IAEA-TECDOC-1357

Management of disused long lived sealed radioactive sources (LLSRS)

INTERNATIONAL ATOMIC ENERGY AGENCY

June 2003

The originating Section of this publication in the IAEA was:

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International Atomic Energy Agency
Wagramer Strasse 5
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MANAGEMENT OF DISUSED
LONG LIVED SEALED RADIOACTIVE SOURCES (LLSRS)
IAEA, VIENNA, 2003
IAEA-TECDOC-1357
ISBN 92–0–105403-3
ISSN 1011–4289

Printed by the IAEA in Austria
June 2003

FOREWORD

From the beginning of the nuclear era, naturally occurring radioisotope sources provided readily available means for conducting nuclear research and applying nuclear technology to practical applications. In 1936 Hevesy and Levi first created neutron sources for basic research by mixing uranium ore with beryllium powder. Medical, industrial and research applications of radiation sources started in the early 1940s. Later, man-made radionuclides were used for these purposes.

Alpha, beta and neutron emitting sources found even wider applications through the use of artificially produced radionuclides such as plutonium-238, americium-241, tritium, carbon-14 and nickle-63. These were used as direct sources of radiation beams of alpha, beta, gamma or X rays and also to produce either secondary radiation (neutrons) or heat to function as a small power source. While their specific properties differed greatly, they had one common feature, namely their long half lives. Indeed, although much of the technology based on these sources is now obsolete, their current activity levels have changed little since they were produced and will be a continuing concern for decades to come.

The physical and chemical properties of many sources, plus the associated manufacturing techniques, make them susceptible to damage and leakage that would spread contamination. These characteristics, the possibility of their loss and the associated long half-lives, indicate that there is a risk of spread of radioactivity to the environment for a long time to come. They are nonetheless manageable, requiring proper conditioning over a period of probably decades until geological disposal becomes a viable available option.

Recognizing the need to properly manage these sources safely, the IAEA's Action Plan on the Safety of Radiation Sources and Security of Radioactive Material calls for the development of documents dealing with the handling, conditioning and storage of such sources. A series of documents have been published on sealed source management and facilities in general, and on more specific targeted areas of concern (e.g. IAEA-TECDOC-1205 on "Management for the Prevention of Accidents from Disused Sealed Radioactive Sources" and IAEA-TECDOC-1301 on "Management of Spent High Activity Sealed Radioactive Sources").

This TECDOC provides advice and technical know-how on the management of disused and spent long lived sealed radioactive sources (LLSRS). It also provides background material for any possible technical assistance to developing countries and serves as a reference for technical staff involved with IAEA programmes on the subject.

Because of the historic nature of many of the sources under this category and the lack of well developed technical procedures recognized on the international level, this publication can serve as a basis for establishing future handling and conditioning procedures.

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CONTENTS

1. INTRODUCTION

1.1. Background

Sealed radioactive sources (SRS) have been used for many decades throughout the world and have enabled unique applications not possible by other means. SRS with half-lives greater than 30 years are termed as long lived sealed radioactive sources (LLSRS). These LLSRS are or were used in research, medicine, agriculture, geology and industry. Smoke detectors, lightning rods, moisture-meters and well-logging devices are a few examples of their broad use. LLSRS were the first to be used from the start of nuclear applications. Many of these sources have become obsolete (have became “disused sources” [1]) creating a need to treat them as radioactive waste. The long lived nature of the radionuclides containing in disused LLSRS requires that special measures will have to be taken in order to protect the population from the related radiation exposure for a long time. Most radionuclides in LLSRS are alpha emitters, but there are long lived beta and gamma emitters as well as neutron sources.

Some of them (particularly smoke detectors with ^{241}Am) may not individually pose any difficulty for management due to their extremely low radioactivity. However, the recently adopted practice of collecting together large numbers of these sources could result in the final total activity that calls for special measures.

Due to the quantities involved, their specific activities, and most importantly their half-lives, the disposal of LLSRS in near surface repositories may be problematic or impossible and require disposal in geological formations that to date are not operational anywhere in the world. In order to render such sources safe while in storage and not to impose undue burden on future generations, the conditioning of these sources should be performed as soon as reasonably practicable. The conditioning process should be sufficiently flexible to accommodate any future requirements that may arise for final disposal.

1.2. Objective

The issues of handling, conditioning, and storage of spent/disused radioactive sources have been dealt with from different aspects in a number of previous IAEA publications [2–6]. This publication belongs to the same group of documents with special emphasis on disused sealed sources containing long lived radionuclides.

The publication provides the sealed source users and the national waste management organizations with the particular guidelines required for handling, conditioning for storage, and storage of disused LLSRS. The guidance is intended to assist in establishing compliance with the present standards, requirements, and adopted practices.

1.3. Scope

The LLSRS addressed in this publication are primarily those containing radionuclides having half-lives greater than 30 years. These sources may contain long lived α-emitters, mainly ^{238}Pu, ^{239}Pu, ^{237}Np, ^{241}Am, ^{226}Ra; β-emitters: ^{14}C, and ^{63}Ni and could be neutron sources such as PuBe, RaBe and AmBe.

Small-size Ra-sources in the form of needles and tubes used for medical applications are not specially addressed in this publication since they have already been dealt with in detail in IAEA-TECDOC-886 [3]. Likewise, although some high activity sources containing ^{90}Sr, ^{137}Cs and ^{60}Co pose a significant hazard for a long time, they are referred to in a separate document [6]. Sources made of ^{90}Sr and ^{137}Cs with a considerable activity are fully covered in the given reference. Considering their half-lives and activities, some aspects of long lived SRS do apply to them and are included in this document for that purpose. Aspects, such as durability of package, data records, selection of material for source conditioning are just some examples.

There are many stages in the management of disused sealed sources. This document covers the steps from when the LLSRS are declared spent or disused to interim storage, but does not include disposal. Although some of the safety and security issues are mentioned briefly in this document, they are not covered in detail. It is, therefore, recommended that the relevant national and international standards [7] relating to the safety and security of sources are consulted in full and are complied with.

In order to gain additional benefit from the material in this publication it is recommended that reference is made to IAEA-TECDOC-1145 [4], which provides information on the handling, conditioning and storage of all types of spent sealed radioactive sources.

2. TYPES AND CHARACTERISTICS OF LONG LIVED DISUSED RADIOACTIVE SOURCES

The application of various LLSRS and most important parameters of radionuclides contained in the LLSRS are summarized in Table I. These parameters are discussed in more detail in the following sections.

2.1. Important parameters

The following parameters of long lived disused radioactive sources appear to be the most important for handling, conditioning and storage:

- Radionuclide and radiation type
- Radiological parameters (activity, half-life, energy, and dose conversion factors)
- The neutron flux (for neutron sources)
- Geometrical dimensions (source structure and design)
- Chemical (compounds or alloys used, solubility) and physical form (solid, liquid or gaseous)
- Physical condition (damaged, leaking, intact with or without a special form certificate).

2.2. Types of sources

The commonly used classification of sealed radioactive sources according to the type of radiation and the fields of application [8] is the following:

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

It should be noted that sources generally emit mixed radiation: α decay is accompanied by γ-radiation, and decay daughters are often β-emitters. Additionally, the conversion of the β particle (electron) energy during absorption results in Bremsstrahlung.

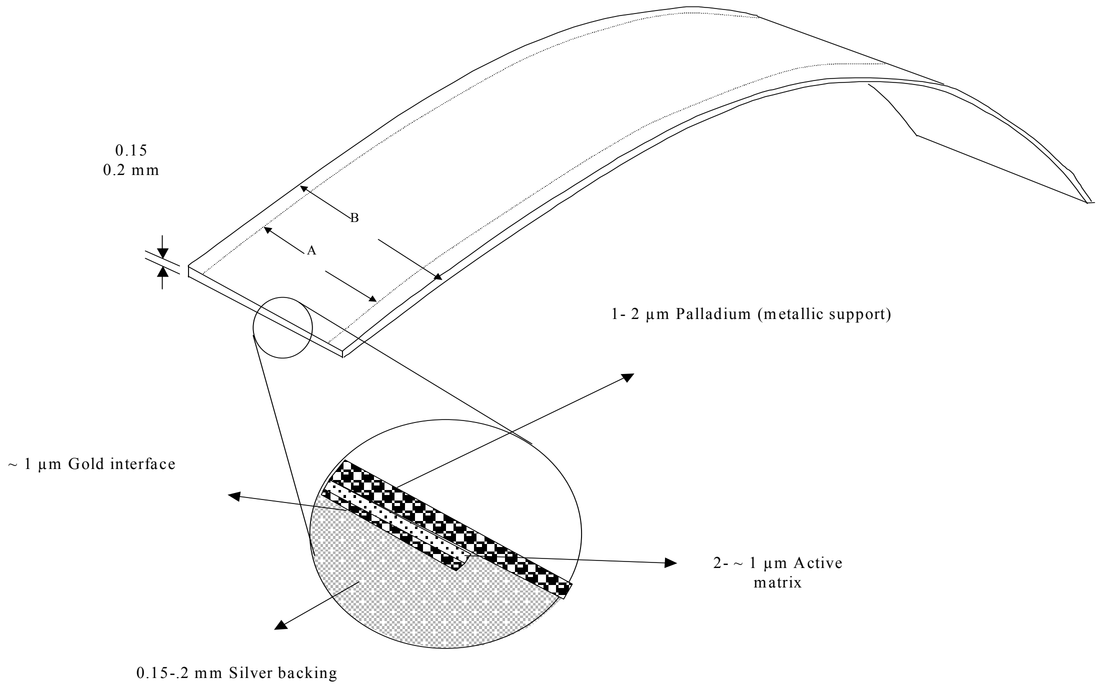
TABLE I. Summary of the principal parameters of radionuclides used in LLSRS

Radionuclides	Half-life (year)	Emission	Eα (MeV)	Eβ (MeV)	Eγ (MeV)	Ambient dose equivalent rate [mSv·m²·(h·GBq)$^{-1}$]	Photon flux (4π) (s·GBq)$^{-1}$	Neutron flux (4π) n·(s·GBq)$^{-1}$	HVL of lead (mm)*	Applications	Activity range (Bq)
^{137}Cs	30.2	β, γ		1.2	0.66	0.092			6	Thickness, level or density measurement, radiography, well logging, sterilization, teletherapy	10^6 to 10^{12}
^{14}C	5730	β		0.156		< 0.001				Thickness measurement	
^{63}Ni	100	β		0.066		< 0.001				Electron capture detector	$2\cdot10^7$ to $5\cdot10^7$
^{90}Sr*	28.1	β		0.54		< 0.001				Thickness measurement	Up to 10^9
										Eye applicators	
										Power generator	Up to 10^{15}
^{226}Ra	1600	α, γ	4·8		0.186	0.001			14	Brachytherapy	$3\cdot10^6$ to $3\cdot10^7$
^{226}Ra in equilibrium		α, γ	<7.7	<2.8	<2.4	0.283			14	Brachytherapy	$3\cdot10^6$ to $3\cdot10^7$
^{226}Ra/Be		neutron						$4.81\cdot10^8$		Well logging	
										Moisture detector	
^{237}Np	$2.2\cdot10^6$	α, γ	4·8		0.029	0.018				Measurement of neutron fluxes	
^{238}Pu	87.7	α, γ	5·5		0.044	0.002				Static electricity eliminator	Max $3\cdot10^8$
										Thermoelectric generators	Max $1.9\cdot10^{12}$
^{238}Pu primary X ray source		X ray					$4.81\cdot10^9$			X ray fluorescence analyser	$6.30\cdot10^8$ to $3.70\cdot10^9$
^{238}Pu/Be		neutron								Well logging	$1.2\cdot10^{10}$ to $1.2\cdot10^{12}$
										Moisture detector	
^{239}Pu	24 181	α, γ	5·2		0.052	0.001				Smoke detectors	
										Gas analyzers	
										Gas chromatography devices	
^{241}Am	432.2	α, γ	5·5		0.060	0.019			0.2	Density measurement	10^9 to 10^{10}
										Static electricity eliminator	10^9 to $4\cdot10^9$
										Smoke detectors	$2\cdot10^4$ to $3\cdot10^6$
										Lightning preventor**	$5\cdot10^7$ to $50\cdot10^7$
										Bone densitometry	10^9 to $10^{10.}$
^{241}Am secondary X ray source		X ray					$7.4\cdot10^6$			X ray fluorescence analyser	$3.7\cdot10^8$ to $1.85\cdot10^{11}$
^{241}Am/Be		neutron						$8.14\cdot10^7$		Well logging	10^9 to $8\cdot10^{11}$
										Moisture detector	10^9 to $9.25\cdot10^9$

* ^{137}Cs and ^{90}Co do not belong to the category of LLSRS by definition. However, since the risk associated with these high activity sources in long term is compared with less active long lived sources, the safety measures be taken to ensure their safe long term storage are almost identical ones.
** Some lightening preventors mad of ^{60}Co in former Yugoslavia (RAG types) contain up to 7.4 GBq.

2.2.1. Alpha sources

As a rule, alpha sources comprise a ceramic or metal support with a fixed layer of such radionuclides as ^{238}Pu, ^{239}Pu, ^{241}Am, or ^{237}Np or ^{226}Ra. The dimensions of these sources vary greatly in size. A typical ^{241}Am radioactive source is shown in Fig. 1.



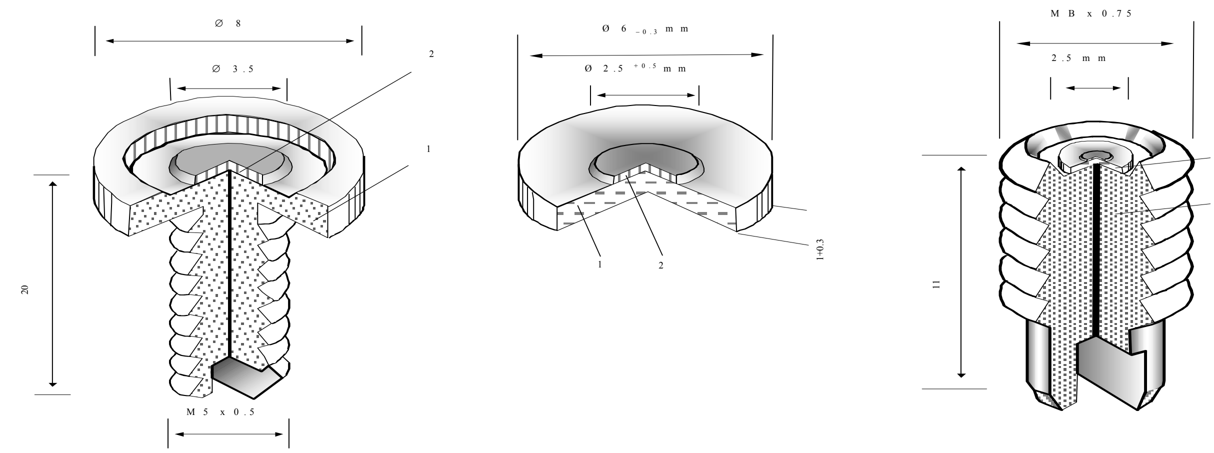
Linear activity		Activity on active area		Active width A	Total width B
µCi/cm	MBq/cm	µCi/cm^2	MBq/cm^2	mm	mm
10	0.37	8	0.296	12.5	20
30	1.11	100	3.70	3	20
40	1.48	32	18	12.5	20
125	4.63	100	3.70	12.5	20
160	5.92	128	4.74	12.5	20
240	8.88	192	7.10	12.5	20

FIG. 1. A typical α emitting radioactive source with ^{241}Am in a strip form to be used for various applications.

Small long lived radioactive sources, which contain ^{241}Am, ^{226}Ra or ^{239}Pu are used in smoke detectors. The activity of these sources is in the order of 10 kBq.

Other α emitting sources are made of titanium disks with an electrochemically deposited layer of neptunium (^{237}Np) oxide. These sources are produced to measure neutron fluxes in nuclear reactor cores.

^{226}Ra sources have been largely replaced by safer, cheaper, and more reliable alternatives. A description of ^{226}Ra needles and tube applicators for brachytherapy is given in IAEA-TECDOC-886 [3]. ^{226}Ra had been used for manufacturing gamma and neutron dose calibration standards. Even these sources are becoming obsolete, and secondary standard dosimetry laboratories provide calibration services using other sources.



Applications: automatic warning smoke and fire detectors, gas chromatographs, gas analysers, etc. The construction of the sources АИА-Д1, АИА-Д2, АИА-Д3 is shown above. Applied to the emitting surface of backing, *1*, made of titanium alloy or corrosion-resistant steel, is deposit *2* of ^{241}Am preparation. To protect the ambient area of the radionuclide, chromium film, from 2 to 4 μm thick, is applied over the preparation deposit. Working life of the sources is 10 years from the date of output.

Source type	Alfa-radiation energy flux, W	Activity of ^{241}Am radionuclide Bq, maximum
АИА-Д1 АИА-Д2 АИА-Д3	$(2.3\text{-}8.6)\text{x}10^{-9}$	3.10^4

FIG. 2. A typical α-emitting radioactive source used in smoke detectors (data for a typical source produced by Mayak, Russian Federation).

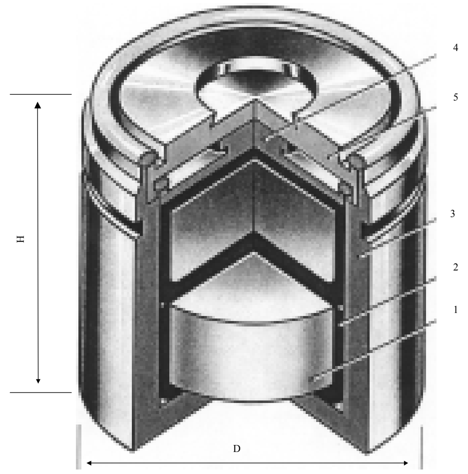
In the past ^{226}Ra and ^{241}Am were used in lightning rods, which have mostly been removed and collected. Their activity is usually in the order of 40 to 70 MBq. In few cases an activity in the range of GBq had been used.

Other disused α-emitting LLSRS contain radioactive material in powder or liquid form inside glass or plastic vials and ampoules. These sources require special precautions during all handling, transportation, conditioning and storage operations.

2.2.2. Beta sources

^{63}Ni sources are prepared on a substrate of metallic tubing or wire, with an electrochemically deposited layer of radioactive material. The length of these sources does not typically exceed 40 mm.

^{14}C sources consist of polymeric (polymethylmethacrylate-PMMA) films glued to an aluminium film. Usually these films do not exceed 70 mm in length and 1 mm in thickness. ^{90}Sr sources are also used especially in medical applications. These sources are usually made of a ceramic matrix encapsulated in steal. But ^{90}Sr eye applicators are based on silver foil technology. In another source application ^{90}Sr had been used with a large activity for the production of small electrical power generation in remote areas (see Fig. 3).



The source is intended for use in radioisotopic thermoelectrical generators. The construction of the source is shown. Active part *1* (pellets) locked in sleeves *2* enclosed in a welded hermetic capsule of corrosion-resistant alloy (body *3*, inner cover *4* and outer cover *5*). Working life is, at least, 11.5 years.

Heat flux (W)	Outside dimensions, mm		Mass, kg, approx.	Activity GBq
	Diameter D, approx.	Height H, approx.		
20-85	60	50 – 120	1 – 2.5	$8\text{-}23\times10^5$
90-900	120	60 - 230	4 - 14	$3\text{-}74\times10^5$

FIG. 3. β-emitting radioactive source (Thermo generator) with ^{90}Sr.

2.2.3. Gamma sources

Most α or β-emitting radionuclides have a useable γ-radiation energy level and so can be used as γ-sources. Generally, stainless steel, or, to a lesser extent, aluminium and titanium, are used for encapsulation of γ-sources.

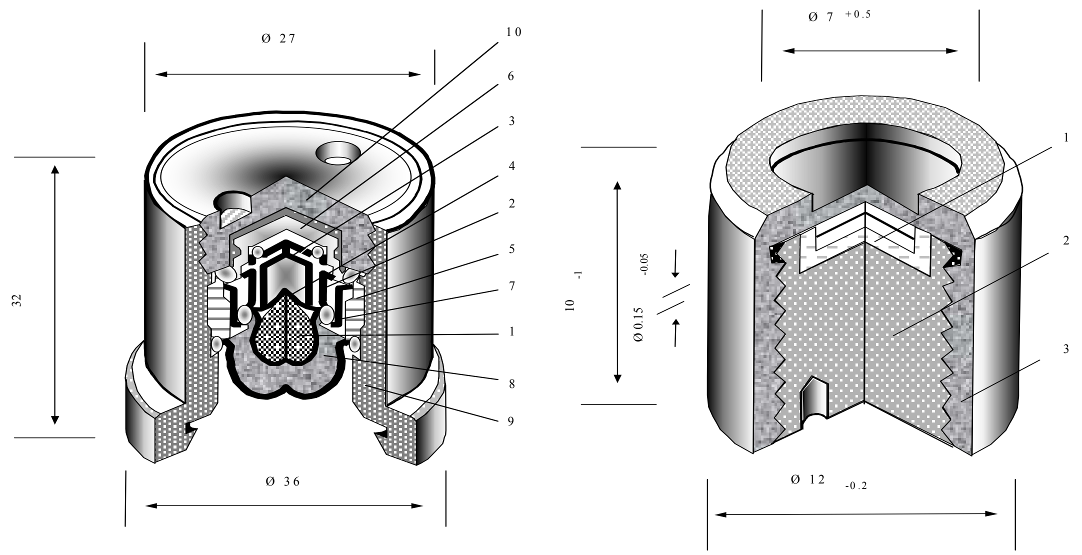
Early radium sources were sealed in glass vials (Fig. 4), but this practice was abandoned many years ago. Nevertheless, they are still encountered.

FIG. 4. ^{226}Ra liquid sources in glass vials.

^{241}Am sources are usually disks up to 40 mm in diameter and up to 7 mm thick, but in some cases are much smaller.

^{238}Pu and ^{241}Am sources are used to generate soft X rays for Roentgen fluorescence analysis (also known as X ray fluorescence analysis). The radionuclide can be placed inside a tungsten casing with an aluminium window. The typical length of these sources is less than 40 mm.

High specific activity ^{137}Cs sources are prepared in sulphate and chloride form. Other soft gamma and X ray sources are also utilized for various applications.



5a: These sources are intended for creation of gamma-radiation photon flux in instruments used in aviation and cosmonautics. The sources ensure photon flux with an energy of 9.55 fJ (Femto Joule). The construction of the sources is shown in the Figure. Active part *1* (a ball-shaped ceramic pellet saturated with preparation of ^{241}Am is enclosed inside a welded hermetic inner capsule comprising body *2*, cover *3* and pressure washer *4*. The inner capsule with its active part is incorporated into a welded hermetic radiator capsule consisting of body *5* and cover *6*. Bushing *7* and protective cover *8* close the inner capsule in the radiator. The parts of the inner capsule and radiator, except for the protective cover, are made of heat-resistant nickel alloy. The protective cover is made of porous graphite. The radiator is secured in body *9* by nut *10*. The body and nut are made of corrosion-resistant steel. Working life of a typical source is 10 years from the date of production.

Exposure dose rate of gamma-radiation, pA/kg**, maximum	
at a distance of 1 m from emitting surface	maximum activity of ^{241}Am radionuclide in source GBq
260 (0.319)	15 GBq
52 (6.38×10^{-2})	2.3 GBq

5b: These X-ray sources are applied in radio-isotopic equipment for: X-ray radiometric analysis of materials for elements. The advantage of these sources is spectrum purity, low background level and long half-life period of ^{238}Pu. The construction of the sources is shown in the Figure. Active part 1 (a steel backing with a layer of ^{238}Pu dioxide applied to enamelled surface) is mounted in an aluminium capsule, comprising body 2 and threaded cover 3. The capsule is leak-proof owing to its glued up threaded joint. The cover end face with a recess is the emitting surface of the source. Working life of the sources is 5 years from the date of their production.

Exposure dose rate at a distance of 0.5 m from emitting surface, pA/kg**, max	Maximum activity of ^{238}Pu radionuclide in source, MBq
180 (0.221)	630
310 (0.381)	1330
600 (0.737)	3700

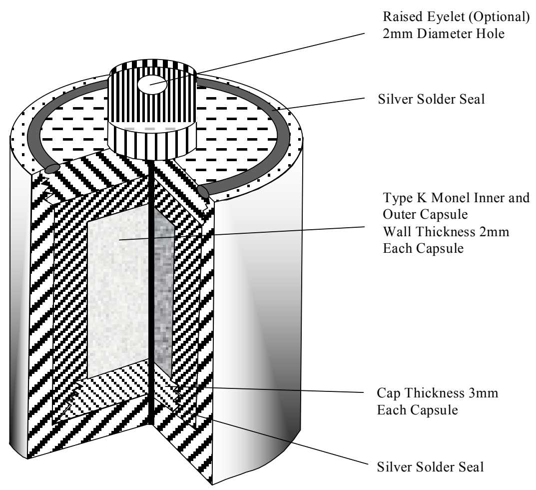
*** Original values are generated in pA/kg, values in brackets are in µGy/h.*

FIG. 5. Typical γ-emitting long lived radioactive sources (data obtained from the Mayak catalogue).
5a: Source with ^{241}Am *5b: X ray source with ^{238}Pu*

2.2.4. Neutron sources

Neutron sources contain certain α-emitting radionuclides to induce (α,n) reactions with light elements, e.g. beryllium, boron, lithium or fluorine. ^{238}Pu is applied for emitting fast neutron sources, while ^{241}Am is used extensively for other neutron source applications. Typically, these sources contain radioactive material together with the target material doubly encapsulated in stainless steel. ^{226}Ra is also used in neutron sources, and presents special difficulties owing to the associated gamma radiation. About 30% of RaBe neutron sources have the activity that exceeds 20 GBq (500 mg) and the activity of a small number of sources exceed 40 GBq (1000 mg) of radium. RaBe neutron sources are typically used for reactor start up operations. When radium is irradiated in a nuclear reactor, some of the target atoms are converted into ^{227}Ac and ^{228}Th, both alpha emitters. If the irradiated target is made into an alpha:beryllium neutron source, neutrons are produced not only from radium alpha particles but also from ^{227}Ac and ^{228}Th particles. The neutron yield from a given amount of radium may be increased by a large factor (over 50 to 1) by this method.

In designing RaBe reactor start-up sources, this process must be considered. Otherwise the neutron output, which has increased greatly while the start-up source was in the reactor, will cause shielding problems on removal.



Filling Material: An intimate mixture of $RaCO_3$ and Beryllium powder. *Capsule:* Double sheathed monel. Each sheath has a 2 mm wall and is silver soldered. The Capsule is also available without an eyelet.

Standard outputs and sizes:

Activity (mg of Ra)	Neutron Output (n/sec) ± 10%	Outside Dia. (mm)	Outside Length (mm)
1	1.3×10^4	11.2	12.9
5	6.75×10^4	12.1	14.4
10	1.35×10^5	13.6	14.1
25	3.38×10^5	14.8	16.2
50	6.5×10^5	16.1	18.3
100	1.3×10^6	17.6	22.2
200	2.5×10^6	20.3	25.9
300	3.75×10^6	20.3	26.4
500	6.0×10^6	22.6	25.6
1000	1.1×10^7	25.9	31.4

FIG. 6. A typical RaBe neutron source (data taken from MDS Nordion catalogue (1967)).

Certain materials (e.g. paraffin, plastics, water) containing low atomic-weight elements provide effective neutron shielding, as these light materials cause neutrons to scatter and loose their energy. This increases neutron absorption probability. In most cases, boron, lithium or cadmium, in the oxide or carbonate form, is added to the paraffin for shielding purposes. High-density shielding is required for the radiation of the induced activity and γ radiation as in the case of ^{226}Ra.

2.3. Radiological parameters

The decay characteristics of the main radionuclides used in LLSRS are shown in Table I. Although most of these sources are seen as having only one radiation type, this is seldom the case and all the radiation emitted requires consideration. For example, all alpha sources emit a small degree of β- and γ-radiation. Also, beta sources tend to produce Bremsstrahlung.

The following equation can be used to calculate gamma radiation field, P [mSv·h^{-1}] for a point source:

$$P = A \cdot H_{10} \cdot r^{-2},$$

Where:

H_{10}	ambient dose equivalent rate factor, [mSv·m²·(h·GBq)$^{-1}$]
r	distance (m)
A	activity (GBq).

If the α-emitter is mixed with a light element such as beryllium then the neutrons emitted are the major component of the radiation, as explained earlier. The activity of such sources (neutron flux) is directly proportional to the activity of the α-emitter.

Another important concern with certain long lived radionuclides is criticality. This is not a problem when dealing with a limited number of sources. However, where numerous disused SRS containing fissile radionuclides are collected and consolidated, specialised procedures should be followed. The safe mass of fissile material that can be managed should be observed (e.g. less than 0.9 kg for ^{238}Pu and 0.102 kg for ^{239}Pu) [9].

Also, nuclear materials may need to be reported to IAEA Safeguards according to the relevant agreements between the IAEA and the Member State.

2.4. Geometrical parameters

Geometrical parameters of sources are important when choosing available techniques for conditioning and storage. Besides typical cases described above, there are particular applications where sources are very large. For example, there are lightning rods greater than 1m in length with ^{226}Ra or ^{241}Am. The geometrical form of some of these devices is complex with radioactive source material distributed on the surface of the structure (Fig. 7). Additionally, similarly large devices using radium sources have been used as process control equipment in manufacturing (Fig. 8). Many of these devices were manufactured many years ago, and little consideration was given to the problems that would be encountered during decommissioning.

FIG. 7. Lightning conductor and radium strips collected from lightning conductors.

A  B

FIG. 8. A photograph of two large size disused long lived sources. A) Source in form of a large shielded process control source in a coal fired power plant. B) Source with a long active tube (within the large tube with flanges at both ends).

2.5. Physical and chemical state

LLSRS can be categorized according to the physical and chemical state of the radioactive material (active part):

- Liquid
- Solid organic
- Solid dispersible powder
- Solid soluble
- Solid inorganic, insoluble and non-dispersible
- Solid metal or metallic alloy.

A source containing radioactive material in a liquid form presents a high risk of leakage. Powder materials are also likely to be a source of contamination. Some organic materials are combustible, or can produce radiolytic gases. A soluble radioactive material can produce a large amount of liquid radioactive waste if it comes into contact with water or other solvent. Therefore, one should consider the physical and chemical state of LLSRS to correctly develop conditioning, storage, and monitoring requirements.

3. GENERAL REQUIREMENTS FOR HANDLING, CONDITIONING AND STORAGE

The approach adopted here covers all aspects involved in the management of disused LLSRS with the exception of disposal. This starts with handling of the unconditioned source to the long term storage of the final package. The steps involved in the management of LLSRS are shown in Fig. 9.

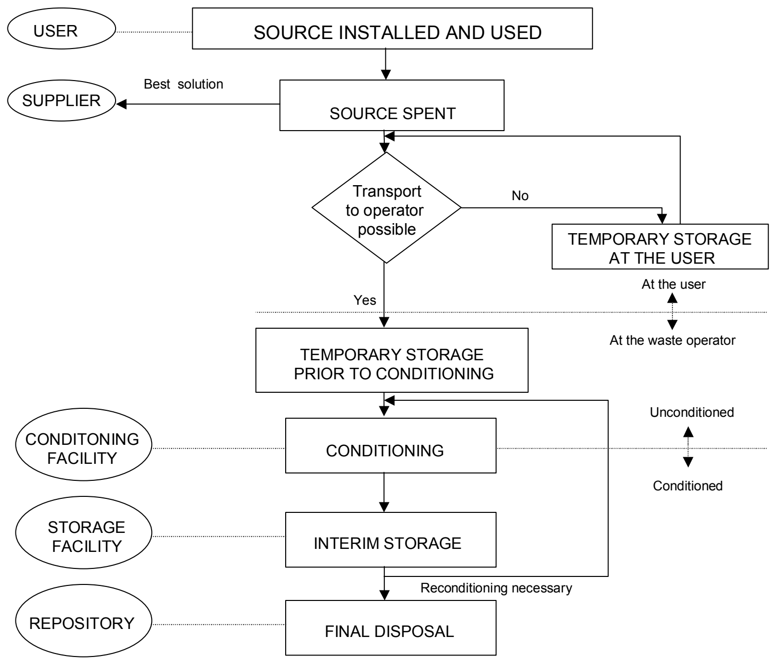


FIG. 9. The management steps for disused LLSRS.

Regardless of the type of the process involved, handling, conditioning and storage shall be conducted within the national regulatory and licensing framework and in compliance with international recommendations. The Member States should adopt regulatory measures concerning handling, conditioning and storage practices. Conditioning and storage of LLSRS are activities, which usually require operating licenses. Licenses should define the scope of the conditioning and storage operations, radioactive material possession limits and any specific conditions that are to be observed. The legal requirements for records keeping should be identified in the quality assurance system, which itself may be part of the license requirements.

The following elements of the national waste management system shall be available to ensure the safe operations with disused long lived sources:

- Source characterization
- Financing
- Technical ability
- Personnel qualification
- Records management system
- Radiation safety.

3.1. Source characterization

Data should be gathered, including the source and device manufacturer, model number, serial number, nuclide, activity and manufacture date. Design specifications and procedures for loading and unloading of sources from the apparatus should also be obtained. This would greatly facilitate planning the handling, conditioning and storage operations and increases the quality of the technical information retained in records. The available information could be verified empirically where possible.

It could be the case that no information on the source or device is available. However, it is possible, with suitable instrumentation, to achieve the following:

- Nuclide identification
- Activity estimation
- Leakage status
- Physical properties of the source and/or device.

This data would be considered as the absolute minimum requirement for handling, conditioning and storage.

3.2. Financing

The last users of the source will normally incur the disused source management costs, which may be very considerable in the case of LLSRS. However, the state must be prepared to provide public funds where sources are orphaned, where ownership information is lost, or where public safety considerations are paramount.

Handling, conditioning and storage costs should be set at a realistic level to avoid compromising safety measures. Excessive costs might cause waste generators to act inappropriately by illegally abandoning or disposing of sources. Exact costs for conditioning and storage for LLSRS cannot be precisely known, but can be estimated. Sufficient funds for the construction and operation of conditioning and storage facilities are a prerequisite of proper management of disused LLSRS. Additional costs for any reconditioning should also be considered. The cost of long term storage, awaiting a disposal route and the cost of disposal are essential components of any economic study.

3.3. Technical capability

Appropriate technical capability to perform the assigned task must be established and maintained at every site where LLSRS are operated or managed as disused sources. This capability includes the facility itself, appropriate equipment, and technical competence of the operators. Acquisition and operation of facilities and equipment should be commensurated with the available technical capability, to facilitate effective and safe operation.

The technical management of disused LLSRS has to be done both at the local level, where the sources were used, and at the central level where the long lived sealed sources are processed and stored awaiting final disposal. Each user needs technical capability to collect, characterize and segregate the LLSRS. Although the safety assessment capability may not be available at the user site, an overall safety assessment of the system, including the long term waste management facility, should be done, possibly with the help of the central waste operating organization, the regulatory body, or through an international peer review.

The user may not need to be aware of details of how the disused source will subsequently be managed, if the job of conditioning and storage is left to the operators of the conditioning and storage facilities. However, there is a need for the user to be informed about the subsequent steps of the LLSRS management in order to appreciate the need to appropriately segregate or classify the sources before collection. This is also important to eliminate the possibility of the user processing the source in any way that makes waste management procedures more complicating, more expensive or causing extra undue risks.

The regulatory body does not usually have the responsibility to act as operator of a waste management facility, however the regulators should possess necessary knowledge and experience to administer laws and regulations and provide clear guidance and direction to the operators of waste management facilities.

3.4. Personnel qualification

The handling and conditioning processes require skilled personnel with the appropriate levels of theoretical and practical knowledge to deal with the wide range of sources. Understanding of the design, construction and mounting of the source in the container and the design and function of the container itself are also very important. This is particularly true when the removal of a source from the device is attempted. Ongoing training of personnel in radiological matters as well as in the relevant technical procedures should also be performed. As this work often involves a high level of manual activity, personnel should also be physically fit.

As each case can be different, the exact number of persons to be involved in handling cannot be prescribed although two persons is considered to be the minimum. At least one person should be experienced in radiological protection.

3.5. Records management system

Complete records are essential for future reference. These records include the information on the characteristics of the source, technical procedures applied, quality assurance measures, and data on the storage location and storage conditions. All of this data will be required later to support further decisions whether to directly dispose of the conditioned sources or to recondition them in order to comply with the prevailing waste acceptance criteria.

The responsible authorities, source users and operators of waste management facilities should establish and maintain documentation and records consistent with legal and quality assurance requirements and their own needs. These records should be kept in a condition that will enable them to be consulted and understood later by people different from, and possibly without reference to, those who generated the records. The basic requirements of record retention include, but are not limited to:

- Designation of the records as permanent or temporary;
- Storage of temporary records for a specified length of time;
- Storage of permanent records in perpetuity;
- Designation of the method of record storage.

For these reasons, Member States should consider establishing secure long term archives. Well kept hard copies, microfiche and/or magnetic media should be considered for preservation of relevant data. At least two media and two record keeping locations are essential for diversity and reliability. Records should also be updated and transferred as recording technology changes.

Records of the LLSRS should be included with the details of the conditioning process for each waste container. The data recorded should include a description of the conditioning procedure actually carried out and names of the team members who carried out the operation. Any old records as they are found subsequent to conditioning should be added to the information on each waste package. Photographic records may prove to be valuable when reviewing documentation for disposal planning.

3.6. Emergency planning

Where disused LLSRS management activities have the potential to adversely affect human health and the environment through an accident, Member States need to provide for emergency planning and make such provisions as might be necessary to respond to the accident. Often, existing emergency response capabilities in the country are reasonably well suited to respond at a level appropriate to the need (i.e. fire protection, traffic control, ambulance and medical services). In this case, it is the responsibility of the operator and the regulatory body to inform the local state authorities and emergency response personnel of this new activity in their area. They are then aware of the new installation, and can assess the equipment and services they provide against this new risk. The regulatory body may consider providing additional funding to local emergency response organizations in order to address any additional needs that may arise.

4. HANDLING

Source handling is the physical manipulation (sorting, moving, etc.) of unconditioned or conditioned source. Handling of the source is needed during its preparation for conditioning, conditioning itself and transportation to a storage facility.

4.1. Contamination control

The ALARA principle should be applied to all the handling operations to minimise radiation exposure. As many LLSRS were manufactured several decades ago, they are now prone to leakage. Therefore, in handling such sources, contamination control and regular contamination checks should be carried out. Special precautions are required for damaged and leaking sources and sources that emit neutrons. Surface wipes for loose contamination, area monitors and personal dosimeters, relevant to the radiation and contamination being handled, should be used.

The handling of disused sources could lead to the inhalation of, or contamination with, toxic materials. Consequently, general and industrial safety rules should be observed. Adequate ventilation and filtration systems should be in place to protect personnel and the environment. Appropriate personal protection equipment is also important to prevent internal and external contamination. This equally applies to conditioning and temporary storage.

These precautions are particularly relevant to sources, which do not have a complete set of records. Any lack of information may increase the risk during the handling and conditioning operations.

4.2.Volume reduction

The storage of radioactive materials is usually expensive and therefore volume reduction is desirable. This can be achieved by the removal of the sources from the original devices and grouping them together with similar sources for conditioning. This will allow the use of standard storage capsules, shields and containers, as well as optimising safety and security measures. Large volume reduction can therefore be achieved and further processing of the source is possible. Source removal requires dedicated facilities and experienced personnel. Damaged and leaking sources will require extra precautions as well as specialised equipment providing both shielding and containment. Care must be taken not to weaken or damage the source.

On the other hand, there may be LLSRS that cannot be reasonably removed from bulky machines or shielding devices. In these cases, long term storage in an unconditioned form may be the only viable solution. The original equipment could then serve as a suitable shield during long term storage. Some conditioning measures to protect the equipment from environmental effects and mechanical deterioration should be considered. In this state the source is unlikely to be acceptable for disposal.

The flammable shielding material of neutron sources can limit the use of flame cutting and grinding tools for volume reduction purposes.

4.3. Packaging for transportation to a conditioning facility

Sources to be transported to the conditioning facility are required to be packaged according to national regulations which in many cases are based on the IAEA transport regulations [8]. The construction of the working shield is usually not directly suitable for transport without the use of an overpack. Therefore, a suitable transport container would be required.

4.4. Safety measures

Some safety measures to be taken during handling could be recommended depending on the type of radiation. These measures are listed in Table II.

TABLE II. Recommended safety measures during handling based on radiation type

Features	Alpha	Beta	Gamma	Neutron
Shield	Paper, halogen-free plastic	Metal foil	Heavy metal, concrete	Light materials, Cd, B, or Li-containing alloys; Combined shielding
Removal from equipment	Ventilated area, or glove box	Ventilated area, or fume cupboard	Remote handling	Remote handling

5. CONDITIONING

5.1. Purpose of conditioning

Conditioning, according to the definition [1], is "those operations that produce a *waste package* intended for *storage* and/or *disposal* and suitable for handling and *transport*. *Conditioning* may include the conversion of the *waste* to a solid *waste form*, enclosure of the *waste* in *container*s, and, if necessary, providing an *overpack*."

Storage is the holding of *radioactive waste* in a *facility* that provides for its *containment*, with the intention of retrieval [1]. *Storage* is by definition an interim measure, and the term *interim storage* would therefore be appropriate only to refer to short term temporary *storage* when contrasting this with the longer term fate of the waste. For the purpose of this document long term storage is defined as the storage for a period of 50–100 years.

The purpose of conditioning and storage of disused LLSRS is to create a safe and reasonable isolation from the environment and to prevent exposure to the general public for a specified period of time. The problems associated with a wide range of sealed source types, their sizes and chemical forms, compounded by long half-lives and minimal encapsulation of α-sources, bring about significant challenges to conditioning LLSRS. Despite these difficulties, conditioning and storage is doubtless safer than allowing sources to remain with users who may lack appropriate expertise, facilities and/or financial resources.

In order to be accepted for storage, the waste package produced by conditioning shall comply with waste acceptance requirements for storage [1] specified by an operator and approved by the regulatory body. Not necessarily that the waste acceptance requirements for storage will be equal to the future waste acceptance requirements for disposal. For disposal in the future, LLSRS may need to be removed from their storage containers and reconditioned to comply with the waste acceptance requirements for disposal. However, for safety and security purposes, the removal should be made difficult for a layman or an intruder.

Conditioning should ensure containment of the radioactive material, provide sufficient radiation shielding, and contribute to physical protection. The activity of the LLSRS will probably outlast any engineering measures taken to provide safe long term storage. Consequently, new storage or waste acceptance requirements for disposal may result in a need to recondition the sources.

The likelihood of reconditioning sources, and ultimately disposal of them, requires that sources remain retrievable in the storage facility. This means each source and its specific storage container must be accessible and retrievable and accompanied by records indicating their location in the store. Hence the availability of the original information on the conditioned source as well as the technical procedures used for the conditioning process is very important.

The ability of an organization to condition disused LLSRS depends, in part, on the conditioning process adopted, resources and materials available, and the quality of information for individual sources.

5.2. Design requirements

The facility for conditioning of disused sources should be designed to meet the technical and functional demands made by the range of sizes, shapes and physical forms of the sources as described in Section 2. The facility may ideally comprise the following:

- Conditioning plant and storage areas in appropriately defined radiological zones.
- Efficient ventilation with suitable filtration system (HEPA filtration system).
- Hot laboratories. These laboratories will be equipped with facilities that are suitable to permit all necessary operations with the range of LLSRS arising in the country. Usually the activity of LLSRS is sufficiently low for safe handling to be performed in a glove box or fume cupboard with the use of appropriate shielding and tools.
- Radiation instrumentation. Most of the operations, with the exception of neutron sources, can be monitored using Geiger-Müller counters. It would be desirable to have access to a neutron measurement device; however, this is an expensive and sophisticated piece of equipment. In addition, a gamma-spectrometer with a sodium iodide detector is required for radionuclide identification. Personal dosimetry and environmental monitoring will also be necessary as required by the national regulator.
- Safeguards measures if necessary.
- Physical protection.
- Mechanical workshop.

- Archive of source and container designs and applications.
- Data processing, storing and retrieving. Data may need to be stored for many decades. Data recording technology changes rapidly, therefore, the method of data storage needs to be under regular review.

5.3. Selection and qualification of the conditioning method

With the exception of radium needles, tubes and applicators, no conditioning methods have yet been developed for LLSRS that have gained the overall acceptance of Member States. Therefore, careful consideration should be given to selecting the most appropriate conditioning methods for all other LLSRS. The following issues (with examples of how they may have an effect) should be addressed:

- Number of sources – affects the conditioning method
- Nuclide(s) – affects the type and thickness of shield/encapsulation
- Chemical form – affects the materials used for conditioning
- Physical form – affects the design of encapsulation
- Activity – affects the thickness and material of the shield
- Life of the package – affects the materials of construction
- Security and safety – affects the materials of construction and overall package design
- Transport[1] – affects the materials of construction and package design.

The detailed technical procedures that are to be developed need to be qualified with emphasis placed on the realistic capability within each country. These qualifications give assurance that the conditioning requirements can be met and can be performed during the design and construction of the facility, the development of the technical procedures and during the actual conditioning.

Examples of such procedures are given in Appendix A.

5.4. Material selection

The selection of materials used for conditioning is very important as a source capsule could experience damage resulting from external environmental conditions or chemical or physical attacks from inside and outside. As many of these sources are α-emitters, and are sealed in a very small volume, internal pressure build-up may cause leakage. The conditioning process should take these problems into consideration and eliminate any possibility of leakage.

Improper conditioning could result in the radioactive material of a disused source entering the environment in the form of:

- gaseous products (e.g. radon)
- liquids (aqueous solutions, leaches, etc.)
- solid particles (powder, aerosols, etc.).

Encapsulation material should be selected to provide assurance that barriers are maintained between the radioactive material and the environment. Other barriers should also exhibit sufficient strength to withstand reasonable mechanical stresses and other environmental effects.

[1] Special attention must be given to the maximum activities of materials allowed for transport.

Therefore, the choice of the materials suitable for such barriers should take into consideration:

- mechanical strength;
- material aging (the lifetime of a barrier should at least exceed the expected storage period in the storage area or the optimal time period covered by the quality assurance plan);
- radiation effects in the barrier material;
- corrosion and fire resistance;
- impermeability to water and humidity;
- radioactive decay products, especially in gaseous form;
- source security.

Stainless steel capsules and concrete lined drums would fulfil the above requirements. If these are not accessible, then more frequent periodic inspection and maintenance of the waste package could be required.

An overview of the conditioning requirements for the different physical and chemical states of the LLSRS is summarised in Table III.

TABLE III. Conditioning approaches with respect to LLSRS physical and chemical state

Physical and chemical states	**Examples**	**Conditioning approaches**
Liquid	Solution of ^{226}Ra in vials	Solidification of liquid
Solid organic	^{137}Cs mixed with epoxy	Avoid high temperatures, allowing for gas generation
Solid powder	^{226}Ra compounds	Encapsulation to prevent dispersal
Solid soluble	^{137}Cs as chloride	Immobilisation in a solid matrix
Large size equipment	Lightning rods	Dismantling and size reduction, encapsulation

5.5. Labeling

A potential weakness in the conditioning and storage of disused LLSRS is the preservation of information of the conditioned radioactive material. Therefore, it is very important to include the necessary information both outside and inside the package, using the most durable material available (stainless steel, aluminium, brass or copper, with punched or engraved data). In addition, it is important to keep a duplicate set of records at an alternative location, e.g. with the regulatory body. It is essential to link a unique identification number to the archived records and to the waste package.

The following information should appear on the labels:

Encapsulation container	Unique identification number Isotope Activity Date of loading
Temporary housing (if operation is interrupted)	Unique identification number Approved radiation labels and warnings Isotope and activity
Waste package	Unique identification number Approved radiation labels and warnings Isotopes and total activity Date of conditioning Dose rate (at surface and at 1 m)

Conditioning of sources of one nuclide per drum simplifies records and allows for easier subsequent management steps.

All records and recording methods should be chosen with reference to their ability to withstand the effects of significant ageing.

5.6. Radiation safety

Health and safety aspects should be addressed in formal procedures dealing with LLSRS conditioning operations. The conditioning process should be properly planned, prepared and documented. Exposure limits, radioactive releases, and contamination levels should be kept as low as reasonably achievable (ALARA principle). Some operations, such as cutting, dismantling, encapsulating, remote controlled welding, weld testing, and source leak testing, should be conducted in controlled areas established for these purposes (hot cells, glove boxes etc.). Alternative procedures, according to prevailing conditions, can be developed but should comply with the same safety requirements. All procedures should be tested and approved prior to implementation.

Conditioned LLSRS should exhibit acceptable surface dose rates for transport and storage purposes. If the conditioning operating area or facility is situated at a distance from the store (as usually is the case), the facility should be equipped with suitable hoisting, transfer, and transport equipment with due regard to safety and maintenance requirements [9].

5.7. Mechanical stabilization

The age of a device or the environmental conditions in which it operated could have led to serious degradation and it may be necessary to repair or upgrade the device as part of the conditioning process. This applies especially to a device that is to be stored in its original form for a long time.

5.8. Smoke detectors

Individual smoke detectors are often exempted from regulatory control, therefore, disposal in general landfill is allowed. However, due to the large number of these devices and the long half-life of the sources, it is becoming a preferable practice to collect them, remove and consolidate the sources and condition for long term storage. The collected sources (see Fig. 10) may pose a significant problem if not properly managed.

In many countries there is a concentration limit of 4000 Bq/g for alpha emitters in individual radioactive waste packages for disposal into shallow ground repositories [10].

FIG. 10. Long lived α-emitting sources in a container.

6. STORAGE OF UNCONDITIONED AND CONDITIONED SOURCES

6.1. Interim and long term storage

Storage (of variable duration) is associated with all steps in radioactive waste processing and the size of each store is affected by the amount of stored material (waste), the time in storage and planned conditioning operations. This publication distinguishes between interim and long term storage, relating interim storage of unconditioned sources and long term storage of conditioned sources. The regulator should discourage the practice of storage on the user's premises and persuade the user to return the source either to the supplier or to arrange for it to be sent to the waste operating organization. On arrival at the waste operator's premises, the source would be conditioned as soon as practicable and sent to the long term storage facility. However, interim storage of sources at the waste operator site waiting for conditioning may be unavoidable.

6.2. Store design

Temporary storage can be either at the user (typically only a very few sources) or at the waste operator (typically many sources). In both cases they need a high degree of physical protection. Accessibility of an interim storage area in the processing facility needs to be flexible to allow for easy source movement without compromising radiation safety and physical protection. The storage areas designated for interim and long term storage should be properly defined and marked.

The design of the centralized spent sealed source facility is discussed in IAEA-TECDOC-806 [5]. It should be suitable for the interim and long term storage of LLSRS and should permit a precise identification of the stored material, its retrieveability or reconditioning as well as monitoring at regular intervals for any release of radioactivity. The store should be constructed from materials that have low maintenance requirements. While it is important to distinguish between the two types of storage facilities, they may physically be situated under the same roof, but clearly separated.

The store layout and loading procedures should minimize the handling of the sources especially in the interim store where long term storage is expected. Interim and long term storage may require different handling equipment. The interim store may be of surface or sub-surface design. Each design has certain advantages and disadvantages. For example, sub-surface storage has the advantage of inherent shielding and easier security measures, but has the disadvantages of more limited access, restricted possibilities for future expansion and increased difficulty in waterproofing. The reverse argument applies to the surface store.

6.3. Operation

The operation of the store should conform to regulatory as well as quality assurance requirements. This implies the existence of a written set of procedures that cover all the source handling and storage processes, the monitoring and leak testing regimens and the keeping of relevant records. These records should be at least in duplicate and in two different locations. The above-mentioned procedures differ in the case of interim and long term storage.

6.4. Personnel qualification

Storage areas should be managed and operated by suitably qualified and experienced personnel (as specified in the operating license). If security personnel are required they should be given basic radiation protection training and familiarization with emergency procedures on a regular basis.

6.5. Records keeping

In addition to the information gathered on the sources during the conditioning stage, their physical location in the store, relevant package identification number and the technical data about the stored package should be collected and archived. The information about the store (e.g. the radiation level, contamination, package inventory, etc.) should be documented and regularly analyzed for any discrepancy, as specified in the quality assurance system.

6.6. Storage period

The long term store should be designed to store the conditioned sources safely for several decades. Conversely, the period of interim storage should be limited. In practice, there may be long delays before conditioning can take place, therefore, extended periods of interim storage may be unavoidable. The period of interim storage should be approved and verified by the regulator. During the period of interim storage an action plan for dealing with the disused LLSRS should be proposed by the user and approved by the regulator.

6.7. Radiation safety

The storage areas should be designated and operated as controlled areas to limit the spread of contamination and to minimize workers' exposure to ionizing radiation. Adequate protective cloths/equipment should be available and be worn/used as required.

As the long term effectiveness of engineered or natural barriers against the release of radioactivity into the environment cannot be guaranteed, a monitoring system of the storage area should be established, signalling any leakage of radioactivity. If technically feasible, monitoring should take place between the individual barriers (e.g. the drum, the storage boundary and the facility boundary) so that migration of radioactivity is detected well before escaping the facility. In this case, measures could be taken to minimise the escaping contamination. Therefore, it is advisable to have initial background measurement of the storage facility before active commissioning.

Radiation and contamination levels should be regularly measured as part of the monitoring programme to detect leaking sources or defective shields and packages. The effectiveness of the ventilation system should also be part of the surveillance programme.

Most of the long lived radionuclides used in LLSRS also have a long biological half-life meaning that they would reside in the body for a long time. In some cases, such as radium, the radioisotope migrates to the bones and is effectively fixed in the body for life. This hazard is compounded by the chemical toxicity of many of the materials encountered in the store. This emphasizes the importance for safety of the storage facility. Radiation monitoring and personal dosimetry should be mandatory. Regular whole body monitoring is recommended.

6.8. Physical protection

Access to the storage areas should be strictly limited and controlled in order to prevent losses of stored materials, which may not be detected until some considerable time after the removal has occurred. In the temporary stores at the user's premises, the security is usually achieved by locking the source in a special room or container. The personnel with authorized access should be kept to the minimum (advisably only one person). Seals can be used for the detection of any unauthorized access. Other appropriate security measures in the interim storage (such as guards, barbed wire fencing, surveillance cameras, alarm systems, etc.) and regular stocktaking should be considered in the context of the prevailing security situation. The effectiveness of the security system should be regularly audited and updated.

7. QUALITY ASSURANCE

According to the IAEA Radioactive Waste Management Glossary [1], quality assurance (QA) is “the planned and systematic actions necessary to provide adequate confidence that an item, process or service will satisfy given requirements for quality, e.g. those specified in the license”.

A QA system is the management tool and procedures whereby QA is realized [11]. The extent to which the QA system will need to be applied will vary considerably, directly reflecting the specified quality requirements of the operation concerned. An effective application of the QA system will be that which provides the minimum level of QA needed to fulfil those specific requirements.

An important part of the QA system will be a quality plan, which is essentially a statement of the methods, procedures, practises and controls to be deployed to ensure the achievement of the quality requirements of specific operations.

In this case, the QA system is a set of documents the contents of which would demonstrate the compliance of the conditioning and storage activities with the prescribed goals of long-term safety and security.

A typical list of these documents would comprise the following

- Acceptance, storage and conditioning procedures for LLSRS
- Testing, dosimetric and monitoring devices and their calibration
- Qualification of personnel and their responsibilities
- Administrative measures, including record keeping, regular checks.

In order for QA to assist the efficient management of LLSRS, it needs to be applied at a realistic level, determined by ‘fitness for purpose’. This will relate to the number of LLSRS, the complexity of the infrastructure and the available personnel.

The QA system will include a number of procedures for the different steps in the management of LLSRS. These will vary from country to country. However, the example shown in Appendix B could be profitably used by an organization that is setting up a conditioning and storage programme. This generic example comprises the forms that could be generated for implementing the acceptance, storage and conditioning procedures.

APPENDIX A
SAMPLES OF LONG LIVED DISUSED SOURCES CONDITIONING

1. Example of AmBe neutron source conditioning

Data on AmBe example needs to be checked by original author

An example of a package for an AmBe neutron source conditioning could be the following:

- the removal of the polythene neutron shield and the placing of the source into a stainless steel capsule (bearing the relevant information) with a screw type lid. The source is held at the center of the capsule by means of a metal cage and the intervening space is filled with borosilicate glass powder,
- the capsule is welded closed, and placed in a larger can that acts as permanent mould,
- the can is placed in a container which then is filled with an alloy of bismuth (50%), lead 20%, tin 20%, and cadmium 10%,
- the can is placed into a suitable lead shield,
- the shield is placed into a concrete lined stainless steel drum with internal barriers to prevent unauthorised access,
- stainless steel labels with engraved details are placed in suitable positions within and outside the drum.

The above example has addressed some of the problems associated with AmBe source conditioning such as:

- epithermal neutrons – 10% cadmium,
- thermal neutrons – boron containing glass, external concrete drum walls,
- gamma radiation – 20% lead in primary can,
- containment – lead shield, low melting point alloy and welded stainless steel capsule,
- security – concrete drum with internal barriers,
- retrievability double encapsulation with accessibility to the first capsule.

2. Example of liquid source conditioning

A second example is the conditioning of a liquid source; for example ^{226}Ra solution in a glass capsule:

- place the glass capsule in a stainless steel tube of suitable size and sufficient head space (1–1.5 cm),
- fill with bentonite to limit movement – glass powder or sand may also be suitable,
- apply lid and weld,
- test for leak-tightness to prevent release of decay product radon,
- place stainless steel capsule into a suitable lead shield,
- place lead shield into concrete drum with security provisions,
- information labelling as in the above example.

APPENDIX B
FORMS THAT COULD BE GENERATED FOR IMPLEMENTING ACCEPTANCE, STORAGE AND CONDITIONING PROCEDURES

1. A form to gather source information from the last user

- Address of the last user
- Source description:
  – nuclide
  – activity
  – shielding
  – manufacturer information (certificate, etc.)
  – leakage status
  – size, weight (with/without shielding)

2. A form to allow for transport

- Verification of user information, preferably in conjunction with an on-site inspection
- Check ability for transport
- Dose rate determination
- Choose appropriate package for transport
- Organize transport according to national regulation
- Upon receipt on site assign storage number

3. A form for on-site verification

- Assign number to package
- Make contamination test
- Make dose rate measurement
- Identify sources where possible
- Put into temporary storage

4. A form for conditioning process

- Select conditioning method
- Assign conditioning run number
- Assign sources in store for the conditioning run
- Assign staff to the job
- Assign drum size
- Fix geometrical arrangement of sources in drum
- Conditioning (signatures of operators)
- Verification by supervisor (signature required)
- Assign drum number

5. A form for storage

- Number of drums
- Make dose rate measurement
- Prepare engraved plates for drum
- Fix plates to/in drum
- Assign storage place

APPENDIX C
CURRENT PRACTICE IN VARIOUS COUNTRIES

1. CZECH REPUBLIC

In the Czech Republic, there are two radioactive waste repositories currently in use that can accept spent sealed sources for interim storage: the Richard repository in Litoměřice and the former uranium mine Bratrství in Jáchymov.

The Bratrství repository is used exclusively for spent radium sources with the rationale that radium that was extracted from the uranium ores from this mine should be returned to its original natural site. Up to the present time about 50% of the radium that had been obtained from this locality has been returned to the mine; the remaining radium is still in circulation and this material may be sent to this or another repository for final disposal.

Table C-1. Summary data on the repository Bratrství

Put into operation	1974
Expected termination	undecided
Depth under the ground	more than 50 m
Total volume of the repository	3500 m^3
Total volume of the adapted area	1320 m^3
Volume of so far stored wastes	240 m^3 (assumed coefficient of filling: 0,5)
Total amount of stored ^{226}Ra	25 g
Residual activity	$8{,}85 \times 10^{11}$ Bq

At present, prior to storage, the sources are conditioned as follows:

The sources are held in lead containers, placed in concrete and sealed in steel barrels. These are overpacked into 200 L barrels (the inner surfaces of which are painted with asphalt paint) and a 5 cm layer of concrete is poured in to surround the inner barrel. The upper face of the concrete layer is again painted with asphalt paint. The barrel lids are fixed mechanically by a steel collar. A general rule for their conditioning in steel barrels is given by the requirement that the surface exposure rate must be less than 1 $mSvh^{-1}$.

There are various amounts of radioactive waste that can be deposited in one barrel, depending on the character of the given radionuclide. A survey of these limits is given in Table C-2.

Table C-2. Limits of activity per one 200 L barrel

Radionuclide	Activity in a 200 L barrel, in Bq
^{3}H	1.10^{13}
^{14}C	3.10^{10}
^{90}Sr	3.10^{11}
^{137}Cs	6.10^{11}
^{241}Am	1.10^{8}
^{239}Pu	1.10^{8}

Activities of radionuclides not mentioned in this Table are limited by the Decree No. 142/97 Coll. Limit of 10^{12} Bq is valid for the naturally occurring radionuclides stored in the mine Bratrství. The radioactivity in the accepted wastes must not exceed 3.10^9 Bq/m^3.

The barrels are kept in mine galleries. After the galleries are filled, it is proposed to close them with brick walls and backfill them with concrete to resist any changes caused by the pressure of the upper rock formations. However, it is expected that in future these galleries may be reopened, as this repository cannot be considered a deep repository for the final disposal. The radioactivity in the underground water and air are monitored. During the operating history of the repository, no increase of radioactivity above the natural background has been observed.

All other radioactive wastes are interim-stored in the mine Richard near Litoměřice at a depth of about 50 to 60 m. This former underground limestone quarry has relatively dry conditions with water-insulating marl stone layers both over and under the storage area. The spent LLSRS are stored in this repository along with the low-active wastes generated in medicine, research, industry, agriculture, etc. Their conditioning is the same as in the case of radium containing barrels in the Bratrství mine. Neutron sources are additionally shielded with a layer of a material with high neutron absorbing properties.

Repository Richard is a dry repository and it is considered a nuclear facility, due to the significant amounts of the stored activity. The physical safety precautions correspond to the current international standards. It was put into operation in 1964.

The Richard mine has a large number of empty underground halls, which are suitable for the storage of barrels. The filled-in halls are bricked-up to prevent unauthorized access. Natural water and ventilation air are continuously monitored.

Neutron sources and long lived high-activity wastes are stored in these repositories, but their transfer to a deep repository is foreseen when such repository is available.

For many decades these repositories were administered and operated solely by the state-owned Institute for Research, Production, and Application of Radioisotopes. At present these repositories are managed by the private company ARAO that has been established as a daughter company of Nycom — a successor to the above institute. However, in the year 2000 according to the provisions of the new Act No. 18/1997 Coll. (Atomic Act), the ownership was transferred to the central state-owned Radioactive Waste Repository Authority.

FIG. C-1. View of a part of the storage area in the former mine Bratrství, Jáchymov, Czech Republic.

2. RUSSIAN FEDERATION

Although a technical proposal on conditioning spent radioactive sources has been developed, the Russian Federation has applied this for short lived radioactive sources only, which have been immobilized into metal lead and lead based alloys in bore hole repositories since 1986*. Spent LLSRS are stored at different locations in shielded containers. This complies with Russian legislation. Storage of spent LLSRS will be continued at the following locations until the decision on their disposal into a deep geological formation is made.

- Regional facilities of the system “Radon” (16 facilities of this system operate now in Russia),
- State Scientific Center NPO “Radium Institute” (St. Petersburg),
- State Enterprise GHK “Krasnoyarsk” (Krasnoyarsk Region),
- Users facilities.

At the regional “Radon” facilities, long lived sources are stored in shielded containers placed in storage rooms or in separate compartments of the near-surface repositories.

FIG. C-2. Standard containers for transportation and storage of sealed radioactive sources. Left – Container KI-8400. Right – transport complex UKT1B:1 – casing, 2 – container KROT-100, 3 – transport casing lid.

At Moscow SIA “Radon” (Sergiev Posad, Moscow Region) there is a large storage facility with a room for the temporary storage of long lived sources. Sources are stored in separate sealed standard containers. Neutron sources are stored in containers with light material shielding (see Fig. C-2). The temporary storage area is ventilated.

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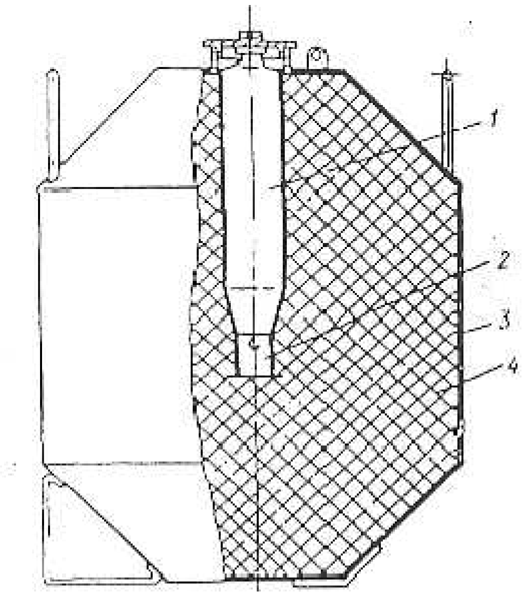

FIG. C-2. Container for transportation and storage of neutron sources.
1 – lid, 2 – place for source, 3 – frame, 4 – paraffin.

Ra-226 sources are immobilised into lead-based alloys using pre-fabricated small size capsules. These capsules are fabricated to immobilise single sources. Capsules are made of stainless steel filled by a lead-based alloy. Inside of each capsule there is conical hole –socket for emplacement of Ra-226 sources (see Fig. C-3A). Sources are placed in these prefabricated capsules thereafter sources are additionally fixed by melted lead-based alloy. There is no welding technique applied which facilitates the immobilisation process and enhances the immobilisation reliability. Capsules after immobilisation and sealing (see Fig. C-3B) are placed into shielded containers for transportation and storage.


A


B

FIG. C-3. Prefabricated stainless steel capsule for immobilisation of Ra-226 sources.
A: The capsule is opened for location of source into the conical socket.
B: The capsule is sealed for emplacement into transportation and storage container.

At NPO “Radium Institute” (St. Petersburg) radium sources are stored in glass ampoules placed in standard shielded containers or in sealed brass cases.

At GHK “Krasnoyarsk’ radium preparations (sources) are stored in sealed quartz ampoules placed in metallic containers. These containers are placed in concrete containers for storage.

The technical proposal for subsequent conditioning of LLSRS applies to the approved immobilization technology. Metal matrices were designed on the basis of lead alloys with significant content of cadmium (about 10%) that provides neutron absorption. The metal matrix material will be sealed in a stainless steel capsule.

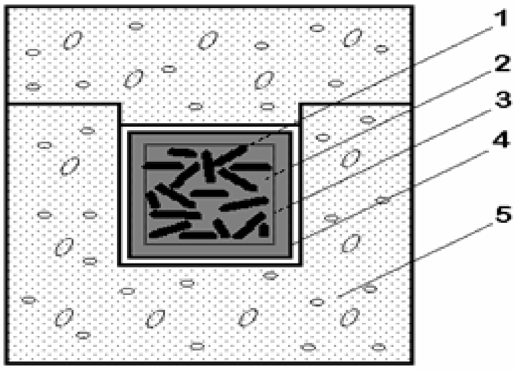

FIG. C-4. Immobilization of long lived spent radioactive sources in metallic matrices.
1 – source, 2 – metal matrix 3 – metallic basket, 4 – capsule, 5 – concrete container.

Sources are loaded into a metal basket inside of a capsule, which is placed inside of large concrete container. Then sources are immobilized in a metal material (lead based alloy).

3. SOUTH AFRICA

Sealed radioactive sources declared as spent/disused, are sent by the user or collected by NECSA (South African Nuclear Energy Corporation) and placed in a quarantine zone where leak tests are conducted and the documentation verified and fed into the register. Here, also the category of the source is determined. This categorization not only is applied in terms of nuclide but also to the possibility of re-cycling of the source and the container type. Process control sources such as ^{60}Co and ^{137}Cs are removed from their containers in a Class II laboratory/workshop and then transferred to the isotope-specific hot-cells for re-encapsulation and re-cycling.

The remaining sources, that include those of long half-lives such as ^{226}Ra, ^{63}Ni, ^{241}Am, AmBe neutron sources and ^{90}Sr, are extracted from their containers and placed in suitably shielded storage facilities, such as bunkers, lead pots or, as in the case of neutron sources, a water tank.

The sources that will not be re-cycled will be placed in 316 L stainless steel cans of 20 to 60 mm diameter. The size of the can is dependant on the size and number of sources – only sources of one nuclide are placed in a can. After welding and testing, the cans will be placed into an 8 L stainless steel waste canister, which has been designed to be able to be lowered and raised in a pipe at the interim pipe store facility. The waste canister is welded closed and, as before, will contain sources of only one nuclide in perhaps a number of smaller cans.

The pipe store has been built to accommodate two types of material, the spent fuel rods from the SAFARI reactor and the waste generated in the ^{99}Mo production process. The latter is also to be used for spent/disused sources. This store consists of 56 below-surface pipes of 7 m length installed in a high-density concrete block. The mild steel pipes are closed with a concrete plug to provide shielding, as the canister only provides containment. 840 canisters can be accommodated in this store.

At present, borehole disposal is being investigated in South Africa. After about 20 to 50 years storage in the pipe store, the canisters would be retrieved, the inner cans removed and placed into these boreholes. If borehole disposal is not accepted then another disposal route would have to be found.

4. EUROPEAN UNION (EU)

This appendix provides information that applies in all fifteen EU member States and also provides some specific references to the situation and practises in individual member States.

Current practice in European Union member States for the management of LLSRS broadly follow a number of basic principles, but these are implemented in a variety of ways.

REGULATORY CONTROL

All Member States operate regulatory systems, which require each user of sealed sources to hold a license. In principle there are many similarities between these systems. In practice, however, there are also many differences. In some cases, most regulatory attention is paid to assessing the competence of the prospective user before issuing a license and thereafter, the amount of attention is limited. This means that the user should have suitably qualified staff and management systems.

In other cases, regulatory control is applied throughout the source life cycle, with particular attention being paid to approval of individual source transfers. The regulatory structures also vary considerably. In countries with small sealed source markets, a single regulator is responsible for all aspects of the use and disposal of sealed sources. In larger countries there may be multiple regulators sharing responsibilities on a regional or functional basis.

When sources are no longer in use, a number of different situations exist. These range from countries which have very few regulations specifically directed at spent sources (e.g. UK) and which rely more on general regulations which cover all aspects of source usage, through to Spain where the owner of a spent source is effectively given permission in legislation to return it to a supplier, to Ireland, Greece and France where the spent source must be returned to the supplier.

MANAGEMENT SCHEMES FOR SPENT LONG LIVED SEALED RADIOACTIVE SOURCES

In every EU member state LLSRS are stored at the users' premises for varying periods after they are declared spent. All EU member states encourage, to varying degrees, the return of LLSRS to the original manufacturer.

Below are some examples giving a summary of the management schemes (other than storage by the user or return to the manufacturer) in a number of the EU member states;

Austria has a centralized system for the management of sealed radioactive sources. In the Austrian Research Centre at Seibersdorf sources are segregated and then all the sources (including LLSRS) are conditioned. The conditioned sources are stored in an engineered aboveground storage facility. Radium needles are welded into stainless steel capsules (that are retrievable), which are positioned in lead shielding and placed into 200 L concrete drums. In the 1980s single radium needles were occasionally cemented directly.

Belgium disposed of spent sources up to 1982. Since then spent sealed sources have been held in unconditioned form in the long-term storage facility at Mol. Spent sealed sources are segregated according to their radiation type, physical/chemical composition, size and level of radiation. It is important that the sources are retrievable throughout the entire storage period. Generally, they are conditioned in a stainless steel inner container that is fitted in a concrete-lined 400 L drum. No direct grouting of the sources is foreseen but dry sand is added in order to reduce the voidage to below 5% of the total volume of the drum.

Denmark has no final disposal route for spent sealed sources and they are currently stored on the site of the Riso National Laboratory. There are two main stores at Riso, one underground for high activity waste and an above ground store for containers with low surface dose rates. Although some sealed sources are in the above ground store, they are usually kept underground in stainless steel drums in three metre deep holes. Sources which cannot be removed from their transport containers due to high dose rates are stored in those containers in a separate secure store.

In **France** ANDRA is the organisation responsible for all radioactive wastes, including sealed sources. ANDRA operates a surface disposal facility for LLW and short lived waste at Centre de l'Aube and is working to develop a deep underground disposal site for I/HLW and will include sealed sources. ANDRA does not yet have the capability to dispose of sealed sources, nor indeed to store them, although it has an intention to set up a storage facility. At present, long term interim storage is provided by CEA. Sealed sources are received for storage at Saclay or occasionally, for recycling, at Marcoule. Stored sources at Saclay are currently held in their transport containers, however, there are plans to volume reduce and transfer them into containers with 1 L cavities. These containers will include various thicknesses of shielding, depending on the contents.

Germany has several options for the removal of spent sources from the users, including direct transfer to local interim stores, or transfer through companies offering a commercial disposal or recycling service. Each German state is required to ensure that an interim storage facility is available to users of radioactivity within its territory. Each facility has its own acceptance criteria. Most of these facilities provide a storage service only and do not condition waste – if required for acceptance then conditioning must be done prior to delivery to the storage facility. There is one disposal facility in Germany at Morsleben that can accept spent sources. The limitations on the isotopes and activity that can be accepted at Morsleben mean that at least one more disposal facility will be required in Germany.

Luxembourg has a small number of sealed sources. There is no central facility for spent sources. They are stored at the users' premises until that can be returned to the original supplier (this is a condition of the license for use). If the original supplier no longer exists then the regulator will arrange disposal to a foreign depository.

The **Netherlands** discourages the storage of spent sources by the user and disposal can be enforced by time limits on the license. The user can either return the source to the manufacturer or send it to the radioactive waste management organisation, COVRA. COVRA collects sources from throughout the country and operates a central treatment, conditioning and long term (at least 100 years) interim storage facility at Borsele. Some sources, especially alpha bearing material, can be placed in 200 L drums inside 1000 L concrete overpacks.

Sources in instruments or holders are not normally volume reduced on receipt, other than by removing excess packing material. However, as disposal prices are based on volume, some customers will reduce volume of sources where possible.

Spain has one organisation (ENRESA) that is licensed for the management and disposal of radioactive waste and they operate a near surface disposal facility at El Cabril. El Cabril can accept for disposal only LLW and ILW containing principally short lived radionuclides, although it has some additional capacity for the temporary storage of other radioactive waste.

In the **United Kingdom**, once a sealed source is declared as being waste the user has three months to dispose of the source to an organisation that holds an authorisation to accumulate and/or dispose of the spent source. If disposal is not undertaken within this period, the user must seek an authorisation to accumulate the waste on his premises. There are a number of options for the management of spent sources, including storage at the engineered interim waste stores operated by UKAEA at Harwell and by Nycomed Amersham in Buckinghamshire. The only commercially available final disposal route in the UK is the LLW repository at Drigg. Due to the specific activity limits (12 GBq/te beta/gamma and 4 GBq/te alpha), which are applied to each waste stream, most spent sources cannot be accepted for disposal at Drigg.

5. BRAZIL (CENTRO DE DESENVOLVIMENTO DA TECHNOLOGIA NUCLEAR/CDTN)

The production and distribution of radioactive lightning rods in Brazil dates back to the early 1970s. The main radioisotope used in this equipment was americium-241, although radium-226 was also used, but in a very smaller scale. Later on, it was decided to discontinue the use of this technique, due to the lack of evidence of their superior efficiency compared to the traditional Franklin lightning rods and to the associated risks. The radioactive material can be released to the environment, due to natural conditions (rain, wind, temperature changes, etc.) or human intervention (stealing or incorrect manipulation) and the long half-life of ^{241}Am — much longer than the lightning rod's structure and even than the building it is supposed to protect — poses the unwanted scenario of the equipment ending up in a scrap yard or landfill site. The risk is aggravated in view of the high ^{241}Am radiotoxicity (consequently, very low Annual Limit on Intake); the critical organs for this radioisotope are kidneys, lungs and bones.

In view of that, the Brazilian nuclear authority decided in 1989 that there was no justification for their use and to withdraw the license for this technique. Therefore lightning rods were taken out of service and collected at different institutes of the Brazilian National Nuclear Commission – CNEN. As a result, the CDTN has received, to date, almost 2000 of these devices, which are at the institute's storage room (Fig. C-5). As it is estimated that around 80,000 rods (a typical lightning rod is shown in Fig. C-6) were installed in the country, it is foreseen that thousands more will be received in the forthcoming years. It was decided to volume reduce the rods in order to optimise the required storage space. A glove box was built for safely dismantling this equipment and is fully operative since September 2002.

The installation where this glove box is located was built according to the applicable regulations. The walls and floor are epoxy painted and an adjacent personnel decontamination and monitoring room is provided.

FIG. C-5. Waste storage room at CDTN.

FIG. C-6. Lightning rod produced in Brazil.

The glove box (Fig. C-7) is made of stainless steel (supporting structure, frame and end walls) and Plexiglas (lateral walls, ports and ceiling) and is operated at negative pressure. The box is fitted with six pairs of neoprene gloves for carrying out the dismantling operations. Several tools are available in the box, such as wrenches, screwdrivers, electrical scissors, etc.

The dismantling operations are carried out by qualified and trained personnel, under the coordination of the supervisor of the installation. The ^{241}Am strips are removed from the lightning rods body using appropriate tools and placed in a stainless steel capsule. A multi-channel analyser is used to measure the activity in each capsule. In order to maintain retrieveability, the capsule has a screwed lid rather than a welded lid. The remaining lightning rod body is checked for contamination and, if necessary, decontaminated and collected in steel drums located below the glove box.

FIG. C-7. Glove box for ^{241}Am lightning rod dismantling.

The glove box is equipped with a HEPA filtration system. The activities carried out in this laboratory follow the general radiation protection recommendations and specific technical procedures established for this operation.

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Technical Meeting
2–6 September 2002, Vienna, Austria