste management system is given in Figure 1.

All different steps have to be evaluated, not only as isolated steps in the process, but also as part of the integrated system where all steps are dependant on each other. This dependance is one of the reasons why quality control is necessary to be included in all different steps.

The first two steps in the system - minimization and segregation of radioactive wastes generated in the utilization of radiation and nuclear materials - are of large importance mainly because they lead to:

- cost reduction; and
- reduction of dose detriments.

The complete prevention of radioactive waste generation is not usually practicable, but minimizing

- the activity content of the waste;
- the volume of waste with which the activity is associated; and
- the amount of material classified as radioactive

are essential objectives in radioactive waste management. The objectives should be taken into full account in the design and operation of all facilities generating waste and waste management facilities.

Despite the use of the best minimization measures, including design features associated with highly reliable, efficient equipment and operating procedures, significant quantities of radioactive waste inevitably arise during radioisotope production and utilization. With increased quantities of radioactive wastes, irrespective of maintaining the minimization

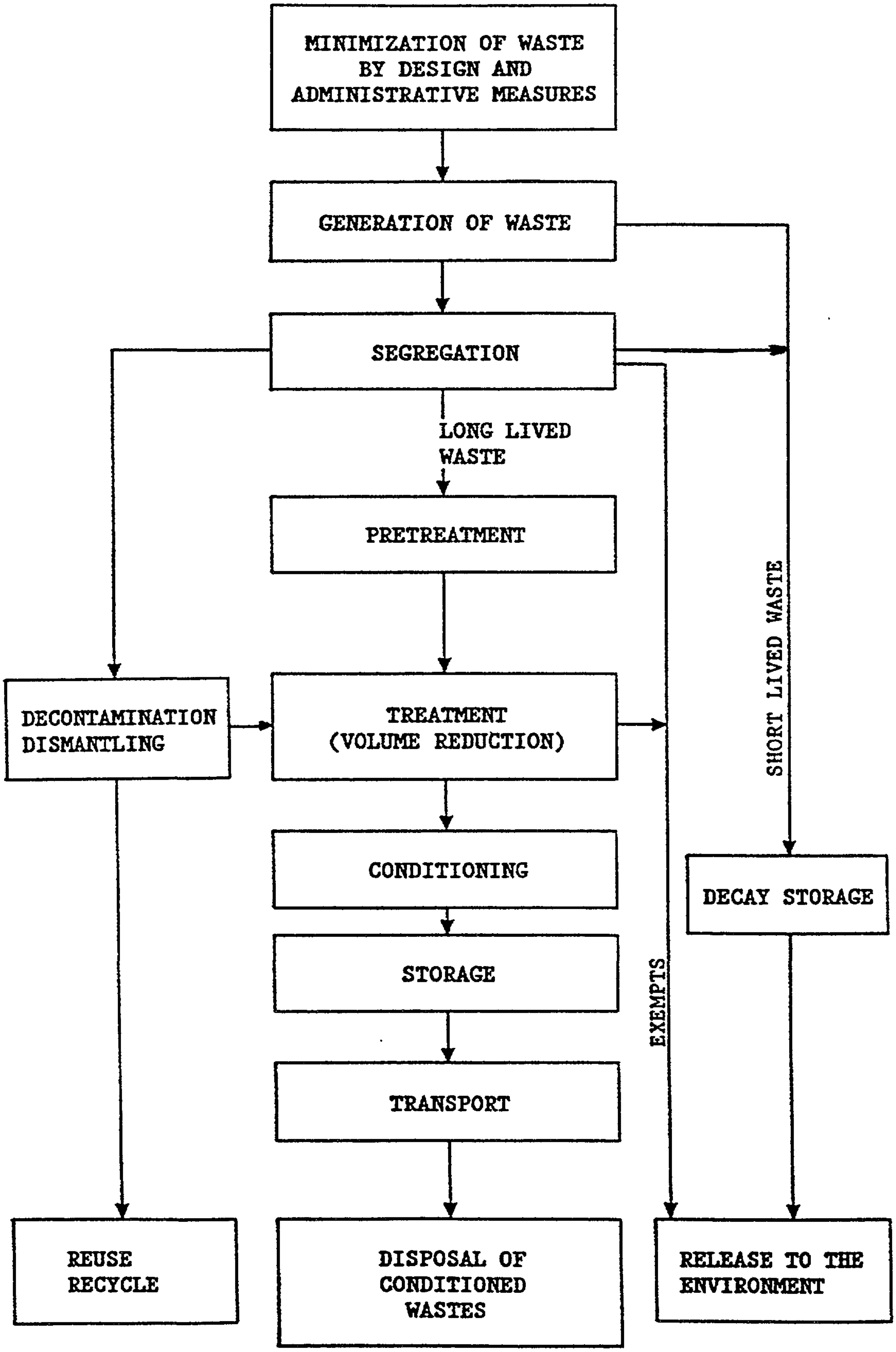


FIG. 1. Flow sheet for a waste management system.

objectives, a further objective, i.e. segregation or sorting of wastes becomes greatly important to take advantage of the safe confinement and economic management of wastes.

The proper implementation of segregation of radioactive waste will also lead to:

- simpler waste treatment methods and facilities;
- reduced incident risks;
- easier characterization of the wastes generated;
- smaller volumes of radioactive waste requiring long term storage and disposal;
- recovering valuable materials for recycling.

Operations at the smallest scale are generally concerned with short half-life radioactivity, permitting the simplest waste management operation, i.e. the decay storage of unconditioned radioactive wastes to be employed as the sole measure, before waste discharge to the environment as exempt or de minimis material.

In countries with larger radioisotope applications having a nuclear research centre and a number of small users, the proportion of wastes containing longer lived activity increases. The simple treatment of wastes by decay storage in unconditioned form must be augmented with treatment of liquid and solid wastes for volume reduction and immobilization, packaging and handling for long term interim storage pending disposal.

The selection of a minimization and segregation strategy is necessarily bound up with the selection of an overall plan for the management of wastes under consideration, and this in turn may be part of a larger scheme embracing many waste types.

1.2. Objectives

The report will serve as one of a series of technical manuals providing reference material and direct know-how to staff in radioisotope user establishments and research centres in Member States without nuclear power and the associated range of complex waste management operations. Considerations are limited to the minimization and segregation of wastes, these being initial steps on which the efficiency of the whole waste management system depends.

1.3. Scope

The minimization and segregation operations are examined in the context of the restricted quantities and predominantly shorter lived activities of wastes from nuclear research, production and usage of radioisotopes. Liquid and solid wastes only are considered in the report.

Gaseous waste minimization and treatment are specialized subjects and are not examined in this document. Gaseous effluent treatment in facilities handling low and intermediate level radioactive materials has been already the subject of a detailed IAEA report [1].

Management of spent sealed sources has specifically been covered in a previous manual [2]. Conditioned sealed sources must be taken into account in segregation arrangements for interim storage and disposal where there are exceptional long lived highly radiotoxic isotopes, particularly radium or americium. These are unlikely ever to be suitable for shallow land burial along with the remaining wastes.

2. WASTE CLASSIFICATION

In most countries, the management of radioactive wastes is conducted within an extensive framework of regulations and requirements set by national and/or state authorities, national waste management organizations and centralized waste processing facilities. The national regulations often relate to transport and disposal requirements, whereas specifications for treatment and conditioning are imposed by waste management organizations. The latter specifications are derived from typical process characteristics and limitations and also include acceptance criteria for disposal of conditioned waste.

Transport regulations are in many countries based on IAEA Safety Series No.6 [3]. The IAEA regulations specify the requirements for packaging and labelling, define shipping categories of radioactive materials according to their radioactivity content (e.g. solid materials) and determine acceptable radiation dose levels.

For release of radioactive effluents to the environment and/or waste disposal a set of requirements is normally imposed on the waste generator with respect to the segregation and packaging of wastes, depending upon size, physical-chemical composition, and radiological composition. These specifications take into account the subsequent volume reduction process and the operational need for segregation at source.

It is evident that several decisions have to be made by the waste generator in order to comply with the above mentioned constraints and to optimize waste management.

A variety of approaches have been used to classify the wide spectrum of solid and liquid wastes that arise from nuclear operations. Categories may be based on:

- radiological characteristics;
- physical-chemical characteristics;
- origin.

The characteristics of individual wastes determine what management schemes can be applied within the limits of national and international regulations.

2.1. Radiological classification

2.1.1. Exemption concept

The 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 [4-7].

There has long been a 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 have insignificant hazard potentials.

Their regulation achieves no benefit and it is usually considered to be more appropriate to segregate and exempt them from the requirements of regulatory controls.

The IAEA has, in co-operation with OECD/NEA, published a Safety Guide on Principles for the Exemption of Radiation Sources and Practices from Regulatory Control in which the basic principles are established [8]. Two basic criteria are specified for determining whether or not a practice can be exempted from regulatory control:

- individual risks must be sufficiently low as not to warrant regulatory concern; and
- radiation protection, including the cost of regulatory control, must be optimized.

Guidance has been given internationally also on the application of the principles to dispose of very low level radioactive waste [4]. The responsibility for setting exemption levels is with the national competent authority. Exemption is therefore an administrative procedure whereby wastes below a certain level of concentration or amount can be deregulated and treated just as if they were not radioactive. Segregation for exemption can be an important means of reducing the magnitude of the waste disposal problem. However, it has to be stressed that waste streams for consideration as exempt wastes must be shown to be below exempt concentrations. The exemption option must not be misused.

The Agency is currently developing guidance on the practical application of exemption principles to the wastes arising from the use of radionuclides in hospitals and research laboratories. In the meantime, and in the absence of specific national regulations governing exempt disposal, reference may be made to the guidance given in IAEA Safety Series No. 70 [9]. The relevant parts of Safety Series No. 70 are reproduced in Annex I.

2.1.2. Classification for disposal

All radioactive waste that cannot be disposed of as exempted waste immediately, or after a reasonable decay time, must be safely disposed of. Disposal can be done in a special facility designated for radioactive wastes, or by approved direct discharge of wastes into the environment, with subsequent dispersion.

Control of the disposal of radioactive wastes is normally exercised through the granting of permits, licences, or authorizations by a competent authority to the disposer. Such licences, etc. usually stipulate disposal routes for various waste forms, and the limits, in terms of specific and/or total activity, as conditions that the disposer must comply with. In granting an authorization the competent authority should consider the capability of the disposer to comply with its conditions which might include record keeping, arrangements for training, and maintaining administrative checks on disposal procedures.

Requirements for release to the environment under authorization

Before attempting to select and design a waste treatment system, the restrictions or limits on release of liquid and gaseous waste effluents should be understood [10]. Determination of these limits is done differently in various countries but does, in any case, require extensive analyses by both the waste producer and regulating authority to arrive at an agreement that releases are acceptable. The basic principles for establishing release limits are set out in IAEA Safety Series report No. 77 [10]. Essentially this states that practices involving releases of radionuclides to the environment should be optimized, that is, that the associated radiation doses to the public and to workers should be as low as reasonably achievable (ALARA), and that doses are below specified limits. The evaluation of these radiation doses may involve the use of environmental models in which the transport of radionuclides to humans through the processes of atmospheric dispersion, deposition and movement through terrestrial and aquatic foodchains is represented. The limitation of dose to members of the public is achieved by limiting the dose to an identified critical group, that is a group of persons who, by virtue of their location, habits etc., are representative of the most highly exposed in the population.

The ICRP prescribes dose limits, but since an individual may be exposed to more than one source of radiation, only a fraction of the whole dose limit should be assigned to any given practice. In its most recent recommendations [12] the ICRP introduced the term "dose constraint" as the fraction of the dose limit which may be applied to a single practice. The dose constraint is to be used as the upper bound for the optimization process. The values of the dose constraint should be set by national authorities. Old and new dose limits as prescribed by the ICRP are given in Table I.

TABLE I
ICRP RECOMMENDED EFFECTIVE DOSE LIMITS ($mSv.a^{-1}$)

	1977 (Old) [11]	1991 (New) [12]
Workers	50	20 [a]
Members of the public	5	1 [b]

a 20 $mSv.a^{-1}$ to be averaged over a period of 5 years with no more than 50 $mSv.a^{-1}$ in a single year.

b 1 $mSv.a^{-1}$, or in special circumstances 1 $mSv.a^{-1}$ averaged over 5 years.

If calculations show that the dose is greater than the dose constraint then the planned discharge cannot be considered further unless some means of reducing the discharge is introduced.

There may be several different options for managing the waste stream, each of them involving some discharge to the environment. For example, from Figure 2, direct discharge, discharge after treatment, discharge after storage. Some of the options initially considered may be discarded for non-radiation protection reasons, for example, purely on grounds of costs or for operational reasons.

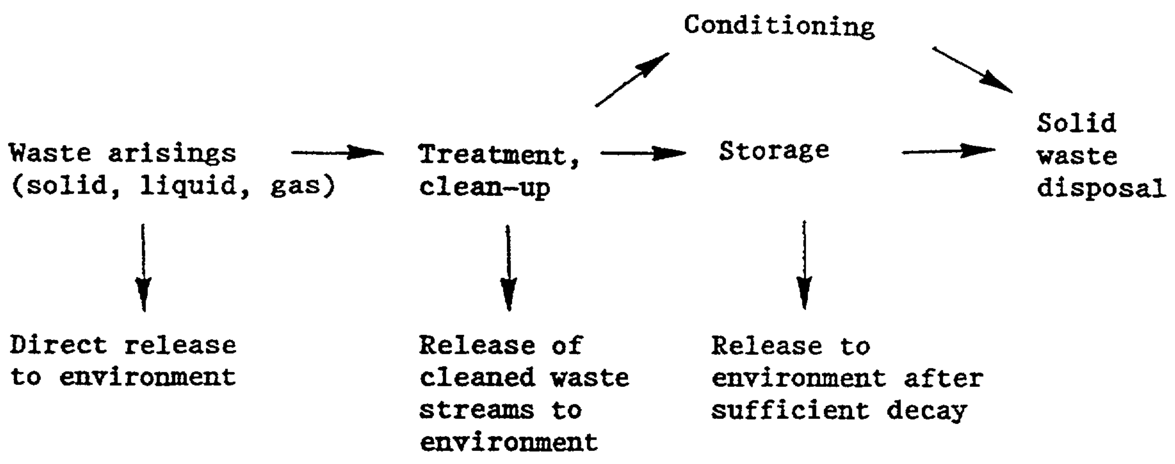


FIG. 2. Options for waste disposal.

The next stage is to optimize protection by choosing the control option for which radiation doses are as low as reasonably achievable (ALARA). Radiation doses and costs involved in all the options must be considered. This involves evaluating radiation doses to operators of treatment and storage facilities as well as to the general public for the releases.

Once an agreement is reached as to the suitability of the proposed waste treatment scheme, a discharge authorization is provided by the national authority to the waste producer which details the specific requirements to be met at the point of discharge in terms of:

- Maximum permissible radioactivity concentration in the effluent;
- Flowrate of the effluent and total volume;
- Daily, monthly and/or yearly radioactivity discharge both for total activity and for individual or groups of radionuclides.

<u>Requirements for ground disposal</u>

For radioactive wastes that cannot be released into the environment, special disposal facilities (repositories) must be provided. For radioactive waste disposal, the most important radiological parameter is the concentration of long lived radionuclides, especially of alpha emitters.

The IAEA has proposed a qualitative classification for radioactive wastes relevant to disposal. Five categories are proposed taking account of properties, such as half-life and heat generating capacity. The categorization assumes that they have been appropriately conditioned and packaged. This classification is shown in Table II [13,14].

TABLE II
GENERAL CHARACTERISTICS OF WASTE CATEGORIES WITH REGARD TO DISPOSAL [13]

Waste category		Important features [a]
I.	High level, long lived	High beta/gamma Significant alpha High radiotoxicity High heat output
II.	Intermediate level, long lived	Intermediate beta/gamma Significant alpha Intermediate radiotoxicity Low heat output
III.	Low level, long lived	Low beta/gamma Significant alpha Low/intermediate radiotoxicity Insignificant heat output
IV.	Intermediate level, short lived	Intermediate beta/gamma Insignificant alpha Intermediate radiotoxicity Low heat output
V.	Low level, short lived	Low beta/gamma Insignificant alpha Low radiotoxicity Insignificant heat output

[a] The characteristics are qualitative and can vary in some cases; 'insignificant' indicates that the characteristic can generally be ignored for disposal purposes.

Categories IV and V are suitable for shallow ground disposal having insignificant alpha activity and heat output with intermediate and low radiotoxicity, respectively. With the exception of spent sealed sources, the wastes generated in developing countries are essentially within these categories. For radioactive wastes which contain more than a specified amount of long lived radionuclides, deep geological repositories are required.

Many developed Member States have regulations classifying their wastes for disposal quantitatively [15,16]. The regulations usually apply restrictions on the concentration of radionuclides in individual packages and in the waste as an average. The values are determined by means of a safety assessment in which the scenarios and routes by which humans could be exposed during operation of the repository and after closure are analysed. It is not usually considered possible to give generally applicable values for beta-gamma emitters because they vary, depending on the characteristics of the disposal site. However, the limiting values for alpha-emitters are less variable and values have been given nationally and in the international literature [17]. Table III shows reference levels for alpha-emitting radionuclides based upon an individual dose limit of 1 $mSv.a^{-1}$.

TABLE III
COMPARISON OF REFERENCE LEVELS FOR CONCENTRATIONS OF RADIONUCLIDES DERIVED IN REF.[17] WITH CRITERIA CURRENTLY IN USE

	Reference Level, Alpha-Emitting Radionuclides ($Bq\ g^{-1}$)	Remarks
UNITED STATES (NRC generic) limit)	400	Non-stabilised waste, near-surface*
	4 000	Stabilised waste, greater depth*
	4 000	DOE package limit in transuranic, alpha-emitting radionuclides
FRANCE (Centre de la Manche)	400	Site average
	4 000	Maximum in one container, embedded waste
	200	Maximum in one container, waste in tumuli
UNITED KINGDOM	4 000	Average per day of disposal operations; Converted from 20 mCi m^{-3} assuming a waste density of 0.2 t m^{-3} (typical of uncompacted LLW); Additional criteria ensure actual concentrations in wastes at Drigg are about a factor of 10 below the limit
NEA, Ref.[17] Section 3-5	10-1 000	Average, for wastes buried within the NRIZ; Excludes ^{226}Ra
	10^3-10^4	Average, for wastes buried at depths below the NRIZ and above 20 m; Excludes ^{226}Ra

* Limits are for single containers and apply only to alpha-emitting, transuranic radionuclides with half-lives exceeding 5 years.

2.1.3. Classification for waste handling and treatment

The radioactivity level in wastes may affect the handling and treatment operations with regard to shielding requirements. A classification system for liquid wastes has been suggested by the IAEA and is given in Table IV [18].

TABLE IV
CLASSIFICATION OF LIQUID WASTES

Category		Activity (m^{-3}) mixed β-γ emitters [a]	Remarks
	1	< 37 kBq	No treatment required; released after measuring [b]
Low level waste (LLW)	2	37 kBq to 37 MBq	Treated, no shielding required.
	3	37 MBq to 3.7 GBq	Treated, shielding may be required according to radionuclide composition.
Intermediate level waste (ILW)	4	3.7 GBq to 370 TBq	Treated, shielding necessary in all cases

[a] Concentration of alpha activity is negligible. The quoted activity may be after appropriate decay storage for any short lived radioisotopes.

[b] Related to the release rates, licensed by the respective competent authority

Similarly, solid wastes have been classified in four categories according to the radiation dose on the surface and the source of radiation (Table V) [18].

This classification was introduced in 1970 and a need for its updating is obvious. Currently the IAEA is preparing a RADioactive WAste Safety Standards (RADWASS) Safety Guide [19] which will revise and update portions of the Agency's documents Safety Series No. 54, "Underground Disposal of Radioactive Wastes: Basic Guidance", and Technical Reports Series No. 101, "Standardization of Radioactive Waste Categories" dealing with waste classification.

2.2. Physical/chemical classification

Radioactive wastes can be classified according to their physical state (liquid, solid, gaseous) and chemical properties. The selection of a treatment process depends to a large extent upon their physico-chemical properties. It is therefore important to know these properties because together with other properties they will help the waste manager to decide which type of treatment is required.

2.2.1. Physical properties

The most important physical properties of an effluent which could influence its treatment include the following:

- conductivity
- turbidity

- emulsifying ability
- density
- viscosity
- surface tension.

The conductivity, if high, could preclude the use of ion exchange methods. Usually a conductivity of 1.0 mS/m is the limit for ion exchange treatment. Turbidity indicates the presence of colloidal particles in the effluent and will need to be removed by some kind of chemical treatment.

TABLE V
PROPOSAL FOR THE CATEGORIES OF SOLID WASTES

Category	Radiation dose on the surface of wastes D (mSv/h)	Remarks
1	$D \leq 2$	β-γ emitters
2	$2 < D \leq 20$	α emitters
3	$20 < D$	insignificant
4	α activity expressed in Bq/m^3	α emitters dominant β-γ emitters insignificant not suspect from the point of view of criticality

Note: Category 1: comprises solid radioactive wastes with beta and gamma emitters and an insignificant amount of alpha emitters whose radiation dose on the surface is not higher than 2 mSv/h. Such solid wastes can usually be handled and transported without any special precautions.

Category 2: comprises solid radioactive wastes with beta and gamma emitters and an insignificant amount of alpha emitters whose radiation dose on the surface is higher than 2 mSv/h and equal or lower than 20 mSv/h. Such solid waste can usually be transported in simple containers shielded with a thin layer of concrete or lead.

Category 3: comprises solid radioactive wastes with beta and gamma emitters and an insignificant amount of alpha emitters whose radiation dose on the surface is higher than 20 mSv/h. Such solid wastes can be handled and transported only if special precautions are taken.

Category 4: comprises solid radioactive wastes with dominant alpha emitters and an insignificant amount of beta and gamma emitters which are not suspect from the point of view of criticality. The activity should be expressed in Bq/m^3.

- other materials that react with water to evolve heat and flammable gases, e.g. hydrides, nitrides, carbides etc.

The risk of fire or explosion is particularly important also during solid waste compaction.

Aluminium capsules are commonly used for isotope target containment. However, aluminium reacts with alkalis (including the alkali in fresh cement grout) to liberate hydrogen. In the additional presence of nitrates, the gaseous product becomes ammonia. Special care of the capsules is required before decay storage.

2.2.3. Biological properties

Biological wastes are characterized by the presence of microorganisms. Both the types and concentrations of those organisms can be important, as they can lead to high biological oxygen demand which may affect treatment. The presence of biodegradable substances in effluent, both organic and inorganic, can cause troubles due to foaming in both chemical treatment tanks and evaporators, particularly the latter. In addition, such effluents may contain toxic substances which could cause complications with the safety of operations. However, these effluents arise at quite specific establishments and can be segregated and treated as required.

Special attention has to be given to faeces of patients in radiotherapy hospital departments. But, the radionuclides applied for radiotherapy are in most cases very short lived and no problems should occur in the treatment of sewage effluents, if enough storage volume is available.

Solid wastes representing particular biological hazard must be segregated in storage and waste management operations. Radioactive animal carcasses, contaminated bedding or paper wastes from veterinary research may require storage in labelled dedicated freezers, or in sealed packs after treatment with lime or formaldehyde. Such wastes will be considered separately in a later manual.

3. WASTE ARISINGS

3.1. Sources of wastes

The primary sources of radioactive wastes in a country without nuclear fuel cycle activities are:

- nuclear research
- production of radioisotopes
- application of radioisotopes
- decontamination and decommissioning of nuclear installations.

As a result of these activities, mainly low and intermediate level wastes are generated.

3.1.1. Nuclear research

Research activities include a variety of activities and facilities, such as research reactors, particle accelerators, and laboratory activities. All may generate radioactive waste, with the type and volume of waste depending on the research conducted. Research activities may be carried out either in small laboratories or in a full nuclear research centre. The nature of the contamination and the type of waste generated at a research centre depend upon the research programme and can vary widely.

The main wastes generated by the operation of a low power research reactor are the liquid wastes, ion exchange resins, irradiated equipment and general trash.

3.1.2. Production of radioisotopes

The research reactor is assumed to provide the irradiation facility for producing some radioisotopes particularly the short lived nuclides ^{32}P, ^{35}S, ^{75}Se, ^{99m}Tc and ^{131}I.

Particle accelerators (including cyclotrons) may be also used to produce by bombardment of targets isotopes such as ^{15}O, ^{13}N, ^{11}C and ^{18}F mostly for positron emission tomography and ^{123}I, ^{111}In, ^{201}Tl, ^{67}Ga and ^{81}Rb for general nuclear medicine. The radioisotopes produced in the particle accelerator and the research reactor are produced on targets and in capsules, respectively. These targets and capsules are removed from the facilities and introduced mechanically into a fully equipped 'hot cell'. Once in the hot cell, the processing of these targets and capsules must be managed safely. The production of radioisotopes results in wastes being generated by a relatively large number of individual generators of small waste volumes. The wastes, which are both liquid and solid in form result from the etching and dissolving of these target materials. These wastes, although small in volume, are quite radioactive because of trace quantities of unwanted radioisotopic contaminants. It is therefore prudent to have storage capacity in the hot cell for waste from several targets and capsules. More than 50% of the wastes will be liquid, which can be easily stored in leakproof containers.

The final step in radioisotope production is the purification. This is generally performed in an adjacent hot cell making for ease of transfer of the bulk radionuclides. The waste generated from the radiomechanical analysis is small in volume and is easily stored with the processing wastes for decay.

It is assumed that the research laboratories would use some of the radioisotopes produced in the adjoining facilities of the research centre. In which case the solid and liquid wastes will contain significant proportions of the radionuclides emplaced, some decay of short lived nuclides will occur within the laboratories, but even in efficient programmes perhaps half will eventually appear in wastes. It is likely that a national research centre could also conduct research work with isotopes purchased from abroad or with natural but radioactive isotopes mined within the country e.g. uranium or thorium.

The most voluminous waste would be dry low level solid waste and contain all items of general trash i.e. paper (sacks, tissues and coverings), plastics and rubbers (laboratory wares and scintillation counting tubes) and metals (foils, cans, shielding and tools). Liquid wastes would be both aqueous and organic and in some cases contain macerated solids or sludges.

3.1.3. Application of radioisotopes

Ionizing radiation and radionuclides are used in industry, medicine, research and teaching within the developing Member State. These main areas of application could be subdivided into a number of more specific applications that are listed below:

<u>Radiography techniques (industrial and medical)</u>

Industrial gamma and X ray radiography (non-destructive testing)

Medical diagnostic radiography

Beta radiography

Neutron radiography

<u>Analytical techniques</u>

X ray fluorescence

Electron capture

Neutron capture and activation analysis

<u>Gauging techniques</u>

Transmission gauges (beta and photon)

Beta backscatter gauge

Gamma backscatter gauge

X ray fluorescence gauge

Photon switching (level gauge)

Selective gamma absorption

Gamma scattering

Thermalization of neutrons

Neutron transmission

<u>Irradiation techniques</u>

Radiation beam therapy (teletherapy)

Brachytherapy

Radiation sterilization, cross-linking, curing and grafting

Food preservation

<u>Techniques involving unsealed radioactive materials</u>

Radioisotope tracer techniques

Therapeutic uses of radiopharmaceuticals

Self-luminous devices

Enhancement of electrical discharge

Uses of thorium

Miscellaneous techniques

Static elimination

Smoke detectors

Lightning warning systems

Dewpoint meters

Nuclear batteries

Inadvertent concentration of radioactivity

Inadvertent production of X rays.

The application of radioisotopes results in generation of various liquid effluents and solid waste, spent sealed sources and Ra needles. Both sealed and unsealed sources would be used in the Member State. The management of sealed sources has been described in detail in another technical manual [2]. It may not be possible to minimize the arising of spent sealed sources, but their segregation from other waste is important, since the opportunity may arise for return to the original supplier.

Some laboratories will produce wastes of similar composition to those from the research centre. However, where patients are treated with radionuclides the proportion of putrescible wastes could arise. Such wastes might pose greater hazards from biological, pathogenic or infectious material than from radionuclide contents.

3.1.4. Decontamination and decommissioning of nuclear installations

Decontamination of installations may result in the generation of secondary liquid waste, decommissioning itself results in the generation of solid wastes. These wastes comprise building and equipment components. The main features typifying decommissioning wastes are the large size of the waste items and the presence of long lived activation products.

3.2. Amount of wastes

Typical amounts of radioactive wastes arising from medical, industrial, research and training activities in a developing country are given in Table VI. As it can be seen from the table most of the waste generated belongs to the category of low level wastes accompanied with a small volume of intermediate level wastes.

Liquid wastes may include process solutions, chemical solutions used for regenerating ion exchange resins, decontamination solutions, contaminated oils etc.

The largest volume of solid wastes is general trash, which includes protective clothing, plastic sheets and bags, rubber gloves, mats, shoe covers, paper wipes, rags, towels, metal and glass, hand tools and discarded equipment [9].

Solid wastes may also include various process wastes, such as spent filter cartridges, dewatered resins and sludges from effluent treatment plants. Animal carcasses and sealed sources arising from industrial research and biomedical activities represent other common forms of solid wastes [9].

TABLE VI

WASTES ARISING FROM MEDICAL, INDUSTRIAL, RESEARCH AND TRAINING ACTIVITIES

Type of Waste	Raw wastes per installation		Radionuclides
	m^3/a	Activity content or surface dose rate	
Nuclear research centres			
Aqueous effluents	100-500	40 kBq/m^3-4 GBq/m^3 (10^{-6}-10^{-1} Ci/m^3	Corrosion products, Cs-134, Cs-137, Tc-121m, P-32,
Organic effluents	0.1-1	40 kBq/m^3 (10^{-6} Ci/m^3)	S-35, Cr-51, Fe-59, Tc-99m, In-111, I-131, U(nat), Th(nat)
Spent ion exchange resins	0.5-1.5	20-40 GBq/m^3 (0.5-1 Ci/m^3)	I-125, Y-90, H-3, C-14
Compactible solid wastes	50-100	< 0.1 mSv/h (< 0.1 R/h)	
Non-compactible solid wastes	5-10	< 0.1 mSv/h (< 0.01 R/h)	
Hospitals			
Aqueous effluents	2-5	40 kBq/m^3-40 MBq/m^3 (10^{-6}-10^{-3} Ci/m^3)	In-111, Tc-99m, I-125, S-35, P-32, I-131, H-3, C-14,
Compactible solid wastes	2-5	< 0.1 mSv/h (< 0.01 R/h)	Co-60, Cs-137, Ir-152, Ra-226
Sealed sources, Ra needles	1-2	1-10 Sv/h (10^2-10^3 R/h)	
Industry			
Sealed sources	1-2	1-10 Sv/h (10^2-10^3 R/h)	Co-60, Cs-137, Ir-152
Smoke detectors	1-2	< 0.01 mSv/h (< 0.001 R/h)	Pu-239, Am-241
Universities and research institutions			
Aqueous effluents	2-5	40 kBq/m^3-40 MBq/m^3 (10^{-6}-10^{-3} Ci/m^3)	C-14, H-3, P-32, S-35
Compactible solid wastes	2-5	< 0.1 mSv/h (< 0.01 R/h)	

Typical distribution of solid wastes generated in research centres is as follows:

- 70% compressible 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% hard materials: metal components, coating or lining fragments, items whose size normally calls for fragmentation;

- 10% debris resulting from plant conversions and operational incidents (concrete, soil, etc.)

4. WASTE MANAGEMENT INFRASTRUCTURE

A national radioactive waste management system shall be developed with the following features:

- National policy

- Appropriate legislation and regulations

- Effective implementation and enforcement procedures

- Appropriate training plans for national enforcement officers, plant operators and managers

- The provision of adequate facilities for radioactive waste management

- Public awareness educational programmes.

4.1. National policy

A national policy for the radioactive waste management shall be established and the roles and responsibilities of organizations involved in its implementation should be clearly identified. The necessary resources shall be provided to administer the policy, i.e. organizational, financial, technical and expertise.

Government policy should be clearly expressed. It could be expressed so as to protect man and his environment from undue exposure to ionizing radiation from radioactive waste by the application of up-to-date internationally accepted waste processing and disposal recommendations etc. In establishing and keeping the policy under review, the government should be advised by appropriately qualified persons whose combined expertise covers all relevant disciplines.

4.2. Legislation and regulations

Waste management legislation should be introduced together with a general radiation protection legislation, nuclear energy legislation or other relevant national legislation regulating the safe use of radionuclides and the protection of man and his environment from undue exposure to ionizing radiation.

Waste management legislation should be accepted by a larger part of the society as possible. To achieve this goal the legislation should be constructed in accordance with the national legal, technical and cultural traditions. In developing countries the legal tradition may not be as well established as in other countries but still the cultural tradition can be strong. Waste management legislation may be reviewed and modified as a result of new policy from time to time.

In order to achieve safe management of radioactive wastes, legislation and/or national policy statements should provide the basis for:

- establishing a regulatory body responsible for regulatory control and enforcement;
- empower the regulatory body to propose or issue regulations;
- setting goals for protection of the worker, the general public and the environment;
- licensing the waste treatment and conditioning facilities;
- exempting small quantities of radioactive wastes from all or part of the waste management regulatory system;
- vest the regulatory body with the rights of access to, and inspection of, premises, facilities and equipment involving radioactive waste to ascertain compliance with the requirements of the legislation;
- allow for appeal against decisions made by the regulatory body.

4.3. Implementation and enforcement

A national legislation is of no practical value if it does not have an organization with enough resources for its implementation. In most countries, the users of radioactive materials are responsible for the safe management of their radioactive wastes in accordance with the law and regulations established by the regulatory body. Enforcement of the legislation and regulations should be carried out by the regulatory body which should have the authority to impose sanctions or to suspend the waste management operating licence, if serious violations of the law or regulations have been made by the operators.

Resources are needed for the implementation of a national waste management regime. They comprise: financial resources and manpower. Many resources can be the same or shared with the resources needed for the general radiation protection regime in the country. In general terms the resources should be adequate to comply with the requirements set up for the waste management regime.

The regulatory body needs, and must have, financial resources in order to function effectively in accordance with the national plan for waste management. The resources can be provided from the national budget, from fees paid by the waste producers and users of the services provided by the regulatory body, or by a combination of national budget and fees, depending on national policy. If at least a significant part of the financial resources are provided by the national budget, this gives the government a way of controlling the level of ambition of the regulatory body by increasing or reducing the funding.

The users of radioactive materials must also have the necessary financial resources for the safe management, including disposal, of the waste generated. This should be considered already when planning the use of radionuclides. However, the government should ensure by appropriate means that money for the safe management of radioactive waste is available for a situation when a user due to bankruptcy or for some other reason does not have the financial resources to take care of his radioactive waste. Otherwise radioactive materials may end up in places where they can endanger the health of people.

4.4. National training programme

For the implementation of a waste management legislation, it is necessary to have enough manpower with the right combination of theoretical education and practical experience. The operating organization shall have a training programme for the operators, supervisors and maintenance personnel for the waste management system. The regulatory body enforcement officers should be trained in enforcing the rules and regulations. If everyone has high theoretical expertise, there is a risk that the practical aspects will not be properly handled and in the opposite situation there might be no one capable of tackling new problems which need the scientific approach for their solution.

A combination of regular training and education of the existing staff and when recruiting new staff members is necessary to maintain a well functioning staff. It is the responsibility of management to ensure that the personnel at all times have the qualifications needed to perform their jobs in a safe, efficient and professional manner. This underscores the need for re-training of personnel.

4.5. Waste management facilities

Facilities include buildings, laboratories, waste treatment installations and waste disposal sites. They should be constructed to comply with the specific requirements, existing or foreseen, of the local or national needs of waste management. The impact on waste management facilities from planned changes in the use of radionuclides, notably increased volumes of radionuclides used or new application areas, must be analysed and all necessary modifications or required new facilities must be implemented in a timely manner to comply with the changed requirements when they occur. In order to manage short term increases in waste volumes to be processed, e.g. as a result of an incident, the capacity of the facilities should be higher than required for normal operations. The extent of the increased capacity should be based on an optimization of waste treatment methods, efficiencies and radiation protection. It is the responsibility of the user to provide them, and of the regulatory body to control that they are adequate for their purpose.

In addition, the radiation equipment for the site and environment monitoring shall be provided. Examples of equipment needed are: surveillance monitors, special radiation detectors, detectors for activity measurements, and calibration sources.

It is the responsibility of the regulatory body to ensure that the licence holders have all the necessary equipment and that it is suitable for the licensee's purpose.

The regulatory body should secure for itself the best equipment available. This does not mean that the most expensive and sophisticated equipment should be procured. In most cases it is preferable to have less sophisticated and cheaper, but reliable equipment which complies with the requirements needed since such equipment often is less sensitive to failure. Also such factors as service and maintenance possibilities should be considered.

The regulatory body should investigate the existence of special equipment that may be needed in, for instance emergency situations, and make arrangements to have access to those when needed. Examples of such equipment are: additional radiation protection monitors, shielded transport containers, decontamination equipment, and remote handling devices.

4.6. Public awareness programme

Member States should provide a public awareness programme to inform the public about radioactive waste matter. The programme may be provided separately by the operating organizations or in conjunction with the national programme.

The public awareness programme is a continuing need, and may need to be reinforced when new large waste management projects are initiated in the planning stage.

5. WASTE MINIMIZATION

National regulations and licensing procedures should secure an important place for waste minimization within the waste management strategy.

Minimization of radioactive waste generation is a vital requirement to be taken into full account from the commencement of design and operation of all the nuclear facilities. Where regulatory body controls waste management through comprehensive safety case presentation as part of the licensing procedure, minimization considerations, often linked with segregation options, will influence virtually all aspects of production and use of nuclear materials. This will include the selection of the process, preparation of starting materials, design of equipment, choice of materials of construction as well as details of operational procedures. Major savings in waste can be made by the particular strategy chosen. The decisions have implications in economics, politics and industrial equipment. They always have consequences in the intermediate and long term, and are very difficult to modify.

The concept of waste minimization is illustrated in Figure 3, which subdivides the topic into three distinct headings: source reduction, recycling and reuse, and treatment.

5.1. Source reduction

Source reduction, the most prominent component of waste minimization, consists of plant and equipment design and process control.

It is essential that the amounts of radioactive wastes are minimized and this must be taken as an important requirement when any new facility is designed. The correct choice materials or equipment in a facility, the choice of internal surfaces for easy decontamination, the selection of highly reliable equipment etc, have a major impact on waste arisings. Once the facility has been constructed, with minimization in mind, it needs to be operated in a careful way with the administrative procedures enforced so that standards are maintained.

The costs, doses and difficulties involved in handling intermediate level waste are usually higher than for low level waste and for wastes at the exemption level. Every attempt should be made to minimize the level of contamination associated with wastes. In addition, unnecessary material must not be allowed to become contaminated, so ensuring waste volumes are minimized.

A more detailed assessment of administrative measures and plant design features for waste minimization now follows:

5.1.1. Plant design

Proper plant design can minimize generation of waste perhaps by up to an order of magnitude. Many general design criteria, which are essential for acceptance of designs of radiochemical plant by regulatory

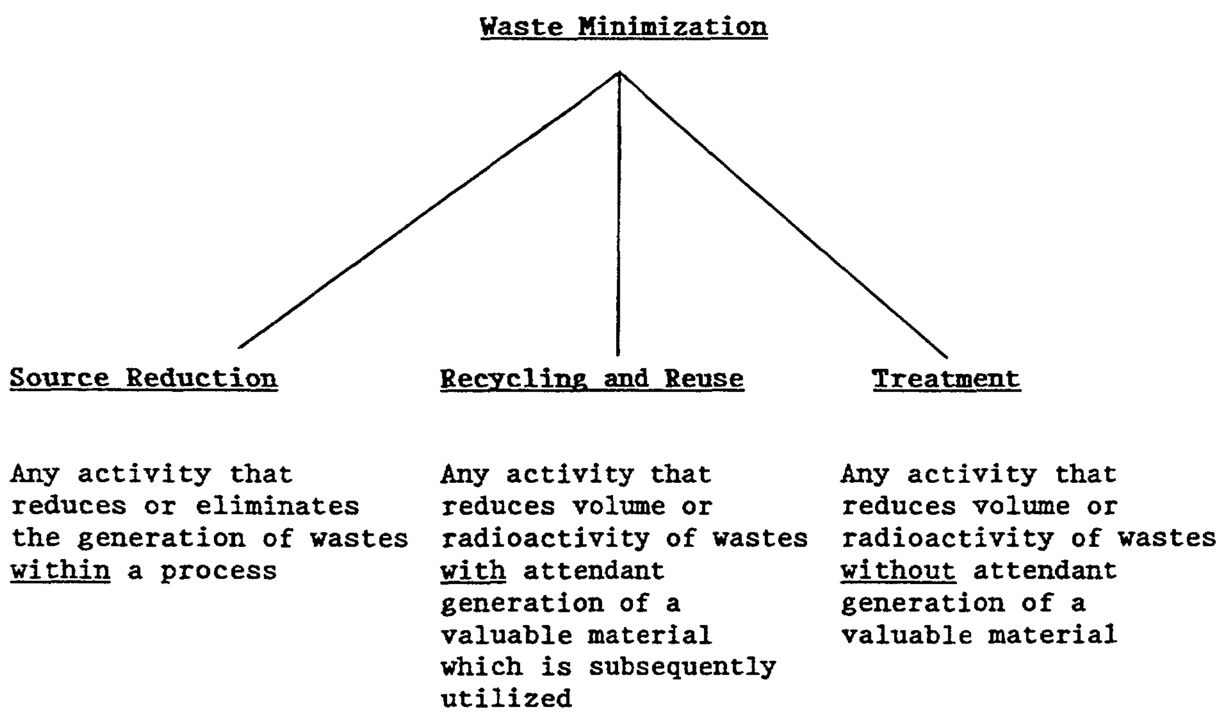


FIG. 3. Defining the concept of waste minimization.

or licensing bodies in developed countries, contribute to the minimization of wastes; some important examples are itemized below:

- Plant design should be based on most effective, reliable and up-to-date technology.

- Process and equipment design should avoid unintended accumulation, and uncontrolled movements of radioactive materials.

- Plant design should ensure that under normal and fault conditions:

  (a) radioactive materials are kept separate from non-radioactive materials,

  (b) where appropriate, radioactive materials and non-radioactive reagents are adequately segregated, and

  (c) radioactive and non-radioactive feed materials and reagents remain within specified limits and are compatible with the safe operation of the plant.

- Monitoring and sampling with appropriate instrumentation and alarms, should be provided to facilitate the control of radioactive materials.

- Controlling the temperatures of radioactive materials where the heat of radioactive decay or chemical reaction may be significant should be provided.

- Arrangements for the management of liquid radioactive materials should be such that chemical reactions, precipitation, acidity, etc can be controlled to within specified limits.

- Where there is a need foreseen to make a temporary opening in any containment, the design should be such as to minimize personnel exposures and the spread of the radioactive materials.

- Design of vessels, pipework, equipment, and containment structures should facilitate decontamination, e.g. after spillage, prior to maintenance or in the course of decommissioning.

- Where facilities are proposed for transferring radioactive materials outside the plant containment, the design should:

  (a) minimize the number of such facilities,

  (b) minimize the risk of spillage or leakage,

  (c) provide, where appropriate, local ventilation, shielding and remote handling devices.

- Excessive spread of radioactive materials during handling, processing, storage and inspection should be prevented by adequate containment.

- Containment and packaging of radioactive materials should be designed to maintain integrity throughout the design life of the plant or package. Consideration is to be given to:

  (a) deterioration of the containment or package with time due to external and internal conditions likely to be encountered during both normal and fault conditions,

  (b) the nature and quantity of the radioactive materials.

- Spread of loose radioactive materials should be controlled by adequate local containment supplemented by appropriate ventilation cleanup systems.

- Design of the plant should provide for:

  (a) decontamination of zones to which access may be necessary;

  (b) decontamination of articles which may have to be removed from contaminated locations;

  (c) ventilation of contaminated zones to limit the spread of contamination;

  (d) the prevention of the spread of contamination when persons leave a contaminated location.

- Estimates of the arisings of materials and items which might constitute scrap should be included in flowsheets.

- It should be demonstrated in design that the locations designated to hold possible scrap materials are:

  (a) suitably situated, of adequate capacity, and provided with sufficient services and equipment to facilitate safe handling, sorting and processing, and

  (b) provided with durable impervious surfaces, adequate ventilation facilities and appropriate change-room facilities.

- Design proposals should describe the system for keeping adequate records of the arising of radioactive scrap, levels of contamination and ultimate destination.

- Design should provide alarm devices to indicate over-filling of containment is occurring. The alarm level should enable corrective action before over-filling occurs.

- Wherever radioactive materials are held in process vessels or pipework, adequate and suitable secondary containment capacity should be provided. Arrangements should be such that should normal containment become defective, the radioactive material can be safely retrieved, conditioned if necessary, and transferred into an adequate alternative containment.

- Design should include a schedule for the inspection and monitoring of secondary containment for leaks and spillage from the materials containment.

In radioisotope production processes, the designs should take account of the following specific factors:

- Reactor capsules require a high level of purity to ensure only the desired radionuclides are produced. Trace impurities in capsules can create the need for extra shielding during processing and a waste disposal problem. This is one of the reasons why high purity aluminium is used for canning target materials for reactor irradiation. Aluminium has no long lived radionuclides produced when it is irradiated by neutrons. Presence of small traces of cobalt and caesium can lead to the generation of ^{60}Co and ^{134}Cs with the consequent long lived waste disposal problem and the need for shielding during handling.

- Targets for the cyclotron must be prepared using pure high quality material and the machine run at the proper current to prevent the generation of undesirable radionuclides that would require management as a waste.

- Improper cyclotron beam currents or unfocused beams can burn targets resulting in appreciable area contamination and unnecessary waste.

- Plastics which do not become activated can be used in place of metals for some cyclotron duties.

- Targets in isotope production may produce less waste in some cases by preparing, from natural elements, isotopically enriched ones, so as to produce only the required daughter isotope. ^{111}In is generally produced from cadmium enriched in ^{112}Cd.

- Target materials may undergo more than one nuclear reaction or may undergo excess burnup. Optimization of the irradiation process in the reactor or cyclotron is of extreme importance in minimization of wastes.

5.1.2. Process control

Waste management often has a low priority in both national institutions and at commercial facilities. Often the responsibilities are too diffuse for ensuring the minimum amount of waste is produced for treatment and disposal. Frequently one group produces waste and other groups under different management collect, transport, process and dispose of the wastes. This long chain of persons involved often leads to the attitude that it is someone else's problem. The 'them' and 'us' attitude must be countered by close liaison between different groups, or preferably when all work activities are undertaken at one site by a unifying waste management group.

The waste management and environmental control functions should be at least designated to an individual for each nuclear facility in the developing Member State who has the responsibility to ensure compliance with all applicable regulations, guidelines and established practices.

This individual can be called Radioactive-Materials Co-ordinator (RMC) with functions outlined in [9] and summarized in Annex II. The officer should be responsible for all procedures and operations involving the use of radioactive materials and any resulting waste, including releases of effluents to the environment. He should also fulfil the role of ensuring that the minimum amount of waste has been produced in the area.

In supporting the RMC, the role of the supervisor is vitally important. The waste management implications of action taken by researchers, operators and the supervisor's own staff must be under constant personal review. Careful operation of equipment should be ensured, prolonging operational life and reducing wastes. Operators should report problems promptly if they relate to waste production or leaks of contaminated liquid.

The following action in the process control could be undertaken to minimize waste at source:

- A facility should be operated consistent with the design objectives. All activities should be supervised to ensure that a suitable standard of operation is achieved and maintained. 'Good operating practices' or 'good housekeeping practices' involving the alteration of existing procedural, organizational, or institutional aspects of a process should be kept.

- Maintenance procedures should be carried out in a manner consistent with radiation protection principles. Proper monitoring equipment for surveying materials considered as contaminated (e.g. a Geiger-Müller or another appropriate counter) should be available at suitable locations.

- Operators and maintenance workers should be adequately trained to understand the consequences in waste management from individual errors which produce waste.

- Detailed manuals for procedures for all phases of the radioisotope processes are required (including covering research and development as far as possible) and the RMC should ensure that they are up to date and applied. These procedures will reduce the error likely in routine processes. Errors in adding chemicals, making transfers, counting of samples, etc. can lead to incorrect radioisotope concentrations, spilled material and other failures which lead to unnecessary waste generation.

- The quantity of radioactive materials within the process should be the minimum and complying with operational requirements.

- All unnecessary 'inactive' materials should be kept out of 'active' areas. Stores staff shall be organised to reduce the amount of inactive material entering active areas not only by removing unnecessary packaging, but by being flexible with regard to the amount of material released e.g. when only three items are required these should be supplied rather than a box of twelve. Tools and other components for radioactive areas should be issued without packaging, wrapping or pallets. Any surplus material should be segregated once in the active areas to avoid becoming contaminated.

- Mechanical transfers between hot cells and other radioactive areas should be used wherever possible.

- Strong plastic bags should be used to prevent double bagging of waste materials for transfer.

- The use of single use protective clothing, i.e. plastic shoe covers and laboratory coats should be minimized. Reuse rubber gloves if non-contaminated.

- When counting liquid scintillation samples one way to minimize waste is through the use of mini-vials instead of the maxi vials. Three times as many samples can be counted using the same quantity of liquid using smaller vials, bringing substantial savings in the volume of waste for disposal.

- The amount of inactive materials including liquids, which are put into enclosures, fume hoods, glove boxes, cells etc. should be kept to a minimum. Reduce water leaks into process systems and regulate indiscriminate flushing/cleaning operations.

- Floor materials should be used that can be easily decontaminated in areas where frequent maintenance is required.

- Staff collecting active wastes from laboratories and other facilities must be encouraged to assist by reporting waste not properly packaged or not accompanied by the correct documentation.

- Radioactive wastes should be segregated according to their radiological, physico-chemical and biological properties.

This latter point is examined in more detail in Section 6.

5.2. Recycling and reuse

Viewed generically, 'recycling' encompasses both reuse and reclamation activities. Decisions as how to treat a waste is principally determined by the character of specific waste streams or waste mixtures. Where treatment should take place (either on-site or off-site), however, is a function of a generator's management practice which includes:

- Proximity to off-site recycling facilities;

- Economic costs related to the transportation of wastes;

- The volume of wastes available for processing; and

- Costs related to storage of waste on-site compared to off-site.

Recycling is characterized by three major practices: (1) direct use or reuse of a waste in a process, (2) recovery of a secondary material for a separate end use such as the recovery of a metal from a sludge, and (3) removal of impurities from a waste to obtain a relatively pure reusable substance.

Examples of recycled waste options may include:

- Transfer of spent sealed radiation source to another user [2] when the source activity is no longer suitable for the original application but there may still be sufficient radioactivity to allow the use for another purpose. This may especially be the case for the high activity ^{137}Cs and ^{60}Co sources. Transfer of sources to other users within the national boundaries of the country offers economic advantages in both source procurement and waste disposal.

- Return to the original supplier. Radioactivity contained in the spent sources may be recovered for incorporation in new sources. Many institutions in different countries routinely refurbish spent sources for economic reasons.

- Reuse of decontaminated materials. Nuclear facilities usually contain considerable quantities of expensive material that have been contaminated but not activated. Much of this material has significant value if it can be sufficiently decontaminated to permit its unrestricted use. A number of methods are available as decontamination techniques [23, 24]. The choice of reuse or disposal of contaminated materials and equipment will depend upon realistic cost/benefit and radiation detriment analysis and the requirements of national regulations. Additional waste minimization could be provided by reuse decontamination solutions and recycle clarified liquors within a process to reduce fresh water additions and volumes of effluent for treatment.

5.3. Waste treatment

Waste treatment comprises of operations intended to benefit safety or economy by changing the characteristics of the waste. Three basic treatment concepts are:

- volume reduction;
- removal of radionuclides from the waste;
- change of composition.

Considerable experience has been accumulated in the satisfactory treatment of the wastes [20,21]. Other technical manuals [25-27] describe in detail methods and equipment for treatment of radioactive waste arising in a developing country without nuclear power.

6. SEGREGATION OF WASTE

6.1. General considerations

In order to facilitate their subsequent handling, treatment and disposal, it is necessary to segregate wastes at the point of origin according to their chemical, physical, biological and radiological properties. The objectives of waste segregation are:

- Remove non-radioactive material or components from radioactive waste;

- Separate waste into appropriate categories (see Section 2);

- Recover valuable materials for recycling and recycle wastes into the process.

This segregation will produce a number of direct benefits, e.g. segregation of non-radioactive waste from radioactive waste at the source will significantly reduce the volume of radioactive waste requiring storage or further treatment; segregation of different types of radioactive wastes will also lead to more efficient waste processing and packaging.

The success of waste minimization depends to some degree upon waste segregation. The segregation should be made on the basis of:

- Origin of waste;
- Physical form and chemical composition;
- Radionuclides involved (total and specific activity, half-life).

Since the radioactive waste streams and systems in developing Member States generally are not complex, a simple-to-implement segregation programme is desirable at the startup of operation in all facilities.

From the point of view of disposal it is necessary to segregate radioactive waste into two principal streams:

- Waste to be discharged to the environment as exempt waste, and

- Waste to be discharged to the environment or disposed of in a specially designed repository under regulatory control.

Principles of categorization of radioactive waste are outlined in Section 2. The regulatory body shall fix a limit on the activity level and other characteristics of the waste for a particular location and facility, below which it can be considered as acceptable to sewers (liquid) and landfill (solid). This limit will depend upon the nature of the sewer system or landfill, local regulations and the kind of work being done. Once this limit is fixed the volume of radioactive waste which has to be handled may be reduced considerably.

In evaluating the impact of direct disposal, the RMC must identify the possible exposure routes for employees such as sewage workers, as well as the degree to which the element or compound is likely to be reconcentrated or dispersed in the immediate environment and the consequent exposure of individuals or groups. The licensing authority must consider the impact of discharges from all licensed premises within a particular environment and assess the individual and collective exposures that could result from the discharges [9].

The design of the process for segregation of liquid and solid radioactive wastes to sort into the groupings for efficient subsequent waste management operations usually includes monitoring, collection, temporary storage, packaging and documenting. Segregation may also be associated with pretreatment steps, such as dismantling, shredding or decontamination for solids and neutralization, settlement or oil absorption for aqueous liquids.

It has to be emphasized however that in a manner similar to minimization, segregation is best managed with a minimum of separate equipment. Careful plant design in the prior user or radioisotope producer operations, combined with administrative controls at the point of origin of the wastes, are the most effective management measures. These bypass the need for much handling and repackaging with associated secondary wastes and operator exposure.

6.2. Solid wastes

6.2.1. Monitoring

If possible, solid wastes should be monitored at the point of generation, depending on background radiation levels, using a standard Geiger-Müller survey meter for mixed gamma-beta radionuclides. If not, the bagged or boxed wastes can be brought to a central monitoring station. Materials found to be non-radioactive, that is below the exemption levels discussed in Section 2.2.1., may be separated and disposed of as normal trash.

Renovations to laboratories, air handling systems, equipment and other areas where radioactivity is present, generally result in large quantities of building materials and bulky items being generated. Hand-held monitoring of this material is labour intensive, but simple. Generally a very high percentage of these materials will be found non-contaminated. All materials found to be radioactive in this manner should be held for decay store for a month prior to further treatment.

The practical subject of conversion of radiation meter readings to concentrations of radionuclides within waste may require expert advice involving calibration of meters with prepared standards. Some commonly used nuclides such as ^{3}H, ^{14}C emit only low energy radiations requiring special instruments.

The assessment of the radioactive waste content of a waste package by monitoring with a Geiger-Müller counter and supported by experiments, to total beta and gamma or specific nuclide contents may be inadequate for shallow land burial. Destructive sampling programmes and treatments followed by nuclide spectrometric analysis are being replaced by shielded bagged waste monitors to detect and measure at the exemption levels for solid active wastes. Various waste monitoring instruments and techniques are available [7,28].

6.2.2. Collection and packaging

Collection practices for solid wastes from radioisotope users normally consist of distributing suitable containers throughout the working area to receive discarded active materials. The containers should be marked with brightly coloured paint (normally yellow) and the radiation symbol to distinguish them from bins meant to receive inactive wastes. Use should be made of different sized and coloured containers to aid segregation at the workplace. Where space allows, containers should be kept in hold areas within ventilated hoods.

Some segregation operations on solid wastes relevant to this report are carried out in gloveboxes, or possibly fumehoods, through direct manual operation. However, some simple remote handling by tongs and a manipulator behind shielding might prove necessary for occasional use. The separate facilities away from the waste source and associated with a waste treatment plant can be reserved largely as backup.

Practical design and operational details of segregation and associated pretreatment operations have been described in several IAEA Technical Reports [20-22]. However, most details are relevant only to complex fuel cycle facilities and large research establishments in a range of countries. Examples serve to strongly illustrate the problems in designing versatile economic and safe segregation operations to meet circumstances where the delivered wastes are mixed and varied in type, size and contamination levels or nature. It may become necessary to combine the range of pretreatments, monitoring, dismantling, shredding and decontamination with the sorting and packing stages. In some cases, operators are required to carry out a proportion of duties in pressurized air-suits, it being established that free operation at table level permits reduced working time. As the waste may be sorted by rakes and pushers (see Figure 4) [20] the operation will be safer. Another example of integrated solid waste treatment, inclusive of sorting, was operated for some years at Seibersdorf, Austria, with the 5 m X 6 m X 3.5 m layout given in Figure 5 [20].

Refuse cans with foot-operated lids are particularly useful for radioisotope laboratories. They should be lined inside with heavy-gauge plastic bags, which can be sealed and taken out when full. The use of plastic bags for trash containment has the advantage that water from wet material will not seep through them and contaminate the floor. Such containers may be used for collection of combustible-compressible wastes. Problems associated with the incineration of plastic materials should, however, be recognized [9].

For non-combustible, non-compressible waste such as broken glassware, metal pieces, etc., which require a stronger container, cans may be used advantageously [9].

When animal carcasses are to be dealt with, they may be deep-frozen pending disposal or placed in wide-mouthed jars containing formaldehyde or in plastic bags containing quicklime. If a liquid preservative is used, the jar should be capped, sealed and put in a can and the surrounding space filled with absorbent material such as exfoliated vermiculite or diatomaceous earth, so that if the jar breaks, liquid does not leak through the can. The packaging of carcasses and other wastes contaminated by longer lived radionuclides may be dictated by the relevant regulations for the national facilities such as shallow burial sites [9, 15].

Some larger radioisotope production plants produce solid wastes initially up to 10 Sv/h or 10^3 rem/h due to short half life contaminants. In addition to small buffer storage within the cell for some decay, these are equipped with a shielded store on the floor below. Drummed wastes, segregated at source, are chuted from the cells to a compartmented carousel and the compartments are individually chosen. The drums are later removed, as adequately decayed according to plan, through a shield port with contact handling only.

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.

The substances creating a hazard in solid radioactive wastes handling requiring segregation at source were listed in detail in Section 2.2.2. The main risk relates to waste materials likely to give rise to fire or explosion during solid waste compaction.

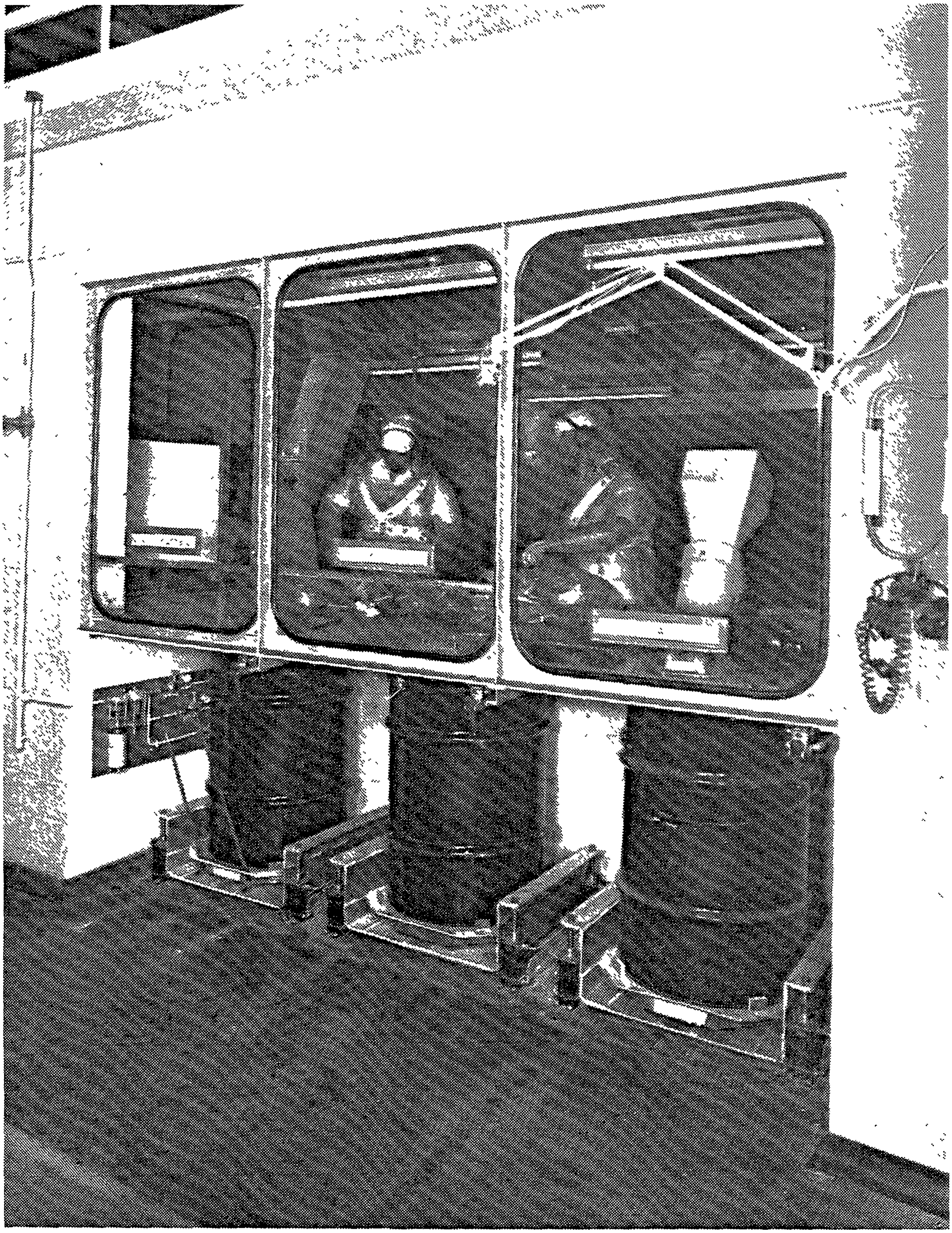
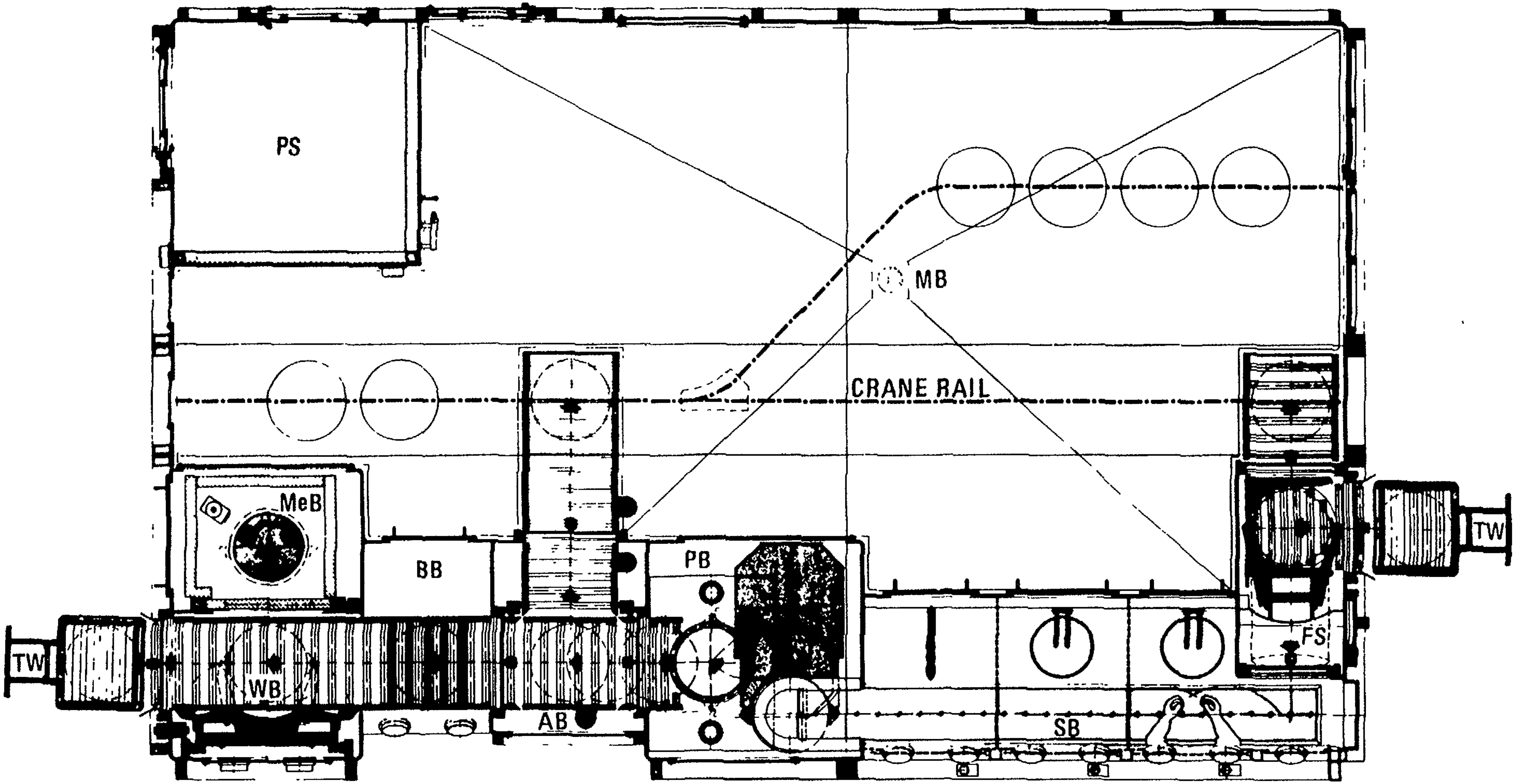


FIG. 4. Sorting operations in the sealed area.



LABORATORY
SGAE SEIBERSDORF

AB (Out)-sluice
BB Concrete Sealing Compartment
FS Sluice for barrels
MB Operations-Compartment
MeB Radiation Testing
PB Compaction-Compartment
PS Sluice for operators
SB Sorting Compartment
TW Barrel-carrier
WB Wash-Compartment

Size and function of radioactive wastes laboratories will be adapted to specific requirements.

FIG. 5. Solid waste treatment box.

6.2.3. Documentation

In order to aid the monitoring process and the determination of radioactivity disposed of as waste, accurate and complete documentation of the radioactive waste at the point of generation is very important. Each container must have a card or sheet of paper attached that requires the following information each time a package of waste is added:

- Date
- Radionuclide
- Amount of radioactivity (best estimate)
- Chemical composition/physical form.

When possible, each item (bag, can) of waste disposed into the container should be tagged with the above information and all individual items summarized on the card attached to the container. The information supplied in this way eases processing and gives accurate determination of the radioactive inventory of the drum. Table VII gives the data requirement for untreated waste items to accompany waste to the treatment facilities [9].

6.3. Liquid wastes

The radioactive-materials co-ordinator must examine the extent to which the direct discharge of low level liquid wastes is in accordance with local or national regulations or whether relevant disposal options will require the segregation, collection and treatment of wastes [9].

Some regulatory authorities may have particular rules about the disposal of even small quantities of carbon-14 and tritium due to their significant half-lives. However, wastes at the levels in use in research laboratories can often be effectively dispersed through conventional waste disposal routes, as any subsequent reconcentration of these radionuclides in any exposure pathway is most unlikely and the collective effective dose equivalent resulting from minor discharges is likely to be regarded by regulatory bodies as insignificant [9].

The present level of tritium in rain water is up to 10 Bq per litre. The level fifty years ago was a tenth of this. If the water consumption of small premises is 10^4 litres per day and the discharge to the drain is 1 MBq per day, the radioactive concentration (without subsequent dilution) is only ten times background and only a small fraction of the level for drinking water that would constitute an annual limit on intake (ALI) for a member of the public. The alternatives of collection, treatment (if any options are relevant), and storage for decay are often unnecessarily expensive and irrelevant. A detailed discussion of the handling of tritium-bearing wastes arising from nuclear power generation can be found in Ref. [29].

The present concentration of carbon-14 in carbon in the immediate environment is around 16 Bq per gram, twice the value fifty years ago. The ALI for workers is just less than 10^8 Bq although the ALI for inhalation of $^{14}CO_2$ is just less than 10^{10} Bq. Effective incineration of ^{14}C-labelled trash is possible. Detailed information on the emission of carbon-14 compounds from nuclear facilities is widely available, including methods of determining radiation exposure resulting from discharges [30].

TABLE VII
DATA REQUIREMENT FOR UNTREATED WASTE ITEMS TO ACCOMPANY WASTE TO TREATMENT PLANT

1. Description of waste and point of arising
    1.1 Facility and operation
    1.2 Quantity (kg) and type
2. Chemical composition
    2.1 Concentrations (mole, ppm, kg)
    2.2 pH (if contains liquids)
3. Radionuclide content (Bq/kg)
4. Contact radiation field (Sv/h)
5. Physical form (liquid, slurry, solid)
6. Physical composition
    6.1 Compactible - combustible
    6.2 Compactible - non-combustible
    6.3 Non-compactible - combustible
    6.4 Non-compactible - non-combustible
7. Important other characteristics
   (presence of toxic, putrescible or flammable materials).

Unused or outdated stock vials of some radiochemicals incorporating tritium or carbon-14 may be treated by incorporating the contents into a suitable binding agent (e.g. cement or cellulose-based fillers) and disposing of the solidified product to an available landfill site or nuclear facilities disposal site.

Individual users should keep the radioactive content of liquid wastes generated in the laboratories to the minimum. In some circumstances, the wastes need to be classified at the point of origin as aqueous and non-aqueous, acidic, alkaline or neutral.

Acidic and alkaline wastes are best stored separately from each other. It is quite likely that because of the inactive ions present in the liquids precipitation may occur when they are mixed. Also, mixing will produce heat, which in turn may result in the production of active aerosols.

Non-aqueous liquids should be stored separately from aqueous ones because mixing of this stream with aqueous solutions will pose problems for subsequent treatment.

Organic wastes can be burnt as fuel if incinerator facilities are available.

6.3.1. Monitoring

Monitoring of effluents usually involves a combination of on-line and laboratory analyses for determining activity and other characterics, and may require the use of proportional sampling techniques. Samples should be counted in most cases by liquid scintillation since radioactivity concentrations will normally be quite low.

6.3.2. Collection

Several litre polythene carboys with sealing disc and screw cap are best suited for collection of aqueous wastes. Each carboy should be distinctly marked 'acidic' or 'alkaline' with proper radiation symbols pasted on. Non-aqueous waste may be stored in appropriate polyethylene or other plastic containers. If glass bottles have to be used, they should be kept in secondary containers to protect them from breaking. Since organic liquids are likely to attack polyethylene chemically, it cannot be used for the collection of non-aqueous wastes.

All the containers mentioned should be kept closed when not in use so as to prevent evaporation. When the containers are full, the activity level and chemical characteristics can be obtained from user records and the contents can be analysed. Surface wipes should be taken from the external surface of the container and checked to make sure that there is no removable external contamination.

If the volume of liquid waste produced in a laboratory is not large, it may be feasible to store the waste in a container for a period of time that will allow the radionuclide present to decay to an acceptable level. In special circumstances separate storage tanks may be needed. The tanks should be constructed with the appropriate materials so that they are immune to chemical attack from the liquids stored in them. Since the volume of non-aqueous wastes produced is normally very small, it may not be necessary to have separate containers for their bulk storage.

6.3.3. Documentation

The same basic provisions discussed in Section 6.2.3. for solid waste, are also required in the case of liquid waste. The containers should be monitored for radiation levels and tagged, giving all details regarding the chemical nature, activity level and concentrations of various radionuclides present in the liquid.

7. CONCLUSIONS

This report has outlined some techniques for treatment of radioactive wastes that are quite distinct from those associated with the nuclear fuel cycle. Quantities of radioactive waste are small and their subsequent treatment and disposal is uncomplicated. Simple options for segregation of radioactive wastes undertaken by small users of radioactive materials will minimize the volume of radioactive wastes and bring the wastes into a form that complies with specifications or acceptance criteria for subsequent treatment steps or final disposal.

Annex I

(Reproduced from Annex II of Safety Series No. 70 [9])

REGULATIONS ISSUED BY THE NATIONAL INSTITUTE OF RADIATION PROTECTION (SWEDEN) ON RADIOACTIVE WASTE NOT ASSOCIATED WITH NUCLEAR ENERGY

This is an English translation of the Swedish regulation (SSI FS 1983: 7) on radioactive waste not associated with nuclear energy, issued on 20 December 1983 by the National Swedish Institute of Radiation Protection.

The National Institute of Radiation Protection hereby issues the following regulations with the authority of §5 of the Radiation Protection Act (Swedish Code of Statutes 1958: 110).[1]

§1. These regulations are applicable to the handling of solid and liquid wastes not associated with nuclear power. The activity limitations specified in §§3 and 8 for wastes apply to each of the laboratories (or corresponding entities) covered by licences issued by the National Institute of Radiation Protection for work with radioactive substances and at which the work results in the production of radioactive wastes.

> Note. The handling of the waste may be controlled for reasons other than radiation protection, for example because of its toxicity or risks of infection or fire. In such cases, these regulations form a complement to other rules or regulations.

§2. If the conditions laid down in §§3–11 are complied with, the radioactive waste may be disposed of locally without specific permission from the National Institute of Radiation Protection. Local deposition means either release into the municipal sewage system or delivery to a municipal refuse disposal plant.

Liquid wastes

§3. The total activity released into the sewage system must not exceed 10 ALI_{min} per month per laboratory (or corresponding entity). On each occasion on which a release is made, the activity must not exceed 1 ALI_{min} and must not exceed 100 megabecquerel. On each release occasion flushing shall be carried out with considerable quantities of water.

The values for ALI_{min} which shall be applied are shown in Table A1 in Appendix 1. If the waste contains more than one radionuclide, the maximum permitted activity shall be calculated in accordance with Appendix 1.

> §4. Release of radioactive waste should be confined to one release point for each laboratory.

§5. At each release point there shall be a visible sign stating that radioactive waste may be released into the sewage system.

§6. Urine and faeces from patients who have been administered radionuclides in connection with diagnosis or treatment may be released to the sewage system without the activity being included in the maximum permitted activity in accordance with §3.

§7. Liquid scintillation solutions need not be treated as radioactive wastes provided that:

(1) the solution does not contain alpha-emitting radionuclides
(2) the activity does not exceed 10 becquerel per millilitre or, if the solution contains only ^{3}H or ^{14}C, 100 becquerel per millilitre.

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[1] *Note. Indented paragraphs are not legally binding regulations.*

§ 8. The total activity supplied to a municipal refuse disposal plant must not exceed 10 ALI_{min} per month per laboratory (or corresponding entity). The maximum activity per waste package must not exceed 1 ALI_{min}.

The values for ALI_{min} which shall be applied are shown in Table A1 in Appendix 1. If the waste contains more than one radionuclide, the highest permitted activity shall be calculated in accordance with Appendix 1.

§ 9. The dose rate at the surface of a package supplied to a municipal refuse disposal plant must not exceed 5 microgray per hour.

§ 10. Radioactive waste in solid form shall be packed in such a way that there is no risk of leakage. When a package is sent to a municipal waste disposal plant it shall carry the following markings:

(1) the warning sign for ionizing radiation
(2) information as to the sender
(3) information as to the dominant radionuclide and its activity
(4) a statement that the surface dose rate does not exceed 5 microgray per hour.

Note. The design of the warning symbol for ionizing radiation is specified in Swedish Standard Specification SIS 03 12 10.

Special rules apply to the transportation of radioactive material.

§ 11. Packages sent to a municipal refuse disposal plant must not contain any sealed radioactive source with an activity exceeding 50 kilobecquerel.

Note. The term "sealed radioactive source" is defined in the Swedish Standard Specification SS-ISO 1677.

§ 12. While waiting for disposal, radioactive waste shall be stored in a satisfactory manner. Storage of waste which is subject to change due to fermentation, rotting or similar processes shall be given special consideration.

§ 13. At the place of storage there shall be a conspicuous sign stating that radioactive waste is stored there.

***

These regulations come into force on January 1st 1985.

Appendix 1

THE CONCEPT ALI_{min}

ALI (Annual Limit on Intake) is defined in ICRP Publication 30, 'Limits for Intakes of Radionuclides by Workers' and it constitutes limits for intakes of radioactive substances by persons employed in radiological work. The limits have been set paying regard to the ICRP annual dose limit (50 mSv). There are different ALI values for oral intake as opposed to inhalation. ALI_{min} for each nuclide means the lesser of these two values.

Table A1 shows the values for ALI_{min} for the most common radionuclides. For nuclides not included in the table, the National Institute of Radiation Protection specifies applicable values.

Wastes which contain more than one radionuclide

For wastes released into the sewage system or sent to a municipal refuse disposal plant the following shall apply to the total activity during one month:

$$\sum_k \frac{A_k}{ALI_{min\,k}} \leqslant 10$$

For the activity in one individual package the following shall apply:

$$\sum_k \frac{A_k}{ALI_{min\,k}} \leqslant 1$$

For each occasion on which a release is made to the municipal sewage system the following shall apply:

$$\sum_k \frac{A_k}{ALI_{min\,k}} \leqslant 1$$

The total activity, however, must not exceed 100 megabecquerels.

A_k is the activity of radionuclide k and $ALI_{min\,k}$ is the ALI_{min} value in the table for radionuclide k (see Table A1).

TABLE A1. ALI_{min} VALUES FOR SOME COMMON RADIONUCLIDES

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

Annex II

(Reproduced from Annex I of Safety Series No. 70 [9])

RADIOACTIVE-MATERIALS CO-ORDINATOR – FUNCTIONS

Reference has been made throughout this publication to a site 'radioactive-materials co-ordinator', and to the various functions of this person, who is appointed with the appropriate independence and authority by the site management as responsible for co-ordinating purchases and stocks of radioactive materials and the disposal of the wastes.

The person should:

(1) Be aware of the characteristics of local on-site and off-site disposal facilities for both ordinary refuse and radioactive waste, including sanitary landfill sites, sewage works, storm water systems, incinerators, etc.

(2) Introduce an approval and recording system for purchases of radioactive substances that relates to on-site stock control methods as well as to any regulations that may be imposed by national authorities.

(3) Make contact with all users of radioactive materials so as to ensure that minimum quantities of radioactive substances are ordered and used in preplanned operations and that the radioactive content and/or volumes of radioactive wastes are minimized and controlled by segregation, treatment and monitoring.

(4) Ensure that reports are made by users detailing (a) wastes that are produced, (b) quantities assigned to disposal routes, and (c) wastes requiring special treatment. From these reports he should produce site records.

(5) Liaise with off-site operators of any centralized facilities that may be available for accepting prepared radioactive wastes.

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