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Handling, conditioning and storage of spent sealed radioactive sources

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

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FOREWORD

The International Atomic Energy Agency (IAEA) has published technical reports on radioactive waste management over nearly the past four decades. These reports, whether of the Safety Series, Technical Reports Series or Technical Documents have served as basic reference material and a survey of the state of the art technology applied to radioactive waste management. The IAEA experience in working with Member States has revealed that the modest infrastructure and the limited budget in many Member States require simple solutions that are of low cost and straightforward without any compromise regarding quality or safety.

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" has been published with the objective of addressing the needs of developing Member States by suggesting technological solutions that can fulfil requirements, implement solutions and meet criteria set in IAEA publications and can also be easily integrated into an overall national programme.

The first of these reports was IAEA-TECDOC-548 on "Handling, Conditioning and Disposal of Spent Sealed Sources" published in 1990. With the sealed sources problem being one of the largest single contributors to radiation accidents in peaceful applications of atomic energy, the report was perceived to be urgently needed and was the first in the series. Owing to the special recent interest of many Member States in developing their infrastructure to deal with spent sealed radioactive sources (SRS) and to the considerable development in this field, it was felt that the report needed to be revised to provide up to date techniques and procedures for Member States in order to assist them in taking advantage of these developments. The present TECDOC provides extensive guidance, examples and information required to safely handle, condition and store spent SRS with a modest infrastructure in place.

The IAEA wishes to express its thanks to all who took part in the preparation of this report. The IAEA officer responsible for this publication was M.A. Al-Mughrabi of the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

Sealed radioactive sources (SRS) are extensively used in agriculture, industry, medicine and various research fields in both developed and developing Member States. The number of SRS worldwide is estimated to be in the millions. If a source is no longer needed (e.g. replaced by a different technique) or it becomes unfit for the intended application (e.g. activity becomes too weak, malfunctioning or obsolete equipment, damaged or leaking source) it is considered spent. An SRS may still be highly radioactive and potentially dangerous to human health and the environment.

A spent source is not necessarily waste. There may be other uses for such a source in other applications, which should always be considered first. If for any technical or economic reason, no further use is foreseen, the spent SRS becomes radioactive waste.

A number of accidents involving spent SRS have taken place around the world [1]. Some of these accidents resulted in human deaths and/or contamination of large areas. In some cases, large amounts of money were involved in the mitigation of the consequences of such accidents. In order to reduce the risk associated with spent SRS, it is important to have a proper infrastructure for their safe management both at the user’s site and in the entire country. It is essential that sources that are in use or declared spent should not impose any danger to the workers, the general public or the environment. Sources in use are under strict regulatory control and during operations a well developed radiation protection system is applied. Spent SRS, on the other hand, may skip the regulatory control and become outside the radiation protection and waste management system. Ideally, all requirements for the safe utilization of sources and management of spent SRS should be available in the country before the beginning of their application.

The IAEA programme on spent SRS was established in 1991 (GOV/INF/595), with the specific purpose to assist Member States in their effort to avoid situations that might result in unnecessary exposure or accidents. It includes provision of technical information in the form of technical documents and manuals such as this report, training of experts and buildup of the required infrastructure by provision of tools, equipment and know-how.

The IAEA is in a continuing process of exploring ways to improve its waste management programme to support its Member States. One area that has become quite apparent to the IAEA is the need to transfer waste management technologies and offer direct advisory services to Member States. One of these new initiatives is specifically related to the conditioning of spent SRS.

1.2. OBJECTIVE

The report is intended to provide reference material, guidance and know-how on handling, conditioning and storage of spent SRS to both users of sealed sources and operators of waste management facilities. Due to the limited availability of disposal practices for spent SRS, disposal is covered in a broad context only.

1.3. SCOPE

The scope of the report covers all types of SRS except those exempted from regulatory control, e.g. smoke detectors, watches or instrumentation dials.

The report contains in some detail technical procedures for the conditioning of spent SRS, describes the means required to assure the quality of the resulting package and discusses the measures to prepare waste packages with a certain flexibility to accommodate possible future disposal requirements.

2. CHARACTERISTICS AND APPLICATION OF SEALED RADIOACTIVE SOURCES

2.1. CHARACTERISTICS AND CLASSIFICATION OF SEALED RADIOACTIVE SOURCES

SRS may be classified according to their application. Such classification would give authorities and users an indication of the safety of radioactive sources in different applications. The International Standard ISO 2919 establishes a system of classification of sealed sources based on test performance and specifies general requirements, performance tests, production tests, marking and certification [2]. Prototypes of sources are tested for temperature, external pressure, impact, vibration and puncture in classes of increasing severity. Sources intended for an application have to meet minimum criteria outlined in the standard.

A sealed source is a radioactive material that is (a) permanently sealed in a capsule or (b) closely bounded and in a solid form. The capsule or material of a SRS should be strong enough to maintain leaktightness under the conditions of use and wear for which the source was designed, also under foreseeable mishaps [3]. In this case only the emitted radiation is utilized. Therefore, first of all, the hazard from external radiation has to be considered, but the possibility of contamination due to fracture of the capsule should not be disregarded.

The radioactive sources are composed of the *radiating isotope* contained in the *filling*, the single or double isotope *holder* that partially or totally surrounds the filling, the outer *cover* that contains the parts mentioned above and the capsule closed airtight by welding or some other method. The capsule is to be tested for leakage periodically [4].

The main features of radioactive sources are:

- The characteristics of the active filling (radionuclide),
- The intensity of radiation (for α, β and γ-emitting sources),
- The neutron emission (for neutron sources),
- The outer dimensions of the active filling and the capsule, and
- Further requirements raised by the particular mode of application (corrosion resistance, resistance to heat, stability, absence of leakage, etc.).

The commonly used classification of sources according to the type of radiation and the fields of application is the following:

- Gamma sources,
- Beta sources,
- Alpha sources,
- Neutron sources, and
- Other sources for special use (e.g. gamma and neutron sources for borehole loggings).

2.2. GEOMETRY AND SIZE

Sealed sources may have high concentrations of radionuclides in extremely small volumes. An unshielded source is usually a tiny piece of metal with dimensions ranging from several millimetres to centimetres. They are produced in many different designs. However, sealed sources, such as for irradiators, can be large. Examples of bare sources and working shields are shown in Figs 1 and 2, respectively. The volume of a shielded source is mainly determined by the shielding itself and depends on the level of activity and the density of the shielding material.

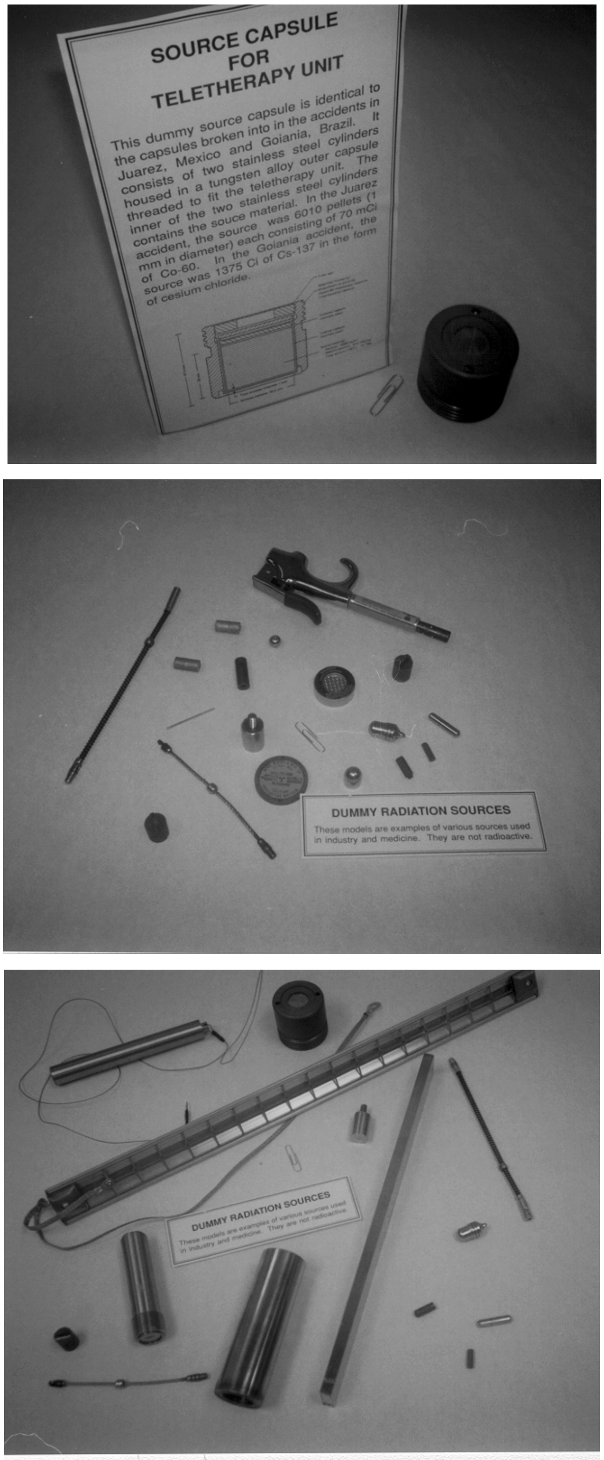


FIG. 1. Bare sealed sources.

FIG. 2a + FIG. 2 b. Sealed sources in their working shields.
(Fig. 2a reproduced by courtesy of the National Radiological Protection Board, Didcot, UK)

2.3. LABELLING

Whenever possible, the capsule and the source assembly should be legibly marked with the following information given in order of priority [2]:

- The word “radioactive”; where this is not feasible the symbol for radioactivity,
- Manufacturer’s name or symbol,
- Serial number,
- Mass number and chemical symbol of the radionuclide, and
- For neutron sources, the target element.

2.4. APPLICATION OF SEALED SOURCES

Table I indicates typical fields of application of various SRS.

TABLE I. APPLICATIONS OF SEALED RADIOACTIVE SOURCES

Application	Radionuclide*	Half-life	Comments
I. Industrial application			
Thickness gauge	^{85}Kr (gas) ^{90}Sr (^{14}C, ^{32}P, ^{147}Pm, ^{241}Am)	10.8 a 28.1 a (5730 a, 14.3 d 2.6 a, 432.2 a)	To measure thickness of paper, plastic and similar materials.
Level gauge	^{137}Cs ^{60}Co (^{241}Am)	30.2 a 5.3 a (432.2 a)	To measure levels in containers (e.g. silos) and packages (e.g. tin cans).
Density gauge	^{137}Cs ^{241}Am (^{90}Sr)	30.2 a 432.2 a (28.1 a)	To measure mass transport on conveyor belts.
Moisture detector	^{241}AmBe (^{252}Cf, ^{226}Ra-Be)	432.2 a (2.6 a)	Neutron source to measure content of sand, soil, etc. May be fixed or portable equipment.
Industrial radiography	^{60}Co ^{192}Ir (^{137}Cs, ^{170}Tm)	5.3 a 73.8 d (30.2 a, 128.6 d)	Used for non-destructive testing. May be used as fixed or portable equipment
Eliminator for static electricity	^{210}Po ^{226}Ra ^{241}Am	138.4 d 1600 a 432.2 a	Used in film industry. May be used as fixed or portable equipment
Roentgen fluorescence analyzer	^{55}Fe (^{238}Pu, ^{241}Am)	2.7 a (87.7 a, 432.2 a)	Portable equipment used to analyze metals
Well logging	^{241}Am-Be ^{137}Cs	432.2 a 30.2 a	Portables units
Sterilization	^{60}Co ^{137}Cs	5.3 a 30.2 a	Used to sterilize medical equipment, and for food preservation
II. Research application			
Electron capture detector	^{3}H (^{63}Ni)	12.3 a (100 a)	Used as detector in gas chromatographs
Tritium targets	^{3}H	12.3 a	Used to produce neutrons by D,T-reactions
Calibration sources	Many different radionuclides		Used for function and efficiency control of instruments and for calibration
Irradiator	^{60}Co	5.3 a	Fixed installation
Eliminator for static electricity	^{210}Po ^{226}Ra	138.4 d 1600 a	Used in analytical balances
III. Medical application			
Clinical teletherapy	^{60}Co (^{137}Cs, ^{192}Ir)	5.3 a (30.2 a, 73.8 d)	
Brachytherapy	^{137}Cs, ^{192}Ir, ^{226}Ra, ^{60}Co	30.2 a, 73.8 d, 1600 a, 5.3 a	Small portable sources
Eye applicator	^{90}Sr ^{32}P	28.6 a 14.3 d	Small calottes
Calibration of gamma camera	^{57}Co	5.3 a	
Heart stimulator	^{238}Pu	87.7 a	Batteries
Bone densitometer	^{241}Am ^{125}I	432.2 a 59.4 d	

* Other radionuclides which may also be used for the application are given in brackets.

2.5. PROPERTIES OF RADIONUCLIDES

While the application of sealed sources is wide ranging, the radionuclides most commonly in use are mostly limited to ^{60}Co, ^{137}Cs, ^{90}Sr, ^{192}Ir and ^{241}Am. Radium has been used for medical applications but due to its undesirable characteristics, its use has been discouraged. Therefore six selected nuclides are discussed in the following text as examples. Their relevant properties are summarized in Table II.

TABLE II. PROPERTIES OF SIX RADIONUCLIDES COMMONLY USED IN SEALED RADIOACTIVE SOURCES

Characteristics	**Unit**	**^{60}Co**	**^{137}Cs**	**^{192}Ir**	**^{90}Sr**	**^{226}Ra**	**^{241}Am**
Half-life	years	5.3	30.2	0.2	28.6	1600	432
Energy							
Alpha	MeV	–	–	–	–	[b]	5.86
Beta max.	MeV	0.31	1.2	0.67	0.54 (2.3)[a]	[b]	–
Gamma	MeV	1.17 1.33	0.66	0.32 0.47		[b]	0.07
Ambient dose equivalent rate, H*(10)[c]	mSv·m^2/ h·GBq	0.37	0.092	0.131	–	0.283	0.019
Half value layer (HVL) of lead	mm	12	6	5.5	–	14	0.2
Dose factor[d]							
Ingestion	Sv/Bq	3.4 E-9	1.3E-8[a]	1.4 E-9	2.8 E-8	2.8 E-7[a]	2.0 E-7
Inhalation	Sv/Bq	1.7 E-8	6.7E-9[a]	4.9 E-9	7.7 E-8	2.2 E-6[a]	2.7 E-5

[a] Short lived daughter products have been taken into account.
[b] In the decay chain there are alpha energies up to 7.7 MeV, beta energies up to 2.8 MeV and main gamma energies up to 2.4 MeV.
[c] For ambient dose equivalent rate, *H**(10), see Ref. [5]. Values are given for 1 m distance from source.
[d] For dose factors see Ref. [3].
For half-life values and radiation characteristics see Ref. [6].

Characterization of nuclides not described in detail but mentioned in Table I can be found in Refs [5–8].

Because of the specific problems caused by the kind of radiation a distinction between β/γ-emitters and α-emitters seems to be useful for a further description.

2.5.1. Selected β/γ-emitting radionuclides

Cobalt

^{60}Co is produced by (n,γ) reaction. If pure cobalt is used as target material the ^{60}Co will be produced almost free of other radionuclides. It decays by emission of beta particles and two gamma photons (1.17 and 1.33 MeV) to the stable nickel isotope ^{60}Ni.

In SRS metallic cobalt is always used since this gives the highest specific activity to the source. Usually it is in the form of thin discs or small cylindrical pellets welded into stainless steel capsules. The metal is stable in air, but a thin layer of oxide forms on its surface and this could cause contamination if unprotected cobalt is handled. For this reason the cobalt used in radioactive sources is nickel plated before activation [8].

Metallic cobalt is not soluble in water. If cobalt in a soluble form is taken up by the body it is evenly distributed, with the exception of the liver where a four times higher concentration may be reached.

Caesium

^{137}Cs is a fission product produced in reactor fuel. It must be purified chemically from other elements before it can be used in a radioactive source. The most widely used radioisotope of caesium is commonly regarded as γ-emitter of medium energy, although the 662 keV energy γ-photons are produced by ^{137m}Ba formed from ^{137}Cs by β^- -decay.

Caesium is an alkalai metal similar to potassium and sodium. It is very reactive and can only be used as a chemical compound in SRS. Caesium chloride powder has often been enclosed by welding in stainless steel capsules. It should be emphasized, however, that caesium chloride is corrosive and can corrode a capsule from inside, thus creating a potential dispersion of the powder. Today ^{137}Cs sources are also prepared in ceramic form, making the radionuclide less dispersible. However, this technique is used only for low activity sources, because such immobilization results in a drastic reduction of specific activity. When taken up by the body the highest concentrations are reached in muscle.

Iridium

^{192}Ir is produced by (n,γ) reaction of metallic iridium. It has a short half-life, only 73.8 days, so that even high activity iridium sources will decay within about five years below the exemption limit, but they still may remain radioactive due to residual long lived radionuclides. It decays via emission of beta particles and gamma photons to stable platinum and osmium isotopes. The decay scheme includes the emission of many different gamma quanta with energies up to about 0.5 MeV. Iridium is a noble metal which is not oxidized in air or dissolved in water [8].

^{192}Ir sources have great importance in the field of non-destructive testing of materials. Besides the general requirement of being properly sealed, the major demand with respect to the sources is that the specific activity be as high as possible, that is, the sources should have a total activity of the order of TBq, and that the dimensions of a point-like source should be approached.

Strontium

^{90}Sr is a fission product produced in reactor fuel. It must be purified chemically from other fission products before it can be used in a radioactive source. Its half-life is 28.6 years and it decays by beta emission to ^{90}Y, with a half-life of 64.1 hours. Both nuclides are pure beta emitters without gamma emission. This pair of nuclides was used in beta and bremsstrahlung sources for medical purposes in eye and skin applicators and in industrial applications for thickness and density gauging.

Strontium is an alkalai earth metal similar to calcium. It is chemically very reactive and can only be used in form of chemical compounds in sources. Typically ^{90}Sr is used as titanate. Foil sources and ceramic sources are known. For foil sources ^{90}Sr titanate is mixed with metallic silver, compressed, sintered and rolled to form strips, plates or discs. These sources are robust, corrosion resistant and suffer no leakage. For ceramic sources ^{90}Sr titanate is mixed with ceramics, fired and protected on the surface by a high melting glaze. The ceramic method produces sources reaching up to about one GBq. Sources are produced by encapsulating a ceramic pellet into a stainless steel capsule sealed by welding and provided with a thin steel window [8].

Because of its similarity to calcium ^{90}Sr is, when incorporated, taken up in the body and stored in the bones and teeth where it can not be removed again. This is known as having a very long biological half-life. ^{90}Sr can therefore cause bone cancer [10].

2.5.2. Selected α-emitting radionuclides

Radium

^{226}Ra is part of the decay chain of ^{238}U. Radium decays by alpha emission to ^{222}Rn, a noble gas with a half-life of 3.6 days. Before the decay chain ends with the stable isotope ^{206}Pb it has generated a further eight radionuclides of which four are alpha emitters. Each decaying ^{226}Ra atom thus gives rise to five alpha particles. During the decay many high as well as low energy gamma photons and beta particles are also emitted. In a radium source there is always not only ^{226}Ra but also its daughter products. Therefore it has a rather high dose factor [3].

The special properties of radium in combination with the widespread use in the past makes ^{226}Ra a dominant problem among SRS.

Radium is an alkalai earth metal. It is very reactive and reacts even with nitrogen. In radioactive sources radium is therefore always used in the form of salts, which may be bromide, chloride, sulphate or carbonate. All are soluble in water in amounts which can give rise to radiological problems. These salts may easily be dispersed as powder if the source encapsulation is damaged. This is one reason why radium is not regarded as an ideal material for use in SRS.

In the body radium behaves like calcium, which means it concentrates in the bone where it has a very long biological half-life.

Americium

^{241}Am has chemical characteristics similar to the rare earth metals, indicating that as metal it is not in a stable form. Normally oxides are used in sources. For neutron sources fine oxide powder is mixed with beryllium powder and sintered to a ceramic-like product which is stable in air and from which the americium is not leached by water. When used as a low energy gamma source the stainless steel capsule has a thin window in one direction to allow the gamma photons to be emitted without undue attenuation [8]. In the human body the element is concentrated in bone and liver, and small intakes give a high committed dose.

2.6. SOURCE PACKAGING

Radioactive sources must be properly packaged for transportation to the place of installation and for temporary storage. Packaging means an assembly of components necessary to ensure compliance with the packaging requirements of transport regulations [11, 12]. It is usually known as a container, which is correctly a component of packaging, or it is a freight container. The container has to confine the radioactive material, to attenuate the radiation and to protect the source against mechanical effects and fire.

2.6.1. Transport containers

The main requirements to be applied for transport containers:

- The container has to be securely closed with a positive fastening device such that it will remain closed during transportation even if subjected to tossing, etc.;
- The maximum dose rate is limited: it may not exceed 2 mSv/h (200 mrem/h) on the surface and 0.1 mSv/h (10 mrem/h) dose rate at 1 m from the surface of the package at any moment during the transport;
- The maximum activity of radionuclides allowed to be put in one package depends on the type of package and on the toxicity of the radioactive material, e.g. the maximum

activity of ^{192}Ir in special form transportable in type A packaging is 740 GBq. For type B packaging, which is constructed in such a way that it is able to withstand more severe traffic accidents, the activity is unlimited but clearly specified in its approval document. Special form radioactive material means either an indispersible solid radioactive material or a sealed capsule containing radioactive material [12];

- Radioactive contamination of the package surfaces should be as low as possible and should not exceed limits set by the national regulatory body. If the latter does not specify such a value, the IAEA values should be consulted;
- The package has to retain its containment and shielding integrity during transport, i.e. to the extent required by specified tests;
- The package has to bear specified labels (including ionizing radiation symbol).

A typical transport container for beta/gamma sources is shown in Fig. 3.

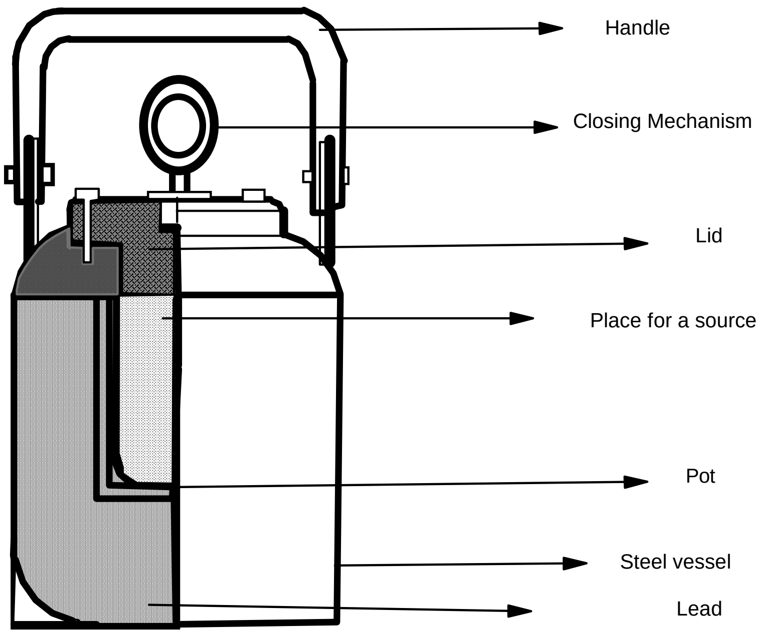


FIG. 3. Transport container for sealed beta/gamma sources

2.6.2. Storage containers

SRS which are temporarily not in use have to comply with certain storage requirements with regard to surface dose rate and radioactive contamination. Some current national regulations may require a lower dose rate on the surface of a storage container compared to a transport container. Transport or working containers may be used as storage containers if the dose rate on their surfaces does not exceed the prescribed level. It is practicable to determine experimentally the “capacity” of a storage container with those amounts of radioisotopes which, if they are put into the container, give the maximum permissible surface dose rate. The values so obtained should be indicated on the identification label in the records.

As in the case of transport containers, storage containers should be lockable and should bear identification labels and the ionizing radiation symbol.

For high activity sources (irradiators or radiographic facilities), the storage container is substituted by the installation itself which attenuates the radiation, protects the source against mechanical and corrosion effects and prevents unauthorized access to the source (Figs 4 and 5) [9].

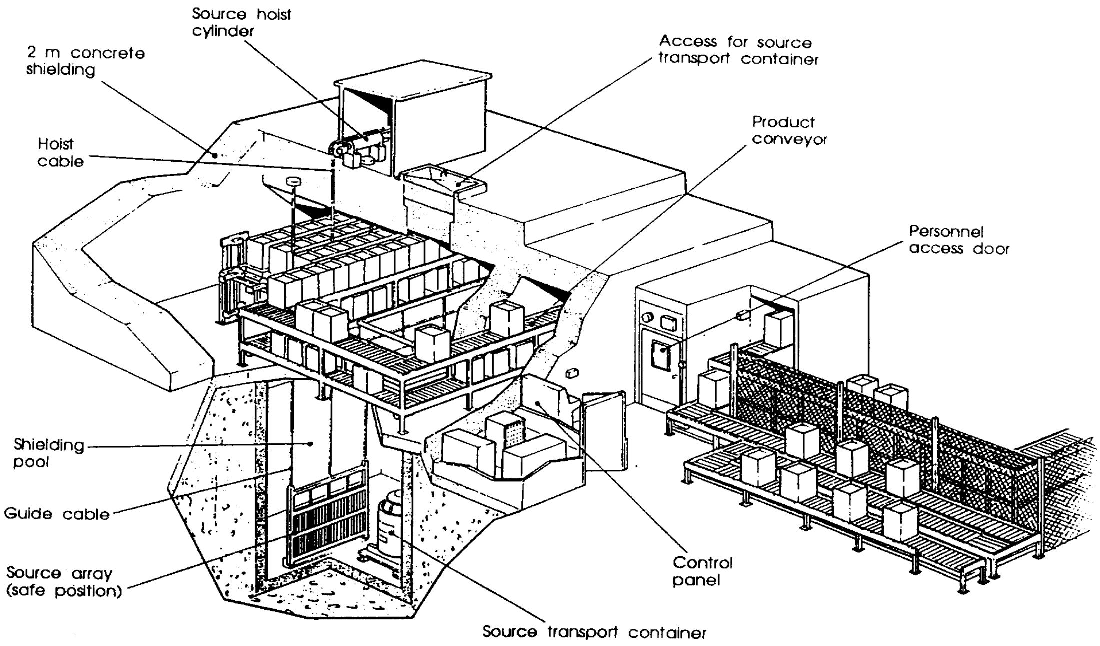


FIG. 4. A panoramic view of a typical wet source storage irradiator.

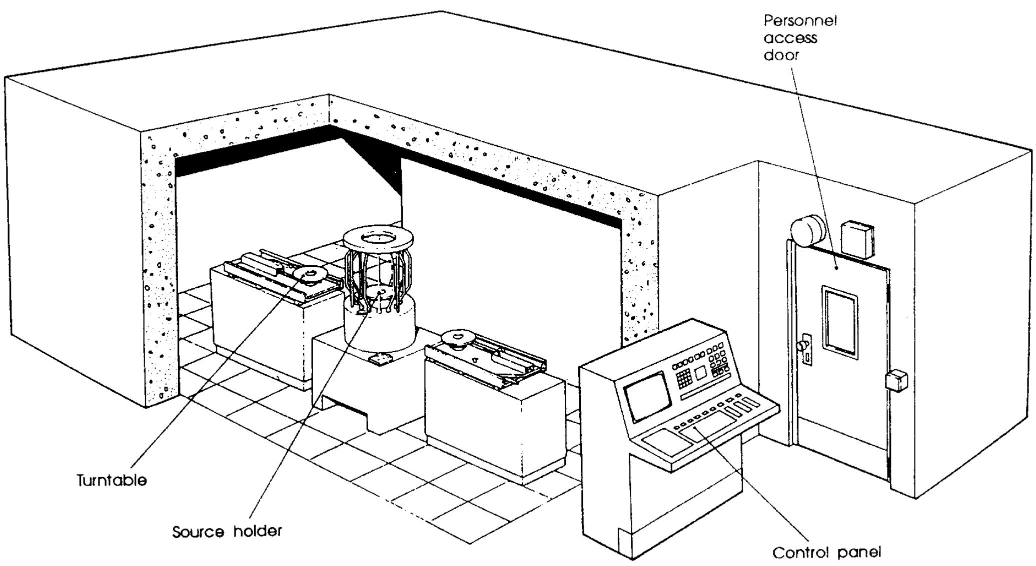


FIG. 5. A panoramic view of a typical dry source storage irradiator.

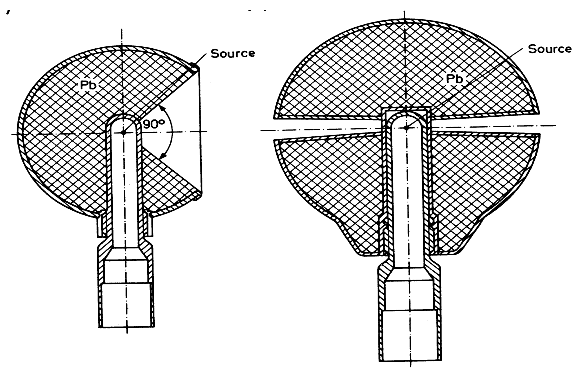
2.6.3. Working containers

The working container is a device which contains the radioactive source during its use and fulfils the following functions:

- It attenuates the radiation, except for the useful beam;
- It protects the source against mechanical and corrosion effects;
- It prevents unauthorized access to the source.

The maximum permissible surface dose rate of a working container is, e.g. 0.2 mSv/h; in some special cases it is 1 mSv/h according to the field of application. The dose rate at the distance of 1 m is also limited because without such a limitation the dose rate would be significantly high even for large distances, because there is no restriction on container size.

Design of a working container depends on the type of source and on the conditions of application. Containers for α- and β-sources are usually made of aluminium or steel, sometimes plastic. A thickness of a few mm, fulfilling mechanical requirements is usually sufficient to fully absorb the primary radiation. The most common containers of γ-sources are made of lead or steel; tungsten or depleted uranium have also come into use. An example of the working container design is shown in Fig. 6 [8].



a) b)

FIG. 6. Collimators for remotely controlled gamma-defectoscopes. (a – for oriented radiation: b – for annular arrangement).

Iron vessels filled with paraffin usually serve as a neutron source container. A layer of paraffin of about 20–30 cm is sufficient to thermalize fast neutrons. Sometimes boron is added to the paraffin to capture thermalized neutrons. If the source also emits intensive γ-radiation as in the case of ^{226}Ra-Be, an additional lead shield is used around the source.

3. INFRASTRUCTURE REQUIREMENTS FOR THE MANAGEMENT OF SPENT RADIOACTIVE SOURCES

3.1. GENERAL REQUIREMENTS

Principal requirements for ensuring radiation protection and safety in the work place with radioactive sources are set out in the Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources [3]. The Basic Safety Standards also deal, in a general manner, with the management of radioactive waste arising from applications of sources of ionizing radiation. Its principal requirements were further elaborated in a number of IAEA publications on waste safety. In particular, the IAEA Safety Standard No. 111-SS-1 on “Establishing a National System for Radioactive Waste Management” [13] sets the elements for a national system required to safely manage radioactive waste and identifies the key responsibilities of the parties involved. All general requirements described in the Safety Standard are applicable to the management of spent SRS as one category of radioactive waste, however some issues specific for spent SRS are delineated in this section. It is recognized that the extent to which the components of a national radioactive waste management infrastructure are developed will vary from country to country depending upon national circumstances.

The basic requirements for a waste management infrastructure relevant to spent SRS are:

- Identification of all parties involved in the different steps of management of spent SRS (including users/owners) and delineation of their responsibilities;
- Establishing a rational set of safety, radiological and environmental protection objectives from which standards and criteria may be derived within the regulatory system;
- Identification of existing and anticipated spent SRS;
- Control of generation of spent SRS;
- Identification of available methods and facilities for the management of spent SRS;
- Need for public information.

Most countries have some legislation and regulations in existence governing radiation protection and safety of radioactive sources. There is usually no specific legislation which deals with the management of spent SRS and it is usually included under radiation protection or waste management legislation. If it is determined that new or additional legislation is needed, a note of caution is necessary in order to minimize overlapping or conflicting requirements, and prevent gaps in coverage of radiation protection and safety.

This section is intended to cover the requirements for safe management of spent SRS in all situations. For less complex situations, not all the requirements may be necessary or appropriate. A Member State must decide to which extent the requirements have to be applied in a particular situation. Furthermore, the organizations referred to below may exist under a different structure or may have a different name. Accepting the responsibilities listed below is the main requirement. In order to ensure compliance it is important to differentiate between the regulatory nature of the work and the operational part.

3.2. RESPONSIBILITIES

Principal parties involved in the management of spent SRS are the regulatory body, the centralized radioactive waste operating organization (CRWOO) if it exists and user/owner (registrants and licensees). The main responsibility for the safe management of an SRS rests with the user/owner who should take all necessary actions to ensure the safety of the source unless the responsibility has been transferred to another person or organization as approved by the regulatory body. Registrants and licensees should bear the responsibility for setting up and implementing the technical and organizational measures that are needed for ensuring security and safety for the sources for which they are authorized. They may appoint other people to carry out actions and tasks related to these responsibilities, but they should retain the responsibility for the actions and tasks themselves.

3.2.1. Responsibilities of the user/owner

In addition to the responsibilities delineated in the Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources [3] and Safety Standards No. SS-111-S-1 [13], the user/owner of an SRS need to:

(a) Propose an acceptable destination for spent SRS;

(b) Store spent SRS on-site if the source cannot be dispatched to any other place;

(c) Prepare the source for transportation to the centralized radioactive waste operating organization (if applicable);

(d) Establish a record-keeping system in such a manner as to facilitate identification, characterization, collection and storage for all SRS (in use and spent);

(e) Appoint a competent radioactive material co-ordinator (RMC).

3.2.2. Responsibilities of the radioactive material co-ordinator

The radioactive material co-ordinator is a person with experience in radiological protection and waste management. In some cases it is not necessary to be a full time job. Usually the duties of the radioactive material co-ordinator would be performed by a radiation protection officer or by the user/owner himself.

The radioactive material co-ordinator, "within his organization or institute" implements the following tasks:

(a) Maintain the record-keeping system;

(b) Establish and maintain contacts with all persons using SRS and provide advice and guidance;

(c) Liaise with the CRWOO;

(d) Ensure that the on-site transfer of an SRS is carried out in compliance with the laid-down safety procedures;

(e) Prepare the SRS for transportation to the CRWOO in accordance with the national transport regulation;

(f) Ensure appropriate shielding, labeling, physical security and integrity of the SRS; and

(g) Report on incidents and accidents with SRS to the management of the facility.

3.2.3. Responsibilities of the centralized radioactive waste operating organization

The CRWOO is designated to manage or to co-ordinate the management of all spent SRS from different users in the country.

If a licensee, holding a licence to use a SRS, is incapable of the appropriate management of the source when it becomes spent or if the licence is revoked or the licensee no longer exists, the CRWOO will take the responsibility for the management of the source, if requested by the regulatory body.

The CRWOO is responsible, in particular, for:

(a) Storing the collected short-lived spent SRS for decay;

(b) Discharging of short-lived spent SRS which have decayed to clearance levels;

(c) Conditioning of spent SRS;

(d) Storing of conditioned spent SRS until a centralized disposal facility is established;

(e) Storing unconditioned spent SRS until a centralized conditioning facility is established;

(f) Establishing and maintaining a record-keeping for all SRS at the facility.

3.2.4. Responsibilities of the regulatory body

In accordance with the Safety Standard No. 111-S-1, the regulatory body, in relation to the control of spent SRS, would conduct the following:

(a) Scrutinize nuclear applications associated with SRS and related waste management activities, consider applications and issue licences;

(b) Regulate the siting, design, construction, commissioning, operation, closure and decommissioning of any facility that deals with SRS;

(c) Conduct inspections to assess that the safety of any facility, that deals with SRS, is in compliance with the applicable regulations;

(d) Initiate enforcement action to correct non-compliance with specified requirements;

(e) Establish and maintain a record-keeping system for all SRS in the country.

3.3. LICENSING

The legal person responsible for any sealed source, unless the source is exempted, should apply to the regulatory body for an authorization which should take the form of either a registration or a licence [3]. The legal person responsible for any radioactive waste management facility should apply to the regulatory body for an authorization which should take form of a licence. A proposal for an authorization should specify the following in a written application to the regulatory body:

(a) Nature and purpose of the proposed facility and equipment;

(b) Suggested operational procedures;

(c) Quantity, type and characteristics of the spent SRS;

(d) Proposed destinations for spent SRS;

(e) Assessments of the safety and environmental impact of the facility under normal and accident conditions;

(f) Decommissioning procedures;

(g) Availability of competent staff and provisions for its further training;

(h) Systems for records-keeping and reporting;

(i) Proposed quality assurance programme;

(j) Contingency plans (in the event of an emergency situation);

(k) Other details the regulatory body may consider necessary.

In addition to the points above, a centralized radioactive waste operating organization should specify the following in the application:

(a) The quantity, type and characteristics of the radioactive waste to be managed (including spent SRS);

(b) The suggested methods, facilities and equipment for management of spent SRS designed to minimize radioactive waste packages to be disposed of;

(c) The proposals for discharge and environmental monitoring;

(d) The supporting research and development proposals.

The holder of a licence (the licensee) should comply with all limits and conditions specified in the licence including the amounts and characteristics of waste which may be generated, treated, conditioned and stored, and all specific radiation protection and physical security measures.

A licence issued as specified above should be:

(a) Valid for a period the regulatory body may determine;

(b) Renewable by the regulatory body if the licensee complies with the licence conditions;

(c) Subject to supervision or revocation if, in the view of the regulatory body, the licensee has failed to comply with the conditions given in the licence.

3.4. SOURCE TRACKING

The use of SRS is expected to be controlled under the radiation protection programme. A specific concern of waste management is to ensure that sealed sources are properly controlled after they are no longer used, and eventually are disposed of. This concern requires that any new source is tracked throughout its life, that commitments for its disposition are made prior to its import, and that a plan is established and implemented for safe management of the source after it has become spent.

A record-keeping system for tracking all SRS should be established by the licensee and maintained by the Radioactive Material Co-ordinator. It should keep a track of a SRS from the time of import into the country until the source has become spent and either is returned to the manufacturer, or permanently disposed of. The tracking system should contain essential information about the source. The information should be reliably stored and archived. The system should enable data to be readily accessible and retrievable, while being resistant to tampering. An acceptable tracking system can range from a manual system (such as card files) to a computerized database.

A source tracking system should at least contain the following information:

(a) Type of source,

(b) Identification numbers (source and container),

(c) Name of the radionuclide,

(d) Activity and date of determination,

(e) Supplier/manufacturer,

(f) Certificate of conformity,

(g) User/owner (authorized institution and responsible person),

(h) Former user (authorized institution and responsible person),

(i) Place of storage (authorized institution and responsible person),

(j) Other information as may be considered necessary.

The RMC should make an effort to obtain the above information if it is lacking in the adopted SRS information system. This information may be obtained by:

(a) Questioning persons,

(b) Consulting documents,

(c) Supplementary measurements, and

(d) Any other means as may be considered appropriate.

In addition to the most relevant record-keeping information mentioned in the list above, the RMC should keep a log-book of everyday activities involving all SRS at the licensee's premises.

The RMC should notify the regulatory body of any significant changes in the information in the record-keeping system.

The IAEA has developed a simple computerized registry, which is available to Member States. This registry system, the Sealed Radiation Sources (SRS) Registry, has been specifically designed to track and store relevant data about SRS.

3.5. QUALITY ASSURANCE

Quality assurance (QA) means all planned and systematic actions necessary to provide adequate confidence that an item, process or service will satisfy given requirements for quality. The objective of quality assurance for the management of spent SRS is to provide the necessary controls over activities which affect the quality of items (products), components and the management system as a whole. Such control is needed to ensure that performance objectives and technical requirements are met and the results can be demonstrated. The main goal of implementing QA is to provide adequate confidence that:

(a) All conditions in licence or authorization are complied with,

(b) Clearance criteria are met when a source is subjected to clearance,

(c) Waste acceptance criteria for disposal are met when the source is intended for disposal,

(d) All records and required information are retained and can be retrieved and comprehended for any future reference.

The grade of application of quality assurance should be commensurate with the extent and complexity of the waste management activities, and with the potential hazard associated with spent SRS being managed. Quality assurance programmes have to be developed by both the holder of a licence to use SRS and the centralized radioactive waste operating organization if it exists. The QA programme needs to be approved by the regulatory body.

The QA programme should provide for a system of document control and records to demonstrate that the required quality has been achieved. When applying a QA programme to all waste management steps, particular attention should be given to document and data control and record-keeping, to qualification and training of personnel, to identifying non-conformance and to corrective actions. Further considerations important for quality are:

(a) Content (inventory) of the waste packages;

(b) Conformity with the conditioning procedures;

(c) Resistance of the conditioned package to external and internal factors, e.g. corrosion, floods, accidents;

(d) Control of the end product or end situation so as to assure conformity between the quality and composition of the end product.

General guidelines for QA measures for waste treatment, conditioning and storage are given in Ref. [14].

4. MANAGEMENT STRATEGY

4.1. SEALED SOURCES UTILIZATION PLAN

A country with a limited nuclear programme should have a utilization plan for SRS. The regulatory body which exercises regulatory control over the use of radioactive material should administer this plan. It should be based on the demands on SRS of all users in the country and must ensure that a minimum number of SRS is purchased, consistent with the objectives of the users, and that the activity and half-life of purchased sources do not exceed the users needs. Administrative procedures and control should be implemented by the regulatory body to ensure that new SRS are not purchased when suitable sources are already available within the framework of the utilization plan.

A source is usually purchased by a user without any undertaking by the manufacturer/supplier to accept the return of the source when it is no longer needed. In effect, the arrangement places the responsibility for the management of the spent source on the user. Sources can be returned to the manufacturer/supplier, if such an arrangement is agreed upon at the time of the source’s purchase.

Frequently, users store spent SRS without any immediate prospect of disposal. From the radioactive waste management point of view it is highly desirable to minimize the number of sources in use or stored pending disposal. Therefore, whenever possible, a spent SRS should be returned to the manufacturer, recycled or allocated to another user. Since the manufacturers/suppliers are aware of the economics of recycling and the demand for sources of various types, they are in the best position to make correct decisions on their final destination. For this reason, and in order to optimize the waste management, it is recommended that sources should be 'leased' by users and not purchased outright. When there is no further use for the source, it could be returned to the manufacturer/supplier in accordance with the leasing contract.

Taking into account the possibility that the manufacturer may cease his business at some time in the future, a user that has leased a source must have a contingency plan how to deal with the spent source in case the original supplier no longer exists.

Procedures should also ensure that the infrastructure required to accommodate the reused source at the new user’s facility is available, and that the relevant documents are exchanged between the old user, the new user and the national regulatory body.

4.2. MANAGEMENT OPTIONS

When a SRS is no longer to be used for its dedicated purpose, the following management options may be considered:

- Transfer to another user for application elsewhere;
- Return to the manufacturer/supplier;
- Storage for decay of sources containing radionuclides with short half-life, followed by discharge as non-radioactive material;
- Transportation to a centralized interim storage facility until a conditioning facility is available;
- Transportation to a central conditioning facility for conditioning followed by interim storage;

- On-site conditioning of the source (at the user's premises) followed by interim storage until a centralized storage/disposal facility is available;
- Transportation of the conditioned source to a disposal facility if available;
- Final disposal in a licensed repository.

An outline scheme for the management of spent SRS is given in Fig. 7. This summarizes the principles discussed above in this section and indicates procedures which are further discussed in detail in later sections of this report.

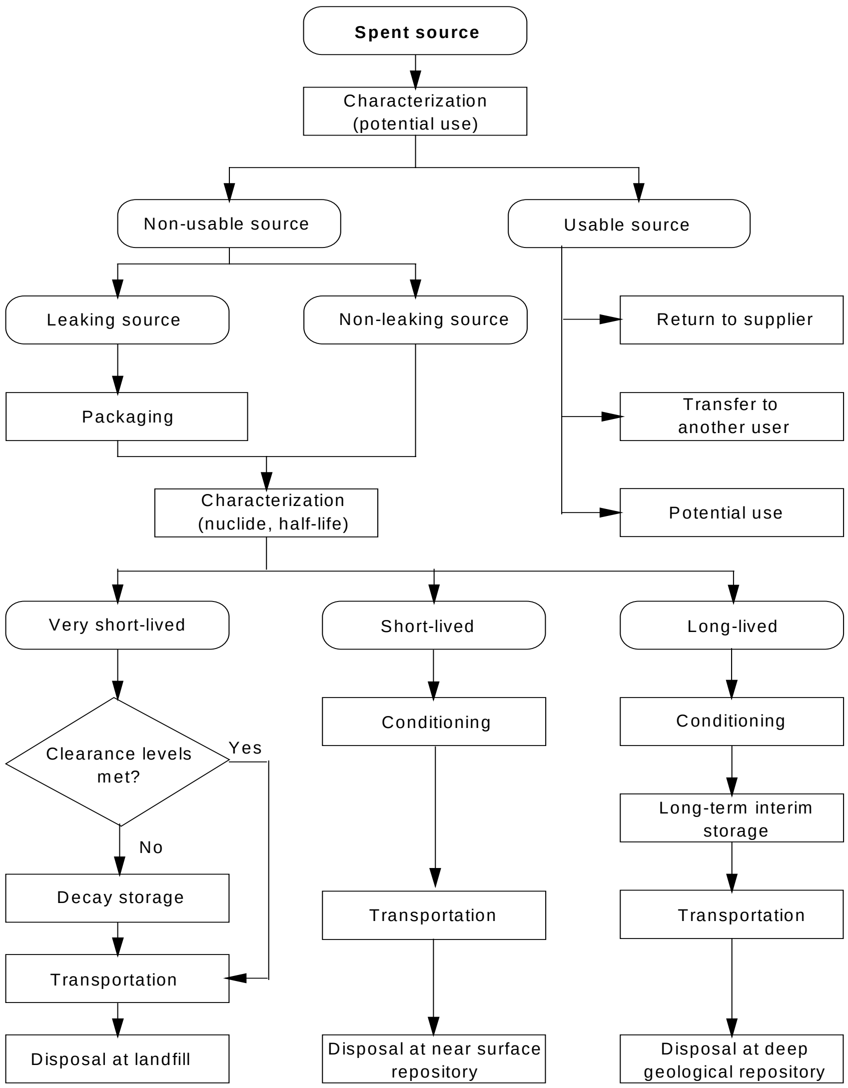


FIG. 7. Management flow diagram for spent SRS.

For spent SRS with high activity (e.g. ^{60}Co and ^{137}Cs used in irradiators and for radiotherapy) the outline scheme is not applicable. For such sources the only management option, except returning the source to the manufacturer, is long term interim storage (several decades) awaiting future disposal.

4.2.1. Transfer to another user

A sealed source is procured with an original activity level appropriate to a specific application. When the source activity is no longer suitable for the original application there may still be sufficient radioactivity to allow its use for another purpose. For example, sources no longer of use for clinical therapy may well be useful in other applications requiring lower levels of activity. Transfer to another user is particularly applicable for high activity sources, e.g. ^{137}Cs and ^{60}Co within national boundaries.

Transfer of sources to other users within the national boundaries of the country offers economic advantages in both source procurement and final waste management, the net effect being a reduction in the number of sources which have to be purchased, managed in use and finally consigned to disposal.

Reuse of sealed sources should be considered prior to the purchase, if circumstances permit. Transfer of sealed sources to another user is subject to approval by the regulatory body. Special attention should be given to ensuring that sealed sources are in a serviceable condition and are suitable for the intended new application.

4.2.2. Return to the manufacturer/supplier

Return to the original manufacturer/supplier is most applicable for high activity sources. This option is, however, not applicable for many old sources as the original supplier is unknown or no longer exists. Also, financial constraints have, in some cases, hindered the return of spent sources as the cost of packaging and transportation may be considerable.

The procedures for the return of spent SRS to the suppliers need to be established. Such procedures, for instance, may include the following arrangements:

- The buyer of a SRS containing a radioactive material should include in the purchase contract a clause permitting the return of the source after its useful lifetime;
- A copy of the contract showing the return clause should be submitted to the regulatory body before a source meeting the requirement outlined in the above paragraph is imported;
- If the buyer for reasons outside his control cannot return the source, the source may be sent to the centralized waste management operating organization for conditioning, storage and disposal at the cost of the buyer.

Source leasing could be practised by developing Member States as the primary mechanism for obtaining sealed sources. Under such an arrangement the user never owns the source but leases it from the supplier for a specified period of time. Procurement contracts should include provisions for the return of sources to the supplier at the end of the contract period.

Returning the source to the original supplier may provide the manufacturer with the opportunity to recycle the radioisotopes contained in the spent sources as it is frequently economically attractive to recover the radioactive component for incorporation in new sources. Return of the spent SRS to a different supplier is another option for consideration. Many institutions in different countries routinely refurbish spent sources for economic reasons.

Sealed sources being returned to suppliers should be packaged and shipped in the original shipping container. If the original shipping container is not available, provisions should be made to acquire a new container or to contract for transportation through a specialized nuclear transport organization. Shipments of SRS should follow the standards which are provided in IAEA transport regulations [11, 12].

4.2.3. Storage for decay

Spent SRS suitable for decay storage are those sources which contain low level and short lived (e.g. ^{32}P, ^{125}I, ^{192}Ir, ^{210}Po) radionuclides. For these sources the radioactivity may decay to clearance levels in a reasonable time. It is considered that 3–5 years is a reasonable time for application of storage for decay option. After decay the sources can be cleared by the regulatory body and can be disposed of as non-radioactive material.

A decay period of about 10 half-lives often allows decay of the activity to levels acceptable for disposal as non-radioactive material (activity reduced by a factor of about 1000). However, disposal of decayed spent SRS to municipal waste areas or other non-radioactive waste landfills should not be made until it is confirmed that the residual activity to be released to the environment meets clearance levels established by the regulatory body.

In establishing clearance levels, or just in clearing spent SRS from further regulatory control on a "case by case" basis, the regulatory body should take exemption levels, established in national radiation protection legislation, into account. As it is recommended by the Basic Safety Standards [3], a clearance level for a particular nuclide should not be higher than the exemption level for that nuclide.

For the radionuclides which are suitable for the decay storage option, some examples and their exemption levels are provided in Table III [3].

TABLE III. EXEMPTION LEVELS FOR SOME SHORT LIVED RADIONUCLIDES

Radionuclide	Half-life (days)	Activity concentration (Bq/g)	Activity (Bq)
^{32}P	14.3	1×10^{3}	1×10^{5}
^{125}I	59.4	1×10^{3}	1×10^{6}
^{192}Ir	74	1×10^{1}	1×10^{4}
^{210}Po	138	1×10^{1}	1×10^{4}

Under the presumption that the values from Table III could be considered as clearance levels, one can use those values for clearing spent SRS in the following way: if the total activity or the activity concentration of a particular nuclide, after the spent SRS has been stored for decay, is lower than the values in Table III, the spent SRS may be considered as, and approved to be, a cleared radioactive source and can be disposed of as non-radioactive material.

4.2.4. Conditioning and interim storage

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

- Operational convenience (e.g. spent sources awaiting collection or another user, transport or a conditioning campaign);
- Safe and secure retention during a period permitting radioactive decay prior to clearance;
- Interim storage of conditioned long lived sources pending the eventual establishment of disposal facilities.

On-site short term storage of unconditioned spent SRS is needed for the sources that can be transferred either to another place for re-use, or return to the original supplier, or to a CRWOO for conditioning, long term storage and ultimate disposal.

On-site conditioning and long term storage is the only option when CRWOO is not available. When the source's activity will decay to clearance levels it can be discharged as cleared waste. The decay storage may be considered for ^{125}I and ^{192}Ir sources subject to a suitable decay store, well developed and implemented administrative procedures, and an adequate quality assurance programme. Longer lived spent SRS that are not expected to decay to clearance levels in a reasonable period of time will continue to be stored on the site.

At the CRWOO conditioning shall be applied for all spent SRS that cannot decay to clearance levels in a reasonable period of time and will be stored for long times and/or disposed of in a licensed repository.

High activity and long lived sources require conditioning followed by interim storage for this option. Sources of these categories, depending on their activity and half-life, will need to be disposed of either in a near surface or a deep geological repository. Storage of these sources in an unconditioned manner is not judged appropriate. Spent SRS containing ^{60}Co, ^{137}Cs, ^{241}Am and ^{226}Ra are some examples of these sources.

4.2.5. Disposal

Disposal is the final step in a radioactive waste management scheme. It consists mainly of the placement of radioactive waste such as spent SRS in a disposal facility with reasonable assurance for safety, without the intention of retrieval and without reliance on long term surveillance and maintenance. The establishment of disposal facilities is a complex and costly operation that needs a large amount of physical and staff resources.

Cost of construction of these facilities is extremely high and specific volume cost is accordingly high. Consequently, space utilization is done as efficiently as possible. Whether these repositories are near surface type or deep geological ones, given waste acceptance criteria are associated with them. Many near surface facilities exist and waste acceptance criteria have been developed for them. However, no deep geological repositories for these kinds of wastes have been constructed yet and therefore specific volume cost and acceptance criteria for a deep underground facility are non-existent so far.

Very long lived SRS such as radium and americium eventually require disposal in deep geological repositories. Other sources that have a relatively shorter half-life but are strong sources, so that their activity is expected to be significant for hundreds of years, may also have to be disposed of in such repositories.

Due to the high cost of disposal, sources conditioned for interim storage should have the flexibility to accommodate future waste acceptance criteria. Furthermore conditioning by complete embedding in concrete may be counterproductive with regard to efficient utilization of repository space. Consequently any conditioning process for interim storage should be carried out with the possibility of the need to retrieve the sources for further conditioning without imposing undue cost.

5. SOURCE HANDLING

Source handling can be defined as any physical manipulation of a source (moving, transfer, relocation, removing from or putting in a container, disassembling the part of equipment containing a source, removing a source from the equipment, measuring, inspecting or testing). A licence should be issued to the user from the regulatory body specifying what handling operations can be undertaken.

The principles outlined in this section are valid for handling of all SRS whether in use, identified as potentially spent or declared as spent. They are also applicable to all stages of the management of spent SRS.

5.1. DECLARING A SOURCE AS SPENT

There are a number of actions to be made by the user regarding the management of a source that can be considered as potentially spent and these are represented in Fig. 8.

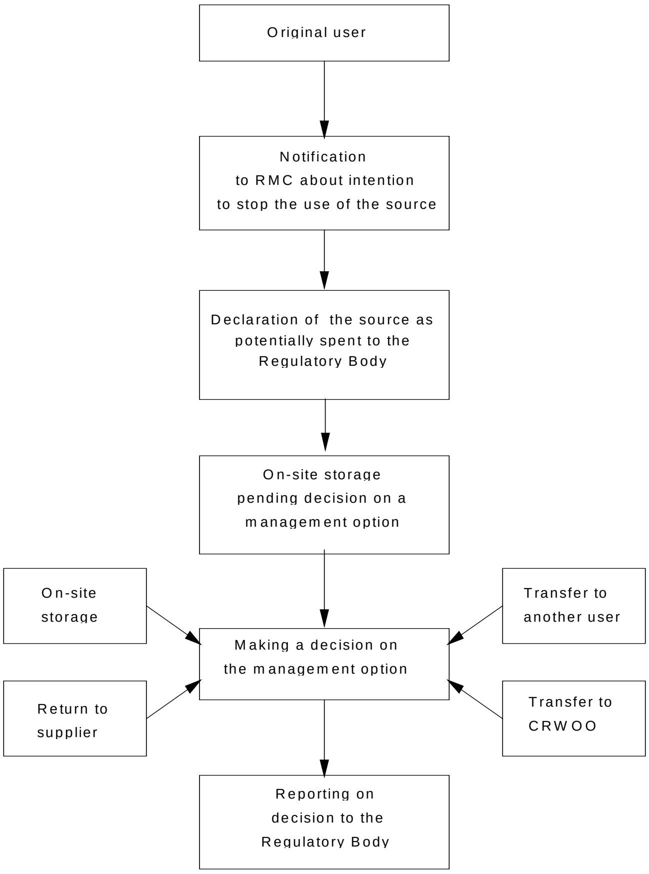


FIG. 8. Steps needed to make a decision on the management option for a spent SRS.

The user of a potentially spent SRS should communicate in writing (Part A of Annex 1) to the radioactive material co-ordinator about his intention to discontinue the use of the source. Then the radioactive material co-ordinator (RMC) will inform the regulatory body (Part B of Annex 1) regarding the declaration of the source as potentially spent.

The next step will be the allocation of a suitable on-site place for safe storing of a source until a decision on its further management is made. Already at this stage it is important to collect all relevant and missing information concerning the source.

5.2. SOURCE CHARACTERIZATION

Before detailed planning is possible it is necessary to have all relevant facts about spent SRS. The majority of spent sources will require long term storage or final disposal because they are leaking, or of unknown makeup and origin, or are excess materials no longer needed for original operations, or are otherwise unusable. The range of these types of sources vary across the sites from certified sealed sources to sources manufactured on-site. For this reason, it is necessary for the RMC to characterize sources into one of the following groups:

(a) *Documented sources*: Sources with appropriate documentation that objectively demonstrates the characteristics of the source. The minimum documentation for this category will be at least one of the following: certificate of traceability, manufacturer documentation, permanent marking on source, or non-destructive assay data. Inventory tracking documentation can also be used as long as there is traceability between the documentation and the associated sources and the activities have been verified;
(b) *Undocumented sources:* Sources that lack appropriate documentation necessary to objectively demonstrate the characteristics of the source. This category will require additional efforts in identifying isotopes and determining associated activities;
(c) *Leaking sources:* Sources in which the confining barrier no longer prevents dispersion of the radioactive material. This category of sealed sources may include leaking sources that have appropriate documentation (documented) and those that lack appropriate documentation (undocumented). Leaking sources are categorized separately because they may require immobilization and/or other additional conditioning approaches.

Each source shall be identified as to its physical characteristics. At a minimum, these shall include the following parameters:

(a) General description of the source;
(b) Date of manufacture;
(c) Name of manufacturer;
(d) Method of sealing the radioactive material, i.e. is the radioactive material electrodeposited onto a backing material or is it encapsulated in Lucite?
(e) Approximate dimensions of the source;
(f) Type of shielding (if any);
(g) Composition of the source (e.g. physical and chemical form);
(h) Weight of the source, including backing material: Only the mass of the source itself should be provided, including any materials that are integral to the sealed source. Shielding that is constructed of an integral manufactured component of the sealed source may be included in the calculation;
(i) Other information (any information that may aid in the characterization of the source).

When information is not available, this shall be stated. The characterization documentation should also state from which basis the above information was derived. For example, was the source visually inspected or was the information obtained from manufacturer specifications?

Sometimes documentation is available from the last user of the source, but it may be necessary to obtain information from national agents of the manufacturer, from the manufacturer or from the national regulatory body. Where the information is incomplete, the RMC should obtain the missing information. If the information is unobtainable, the RMC must make a worst case estimate of the required information and record that he has done so.

All information on the source should be collected and filed in a structured way to facilitate retrieval when needed; it should be retained in duplicate and in separate locations. The RMC must carry out audits at regular intervals to ensure that the recorded information is correct. Details of the labelling and record keeping requirements have been given earlier in Section 3.4.

5.3. COLLECTION AND SEGREGATION

The first handling step for a spent SRS is to collect it from the user for safe storage pending a decision on the future management step. This work is usually carried out by the CRWOO or a similar organization. Prior to collection all possible information on the source should be collected. The user could be requested to complete a questionnaire to be sent to him. A typical form is provided in Figs 9a, 9b and 9c. The collected sources need to be segregated and placed in an appropriate container to facilitate further processing. Leaking sources shall be segregated from other sources and separately collected to avoid cross-contamination.

For transferring to the storage place, the spent SRS should be placed into original containers or containers comparable to those in which they were originally received. In case of radiography or teletherapy equipment the spent SRS should be properly returned to its shielded position. If other than original containers are used, their design should take into account the geometry of the source, its activity, and handling requirements.

When sources are transferred, the following cautions should be taken:

(a) The sources should not be endangered by mechanical damage (e.g. drop down from a height, struck by a handling machine or a fork lift);
(b) The safety systems on the sources should be checked for their functionality (e.g. locking mechanism of the sources is intact);
(c) For a bare source proper shielding equipment should be provided. It is also advisable to practice the different steps on a similar dummy source and to estimate the exposure to the staff involved. Several operational steps should be carried out once a source is received at the facilities. A typical procedure is illustrated in Figs 10a and 10b.

5.4. SELECTION OF AN APPROPRIATE MANAGEMENT OPTION

The possible options were discussed in Section 4. The management option selected for a particular SRS will depend on a variety of relevant factors including activity, radioisotope content, terms of the purchasing contract and physical condition of the source.

After the management option has been selected, the RMC will notify the regulatory body (Part C of Annex 1) regarding the decision made. It will be an issue for national policy as to how the radioactive material co-ordinator and the regulatory body interface on the spent SRS management decisions. However, it is recommended that particularly, but not exclusively, in the case of transferring a potentially spent source to another user the RMC liaises with the regulatory body.

If the options of returning the sources to the supplier or another user are not available, the role of a CRWOO is invaluable. Depending on the number, type and activity of the sources as well as the available infrastructure in a country, the CRWOO needs to set up a strategy to deal with these sources and must have the required technologies to implement the strategy.

If the number of sources is small and no CRWOO exists, the regulatory body in co-ordination with the user may come to a suitable solution for the safe and proper storage of the sources. It is advisable that the regulatory body does not get involved with the actual operations. Costs for handling, conditioning or disposal of such sources are normally borne by the user.

NAME OF FACILITY: ………………………………………………………………………………
TITLE: RETURNS QUESTIONNAIRE FROM ………………………….. FACILITY ID: ………

Complete this questionnaire fully and return it to the Spent SRS Disposal Facility at the address given. Complete a separate form for each transport package.
You must NOT ship sources to the Facility until given written authorization to do so.

Page 1 of ……

Source details	*Source 1*	*Source 2*	*Source 3*	*Source 4*	*Source 5*	*Source 6*
1. Radionuclide						
2. Nominal Activity (Bq)						
3. Source serial number						
4. Physical dimensions of source (mm)						
5. Manufacturer						
6. Date of supply						
7. Is source damaged? (state YES/NO)						
8. Is source leaking? (state YES/NO)						
9. Is source contaminated? (state YES/NO)						
10. Give date of latest leak test						
11. Is source Special Form approved?						

If any source that you propose to return to the Facility is mounted in a holder/housing, please provide full details (i.e. weight, dimensions, drawings, etc.) on the sheet provided.

If you have a transport container, tick here ☐

Provide full details (i.e. weight, dimensions, drawings. etc.) on the sheet provided.

Declaration:

A trained, competent person is available who will be responsible for the following:

a) Packaging the source(s) correctly and safely;
b) Understanding and conforming to the relevant national regulations controlling the safe transport of radioactive materials;
c) Measurement of the surface dose rate and transport index of the loaded package;
d) Labelling the package correctly for transport;
e) Completing the Dangerous Goods Declaration (Shipper’s Certificate) which MUST accompany the package.

The name of this trained person is: ☐

I agree to abide by the terms and conditions of acceptance of spent sources as set out by the Facility and as available on request.

Signed by: ……………………………………. Full name: ………………………………………

Company/Organization name and address: …………………………………………………………………..

Position held in company/Organization: ……………………………………………………………………..

Date: …………………………………

FIG. 9a. Returns questionnaire.

NAME OF FACILITY: ………………………………………………………………………………
TITLE: RETURNS QUESTIONNAIRE FROM ………………………….. FACILITY ID: ………

Source holder/housing details:

Source number:

Dimensions of holder/housing:
Length (mm)
Width (mm)
Height (mm)

Material(s) of holder/housing:

Mass of holder/housing (gm):

Is the source part of a large equipment? Type: ………………………

Sketch of holder/housing

State any other possible hazard other than radiation (e.g. chemical, inflammable, toxic, biological)

FIG. 9b. Returns questionnaire.

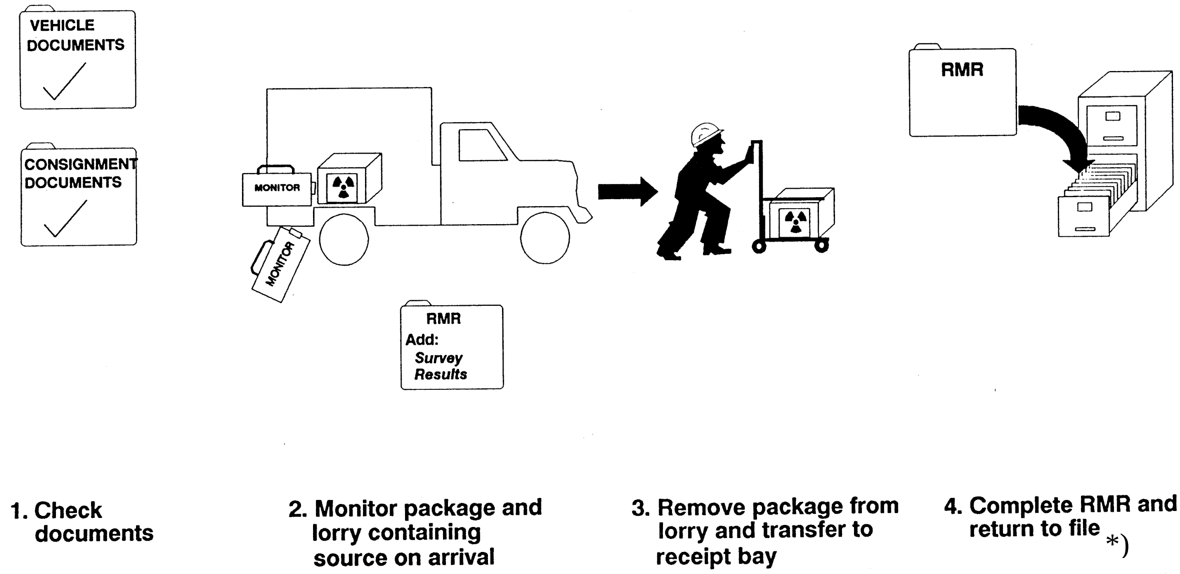
NAME OF FACILITY: ………………………………………………………………………………
TITLE: RETURNS QUESTIONNAIRE FROM ………………………….. FACILITY ID: ………

Transport container details:

Design number:		
Dimensions of container:	Diameter (mm) Height (mm)	
Shield thickness::	mm	(state NIL if unshielded)
Mass of container:	kg	
Shielding material:		(state N/A if shield thickness is NIL)

Sketch of container

FIG. 9c. Returns questionnaire.



* RMR – Radiation Monitoring Report.

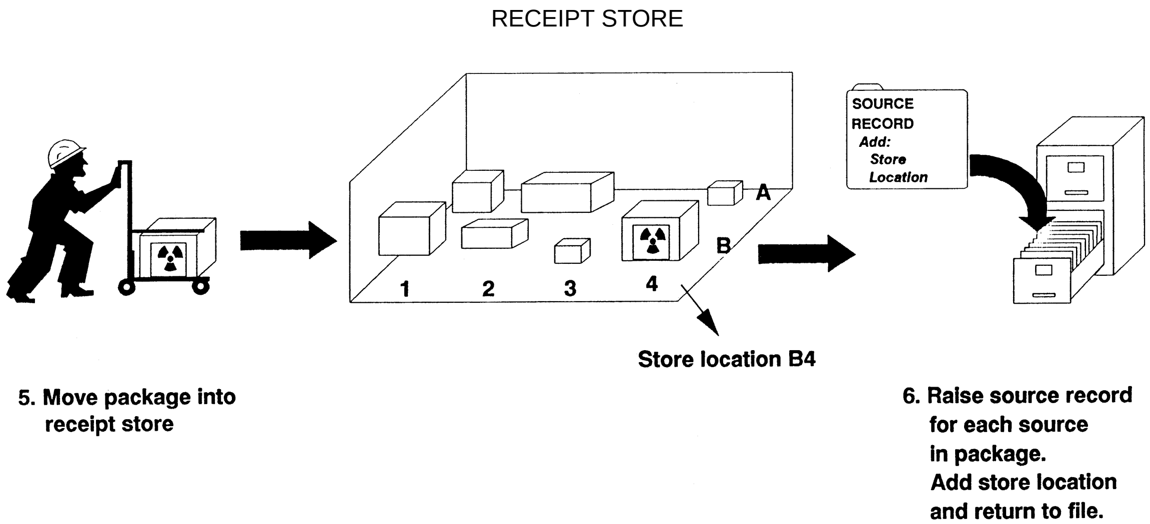


FIG. 10a. Receipt of packaged source.

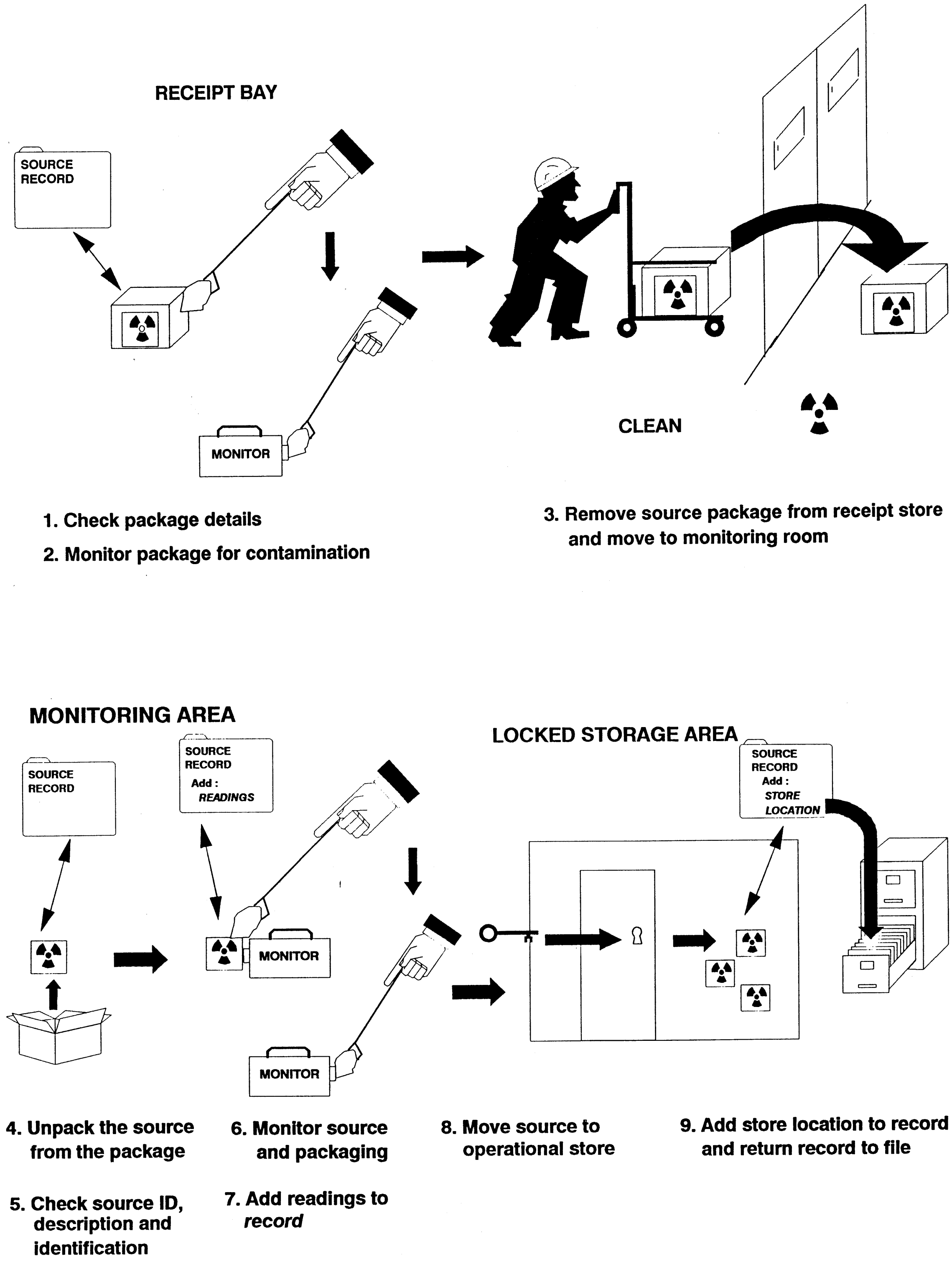


FIG. 10b. Unpacking of source package and transfer to operational store.

5.5. RADIATION AND CONTAMINATION CONTROL

Radiation control should be maintained over potentially spent SRS whilst on site. In planning and implementing the source handling, consideration shall be given to the factors that could affect the safety of the source and lead to potential exposures to workers and the public and/or contamination of the environment. These factors have to be taken into account whether the spent SRS is being handled bare, in a container, in a transport package, or in its original housing/enclosure in which it had been used as a part of an installation. All handling operations should be planned, tested and implemented jointly with the radiation protection officer.

Before handling of a spent SRS, smear tests on the source should be carried out to check for any leakage. Proper handling of a leaking source is a challenging operation since it may result in the spread of contamination. Therefore, suitably qualified and experienced personnel are required to perform the operation where leaking sources are involved. The leaking source shall be overpacked and the areas where leaking sources are manipulated should be covered e.g. by a plastic sheet in order to facilitate decontamination and prevent the spread of contamination.

Suitable radiation monitoring should be used throughout all handling operations. Handling of spent SRS will generally be carried out in a controlled area. Precautions should be taken to restrict internal and external radiation exposures to a minimum according to the ALARA principle by applying the time, distance and shielding means. Special precautions have to be taken to prevent inhalation of airborne contamination if leaking spent SRS are to be handled. For proper contamination control it is always necessary to have appropriate instruments and equipment available, since there is always a risk for a source to be damaged during the work. All persons engaged in the work should be provided with personal dosimeters that are evaluated regularly. Consideration should be given to head and finger dosimeters, and personal digital dosimeters. Contamination monitoring should be carried out during and after every step of the work.

Examples of shielding that could be needed during the handling operations are the following:

- *Gamma radiation*: dense materials (lead, depleted uranium or concrete);
- *Neutron radiation (Am-Be, ^{252}Cf, Pu-Be):* hydrogenous materials (paraffin high-density polyethylene). Neutron absorbing material (e.g. cadmium, gadolinium or lithium) may also be required.

In the cases of transferring the source to another user or returning to the supplier or transferring to a CRWOO, it must be ensured that radiation, contamination and activity levels are within the limits given in the national or the IAEA Transport Regulations [11, 12].

5.6. GENERAL SAFETY REQUIREMENTS

When handling spent SRS industrial and radiation safety must be observed. Sealed sources may be an integral part of an equipment. This equipment may be connected with a chemical/physical process and special precautions may be required to avoid certain dangers. Sealed sources may also have a special chemical/physical form that may require special precautions. Sources may also be leaking which would again require special general and radiation safety measures.

5.6.1. Assessment of hazards

Before a source is handled on its own, as part of a mixture of waste or as part of an equipment, it is important to make an assessment of the possible hazard involved. A mixture of waste or a piece of equipment may involve toxic material, chemically active substances, flammable material or biologically hazardous substances. It is essential to fully assess the type and nature of all risks involved before a source is handled. If the personnel involved do not have a clear idea on the mixture of waste or equipment, specialists in the respective field or previous users/owners should be consulted.

5.6.2. Safety and radiation protection measures

Sealed sources when handled present a potential risk. This risk depends on the source activity, chemical form and the possibility of radioactive material leakage. Before a source is handled, a complete assessment of the possible risk should be analysed and a radiation exposure dose estimate must be carried out according to the written handling procedure to fully provide for the radiation safety and radiation protection requirements.

5.6.3. Contingency and emergency plans

When sealed sources are handled according to written procedures and full account is taken of safety and radiation protection measures, there is still a possibility of a course of events taking place that may not be according to plans. Handled sources may drop free from their shields or begin to leak radioactive material during operational procedures being carried out. It is important prior to conducting any operational procedures to have contingency plans and written emergency procedures to handle any unplanned event. Such plans require a careful consideration of the nature of the danger involved and suitable tools to allow safe handling of the sources involved and bring the situation under control.

6. ON-SITE STORAGE

Storage in general may be defined as the placement of the source in a facility where isolation, environmental protection and human control (for example, monitoring) are provided with the intent that the source will be retrieved.

On-site storage of the spent source may be required either to allow the source activity to decay to clearance levels [15, 16] or prior to its dispatch to another location. The on-site storage time should be kept as short as practicable. It should be noted that keeping spent SRS on the site without observing proper storage regulations is the most frequent cause of accidents and loss of control. However, it is recognized that there may be no viable alternative to on-site storage for some time.

6.1. PREPARATION OF SOURCES FOR ON-SITE STORAGE

All spent SRS to be stored on-site should meet the following requirements:

(a) The source should be packaged in such a way that the package integrity can be assured during the entire planned storage time;

(b) In the storage systems considered here, the sources are assumed to be packaged in a lead casket which has appropriate shielding properties with the casket placed in a lidded thin gauge steel container (Fig. 11). The casket illustrated has a capacity of 75 mL and could contain several sources. For these cases it is recommended that there is a package information sheet detailing which sources are contained in the container (the "Source Information Form" in Annex 2 may be used as a guideline);

(c) The surface dose rate of the storage package should comply with the requirements of the storage facility;

(d) High activity strontium or other beta emitting sources should not be stored in lead containers in order to avoid bremsstrahlung;

(e) Each storage package shall be marked with the ionizing radiation symbol, the word "radioactive", and the Identification Tag shall be attached to the package. It is advisable that labels in the case of long term storage are made to withstand storage conditions with undue degradation.

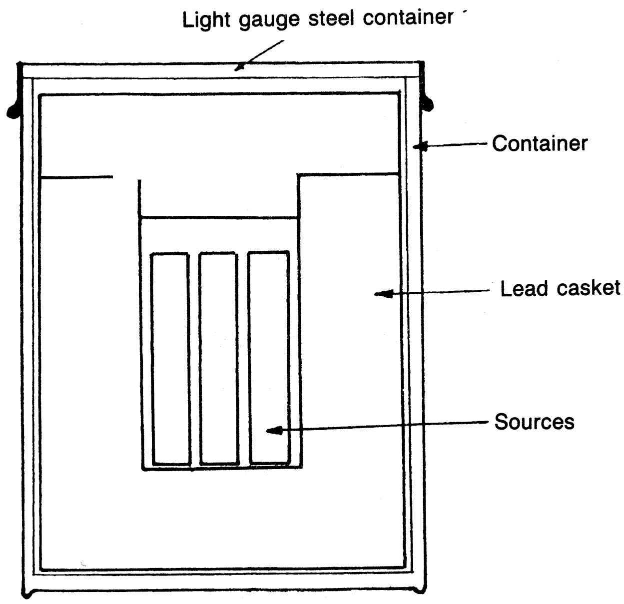


FIG.11. Diagram of typical casket, sources and container.

Radium sources are a special case and therefore should be stored accordingly. Due to their production to earlier standards and their undesirable characteristics, leakage of these sources is highly possible. Their chemical form also makes the spread of contamination a real and serious possibility. Their very long half-life makes their disposal only suitable in deep geological repositories. Accordingly, the conditioning of radium sources needs strict requirements and a quality assurance procedure to guarantee their safe storage for an extended period of time (e.g. 40–50 years). A special procedure has been adopted by IAEA for this task. Details of the requirements and the general approach can be found in Ref. [17].

6.2. DESIGN GUIDANCE FOR ON-SITE STORAGE FACILITIES

A storage facility must be properly designed and constructed and be licensed by the regulatory body. General guidelines for storage facilities which can accommodate spent SRS are as follows:

(a) Location of the on-site store should be remote from working places or other areas regularly attended by personnel or public;

(b) Transfer of sources to and from the store should be facilitated (e.g. lift transfer is preferred to staircase transfer);

(c) The loading capacity of the floor must be taken into consideration in planning of any storage facilities;

(d) Physical barriers to intrusion, surveillance, high security lock, alarm system or trained guards or any combination of these should be provided as appropriate. The physical protection measures should be viewed as a whole, taking into account the combined effect of individual precautions;

(e) The store should be properly marked with a symbol of ionizing radiation (trefoil) and the word “radioactive”;

(f) The on-site store should be large enough to permit the sources to be stored in an orderly manner in order to visually identify the individual groups of sources (to be cleared at different times);

(g) Surfaces in the store should be smooth to facilitate decontamination whenever required;

(h) Radioactive sources should be stored away from non-radioactive material;

(i) Radioactive sources being stored for decay should be separated from sources in use, and from sources not suitable for decay storage;

(j) Shielding (either in the walls or as movable shielding material) should be provided to ensure that the dose rate at any accessible place within or outside the store does not exceed the applicable value prescribed by the regulatory body;

(k) Additional shielding for containers with high surface dose rates, e.g. Tc-generators should be provided (this may be needed in cases where the store is visited regularly and where a large number of sources and other waste packages are being stored);

(l) Appropriate ventilation should be provided whenever there is a risk for airborne activity, in particular when significant quantities of ^{125}I, ^{131}I or ^{226}Ra are stored.

A large number of alternative storage systems may be envisaged which would meet the above criteria. Depending on the quantities of waste to be stored, arrangements for on-site storage can range from a shielded cabinet to a dedicated separate room. This report only gives a few examples to illustrate possible schemes. A user may find that one of these will meet his individual requirements, but it should be stressed that local conditions may also suggest another completely satisfactory arrangement. Options should be examined to determine the most cost-effective scheme.

All sources received at the store should have a receipt and a source record form filled out. Typical forms and relevant information are listed in Figs 12a and 12b.

6.2.1. Storage in safes

This option, which is only suitable for a small size and a small number of containers, utilizes floor safes which are mass produced, inexpensive, readily available and recognized as a very secure system. Unauthorized intrusion is extremely difficult and the safe removal would not be an easy operation if the safe is installed in a foundation.

A diagram of a typical floor safe produced by several manufacturers is shown in Fig. 13. These safes, which range in size from 30 L to 60 L of storage capacity, provide protection against a range of attacks including use of levers, sledge hammers, grinders, drills, oxy-acetylene and explosives.

Should it be required to convert to a system of long term storage without access and minimum surveillance these safes can be capped with reinforced concrete lids.

NAME OF FACILITY: …………………………………………………………………………………	
STORAGE AREA:…………………………………………………………………………………………	
TITLE: RADIOACTIVE MATERIALS RECEIPT	FACILITY ID: ………

1) To be completed by **RECEIVING STAFF MEMBER** to procedure B at point of arrival.

CONSIGNOR/SUPPLIER:	No. OF PACKAGES
BRIEF DESCRIPTION OF PACKAGE:	PACKAGE SERIAL NO. (if applicable)

	INFORMATION PRESENT?		COMMENTS/SPECIFY				
SHIPPERS CERTIFICATE	YES	NO					
CONSIGNMENT DOCUMENTS & CARRIER'S REF. NO.	YES	NO					
CONSIGNEE	YES	NO					
ISOTOPES DECLARED	YES	NO					
ACTIVITY OF EACH ISOTOPE DECLARED	YES	NO					

TRANSPORT CATEGORY (tick box)	EXEMPTED	WHITE I	YELLOW II	YELLOW III

2) **VEHICLE SURVEY** (To be completed on arrival of the transport vehicle at the facility before the consignment is offloaded.

SURVEYOR:		TRANSPORT INDEX	YES	NO	*STATE*	DECLARED		ACTUAL	
		SURFACE DOSE RATE mSv/hr	YES	NO		DECLARED		ACTUAL	
DATE:		CONTAMN.	YES	NO	*VALUES*	alpha(cps)	beta (cps)	gamma/X (cps)	

3) **PACKAGE SURVEY** (To be completed on receipt of package before unpacking)

SURVEYOR:		TRANSPORT INDEX	YES	NO	*STATE*	DECLARED		ACTUAL	
		SURFACE DOSE RATE mSv/hr	YES	NO		DECLARED		ACTUAL	
DATE:		EXTERNAL CONTAMN.	YES	NO	*VALUES*	alpha(cps)	beta (cps)	gamma/X(cps)	

4) To be completed by **Health Physicist**

The consignment appears to conform to description as supplied by customer. The consignment appears to be in a satisfactory condition for storage. The transport vehicle is free from detectable radiation and contamination and it is cleared to leave the facility.

Consignment accepted by (name)	Signature:	Date:

Fig. 12a. Radioactive materials receipt.

SPENT SEALED RADIOACTIVE SOURCES FACILITY (NAME OF FACILITY): ………………………………………………………………………………………………………   STORAGE AREA: ………………………………………………………………………………………
TITLE: SOURCE RECORD …………………………………. FACILITY/SOURCE ID: ………

A Source Record Card must be completed for each source received into the Facility

1. **Source details**

Radionuclide	Physical Form SOLID/LIQUID/GAS*
Activity (MBq)	Activity Reference date

2. **Consignment Details** (procedure C3)

Consignor *Name: ……………………………………………* *Address: ……………………………………………* …………………………………………… …………………………………………… …………………………………………… …………………………………………… …………………………………………… *Contact Name: ……………………………………*	Transport Package *Identification number:……………….Type:……………* *Mass: ………………………kg Category:………………*	
	Outer Package *Design Type: ………………* *Height:………………mm* *Width or diameter: ………* *…………………………mm* *Length: ………………mm*	Inner Package *Design Type: ………………* *Height:………………mm* *Width or diameter: ………* *…………………………mm* *Length: ………………mm*

3. **Cross references**

Facility Source ID for other sources in the same package

4. **Receipt and Sentencing** (procedure B3.10)

Date into receipt store: *Receipt store location:* Signed:	*Processing route:* DECAY* ENCAPSULATION* Signed:

5. **Unpacking** (procedures C3.1 & 3.2)

	Comment/Results/Action	Date & Signature
Visual Examination		
Contamination		
Radiation		

6. **Decay/Operational* Storage**

	Comment/Results/Action	Date & Signature
Storage Location		
Inspections during Storage		
Release from Storage		

7. **Earliest Release Date** for Disposal or Encapsulation

8. **Disposal/Encapsulation***

	Comment/Results/Action	Date & Signature
Release from Store		
*Inspection for Disposal/ Encapsulation**		
*Encapsulation**		
*Drum Identification Number**		
*Disposal Route**		
Disposal/Encapsulation Complete		

*** delete as applicable**

Fig. 12b. Source record form.

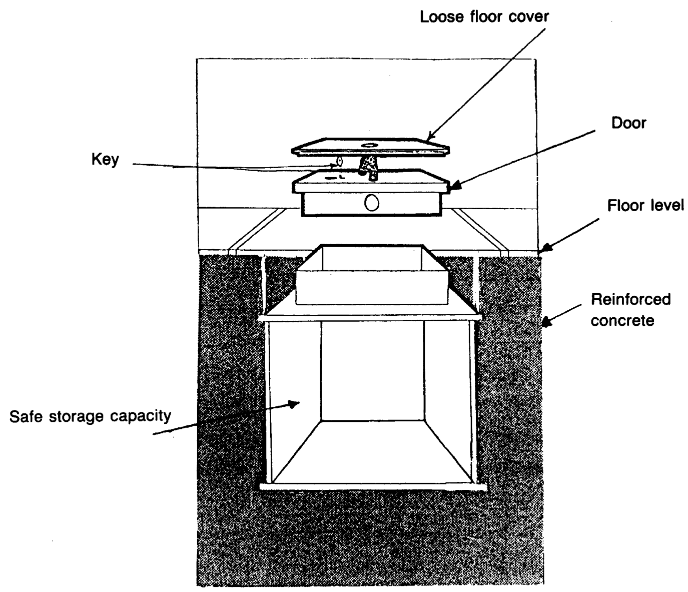


FIG. 13. Typical floor safe.

6.2.2. Storage in strong rooms

This scheme is suitable for all sizes of containers, large, medium and small. The containers are stored in a strong room with a secure door, high security locks and an intruder alarm. The room is only accessible to a small number of authorized personnel. Small and medium sized containers may be arranged for convenience on shelves whereas large containers would be placed on the floor. As an additional security measure, floor safes, each housing several small packages, may be provided in the strong room. This system can provide secure storage for a large number of sources but still offers ready access when required.

6.2.3. Storage in concrete bunkers

A reinforced concrete bunker could be used for the storage of small, medium and large containers depending upon the size of the bunker. A comparatively small bunker with a capacity of a few cubic meters and designed with a heavy lid could serve as a cheap but secure system for the storage of small and medium packages.

A larger bunker with a heavy lid could house large packages as well as small and medium ones and would be useful where there are larger numbers of sources for storage (Fig. 14).

If required, these bunkers could easily be converted to long term storage facilities requiring minimum surveillance by sealing the entries with reinforced concrete.

6.2.4. Wet storage system

In certain facilities, particularly in the large industrial irradiators with ^{60}Co sources, a water basin is used for the shielded position of sources from which they are moved into the working position. These water basins could be used for the on-site temporary storage of spent ^{60}Co sources. However, the basin should conform with all the necessary technical and regulatory requirements, i.e. depth of approximately 5 to 6 m, ventilation, water circulation through ion exchange resins, etc.

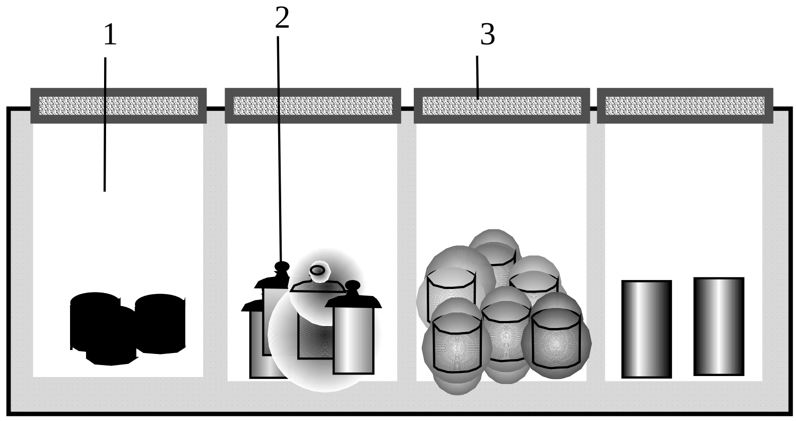


FIG. 14. Concrete bunker for interim storage of spent SRS (1 - compartments, 2 - waste packages, 3- concrete lid).

A high degree of technical expertise is required to design, commission and operate such a facility. Because of the complexity and its limited special application wet storage is not recommended as an alternative where the required infrastructure cannot be made available.

6.2.5. Comparison of on-site dry storage systems

The storage facilities described above are compared with respect to various criteria in Table IV. This summarizes the main features of the various schemes and offers a simple means of selecting an appropriate option for individual users.

TABLE IV. COMPARISON OF ON-SITE DRY STORAGE SYSTEMS

Type	**Safes**	**Strong room**	**Strong room with safes**	**Concrete bunkers**	**Wet storage**
Capacity	Low/medium	High	High	High	High
Cost	Low	Medium	Medium	Medium	High
Flexibility (container size)	Limited	High	High	High	High
Containment	Good	Good	Good	Good	Good
Radiation protection	Good	Good	Good	Good	Good
Security	Good	Good	Very Good	Good	Good
Access	Good	Very Good	Good	Poor	Very good
Surveillance required	Regular	Regular	Regular	Infrequent	Regular

6.3. RADIATION AND CONTAMINATION CONTROL

The storage areas must be designated as controlled areas, to minimize exposures of workers to ionizing radiation and to limit the spread of radioactive contamination, if any. Regular contamination and radiation surveys of the storage area should be conducted by the radioactive material co-ordinator during the entire storage period in order to confirm that radiological conditions remain satisfactory. In addition, if sealed sources containing long lived, volatile or radiotoxic nuclides (e.g. radium) are stored, monitoring of airborne activity levels should be provided. Detection of airborne or surface contamination will indicate the presence of leaking sources. Any serious abnormality shall be investigated and appropriate actions taken. This shall be reported to the regulatory body.

It is recommended that personal protective equipment should be worn during access to the storage areas (e.g. personal dosimeters, overshoes, overalls, respiratory protection devices may be required).

7. CONDITIONING OF SPENT SEALED RADIOACTIVE SOURCES

The objective of conditioning is to produce a waste package acceptable for handling, storage, transportation or disposal. For these reasons, the waste package produced in a conditioning process should comply with the transport regulations, requirements for long term storage and/or waste acceptance criteria for disposal, as applicable. If waste acceptance criteria for disposal do not exist at the time of the conditioning, the waste package produced shall be fully characterized and the conditioning procedure has to take in consideration retrieving of the sources.

Conditioning could offer, in general, the following benefits for long term storage and disposal of spent sources:

- Reduce the migration and/or intruder exposure potential for radionuclides and, therefore, may allow higher package activity limits;
- Provide for greater confinement of leaking sealed sources.

7.1. PLANNING FOR CONDITIONING

There are many technical and non-technical factors that influence the choice of a conditioning method. The following requirements and other factors should be taken into account while planning a conditioning operation:

- Source characteristics (type of ionizing radiation, activity, specific activity, half-life, chemical toxicity, integrity);
- The number and physical size of spent SRS/caskets;
- Chemical and physical form of the radioactive material;
- Heat generation either due to source material and/or conditioning method;
- Compliance with regulations (e.g. acceptance requirements for storage and/or disposal, clearance levels, radiation protection and safety requirements);
- Physical infrastructure;
- Manpower and personnel competence;
- Cost and resources (equipment and materials required for conditioning);
- Storage period and location.

The relative importance of the above factors will depend on the particular situation in the country.

7.1.1. Licensing

Conditioning of spent SRS is an activity for which an operating licence should be obtained. The operating licence should define the scope of the conditioning operation as well as any specific requirements that must be observed (see Section 3.3.). A safety analysis report should be submitted as part of the licence application.

7.1.2. Transport regulations

If the conditioned source is expected to be transported to another location, the activity in the package should respect A1/A2 values as set out in the IAEA transport regulations [11, 12]. In these regulations a Type A package is defined as a packaging, tank or freight container containing an activity up to A2, or, up to Al if the contents meet the definition of 'special form radioactive material'. *"Special form radioactive material shall mean either an indispersible solid radioactive material or a sealed capsule containing radioactive material"* [12]. (It may be expected that many sealed sources meet the requirements to be classed as 'special form radioactive material', especially sources manufactured according to today's standards. These include dimensional limits, an impact test, a percussion test, a bending test and a heat test.) If the amount of activity in the package exceeds Al, a Type B package, which is much more robust, must be used. For detailed specification of tests and other criteria for a type A or type B container the IAEA Safety Standards for Transport Regulations can be consulted [11, 12].

It is recommended that only A2 values are conditioned, because of the possibility of the withdrawal of special form certificates, causing a conditioned A1 value spent source to need a Type B container. Such a container may not be available to deal with the volume of such a conditioned source.

7.1.3. Manpower and personnel competence

The conditioning process requires skilled personnel with an appropriate level of theoretical knowledge and practical experience, self-discipline, and with a feeling of responsibility for high quality of work.

The number of persons needed is not prescribed. Nevertheless, the presence of at least two persons is usually required during any operation with radioactive material. The personnel qualifications recommended for each conditioning task are outlined in Table V.

TABLE V. PERSONNEL QUALIFICATION AND EXPERIENCE

Personnel	**Qualification/experience***
Operations manager	Radiochemist or a radiophysicist trained to university degree level with experience in radioactive waste management
Radiation protection officer/Supervisor	Experienced in radiological protection procedures and regulations
Task manager	Experienced in the selected conditioning methods, operations conditioning and quality control
Skilled operator	Practical experience with the handling of radioactive materials

* Training programmes should be provided as required.

7.1.4. Quality assurance programme

For any conditioning process the conditioner shall prepare and implement a quality assurance programme covering the process, the technical installation and the final product. This programme shall be prepared and approved by suitably qualified and experienced people such that it meets the conditions of the licence issued by the regulatory body for such processes.

After execution of the conditioning a certificate of conformity shall be prepared by the conditioner confirming that the process has been carried out in accordance with the approved quality assurance programme. This certificate of conformity shall detail the characterization data of the waste packages, e.g. radioactivity content, physical and other relevant properties.

7.2. SUGGESTED METHODS OF CONDITIONING

7.2.1. Embedding in concrete

The option suggested is based on the enclosure of the source in a Type A package (e.g. mild steel 200 L drum). Such packages would have a minimum weight of about 350 kg and their handling and transportation would require mechanical equipment, e.g. a fork lift truck. Conditioning in this way will prevent unauthorized removal of the source because of the bulk, weight and robust nature of the package and it also provides a barrier against loss of containment of radioactive materials.

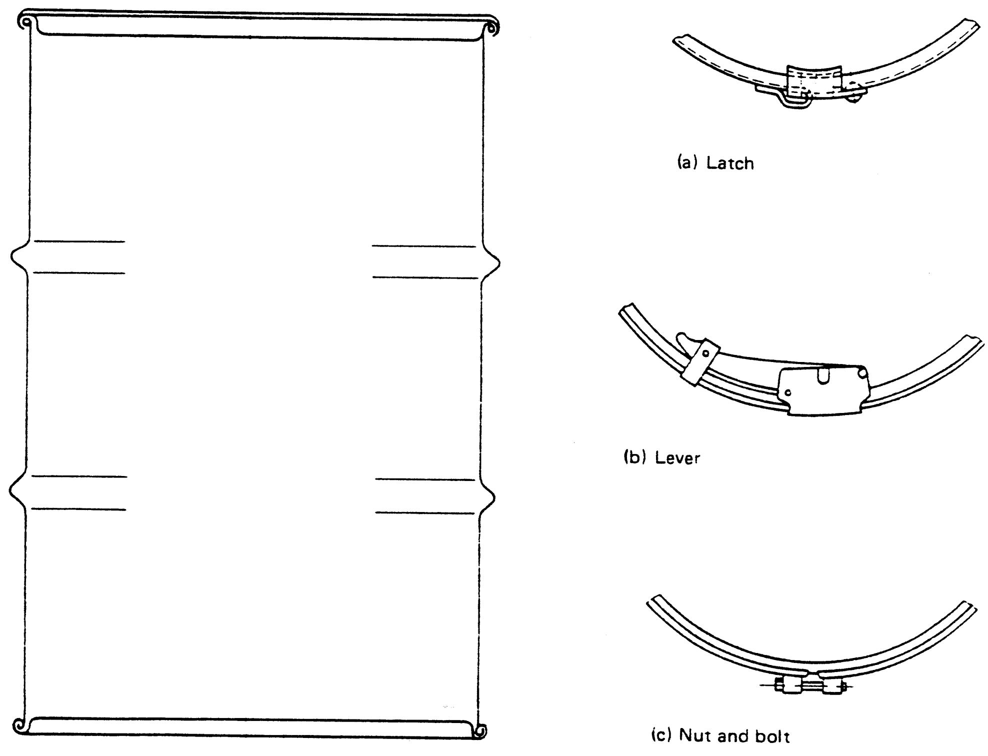


FIG. 15. Typical 200 L drum lid closing mechanisms.

The source in its shielding is placed in the centre of a 200 L steel drum with concrete lining, welded bars and closed with a lid. Typical lid closing mechanisms are shown in Fig. 15. The concrete lining drum is prepared by inserting a removable spacer into the centre of the drum and grouting concrete between the spacer and walls. The diameter of the spacer should form a cavity depth from the top of the drum sufficient to contain the shielded source. Before positioning the shielded source, a hardening time should be observed, so that the concrete liner is not damaged. Leaking sources should be placed in the drum in their overpacks. If the physical volume, activity, and resulting surface dose rate permit, more than one source could be conditioned in the same drum.

This conditioning procedure is suitable for any type of source, assuming its size (including casket and container) allows it to be conveniently accommodated in the centre of the drum. Because the source remains in its casket it is not necessary to rely upon the shielding properties of the cement mortar lining. It may be considered that a package which is safe to transport through the public sector will also be suitable for interim storage on a secure site. In order to facilitate disposal, long lived alpha and neutron sources should be conditioned separately from beta/gamma sources as they may require different disposal routes. High activity gamma sources which are usually contained in heavy shielding devices may not be suitable for conditioning by the methods described above. Such sources should be retained in their shielding devices and stored on a secure site pending further management options.

When the details of the conditioning process in a steel drum are decided upon, all equipment and materials must be collected. Although there might be some differences depending on exactly how the conditioning is to be carried out, the following, while not exhaustive, may be required:

- 200 L steel drums without any corrosion or mechanical damages;
- A mould for preparing a cavity inside the drum;
- A cement mixer or provisions for manual mixing;
- A vibration device or provisions for manual compaction of concrete;
- Steel reinforcement bars (min. 3 bars per drum);
- Steel bars (8 × 30 × 500 mm for securing the lead shielding in the drum);
- Additional shielding material required to meet dose rate criteria on the waste package;
- Lead bricks 50 × 100 × 200 mm (as portable radiation shielding during work);
- Handling tools (two forceps 300 mm long, one tong — preferably with parallel grip — 1000 mm long);
- A mirror with handle;
- Plastic sheets (to protect against contamination during work);
- Labels (for storage and transportation);
- A fork lift truck or other lifting equipment;
- Materials and equipment for encapsulation (cement, sand, water, steel bars, etc.).

A prefabricated 200 L steel drum is presented in Fig. 16. A general description of some important aspects of source conditioning is illustrated in Figs 17a–c.

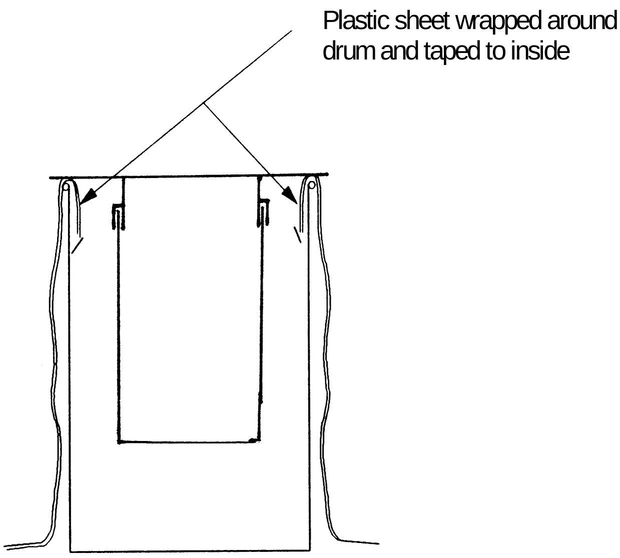


FIG. 16. Preparation of drum – Wrapping with plastic sheet (mold required only for retrievable sources).

7.2.2. Encapsulation in stainless steel

Conditioning of Ra, Am, Am-Be, Ra-Be and other long lived spent SRS for interim storage will include stages for their encapsulation in stainless steel capsules (to facilitate their retrieval for final disposal in deep geological repositories), placement of the welded capsules inside in a lead container for shielding (in case of long interim storage followed by transportation), and placement of the container into a 200 L mild steel drum with a concrete lining. In the case of neutron sources, hydrogenous material such as wax or high density polyethylene should also be considered. The concrete is used for physical protection and security of the sources and is not relied on for the dose rate reduction. This package could be filled later with cement mortar to totally immobilize the source or it could be opened to retrieve the source for future final conditioning.

Other encapsulation techniques may be used with approval by the regulatory body.

The capsule used for encapsulation of long lived sources is a stainless steel tube with a lid welded to one end (see Fig. 18). An appropriate number of capsules should be prepared in this way in advance, in order to ensure the sufficient number for encapsulation of all available sources. After placing the source inside a stainless steel capsule the second lid is welded and the welded capsule is tested for leak tightness in the case of radium sources by using e.g. the vacuum bubble test [18]. A vacuum chamber for the bubble test is shown in Fig. 19.

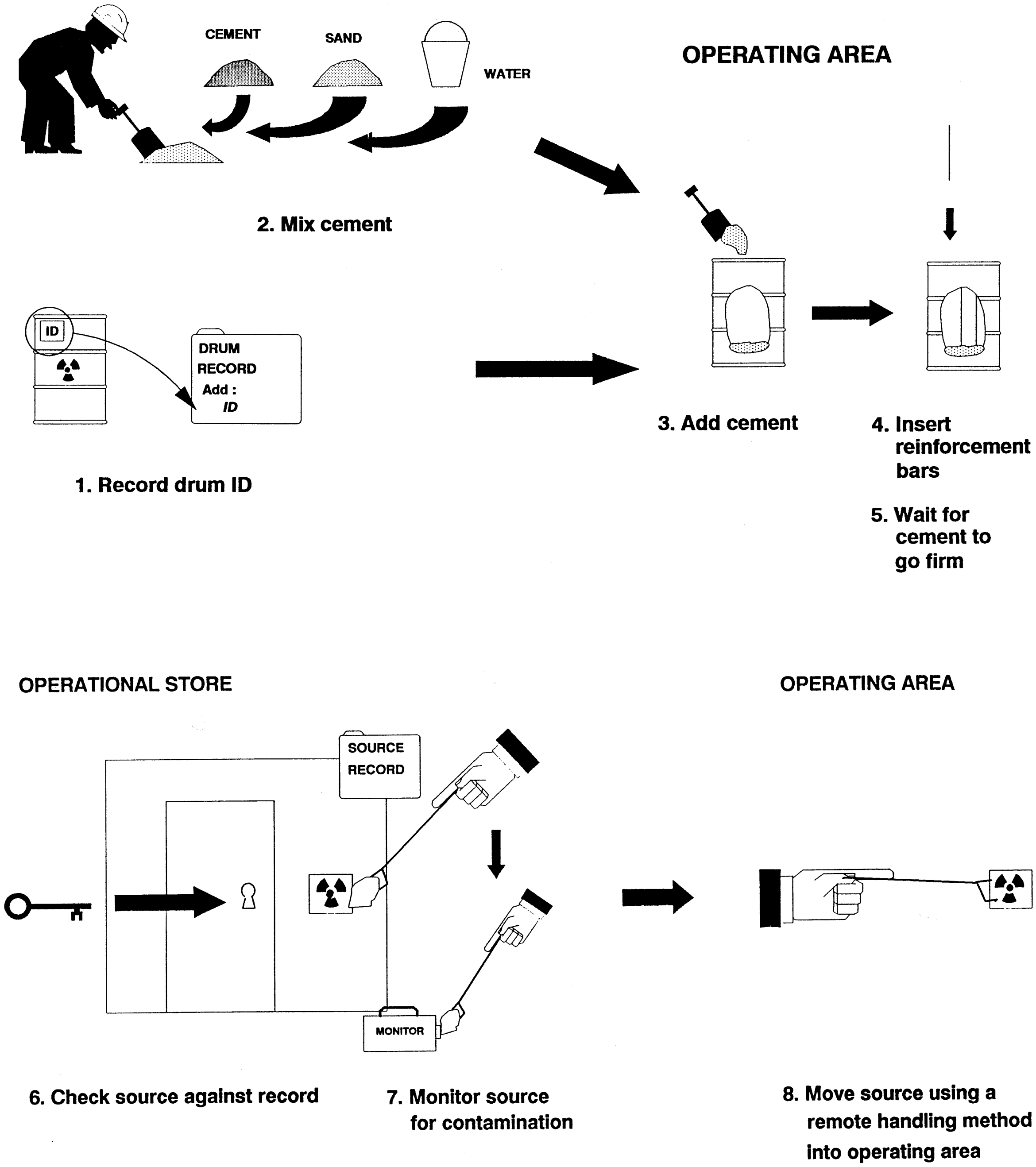
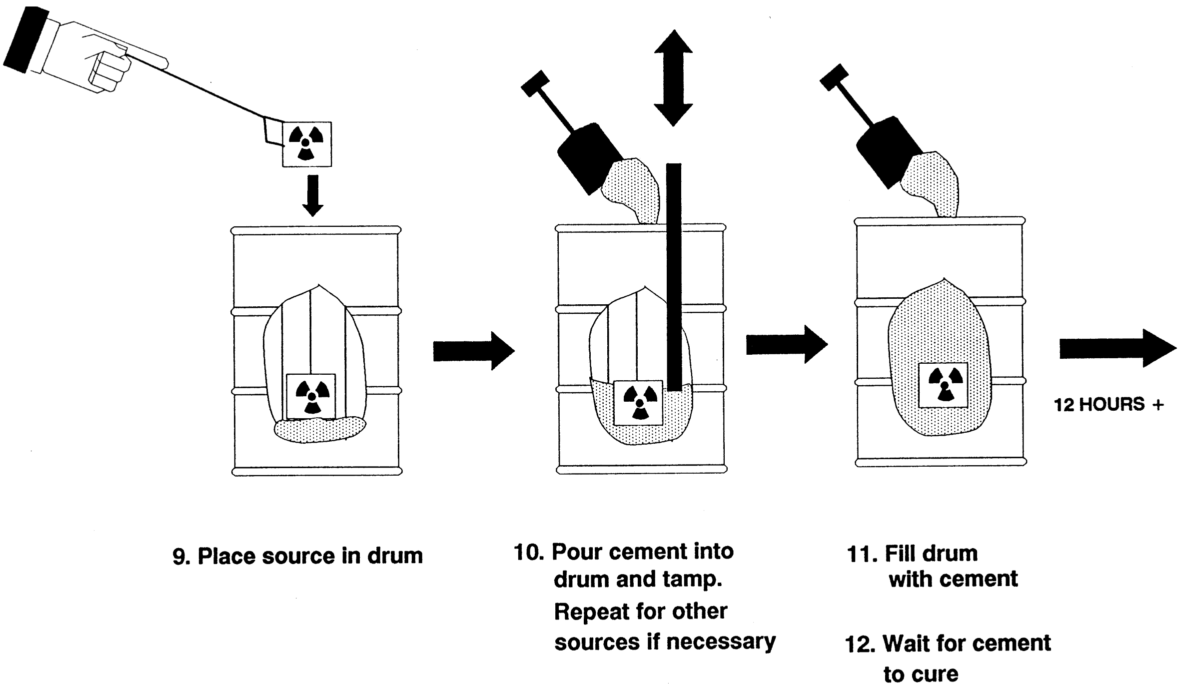


FIG. 17a. Cementation of source.

For irretrievable sources



For retrievable sources

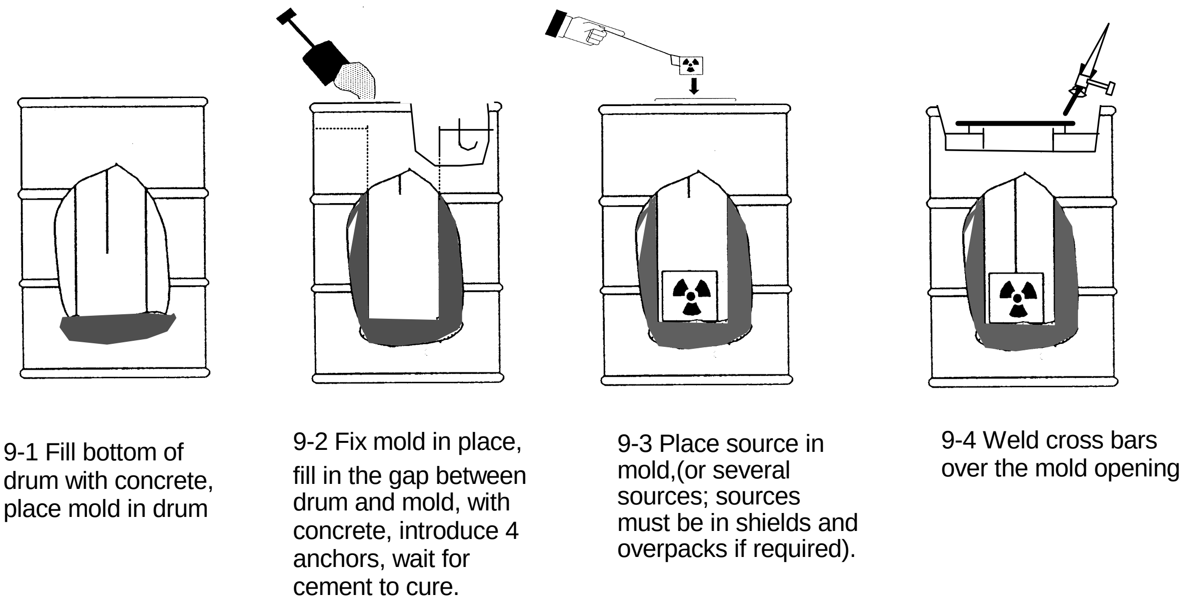


Fig. 17a (cont.). Cementation of source.

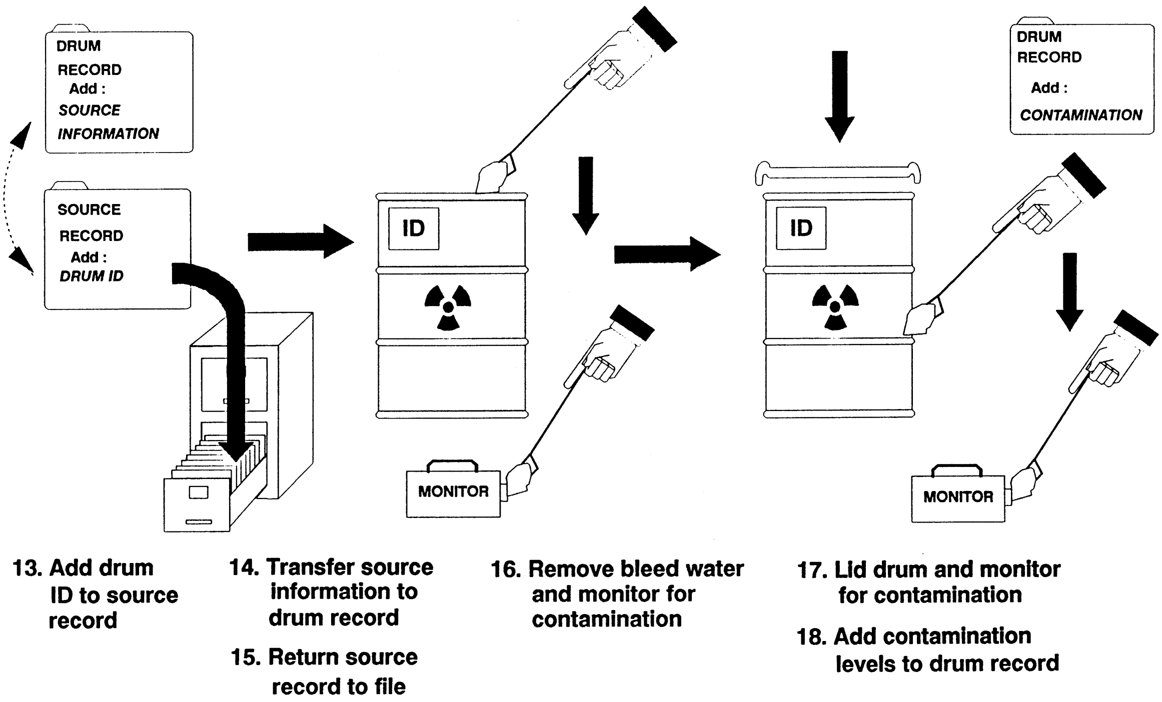


Fig. 17a (cont.). Cementation of source.

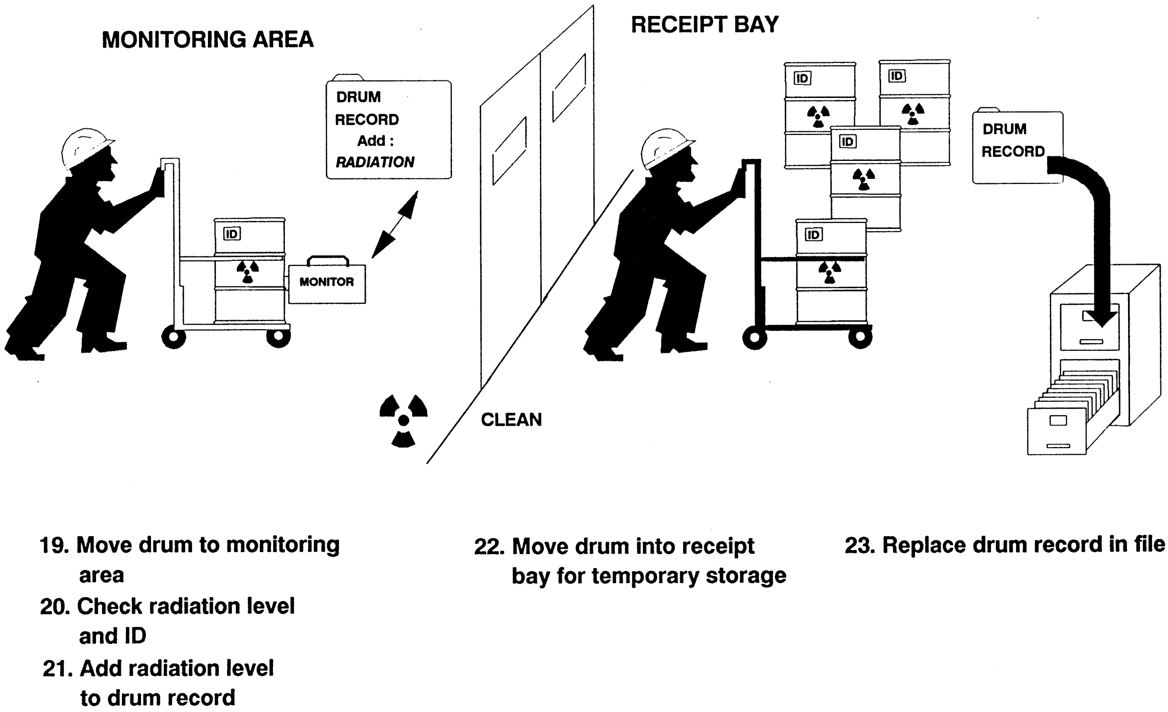


FIG. 17b. Transfer of completed drum to receipt/dispatch bay.

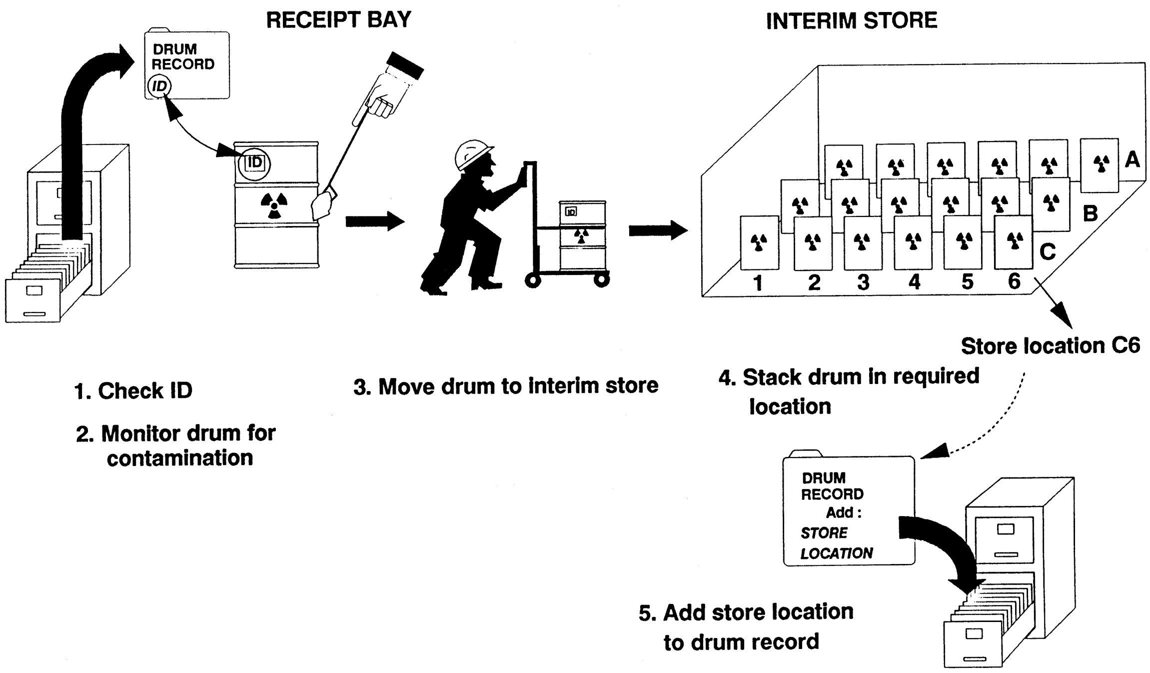


FIG. 17c. Transfer of completed drum to interim store.

FIG. 18. Typical stainless steel capsules.

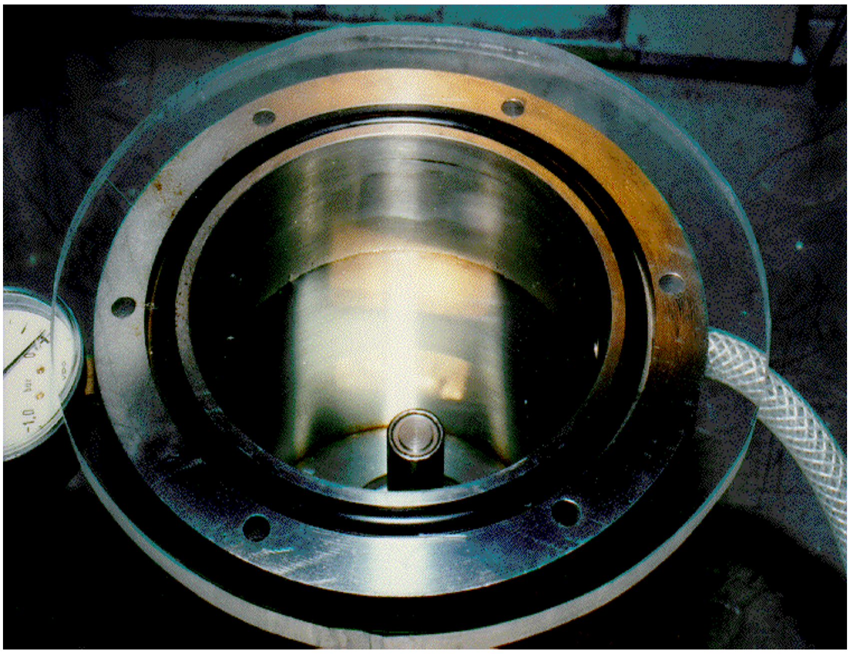


FIG. 19. Vacuum chamber for the bubble test.

Adequate shielding of the encapsulated sources must be provided for radiation protection reasons. The maximum activity per capsule multiplied by the number of capsules shall not exceed A1/A2 limit values depending on the form of the radioactive material in the source. The total activity within the lead shielding device must be limited in such a way as not to allow the dose rate to exceed 20 mSv/h at the outer surface of the capsule in order to ensure that the dose rate will be less than 2 mSv/h at the outer surface of the complete package. A lead shielding device is shown in Fig. 20.

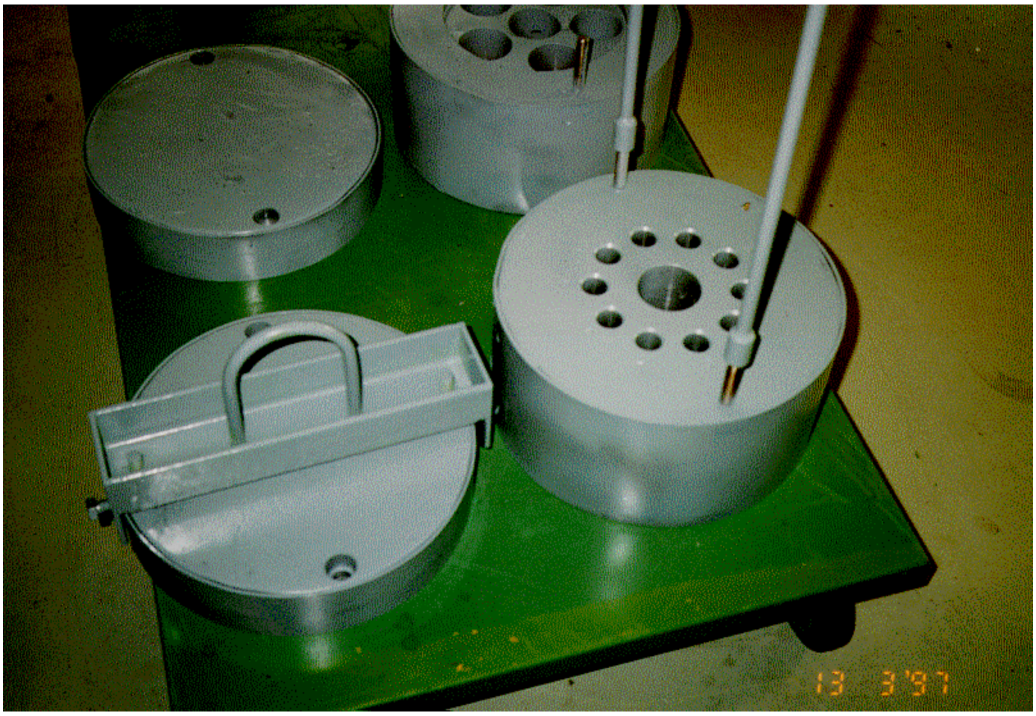


FIG. 20. Lead shielding device used for storage of the welded capsules.

The following tools and equipment are needed for encapsulation of long lived sources in the stainless steel capsules:

- Prefabricated capsules of stainless steel;
- An engraving tool;
- Dedicated handling tools (e.g. long tongs);
- TIG welding equipment with a welding current in the range of 5–50 A;
- The bubble test equipment (vacuum chamber with glycol/water, vacuum pump, vacuum meter);
- A lead shielding container for a number of capsules.

The conditioning procedures for spent SRS are described in detail in Ref. [17].

For the conditioning of other long lived spent SRS such as ^{226}Ra/Be, ^{241}Am/Be, ^{252}Cf that emit neutron radiation, hydrogenous materials (e.g. high-density polyethylene, wax, etc.) should be included in the shielding design and are subject to the approval of the regulatory body.

For each conditioned drum a drum record should be issued including main data on the drum (Fig. 21a). For radium sources where special procedures apply, special forms have been developed and are included in Annex 2. The store where the drum is kept is required to prepare a record for all stored drums as illustrated in Fig. 21b.

SPENT SEALED RADIOACTIVE SOURCES FACILITY: ……………………… ……………………
TITLE: DRUM RECORD …………………………………. DRUM ID: ……………….………

A Drum Record Card must be completed for each drum generated and the details cross-referenced on the relevant Source Record Cards.

1. Drum Details (procedure D)

Nature of Contents	CEMENTED* NOT CEMENTED*	Original Radiological Status of Drum *Maximum contact radiation level ……………mSvh^{-1}*
Drum Mass………………………..kg		*Maximum Radiation level at* *1 metre from surface of drum …………………mSvh^{-1}*
Drum lidded	YES* NO*	*Maximum contamination level on surface of drum* *alpha………….Bqcm^{-2} beta/gamma……..…..Bqcm^{-2}*

2. Waste Details (procedure D)

2.1 Sources Activity reference date

Facility Source ID	Radionuclide(s)	Activity MBq	Facility Source ID	Radionuclide(s)	Activity MBq

2.2 Miscellaneous Solid Waste

Material		Estimated weight %	Radionuclides	Activity MBq and ref. date
Wood				
Paper				
Plastic				
Others (specify)				

3. Disposition

	Drum Prepared	Drum to Receipt/ Despatch Bay	Drum to Interim Store
Date			
Storage			
Signature			

***delete as appropriate**

Fig. 21a. Drum record form.

SPENT SEALED RADIOACTIVE SOURCES FACILITY: …………………………………………	
TITLE: STORE RECORD ………………………………….	STORE LOCATION: ………

The details on this store record card must be cross referenced on the appropriate Source Record Card or Drum Record Card

PACKAGE/DRUM ID	SURFACE RADIATION mSv/hr	DATE IN/ SIGNATURE	DATE OUT/ SIGNATURE	COMMENTS

Fig. 21b. Store record form.

8. TRANSPORTATION

Any transportation of radioactive material must be done according to applicable national or international transport regulations. These are usually based on the IAEA Safety Series No. 6 [11] or the updated version, IAEA Safety Standards Series No. ST-1 [12].

The national regulatory body should be consulted prior to transportation of spent sources. If there is no such authority with adequate expertise established in the country, assistance from the IAEA may be sought.

9. STORAGE OF CONDITIONED SOURCES

Until disposal sites are available, a national interim storage facility for conditioned waste including spent sources can be developed in several different ways. It should be stressed that most of the countries do not have final repositories and therefore in most cases interim storage is the only alternative for the foreseeable future.

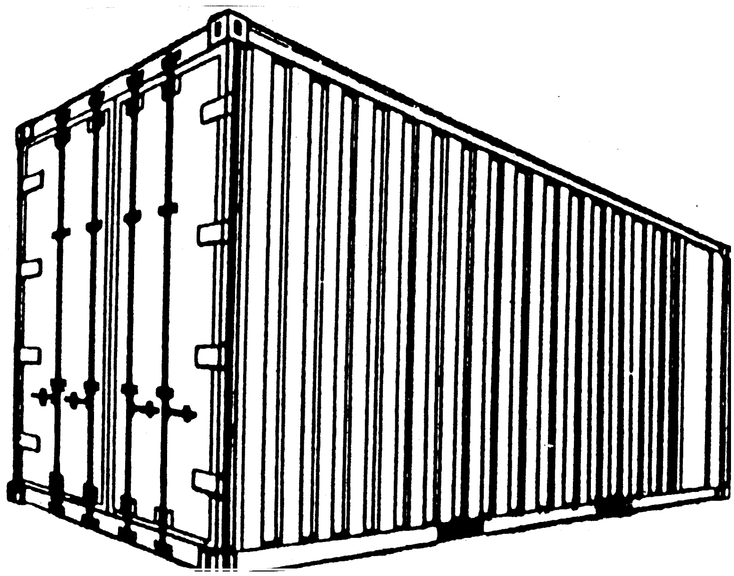
A simple way, especially for Member States not operating a complete nuclear fuel cycle, is the application of a large transportable container normally used as a shipping container (Fig. 22). The container could be set up at a suitable place, i.e. at a centralized collection site, in a small nuclear research centre, nuclear power plant or a guarded area under government control. Depending on the size, between 40 and 70 drums could be stored within such a container serving as a barrier against unauthorized contact with the waste. Later, when a repository is available, the container, including waste drums, can be transported directly without requiring additional reloading steps.

Another solution for interim storage of conditioned spent SRS, especially for Member States with a small nuclear research centre, is the erection of a simple hall on the ground surface with a steel frame construction and corrugated metal sheets covering the walls and the roof (Fig. 23). The storage hall should be built above ground water level and not be reached by a potential flood or ground water. Where this is not possible, the building must be constructed with appropriate protective systems to prevent the ground water from leaking into it or alternatively above ground level. The height of the storage place and its structure should take into consideration the potential flood levels and duration. The capacity for the waste storage facility should be designed for a sufficient period. The possibility of capacity extension should be provided for in the design of the facility.

To prevent radioactive exposure to on-site personnel and to minimize costly radioactive protection efforts, it is recommended that the interim storage facility should be constructed away from waste treatment plants or other buildings.

At the end of the interim storage period it must be possible to identify, retrieve and transport the conditioned sources to the disposal site. Drum stacking must be done in a systematic fashion for good access and easy retrievability (Figs. 24a-c). This should take fully into consideration fork lift or crane access to all locations as well as drum manipulation to reach and retrieve any drum.

Countries that make extensive use of sealed sources and have spent SRS in many institutions would require a centralized spent SRS facility and an elaborate interim storage system. An IAEA reference design for a centralized spent SRS facility is described in Ref. [18].



Container	6’ Container	10’ Container	20’ Container
Payload	6 t	9t	18t

FIG. 22. Large-scale container.

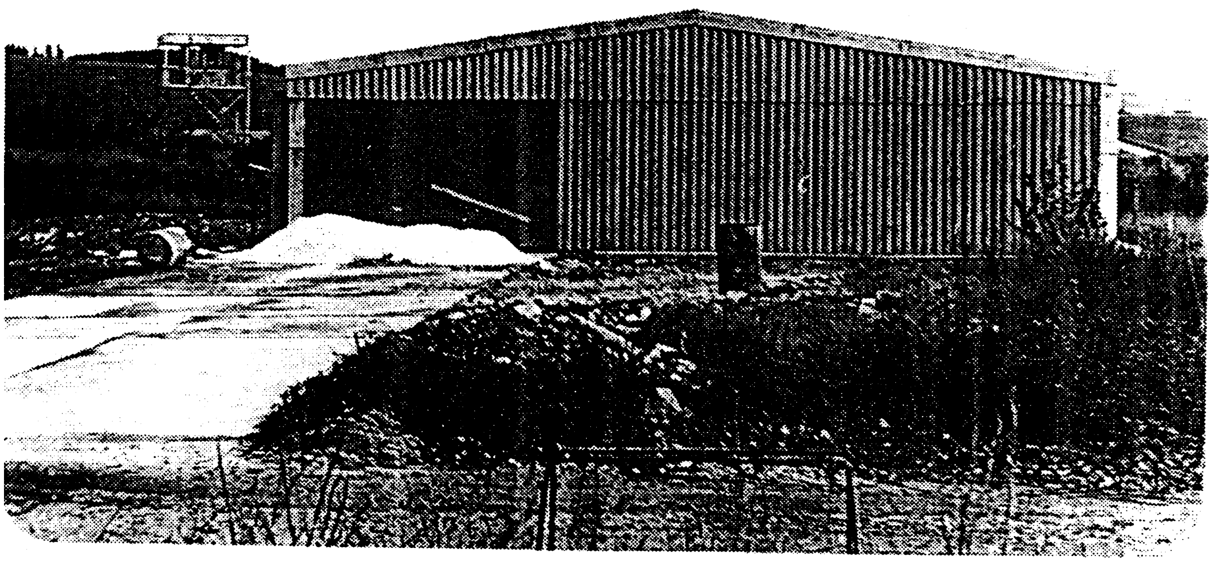


Fig. 23. Interim storage hall.

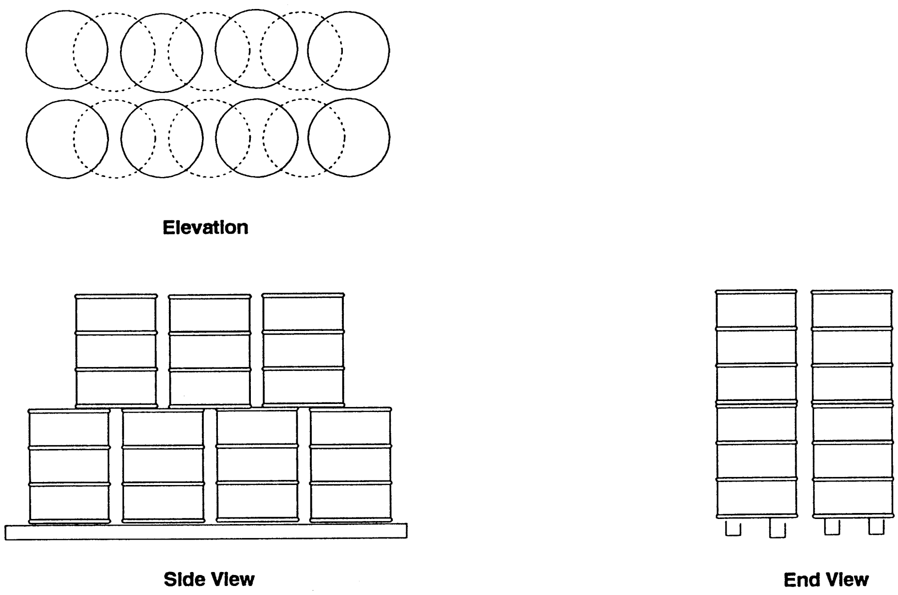


FIG. 24a. Drum stacking options — Vertical arrangement.

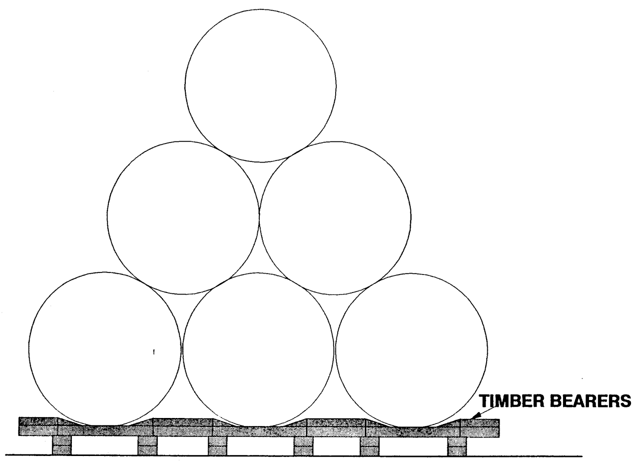


FIG. 24b. Drum stacking options — Horizontal arrangement.

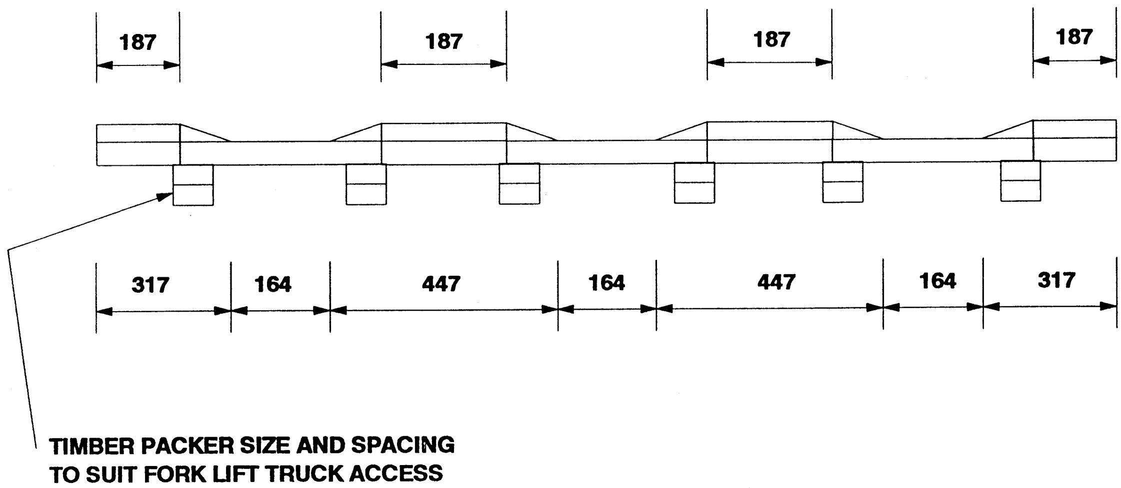


FIG. 24c. Drum stacking options — Detail of timber bearer.

10. DISPOSAL OF CONDITIONED SOURCES

10.1. GENERAL

The establishment of a disposal facility is a complex and costly operation that needs a large amount of technical and staff resources. The user of a source should always take the high disposal costs into account when planning to buy a new source.

Disposal options may include a landfill for sources below the clearance limit and a near surface repository for short lived sources. For long lived spent sources, notably radium, that cannot be returned to the manufacturer as well as other conditioned waste with the activity content exceeding the criteria for disposal in a near surface repository, controlled long term storage is the only practicable option at the present time. Geological repositories for these waste categories are being developed in several countries where the volume of such waste justifies it. Usually, disposal concepts do not require continued surveillance. However, in particular cases, such as near surface repositories, surveillance of the site during a limited period of time (referred to as the period of institutional control) may be part of the disposal concept. Furthermore, deep geological disposal facilities remain under surveillance at least during the whole operational period up to its sealing. In many cases, termination of surveillance will be a matter of special decision or even licensing.

Other options that have been considered and used in some countries are old mines (e.g. salt, uranium mines) and shallow and keep pore holes. Safety analysis for such options should be carried out and a license for such use must be granted prior to usage.

10.2. DISPOSAL CRITERIA

It is not possible to specify a disposal route for individual radionuclides contained in sealed sources since the regulations and environmental conditions vary considerably from country to country. However, there are certain common factors that must be considered in selecting a final disposal route for spent SRS. The factors listed below require evaluation under acceptance criteria of the repository, guidelines and standards established in each country by the National Regulatory Body:

- Radionuclide;
- Activity of the source;
- Migration characteristics of the radionuclides;
- Nature, mass and size of the spent source disposal package;
- Disposal site characteristics;
- Time period that the disposal site will be under institutional control;
- Engineered and natural barriers;
- Toxicity of any other non radioactive material deposited with the source.

Only after a careful safety assessment including the above factors, can a disposal site and a disposal route for a specific sealed source be defined.

As an example, US procedures [19] specify that the activity of small concentrated sources, such as small check sources (<3.7 MBq), may be generally averaged over the waste volume when mixed with low level solid waste streams. Care needs to be taken to differentiate between the volume of the waste form and the volume of the waste container if the latter is significantly larger (e.g. greater than 10%). For sources that are 3.7 MBq or greater, the volume or mass used in determining the radionuclide concentration is that of the source. Thereby, sources <3.7 MBq could be disposed of with other wastes and the activity averaged over the entire waste volumes. Sources ≥3.7 MBq would have to be profiled as a separate waste stream and the volume or mass of the source itself would be used in determining the radionuclide concentration. All sources containing alpha-emitting nuclides must be evaluated individually, considering only the mass of the source itself and any component integral to the source.

10.3. ECONOMIC CONSIDERATIONS

It would be possible to establish safe near surface repositories, suitable for most radioactive waste generated in almost every country. However, many countries generate only small quantities of radioactive waste, up to a few cubic meters per year. The cost of disposal per unit of waste would be very high if they have to establish their own repositories. Thus, combined efforts should be made, among several countries in a region, to set up a regional repository. In this way a better site may be selected, and also additional engineered barriers could be constructed and more efficient control measures put into effect. Factors influencing the development of multinational repositories are described in Ref. [20].

The cost of construction of a deep geological repository will be extremely high. It would be difficult to justify the construction of such repositories in countries having a few long lived spent SRS. The amounts of radioactive material in these sources are, however, negligible compared to that in the high level waste from nuclear power programmes, for which deep geological repositories will have to be built. The addition of spent sources to the high level waste or spent fuel from nuclear reactors going into a deep geological repository is a viable option.

11. CONCLUSIONS

The technical manual provides guidelines to various operations required to manage spent SRS. These guidelines, while in compliance with the basic safety standards and relevant waste safety requirements, are only one way to fulfil these requirements. The reader is expected to consider actual conditions and prevailing situations to make his procedures and actual guidelines effective according to his conditions and available infrastructure. The reader is also expected to upgrade the infrastructure if it does not fulfil all requirements and should not under any circumstances compromise the safety and radiation protection requirements to accomplish a certain operational objective.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Planning the Medical Response to Radiological Accidents, Safety Reports Series No. 4, IAEA, Vienna (1998).

[2] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Sealed Radioactive Sources — Classification, ISO 2919:1980, ISO, Geneva (1980).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[4] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Radiation Protection — Sealed Radioactive Sources — Leakage Test Methods, ISO 9978:1992, ISO, Geneva (1992).

[5] PETOUSSI, N., et al., "Dose distributions in the ICRU sphere for mono-energetic photons and electrons and for ca. 800 radionuclides", GSF-Bericht 7/93, Forschungszentrum für Umwelt und Gesundheit GmbH, Neuherberg (1993).

[6] PFENNIG, G., KLEWE-NEBENIUS, H., SEELMANN-EGGBERT, W., Chart of the Nuclides, 6th Edition, Karlsruhe, Germany (1995).

[7] MÜNZE (Ed.), Isotopentechnik, Fachbuchverlag Leipzig (1991).

[8] FÖLDIAK, G. (Ed.), Industrial Application of Radioisotopes, Akadémiai Kiadó, Budapest (1986)

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, The Safe Use of Radiation Sources, Training Course Series No. 6, IAEA, Vienna (1995).

[10] VOLF, V., "Massnahmen zur Ausscheidungsintensivierung von radioaktivem Strontium und Cäsium" (Possible measures for stimulating the elimination of radioactive strontium and caesium), Kernforschungszentrum Karlsruhe GmbH (1987).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material, 1985 Edition (As Amended 1990), Safety Series No. 6, IAEA, Vienna (1990).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material (1996 Edition), Safety Standards Series No.ST-1, IAEA, Vienna (1996).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Establishing a National System for Radioactive Waste Management, Safety Standard No. 111-S-1, IAEA, Vienna (1995).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Quality Assurance for Radioactive Waste Packages, Technical Reports Series No. 376, IAEA, Vienna (1995).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Clearance Levels for Radionuclides in Solid Materials, IAEA-TECDOC-855, Vienna (1996).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Principles for the Exemption of Radiation Sources and Practices from Regulatory Control, Safety Series No. 89, IAEA, Vienna (1988).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Conditioning and Interim Storage of Spent Radium Sources, IAEA-TECDOC-886, Vienna (1996).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Reference Design for a Centralized Spent Sealed Sources Facility, IAEA-TECDOC-806, Vienna (1995).

[19] US NUCLEAR REGULATORY COMMISSION, Branch Technical Position on Concentration and Encapsulation, NRC, Washington, DC (1995).

[20] INTERNATIONAL ATOMIC ENERGY AGENCY, Technical, Institutional and Economic Factors Important for Developing a Multinational Radioactive Waste Repository, IAEA-TECDOC-1021, Vienna (1998).

Annex 1

DECLARATION OF A SPENT SOURCE OR A POTENTIALLY SPENT SOURCE

PART A

To: RMC........

Source: *(full identification of the source: Model, Serial No., Nuclide, Activity, and Date of Measurement)* ……

Owner *(name and address of the owner of the source).*………………………………………………………… ……

◊ The source will no longer be used
◊ The source cannot be found
◊ The source cannot be removed from its assembly/is damaged/is leaking

....	....
Name of the user of the source	Signature

PART B

To: Regulatory Body........

◊ The source has been declared as a potential SPENT SEALED RADIOACTIVE SOURCE
◊ The source is not accounted for/is damaged/leaking/cannot be removed from its assembly.

The source is now stored at/the immediate actions to recover the source are.. .... *(name the place where it is stored and its identification, e.g. stored in a 5 kg yellow lead container marked with identification number XXXX).*

I take the responsibility to ensure that the source is properly managed until the next management stage has been decided/an investigation into the whereabouts of the source is carried out/remedial actions are carried out

....	....
Name of the RMC	Signature

PART C

The above SPENT SEALED RADIOACTIVE SOURCE has been consigned as follows

◊ Decay storage *(give location of storage)* and will be disposed on *(enter date)*
◊ Return to supplier
◊ Transfer to another user *(give entails of new user location and responsible person)*
◊ On site interim storage *(give location of storage)*
◊ Transfer to a Centralized Waste Operating Organization

....	....
Name of the RMC	Signature

One copy for the Radioactive Materials Co-ordinator for filing
One copy for the former user of the source for documentation
One copy to the Regulatory Body for information

Annex 2

SOURCE INFORMATION FORM*

Part 1: Information on Source (one information sheet is required for each source)		
File identification number (Detailed records):		
Identification number of source (if any):		
Type:	**Dimensions:**	**Activity (Bq): Nuclide**
Name of last keeper:	**Address of last keeper:**	**Calibration date:**
Source integrity:		

Part 2: Encapsulation	
Identification number of capsule:	
Total radium activity (if any) in capsule (mg):	**Date:**
Number of source(s) in capsule:	
Type of leak test applied: **Re-encapsulation required (yes/no):**	**Pass/fail:** **New capsule ID No.:**

Part 3: Lead Shielding (optional)	
Position of capsule in shielding:	**Total number of capsules in shielding:**

Part 4: Storage Drum and Interim Storage	
Identification number:	
Contact dose rate:	**Dose rate at 1 meter from surface:**
Position of drum in store:	**Date of loading:**

Part 5: General Details	
Place of conditioning:	**Date of conditioning:**
Responsible Conditioner:	**Signature of Responsible Conditioner:**

*For radium or other small sources to be encapsulated in stainless steel.

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