IAEA-TECDOC-886

Conditioning and interim storage of spent radium sources

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FOREWORD

The first practical applications of radioactive material was the use of sealed radiation sources in medicine and industry. Originally only sources made from naturally occurring radionuclides, primarily radium, were available and became frequently used. With the development of production of a number of new radioisotopes, also the production of radiation sources containing isotopes other than radium (safer and easier to handle) had been increased. Consequently the production of radium sources was stopped in the 1960s and the number of spent radium sources increased.

Experience gained from the IAEA Waste Management Advisory Programme (WAMAP) Missions have shown that spent radiation sources are stored under conditions which in many cases are not appropriate. The origin, history and even the characteristics of many spent sealed sources are unknown due to incomplete or lacking registry.

The IAEA's Spent Radiation Sources Programme was established in 1991. The programme includes, among others, the development of technical documents and manuals to disseminate guidance and recommendations on issues associated with the safe management of spent radiation sources. Currently, the following reports have been published:

- Handling, Conditioning and Disposal of Spent Sealed Sources, IAEA-TECDOC-548 (1990),

- Methods to Identify and Locate Spent Radiation Sources, IAEA-TECDOC-804 (1995) and

- Reference Design for a Centralized Spent Sealed Sources Facility, IAEA-TECDOC-806 (1995).

Although in all of these publications some specific aspects have been discussed, there are a number of reasons why a separate technical document was needed on conditioning and interim storage of spent radium sources. The unfavorable radiological characteristics of ^{226}Ra require special conditioning techniques which result in a safe containment from both radiological and physical security points of view. However, acceptance criteria for waste packages with regard to deep geological disposal of long lived, alpha bearing waste have not yet been established and therefore the possibility to retrieve and recondition radium sources should be maintained. This requirement is also taken into account in the present report.

This report is of main interest to waste management operators and regulators in Member States where spent radium sources are still being collected for conditioning and stored for eventual disposal in a deep geological repository. The methods and procedures proposed can also serve as guidance to IAEA experts assisting developing Member States in managing their radioactive waste, especially spent radium sources.

The first draft of this TECDOC was prepared by the IAEA Secretariat with the assistance of a group of consultants in 1994. The draft was revised by an Advisory Group and finalized by the Secretariat. The IAEA wishes to express its thanks to all those who took part in the preparation of this report.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Since Pierre and Marie Curie isolated radium from pitchblende in 1898, and this element became available in the beginning of the 20th century, numerous uses were found and developed in medicine, industry, and personal applications.

Until the late 1940s no radionuclide other than radium was available in significant quantities for use as sealed radiation sources. When particle accelerators and research reactors became available, during the 1950s, sources with many different radiation characteristics could be produced. These were safer and easier to handle than those containing radium, and could be used for many new purposes. Consequently the production of radium sources has stopped.

When the main producers stopped production of radium in the 1960s, the total quantity of radium produced by the main refiners was estimated to be a few kg [1]. Various devices using radium were developed and distributed. The quantity of radium in the devices varies in the range of 10^6–10^{11} Bq.

Continuous progress concerning the knowledge of the hazards associated with the use of radioactive material, and the characteristics of most of the devices containing radium, calls for a well planned and carefully executed collection and ongoing management of those items under the direction of responsible authorities.

The radium isotope of concern in radium sources is ^{226}Ra. Although small amounts of other isotopes of radium may have been present at the time the sources were produced, the half lives of the other isotopes (primarily ^{228}Ra) are sufficiently short, that only ^{226}Ra remains in quantities of concern.

^{226}Ra is an alpha emitter with a half-life of ~1600 years. It is generally believed that due to the specific activity of the sources and the half-life of ^{226}Ra, final disposal in a suitable geological repository is necessary. Since such a repository does not yet exist anywhere in the world, and probably will not be in operation for some decades into the next century, it becomes a necessity to conceive a long term interim storage facility for this type of waste until such time as a suitable final solution becomes available. The radioactive characteristics of ^{226}Ra and its daughters, particularly the gas ^{222}Rn, necessitates that radium sources are suitably conditioned before interim storage. The solution chosen for conditioning should take into account that acceptance criteria concerning waste packages for geological disposal have not yet been established. Consequently, techniques developed for re-encapsulation of radium sources must avoid causing difficulties for later management.

As radium sources had been manufactured and used for a long time, their tracking can present some difficulties, and a clear policy must be established at a national level to guarantee the protection of man and his environment.

1.2. OBJECTIVES

The objective of this report is to provide waste management operational organizations and regulatory bodies with technical information and recommendations on issues associated with the management of spent radium sources.

1.3. SCOPE

This report is intended to provide technical information and recommendations on activities related to the management of spent radium sources, including preparation of sources at the user premises, conditioning and interim storage, together with an appropriate quality assurance programme.

Radium sources addressed in the present report are mainly those which have been used in medicine and for industrial applications, in the form of sealed radiation sources. Figure 1 presents the main steps for their management. Unsealed radium sources (e.g. consumer products containing luminescing paint) and material contaminated with radium are not considered specifically in this report.

For some sources such as those designed to generate radon and neutron generating radium–beryllium sources with activities of 1 GBq (a few tens of milligrams) or higher, special precautions may be necessary before the conditioning methods described in this report are applied.

The report does not deal with disposal. Conditioning techniques presented here are sufficiently flexible to permit further conditioning to be carried out if required before, for example, disposal.

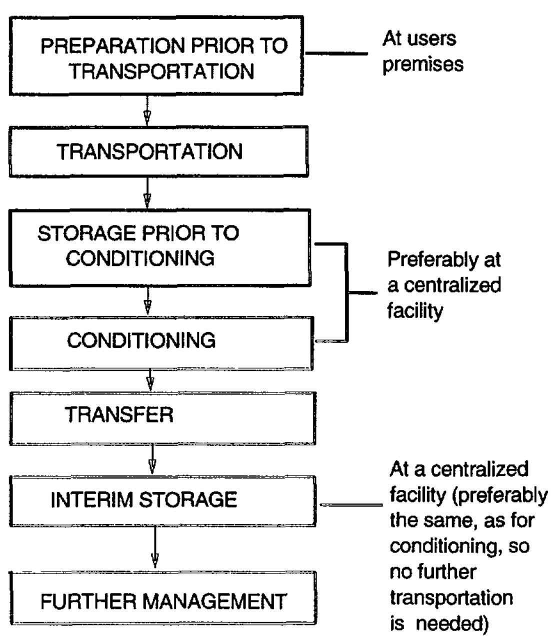


FIG. 1. Flow chart for the management of spent radium sources ("further management" is not considered in this report).

2. INFRASTRUCTURE

2.1. LEGAL REQUIREMENTS

The overall objectives of waste management, which are also applicable to spent radium sources, are to safely collect, handle, condition, transport, store, and dispose of waste, in order to protect human health and the environment now and in the future without imposing undue burdens on future generations. To meet these objectives, the internationally agreed principles as presented in the RADWASS Safety Fundamentals document [2] should be applied.

Member States should develop, as part of a national policy for radioactive waste management [3], policies and strategies related to conditioning and storage of spent radium sources from medical, industrial and research activities. The components of a national waste management system will vary from country to country depending on the amount of waste and the administrative and governmental structures. However, as a minimum, the national policy should include laws and regulations, implementing organizations, licensing and controlling authorities, and mechanism for funding.

The establishment of a national radioactive waste management policy and a clear separation of responsibilities between the different entities involved in waste management are the necessary conditions for short and long term safety to be guaranteed.

The state should establish and implement a legal framework, set up a regulatory body and define the responsibilities of the regulatory body, the waste producers and the entity in charge of long term waste management [3].

The means of providing facilities for waste management will vary from country to country. In some countries, specialized organizations have been established for this purpose. In others, it remains the sole responsibility of the user, but it is generally accepted that the state shall have the ultimate responsibility for the long term management of radioactive waste, especially if the user is incapable of appropriate handling or no longer exists. As far as long-lived radioactive waste is concerned, including spent radium sources, it seems suitable to establish a centralized organization for the management of these wastes. The duration of the storage period and the socio-political considerations linked to the creation of storage and disposal facilities should be taken into account. This could ensure that the storage facility is kept in safe condition and that waste data are conserved.

2.2. NATIONAL INVENTORY OF SPENT SOURCES

Spent radium sources are probably the oldest radioactive waste produced in a country. For that reason there is often a lack of data concerning their existence, location, and nature. It is necessary to establish a national inventory of all spent radium sources distributed in the country. This can be achieved by sending a questionnaire to organizations likely to have used radium sources at some time including hospitals, universities and industries, as well as to local authorities in charge of health or protection of the environment. Information useful for establishing a national database of spent radium sources is available in Refs [4] and [5].

2.3. RECORD KEEPING

It is of vital importance to establish and maintain records of all operational activities relative to each phase in the source preparation (for storage), conditioning and interim storage processes. At some future time these records may be the only information that exists for these wastes. If information is lost, it may become necessary to open the containers for identification, testing, and reconditioning at some future time.

If there is a lack of information at the moment of collection before operational storage, especially concerning the description of the source and the evaluation of its activity, appropriate measurements have to be done and the results recorded.

As it is difficult to know precisely what information may be required after several tens of years, any information available should be included in the records even if some may not seem necessary.

To minimize the risk of loss or destruction, it is recommended that at least two independent sets of records be maintained, one of which should be kept by the national regulatory body.

3. SOURCE TERM

3.1. GENERAL

For the purpose of this publication radiation source is an object having a radioactive substance as its primary source of ionizing radiation. Depending on the type of application, activities involved etc., the radioactive material is enclosed in an inactive capsule or coated to prevent, under normal conditions of use, any dispersion of the radioactive substance.

Radium used in medicine, research and industry is in the form of sealed sources (mostly as salts), luminescent material, silver foils, radium bromide solutions etc. In medicine, they are used in the form of needles and tubes for brachytherapy or applicators for external betatherapy. For research and in industry, radium is used for instrument calibration, radium–beryllium (Ra–Be) neutron sources, moisture detectors, fire detectors, lightning preventors and items for elimination of static electricity.

3.2. SOURCE CHARACTERISTICS

^{226}Ra is part of the decay chain of ^{238}U. ^{226}Ra decays with an alpha emission to ^{222}Rn, a noble gas with a half-life of 3.82 days. Before the decay chain ends with the stable isotope ^{206}Pb, a further eight radionuclides of which four are alpha emitters are generated. Each decaying ^{226}Ra atom thus gives rise to five alpha particles. During the decay many gamma quanta and beta particles are emitted. In a radium source there are ^{226}Ra and decay products. ^{226}Ra is a very radiotoxic radionuclide having a low annual limit of intake. Some important characteristics of ^{226}Ra are presented in Table I [1].

TABLE I. CHARACTERISTICS OF ^{226}Ra USED IN SEALED RADIATION SOURCES [1]

Characteristics of ^{226}Ra in equilibrium with its decay products	
Half-life	1600 years
Alpha energies Beta energies Gamma energies	up to 7.7 MeV up to 2.8 MeV up to 2.4 MeV
Gamma constant	220 μSv/h at 1 m from a 1 GBq source
Half value layer (HVL) of lead Half value layer (HVL) of concrete	14 mm 70 mm
ALI (oral) ALI (inhalation)	7×10^4 Bq 2×10^4 Bq

Note: Neutrons are also generated by Ra–Be sources.

A simplified scheme for the ^{238}U decay series, which includes ^{226}Ra, is presented in Fig. 2 [6].

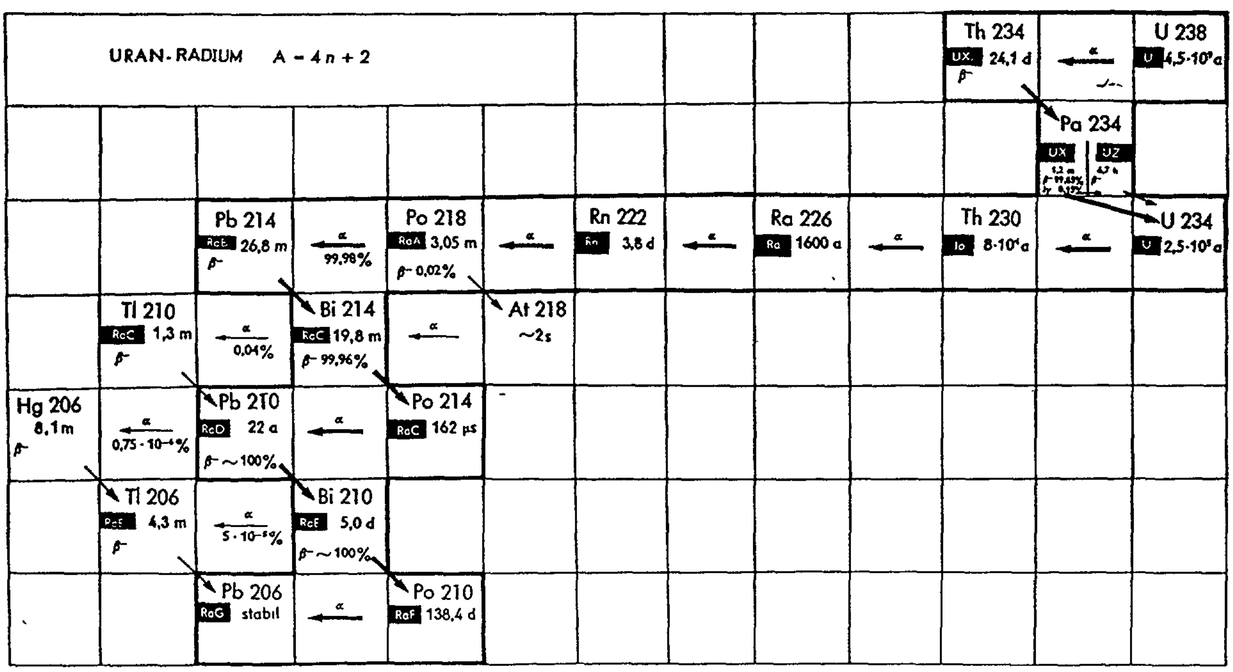


FIG. 2. A simplified scheme for the ^{238}U decay series, which includes ^{226}Ra.

The decay of each atom of ^{226}Ra yields five helium atoms formed from the alpha particles emitted in the decay chain. This generates overpressure in the sealed radium source (about 0.2 atmospheres per year for one gram of radium assuming a free volume of 1 cm^3) which facilitates leaking and spread of contamination. If water of crystallization is present in the source the alpha particles emitted in the decay chain decompose the water into oxygen and hydrogen, which further increases the overpressure. Leaking radium sources have always been a major radiation protection problem. In the early days there were explosions of large standard radium sources encapsulated in glass, and explosive ruptures of metal sealed sources have also been reported. This characteristic of ^{226}Ra is another reason why it is regarded as unsatisfactory from the radiation protection point of view.

Hospitals were among the largest users of sealed radium sources. They were mostly used for brachytherapy. These sources are small, and were often handled one by one without any shielding during use. The inventory of radium sources in a large hospital could be in the hundreds. There is a real risk that sources may be lost if very strict procedures are not followed, and in fact losses have occurred.

Old radium sources may represent the largest single problem in the management of spent radiation sources. An additional problem with these sources is that they are often leaking, due to internal overpressure, or mishandling. Many of the sources and source users may not be registered with the National Regulatory Authority. The small size of the sources, portability and high apparent value (due to the materials of encapsulation) increase the risk of theft.

A range of radium sources other than those used as sealed sources or applicators in medicine and industry also exist. These sources can be radium salt solutions, luminous paint or silver foils containing radium, and have been used in industrial applications. Radium salt (bromide) used in certain types of electronic valves and radium sulphate used in starting switches in a similar manner. Quantities in the former were of the order of tens of kBq and in the latter hundreds of Bq. The main uses of silver foils containing radium were in manufacture of instruments, lightning preventors, smoke detectors, electronic items, research etc. These materials once procured by the users, were retained by them for a very long time owing to the long half-life of ^{226}Ra, resulting in long usable life. Luminous powder is used in a number of applications in industry. One of the methods of manufacturing was by evaporating to dryness a mixture of radium bromide, potassium sulphate and zinc sulphide. Luminescing powder was mixed with a suitable carrier to form a paint. The radium content of the paint varied from 0.2–5 MBq (0.005–0.12 mg) of radium per gram depending upon whether it is used in clocks, watches or instrument dials. Ra–Be sources producing neutrons were used mainly for research and industrial applications. The management of these sources is not specifically covered by this report. Special consideration should be given to the handling and storage of unsealed radium sources and Ra–Be sources.

3.3. QUANTITIES — ACTIVITY AND VOLUME

In general sealed radiation sources have small volumes and high source strength. Radium sources used for medical purposes have activities in the order of 40–400 MBq (1 to 10 mg of ^{226}Ra). The typical volume of a source is of the order of a few tens of cubic millimeters. However, this volume may increase many fold when such sources are conditioned.

Estimates of the number of spent radium sources which need conditioning and disposal vary widely. It is believed that large numbers of spent radium sources are located in developing countries where source management technology assistance is needed.

The activity range for medical radium sources rarely exceeds 4 GBq (100 mg) with the average source being about 200 MBq (5.6 mg) for needles and about 260 MBq (7 mg) for radium tubes. Over 90% of the radium needles and 78% of the radium tubes are within the activity band of 40–400 MBq (1 to 10 mg). However, activity levels of some non-medical radium sources have higher activity levels [4]. About 30% of the Ra–Be neutron sources exceed 20 GBq (500 mg) and a small number of miscellaneous sources can exceed 40 GBq (1000 mg). Tables II and III [7] indicate typical values of radioactivity associated with ^{226}Ra in sources used for medical and non-medical applications.

TABLE II. SUMMARY OF DATA FOR MEDICAL RADIUM SOURCES (USA) [7]

Activity range GBq (mg)	Needles %[a] (mg)[b]	Cells % (mg)	Plaques % (mg)	Nasopharyngeal Appl. % (mg)
≤ 0.004 (≤ 0.1)	0.01 (0.01)	–	0.6 (0.007)	–
0.004-0.02 (0.1-0.5)	0.14 (0.45)	0.3 (0.46)	–	–
0.02-0.04 (0.5-1)	2.2 (0.73)	5.4 (0.61)	0.6 (0.89)	–
0.04-0.2 (1-5)	52.1 (3.05)	40.9 (3.20)	30.6 (3.42)	3.1 (3.28)
0.2-0.4 (5-10)	40.0 (7.72)	37.4 (7.57)	41.9 (8.18)	4.6 (9.44)
0.4-2 (10-50)	5.3 (15.4)	15.8 (17.6)	24.1 (17.5)	81.5 (44.7)
2-4 (50-100)	0.13 (71.7)	0.2 (66.9)	2.2 (61.0)	10.8 (67.4)
>4 (>100)	0.04 (118.0)	–	–	–
Weighted Ave.[c] (mg)	5.65	7.09	10.01	44.2
Est.total no. of sources	7,669	3,355	320	65

[a] The percent of sources in the activity range compared to total sources.
[b] Weighted average in the activity range.
[c] Weighted average for each type of source.

TABLE III. SUMMARY OF DATA FOR NON-MEDICAL RADIUM SOURCES (USA) [7]

Activity range GBq (mg)	Ra–Be sources %[a] (mg)[b]	Activity range GBq (mg)	Other sources % (mg)
≤ 0.04 (≤ 1)	10.5 (0.36)	≤ 4E-5 (≤ 0.001)	38.4 (6.13E-4)
0.04-0.2 (1-5)	14.0 (3.75)	4E-5 - 4E-4 (0.001-0.01)	36.0 (4.09E-3)
0.2-0.4 (5-10)	11.6 (9.49)	4E-4 - 4E-3 (0.01 - 0.1)	3.5 (4.87E-2)
0.4-2 (10-50)	14.0 (18.6)	4E-3 - 4E-2 (0.1-1)	9.7 (4.88E-1)
2-4 (50-100)	2.3 (100.0)	0.04-0.4 (1-10)	10.2 (3.17)
4-20 (100-500)	17.4 (302.0)	0.4-4 (10-100)	0.4 (54.9)
20-40 (500-1000)	4.7 (678.0)	4-40 (100-1000)	1.3 (464.0)
>40 (>1000)	25.5 (1,431.5)	>40 (>1000)	0.5 (3,210)
Weighted Ave.[c](mg)	457		22.7
Est. total no. of sources	86		1,703

[a] The percent of sources in the activity range compared to the total number of sources.
[b] Weighted average in the activity range.
[c] Weighted average for each type of source.

Based on the data available so far, the identified quantity of radium in developing countries is about 4.5 TBq corresponding to 122 g, and the total quantity is estimated to be 8–10 TBq (200–250 g). With an average quantity of 8 mg per source, the number of sources is in the order of 25 000 to 30 000. The estimated total quantity of radium for the entire world is a few kg [1].

3.4. PHYSICAL AND CHEMICAL FORM

For applications in medicine and industry radium was usually encapsulated in platinum, platinum–iridium and other alloys, and sometimes in gold. Such capsules are commonly called needles or tubes depending on their use. Typical dimensions of needles are 1.7 mm diameter and 15–20 mm in length and of tubes 3 mm diameter and 20–25 mm in length. For special applications medical sources can have lengths of up to 60 mm and more. Typical dimensions of cell-filled needles are 0.8 mm in diameter and 15 to 45 mm in length. The physical configuration of sources for medical use is presented in Fig. 3 [7]. Some typical radium sources used in medicine are shown in Fig. 4.

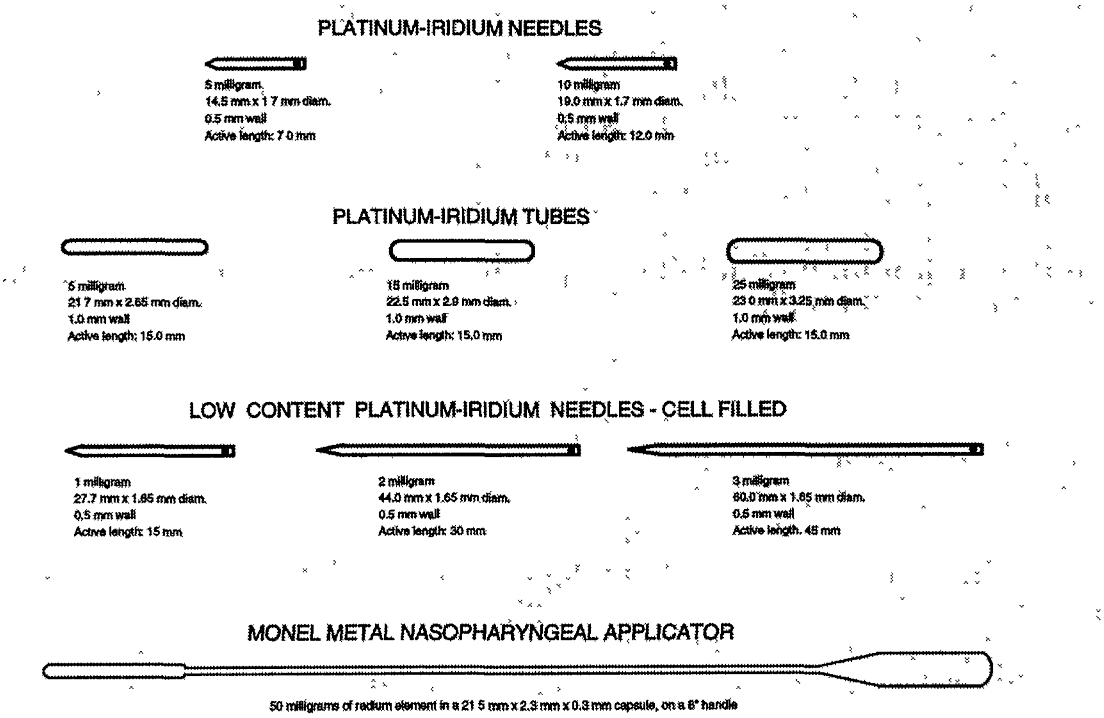
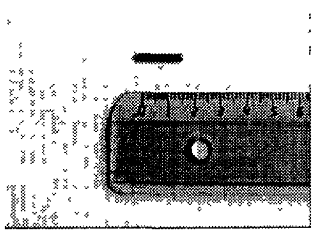
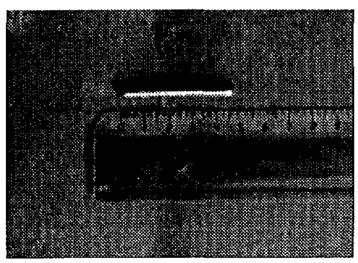


FIG. 3. Typical dimensions of medical radium sources [7].



(a)



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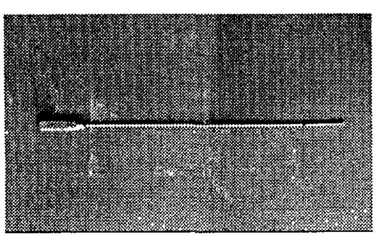

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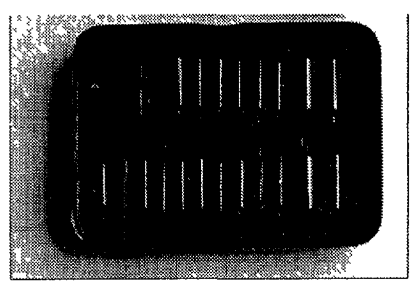

(d)

FIG. 4. Typical radium sources used in medicine.
(a) and (b) tubes of typical sizes, (c) monel metal nasopharyngeal applicator, (d) a set of tubes.

Radium-226 is an alkaline earth metal and is highly reactive even with nitrogen. In radiation sources radium is therefore always present in the form of salts, such as bromides, chlorides, sulfates or carbonates which are considerably less reactive. All are sufficiently soluble in water to give rise to radiological problems. The salts may easily be dispersed as powder if the source encapsulation is leaking. Leakage may be caused by over pressurization of, or physical damage to the source. This is one reason why ^{226}Ra is not regarded as an ideal material for use in sealed sources.

In the body radium behaves like calcium, which means it concentrates in bone where it has a very long biological half-life [4].

4. INTEGRATED SOLUTION

The management of spent radium sources consists of the following stages:

- preparation of sources for transport (usually at the users premises);
- transport (from the users premises to the conditioning facility);
- operational storage (temporary storage at the centralized storage and conditioning facility);
- source conditioning (encapsulation and shielding);
- interim storage (storage of the completed packages);
- further management.

The interdependencies between the stages must be taken into account as measures taken at one step may foreclose alternatives for, or otherwise affect, a subsequent step. Furthermore, in order to minimize transport of radioactive materials, it is preferable that conditioning and storage of spent radium sources would be done in the same facility.

Conditioning should take into account the fact that acceptance criteria for future management of radium sources waste packages are not yet specified. Conditioning techniques that could cause difficulties at a later stage (e.g. need for difficult or costly re-conditioning) should be avoided.

There is a common interest for ongoing management to reduce the volume of the radioactive material to be handled. Thus it is recommended that where practical, sources be removed from devices.

It is preferable to avoid all irreversible treatment of spent radium sources, particularly direct embedding in a matrix which might not necessarily be compatible with later management stages. Conditioning techniques should allow for easy retrieval of the source at a later time.

The durability of the conditioned package, including identification mark, should be in accordance with the length of the foreseen storage period, which may be decades or longer.

Taking into account all these constraints, the storage must be safe, especially with regard to radiation, contamination, fire risks and physical safety.

5. PREPARATION FOR TRANSPORTATION

5.1. GENERAL

Spent radium sources must be prepared prior to transportation to the centralized conditioning facility. Preparation should include the following steps:

- compilation of information on the source;
- controlled handling and packaging.

Compilation of information on the history of the source can be carried out by the owner. This information should be made available at the earliest opportunity. Qualified assistance (e.g. Operations Manager listed in Section 6.2.3) should be obtained before the source is handled or packaged for transport.

Detailed planning should be carried out by trained personnel before source preparation and transportation. The source preparation and transport operations should be detailed as part of the Quality Assurance Programme (See Section 8) covering all aspects of the source management operation.

5.2. SOURCE INFORMATION

Any available information on the source should be collected. Preferably, the information should include the following details :

- supplier of the source;
- date of production;
- activity/radionuclides;
- physical and chemical form;
- source dimensions, geometry;
- results and date of previous leak test;
- user of the source (details and persons responsible);
- measured dose rate;
- details of shields;
- gross weight (including shielding pots).

It is important that all information on the source is retained and dispatched with the source. The information should also be included in a centralized registry of spent radiation sources. Information on the design of a computerized registry system is available from Ref. [5].

5.3. SOURCE HANDLING AND PACKAGING

Qualified assistance must be obtained before the source is handled and packaged for transportation. If reasonable identification of the source is not possible, it should be assumed, as a worst case, that the source contains radium. The possibility that the source is a neutron source (Ra–Be) requiring special handling should be considered. Prior to transportation, it will be necessary to obtain the following minimum information on the source:

- estimate of the radionuclide and activity;
- indication of the integrity of the capsule.

An estimate of the activity of the source can be obtained by measuring the dose rate at a known distance (usually 1m). The integrity of the source capsule can be assessed by physical inspection and monitoring the vicinity of the source for radon emanation and surface contamination.

All operations should be planned before the source is handled. The source should be handled using forceps or tongs and never by hand. All handling operations should be carried out in a controlled area.

The areas around the source need to be surveyed for contamination during and after the handling. The planning and implementation of decontamination (as applicable) and management of operational waste arisings is not within the scope of this report and is described in Ref. [8].

If the radium source is found to be leaking, it will be necessary to transfer it to a suitable container before it is packaged for transportation. Preferably, the source should be contained in the capsule intended for conditioning, provided an adequate temporary seal can be obtained. If this is not available, the source should be contained in a simple metal can, which is sealed to prevent the spread of contamination. The size of the can should be kept to a minimum.

5.4. TRANSPORT OF SOURCES TO PLACE OF CONDITIONING

Spent radium sources are often stored at the place of use (hospitals, research institutes, industries, etc.) and must be transported to the place of conditioning. Source transportation should be arranged by personnel experienced in the transport of radioactive material, and must be carried out in accordance with national and international transport regulations.

It is outside the scope of this report to discuss all details of the IAEA recommendations on the transport of radioactive materials [9] which are applicable to transportation of spent radiation sources, but a few comments can be made:

(a) Small radiation sources can be transported as Type A packages. A Type A package is designed to withstand normal conditions of transport, including mishaps. Activity limits specific to each radionuclide apply. In the case of radium the activity limit for a Type A package is 20 GBq which is equivalent 500 mg.

(b) Type A packagings (in transport terminology, packaging is the enclosure which together with the source forms the package) are commercially available at a reasonable price.

(c) The National Regulatory Authority for transport of radioactive material should be consulted prior to the transport of spent radium sources. If there is no such authority with adequate expertise established in the country, assistance from the IAEA should be sought.

Before transportation of spent radium sources, it must be ensured that radiation and contamination levels are within approved limits [9]. Special consideration should be given to Ra–Be sources. Additional shielding for neutrons may be required.

If transportation is carried out within one country only, national transportation regulations must be observed. In the case where two or more countries are involved, the regulatory authorities responsible for authorizing the transportation of radioactive materials in each country must be contacted in advance. It is important to fulfill every requirement before transportation takes place.

6. SOURCE CONDITIONING PROCESS

6.1. GENERAL

Administrative and technical condititons for the safe receipt and temporary storage of sealed sources at the centralized facility are described in Ref. [10].

Source conditioning is required before long term interim storage to avoid the release of radioactive material and to limit radiation exposure. It is recommended that the containment of the radioactive material is achieved by high integrity encapsulation designed to control the radon emanation problem. Radiation exposure should be limited by appropriate shielding. The shielding container should be designed to maximize the physical security of the sources.

6.2. PLANNING FOR CONDITIONING

Detailed planning should be carried by qualified personnel prior to source conditioning. The conditioning operation should be detailed as part of the Quality Assurance Programme (see Section 8) covering all aspects of the source management operation.

The source conditioning procedure should include, as a minimum, detailed consideration of the following:

- regulatory requirements;
- facility requirements;
- personnel required;
- records;
- radium inventory per package;
- selection and qualification of the procedure;
- equipment and material required;
- preparation of containment;
- safety.

6.2.1. Regulatory requirements

Conditioning of radium sources is an activity for which an operating license should be obtained. The operating license should define the scope of the conditioning operations as well as any specific condition that must be observed (see Section 2).

The conditioning operation is governed by criteria for acceptance of a package produced for interim storage and, eventually, for final disposal. Source conditioning should not prejudice future options for transportation [9] and further management [11–13].

6.2.2. Facility requirements

The conditioning and storage facility should be designed to meet technical and functional specifications in agreement with legislative requirements [10].

6.2.3. Personnel requirements

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

The number of persons needed is not prescribed. Nevertheless, the presence of at least two persons is usually required during any operation with radioactive material. On the other hand too many persons should be avoided.

The personnel qualifications recommended for each conditioning task are outlined in Table IV.

TABLE IV. PERSONNEL QUALIFICATIONS AND EXPERIENCE

Personnel category	Qualifications/Experience
Operations Manager	Experienced radiochemist or a radiophysicist trained to university degree level with experience in radioactive waste management
Radiation Protection Supervisor	Experienced in radiological protection procedures and regulations
Task Manager	Practical experience with the handling of radioactive materials and quality control
Skilled operator	Experience in the selected conditioning methods and operations

Training programmes should be provided as required.

6.2.4. Records

Before detailed planning is possible it is necessary to have all relevant facts about radium sources to be conditioned, such as:

- source type, geometry and dimensions;
- physical and chemical form;
- activity or weight of radium;
- last user of source; name and address;
- results and date of the last leak test;
- measured dose rate at a known distance (usually 1 m distance).

The information can be obtained from existing documents at the last user. Other sources may be previous user, producer of the source or the National Regulatory Authority.

All information should be collected and filed in a structured way to facilitate retrieval when needed. All information on the source should be retained in duplicate at separate locations [5]. A unique identification number should be placed on the outer surface of each encapsulation container and drum used for storage. The encapsulation container should be permanently labelled (eg. by engraving). A temporary label should be affixed to the storage drum until the contents have been finalized. It is recommended that the following information should be included on the labels as detailed in Table V.

TABLE V. LABELLING REQUIREMENTS

Object to be labelled	**Information**
Encapsulation container	Unique identification number Isotope Activity Date of loading
Temporary storage drum	Unique identification number Approved radiation markings Isotope
Permanent storage drum	Unique identification number Approved radiation markings Isotope Total activity Dose rate

The information on the sources to be placed in each encapsulation container should be recorded together with the appropriate capsule and drum identification numbers. The information should be summarized on a form similar to that shown in Fig. 5.

6.2.5. Radium inventory in each package

Conditioning of spent radium sources with cement in a 200 L drum or in another suitable container gives a package which is suitable both for safe transportation and storage. The 200 L drum containing conditioned sources, represents a Type A package according to the IAEA transport regulations [9].

The activity limit of radium in a Type A package is 20 GBq, corresponding to 0.5 g according to the IAEA transport regulations [9], provided that the surface dose rate and the dose rate at one meter from the surface of the package does not exceed 2 mSv/h and 0.1 mSv/h, respectively.

Part 1: Information on Source (an information sheet is required for each source)		
File Identification Number (Detailed Records) :		
Identification number of source: (if any)		
Type:	*Dimensions:*	*Activity:*
Name last keeper:	*Address of last keeper:*	
Source Integrity:		

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

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

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

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

Fig.5. Source Information Form.

6.2.6. Selection and qualification of the conditioning method

A conditioning process is required in order to provide high integrity containment for the radium sources and to minimize radiation dose rates for storage and transportation. The method of source encapsulation should take into account the following factors:

- number of sources to be encapsulated;
- size of sources;
- activity of the sources;
- type of ionizing radiation (alpha, gamma, beta, neutrons, etc.).

Special radiological precautions should be taken when handling Ra–Be sources with activities greater than 1 GBq (a few tens of milligrams). It is recommended that to achieve adequate containment of the radium and radon, the spent sources should be enclosed in a leak-tight stainless steel capsule. Preferably, the capsule should be sealed by welding (see Annex). Alternatively, a suitable container with a screw top and metal gasket seal could be used [7].

The objective of shielding is to reduce the radiation levels at the surface of the package to acceptable levels and to provide physical security for the sources. The design of the shielding package should take into account the following factors:

- total activity of the sources to be stored in the package;
- retrievability;
- physical security;
- radiation protection;
- storage period.

If it is envisaged that the shielding package could be used for transportation of the encapsulated sources in the future, the total activity of the sources contained within the shielding package should be limited to 20 GBq. During interim storage it is advisable to keep the conditioned radium sources retrievable, to avoid prejudicing their further management. In order to ensure physical security of the sources, the shielding package should be closed by a locking device and should have a gross weight of at least 100 kg. The shielding package should be designed to limit radiation exposure and withstand storage periods of several decades.

It is recommended that the shielding container consists of a lead liner, contained in a concrete and steel overpack. An example of the shielding container is given in the Annex.

6.2.7. Equipment and material required

When the details of the conditioning process are decided upon, all equipment and material required must be collected. Although there might be some differences depending on exactly how the conditioning is to be carried out, the following may be required:

Source encapsulation

- stainless steel capsule for encapsulation;
- welding equipment;
- leak-testing equipment;
- engraving tool;
- dedicated handling tools (e.g. long tongs);
- plastic sheeting.

Shielding drum

- 200 liter steel drums without any inside or outside corrosion and mechanical damage, preferably with galvanized and/or painted surfaces;
- additional shielding material required to meet dose rate criteria on the waste package;
- mould for preparing cavity inside 200 liter drum;
- cement, sand and water according to specified mixture;
- cement mixer or provisions for manual mixing;
- vibration device or provisions for manual compaction of mortar;
- steel reinforcement bars or reinforcement nets.

General

- personal dosimeters;
- regularly calibrated dose rate meters and contamination monitors;
- labels (for storage and transportation);
- fork lift truck;
- lifting equipment;
- respiratory protection (as required);
- airborne contamination monitoring equipment;
- personal protective clothing.

6.2.8. Safety considerations

During the source encapsulation and shielding process precautions should be taken to restrict internal and external radiation exposures to a minimum according to the ALARA principle [14]. Work involving the handling of radioactive materials should be carried out in a controlled area. Special precautions have to be taken to prevent inhalation of airborne contamination if leaking radium sources are to be handled. For proper contamination control it is always necessary to have appropriate instruments and equipment available, since there is always a risk that a source will be damaged during the work. Contamination and radiation monitoring should be carried out during and after all work. Prior to transportation of the encapsulated sources, radiation and contamination levels must be within the limits given in the IAEA Transport Regulations [9]. Measures to monitor and control external radiation levels are necessary. Shielding may be required. For gamma radiation, dense materials (lead, steel or concrete) are required. For neutron radiation (Ra–Be sources) hydrogenous materials (e.g. high density polyethylene) should be included in the shielding design. Suitable radiation monitoring should be used throughout all handling operations.

All persons engaged in the work should be provided with personal dosimeters that are evaluated periodically (e.g. monthly) or at the end of a campaign. Consideration should be given to the requirement for head and finger dosimeters, and personal digital dosimeters.

During the production of the shielding package safety precautions should be observed. Handling of heavy packages and the handling of lead should be given special consideration.

7. STORAGE OF UNCONDITIONED AND CONDITIONED SOURCES

7.1. STORAGE AND SAFETY CONSIDERATIONS

7.1.1. Design and operation of the storage facility

The storage facility must be designed and operated in accordance with regulatory requirements. Operation of the storage facility should be clearly stated in the Quality Assurance Programme (see Section 8) for spent source management.

The storage facility will require two separate storage areas [10], an Operational Store for the temporary storage of unconditioned sources, and an Interim Store for the long term storage of conditioned sources.

7.1.2. Personnel requirements

The facility should be managed and operated by suitably qualified and experienced personnel as described in Table IV.

7.1.3. Information requirements

Information on the sources and the various stages of the conditioning process should be collected and stored as described in Sections 5 and 6. The location of the drums in the interim store should be recorded as shown in Part 4 of Fig. 5.

7.1.4. Storage period

The storage period of the unconditioned spent sources should be kept to a minimum. Due to the uncertainty concerning the further management of the sources, a storage period of several decades should be assumed for conditioned sources.

7.1.5. Safety considerations

The storage areas must be designated as controlled areas, to limit the spread of possible radioactive contamination and minimize worker exposures to ionizing radiation. Storage areas must be regularly monitored for radiation and contamination levels. Detection of airborne or surface contamination will indicate the presence of leaking sources. Provision should be made for the adequate ventilation of the storage areas. It is recommended that personal protective equipment should be worn during access to the storage areas (e.g. overshoes, coveralls, respiratory protection, etc.).

The safe storage of spent radium sources will involve the attainment of the following measures (see Section 6):

- high integrity containment of the sources (robust, gas-tight containment);
- adequate shielding of the sources;
- physical security to prevent inadvertent possession or theft of the sources.

7.1.6. Storage location

Users of radium sources, other than nuclear establishments, seldom have the technical capability or equipment to condition sources for interim storage. Therefore only temporary storage should be practiced at the users' establishments. Conditioning, operational and interim storage should take place at a centralized facility.

7.2. STORAGE PRIOR TO CONDITIONING

7.2.1. Temporary storage at users establishment

As there are special risks attached to use of radium sources, e.g. long half-life, radon leakage, pressure build-up in sources, leakage of radium causing contamination, and possible neutron emission (Ra–Be sources), the use of these sources is strongly discouraged. Furthermore, the users are urged to arrange for transfer of the sources to a centralized facility for conditioning and interim storage as soon as possible. If the sources have to be stored at users' establishments, due to lack of a centralized facility, the basic safety requirements of containment, shielding, physical security and record keeping must be fulfilled. Temporary storage facilities may range from simple steel cabinets where sources are kept in lead pots, to dedicated rooms with built-in facilities [15].

7.2.2. Operational storage at the centralized facility

After transportation of the sources from the user's establishment, the sources may be stored temporarily in their transport packages in the operational storage area [10]. Comprehensive radiological protection controls should be available in this area as leaking sources must be assumed to be present.

The means to handle and store radium sources which are in accordance with regulatory and safety requirements should be available at the centralized facility. It is expected that the centralized facility should provide, as a minimum, the following services:

- comprehensive radiation protection;
- access control (radiation/contamination controlled areas);
- quality control;
- physical security;
- handling equipment (hoists, fork-lift trucks, etc.);
- maintenance services;
- Regulatory Authority control.

7.3. INTERIM STORAGE AWAITING FURTHER MANAGEMENT

7.3.1. General

The interim store should be designed for the storage of completed packages. It must be expected that conditioned radium sources will have to be stored for several decades until further management has been established. During this storage period special attention must be given to the following aspects:

- all available information regarding the sources and their conditioning must be reliably preserved;
- physical security must be consistently assured and maintained;
- regular inspections and monitoring must be performed (preferably every 6 months but at least yearly);
- provision of regular radon monitoring (For occupied areas, the frequency should be weekly or monthly, whereas for unoccupied areas the frequency could be the same as the other monitoring);
- general maintenance.

Carefully selected conditioning and storage methods should be employed in order not to compromise final disposal requirements and to avoid possible costly reconditioning.

7.3.2. Preferred storage methods

The shielding provided for interim storage should not form an integral part of the conditioned waste package. As described in the Annex, the sealed capsule containing the source(s) should be placed in an adequately shielded package or, alternatively into an engineered storage system with integral shielding. An example of a suitable shielding package is described in detail in the Annex.

If an engineered storage system is employed it must be operated to ensure that no unauthorized or unintentional removal of the sealed containers can take place.

A range of alternative shielded storage systems are described in Ref. [15]. Storage systems should be designed to withstand storage periods of several decades with ensured retrievability.

7.4. INSPECTION, MONITORING AND MAINTENANCE PROGRAMME

It is important that an inspection and monitoring programme is established. If the capability is not available within the interim storage facility it should be contracted from a competent organization. Inspection and monitoring should be performed regularly (preferably every 6 months but at least yearly). For areas that are occupied routinely, more frequent (weekly or monthly) radon monitoring is required. Results of the inspection and monitoring should be reported to the regulatory authority on a regular basis.Necessary inspection and corrective actions are detailed in Table VI.

TABLE VI. INSPECTION AND CORRECTIVE ACTION REQUIREMENTS

Targets of inspection	**Corrective action** (if the results are unsatisfactory)
Presence of all containers	Inform regulatory body
Operation of retrieval equipment	Repair or replace
Condition of outer container	Repair or replace
Condition of the storage areas	Repair
Security seals (if any) and locks	Inform Operations Manager and check contents of drum
Monitoring equipment	Recalibrate, repair or replace
Monitoring results	Inform Operations Manager, identify leaking capsule and re-encapsulate
Marking labels	Inform Operations Manager, replace labels
Operator's training	Provide training as required

Scheduled preventative maintenance should be performed on handling equipment, locks, buildings and systems, measuring and monitoring equipment as far as practicable.

Radiation and contamination monitoring equipment should be regularly calibrated.

Maintenance of containment capsules and engineered storage facilities should only be done on a corrective basis if test and monitoring results show that it is necessary. This maintenance involves radiation and contamination risks and should be done only after proper planning and training, using appropriate equipment.

Comprehensive records of maintenance must be kept in order to accumulate experience in storage practices and to permit safe retrieval for further management.

A summary of the inspection and maintenance activities should be reported to the Regulatory Authority regularly.

8. QUALITY ASSURANCE

8.1. INTRODUCTION

Quality assurance means all those planned and systematic actions necessary to provide adequate confidence that an item, process or service will satisfy given requirements for quality. Internationally accepted requirements for quality assurance are given by the International Standards Organization in ISO 9000 [16]. Quality assurance programmes relevant to conditioning and interim storage of spent radium sources will include, as a minimum, the following areas:

- preparation for transportation to the centralized facility;
- all transportation of radioactive materials;
- source conditioning process at the centralized facility;
- interim storage.

Quality assurance programmes aim to ensure confidence that all operations are optimally managed, and that a conditioned package is produced in compliance with the specifications for storage. Training of personnel is an integral part of Quality Assurance.

General guidelines for quality assurance concerning conditioning and storage are given in the IAEA publication on Quality Assurance for Radioactive Waste Packages [17]. Specific considerations relevant to conditioning and storage of radium sources are presented in the following sections.

8.2. PREPARATION FOR TRANSPORTATION

The preparation of sources prior to transportation to a centralized facility is a crucial issue for the protection of workers, the population, and the environment. Written procedures should be established, as a minimum, for the following operations:

- collection, reporting, and recording of all available source information described in Section 4.2;
- checking the characteristics of the source (estimating the activity, and determining the integrity of the source);
- handling and containment of the source;
- packaging and preparation of the labels and documentation needed for transportation;
- control of the package before transportation (physical inspection, checking for external contamination, measuring dose rate).

8.3. SOURCE CONDITIONING PROCESS

The quality of the conditioning process and the resulting waste package must be strictly controlled to ensure safety during storage and subsequent handling operations. Written procedures must be established, as a minimum, for the following operations:

- determination of radionuclides and activity of sources;
- quality control of the different components of the package, procured or manufactured at the facility (drum, concrete, shielding components);
- planning for encapsulation and packaging of sources, in order to comply with regulatory requirements, transportation, and acceptance criteria for interim storage);
- conditioning process: placement of sources inside capsules, labelling of capsules, sealing of capsules, testing for leak-tight seals, inspection of capsules before packaging, preparation of package, placement of capsules into the package, closing and labelling the package;
- tests and measurements to be made on the conditioned packages, (surface contamination, dose rate, etc.);
- record keeping of data obtained by carrying out the activities described in Section 6.2.4.

In development of spent radium source Quality Assurance Programmes, acceptance criteria for the interim storage should be considered. The written procedures mentioned above are an important component for demonstrating compliance of the packages particularly with the following criteria:

- radionuclides and activity content;
- dose rate, surface and airborne contamination;
- configuration and weight;
- mechanical integrity and structural stability;
- identification and traceability.

8.4. STORAGE

It is important that the management of the storage facility is based on a Quality Assurance Programme which will define the implementation and maintenance of a system for assuring the quality of products and services. As a minimum, the following items and related procedures should be assured:

- detailed organization structure and responsibilities;
- receipt of packages, documentation verification, measurements for dose rate and surface contamination, and physical inspection;
- handling, storage and identification of packages;
- periodic inspection of stored packages for number of packages, contamination, leakage, physical integrity;
- monitoring of the facility for radiological protection;
- record keeping of all important events during the storage period;
- maintenance of records.

9. REGIONAL CO-OPERATION

The option for regional co-operation in waste management should be seriously considered. The benefits in terms of shared costs, greater safety and better technology is obvious, it makes good sense. Such co-operation between countries could involve conditioning of sources, transport, interim storage and final disposal. This option should be implemented taking into account existing international safety and environmental standards and conventions. Some countries will never build a storage or disposal facility suitable for radium sources and can only consider regional co-operation.

The present public opinion and most national policies are not in favor of sending radioactive waste, including spent radium sources, out of the country or accepting other countries waste. Careful and sensitive efforts should however be started and continued, possibly through the mediation of a trusted organization such as the IAEA. It may not be achieved in the near future and may take many years. It is therefore prudent that concerned waste managers promote the idea.

Clear, understandable, quantitative evidence of the benefits on regional co-operation should be presented at international conferences on radioactive waste management, on regional co-operation and on environmental, health and safety issues. Discussions with national authorities, organizations and eventually with the public of the countries concerned, should be initiated.

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Annex

EXAMPLE CONDITIONING PROCESS FOR SPENT RADIUM SOURCES [1]

A-1. INTRODUCTION

Conditioning for interim storage should include stages for over-encapsulation and shielding.

Radium sources leaking radon are difficult to deal with since radon is an inert gas and any encapsulation needs to be gas tight. Radium sources should be packaged for storage to allow retrievability (see Section 5) and to provide long term radiological safety and physical security. The preferred method of over-encapsulating radium sources is to enclose them in a welded stainless steel container. Other encapsulation techniques are described in [A-1].

The following description of one specific conditioning process should be considered as a practical guidance to a satisfactory solution.

A-2. CONDITIONING

A-2.1. Encapsulation

For encapsulation of radium needles, or similar shaped radium sources, a stainless steel capsule as shown in Fig. A-1 should be used. The design is simple, it is actually a tube with a lid welded to each end. The lid is constructed to support the task of welding in the most convenient manner. Preparing such a capsule means welding a lid to one end of the tube and to check the leak-tightness of the weld, using compressed air and a cup of water (Bubble Leak Test, see ISO Standard 9978 [A-2]). An appropriate number of capsules should be prepared in this way in advance, in order to make sure that there are enough capsules to take the number of sources requiring encapsulation.

When loading a capsule with radium sources, forceps should be used. Adequate shielding should be provided for radiation protection reasons. Using forceps, the radium needles can be transferred into the capsule. A maximum total inventory of about 4 GBq (100 mg) of ^{226}Ra for one capsule should be observed.

A lead shielding device used during loading of the capsules, keeps the radiation dose to the operator reasonably low. The same shielding can be used during the welding process, where a lid is welded to the capsule to close and seal it as shown in Fig. A-2.

For sealing a capsule, the technique of Tungsten Inert Gas welding (TIG-welding) is most appropriate. Due to the design of the capsule, under normal welding conditions a neat welded gas tight seam can be obtained (Fig. A-3).

After welding, the leak-tightness of the encapsulation has to be demonstrated. Suitable leak test methods are described in ISO Standard 9978 [A-3]. The vacuum bubble test is the preferred method (Fig. A-4).

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[1] This process is used in Forschungszentrum Seibersdorf, Austria.

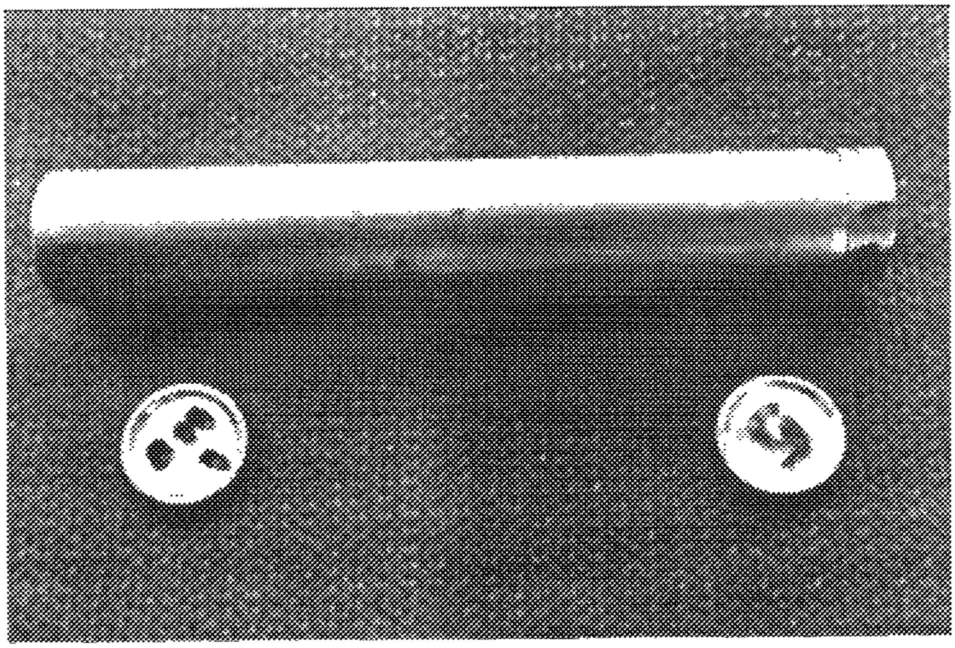

FIG. A-1. Stainless steel capsule for radium sources (needles and the like) before welding.

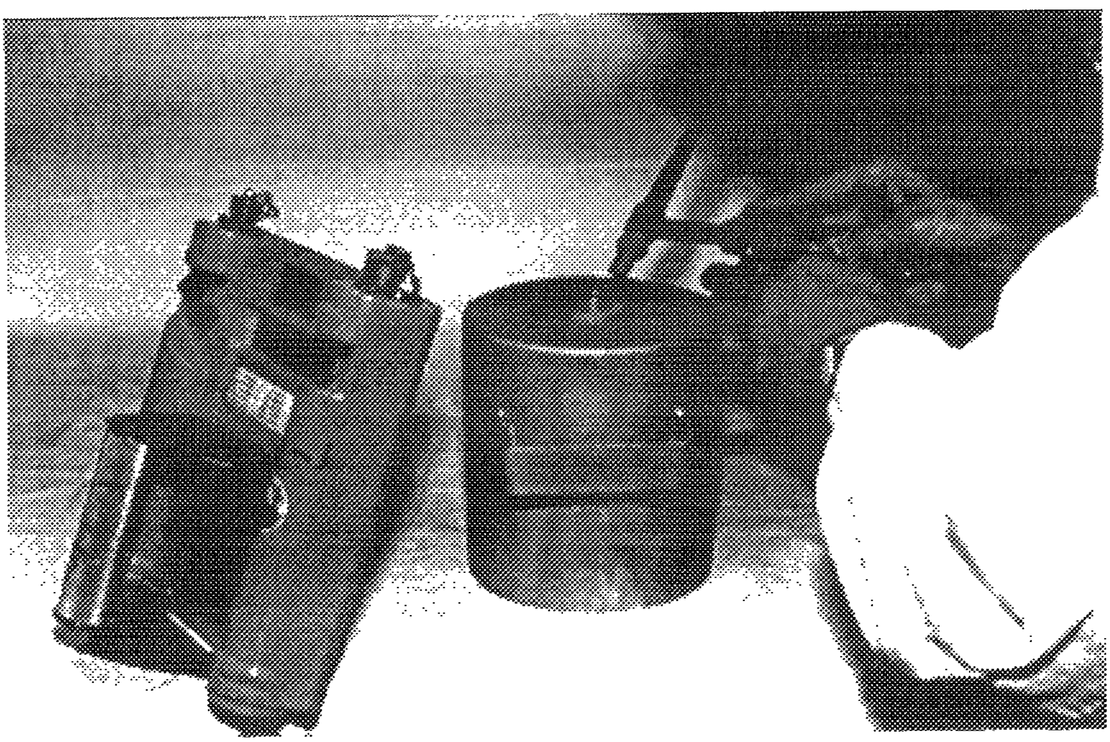

FIG. A-2. Welding of stainless steel capsule within lead shielding device.

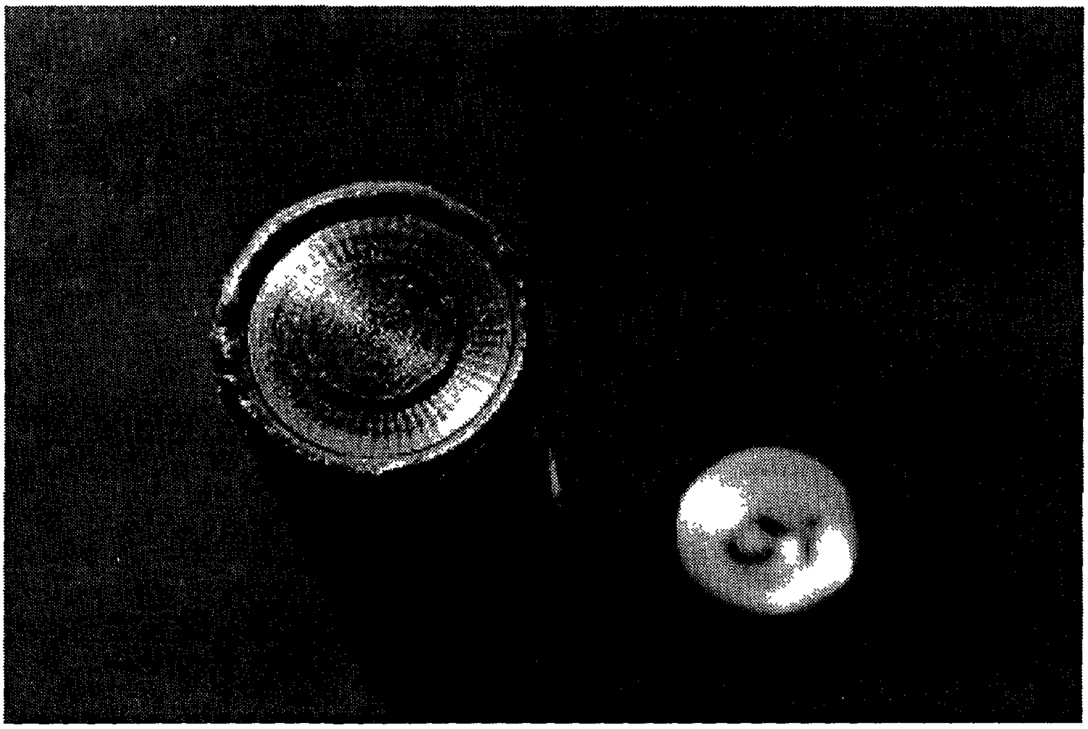

FIG. A-3. Welded stainless steel capsule.

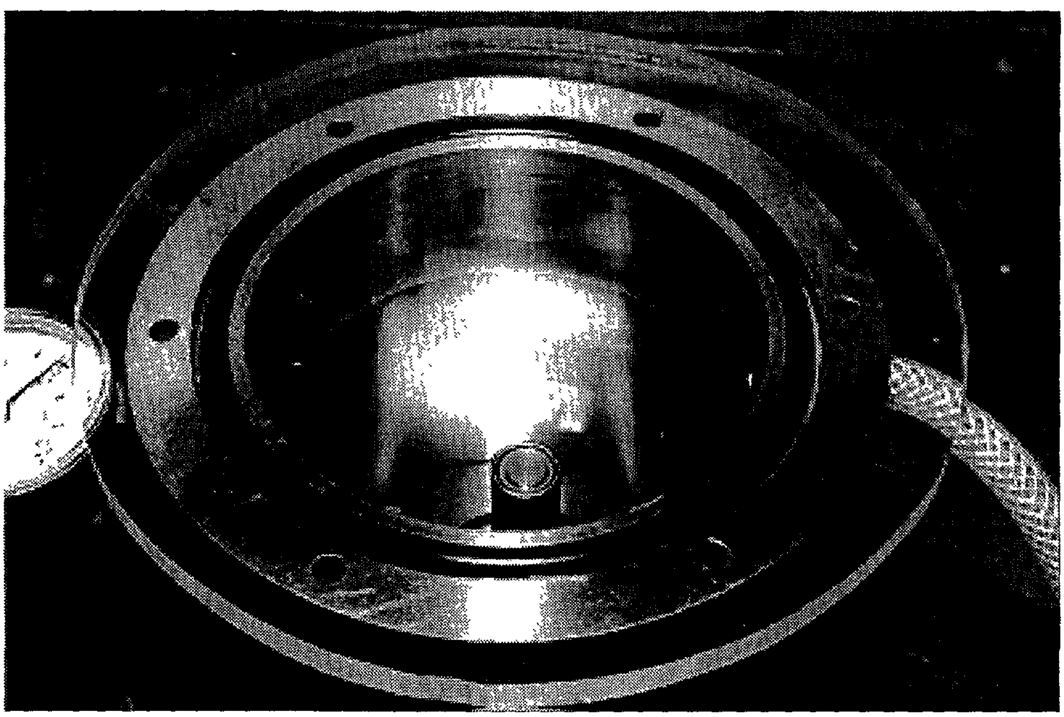

FIG. A-4. Vacuum chamber for bubble test.

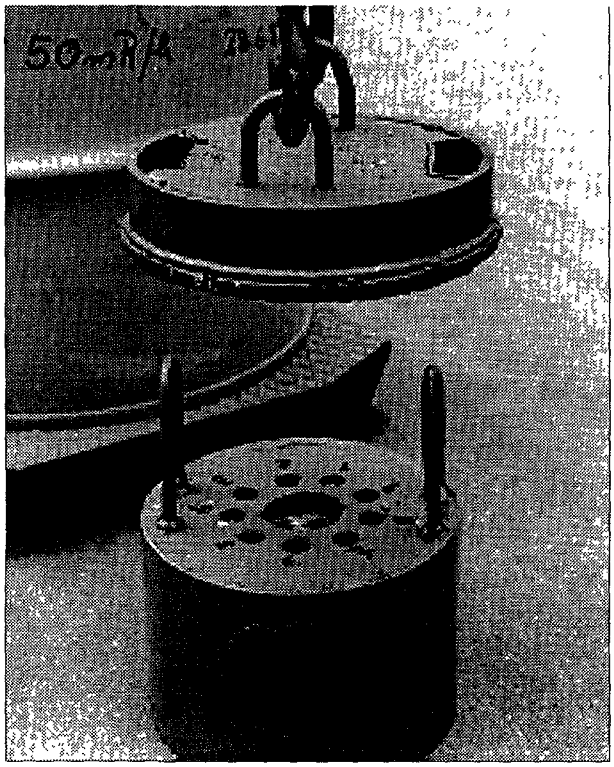

FIG. A-5. Lead shielding device for storage.

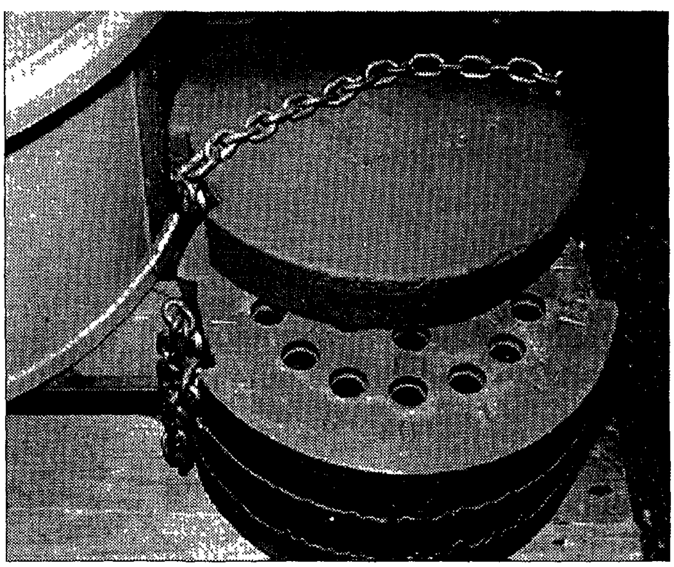

FIG. A-6. Lead shielding device for storage.

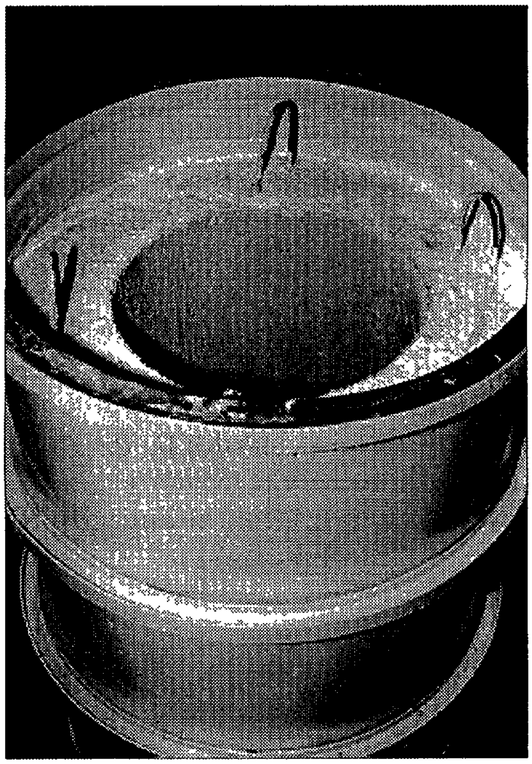

FIG. A-7. 200 L drum, prefabricated.

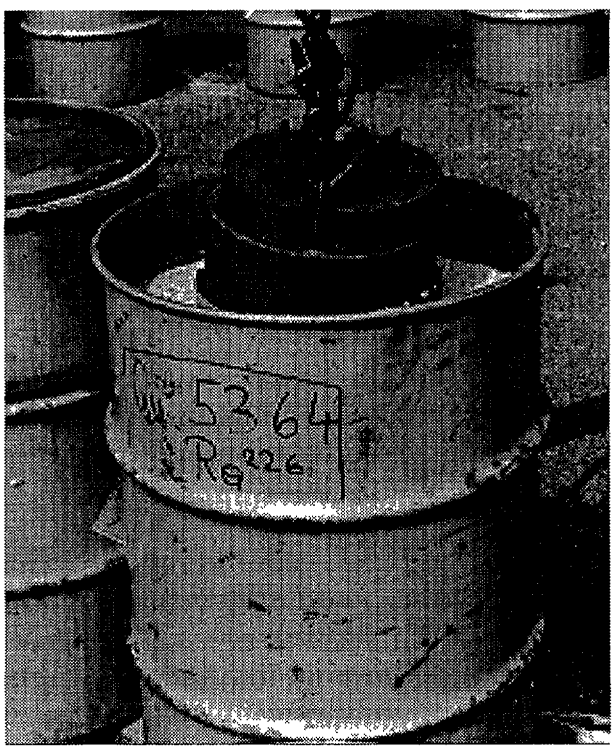

FIG. A-8. Placing of the lead container in the prefabricated drum.

After successfully passing the leak test, the sealed capsule should be dried and placed in one of the positions provided in the lead shielding device for storage (Fig. A-5).

Using tongs with a good grip, the loaded capsules (containing the radium needles) can be placed into the lead shielded container (Figs A-5 and A-6). This is then closed with a shielded lid.

It has to be made sure that the number of capsules (including their radium contents) within the lead shielding device is limited in such a way, as not to give more then 20 mSv/h on any position of its outer surface. From experience this ensures a dose rate of less then 2 mSv/h at the outer surface of the complete package, as demanded by the IAEA Transport Regulations. In addition to the dose rate limit the total quantity of radium within the package (serving as type A package according to transport regulations) should be limited to 500 mg.

A-2.2. Packaging for storage

The shielded container containing the capsules is placed in the center of a concrete-filled 200 L drum.

The concrete filled drum is prepared by inserting a removable spacer into the center of the drum, and loading the drum with an appropriate quantity of concrete as shown in Figs A-7 and A-8. Considering the shielding device shown in Fig. A-6 the diameter of the spacer should form a cavity of about 340 mm in diameter and 560 mm in depth from the top of the drum. Before positioning the lead shielding device, a hardening time should be observed, so that the concrete liner is not damaged.

Concrete around the lead shielding completes conditioning as a final step before interim storage and has the objective to:

- give additional radiation shielding (except from top);
- give physical security of the sources;
- provide a sufficiently large waste package to ensure that the package is not moved by mistake;
- provide an appearance which is not attractive for scavenging;
- enable a permanent and unambiguous marking on the waste package;
- keep the sources retrievable during interim storage.

The 200 L drum is suitable for most normally occurring radium sources, shielded with lead and concrete as shown in Figs A-7 and A-8. The size is such that the waste package can be handled, but large enough to prevent people from taking the package by mistake. Drums of this kind are available all over the world.

In order to obtain the required quality of cement mortar, it is advisable to consult national experts on construction materials. Reinforcement of the concrete should be used to increase the mechanical strength of the package. For this also, national experts on construction should be consulted. Although a reinforcement net gives the best results, it may be adequate to use only a few reinforcement bars with a diameter of 5–10 mm.

Before the lead shielding device is positioned in the drum, it has to be made sure that the lid can not be opened easily. A steel bar should be welded across the lid of the lead body.

In a similar way provision should be made with reinforcement bars, mentioned before, in order to enable the welding of a steel bar across the cavity, where the lead shielding is placed in the drum. For interim storage the drum has to be closed by its lid and an appropriate security seal should be applied.

In this way radium sources are kept retrievable during interim storage but cannot be taken away by mistake.

Throughout the conditioning process, it is very important to establish and maintain records as indicated in Section 6. Conditioning without documentation is useless.

It should be kept in mind that this kind of conditioning (sources kept retrievable) is intended for interim storage under controlled and safe conditions as described in the main text.

A-3. RADIATION PROTECTION MEASURES

Measures to control and monitor external radiation levels are necessary. These measures include the use of fixed or portable shielding, such as the lead shielding device shown in Fig. A-2 or mobile lead bricks. Suitable radiation monitoring instruments should be used to determine radiation levels at the work place. The handling of radium sources is a very onerous operation since the sources may be leaking.

Considering Figs A-1 and A-2, operators should be aware that due to the lack of shielding above the capsule radiation beam on the upper side has to be expected. The emerging angle of the beam depends on how deep the sources rest in the capsule and shielding. For radiation protection reasons this angle should be kept as small as possible. Therefore it is very important to load sources carefully into a capsule using a mirror to check their positioning. During the loading operation and the following welding process, it has to be especially observed that fingers and head of the operator are kept out of the radiation beam. At the same time airborne contamination should be controlled, in order to protect the operators, since leaking sources cannot be excluded.

It is very important not to touch sources by hand and to be aware of incidents which might occur in the process. Handling time should be kept as short as possible by careful planning and training.

Regarding personal protection and safety refer to Section 6 in the report.

A-4. EQUIPMENT

The equipment in the following list is the minimum required for over-encapsulation and conditioning of radium sources.

- capsules of stainless steel (Fig. A-1);
- TIG-welding equipment with a welding current in the range of 5–50 A;
- vacuum bubble test equipment (vacuum chamber with glycol/water, vacuum pump, vacuum meter);
- lead shielding container for a number of capsules (Figs A-6 and A-7);

- shielding device for welding (Fig. A-2);
- 200 liter drums without any corrosion or mechanical damages, precemented in a form that the lead shielding can be placed in a center cavity (Fig. A-8);
- cement, sand and water according to mixture formulation;
- cement mixer or provisions for manual mixing;
- vibration device or provisions for manual compaction of mortar;
- steel reinforcement bars, 8 mm Ø, 800 mm in length (5 bars per drum);
- steel bars 8 x 30 x 300 mm and 8 x 30 x 500 mm (for securing the lid on the lead shielding and the lead shielding in the drum);
- three lead bricks 50 x 100 x 200 mm (as portable radiation shielding during work);
- handling tools (two forceps 300 mm long, one tong — preferably with parallel grip — 1000 mm long);
- mirror with handle;
- plastic sheets (to protect against contamination during work);
- dose rate meter and contamination monitor;
- personal dosimeters;
- T.L. dosimeters;
- metal plates (for permanent marking of packages);
- ventilation equipment (to avoid inhalation during work);
- fork lift or crane (to handle shielding and cemented drum);
- personal protective clothing.

REFERENCES TO ANNEX

[A-1] AEA TECHNOLOGY, IAEA Spent Sealed Source Facility, AEA Technology, Harwell (1993).

[A-2] ISO Standard 9978 (1992).

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