IAEA-TECDOC-548

HANDLING, CONDITIONING AND DISPOSAL OF SPENT SEALED 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 Series (TRS) and Safety Series (SS) documents on radioactive waste management over nearly three decades. These documents have served Member States presenting basic reference material and comprehensive surveys of the "state-of-the-art" technologies applied to radioactive waste management.

The need for assistance in specific waste management problems facing many developing countries has been demonstrated in IAEA activities including technical assistance missions and Waste Management Advisory Programme (WAMAP). TRS and SS documents are usually prepared by experts from developed nations reflecting:

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

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

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

The series entitled "Technical Manuals for the Management of Low and Intermediate Level Wastes Generated at Small Nuclear Research Centres and by Radioisotope Users in Medicine, Research and Industry" will serve as reference material to experts on technical assistance missions and provide "direct know-how" for technical staff in developing countries.

Currently, the following manuals have been identified,

- minimization and segregation of radioactive wastes
- interim storage for decay, for untreated and conditioned wastes
- handling, conditioning and disposal of spent sealed sources
- handling, treatment and conditioning of solid radioactive wastes
- treatment and conditioning of carcasses and biological material

- treatment and conditioning of radioactive effluents
- treatment and conditioning of radioactive organic liquids
- treatment and conditioning of spent ion exchange resins from research reactors
- design of a centralized waste processing and storage facility.

The order of preparation of the manuals is based on priority needs of Member States and is recognized that additional areas of technical need may be identified as this programme is implemented. In this regard the programme is flexible, should other manuals or modifications prove necessary. The documents should be regarded as interim until completion of the series and feedback from users is incorporated.

This document is the first in the series and covers "Handling, Conditioning and Disposal of Spent Sealed Sources". The subject has proved to be urgently needed in many developing countries with inventories of spent sealed sources. The hazards associated with old or spent radiation sources that are not properly managed, include inadvertent radiation exposure and contamination of unsuspecting members of the public and have been well documented (incident reports from Mexico-1983, Morocco-1984 and Brazil-1987). This document provides the technical guidance and know-how necessary to permit developing Member States to safely handle, condition and store spent sealed radiation sources.

The IAEA expresses gratitude to the consultants, Mr. D. E. Saire (DOE, Office of Nuclear Energy, USA) and Mr. D. W. Clelland (Nuclear Industry Consultant, UK) who prepared the original draft in June 1988 working in conjunction with W. Baehr as responsible officer from the IAEA. The final report was the responsibility of G. R. Plumb of the Division of Nuclear Fuel Cycle and Waste Management.

EDITORIAL NOTE

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1. INTRODUCTION

Sealed sources are high integrity capsules each containing a small mass of a specific radioisotope in concentrated form. The isotope in each case has been chosen for a specific application and the radiation level from the source is usually intense. A very high degree of containment of the radioactive material is provided in the design of the capsule. This facilitates handling in transport and use. The activity of the source depends upon the duty required and varies from less than 1 microcurie (37 MBq) to powerful sources containing thousands of curies (370 TBq). The higher activity sources are usually double encapsulated in a corrosion resistant metal such as stainless steel. The main categories of sources and their fields of application are,

- gamma sources: used in industry, radiotherapy clinical therapy and sterilisation
- beta sources: used in industry (eg. thickness gauges), clinical therapy, education and training
- alpha sources: used as heat sources, in analytical practices, education and training
- neutron sources: used in analytical practices, industry, calibration techniques, education and training.

Table 1 provides a summary of widely used sealed sources and their fields of application.

Table 1

List of Radionuclides and Their Application as Sealed Source

Application	Radionuclide	Half-life	Comments
I. Industrial application			
Thickness gauge	^{85}Kr ^{90}Sr (^{14}C, ^{32}P ^{147}Pm, ^{241}Am)[a]	10.3 y 28.1 y	To measure thickness of paper, plastic, and similar.
Level gauge	^{137}Cs ^{60}Co (^{241}Am)	30 y 5.2 y	To measure levels in containers (e.g., silos) and packages (e.g., tin cans).
Density gauge	^{137}Cs ^{241}Am (^{90}Sr)	30 y 433 y	To measure mass transport on conveyor belts.
Moisture detector	$^{241}AmBe$ (^{252}Cf, $^{226}RaBe$)[a]	433 y	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)[a]	5.3 y 74 d	Used for nondestructing testing. May be used as fixed or portable equipment.
Eliminator for static electricity	^{210}Po	138 d	Used in film industry. May be used as fixed or portable equipment.
Roentgen fluorescence analyzer	^{55}Fe (^{238}Pu, ^{241}Am)[a]		Portable equipment used to analyze metals.
Sterilization	^{60}Co	5.3 y	Used to sterilize medical equipment and food-stuif.
II. Research application			
Electron capture detector	^{3}H (^{63}Ni)[a]	12.3 y	Used as detector in gas chromatographs
Tritium targets	^{3}H	12.3 y	Used to product neutrons by D, T reactions
Calibration sources	Many different		Used for function and efficience control of instruments and for calibration.
Eliminator for static electricity	^{210}Po	138 d	Used in analytical balances.
III. Medical application			
Clinical radiotherapy	^{60}Co (^{137}Cs, ^{192}Ir)[a]	5.3 y	
Eye applicator	^{90}Sr, ^{32}P	28.5 y 14.3 y	
Bone densitometer	^{241}Am ^{125}I	433 y 60 d	

a) The brackets give other radionuclides which may be used for the application.

2. CHARACTERIZATION OF SEALED SOURCES

2.1 General

Sealed sources are available with a wide range of activities and designs for many different applications in industry, research, medicine and institutions. While Table 1 shows that the application of sealed sources are wide ranging the radionuclides in common use are more limited, particularly, ^{3}H, ^{60}Co, ^{90}Sr, ^{137}Cs, and ^{241}Am. Table 2 lists sealed sources according to their activity levels. This information is taken from a sealed source registry maintained by the United States Nuclear Regulatory Commission (USNRC)[1,2].

Table 2

Distribution of Activities Among Sealed Source Designs
(United States)

Activity Range (Ci)

Radionuclide	.001-.009	.01-.09	.1-.9	1-9	10-90	100-900	1,000-9,000	10,000-90,000	Total
H-3	1[1/] (3.7)[2/]	-	10 (37.0)	11 (40.7)	5 (18.5)	-	-	-	27
C-14	1 (50.0)	1 (50.0)	-	-	-	-	-	-	2
Co-60	2 (1.2)	24 (14.5)	27 (16.4)	23 (13.9)	25 (15.2)	31 (18.8)	14 (8.5)	19 (11.5)	165
Ni-63	2 (25.0)	6 (75.0)	-	-	-	-	-	-	8
Sr-90	5 (6.6)	13 (17.1)	28 (36.8)	27 (35.5)	3 (3.9)	-	-	-	76
Cs-137	5 (2.6)	42 (21.6)	62 (32.0)	41 (21.1)	17 (8.8)	16 (8.2)	11 (5.7)	-	194
Pu-238	-	1 (3.7)	9 (33.3)	7 (25.9)	10 (37.0)	-	-	-	27
Am-241	5 (3.5)	25 (17.7)	47 (33.3)	49 (34.8)	15 (10.6)	-	-	-	141
Pu-238/Be[3/]	-	-	-	1 (33.3)	2 (66.7)	-	-	-	3
Am-241/Be[3/]	-	4 (25.0)	-	4 (25.0)	8 (50.0)	-	-	-	16

1/ Indicates the number of source designs for the activity range.

2/ Indicates the percentage of source designs as compared to the total number of desi

3/ These are neutron sources, plutonium-beryllium and americium-beryllium.

Table 1 indicates the fields of application of sealed sources of different activity levels. A wide range of applications is indicated for sources containing ^{137}Cs, ^{60}Co, ^{241}Am, and ^{90}Sr since the number of different source designs employing these radionuclides is large. The wide application of ^{137}Cs sources may be noted with 194 individual designs covering an activity range from a few millicuries (industrial gauging) to large sources containing many thousands of curies (clinical radiotherapy). Sealed sources containing ^{60}Co are also widely used with 165 registered designs. High activity ^{60}Co sources accounting for about 12 percent of the total have activities ranging from 10,000 to 90,000 curies and are commonly used for sterilisation of medical equipment, food products etc. High activity ^{60}Co and ^{137}Cs sources used in hospitals for teletherapy are usually contained in heavy lead shielding casks.

Alpha emitting radionuclides which bombard a target producing a field of neutrons are used in well logging, mineral exploration, analytical practices and reactor start-up. Beryllium is often used as a target material with an alpha source utilising the high yield of neutrons from alpha-neutron reactions. ^{238}Pu and ^{241}Am are also extensively used as sealed sources. Figure 1 shows an example of a $^{241}Am/Be$ neutron source and Figure 2 a ^{241}Am gamma source[3].

The number of sealed sources requiring disposal is considerable, but, because sealed sources are intense concentrations of radionuclides in extremely small masses the total volume of the waste involved is small. For example, a sealed source 40 mm long and 13 mm diameter would have a volume of about 5 ml and so even if 10,000 sources had to be stored or disposed of the total volume would only be 50 litres.

In consideration of possible final disposal schemes, alpha sources should always be separated from beta/gamma sources as the disposal route will probably be different (shallow land burial vs. deep geological repository).

2.2 Radium Sealed Sources

For some time ^{226}Ra was extensively used in sealed sources in industry and medicine but is now being replaced by ^{137}Cs, ^{3}H, ^{192}Ir and ^{241}Am. However, large numbers of spent ^{226}Ra sealed sources (medical needles, cells and plaques) remain in inventories throughout the

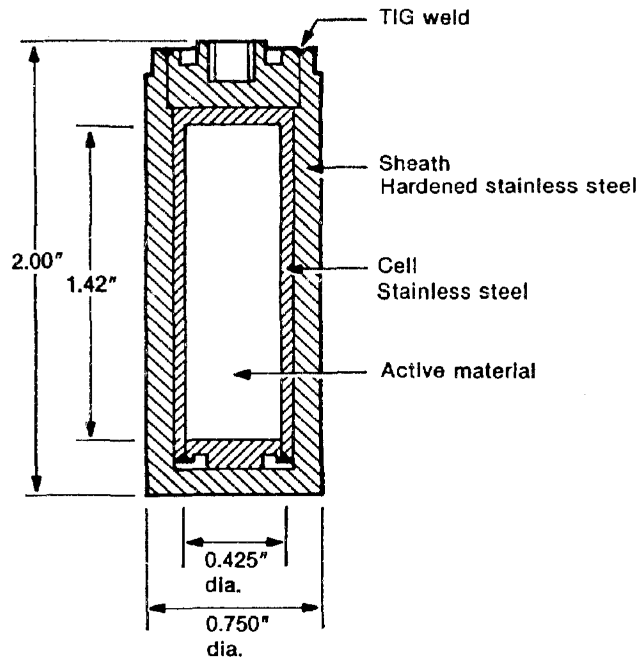


FIG. 1. Typical oil well logging source: americium-241–beryllium neutron source.

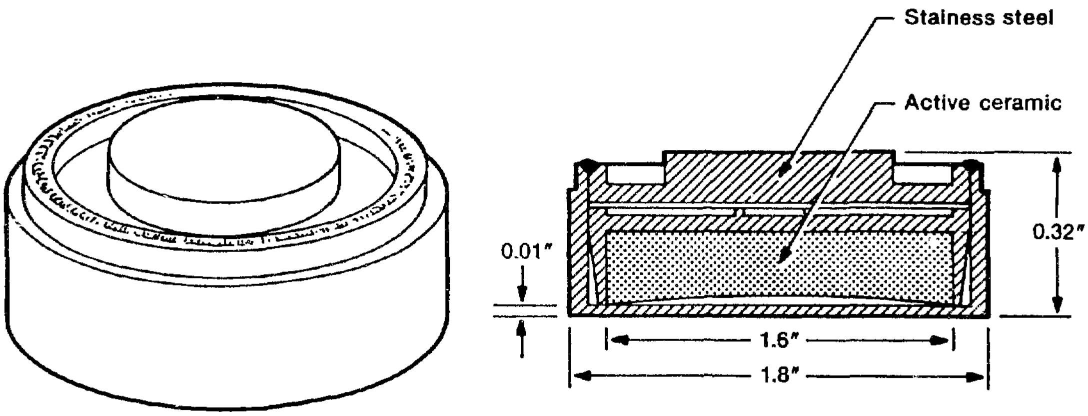


FIG. 2. Typical low-energy gamma source: americium-241.

world and need to be disposed of in a safe manner. Figure 3 shows some of the different designs for medical sources containing ^{226}Ra. The radium is usually encapsulated in a platinum-iridium alloy or in some cases gold.

Estimates of the number of spent ^{226}Ra sources which need conditioning and disposal vary widely. It is estimated that in the USA about 1,100 spent radium sources arise annually[2]. Other information indicated that large numbers of spent radium sources are located in developing countries where source management and disposal technology assistance is needed. The Agency has estimated that 1,250 radium needles and 400 radium tubes may need to be disposed of annually.

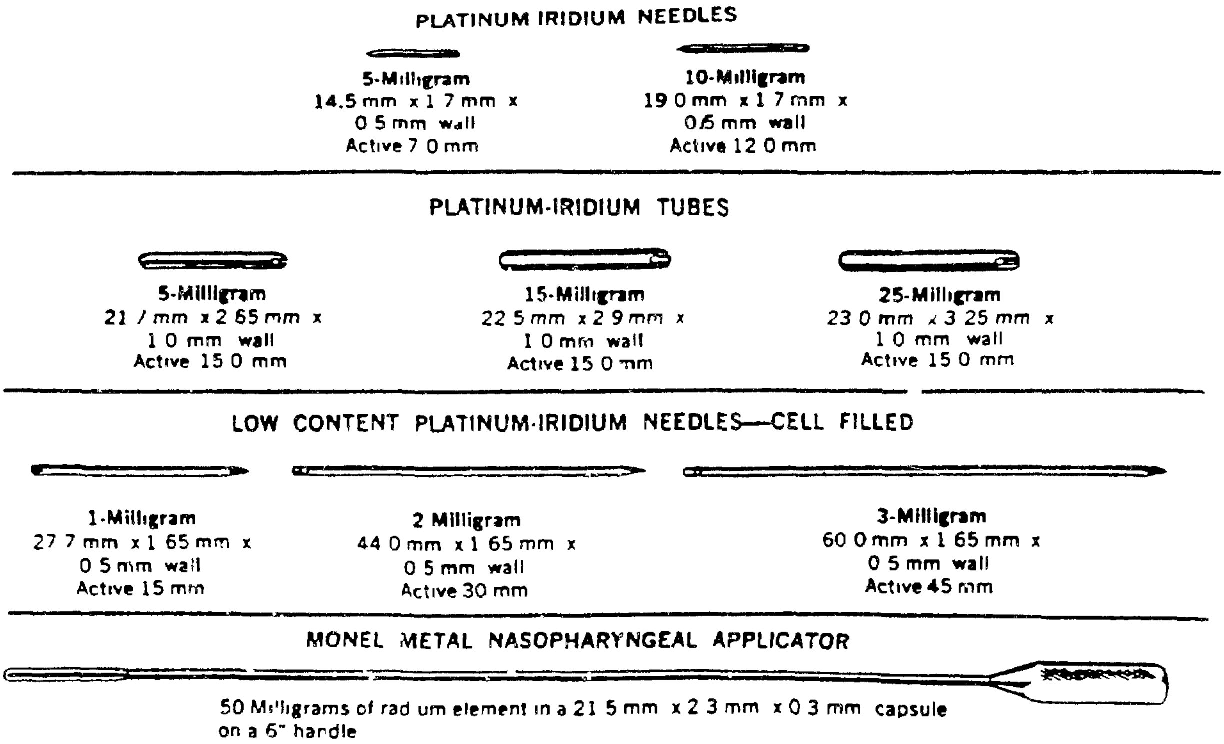


FIG 3 Typical medical radium sources [2]

Table 3
Summary of Data for Medical Radium Sources[2]
(United States)

Activity Range (mg)	Needles	Cells	Plaques	Nasopharyngeal Applications
≤ .1	0.01[1/] (0.01)[2/]	-	0.6 (0.007)	-
.1 ≤ .5	0.14 (0.45)	0.3 (0.46)	-	-
.5 ≤ 1	2.2 (0.73)	5.4 (0.61)	0.6 (0.89)	-
1 ≤ 5	52.1 (3.05)	40.9 (3.20)	30.6 (3.42)	3.1 (3.28)
5 ≤ 10	40.0 (7.72)	37.4 (7.57)	41.9 (8.18)	4.6 (9.44)
10 ≤ 50	5.3 (15.4)	15.8 (17.60)	24.1 (17.5)	81.5 (44.7)
50 ≤ 100	0.13 (71.7)	0.2 (66.9)	2.2 (61.0)	10.8 (67.4)
> 100	0.04 (118.0)	-	-	-
Weighted Ave. (mg)[3/]	5.65	7.09	10.01	44.2
Est. total number of sources	7,669	3,355	320	65

1/ The percent of sources in the activity range compared to total sources.

2/ Weighted average activity in the activity range.

3/ Weighted average for each type of source.

Table 4

Summary of Data for Non-Medical Radium Sources[2]
(United States)

Ra-Be Sources-Activity Range (mg)		Other Miscellaneous Sources (mg)	
≤ 1	10.5 1/ (0.36) 2/	≤ 0.01	38.4 (6.13E-4)
1 < 5	14.0 (3.75)	.001 ≤ .01	36.0 (4.09E-3)
5 < 10	11.6 (9.49)	.01 ≤ 0.1	3.5 (4.87E-2)
10 < 50	14.0 (18.6)	0.1 ≤ 1	9.7 (4.88E-1)
50 < 100	2.3 (100.0)	1 ≤ 10	10.2 (3.17)
100 < 500	17.4 (302.0)	10 ≤ 100	0.4 (54.9)
500 < 1,000	4.7 (678.0)	100 ≤ 1,000	1.3 (464.0)
> 1,000	25.5 (1,431.5)	> 1,000	0.5 (3,210)
Weighted Ave 3/ (mg)	457		22.7
Est. total number of sources	86		1,703

1/ The percent of sources in the activity range compared to the total number of sources.

2/ Weighted average activity of source in the activity range.

3/ Weighted average for each type of source.

In developing countries, the activity levels of radium sources which will require disposal varies widely depending on the source design and field of application. USNRC has collected data on medical and nonmedical sources which will require conditioning and disposal in the United States. Tables 3 and 4 provide the activity range and estimates of the percentage of sources in each activity range for medical and other radium sources[2]. The activity range for medical radium sources rarely exceeds 100 milligrams with the average source being in the order of about 5.6 mg for needles and about 7 mg for the radium cells. Over 90% of radium needles and 78% of radium cells are within the activity band of 1 to 10 mg. However, as shown in Table 4, activity levels of nonmedical radium sources have higher activity levels. About 30 percent of the Ra-Be neutron sources exceed 500 mg of radium and a small number of miscellaneous sources can exceed 1,000 mg radium.

3. LEGISLATION AND REGULATIONS

The development of legislation relating to practices involving radioactive materials varies greatly from one country to another and is generally at a starting point in many developing countries particularly those so far without a nuclear energy programme but using radioactive materials in medicine, industry, research institutes and universities.

With respect to the management of spent sealed sources there is usually no specific legislation which deals with this area and present practices may be included under radiation protection and waste management legislation. Spent sealed sources however have very special characteristics, being very concentrated, often very small, and sometimes containing long lived isotopes. Robust construction of the source ensures that they will remain in a concentrated form for a long time and lastly they are very numerous.

The exceptional characteristics prevent the application of generally accepted waste management practices and there is a need for the development of specific legislation. The guidelines in this document will aid the process of establishing safe procedures where there is a priority need for the development of formal regulatory guidelines on mangement and disposal of such spent sealed sources.

4. RESPONSIBILITY FOR THE MANAGEMENT OF SPENT SEALED SOURCES

Common practice in the supply of sealed sources involves outright purchase of the source by the user without any undertaking by the manufacturers/suppliers to accept the return of spent or surplus sources. In effect, the arrangement places responsibility for the management of such spent sources on the user.

Since presently there are virtually no developed and authorised disposal facilities for spent sources in developing countries, the users currently store these without any immediate prospect of disposal. The completion therefore of a satisfactory waste management system has not been achieved.

From the point of view of radioactive waste management it is highly desirable to minimise the number of sources in use or stored pending disposal. Therefore, whenever possible a spent source should be recycled or allocated to another user. A mechanism for the correct 'sentencing' of surplus spent sources is required deciding the most appropriate action between, use, recycle and disposal.

Since the manufacturers/suppliers are in touch with the economics of recycle and the demand for sources of various types they are in the best position to make correct 'sentencing' decisions. Because of this, and to obtain the best waste management system it is recommended that sources should be 'leased' by users and (not purchased outright) when spent or surplus returned to the manufacturer/supplier for sentencing.

An outline scheme for the management of sealed sources is given in Figure 4. This summarises the principles discussed above in this section and indicates procedures which are discussed further in detail in later sections of this document.

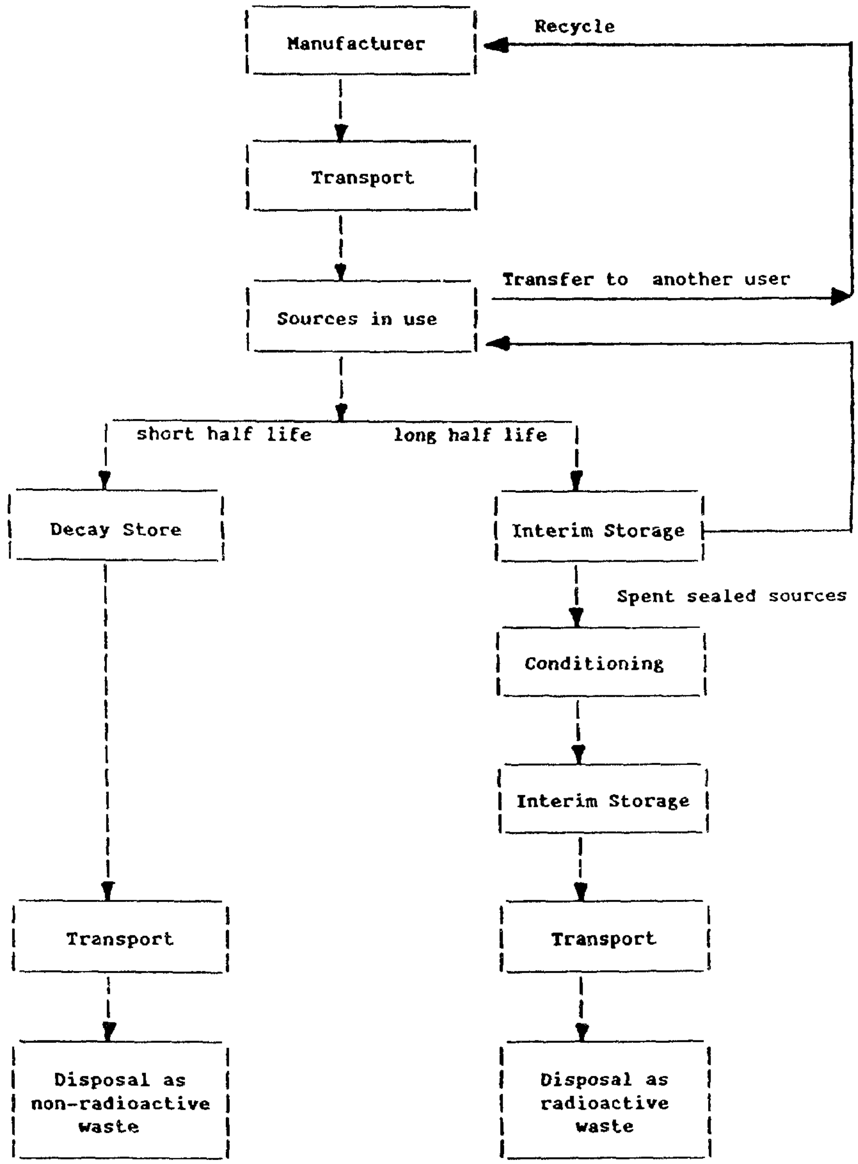


FIG. 4. An outline scheme for the management of sealed sources.

5. OPTIONS IN THE MANAGEMENT OF SPENT SEALED SOURCES

5.1 General

Sealed sources become surplus when the activities of the sources have decayed to the extent that they are no longer suitable for their original purpose, the experiment or programme using the source is completed or discontinued, the source develops a leak or the source apparatus becomes outdated or difficult to operate. While a source may not be suitable for its original purpose, it still may be highly radioactive and should be treated as a hazardous material.

Users may have the following management options to consider:

- transfer the source to another user for application elsewhere at the current activity level,
- return of the spent sealed source to the original supplier,
- decay storage of sources containing radionuclides with short half-lives,
- collection, and storage of the source in an interim facility until a conditioning facility is available,
- conditioning of the sealed sources and interim storage until a repository is available.

The option selected for a particular sealed source will depend on the variety of relevant factors including activity, radioisotope content, terms of the purchasing contract and physical condition of the source.

5.2 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 the use for another purpose. This may especially be the case for the high activity ^{137}Cs and ^{60}Co sources. Sources no longer of use for clinical therapy may well be useful in other applications requiring lower levels of activity. 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.

All countries with limited nuclear programmes should develop a sealed source utilization plan. The national body (competent authority) which exercises regulatory control over the use of radioactive materials should administer the plan. Such a plan should provide for

- reviewing the sealed source requirements of all users
- ensuring that the minimum number and activity levels of sealed sources are purchased (including source lease plan discussed in Section 4 and 5.1 above) consistent with the objectives of the users
- development of a "logistical use plan" for the projected life of sources
- maintaining records and controls to implement logistical use plans
- adequate equipment (source caskets, shipping containers) and instruments necessary in the transfer of sources between users.

Administrative procedures and control should be implemented by the competent authority to ensure that users do not obtain new sealed sources when suitable sources are already available within the framework of the national sealed source utilisation plan.

5.3 Return to the Original Supplier

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 source to the supplier at the end of the contract period. Leasing should be practised by users requiring sources with initial activity levels of 100 GBq or more, or that containing long life radionuclides[4].

Returning the source to the original supplier may provide the manufacturer with the opportunity to recycle the radioactivity contained in the spent sources as it is frequently economically attractive to recover the radioactive component for incorporation in new sources. Disposal of the spent sealed source 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 (lead casket with overpack). If the original shipping container is not available, provisions should be made to acquire a new container or to contract for transport through a specialized nuclear transport organisation. Shipments of spent sealed sources should follow the standards which are provided in IAEA transport regulations[5].

Sealed sources with radionuclides of short half-lives can be procured on a direct purchase basis. On-site management control of spent sealed sources with short half-lives should provide safe handling and storage for the time required for the activity to decay to such a level that they can be considered inactive material (indicatively 70 kBq/kg (2 nCi/g) and disposed of as non-radioactive waste. Decay storage of short half-life sealed sources is discussed below.

5.4 Decay Storage of Short Half-Life Spent Sources

A decay period of about 10 half-lives is often enough to allow decay of the activity to levels acceptable for disposal as non-radioactive waste. However, disposal of decayed spent sealed sources to municipal waste areas or other non-radioactive waste fill/burial sites should not be made until it is confirmed that the residual activity to be released to the environment meets the standards/guidelines established by the national competent authority. Spent sealed sources containing the following radionuclides may be considered for decay storage:

Nuclide	Half-life (days)
^{32}P	14.3
^{192}Ir	74
^{210}Po*	138

* Depending upon the activity level of the source.

During decay sources should be retained in their original shipping casket and overpacks (or suitable replacements) each labelled to show,

- the container holds radioactive material (using the conventional trefoil radiation warning symbol)
- the radionuclide contained in the source
- the activity level and the date decay storage was commenced
- the estimated date when the source may be disposed of as nonradioactive material.

Administrative controls and surveillance should be maintained over the spent sealed source during the decay storage period. Periodical examination and testing of the sealed source is advisable to ensure that there is no leakage of radioactivity from the source. In the event of a loss of containment, the source should be removed and conditioned using one of the options described in Section 5.6.

The area for decay storage may be within existing facilities or a specially constructed building. It should be located to avoid in-leakage of ground or rain water and areas with a history or prospect of flooding. Special shelving may be convenient for small packages. The floor in the storage area should be constructed for easy decontamination, e.g. concrete with an epoxy overlay is recommended. Access to the storage area should be restricted to qualified staff who have a need to enter. Security measures should be instituted to reduce the risk of entry by unauthorized persons.

5.5 Interim Storage of Spent Sealed Sources

5.5.1 General

Storage may be defined as the placing of the source in a system with the intention of retrieving it at a future time for a further purpose. Storage therefore by definition involves retrievability.

The object of storage may be to await decay, transport, disposal or the identification of another user. In storage, containment, radiation protection of operators and security must be ensured.

A large number of alternative storage systems may be envisaged which would meet these criteria. However, this document only gives a few examples to illustrate possible schemes. A user may find one of these will meet his individual requirement, 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 storage systems with good access require a secure site and therefore have to be associated with appropriate security measures, e.g. one or more of the following

- surveillance,
- physical barriers to intrusion,

- high security locks,
- alarm systems, and
- guarding by trained personnel.

The security system requirements should be viewed as a whole, taking into account the combined effect of individual precautions. Where one is very strong the others may not need to be very substantial.

The extent of the hazard and risk should also be bo· in mind when judging the security measures, e.g. a large centralized store with many high strength or long life sources may justify more elaborate precautions than a small store containing a few low strength, short half-life sources.

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. 5). The casket illustrated has a capacity of 75 ml and could contain several sources. All containers consigned to interim storage should be marked with the following information as the minimum
- the trefoil symbol for radioactive material
- source type
- serial No.
- source strength, Ci/date, etc.

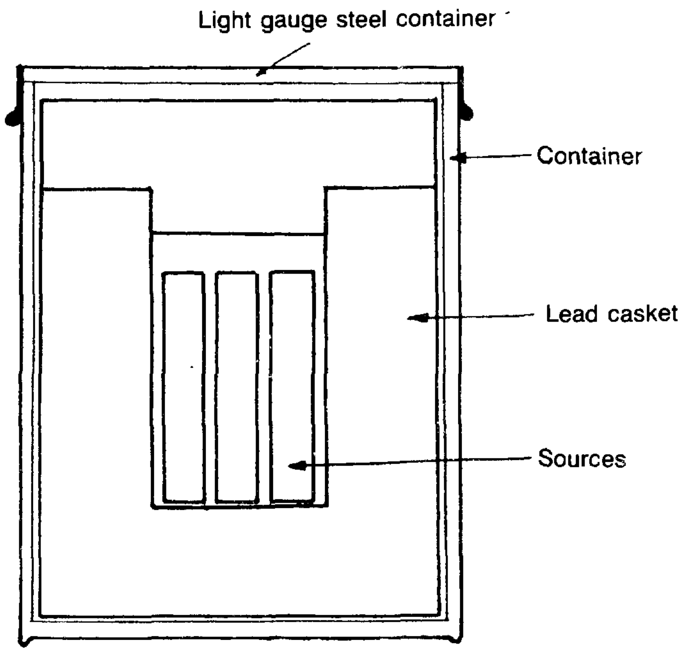


FIG. 5. Diagram of typical sources, casket and container.

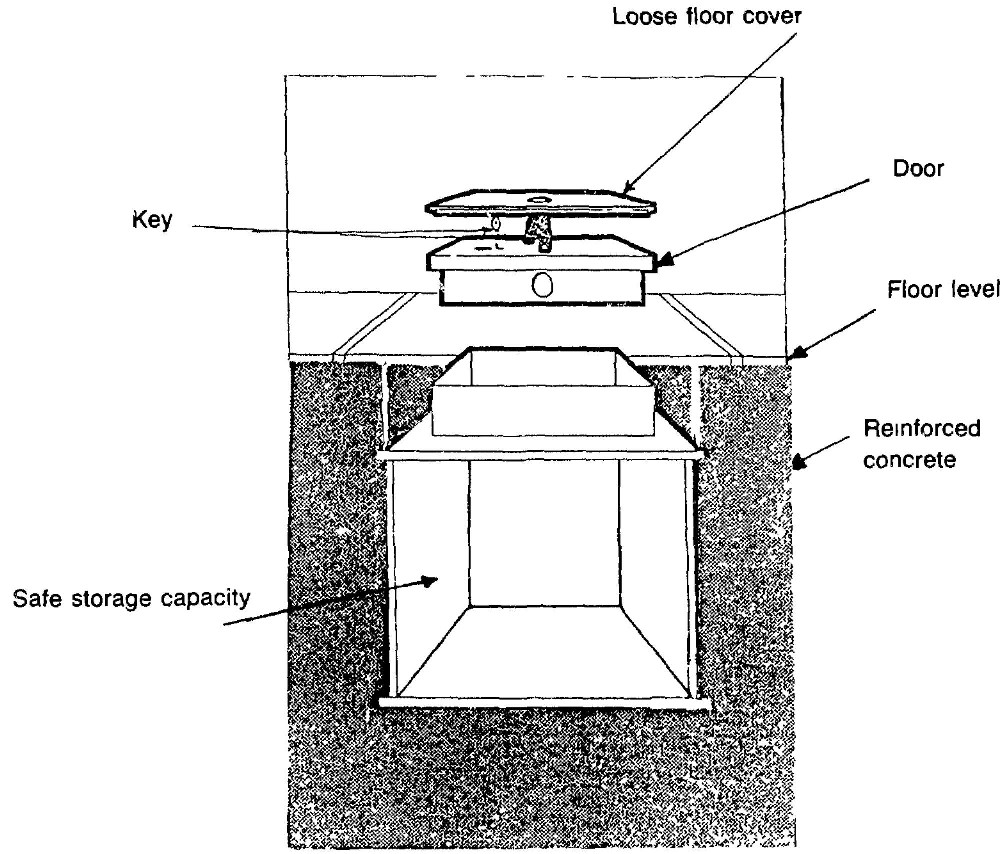


FIG. 6. Typical floor safe.

The interim storage options are described in the following sections:

5.5.2 <u>Storage in safes</u>

This scheme, which is only suitable for small packages, utilises floor safes which are mass produced, inexpensive, readily available and recognised as a very secure system. Unauthorised intrusion is extremely difficult and because the safes are set in a reinforced concrete floor they cannot easily be removed. Each safe could house several containers. This system is particularly suitable for small numbers of sources but could be expanded in units for larger numbers if required.

A diagram of a typical floor safe produced by several manufacturers is in Figure 6. These safes which range in size from 30-60 litres of storage capacity provide protection against a range of attacks including, use of levers, sledge hammers, grinders, drills, oxy-acetylene and explosives. Prices range from $400-750 depending on the size and specifications.

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.

5.5.3 Strong-room storage

This scheme is suitable for all sizes of packages, large, medium and small. The packages 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 authorised personnel who have a need for access.

Small and medium sized containers may be arranged for convenience on shelves whereas large containers would be on the floor.

As an additional security measure, floor safes may be provided in the strong room each housing several small packages.

This system can provide secure storage for a large number of sources but still offer ready access when required.

To convert this system to long term storage without access and requiring minimum surveillance the door-way may be sealed with reinforced concrete.

5.5.4 Storage in a concrete bunker

A reinforced concrete bunker could be used for the storage of small, medium and large packages depending upon the size of the bunker.

A comparatively small bunker with a capacity of a few cubic metres and designed with a heavy lid weighing a few tonnes 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 and would be useful where there are larger numbers of sources for storage.

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

Table 5

Comparison of Storage Systems

TYPE	SAFES	STRONG-ROOM	STRONG-ROOM WITH SAFES	CONCRETE BUNKERS
CAPACITY	Low/medium	High	High	High
COST	Low	Medium	Medium	Medium
FLEXIBILITY (Container size)	Limited	High	High	High
CONTAINMENT	Good	Good	Good	Good
RADIATION PROTECTION	Good	Good	Good	Good
SECURITY	Good	Good	Very Good	Good
ACCESS	Good	Very Good	Good	Poor
SURVEILLANCE REQUIRED	Regular	Regular	Regular	Infrequent

5.5.5 Comparison of interim storage systems

The interim storage systems described above are compared with respect to various criteria in Table 5. This summarizes the main features of the various schemes and offer a simple means of selecting an appropriate option for individual users.

5.6 Conditioning of Spent Sealed Sources

5.6.1 General

Although the immediate objective of conditioning is to facilitate interim storage it is important that it should also facilitate transport, when that is eventually required, eg. to consign the package to a disposal facility. It is also important that the conditioning process will produce a package likely to be suitable and acceptable at a final disposal repository.

For these reasons the conditioning processes described below involve,

- the production of a package type which is recognised in, and conforms to IAEA transport regulations[5], and,
- the use of an immobilisation matrix (cement mortar) which is already widely accepted in many countries (UK, France, FRG etc.) for interim storage and in dispcsal repositories.

In order to further facilitate final disposal it is recommended that long life alpha sources should be packaged separately from beta/gamma sources as they may require different disposal modes.

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.

The methods of conditioning described in this manual therefore are based on Type A and Type B packages as defined in IAEA transport regulations[5]. 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 A1 if the contents meet the definition of 'special form radioactive material'.

'Special form radioactive material' means an indispersible solid radioactive material or a sealed capsule containing radioactive material. It may be expected that many sealed sources meet the requirements to be classed as 'special radioactive material'. These include dimensional limits, an impact test, a percussion test, a bending test and a heat test. The transport regulations may be consulted for details of these tests and other criteria. The manufacturer of a sepcific source should be able to define its status with respect to the requirements for 'special radioactive material'.

A list of the values of A1 and A2 are given in Table 6 for the nuclides commonly used in sealed sources. For a complete list, IAEA transport regulations should be consulted.

If the amount of activity in the package has to exceed A1 a Type B package, which is much more robust, must be used. Detailed requirements of this type of package are given in the IAEA transport regulations.

Table 6

A1 and A2 Values for Radionuclides [5]

Nuclide	A1		A2	
	TBq	Ci	TBq	Ci
3H	40	1000	40	1000
14C	40	1000	2	50
60Co	0.4	10	0.4	10
63Ni	40	1000	30	800
90Sr	0.2	5	0.1	2
137Cs	2	50	0.5	10
226Ra	0.3	8	0.02	0.5
238Pu	2	50	0.0002	0.005
241Am	2	50	0.0002	0.005

Very powerful gamma sources will be contained in heavy shielding devices which might weight typically 500 kg or more and would not therefore be suitable for conditioning by the methods described below in this manual. Such sources, if surplus and requiring storage should be retained in their shielding devices and stored in a strong room (see section below) on a secure site to await disposal.

Other sources may be conditioned by the methods described in the following section.

5.6.2 Conditioning in a Type A package

This storage option is based on the immobilisation of the source within a Type A package. The source in its cask and container is placed in the centre of a 200 litre drum and the drum filled with cement mortar. 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 a 200 litre drum. Because the source remains in its casket it is not necessary to rely upon the shielding properties of the cement mortar matrix. The activity in the package must however conform to A1/A2 levels as set out in IAEA transport regulations[5].

Conditioning in this way prevents unauthorised 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 material. The adoption of this method will depend upon a number of factors, including,

- the number of spent sealed sources
- the half life and activity of the sources
- the toxicity of the radionuclides in the sources
- the final disposal scheme for the sources.

Such packages would have a weight of about 450 kg and removal and transportation would require mechanical equipment, eg. a fork lift truck.

Conditioning in Type A packages may be an attractive option for Institutes or other users having a small number of spent sources and wishing to provide additional security and containment. A procedure for the incorporation of spent sources in such packages is set out below.

Equipment and supplies required,

- spent source in casket within steel container
- 200 litre drum, free from rust spots or other defects (inside and outside)
- cement mortar (typically, 1 volume cement, 3 volumes sand and water to desired consistency)
- cement mixer or provisions for manual mixing
- steel reinforcing bars (3 per package) 5-10mm diameter and 650mm long
- water absorbent material (vermiculite, bentonite or other).

Procedure Steps:

a) Assemble all equipment and supplies required to proceed with the conditioning process as listed above.
b) Open and inspect the Type A 200 litre drum for rust spots or other defects. Only use drums that are inspected and found to be free of defects.
c) Mix sufficient concrete to fill the drum to approximately half of its volume. The mixing step can be performed in an automatic concrete mixer or by hand in a designated area where the ingredients (water, cement, sand, etc.) can be well mixed.

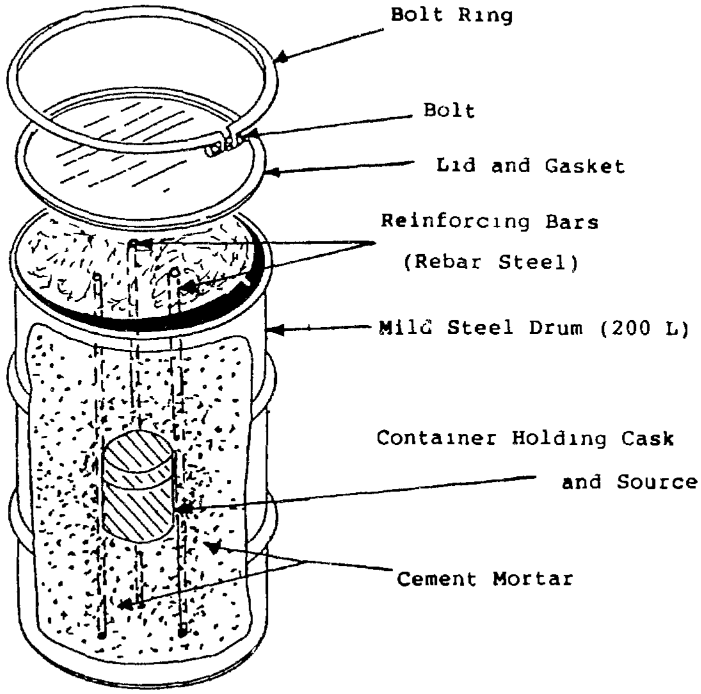


FIG 7 Conditioning in Type A package

d) Place the concrete mixture in the drum and shake the drum to assure that no voids (air pockets) has been formed in the concrete.

e) Tap the outside of the drum with a metal or wooden rod to ensure that a homogeneous mixture of concrete has formed.

f) Cut three equal lengths (65 cm) from the 0,5 - 1 cm diameter reinforcing bar (rebar) steel. Once cut the steel rods should reach about 15 cm from the top of the drum.

g) Insert the three pieces of rebar steel into the concrete in the drum as shown in Figure 7 and let the concrete begin to harden.

h) Using appropriate radiation protection and handling procedures place the source casket(s) into the centre of the drum and push it down into the concrete so about 5 cm of the casket is covered by the concrete. The rebar steel rods should serve to guide the placing of the casket holder(s) into the centre of the drum.

i) Let the concrete set for several hours then prepare a sufficient amount of new concrete to fill the drum to about 2,5 cm from the top (repeat of step c).

j) Once the drum is filled, repeat step e.

k) Check the outside of the drum to ensure that no concrete has been spilled on the outside surface. For the event clean the drum surface immediately.

l) Allow the concrete to set for 24 hours in a secure location that is secure and free from personnel traffic.

m) After the concrete has set, fill any void space at the top of the drum with an adsorbent material (i.e. diatomaceous earth, clay material, etc.) to adsorb free liquid.

n) Install the drum head and bolt ring as shown also in Figure 7.

o) Tighten bolt ring by screwing the closure device, tapping the ring during tightening.

p) Inspect drum integrity and perform wipe tests to determine presence of contamination on the drum. Conditioning of a sealed source should not result in any contamination on the outside of the drum. If decontamination is necessary, the removable contamination on the external surface should be reduced to levels as low as practicable. Guides for the limits of non-fixed contamination on surfaces as published in IAEA Safety Series No. 6, "Regulations for the Safe Transport of Radioactive Material" should be followed. These are summarized below:

Contaminant	Maximum Permissible Level	
	Bq/cm^2	($\mu Ci/cm^2$)
Beta-gamma emitting radionuclides	4.0	(10^{-4})
Alpha emitters	0.4	(10^{-5})

q) Place appropriate radiation labels on drum to ensure proper identification for storage or shipment. Regulations for the safe transportation of radioactive material place a limit on surface radiation of 200 mrem/h (2 mSv/h).

r) If the drum is to be shipped off-site to a storage or disposal site allow the concrete drums to cure (harden) for a minimum of 30 days.

Interim storage of the conditioned spent sealed source in a secure area is necessary to assure proper control and management of the sources until transported to disposal site.

5.6.3 Conditioning in a Type B package

The package, shown in Figure 8, is fabricated of stainless steel. This comprises a length of pipe with a plug welded to the bottom. The

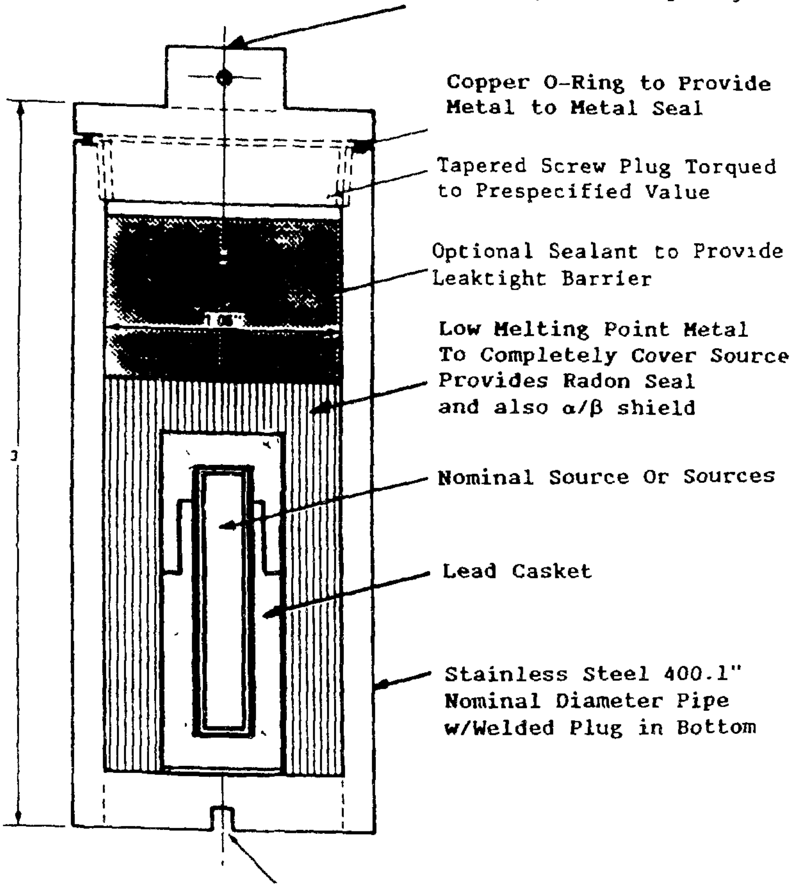


FIG. 8. Sealed source in a Type B package.

bottom is fitted with a source holder and the top has a tapered stainless steel screw plug which is sealed to the pipe with a copper O-ring. This provides a tight metal to metal seal.

This conditioning method is only suitable for alpha and beta sources due to the low shielding properties of the package.

U. S. Department of Transportation (USDOT) regulations (49CFR 178.34) for type 2R containers (fabricated metal pipe) provides examples of various pipe dimensions that could be used as a Type B package. This offers the advantage of placing several small sources in a single package meeting Type B criteria. Such a package could also be used to serve as a casket for spent sources (assuring its shielding properties were adequate) the original lead casket is no longer available.

There are two options for immobilising spent sources in such a package. The first uses Portland cement as the matrix and the second employs a low melting point (65 degrees Celsius) lead-bismuth alloy. Several low melting point alloys are available commercially.

The advantages of using the cement are low cost, easy handling and availability, however, as cement is in the ultimate a porous material containment of gases would depend entirely on the mechanical seal of the package. The use of the alloy provides an additional barrier to gas leakage and a contribution to the shielding properties of the package.

A procedure for immobilising spent sources in this type of package is set out below.

Equipment/supplies required

- spent source(s)
- stainless steel Type B package
- Portland cement or lead/bismuth alloy
- torque wrench and vice.

Procedure steps:

a) determine the number of sources and total activity to be contained in the package.

b) place the spent source contained in its casket in the Type B package. All transfer operations should be carried out in a ventilated environment from which the air is filtered.

c) in the case of alloy encapsulation, melt sufficient alloy (a water bath could be used) and half fill the package ensuring that the source remains in a central position in its casket after the alloy has been added.

d) allow the alloy to cool and solidify thus securing the source in the desired position, and then pour in the rest of the alloy to cover the source. Care should be taken not to overfill as space must be left to allow the screw cap to be entered.

e) after the package is cool lubricate the threads at the top of the package with a high temperature sealing compound (eg. high temperature silicone gasket material).

f) place the package into a vice and secure

g) insert the copper O-ring and hand tighten

h) screw down the cap with the torque wrench and allow the gasket material to set for at least 12 hours

i) seal the cap with an epoxy resin or similar sealing material

j) perform a wipe test on the outer surface of the package to check the absence of contamination.

If a cement matrix is used in place of the alloy, the same procedure is followed with substitution of a prepared cement/water mixture.

Such a package is a low volume secure containment for spent sources which can be stored in a number of different ways as discussed below in this manual or it can serve as a container for additional conditioning.

If the surface dose on the package exceeds 200 mrem/hr it could be encapsulated in a cement matrix using a 200 litre steel drum.

5.6.4 Conditioning of radium needles in concrete

The use of concrete as a immobilizing agent for conditioning spent sealed source packages has been presented in Section 5.6.2. A similar procedure can be used for the conditioning of low activity radium needles using activated carbon (a highly absorbent powdered or granular carbon, also referred to as activated charcoal) as the packing media to adsorb radon gas that may leak from the needles. The process is based on a two-step sequence which includes packaging of the radium needles with the lead casket in a small can of tin plate and the interim volume filled with activated carbon followed by encapsulation of the sealed can with concrete inside a 200 litre metal drum or pre-fabricated concrete vessel. The procedural steps for this option for conditioning radium needles follows:

a) Select a metal can of tin plate that is capable of forming an air tight seal either by welding, soldering with a low melting alloy, screw torque turning or other acceptable closure methods.

b) Following established radiation protection procedures, place the casket of radium needles into the can and add sufficient activated carbon to completely cover the needles and fill the can.

c) Seal the cap to the can using an appropriate closure method (i.e., welding, soldering or screw-type cap) that ensures an air tight seal.

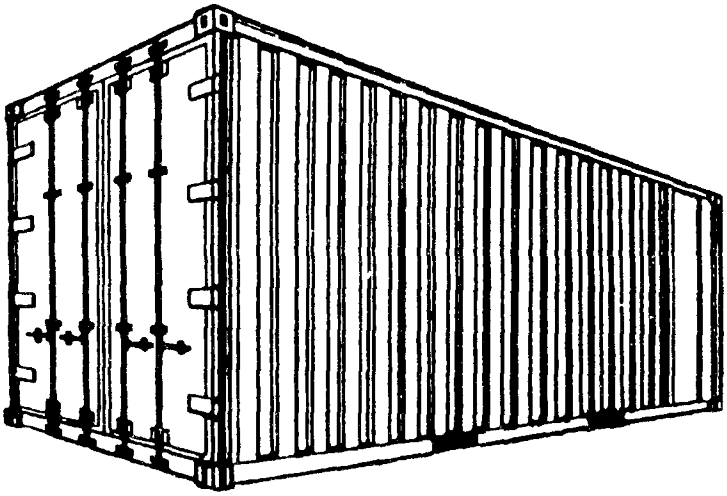
d) The sealed can containing radium needles including casket can now be conditioned with concrete in a robust 200 litre steel drum following procedures similar to those described in Section 5.6.2.

The can should be sized so that it only occupies a small fraction of the volume capacity of the 200 litre drum or concrete vessel. Depending on the activity levels of the radium needles to be packaged, several cans may be placed into a robust 200 litre steel drum as long as the radiation level at the surface of the outer container does not exceed 200 mrem/h (2 mSv/h).

5.7 Interim Storage of Conditioned Spent Sealed Sources

After the waste has been immobilized, the waste packages are normally placed in an interim storage facility for a period of days or occasionally for many years. The main reason for interim storage of the wastes is usually because a repository site is not immediately available. Also, interim storage can be used to take advantage of the activity decay with time, thereby facilitating later handling, transport and disposal of the wastes. Until repositories are available, the national interim storage facilities for conditioned waste can be developed in several different ways.

A simple way especially for Member States not operating a complete nuclear fuel cycle, is the application of a large transportable contrainer normally used as a shipping container (Fig. 9). The container could be set up at a suitable place, i.e. at a centralized collection site, in a small Nuclear Research Centre, NPP or a guarded area under government control. Depending on the size, between 40 and 70 drums could be stored within a container serving as a barrier against unauthorized contact with the waste. Later on when a repository is available, the container, including waste drums, can be transported directly without additional reloading steps.



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

FIG. 9. Large scale container.

Naturally these containers can also be used for temporary storage of waste contaminated with short-lived radioisotopes for decay or untreated waste waiting for further treatment.

Another solultion for interim storage of unconditioned and conditioned waste, especially for Member States having a small Nuclear Research Centre, is the erection of a simple hall on the ground surface with a steel construction and corrugated transit sheets covering the walls and the roof (Fig. 10). The storage hall should be built above ground water level and not be reached by a potential flood or ground water. Where this is not possible, the building must be constructed with appropriate protective systems to prevent the inleakage of ground water. The capacity for the waste storage facility should be designed for a period of 10 years.

On the supposition that the generation of radioactive waste in a small Nuclear Research Centre will be approximately constant during 10 years, the estimated volumes of conditioned wastes after this period are in the range *of 150-300*^{3} *m*^{3} *corresponding* to 750-1500 (200 litre) drums.
Considering a total number of 1500 (200 litre) drums after 10 years, a storage area of nearly 200 m^2 should be included in the planning, based on the assumption that drums are stacked 3 units high using simple handling by fork lift truck.

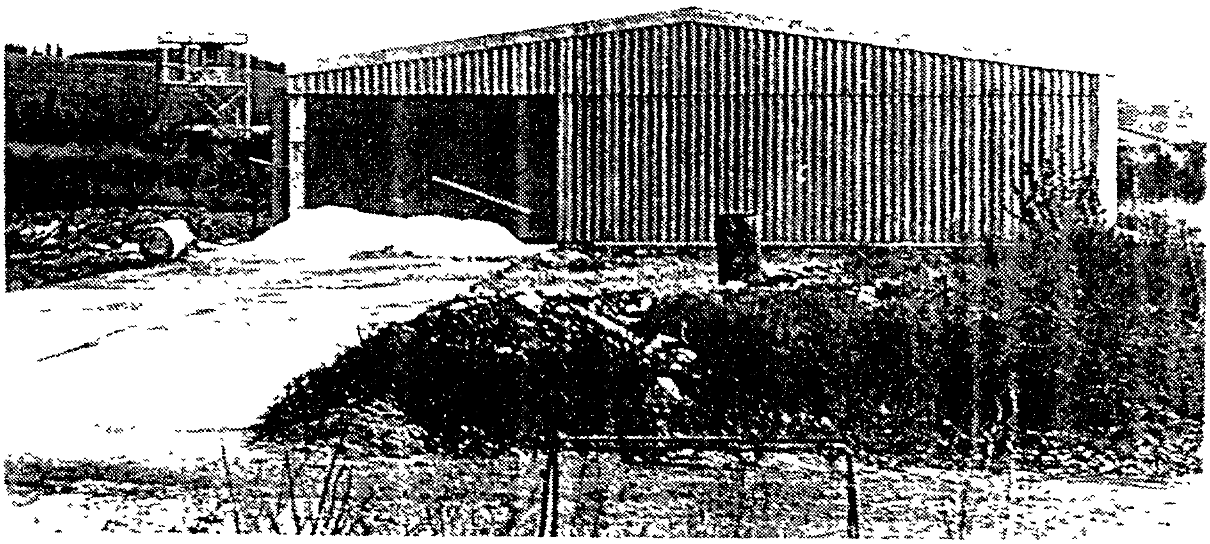


FIG 10. Interim storage hall

The possibility of capacity extension should be provided for in the design of the facility.

To prevent radiation exposure to on-site personnel, 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, the waste containers must be capable of being identified, retrieved and transported to the final disposal site. The final disposal of conditioned wastes is not covered in this report as the subject has to be considered under the special situation of the respective Member States.

6. TRANSPORTATION OF SPENT SEALED SOURCES

The transport of spent sealed sources to an interim storage facility, central waste management facility or to the disposal site may require special packaging to comply with IAEA and/or national competent authority requirements that govern the transportation of radioactive material. IAEA Safety Series No. 6 (1985 Edition, "Regulations for the Safe Transport of Radioactive Material") sets a limit on the quantities of radionuclides that may be shipped in a certified Type A container. These values are based on a classification of the radionuclides expressed as A1 and A2. A1 is defined as the maximum activity of special form radioactive material that is permitted for shipment in a Type A package. A2 is the maximum activity of the radioactive material, other than special form radioactive material, permitted in a Type A package. Special form radioactive material is defined as either an indispersable solid or sealed capsule containing radioactive material.

Because the activity level of most spent sealed sources is comparatively less than the A2 level, they can be transported in Type A packages. In cases where the activity level is greater than A2, transport in a Type A package may still be acceptable if the sources have been tested and shown to conform with the requirements for classification as special form radioactive materials. Sealed sources will often meet the requirements since high standards of mechanical strength, chemical stability and containment are important objectives in the design and manufacture of sealed sources.

Sources of high activity (greater than A1) are transported in a Type B container. As an option, it is possible to use a certified "overpack" on a Type A package to qualify the package as a Type B container. Overpacks for Type A 200 litre drums are available from a variety of firms involved in nuclear materials packaging and shipment.

Because of the small amounts of radioactive substances contained in sealed sources, criticality concerns are not a factor during their use and transport.

7. FINAL DISPOSAL OF CONDITIONED SPENT SEALED SOURCES

Final disposal schemes for spent sealed sources are currently under review in many countries and options have been identified which include shallow land burial, use of suitable abandoned mines and deep geological repositories. In reviewing disposal options, the regulations and requirements of the disposal site are dominant factors in determining its suitability for the final disposal of spent sealed sources. In many cases, shallow land burial (with or without engineered barriers) would be acceptable for the final disposal of spent sealed sources depending on the nature of the source and the source disposal package. However, sources containing long-lived radionuclides such as 226-Ra (> 100 MBq), high activity 137-Cs or actinides (> 100 nanocuries) are likely to require disposal in a deep geological repository.

It is not possible to specify the disposal route for individual radionuclides contained in sealed sources since the regulations and environment conditions vary considerably from country to country. However, there are certain common factors that must be considered in selecting a final disposal site for radioactive spent sealed sources. The factors, listed below require evaluation under criteria, guidelines and standards established in each country by the national competent authority:

- half-life of the radionuclide
- activity of the source
- toxicity and migration characteristics of the radionuclide contained in the source
- nature of the spent source disposal package
- disposal site characteristics
- time period that the disposal site will be under institutional control.

Only after careful assessment of the above factors can a disposal route for a specific sealed source be defined.

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