IAEA-TECDOC-1301

Management of spent high activity radioactive sources (SHARS)

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

September 2002

The originating Section of this publication in the IAEA was:

Waste Technology Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

MANAGEMENT OF SPENT HIGH ACTIVITY RADIOACTIVE SOURCES (SHARS)
IAEA, VIENNA, 2002
IAEA-TECDOC-1301
ISBN 92–0–114502–0
ISSN 1011–4289

Printed by the IAEA in Austria
September 2002

FOREWORD

Sealed Radioactive Sources have found diverse applications in many agricultural, industrial and medical uses as well as other technical and scientific research areas. Some of these areas and applications require that the radioactivity involved be high. In earlier applications, a relatively long lived radioisotope (Cs-137, half-life ~30 years) was utilized. Over time, source manufacturers have tended to use shorter lived radioisotopes (Co-60, ~5-year half-life), however many such sources had already been manufactured using longer lived isotopes. Many early sources, not manufactured to current standards, were utilized when no clear regulatory control was enforced and with no clear vision of their destiny once declared as waste. Moreover, they are sometimes stored under unacceptable conditions or have escaped regulatory control.

Most of these sources have high specific activity and therefore are relatively small in size, increasing the probability of their loss and misplacement. The risk of their involvement in an accident is relatively high if proper management is not adopted. Such accidents can be over exposures to individuals or contamination of the environment. The physical characteristics of the sources make them easily transported through borders, giving the potential of causing harm not only in their country of origin but also beyond.

Accidents involving loss of control of high activity sources have occurred every year, causing deaths of several people and varying injuries to a larger number of persons somewhere in the world. This has increased the awareness of the problem and many countries are in the process of setting up infrastructures to manage such sources safely. On the international level, the IAEA has developed an action plan (GOV/1999/46-GC(43)) aiming at enhancing the IAEA's programme on the subject and initiating new activities. One of these activities is the development of this report to specifically provide information on the management of high activity sealed radioactive sources.

This publication provides technical advice to those who need to manage disused and spent high activity sources and discusses relevant issues involved. It also provides background information for any possible technical assistance to be provided and serves as a reference for technical staff sent by the IAEA to provide advice to Member States.

Because of the current problems involved — namely that a large number of these sources have no licensed transport container and no valid special form certificate — rendering them safe is a difficult task. International co-operation on this subject may be required to rectify the situation. The report can also serve as a basis to establish future co-operation.

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CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The applications of sealed radioactive sources have been widespread. The nature and quantity of the radionuclides utilised depend on the intended purpose. While most sources are of relatively low activity, there are many of high or very high activity. These high activity sources have been responsible for most of the radiological accidents involving loss of life or disabling injuries to the public [1].

High activity sources are utilised for various applications: for example, sources of the order of 100 TBq (several thousand curies) are used worldwide for teletherapy in radiology. Sources in the TBq–PBq range (up to tens of thousands curies) are used in research irradiators and sources of tens of PBq (several hundred thousand curies) are used for sterilisation and food irradiation.

The radionuclides which have been most commonly used to produce high activity sources are Co-60, Cs-137 and Ir-192. There are also a small number of applications which use other radionuclides such as Sr-90 and Am-241 mixed with beryllium to produce neutron sources.

The IAEA-TECDOC-1191, “Categorization of Radiation Sources” [2], lists the various applications for each of the radionuclides of interest, along with the likely range of activity for that application.

There are large number of high activity sealed radioactive sources in use world wide. Due to the limited operational lifetime of sealed radioactive sources there are many that are no longer in use and require safe management.

Many reports discuss the management of radioactive waste generated by nuclear power plants. There are also some reports on the management of spent sealed radioactive sources. However, there are no reports known that have been prepared specifically to address the management of spent high activity radioactive sources (SHARS). This publication describes the management options that are currently available for SHARS and also discusses the development of a waste management strategy within the context of international experience.

1.2. OBJECTIVE

The objective of this report is to provide all people involved in the handling and management of high activity sources with sufficient information about processes that are required for the safe management of SHARS. This includes examples of spent source management that are already taking place and also a description of the range of appropriate options that are available for each stage in the management process. This report also aims to identify the important issues to be addressed in order to develop a waste management strategy as part of the integrated management strategy that takes account of international experience and the guidance and principles that have been learned from that experience.

1.3. SCOPE

This report relates specifically to SHARS, which are spent sources that have the potential, with short exposures, to produce acute health effects if handled incorrectly. In addition, they may also incur significant economic costs in any retrieval or environmental remediation operation, following loss of or damage to such a source. SHARS therefore include all of the sources in Category 1 of the document “Categorization of Radiation Sources” [2], i.e. industrial radiography, teletherapy equipment and irradiators. Many sources in Category 2 also have such potential, for instance, high activity sources used in brachytherapy, fixed industrial gauges and well logging. Table I, while not exhaustive, lists typical sources which fall within the scope.

TABLE I. ACTIVITY RANGE FOR VARIOUS RADIONUCLIDE APPLICATIONS

Nuclide	**Application**	**Typical activity**	**Maximum activity per source decayed 30 years**
Am-241/Be	Neutron Moisture Gauging	1.11 GBq–9.25 GBq	8.8 GBq
Co-60	Sterilisation Plants	4 PBq–400 PBq	8 PBq
Co-60	Industrial Radiography	Up to 45 TBq	872 GBq
Co-60	External Beam Therapy	Up to 1000 TBq	20 TBq
Cs-137	Industrial Radiography	Normally up to 3.7 TBq (sources available to 81 TBq)	1.85 TBq
Co-60	Medical Brachytherapy	Up to 74 GBq	37 GBq
Ir-192	Medical Brachytherapy	Up to 370 GBq	Nil
Ir-192	Industrial Radiography	Up to 11 TBq	Nil
Se-75	Industrial Radiography	1.11 TBq	Nil
Sr-90	Medical Radiography	~1 TBq	~500 GBq

The report provides guidance on the technical, administrative and economic issues associated with SHARS from the moment they cease to be in use through to disposal, including temporary storage, transport, conditioning and interim storage. Detailed rules and regulations for transport are outside the scope and relevant transport documents are referenced for that purpose.

The risks associated with handling SHARS are such that many users may not have the capability to manage them safely. This guidance aims to provide understanding of these processes to those organisations which may require expert services in the field or intend to establish the required infrastructure.

1.4. STRUCTURE

The first part of this report (Section 2) is structured in such a way as to provide an understanding of the nature of SHARS, including source manufacture and the nature of the equipment that uses them. Section 3 identifies some of the issues that need to be considered in formulating a generic approach to the management of SHARS. The report then progresses sequentially through the steps that form the waste management process for spent sealed sources (Section 4). This begins with a general description of the sealed source management process and is followed by descriptions of the issues that affect transport; treatment, conditioning and interim storage; and finally, discussion of issues leading to the development of disposal. The report contains many illustrations and photos provided by the contributors of the draft. Only where it was specifically requested the copyrights were quoted.

There is a section that discusses the legal, regulatory and economic considerations (Section 5) that play an important role in the establishing and implementation of sealed source management.

The Appendix provides summary descriptions of the current high activity sealed source management undertaken in a number of countries to demonstrate a range of scales of operation and states of advancement.

1.5 DEFINITIONS

For the purpose of this report, the following terms are used within the following definition:

Sealed source	Radioactive material that is (a) permanently sealed in a capsule or (b) closely bounded and in a solid form. The capsule or material of a sealed source shall be strong enough to maintain leaktightness under the conditions of use and for which the source was designed, also under foreseeable mishaps [3].
Device or equipment	Complete equipment including sealed source, source holder plus all other mechanical and electrical components.
Source holder	Components that contain the sealed source in the shielded position plus the shielding material within the device.
Storage (interim)	The placement of SHARS containing equipment in a nuclear facility where isolation, environmental protection and human control (e.g. monitoring) are provided with the intent that the spent sources will be retrieved for exemption or processing and/or disposal at a later time.
Temporary storage	The placement of SHARS containing equipment in a storage facility within the user’s premises where isolation, environmental protection and human control (e.g. monitoring) are provided with no intention of any treatment and with the intention that the SHARS be removed to an SRS facility within a reasonably short period of time (preferably not more than a few months).

2. CURRENT STATUS OF SPENT HIGH ACTIVITY RADIOACTIVE SOURCES

2.1. MANUFACTURE OF SOURCES

Category 1 [2] sources are normally doubly encapsulated in stainless steel forming a robust containment that satisfies the provisions of "Special Form Radioactive Material" as described in TS-R-1 [4]. The capsules are welded by the tungsten inert gas method (TIG welding), electron beam or laser. Although primary encapsulation by stainless steel is preferred in the case of gamma emitting sources, other metals have been used to suppress the activation of the primary capsule for neutron sources.

The radioactive content is usually a metal in the case of cobalt and iridium, and salt (e.g. chloride or nitrate) in either powder or ceramic form in the case of caesium. The large volume of ceramic sources precludes their use above approximately 400 GBq (~11 Ci) but ceramic is the preferred option for smaller sources where the lower dispersability and insolubility of a ceramic material are desirable features.

2.2. WORLD INVENTORY

Accurate information on the numbers of high activity sealed sources in use worldwide is not available. Furthermore, the constantly changing status by the deployment of new sources and decommissioning of old sources makes any attempt to obtain an accurate number of SHARS difficult. An estimate of source numbers was made by the IAEA based on data available in IAEA-TECDOC-620 "Nature and Magnitude of the Problem of Spent Radiation Sources" [5]. This included information on high activity sources such as commercial irradiators and teletherapy devices. The number of irradiators for sterilisation and food preservation was 142 (average 40 PBq Co-60 or 400 PBq Cs-137). Due to the close regulatory scrutiny of such irradiators, this is likely to have been an accurate figure. The number of teletherapy devices was estimated as 2,600. While it may seem reasonable to assume that the high activity of such sources would also ensure close regulatory scrutiny and therefore accurate inventory information, there is some evidence that this figure may have been an underestimate. Information from one major supplier[1] of radiation therapy equipment indicates that 2,500 units have been installed by one company alone. The company has encapsulated over 5000 sources and over 1500 PBq (40 million Ci) over the past five decades and installed over 2500 cobalt-60 radiation therapy units in more than 50 countries. It is therefore concluded that a very large number of SHARS exists.

2.3. EXAMPLES OF EQUIPMENT CONTAINING HIGH ACTIVITY RADIOACTIVE SOURCES[2]

2.3.1. Industrial irradiators

Gamma irradiators are used worldwide for, inter alia, sterilization of medical supplies and food irradiation (see Figure 1). These involve the use of arrays of very high activity sources (average total activity per sterilisation unit is 40 PBq, over one million curie, Co-60). Large volumes of material to be irradiated are passed through the source beam after entering the irradiation room via a labyrinth system. A similar labyrinth with access control is provided for

[1] Private communication.
[2] Examples given above are from civilian applications. Management aspects provided in this report apply equally to sources used for military applications.

personnel entry. The source array is normally lowered into a pool for wet storage and source loading operations. The pool water is kept clean by circulating the water through a filter and a de-ionising system.

Some of the industrial sterilisation plants are designed to re-use sources (especially Co-60) from teletherapy by incorporating them in source arrays. A practical minimum activity for this re-use is 1 TBq (~27 Ci).

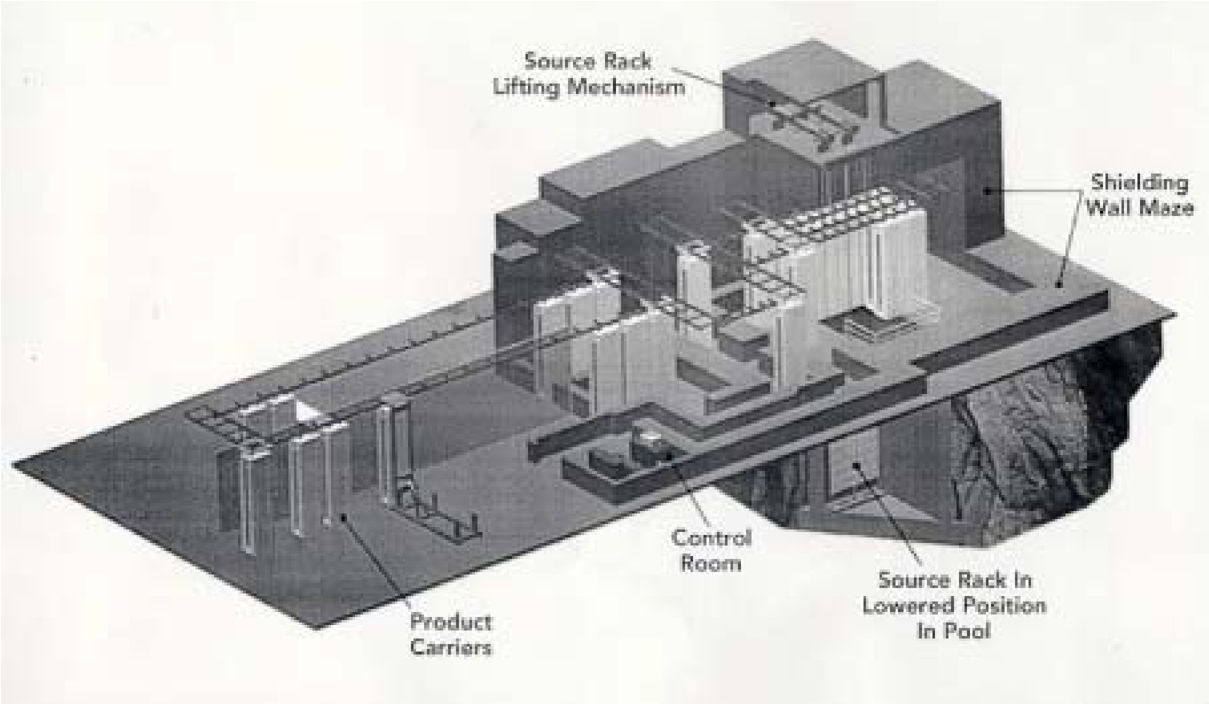


FIG. 1. Layout for a sterilization plant.

2.3.2. Teletherapy equipment

Teletherapy is the use of radioisotopes as a source of beams of gamma radiation for medical treatment. Teletherapy equipment usually consists of a "teletherapy head" mounted on a mechanism, which allows the position and orientation of the head to be adjusted in order to direct the radiation beam at the affected organ of the patient. The equipment is located in a shielded room, usually with interlocked doors and a labyrinth entry. It is operated from a control point outside the room, from which the operator can view the patient through a leaded glass window or by closed circuit TV.

The sealed source is mounted inside the teletherapy head, which usually contains several hundred kilograms of high density shielding material. The head incorporates a shutter mechanism and beam collimating system. The shield material may be lead, tungsten or depleted uranium, in a steel shell.

Teletherapy equipment became available in 1951, and initially used Cs-137. This nuclide continued to be used through the 1960s, but was gradually superseded by Co-60 for safety reasons. Some of the reasons for phasing out Cs-137 were the long term problems involved with the management of caesium sources and their chemical form (CsCl) being soluble and corrosive.

Originally, sources were placed into the teletherapy head by the manufacturer using a shielded facility. The head was then placed inside a transport overpack for delivery to the hospital. An example of a 1960's style head and its transport overpack are shown in Figures 2 and 3. This type of head contained a Cs-137 source with 75 TBq (~2000 Ci) inside a lead shield encased in steel. It was originally delivered to the user in a steel drum with wood/cork spacers. The need to remove the source from the head was not envisaged, due to the long half-life of the caesium.

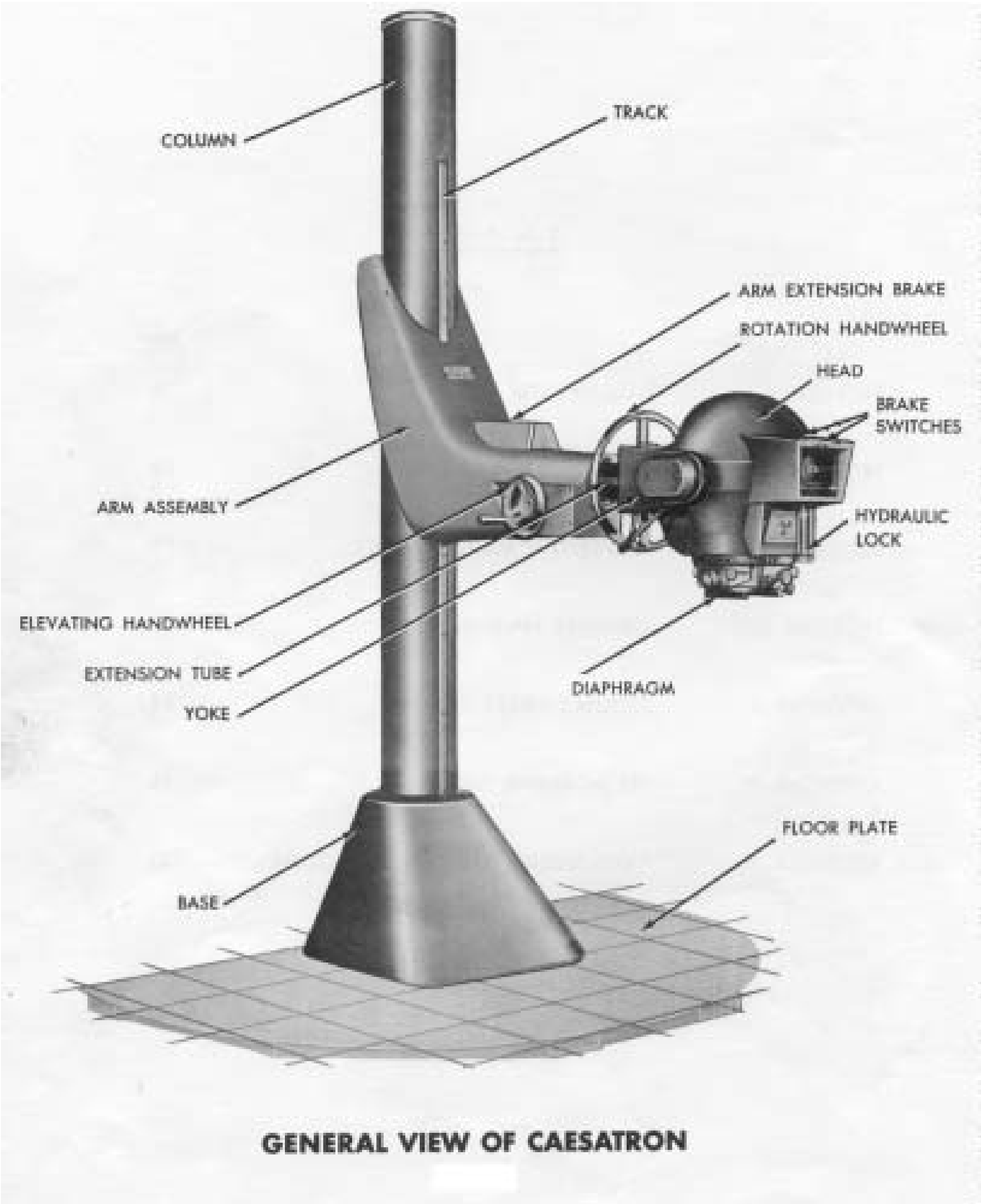
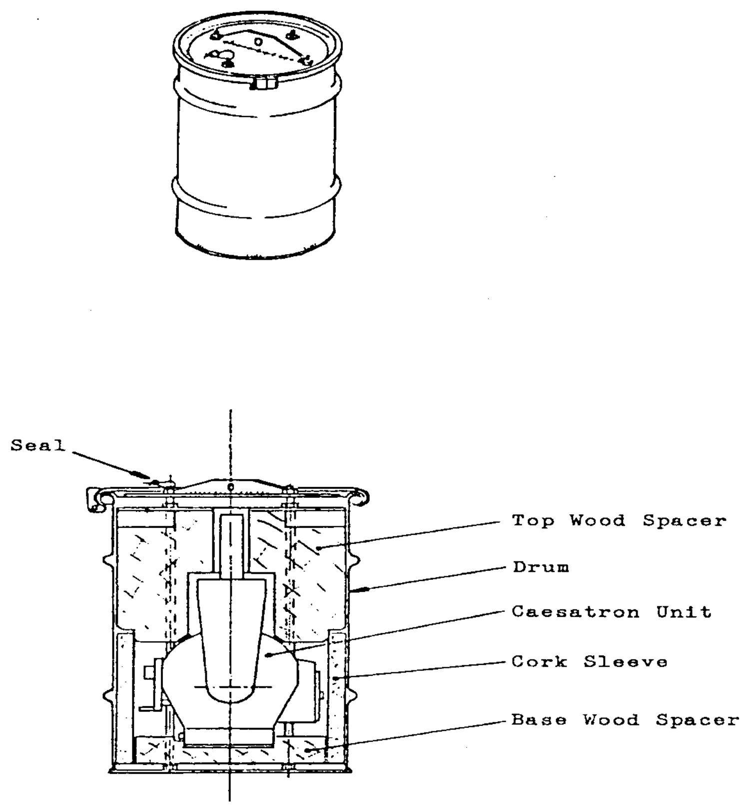


FIG. 2. Early caesium teletherapy unit (circa 1960).



Description of package, dimensions and weight:

Packaging	Steel insulated drum carrying a lead in steel irradiator
Dimensions	520 mm diameter × 864 mm high
Gross weight	298 kg

FIG. 3. Transport package for early caesium teletheraphy unit — does not comply with current standards.

As Cs-137 was replaced by Co-60, it became necessary to renew sources at regular intervals, usually every 5 to 7 years. Teletherapy equipment was therefore designed to allow the SHARS to be removed from the head and transferred to shielded transport containers in situ. An example of a Co-60 unit, capable of in situ source exchange is shown in Figure 4. Teletherapy heads can contain up to 550 TBq (~15 000 Ci) of Co-60.

2.3.3. Research irradiators

Research irradiators have been produced principally for gamma irradiation using Cs-137 and Co-60; the former being used to an increasing degree for blood irradiation. There is no standard design principle for irradiators used for research purposes due to the range of applications. In many cases, research establishments have produced irradiators based on their own designs. There are, however, two main design principles; those in which the source position is fixed and those in which the source can be moved to an exposed position. For some of these irradiators the source is shipped pre-installed and for other designs the source can be loaded after installation and changed using a shielded transport container.

FIG. 4. Teletherapy machine (Co-60, TEM) of a type designed for on-site source exchange.

Irradiators in which the source is moved out of its shielded position into an exposed position are normally used for the irradiation of large samples. These are typically sited in a shielded room or cell of considerable volume, into which samples are placed. With the doors interlocked, the source is then brought out of its shielding by a remote mechanism. A teleflex type system similar to that used in industrial radiography applications (see Figure 5) is often used in these irradiators.

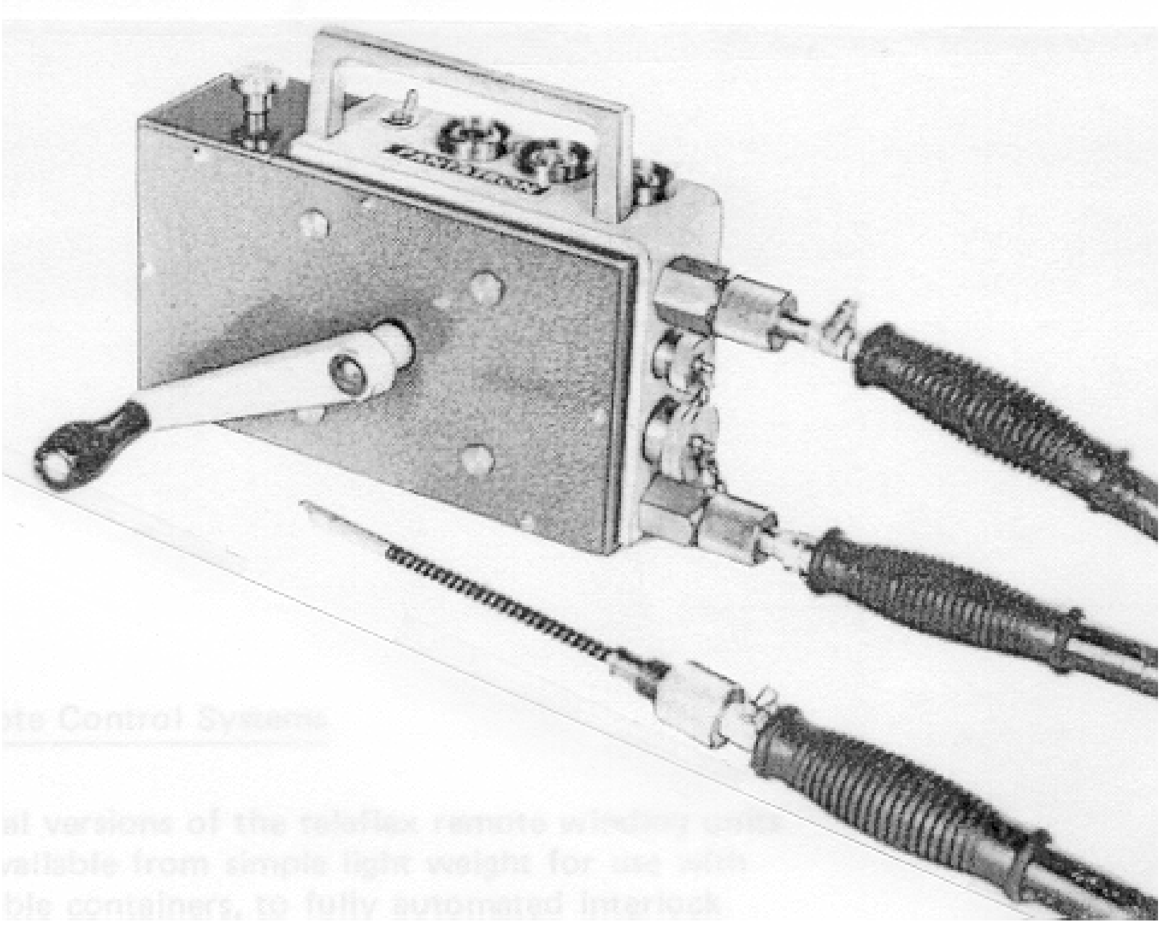


FIG. 5. Typical remote winding unit for industrial radiography — "teleflex" type system.

An alternative approach is to hold the source in a fixed position and to move the sample into close proximity. From the early 1960s, there was a considerable market for fixed source irradiators. A number of companies developed a range of products based on similar principles and some of these products are still being sold today. A typical fixed source irradiator may have one or more sources positioned in the centre of a large, shielded source holder, weighing perhaps a few tonnes. A sample is then placed in a sample chamber. The sample chamber may then be moved into position, close to the source. An example of a fixed source irradiator is shown in Figure 6. This irradiator is a typical Co-60 irradiator, capable of holding up to 150 TBq (~4000 Ci), with up to 16 sources being positioned in a circular array around the sample chamber. Research irradiators can range in radioactivity from several GBq to as high as 1 PBq.

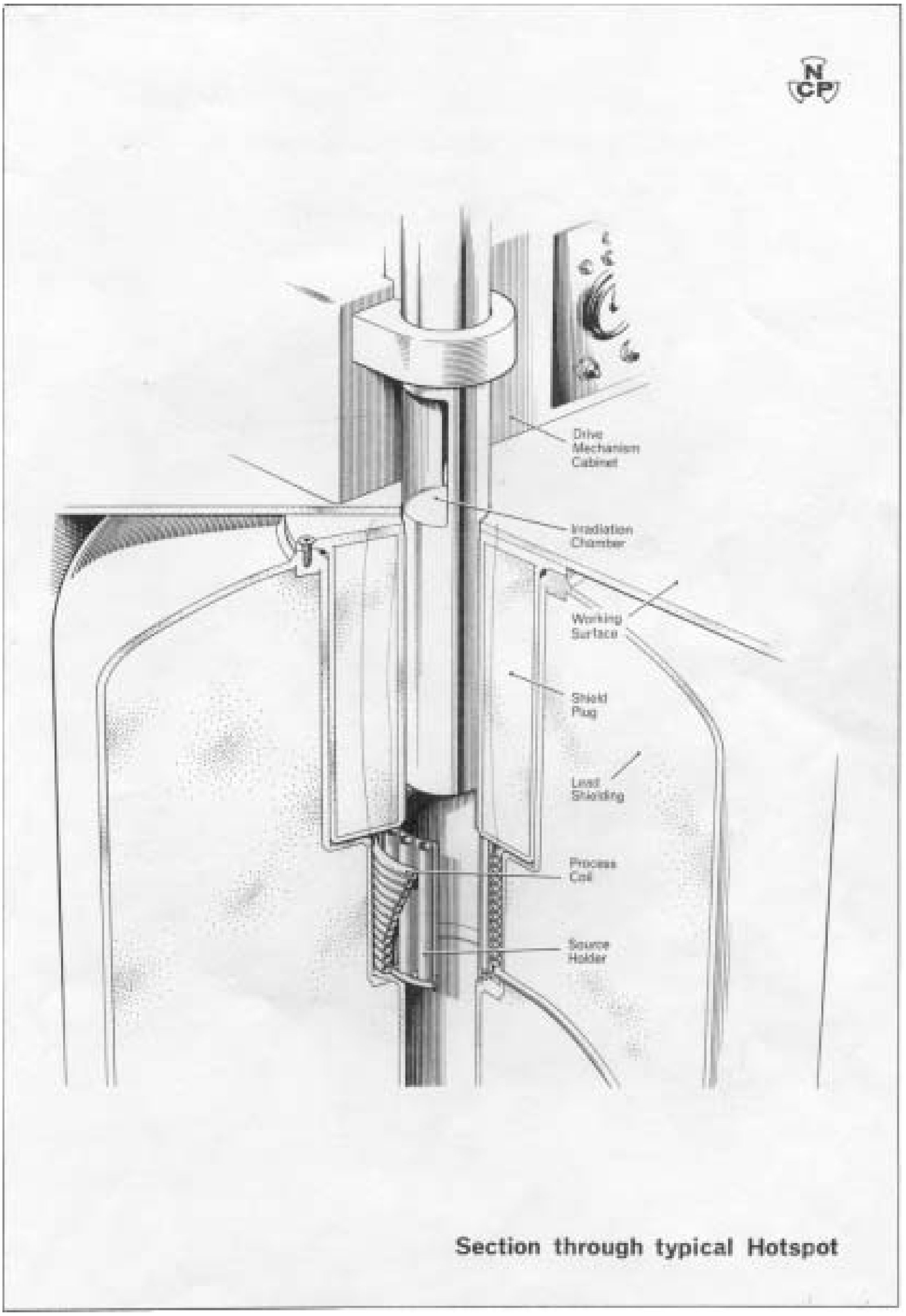


FIG. 6. Typical research irradiator — fixed source carousel, Co-60,150 TBq (~4000 Ci).

2.3.4. Industrial radiography equipment

Sources containing Cs-137, Co-60 and Ir-192 are widely used in industrial radiography, for the inspection of pipework welds, etc.

Most industrial radiography equipment consists of a radiography unit, which may contain depleted uranium as shielding material, and one or more sealed sources. The source is held in a flexible assembly sometimes called a source holder, pencil, shuttle or pig tail (see Figure 7) and for use is wound out of the radiography unit into a flexible guide tube (see Figure 5). The radiography unit is often also a transport container, within the meaning of the international regulations for the Safe Transport of Radioactive Material [4]. While the majority of industrial radiography units are relatively small, typically 20–30 kg, there are a number of types which weigh several hundred kilograms and may contain high activity sources. There are larger units of older design that are Type A transport containers and the activities of the sources are therefore restricted to Type A quantities. For instance, the unit shown in Figure 8, weighing 700kg, can contain two sources in separate channels (Co-60 up to 400 GBq and Cs-137 up to 2 TBq).

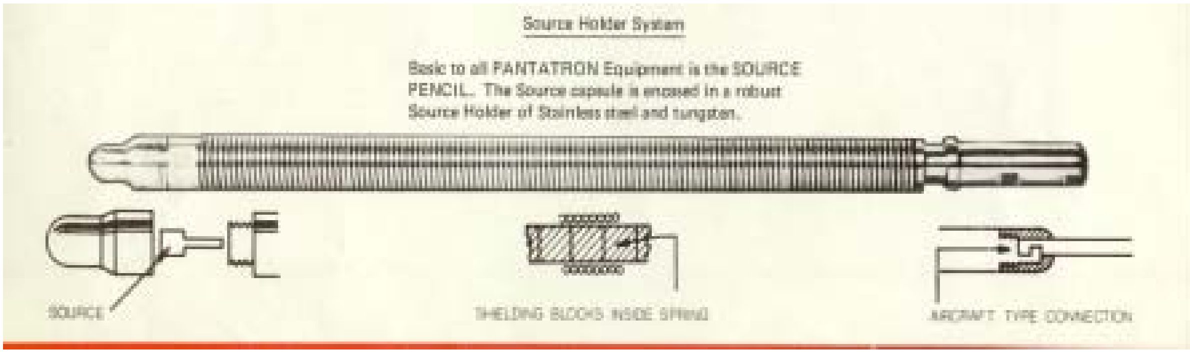


FIG. 7. Typical industrial radiography source pencil.

However, there are a number of radiography unit designs, which can contain sources that require Type B containers for transport. The unit shown in Figure 9 is a mobile unit, weighing over 800 kg and containing up to 1850 GBq (~50Ci) of Co-60 and 3700 GBq (~100Ci) of Cs-137 in two channels. The unit shown in Figure 10 provides an external beam using a Co-60 source with activity in the range of 3.7–74 TBq.

Where a teleflex or winding gear system is used, the sources can easily be transferred from the radiography unit to a transport container at the user’s premises. Alternatively, the radiography unit can be placed into a suitable Type B container for transport since many of the older radiography units no longer comply with current transport package requirements [4].

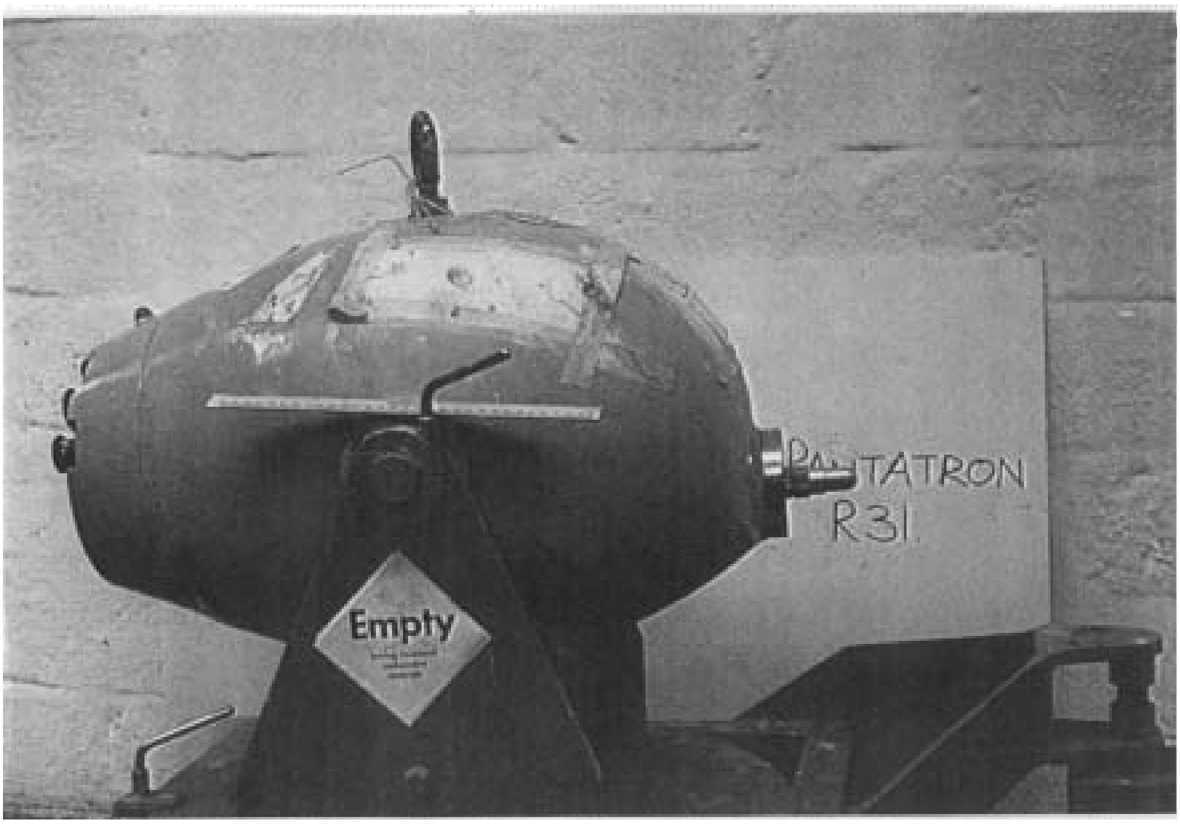


FIG. 8. An industrial radiography source holder designed to contain up to type A limit of Cs-137 and Co-60 (2 source channels).

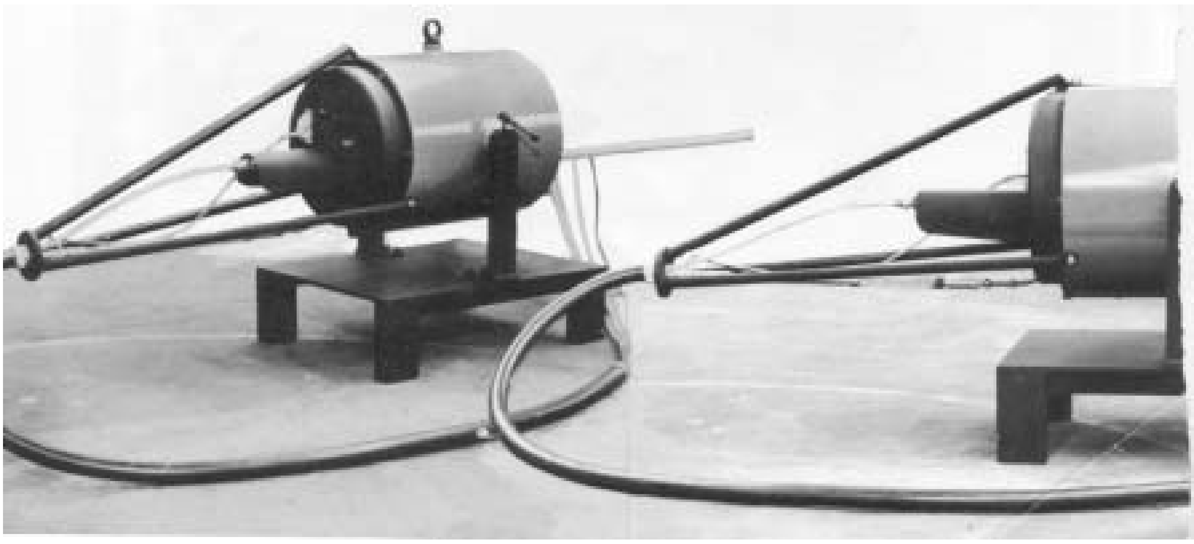


FIG. 9. Mobile industrial radiography equipment for Type B quantities of Cs-137 and Co-60 (2 source channels).

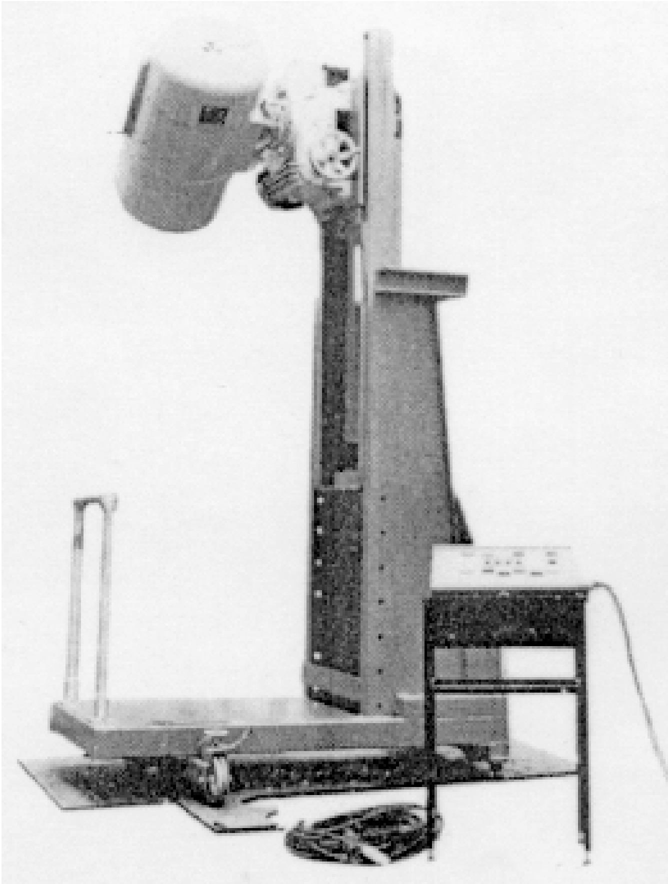


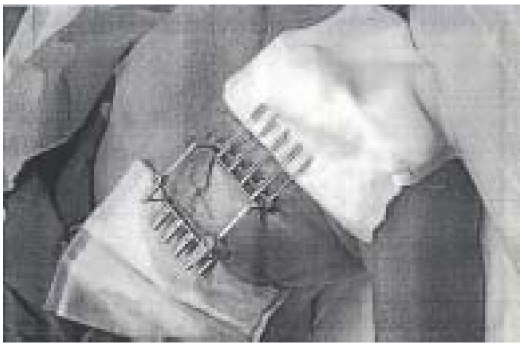
FIG. 10. A mobile industrial radiography unit for external beam radiography using up to 74 TBq (2000 Ci) Co-60.

2.3.5. Brachytherapy equipment

Brachytherapy involves the placement of a radioactive source within human tissue to deliver a localised dose and is frequently applied to treat recurrent disease in an area previously treated by external beam radiation.

Originally, brachytherapy techniques involved the use of individual needles or manual afterloading. Relatively low activity sources were used in these applications. However, remote afterloading techniques were developed in the 1970's. These techniques involve the use of machines which can contain a large number of relatively low activity sources but which, taken together, represent a significant inventory stored in a single, relatively transportable container. An example of brachytherapy equipment and illustration of its use is shown in Figure 11. This equipment can contain up to eight "source trains", each consisting of a series of smaller sources. The total combined activity of the sources in the example shown is 185 GBq (5 Ci) of Cs-137.

Automatic loading



Manual loading

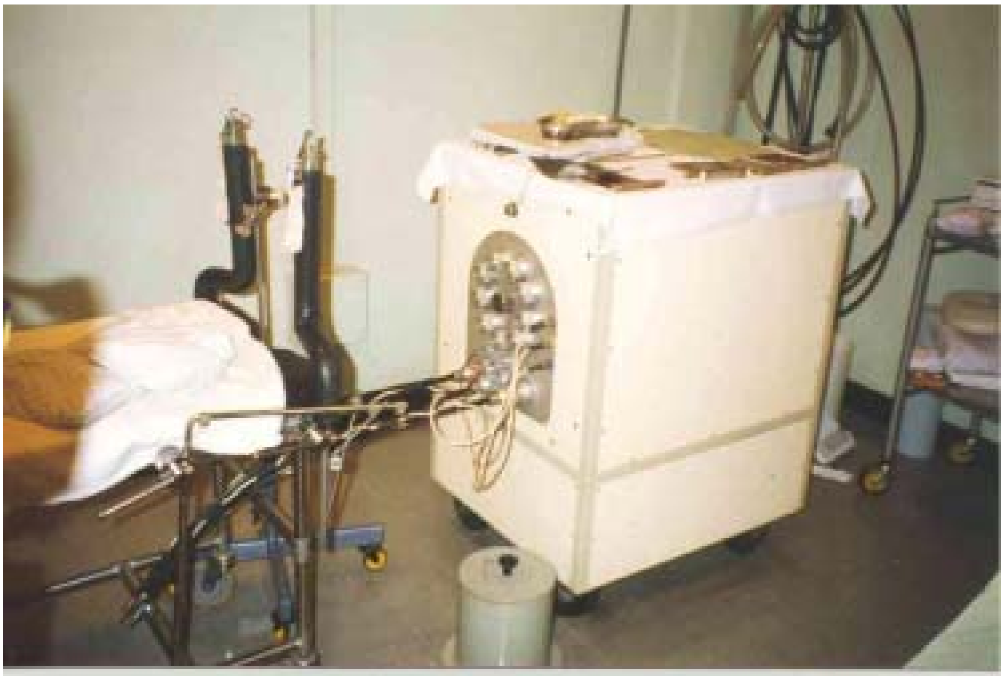


FIG. 11. Braychytherapy equipment containing a range of sources, totalling up to 185 GBq Cs-137 (or Co-60).

Remote afterloading equipment is used to arrange sources into an appropriate configuration and to transfer them either pneumatically or by a cable, into the patient applicator.

Ra-226 and Cs-137 have been widely used in this application, although Ir-192 and Sr-90 are now more common, having been replaced for reasons of increased safety. Most of the high dose rate brachytherapy machines have been in the range 40–300 GBq.

2.3.6. Nuclear logging equipment

Nuclear logging equipment is used for mining purposes for oil, coal and various ores. While some logging techniques do not depend on having a radioactive source, a large number use sealed sources (i.e., gamma or neutron emitting sources) to induce radioactivity for the intended purpose. (ν –ν) techniques (n, n') or (n, ν) methods all require the logging equipment to have a sealed source of the neutron or gamma emitting type. The activity of such sources usually ranges from several tens to several hundreds of GBq. The most commonly used nuclides for gamma sources are Cs-137 and Co-60 while Am-Be, Cf, and Ra-Be are used as neutron sources [2].

Table II gives some useful data on most important neutron sources and Figure 12 gives a schematic diagram of a neutron source.

TABLE II. THE MOST IMPORTANT NEUTRON SOURCES [12]

Source	Nuclear reaction	Half-life of the radioisotope, $t_{½}$	Yield of neutrons		Mean energy of neutrons, MeV
			For (ζ, n) sources: 1/(TBq s); for (ν, n) sources: 1/(TBq s g target)	For (ζ, n) sources: 1/(Ci s); for (ν, n) sources: 1/(Ci s g target)	
^{226}Ra-Be	^{9}Be(ζ,n)^{12}C	1602 y	4.6×10^{8}	1.7×10^{7}	5
^{239}Pu-Be	^{9}Be(ζ,n)^{12}C	2.44×10^{4} y	4.8×10^{7}	$1.8. \times 10^{6}$	4
^{241}Am-Be	^{9}Be(ζ,n) ^{12}C	458 y	5.7×10^{7}	2.1×10^{6}	4
^{252}Cf	Spontaneous fission	2.65 y	1.2×10^{11}	4.3×10^{9}	1

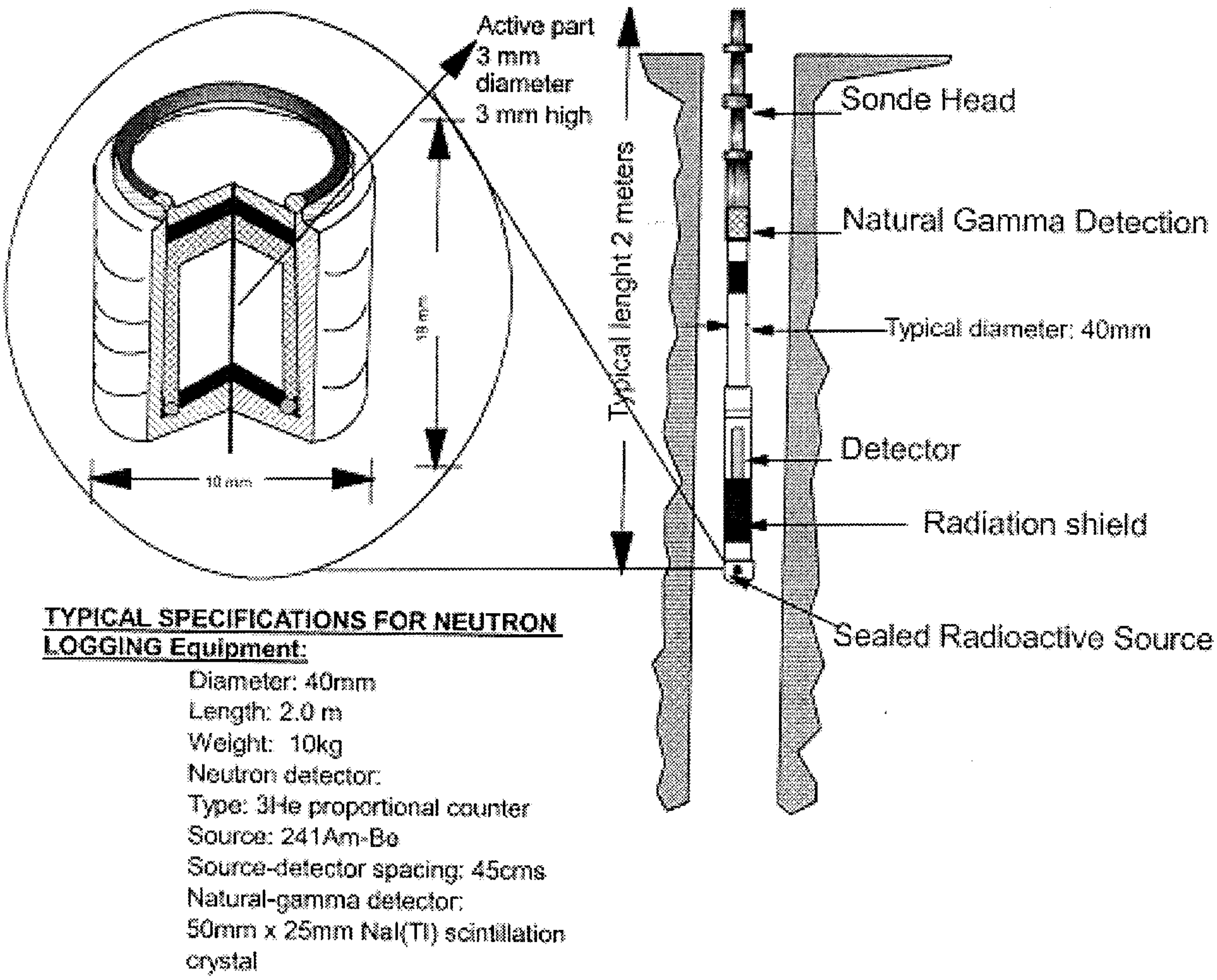


FIG. 12. A schematic diagram of a neutron source and borehole logging equipment.

The source usually consists of a chemical compound of the radionuclide (e.g. americium oxide, radium sulphate, radium bromide, polonium oxide) mixed with the light element powder (e.g. beryllium, boron, calcium fluoride, lithium hydroxide). The sources contain a significant amount of actinide activity and its mixture with light material makes leakage a serious radiological hazard. Actual logging probes are more complicated and include secondary radiation detection equipment as well as the power supply and electronic systems associated with radiation detection data processing and control. When dealing with such equipment as waste, design data and associated diagrams, as well as source removal/replacement procedures, should be available.

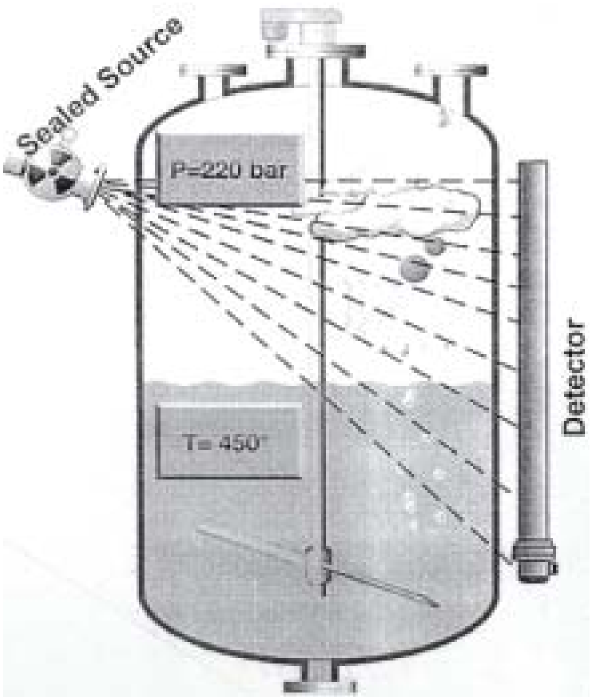
Such sources are regularly transported in Type A or B neutron shielded containers between facilities, and present no significant transport difficulties.

Although seen as Category 2 [2], oil well logging sources emit neutrons which cannot be measured with normal GM tube type detectors. This implies that these sources, when lost, may be overlooked as dangerous whereas neutrons are many times more biologically damaging than beta/gamma radiation. Furthermore, neutron interaction with matter is strongly dependent on the neutron energy. This should be observed when dealing with such sources especially for shielding design.

2.3.7. Industrial gauges

These instruments are used for the control of process parameters in industrial plants. The most widespread applications involving the use of high activity sources include density, thickness and level measurement (see Figure 13). The nuclides Co-60, Cs-137 and Am-241 are commonly used and activities in the range 10–100 GBq are common, with some applications using up to about 1 TBq. Nevertheless, the tendency is towards the use of lower activities due to the improvement of the detector sensitivity. The largest proportion of these devices consist of a shielded source container and a simple sliding or rotating shutter that, when closed, attenuates the beam. A small number of these containers operate by the movement of the source on a rod to align with a hole in the shield. Steel lined lead is the preferred shielding material although tungsten, depleted uranium and steel are frequently used to accommodate environmental conditions and geometrical considerations.

Radiometric measurement



Functions

- Level measurement;
- Interface layer detection;
- Measurement of minimum and maximum levels;
- Density measurements;
- Process control (material flow/ supply).

In normal and extreme process conditions, e.g.:
- High pressures;
- High temperatures;
- Toxicity;
- Abrasion;
- Viscosity.

FIG. 13. Various functions attained by sealed sources in process control.

3. GENERAL MANAGEMENT ISSUES

An effective SHARS policy needs to outline general principles to be applied to the management of these sources through their life-cycle. The policy has to be developed taking into account the technical and financial resources available in the prevalent social and political climate. Without an agreed policy it is not possible to set appropriate programmes of work and allocate the required resources to carry out the tasks for the management of SHARS in a safe and economical manner. The policy should be reviewed on a regular basis to account for changes that could affect the management of SHARS.

There are a number of generic policies which can be adopted by a state for the management of SHARS. These are:

- Limiting the number of SHARS within the territory;
- Recycling or re-use;
- Handling unexpected SHARS
- Storage prior to disposal.

3.1. LIMITING THE NUMBER OF SHARS WITHIN THE TERRITORY

This policy cannot be conducted without consideration of all factors. Each application should be evaluated on a case-by-case basis to assess the benefit of using high activity sources against any disadvantages resulting from the spent source liability.

There are several possibilities which can be used to achieve this policy. These are:

- **Limiting the import of high activity radioactive sources:** This could be applied when viable alternative technologies exist. However, due to the wide range of applications and long history of use of sealed sources, it is unlikely that their total elimination is practical.
- **Requiring guarantee of return to the supplier:** Agreeing such an arrangement with the supplier at the time of purchase would be an effective option wherever possible. However, the source supplier may not be able to offer a guarantee, or may need to restrict the nature of the guarantee due to business, political or regulatory reasons. In the event that a guarantee is supplied, the source supplier may have ceased to exist by the time the source needs disposal. Nevertheless, when the option of return to the manufacturer is available, much effort should be made to finance this option.
- **Arranging transfer of existing SHARS:** This option may include the transfer to a source processor, who may or may not be the manufacturer, or transfer to a long term storage facility.

3.2. RECYCLING OR RE-USE

States should adopt the policy of encouraging the recycling or re-use of radioactive sources wherever possible. This can be accomplished either by utilising the source for a different application within a country or by returning it to a supplier for re-use or recycle. Economic, environmental and safety issues involved in recycling/re-use make this issue challenging and the following are required to be evaluated:

- commercial demand for the recycled product;
- storage costs when recycling is not immediately viable;

- technical requirements for re-use, recycling and storage;
- safety and regulatory standards and requirements;
- social acceptability of the recycling and storage processes.

Member States, through international co-operation, should provide guidance, control and economic incentives for both users and suppliers to explore recycle and re-use. Conditions for which long term storage is more viable should be identified by stakeholders. The preference can be based on economic, safety or technical grounds. Source manufacturers or other source processors are likely to be in the best position to provide re-use/recycle services, and the policy in a given Member State may therefore be aided by strategies which encourage return of radioactive sources to the manufacturer.

All stakeholders will have some financial commitments in the recycling/re-using of SHARS. Financial provisions to meet the forecasted cost should be created during the lifetime of the sources in order to meet such costs when they arise. Legal and administrative arrangements may need to be simplified if such an option is to be developed on a wider scale. International co-operation and information exchange is an important component for this issue. An overall strategy on the national and possibly the international level may be required.

3.3. HANDLING UNEXPECTED SHARS

These sources (often known as "lost" or "orphan" sources) occur when SHARS are discovered unexpectedly. These SHARS may not have supporting documentation and determination of ownership may be impossible. General policy to handle unexpected cases should be available, locally and on a national level. Of primary importance are the safety implications of discovering these SHARS.

Typical cases of unexpected SHARS include:

- SHARS found in scrap metal.
- Decommissioned industrial complexes.
- Illicit trafficking.
- Abandoned equipment.
- Unintentional disposal along with conventional waste.
- SHARS outside regulatory control (e.g. resulting from bankruptcy).

3.4. STORAGE PRIOR TO DISPOSAL

Two alternatives have to be considered, decay storage and interim storage.

3.4.1. Decay storage

For various reasons it may be beneficial to allow the SHARS to decay to a certain level prior to further actions. This can be accomplished by authorised storage at the users' (or a third party's) premises. Storage at a centralised storage at the users' premises may be suitable for short term storage of SHARS with short half-lives, most typically Ir-192. It depends on the acceptance criteria of the near surface repository of the Member State or relevant applicable clearance levels. Storage in a centralised facility provides better opportunities for the safe and secure storage over an extended period of time and the reduction of risks associated with storage on the users' or a third party's premises. Although there may appear to be substantial cost in establishing and administering a centralised facility, it is probably less expensive than proper administration of safe and secure storage in the users' or third parties' premise. This also reduces the likelihood of costly mitigation of consequences of accidents. This by no means should be taken as a long term solution.

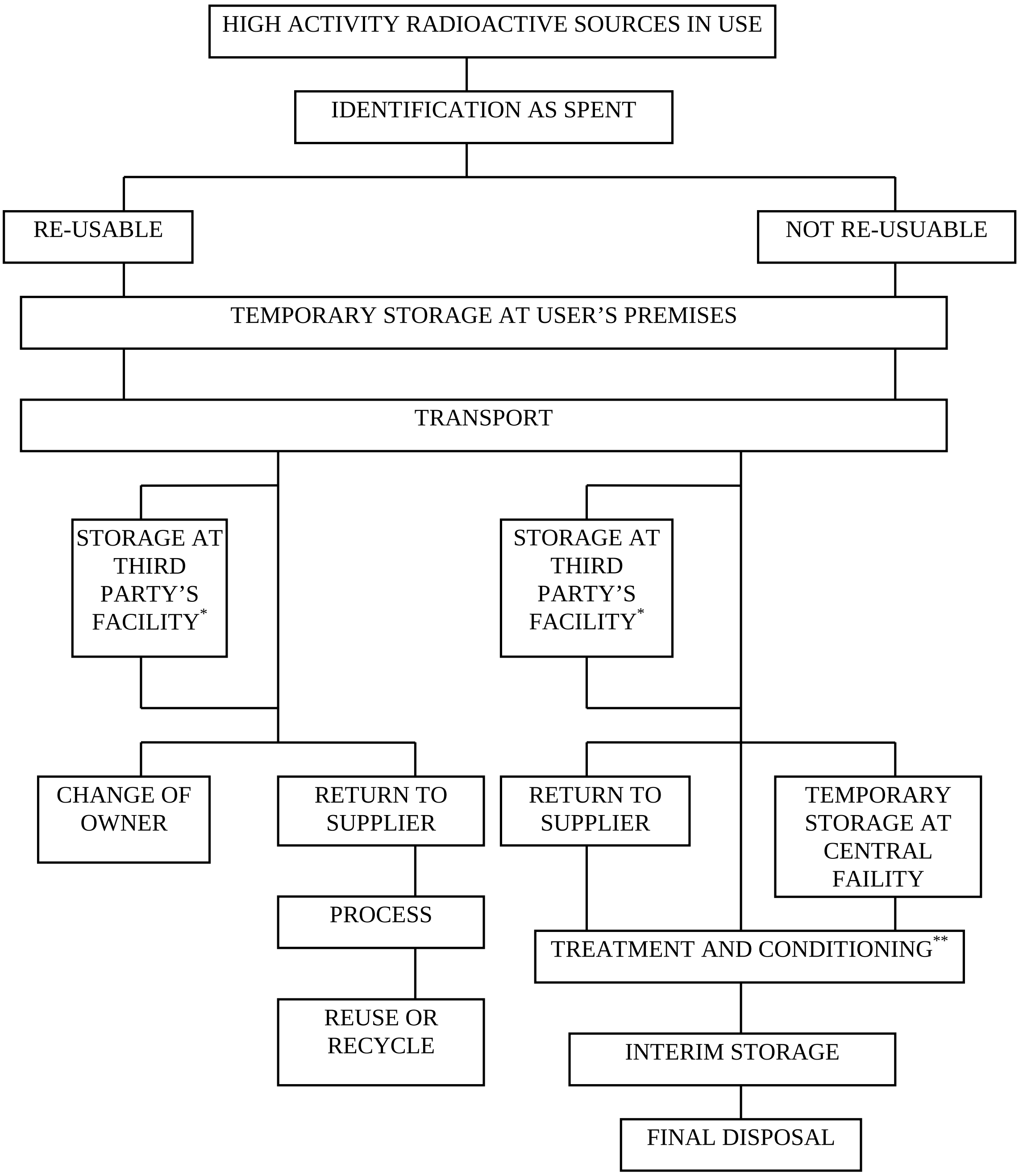
3.4.2. Interim storage

For radionuclides with half-lives greater than five years and for which a near surface repository may not be viable, a deep repository may be required. In order to adopt a disposal policy, it is necessary to pursue a strategy of setting up one or more central or regional interim storage facilities. In addition, appropriate treatment and conditioning facilities will be required prior to disposal. This is the most acceptable policy for adoption by states which operate research or power reactors and for which deep disposal of high level waste is the chosen option. The inclusion of SHARS for deep disposal will have only a small impact on the design of the facility. However, for states with no reactor facilities the cost of establishing such a facility may be disproportionally high. One possible solution to this problem could be to develop international co-operation for a regional disposal facility. Nevertheless, the safe and secure operation of centralised interim storage requires a comprehensive and active national regulatory programme. Centralised interim storage is probably the safest and most cost-effective means to handle SHARS, despite the administrative cost involved. It is worth mentioning here that the implication of one SHARS involved in an accident can exceed the cost of construction of an interim storage by an order of magnitude or in some extreme cases by several orders of magnitude.

4. TECHNICAL ASPECTS OF MANAGEMENT OF SPENT HIGH ACTIVITY SEALED SOURCES

4.1. INTRODUCTION

The different stages in the management system are presented in Figure 14.



* Not encouraged, only in limited clear cases.
** Treatment and conditioning could take place before or after interim storage.

FIG. 14. Management of SHARS.

The first stage in the process of management is to identify a source as being disused/spent. Such changes of status requires the notification of the appropriate regulatory body. At this stage temporary storage of the SHARS is important. When preparing for temporary storage consideration should ideally be given to the possibility of future recycling. Sources that may be recycled or re-used in the future may well be segregated at this point to ensure that they are stored safely, but are also accessible.

The second stage is that of temporary storage (see Section 4.2.1), whilst awaiting transport to an interim storage, disposal or recycling facility. The purpose of temporary storage is to provide the best practicable level of security and radiological protection in storage conditions that maintain the integrity of the source containment. This would take place either at the site of the user or at the premises of a licensed third party. It should be noted that temporary storage may also take place in association with other steps in the management process.

- For certain mobile equipment, such as industrial radiography equipment, it is recommended that the complete equipment be transferred to temporary storage.
- For larger mobile equipment, such as remote afterloading brachytherapy machines, a source exchange may be carried out at the operational location and the source transferred to temporary storage in a shielded container.
- Permanently installed equipment, including teletherapy machines and irradiators which cannot be moved without an element of dismantling may be stored in situ for temporary storage. If it is required to dismantle or move a machine, it should only be performed by personnel with suitable qualifications and experience.

Once a suitable route has been identified for transportation to interim storage, which is the third stage (see Section 4.2.2), it will be necessary to arrange transport of the source to the selected location. This will typically involve road transport, although sea, rail and air transport is also possible. It may involve transport across international boundaries.

Major issues are involved in transporting SHARS. The difficulties and costs are very often the main reason that spent sources are kept in temporary storage rather than being transferred to a suitable interim storage or disposal facility. Temporary storage does not satisfy the safety, infrastructure and control requirements of extended storage. Experience has shown that most accidents occur while sources are in temporary storage, therefore efforts should be made to transfer the SHARS to an interim (maybe central) storage facility within a reasonable time.

When a source is received at a central facility, some level of treatment and conditioning may be required before it can be placed into interim storage (see Section 4.2.3).

One of the interim storage requirements will be the segregation of SHARS. Segregation is important for safety, daily operations and future disposal requirements. This segregation policy will typically involve separation by half-life, isotope, radiation and activity levels.

Finally, sources will be recovered from interim storage and following any further treatment and conditioning, will be transported to a final disposal site.

4.1.1. Technical implementation

This section is intended to provide organisations involved with the management of SHARS with a general understanding of the technical issues involved in their management. The information in this section does not equip an organisation to carry out any of this work itself. This should only be done where the licensed organisation employs suitably qualified and experienced staff and operates suitable facilities. Such work should only be undertaken with the knowledge and approval of the relevant regulatory authority.

The following approach assumes that the SHARS is not immediately replaced by a source supplier and exchanged for a new source. This section of the report is presented generally in the order in which the implementation of SHARS management will take place. When replacement occurs the SHARS becomes the responsibility of the source supplier and for most countries this means that the source will be exported from the country. Source manufacturers, accepting SHARS, should already have a well defined route for dealing with these materials.

Following temporary storage, the SHARS would be transported for treatment and conditioning. After this, a period of interim storage would ensue. Currently some countries are developing a final disposal facility able to accommodate SHARS. At the moment the only management option is the long term interim storage of maybe several decades or more.

Lost (or “orphan”) SHARS, are an internationally recognised problem. Regaining control of the lost SHARS is important whenever the opportunity arises. Following the discovery of a lost SHARS, it is necessary to characterise the device (identifying the physical and radioactive properties) and, following retrieval, the waste management processes will be broadly similar to those described in the following sections.

The exact order of the processes in the technical implementation of SHARS management may vary depending on the particular circumstances in any country. However, each of the steps described in the remainder of this section will need to be undertaken.

4.2. TEMPORARY STORAGE

Temporary storage takes place at the time a SHARS is stored on a temporary basis at a user’s or third party’s facility after being taken out of service. This could begin at the time of a source change, but more typically begins when a device that used a high activity source is taken out of service under circumstances that require local storage. Administrative controls and security are not likely to be sustainable at user’s or third party’s facility for the time period required for the source to decay to the required level for near surface disposal. Therefore, temporary storage is recommended to be as short as possible until the SHARS can be transported to an interim storage facility or to a facility where the source can be processed. Temporary storage should include plans for such a transfer, and the condition of SHARS in temporary storage should be maintained so that transport and source retrieval from the source holder are still possible later.

Specific safety and operational features of the facility and administrative controls are typically required as conditions of an operating license issued by the regulatory authority. The regulatory authority normally verifies periodically that the facility is appropriately maintained. However, the activities described in this section must be performed regardless of the extent, or even absence, of such monitoring by the regulatory authority.

Wet storage is a possible option for temporary storage. However, this approach would only apply to high activity source manufacturing facilities, and to large irradiators of the pool-type (it is important to regulate water chemistry in this case).

4.2.1. Preparation for temporary storage

Source preparation can take two forms:

- Source may be removed from its operational location and transferred to temporary storage within the control of the user organisation.
- Alternatively, the source may be made safe for temporary storage in its operational location.

If the first option is chosen, sufficient infrastructure (i.e. industrial and nuclear) should be in place. The process at this stage should not include separation of the sources from the working shield nor should any attempt be made to disable any interlocking system or safety feature retaining the source within its shield and in the unexposed position. Transfer of the source from its working shield should only be done according to approved procedures, by trained personnel, and to a transport container specifically designed for that equipment, in which the transfer of the source can be completed without exposing the source. The maintenance of the effectiveness of the original shield and any safety/security features cannot be overemphasised at this stage.

If the equipment is facility fixed, temporary storage should be conducted by leaving the source in its unexposed position in the facility. Measures should be in place that guarantee that the source is maintained in that position, is unaffected by environmental conditions and eliminates intrusion. Regular inspection of such a facility should be carried out on a routine basis. If the source's normal storage position (shielded position) is attained by wet storage (in case of pool-type irradiators) the quality and level of the water must be well maintained for the whole period of temporary storage.

The SHARS is then further prepared by adding securing mechanisms as required to ensure that the source cannot inadvertently be moved from its safe position in the source holder. However, the mechanisms should be designed and installed in a manner that allows for their removal so that the source can be subsequently removed from the source holder. A durable tag should be attached to the added or modified part identifying its function, reason for installation, warnings or precautions that should be made known. Reference to any instructions and authorization that may be needed for their removal will also be included.

Preparation also includes wipe tests for contamination that might be present and inadvertently be spread during temporary storage. If such contamination exists, measures must be taken that will contain the contamination during the expected temporary storage time period and efforts made to determine how the contamination occurred. In addition, a radiation survey should be performed to ensure that radiation from the source holder does not exceed the manufacturer's specification and is otherwise satisfactory for storage in the planned storage area.

The SHARS device should be wrapped or otherwise protected as required against environmental damage (such as corrosion) under the planned storage conditions, and to prevent dirt, insects, or other unwanted material from entering sensitive parts of the source holder mechanism.

A durable label should be installed on the device that identifies the important characteristics of the source or sources, such as isotope type, manufacturer, model, serial number(s), and activity at an identified calibration date.

Warning signs should be installed as needed to ensure that the nature of the safety risk during storage is obvious to personnel who may encounter it. These signs should be installed even though security measures are also in place and should be written in languages that are understandable by the persons who could reasonably enter the facility. The presence of radiation warning symbols alone should not be considered as adequate warning during temporary storage.

4.2.2. Temporary storage facility

The facility used for temporary storage of SHARS must be constructed so as to prevent exposure to adverse environmental conditions and possible intrusion of animals that might compromise the integrity of the source holder. In selecting the facility, consideration should be given to the possibility of flood, fire, or other events that could compromise the safety of the storage facility and SHARS. Design guidance for on-site storage facilities are given in the TECDOC-1145 [8].

Security of the temporary storage facility must be sufficient to ensure that unauthorized personnel are prevented from entering. In order to control this security and also unnecessary radiation exposure, the secure area should be used for temporary SHARS storage only. Where this is not possible, the SHARS should be clearly segregated from other stored material. Persons authorized to enter for other purposes should be trained as to the presence and significance of the SHARS.

In addition to the signs on the SHARS itself, additional signs should be mounted at strategic points within and/or on the outside of the temporary storage space to provide warnings in order to discourage casual or unwanted intentional intrusion.

4.2.3. Administrative controls and documentation

A designated person trained in radiation safety should be identified as in charge of administrative control of the SHARS temporary storage site. A written plan should be developed for such administration that should require, but not necessarily be limited to, performing the following:

- Checks of the storage area security systems
- Any special tests required to ensure integrity of the SHARS source holder
- Wipe tests, radiation surveys, and testing of the functioning of the radiation monitors
- Checks that all signs and labels are present and readable
- Checks that all persons authorized to enter the storage area are appropriately trained
- Efforts to be made to minimise the period of temporary storage
- Responsibility does not lapse with change of personnel or facility ownership.

Information in the documentation retained for each SHARS in temporary storage should be included in the national inventory of sealed sources(see Section 5.1.1).

All official documentation pertaining to the source and the device must be retained for reference and transfer when the source is moved to interim storage. The documentation should be retained in an obvious but secure location under the control of the designated administrator. It should include, but not necessarily be limited to:

- The source certificate or other pertinent information about the source
- Procedures related to source handling, such as loading and unloading instructions and identification of suitable shipping and storage containers
- Drawings and other technical information about the source and the device
- Information about administrative checks performed during storage.

A typical source used in medicine and industry is Ir-192. This radionuclide has a short half-life (74 days) and could simply be decay-stored under temporary storage conditions. The period of decay-storage will depend on a number of factors including the initial activity of the source, the clearance levels and/or acceptance criteria for waste disposal as well as the irradiation history of the source material.

4.2.4. Examples

The procedures followed in the examples below are not to be seen as exclusive but give only a possible approach to the handling of the SHARS as described in the previous sections. These examples describe realistic situations in which minimum safety requirements are achieved with limited resources, where no other practical options were available. Once temporary storage conditions are established, efforts must also be made to plan for transfer to centralised interim storage as soon as possible.

(1) A Co-60 teletherapy unit at a hospital was obsolete. No abnormal radiation levels were detected. No licensed transport container for the source can be accessed for one month. The equipment remains intact. The shutter/source rotating mechanism was fitted with a removable bracket to prevent the source from being exposed. Knowledgeable persons removed the head from the equipment. The head was much smaller and more easily handled than the remaining parts and contained the source within the radiation shield. A special temporary storage room was considered for the purpose with required security locks and warning signs. Due to financial limitation, construction of a specific store was impractical. A storage location was therefore identified in a warehouse containing other equipment. An area with one meter clearance erected around the source holder was cordoned off with rope, and a sign attached to the rope cautioning that radioactive material was stored behind the rope and entry should only be by those authorised. Persons who are expected to use the warehouse are provided instruction concerning the SHARS and the associated hazard. The outside locks of the facility were improved to protect against unauthorised access and a cautionary notice was placed on the outside of the main access door stating that radioactive material was stored inside. Usage of the local language was necessary in this case.

    This arrangement is insufficient for longer term temporary storage. A better option would be to construct a partition wall, or a room within the warehouse, that would provide a more secure separation between radioactive and non-radioactive equipment.

(2) An Ir-192 radiography device was deemed unsafe owing to worn couplings. As its volume could not be reduced other than the removal of the winding gear and guide tube, it was retained completely. The safety mechanisms, which prevent the source from falling out of the radiological shield, were checked, the shutter was found to be closed and locked, and surveys showed no contamination or abnormally high radiation levels existed. The device was stored in a closet containing additional radiography equipment that was currently in use. The shelf on which the device was located was covered in front with two strips of wide plastic tape with a sign on the front giving details of the

equipment and stating the device to be in storage and not to be removed. The room was locked, access was limited to authorised personnel, radiation signs were displayed clearly on the door and the area was equipped with a radiation monitor and an audible alarm.

In this example the device should be made inaccessible to accidental use. Additionally, administrative controls are lacking and could be improved with a written plan specifying the period for which the device should be stored and a course of action for repair, disposal and assigned responsibility.

(3) A large-scale wet storage irradiator was no longer commercially viable and it was decided to suspend operations. The control system may be required for the eventual removal of the sources and, more importantly, for the circulation, filtering and monitoring of the pool water. It was therefore important that the system be selectively disabled. The source rack cables were disconnected, the motor power wires were isolated and a mechanical device was attached to the lifting mechanism that prevented the upward movement of the sources. Tags with indelible writing were attached to the disconnected power supply and to the mechanical device, providing strong warnings concerning reconnection of power and removal of the mechanical device, plus reference to location for retrieval procedures. The maintenance of the irradiator was important and a schedule was drawn up which addressed the routine inspection of the level and both the radiological and chemical quality of the water. The inspection also included that of the radiation warning signs and the general security of the building.

In the case of underwater storage, the physical cleanness and the chemical composition of the water are both important factors for any future manipulation of stored sources. Filtration of the water, and prevention of biological growths such as algae as well as deposition of chemical “scaling” should be prevented to make any source identification or manipulation possible with ease.

Water chemistry is also very important. Most sources are encapsulated using stainless steel. Some salts such as NaCl may have a damaging effect on the capsule of the sources especially if pool temperature is somewhat elevated (e. g. 30°C–50°C). It is necessary to ensure maintenance of the facility over the proposed storage period, which may be several decades. Other compounds in hard water such $CaHCO_3$ can cause scaling.

4.3. TRANSPORT OF HIGH ACTIVITY RADIOACTIVE SOURCES

The absence of low-cost transport options for high activity sealed sources is currently a major worldwide issue and is resulting in large numbers of SHARS being stored at users’ premises, often in unsuitable conditions. The problem exists both in developed and developing countries. Technically, solutions exist for all high activity source transport. However, it is often difficult for users to obtain funding for operations, which are seen to be end-of-life and to have no immediate benefit.

There are many cases in which SHARS remain at the users’ premises due to problems in identifying a suitable and economical method of transporting the source to a long-term storage or disposal facility in accordance with the appropriate international regulations [4]. There are two main reasons for these difficulties. These are the absence of a valid “Special Form Certificate” for the source and the absence of a suitable licensed transport container. It is important that solutions to these problems become available if sources are to be safely transferred from storage at the users' premises to a suitable central storage or disposal facility.

Absence of Special Form Certificate

High activity sources are generally encapsulated fulfilling the requirement for "Special Form Radioactive Material" when they are manufactured. They are then delivered to the end user either in a Type A or Type B package, depending on the activity. In the case of Type B, the approval certificate for the container used will define the permitted contents. In order to avoid costly over-engineering, most transport container designs for Special Form sources take into account the containment provided by the source capsule. The permitted contents for the containers will therefore specify that the contents must be Special Form.

The activity limits of a type A package are specified in the IAEA Safety Standards Series No. TS-R-1 "Regulations for the Safe Transport of Radioactive Material" [4]. For the special form of the radioactive material, A_1 value applies (or A_2 value if it is not special form). For example, for some typical isotopes, those values are[3]:

Cobalt (Co-60): $A_1 = A_2 = 0.4$ TBq (~1 Ci),
Caesium (Cs-137)[4]: $A_1 = 2$ TBq (~55 Ci), $A_2 = 0.6$ TBq (~16 Ci),
Iridium (Ir-192): $A_1 = 1$ TBq (~28 Ci)[5], $A_2 = 0.5$ TBq (~14 Ci),
Strontium (Sr-90): $A_1 = 0.2$ TBq (~5 Ci), $A_2 = 0.1$ TBq (~2.8 Ci),
Americium (Am-241): $A_1 = 10$ TBq (~280 Ci), $A_2 = 1.10^{-3}$ TBq ($\sim 2.8 \times 10^{-2}$ Ci).
Californium (Cf-252): $A_1 = 0.05$ TBq (~14 Ci), $A_2 = 3.10^{-3}$ TBq ($\sim 8.10^{-2}$ Ci).

In many cases, Special Form Certificates no longer exist for spent sources. This is usually because the capsule design is obsolete or because the source manufacturer is no longer in business and therefore no longer in a position to extend the validity of the certificate. In both cases, once the Special Form Certificate expires, it is not renewed by the relevant competent authority.

Adequacy of Original Transport Container

Even if the "Special Form Certificate" remains valid, the container in which the source or device was delivered may no longer comply with current transport regulations.

An example of this would be the early teletherapy heads which were delivered complete with their sources, in simple overpacks (see Figure 3) and which were not designed for easy source removal outside a shielded cell facility.

Options for Transporting Spent Sources

The method by which a source is transported from the user's premises, to a storage facility, will depend, among other factors, on the age and type of source, the age and type of device,

[3] The curie values are approximate and quoted here for those who are more familiar with it.
[4] A_1 and A_2 values include contribution from daughter nuclides with half-lives less than 10 days.
[5] The quantity may be determined from measurement of the rate of decay or a measurement of the radiation level at a prescribed distance from the sources. Values quoted in Curie are approximate.

the availability of suitable transport containers, the handling capability of the receiving facility and the requirements for conditioning and storage.

There are initially two possibilities for the transport of SHARS, i.e. the source transported in the original source holder and with the source holder removed (see Figure 15).

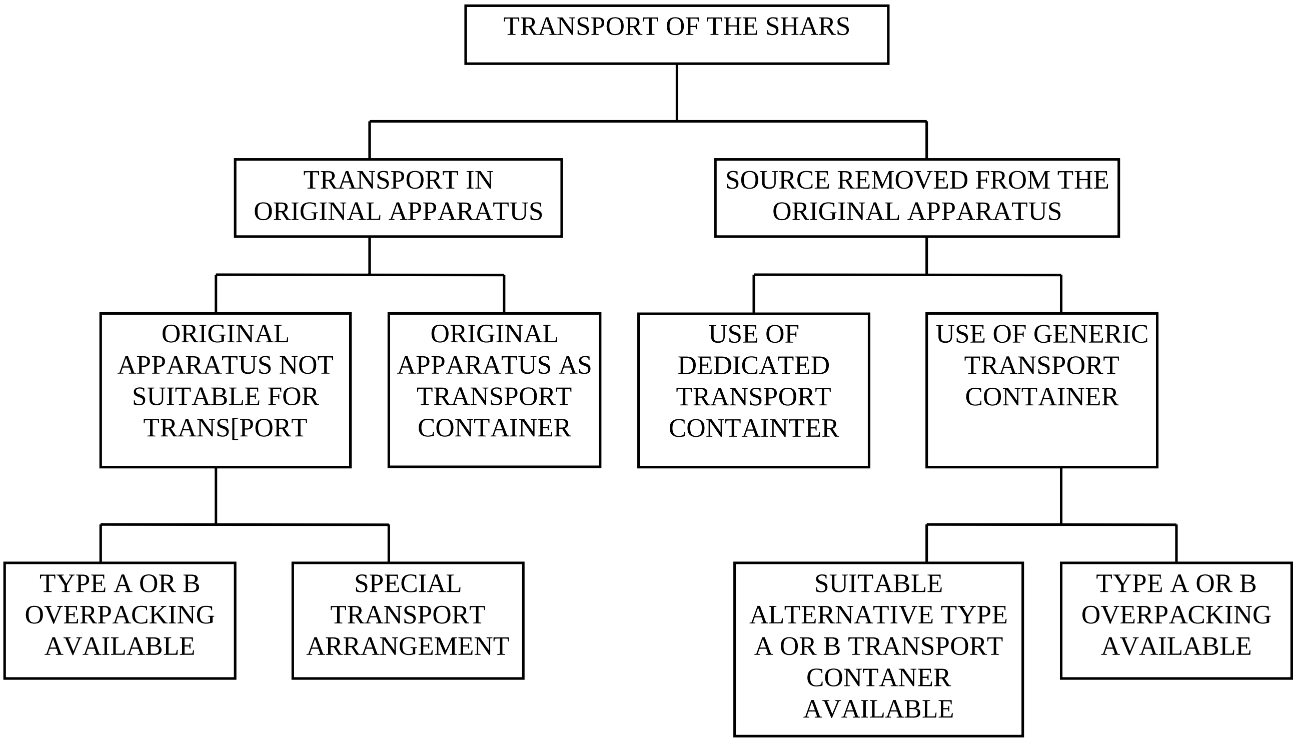


FIG. 15. Possible ways of SHARS transport.

Considering the large number of SHARS worldwide; absence of “Special Form Certificates” and adequate transport containers, means that urgent attention should be given to SHARS transport. Innovative solutions and the possibility of international or regional co-operation for providing transport should be addressed urgently. The following sections discuss the various possibilities. While ideas are provided to give the reader information on the different possibilities, this does not negate seeking the regulatory approval of the option(s) selected by the user.

4.3.1. Source transported in original source holder

There are two possibilities within this approach:

4.3.1.1. Use of original source holder as transport container

In some cases, the source holder can be used as a Type A or a Type B transport package, or an integral part thereof. As explained above, this was often the method used to deliver the source from the manufacturer to the end user. However, this method may no longer be applicable. It is often the higher activity sources which can no longer be transported in this way. Typically, the sources which can still be transported in their source holders are the smaller industrial radiography sources, weighing perhaps only 20 to 30 kg. If this method is to be used, it is important to ensure that all safety mechanisms are functioning correctly, e.g. shutter securing mechanism.

This approach is certainly safe, convenient and cost-effective for the user, as it minimises the radiation dose in handling, avoids the need to hire a transport container, and simplifies the disposal of any associated depleted uranium. It can also be convenient from the point of view of the receiving facility, as radiation dose is minimised, as long as the disposal acceptance conditions do not require the source to be removed from its holder. Even if the source needs to be removed from its holder prior to long-term storage or disposal, it is likely that the receiving facility will be better equipped to do this than the user.

It is important for the regulatory body to be able to assess whether an original source holder complies with current transport regulations to qualify as a transport package. If the regulatory body has insufficient experience to make this assessment then it will need to call on international help.

If the original source holder does not qualify as a transport package, and transportation is necessary, then approval may be granted under Special Transport Arrangement conditions. Again, international assistance may be required to identify and evaluate the acceptable parameters to allow transport. Each movement will need to be considered on a case-by-case basis.

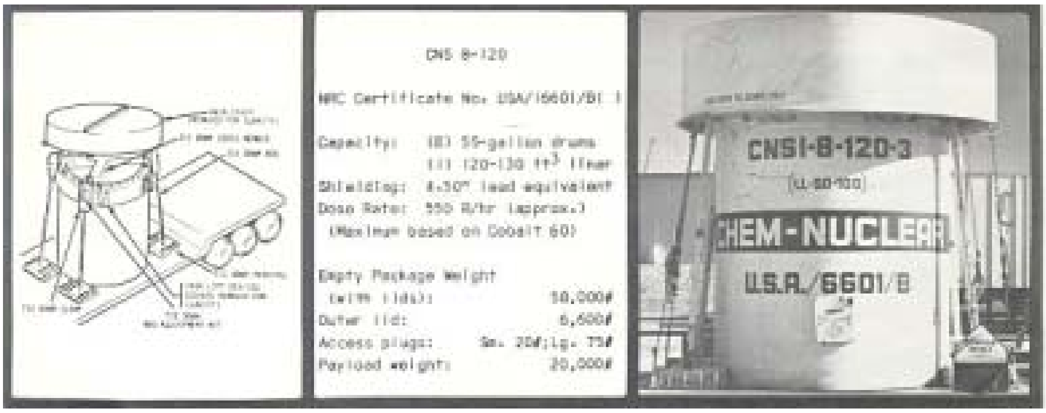
4.3.1.2. Transport of the source and its holder in an approved transport container

If it is not possible or practical to remove the source from its holder at the user's site, then it may be necessary to transport it in an approved transport container with sufficient cavity size to hold both the source and its holder.

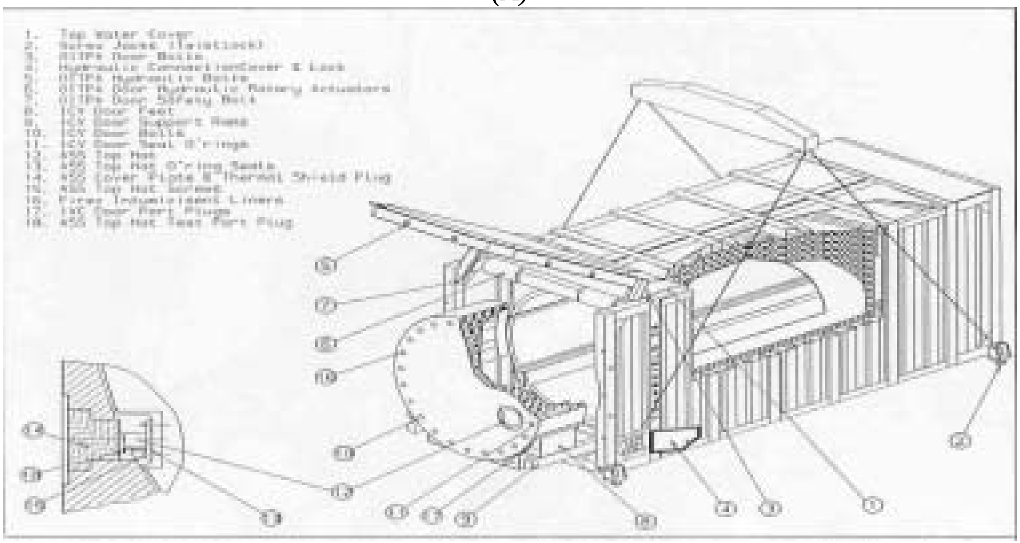
For smaller source holders, with total weights up to about 500 kg, and activities within Type A limits, this can be a relatively simple proposition. A number of Type A package designs exist, which would be suitable for transporting such sources. A typical example is shown in Figure 16. This container is a steel drum Type A overpack, without shielding. Source holders may be transported in this kind of container, as long as they have suitable integral shielding and are held rigidly inside the container whilst in transit.

FIG. 16. Type A transport container with large internal volume and load capacity (approximately 300 kg).

For larger source holders or for Type B activities, the options for transporting the complete source holder are more limited. The transport containers available are by necessity large and complex, designed to provide containment for open source radioactive material inside a large internal cavity. Figure 17 shows a type B container transported on a low bed truck and a Type B container, based on an ISO transport container. The container in the later case, comprises a 5.5 m long by 1.9 m diameter pressure vessel on tracks running inside the ISO transport container. The pressure vessel is capable of a range of payloads, including 500 litre drums. It is therefore suitable for transporting large source holders.



(A)



(B)

FIG. 17. (A) Type B container designed for low-bed transport.
(B) General arrangement of AEA Technology's transactive Type B shipping package.

Additionally, these containers are expensive and the high cost may be difficult for a developing country, with a relatively small number of SHARS, to justify. In this case, there is a strong argument for international co-operation on such issues. It would be important to smooth out any potential difficulties over transboundary movements.

Within a national boundary where no suitable transport container exists, it may be possible to apply to the competent authority for a Special Transport Arrangement. This may, for instance, be based on re-using an original dedicated transport container, which no longer meets all the most recent requirements. While this option is available in principle, competent authorities in many Member States would be unlikely to accept this approach due to the availability of fully compliant alternatives.

4.3.2. Source removed from the original equipement

SHARS are usually associated with high exposure dose delivered even with a short encounter with such sources. This makes any attempt to remove the source from the original source holder a process conducted only when absolutely necessary. For safety reasons, a minimum required infrastructure and technical/administrative preparations should be in place. Extensive radiation protection experience is necessary for radiation workers intending to conduct such an operation.

Once the source is removed from the source holder, at no time, even momentarily, should the source be insufficiently shielded. The shield that eventually will house the source should be designed to have acceptable surface dose rate, provide for the required protection of the source according to relevant regulations and the possibility of source retrievability with acceptable exposure to personnel involved. The shield should also be designed to withstand accidents according to the package type required for the source. The source should be secure in such a way that accidental drop of the source from the shield is not possible. For the latest full detailed requirements of the various types of packages, the reader should refer to IAEA Safety Series No. TS-R-1 (2000 Edition) [4].

Technical procedures for source removal should be well tested, exercised and emergency procedures, in case of their failure, should be developed. Actual procedures for source transfer should be familiar to the staff involved. The workers should also have a good idea on physical appearance of the source itself.

In the course of the preparation the following points should be considered:

1. Dose distribution of the source within the original equipment in the “on” and “off” position is desirable.
2. Repair manual (especially material related to source movement mechanism, trouble shooting and miscellaneous repairs) should be available and well understood.
3. Tools, materials, parts or special equipment required for the work should be available and well tested.
4. Design data, diagrams and any photos/illustration are of immense value.
5. Power supplies and safety interlocks for the source mechanism or other tools or equipment should be guaranteed to be on the on/off position as required and that it can not be inadvertently be turned on or off by tampering with during the work.
6. Source drawer movement and unloading port alignment are guaranteed and do not require direct inspection or manual adjustment during source transfer.
7. Unexpected problems due to jammed mechanisms should be well studied and solutions available to such potential problems prior to actual work. It should be kept in mind that maximum protection is guaranteed when the source is in the original equipment or the target storage shield.

For this option there are a number of solutions:

4.3.2.1. Transfer source from equipment into dedicated transport container

Many types of source holder are designed to allow source exchange in the field. These include most modern industrial radiography and cobalt-60 teletherapy units. For industrial radiography units the process is simple, involving winding the source out of the source holder into a relatively small shielded container. An example of a transport container designed for dedicated use with an industrial radiography source is shown in Figure 18.

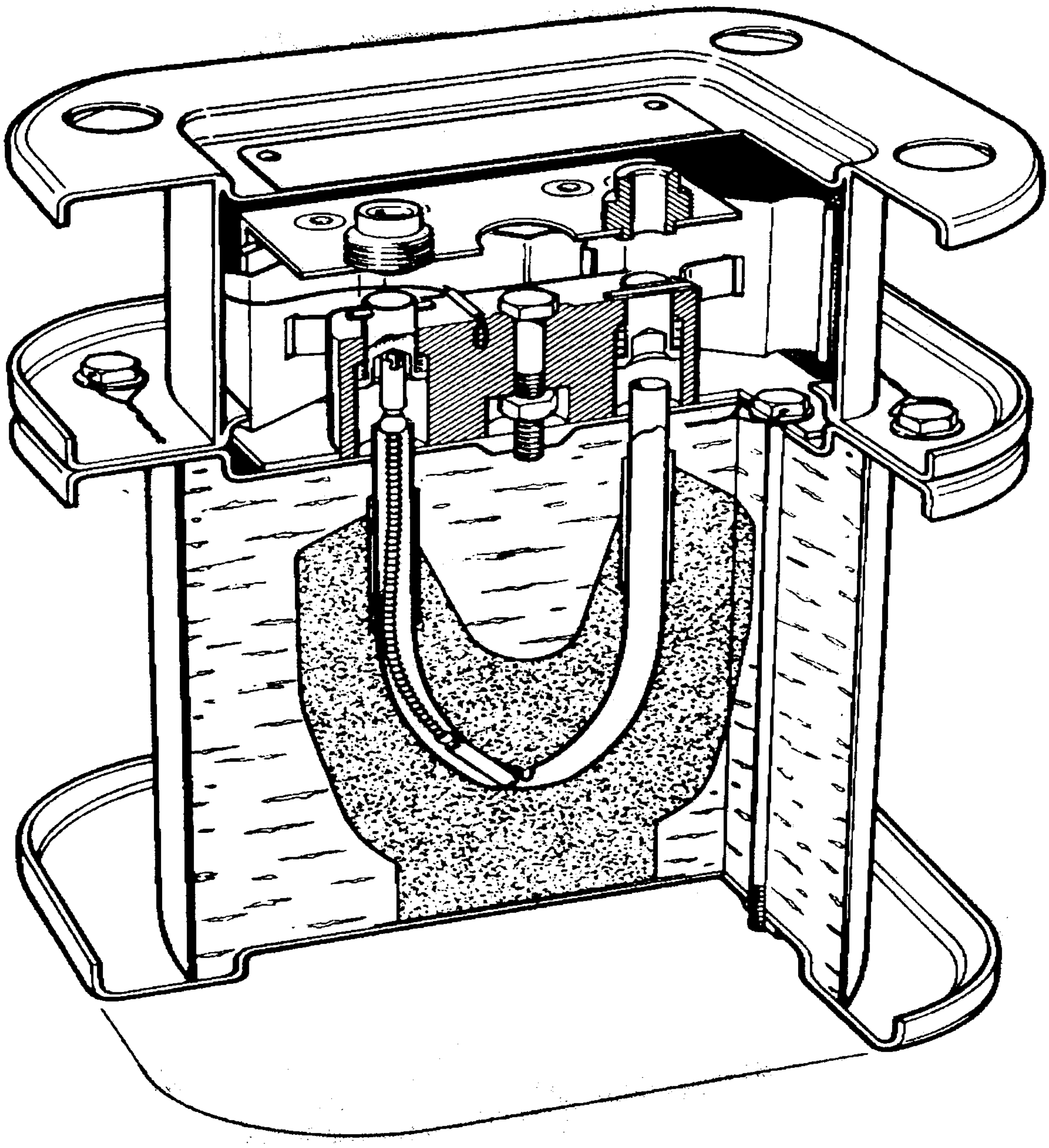


FIG. 18. Industrial radiography source transport container (Type B, 8.8 TBq Ir-192).

For teletherapy units, a large dedicated transport flask is mated to the teletherapy head, and the source is pushed or pulled from the head into the transport flask. The engineered fit between the teletherapy head and the transport containers ensures minimum radiation dose to the operators. This type of transfer/transport container is generally the property of a manufacturer/supplier. Figure 19 illustrates the general idea of such operation.

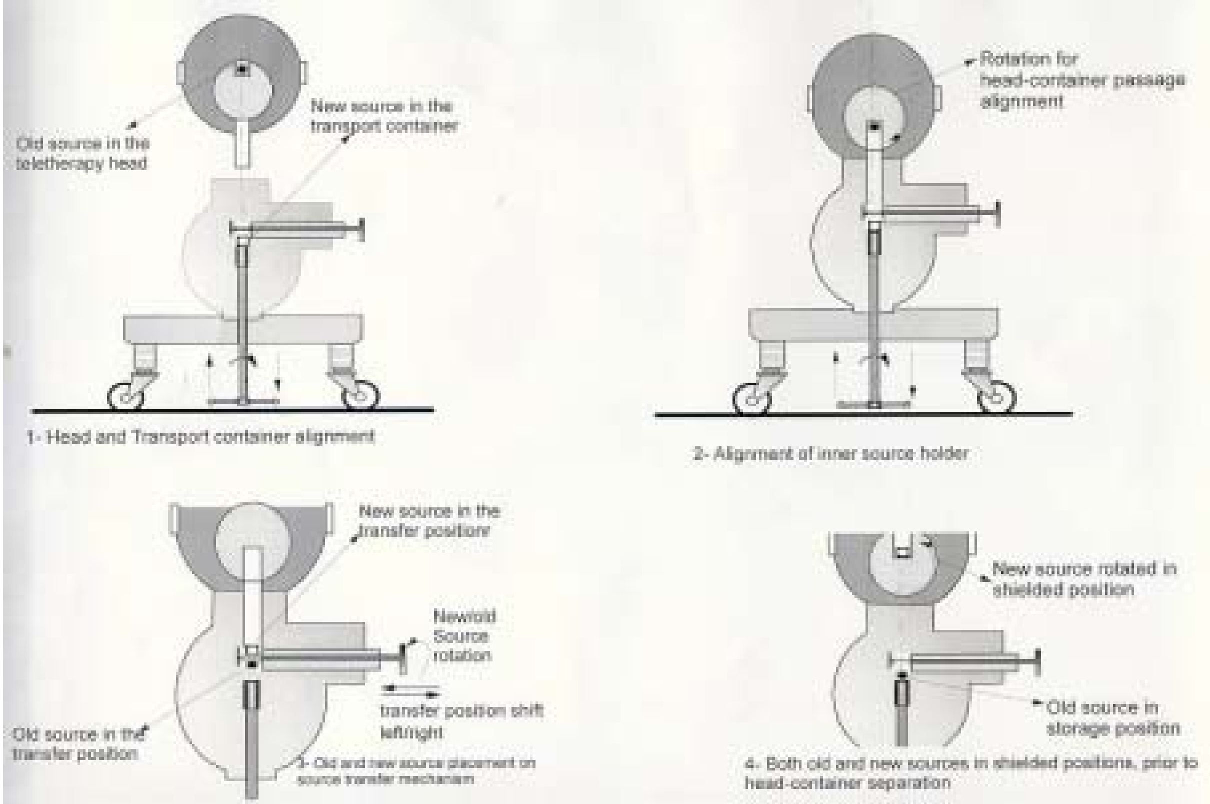


FIG. 19. Schematic diagram illustrating source exchange in a teletherapy unit.

4.3.2.2. Transfer source from equipment into generic transport container

For many of the older teletherapy units and older high activity industrial radiography units, dedicated source transport containers are not available, or transfer in the field is not appropriate due to the design.

If no dedicated source transport container exists, it may still be possible to transfer the source into a suitable alternative transport container. Indeed this may be essential if the receiving facility is unable to handle the source inside its holder (e.g. due to size), or if no transport package exists in which to transport the entire unit (source inside holder, see below).

Where transfer of the source out of the source holder and into a shielded transport container is proposed, there are a number of highly versatile transport containers available. Figure 20 shows a series of nested containers, each with shielding thickness of 50 mm. These can be nested inside each other to give a range of Type A and B formats with total shielding thickness of up to 150 mm. This container design offers large internal cavity and considerable flexibility.

FIG. 20. Cs-137 shielded inner container being loaded into a Type B outer container following removal of Cs-137 sources from a research irradiator.*
(with the permission from Inderühle Logistics, Switzerland)*

Generic containers, such as the one described above, are not designed for the specific purpose of transferring sources from a particular design of source holder. Therefore, it will normally be necessary to produce a custom-engineered solution to transfer the source into the container with minimum radiation dose to the operators. For instance, the container may be mated directly with the source holder, or alternatively a two-stage transfer using a custom-built transfer flask may be possible. Unshielded source transfer should be avoided in all cases involving SHARS. If this approach is to be used, technical procedures with innovative approach that fulfil the regulatory requirement need to be developed, well tested and carried out by well qualified personnel.

On receipt at the source handling, storage facility, consideration will also be required as to how the source is to be removed from the transport container. Often this is achieved inside a contamination-free, shielded, remote-handling cell.

If there is insufficient local expertise to perform the source removal or vital procedures, if equipment or tools are unavailable, then a supplier/manufacturer of similar containers/sources, or a foreign waste management organisation could be requested for assistance.

4.4. INTERIM STORAGE

The subject of treatment conditioning and storage of spent sealed radioactive sources is covered in TECDOC-1145 [8] and TECDOC-806 [10]. However, these documents focus more on low and medium active sources. Aspects that are more relevant to SHARS are presented here.

4.4.1. Preparation for interim storage

The management of SHARS will require a specific approach to treatment and conditioning. A number of different solutions are described below and presented in Figure 21.

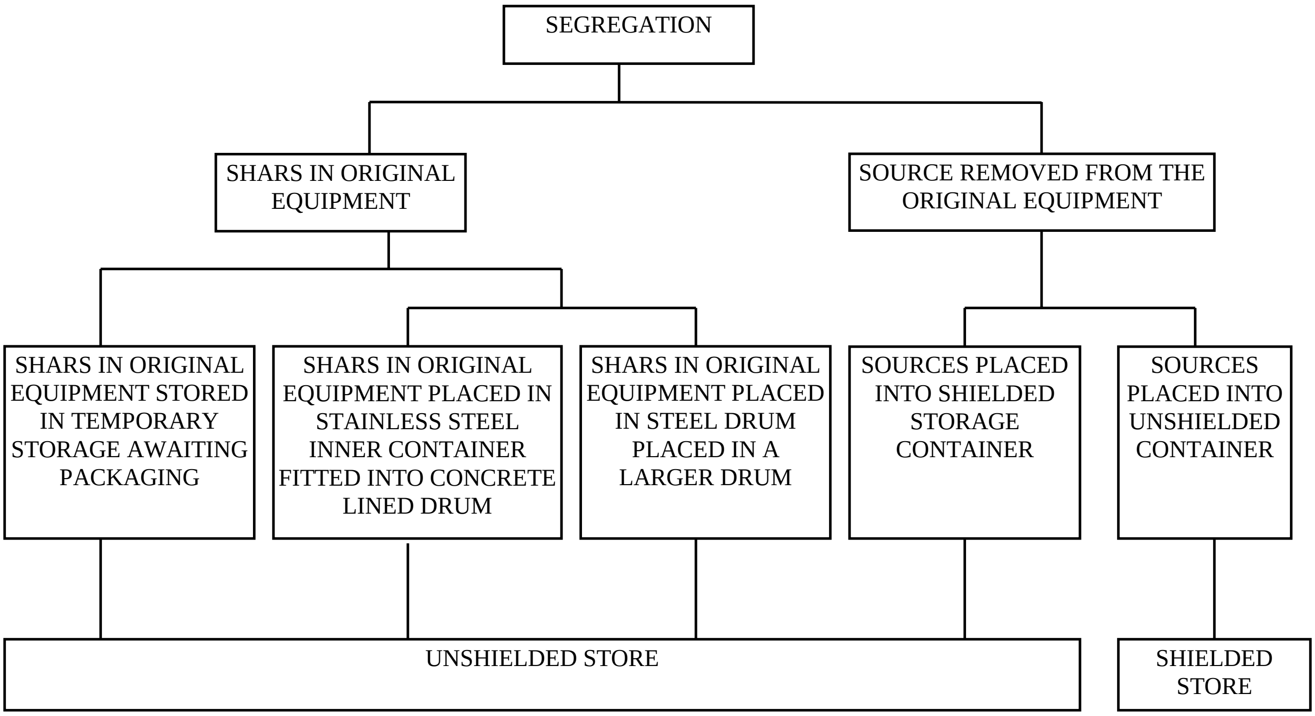


FIG. 21. Flow diagram for SHARS preparation for interim storage.

SHARS stored in original source holder (e.g. exposure head)

This approach should be treated as a temporary measure, or a measure only to be taken in special circumstances. For example, if a shielded facility is not available for removing SHARS from source holders, and the source holder is too large to be placed in a suitable container, there may be no other choice. A number of research irradiators, which can weigh several tonnes may fall into this category. In these circumstances, efforts should be made to identify and arrange storage in facilities in which these sources may be treated and stored. It is important to maintain the signs, labels, security and the control program (monitoring, leak testing, etc.).

SHARS and original equipment placed in storage container

The use of concrete lined drums or concrete boxes for storage of SHARS in source holders is quite common. Typically, a 100 litre drum will be set inside a 200 litre drum using concrete, or for larger items, 200 litre drums may be cemented into larger overpacks. Concrete boxes have the advantage over drums that they are more easily stacked, and can contain greater volume and load. Figure 22 shows a typical storage place where concrete boxes are used.

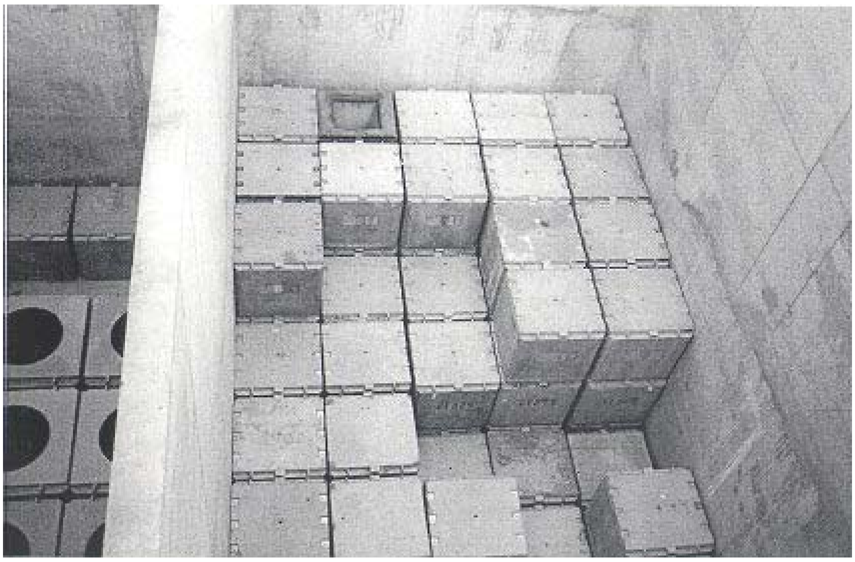


FIG. 22. Concrete vaults used to house concrete boxes.

The source holder can be stored in a standard container such as those described above. The container should be compatible with interim storage facility requirements and any proposed disposal site requirements. The aim of this practice is to protect the device from external damage and to prevent leakage. The preparation method should preserve the retrievability for any future management options.

Two examples are mentioned here. The choice of method will be a matter of the security required and the storage period involved.

In the first example the source holder is placed into a stainless steel inner container fitted into a concrete lined drum. In order to eliminate voidage and increase mechanical stability, the inner container is filled with an inert material (e.g. dry sand) and the lid is welded. Cement grout is added to cover the inner container and fill the external drum. Data concerning the source are attached to the drum using durable labels.

The second example is similar in placing the source holder in a steel drum. The steel drum is placed in a larger drum and only the space between the container and the outer drum is filled to form a concrete lined drum. The inner container is secured in the drum, in addition of being attached to the cement lining when it sets, by welding steel rods across the top. Anchors are placed in the cements, while the cement is still wet for welding the bars.(see Figure 23) For details of these option refer to the IAEA-TECDOC-1145 [8].

FIG. 23. Concrete lined drums used to house the sources with the storage shield. Notice the durable stainless steel tags welded to the cross bars.

These two solutions may be the most appropriate in countries that do not already have developed facilities for the handling and management of high activity radioactive sources. If possible, the SHARS should be placed in containers, which will eventually be used for disposal of their contents.

Dismantling the SHARS from the Source holder

The source can be removed from the source holder in a hot cell. This dismantling operation will reduce the volume to be stored and disposed. It is advantageous, if the inventory of SHARS is large. The design of the storage container will be determined by the inventory of SHARS and whether the container will need to be used for transportation purposes.

The walls of the hot cell will need to compensate for the shielding of the highest activity SHARS that are to be handled. The inner part of the cell may be lined with stainless steel or have an epoxy coating. Ventilation will ensure a negative pressure cell in order to avoid any transfer of possible contamination to other areas.

The hot cell will be fitted with a shielded door large enough to permit a shielded storage container to be introduced into the cell. The hot cell will be checked for contamination before the SHARS is introduced. The source holder will be placed in the cell and as much manual dismantling as safely as possible will be performed prior to closing the cell.

Securing mechanisms may be manually released and screws can be unlocked. According to the dismantling procedure, every tool needed will be introduced in the cell before its closure and the opening of the shield. The source holder will then be dismantled inside the hot cell using master slave manipulators (MSMs) and lifting equipment. The lifting equipment will be particularly required for the dismantling of older source holders where the source was not intended to be removed.

The source will be removed from the source holder using the MSMs and placed into the shielded storage container. The empty source holder will be checked for contamination and, if clean, reused, recycled or disposed. If the source holder is contaminated it will be cleaned to clearance levels. Special consideration will be required if the source holder is constructed with depleted uranium.

A shielded storage container may be designed to accommodate a number of SHARS. When the container is full it may be placed into a concrete lined drum, similar to that in the immobilisation solution described above. This operation can only be performed inside a hot cell. The waste containers used may therefore include some additional shielding.

Alternatively, an unshielded storage container may be designed to accommodate a number of SHARS which could be placed into shielded storage (e.g. well type store). In some cases, conditioning may be carried out prior to placing the containers in interim storage.

4.4.2. Interim storage facilities

There are various options for the interim storage of SHARS. An interim storage facility may need to use more than one of these options in order to provide interim storage for the full range of SHARS which it may be expected to receive.

4.4.2.1. SHARS consolidated in shielded container in unshielded store

Where a shielded interim store is not available, it may be appropriate to store consolidated SHARS in a shielded container within a secure store. Normally, the shielded containers are approved transport containers which are delivered to the store on a non-return basis. Some additional shielding may be provided by the structure of the facility (e.g. concrete walls).

It is important to distinguish between storage of SHARS in this way as a fully approved and regulated strategy, rather than as a temporary measure at a user’s premises. A number of serious accidents have occurred as a result of storage of sources in transport containers under inadequate management systems.

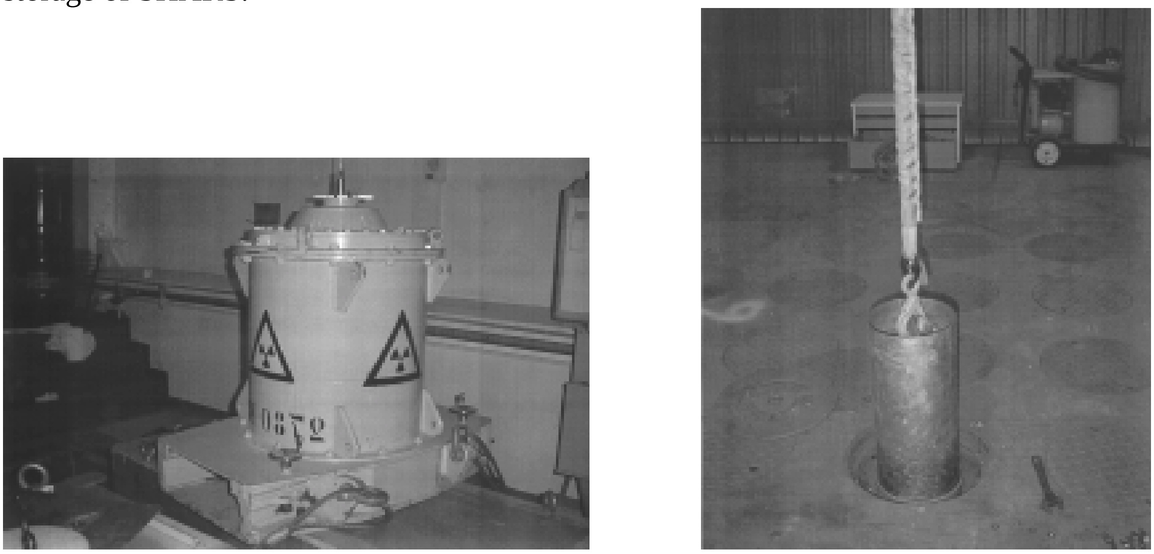
Interim storage facilities need to consider the possibility of recovering the sources from their containers for further conditioning prior to disposal. In addition, the original transport containers may no longer comply with current transport regulations [4].

There will be operational limits which will often include segregation requirements. These segregation requirements are based on anticipated future conditioning and disposal requirements and may include container dose rate limitations, segregation by radionuclide groups (e.g. by half-life or type of radiation).

4.4.2.2. SHARS consolidated in unshielded container in shielded store

There are various examples of this approach involving dry storage of the consolidated sources, such as tube stores directly beneath a source treatment cell. In these cases, sources are kept in a number of relatively small volume containers with a few sources in each container. Recovery of an individual source is relatively easy. This approach has the advantage that transport containers are not required when moving consolidated sources between the treatment facility and the storage facility.

Alternatively, consolidated SHARS may be stored in a radioactive waste store specifically designed to receive wastes of various types from other facilities. An example of such a waste store, consisting of a series of underground storage tubes, is shown in Figure 24. In this facility, remotely handled radioactive waste in steel cans, typically 10 litres volume, are transported from the treatment facility in a bottom loading, shielded transport flask. The flask is placed on a loading machine located over one of the tubes and the waste container is lowered into its storage position. The advantage of this method is that it allows a range of different waste streams to be received for storage in a single facility. However, the activity per can may be limited by the shielding provided by the transport container, rather than by the volume of the can. Facilities of this type are unlikely to have been designed specifically for the storage of SHARS.



(A) *(B)*

FIG. 24. (A) Bottom loading. Shielded transport flask
(B) Pipe store for sealed sources and other encapsulated LILW.

Following a period of interim storage, it is likely that the waste containers will be retrieved for further conditioning prior to disposal.

Practical issues, which should be considered when using this approach include:

- the need to segregate SHARS when placing them in the store;
- heat generation, activity and dose rate limits for each container and for the store;
- the future need to retrieve, condition and transport the consolidated sources.

4.4.3. Administrative controls and document retention

For either interim storage option, it is important to keep records of:

- the condition and maintenance of the store;
- regulatory inspections;
- the inventory of SHARS;
- the location of stored SHARS.

These records are important for the safe management and operation of the store according to the ALARA principle.

At each stage of the management of the SHARS, the organisation involved should keep information about the sources (see paragraph 5.1.1). This information should be transferred with the source when it is accepted by the waste management organisation for interim storage.

SHARS in their original shields can be stored temporary on metal racks (Figure 25). In cases were the sources show higher surface dose rate or may develop radiation leakage shielded vaults may be a better option (Figure 22).


FIG. 25. SHARS stored in their original working shields on metal racks, notice that each position is assigned a unique reference number.

4.5. DISPOSAL

Disposal refers to the process defined in the IAEA Radioactive Waste Management Glossary, 1993 [11] as the emplacement of waste in an approved, specified facility without the intention of retrieval. There are two types of disposal.

Geological disposal — the isolation of waste, using a system of engineered and natural barriers at depths up to several hundred meters in a geologically stable formation. Typical plans call for disposal of long-lived and high level wastes in geological formations.

Near surface disposal — the disposal of waste with or without engineered barriers, on or below the ground surface where the final protective covering is of the order of a few meters thick, or in caverns a few tens of meters below the Earth's surface. Typically short-lived, low and intermediate level wastes are disposed of in this manner.

In practice virtually no country disposes of SHARS, due to the lack of a geological depository. Reasons for this include:

- Technically demanding — experience has shown that the establishment of a waste disposal facility is technically challenging.
- Costs — deep disposal is very costly although various approaches exist which attempt to spread the costs.
- Public opinion — this emotional issue is one that requires careful consideration.

4.5.1. Characteristics of high activity spent sources relevant to disposal

- Levels of activity — The basic property of SHARS by definition is the remaining high activity. It is this high activity that limits disposal to a geological repository (except in the case of short lived radionuclides).

- Physical and chemical characteristics — Although robust construction is employed in the manufacture of SHARS they are not indestructible. The chemical form of the radioactive contents determines dispersability and radionuclide migration.

- Heat and dose — The high specific activity of a SHARS is responsible for elevated local temperatures and may result in radiological damage to the source vicinity.

- Gas and gas generation — Gas generation due to radiolysis, decay products and corrosion must be considered.

5. LEGAL, REGULATORY AND ECONOMIC CONSIDERATIONS

The state of advancement and the nature of the legal system regarding the management of SHARS are different in every country. Most countries' legal systems are based on producing a number of laws that state the legislator's policy. The detailed implementation of these laws is then governed by supplementary legislation including regulations and ordinances.

A number of countries have issued laws on the safe (or peaceful) use of atomic energy and laws on Radiation Protection. That law is implemented via a number of regulations that will normally include the safe use of radioactive sources and their subsequent management after the end of their operating life.

This section will deal with legal and economic aspects related to SHARS and their management. The section is provided to describe aspects specific to SHARS. For details, the Agency safety requirements and guidelines should be consulted. The characteristics of a national regulatory infrastructure are described in more details in an IAEA publication on the subject "Organization and Implementation of a National Regulatory Infrastructure Governing Protection Against Ionizing Radiation and the Safety of Radiation Sources" [13].

5.1. GENERAL LEGAL CONSIDERATIONS FOR MANAGEMENT OF RADIOACTIVE MATERIAL

The parties involved in the manufacture, transport, use, and storage of sealed radioactive sources are responsible for the safe management of all radioactive material in their possession. This principle applies equally to radioactive by-products and waste from the manufacturing process as it does to finished sealed sources in possession of the end user. In most cases this obligation is specified in a framework of laws and regulations under which the facility operates. Ultimately, the source material ownership is transferred to another party, or the source material is retained in a safe and secure location until it becomes non-hazardous through decay.

5.1.1. Typical legal obligations

Below are the parties who are typically involved in the chain of manufacture, use and storage of radioactive sources, and their typical legal responsibilities.

An *Irradiation Facility* typically irradiates inactive material to produce useful radioisotopes, or refines them from the by-products of other nuclear processes, and delivers the radioisotopes in bulk form to the Source Manufacturer. The Irradiation Facility is responsible for the safe operation of its facility under applicable laws and licenses, and for the safe disposition of all by-products of the production process, which may include isotopes other than those in the final product. For high activity sources that later become SHARS, Irradiation Facilities are nuclear reactors. At these facilities, radioactive waste from the irradiation process is usually conditioned and placed in an interim storage facility, all of which is intended for eventual disposal in permanent facilities.

A *Source Manufacturer* usually accepts ownership of the active material at time of delivery from the Irradiation Facility. The Source Manufacturer then becomes legally responsible for the safe handling of the radioactive material and for its subsequent transfer of ownership. Usually, the Source Manufacturer encapsulates the source to specific standards or legal requirements in facilities that are designed and licensed for the purpose (e.g. hot cells and glove boxes), and subsequently sells the encapsulated source to the User. The Source Manufacturer is responsible for ensuring safe operation of its facilities under all applicable laws and licenses and for the safe disposition of all waste material from the encapsulation process. This waste material is typically transferred back to the Irradiation Facility under terms of a contract associated with the purchase of the radioactive material. The Source Manufacturer also accepts responsibility for providing a transport container that meets national and international transport laws and license requirements, and helps make delivery arrangements for the source. In addition, the Source Manufacturer is typically required to supply to the user and Regulatory Authority a source certificate that contains comprehensive information about the source such as model and serial number, radionuclide, activity, date of calibration, capsule type, special form certificate number, and manufacturer information.

An *Equipment Manufacturer* provides the equipment into which a source will be loaded, either before shipment to the User's site or after installation. The Equipment Manufacturer is typically required by regulations to provide to the User all information needed to safely and properly operate and maintain the equipment. This includes all relevant information about the source and source transport mechanism, including means of securing the source in a safe condition, interlocks, and how to respond in emergency conditions.

A *Shipper (or Distributor)*, trained in the transport of dangerous goods and authorized by legal bodies, is responsible for carrying out all shipping operations in accordance with laws that pertain. The Source Manufacturer (who typically continues ownership of the source during shipping) and the Shipper therefore both have legal responsibilities during shipment operations. Insurance is usually purchased to cover costs that might arise during shipping due to possible accidents that damage the product or the environment, or cause injury to persons.

A *User* usually accepts ownership of the source material at time of delivery from the Source Manufacturer or importer. The User then becomes legally responsible for the safe handling of the radioactive material under all applicable laws and licenses, and for its subsequent transfer of ownership. License conditions typically require the User to securely retain a copy of the source certificate information provided by the Source Manufacturer. Although not usually required by license, the User should also ensure that it securely retains all technical information about the equipment provided by the Equipment Manufacturer. When a spent source is exchanged for a new one, this may be performed by experts from outside the User's facility, but is normally performed under the license conditions and radiation safety practices for which the User is responsible. During such an exchange the Source Manufacturer typically takes the spent source back; the exchange therefore creates no new waste issues for the User. When the equipment is eventually decommissioned, the disposition of the final source then becomes an issue. Local decay to a safe condition is typically not practical for SHARS due to the long half-life and/or high activity of the source. The User must therefore transfer ownership of the source to another party, such as a Source Manufacturer or an Interim Storage Facility Operator. If the User stores the source prior to a formal transfer of ownership (temporary storage), the User remains responsible for the safety and security issues during the storage period.

An *Interim Storage Facility Operator* for a spent source provides storage of conditioned and unconditioned spent sources. The Interim Storage Facility Operator is legally responsible for safe and secure storage of the sources under its ownership, and typically operates under license conditions established by a regulatory authority. This responsibility terminates when the source has decayed sufficiently to be disposed of as non-hazardous material, or until the source is legally transferred to another organisation such as a disposal facility. As a requirement of its license, the Interim Storage Facility Operator maintains an up-to-date inventory of all sources in its possession, including all details provided by the Source Manufacturer.

A *Regulatory Authority* in a particular country is created and empowered by national laws. There may be several regulatory authorities with different jurisdiction. Its legal responsibilities usually include all aspects of safety of radioactive materials, including licensing and auditing of Users and Storage Facilities, approving transport container licensing, and regulating the transport of radioactive material within the country. The Regulatory Authority has a legal obligation to protect public health through an appropriate level of diligence. Usually, it also is empowered to issue fines for infractions of licensing conditions or legal infractions, to suspend operations, or start criminal legal proceedings in extreme cases. In order to ensure a high degree of safety, a Regulatory Authority should maintain an inventory of all SHARS in its territory and ensure that the inventory is always kept up to date. To facilitate equipment decommissioning, the Regulatory Authority should also retain a copy of the technical details of the equipment containing SHARS that is pertinent to source security, removal, and transport.

To support the legal obligations listed above, Member State governments should ensure that legislation is passed to create and empower a regulatory authority, and ensure that a waste management facility is established and appropriately funded.

5.1.2. Financial considerations: costs for transfer of radioactive material and meeting legal requirements

All parties who own radioactive material during the process of manufacturing, transporting, using, and temporary storage of SHARS typically transfer ownership of the material to another party. Eventually, the material will reside in an Interim Storage Facility, where it will either decay to a safe level or be held pending transfer to a disposal facility.

The costs of ownership transfer of radioactive material during the manufacture and replacement of a sealed source are reflected in the purchasing price for the original and replacement sources, as this is usually the means by which the manufacturer recovers its costs. When a source is replaced, the manufacturer usually takes the spent source back as part of the transaction. However, when the equipment is eventually decommissioned, the ownership transfer of the final source in the equipment must be managed as part of the cost to the User associated with return of the facility to general use. In essence, the total ownership transfer costs are part of the total cost to the User for providing the service for which the source was purchased. For high activity sources, these services include industrial radiography, material irradiation, sterilization and cancer therapy.

Table III shows a breakdown of total ownership costs for a hypothetical cancer therapy machine using a Co-60 source, in which the machine is purchased new, and operated for 25 years with four source changes before being retired from service. From this table it can be seen that the cost of ownership transfer of radioactive material for this example is approximately two percent of the cost of ownership. If the total cost of the source left with the user (initial source purchase, final source ownership transfer, part of source replacement) is considered, that cost is approximately five percent of the total of the cost of ownership for this hypothetical example. Please note that estimated cost here is from a developed country with a local supplier. Costs in a developing country may vary substantially, especially source replacement and staff cost.

TABLE III. TOTAL OWNERSHIP COST FOR THE USER OF A HYPOTHETICAL COBALT CANCER TREATMENT MACHINE OVER A 25-YEAR LIFETIME[a]

COST ITEM	COST BASIS	LIFETIME COST	% OF TOTAL
EQUIPMENT PURCHASE	Treatment machine and installation without a source	\$300,000	14.2
INITIAL SOURCE PURCHASE	When purchased and installed with the machine (1% of this is waste ownership transfer cost)	\$50,000	2.4
SOURCE REPLACEMENTS	Four replacements, including ownership transfer of replaced source (20% of this is waste ownership transfer cost)	\$240,000	11.3
STAFF COSTS	Two operators at \$25,000 per year each for 25 years	\$1,250,000	59.0
MAINTENANCE COSTS	\$10,000 per year including parts, labour, supplies and utilities	\$250,000	11.8
MACHINE DISPOSAL	Cost for removal and disposal, offset by scrap metal value	\$0	0
FINAL SOURCE OWNERSHIP TRANSFER[b]	Return to manufacturer or transfer to an interim storage facility	\$30,000	1.4
TOTAL COST OF OWNERSHIP		\$2,120,000	100

[a] Costs are estimates only. Final source ownership transfer cost estimate is based on availability of the manufacturer or local interim storage and a suitable transport container. Cost may substantially differ under other circumstances. Consideration of additional fees applied to the user after final source ownership transfer are also not included.
[b] Note that final source ownership transfer is a small fraction of the overall cost, but not a negligible amount.

5.1.3. Other financial considerations

Both the User and the Source Manufacturer have licensing costs and operating costs related to regulatory requirements. Regulatory Authorities issue licenses to facilities handling radioactive materials and perform inspections, and at least some of the costs of these activities are passed on to the licensee as licensing fees. Regulatory license costs for the Irradiation Facility and for the Source Manufacturer are typically built into the price of the source as delivered to the User, and the User’s regulatory costs become an operating expense borne during the time of use of the source. Licensing cost of shipping containers, the costs of shipping are also passed to the user in the costs of sources and source replacements. These expenses, which are necessary to meet legal and safety requirements become additional costs to the User.

5.2. LEGAL AND FINANCIAL PROBLEMS CONTRIBUTING TO RADIOLOGICAL ACCIDENTS

In general, Irradiation Facilities and Source Manufacturers operate under license conditions from Regulatory Authorities and the loss or mismanagement of waste material is rare. Similarly, regulations for transport of Hazardous Goods, and radioactive material specifically, are also well developed and thus shipping operations are not known to result in radiation accidents. The principal problem appears to be related to spent sources after the decommissioning phase, i.e., when equipment use is discontinued and ownership transfer is required for the final source in the equipment. Below are some of the legal and financial conditions that contribute to the likelihood of radiological accidents in these circumstances.

5.2.1. Inadequate financing of the ownership transfer costs

Once equipment has been purchased and delivered, a facility might not provide for the cost of ownership transfer of the source when the equipment is eventually retired. This can be because the facility owners do not have a budgetary mechanism for accruing for a cost that will be realized only well into the future (perhaps decades) and for which the exact value can only be estimated. It could also be because the facility assumes that it can cover the ownership transfer cost out of its operating budget or as a condition of purchase of new equipment. This can lead to financial pressure when the time for ownership transfer arises, with the corresponding temptation to use less expensive options. These alternatives could result in a higher likelihood of loss of control of the spent source.

5.2.2. Facility bankruptcy or other unplanned closure

If (for example), a facility owner becomes insolvent, or a facility is closed due to abandonment, war, natural disaster etc., the assumed method of financing source ownership transfer may no longer be possible. Insurance or emergency funds from public agencies may be available to assist in these circumstances; otherwise, costs of ownership transfer will need to be undertaken by other institutions that may not have participated in the benefits for which the source was purchased.

5.2.3. Unavailability of an ownership transfer path

At the time of decommissioning of equipment, the original source manufacturer might not be in business, or might be unable to retrieve the source due to the age or condition of the equipment or changes in applicable regulations. If transfer to a storage facility operator is not practical, then the user will need to store the source safely and securely until a practical solution is available. Although this is not likely to be a high cost on a yearly basis, the storage time could exceed the ability of the facility to reliably ensure safe and secure storage, and could in fact exceed the operational life of the facility. In these situations, the cost of source ownership transfer is deferred by temporary storage, but not solved.

5.2.4. Inadequate regulatory oversight

In some countries, the need for radioactive material for a variety of purposes precedes the establishment of an official Regulatory Authority to oversee radiation safety. Even in cases where such an authority exists, it may not exercise oversight with appropriate diligence in all cases due to a number of problems such as inexperience of the staff or funding problems. In these cases, unsafe practices by the owners of the source could go unnoticed and may lead to radiological accidents.

6. SUMMARY AND CONCLUDING REMARKS

High activity radiation sources have many beneficial applications in the agriculture, industrial, medical and research sectors. When operated and maintained in accordance with manufacturer's specifications and good working and regulatory practices, systems using high activity radiation sources pose minimal risks relative to their benefits. Likewise suitable management systems for SHARS ensure that they can be safely and securely controlled. For the majority of SHARS worldwide this is the case. This report has discussed aspects of management of SHARS that are intended to be helpful to the reader to ensure that SHARS are safely handled and stored for the time period for which they remain hazardous. Technical information has been provided for current practice, as well as references to other documents. The reader should, of course, explore additional sources of supplemental or detailed information, such as manufacturers, the IAEA, consulting groups or regulatory organizations.

The discussion in this report has identified aspects of SHARS handling and management that, if not well controlled, could result in increased likelihood of serious radiation accidents. These subjects are summarized below, along with some suggestions for how to improve safety. In addition, there is a separate publication that specifically addresses management for the prevention of accidents (TECDOC-1205) [9].

1. Return of SHARS to the supplier

The return of SHARS to the supplier is the most preferable route for the user. This method automatically negates the issues that arise from temporary and interim storage. Recycling/reuse of SHARS is another option. This can be accomplished either by utilising the source for a different application within a country or by returning it to a supplier for reuse or recycle.

If these two options cannot be met storage has to be implemented.

2. Allowance for ownership transfer or storage cost

Sometimes a SHARS is not correctly managed because funding was not provided ahead of time for its management. The purchaser should, at the time of purchasing the source, plan for its eventual storage or transfer of ownership. In this way, the purchaser can estimate the expense and make allowance for how this cost will be covered later when the source is retired from service. This approach also allows the purchaser to make the most informed choice possible as regards cost versus benefit of the high activity source in comparison to any other technology that may accomplish the same end.

Regardless of the existence of prior budgetary consideration, owners of a SHARS must resist the temptation to take a less expensive but more hazardous option at the time of decommissioning. The SHARS should be transferred to the safest available licensed storage facility as soon as possible after discontinuing use.

3. Temporary storage considerations

Guidance has been provided in Section 4.2 for safe temporary storage of SHARS in the event that there is no opportunity to return the source to the manufacturer or transfer it to an interim storage facility. Temporary storage can be safely performed, but could require storage longer than the facility can reliably maintain suitable space, safety precautions or security. For these reasons, temporary storage should be performed only when no other options are available, and only for such time as is needed until transfer of the SHARS to a more suitable storage location is possible.

4. Good regulatory oversight

Good regulatory practice should be in place wherever high activity sources are in use, and this oversight should continue during the storage of SHARS until the end of the period of institutional control for the repository. Many of the more serious radiological accidents could have been avoided if the local regulatory authority had an appropriate and active programme to ensure safe handling and storage of spent sources. The costs of this service, that are passed on to the user in the form of license fees, must be reasonable and reflect the cost of providing efficient regulatory service for the user's specific facility.

5. National inventory of SHARS and equipment

In some cases the equipment or source manufacturer is no longer in business at the time that a high activity source is taken out of service. The user should maintain periodic contact with the Source Manufacturer during the period they have ownership of the source. The owner should keep an accurate registry of the sources in its possession. This information should also include all available technical information about the source and the equipment, in particular information related to safe removal, handling and storage of the source. If this information has not been retained by the user, management of the source becomes much more difficult and expensive, as well as potentially more hazardous. To protect against this possibility, the national regulatory body should also maintain a complete and up-to-date set of this technical information as part of an overall registry of SHARS within its territory.

6. National spent source interim storage facility

The ultimate goal for SHARS is safe disposal. Geological disposal facilities suitable for SHARS are under design and analysis in many countries, but none currently exist. Safe long-term storage of SHARS is nonetheless quite practical under the jurisdiction of appropriately trained personnel in a proper facility. Centralizing the problem of spent sources in a particular country by setting up an appropriate storage facility could virtually eliminate accidents in that country. The storage facility would take ownership of the SHARS for a fee, thus relieving the users of further legal and financial responsibility. The costs to the users may be the full cost or partially subsidised by the government. The costs should be set at a level to prevent the users from seeking unsafe options.

7. International co-operation between regulatory authorities

At present international regulation of transport and transfrontier movement of radioactive material is complex and nationally based in a manner that often impedes the transport of SHARS to suitable storage facilities. Co-operation between relevant authorities would be beneficial to overall safety and substantially reduce costs. This requires international co-operation between regulatory authorities concerning transport of SHARS across international boundaries. Regulatory authorities should give consideration to the principle that the return of a SHARS to a manufacturer should not be treated as a transfer of radioactive waste, especially for those SHARS that may be reused or recycled. This would avoid the protracted period of negotiation required to obtain approval for transfrontier shipments and minimise the time the

SHARS is in temporary storage. It would also encourage the reuse of radioactive material, minimising the worldwide inventory.

8. International transport overpack for SHARS

At present it is often very expensive or impossible to transport some SHARS internationally because the original transport container is not available or its license has expired. An overpack that is licensed to transport SHARS of different designs would be very helpful in moving SHARS to suitable facilities when these facilities are not locally available.

9. International co-operation concerning management of SHARS

It is possible that regionally-operated facilities could offer more consistent and cost-effective services, particularly in regions consisting of a number of small Member States that may not have the infrastructure or technical capabilities for managing SHARS. This would require regional agreements between Member States concerning management and transboundary movement of SHARS.

APPENDIX

A. MANAGEMENT OF SHARS IN BELGIUM

GENERAL

The Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ONDRAF) is the only route for disposal of radioactive waste in Belgium. The National Institute for Radio-Elements (IRE), acting as an ONDRAF subcontractor, is in charge of the treatment, conditioning and storage of spent sealed radioactive sources in Belgium. To carry out its mission, IRE, the former Belgian manufacturer of sealed radioactive sources, uses concrete hot-cells for the treatment and the storage of solid and liquid radioactive waste.

HANDLING

After use, many sources are shipped back to the manufacturer to be replaced by new ones. In this case, spent sources are recycled or stored for decay in the production hot-cells before being transferred in shielded containers to the IRE facility for long term storage.

When possible the spent sealed sources are removed from their devices or transport containers. After IRE control and registration, they are transferred into lead shielded storage containers or into appropriate steel drums for temporary storage.

Spent sealed sources are segregated according to their emitted radiation (ζ,η,ν or neutron sources), the characteristics of the active filling, source chemical/physical composition, their intensity of radiation and their outer dimensions.

Spent sources are handled according their dose rate. The handling is qualified as “contact handled”, “light remote handled” (requiring shielded wall and tongs) or “remote handled” (treated in hot-cell with master-slave manipulators).

Retrievability of the source is essential during the whole storage period. Generally they are conditioned in a stainless steel inner container fitted into a concrete lined 400 litres drum for a period of interim storage waiting for disposal. No direct grouting of the sources is foreseen but dry sand is added in order to reduce void age to below 5% of the total volume of the drum.

Table I.I shows the categorisation scheme, which is the base of the segregation, taken into account the handling means and the final packaging.

STORAGE

The segregated sources, placed into shielded containers, are stored in a dedicated storage area.

Older spent sources may still be temporarily stored in their devices or transport containers at the national near surface storage facility at Dessel.

TABLE I.1. CATEGORIZATION SCHEME IN BELGIUM

	Catégories				Handling means		Monitoring	Packaging	Storage container
	Sources	Isotope	Half-life	Applications	Minimum				
1	η,ν	Average activity	Short						
		^{192}Ir	73,8d	Gammagraphy	Lead hot-cell	M/S.manipulators	η,ν Detection	Lead shielded pot	400L Drum with concrete
		^{170}Tm	134d	Gammagraphy	shielded screen	Tongs		Stainless steel basket	for decay
		^{169}Yb	32d	Gammagraphy	shielded screen	Tongs		Stainless steel basket	to
		^{75}Se	120d	Gammagraphy	shielded screen	Tongs		Stainless steel basket	clearance level
2	η,ν	High activity	Long						
		^{60}Co	5,3y	Gammagraphy	Lead hot-cell	M/S.manipulators	η,ν Detection	Lead shielded pot	400L Drum concrete + Pb
		^{60}Co	5,3y	Gauges Calibration	shielded screen	Tongs		Lead shielded pot	400L Drum concrete + Pb
		^{137}Cs	30,2y	Gammagraphy Gauges Calibration	shielded screen	Tongs		Lead shielded pot	400L Drum concrete + Pb
3	η,ν	Very high activity	long						
		^{60}Co	5,3y	Teletherapy	Concrete hot cell	M/S.manipulators	η,ν Detection	Lead container	400L drum or Concrete container
		^{60}Co	5,3y	Irradiators	Concrete hot cell	M/S.manipulators		*Transport container*	*Return to supplier*
		^{137}Cs	30,2y	Irradiators	Concrete hot cell	M/S.manipulators		*Transport container*	*Return to supplier*
4	**Special**	**Isotopes**							
		^{226}Ra	1600y	Lightning rods Static eliminators	Gloves box	Tongs	ν Detection	**Tight container**	Lead shielded container
		^{85}Kr	10,7y	Gauges Lightning rods	Gloves box	Tongs	**Air control**		
		^{3}H	12,3y	Electron capture detectors X-Ray Fluo. Analyser	Gloves box	Tongs	**^{3}H Control**		
5	Neutron	Sources							
	Neutron	$^{241}Am/Be$	432,2y	Moisture detectors Oil well logging	Neutron protection		Neutron detector		Neutron protection
	Neutron	^{252}Cf	2,65y	Moisture detectors Oil well logging Brachytherapy	Neutron protection				
	Neutron	$^{226}Ra/Be$	1600y	Moisture detectors Oil well logging	Neutron protection				
	Neutron	$^{238}Pu/Be$	87,74y	Moisture detectors Calibration instrument	Neutron protection				

A specific case: management of Co-60 teletherapy sources

Transport of teletherapy head

When a teletherapy source is no longer needed and when return to the supplier is not possible, the owner or its health physics service requests that ONDRAF organize transport. Every characteristic of the source (model, isotope, activity, weight, volume, external dimensions, tightness, place, surface dose rate and any possible contamination) has first to be compiled in a request form for transfer.

In case of a suitable shielded transport container is not available, the source is transported inside the teletherapy head, which is placed inside an overpack.

After the shutter on the teletherapy head is locked, the head is disassembled by the supplier, the company that maintained the unit or another qualified operator (Figure I.1). The exposure head is then placed into a 400 L drum (Figure I.2) and immobilized with wedges (Figure I.3).

The drum is placed into a Type B packing cask and, after control by the health physics service is transported to the storage site (Figure I.4). The transport is organized by ONDRAF after the authorization of the Federal Agency for Nuclear Control.

The owner of the SHARS pays for all the operations as well as for storage.

FIG. I.1. Teletherapy head disassembled.

FIG. I.2. The head is placed in a 400 litres drum.

FIG. I.3. Drum immobilised with wedges.

FIG. I.4. Control of the casks.

FIG. I.5. Tungsten basket with source.

FIG. I.6. Inner basket with source.

TREATMENT

Some years ago, IRE produced high activity teletherapy cobalt sources. At the time, the spent sources were returned to IRE-subcontractor facility and removed from their original device or transport container.

In most devices the Co-60 source is placed into a tungsten basket (Figure I.5) which is screwed on to a depleted uranium drawer.

A lead shielded container was designed for the temporary storage of teletherapy spent sources (Figure I.7). The inner stainless steel basket allows the storage of 10 teletherapy sources (Figure I.6). After a period of decay in temporary storage, the sources were placed into the lead shielded container. When filled this lead shielded container can be lifted by the crane and placed into a concrete shielded container for temporary storage. This operation can only be performed inside a hot cell.

The dose rate at the surface of the concrete container was about 0.25 mSv/h and 20 µSv/h at one meter for an average total activity of 10 to 12 000 Ci Co-60 (~36–430 TBq).

More than 200 spent sources were treated this way.

A new concrete hot-cell has been built to allow the dismantling of the teletherapy heads where it will be possible to remove the head from the drum and to remove the spent radioactive source.

If there is insufficient local expertise to perform the source removal, or if equipment or tools are unavailable, then assistance from the supplier/manufacturer of the containers/sources will be requested.

A lead shielded inner storage container was built directly beneath the source treatment cell to accommodate 10 teletherapy sources.

It is envisaged to use 400 litre steel drums in place of concrete containers. In this case the shielding of the inner storage container should be increased. It is expected that this packaging could be used for transportation and also for future disposal of the sources.

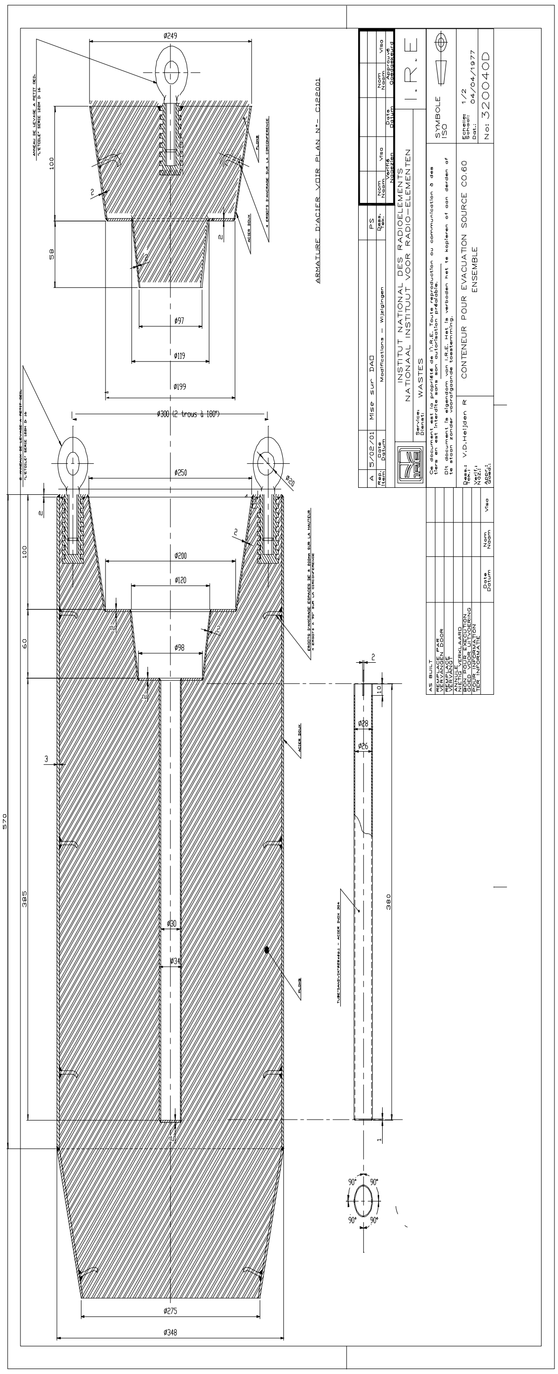


FIG. I.7. Storage shield.

B. MANAGEMENT OF DISUSED TELETHERAPY SOURCES IN CUBA

The Center for Radiation Protection and Hygiene (CPHR) is responsible for centralized collection, transportation, conditioning and long-term storage of disused radioactive sources in Cuba.

INVENTORY OF DISUSED TELETHERAPY SOURCES

An updated inventory of all stored wastes and disused radioactive sources is kept at CPHR. The current inventory of stored teletherapy units is presented in Table I.2.

TABLE I.2. INVENTORY OF DISUSED TELETHERAPY UNITS IN THE STORAGE FACILITY

Code in the Storage	Radio-nuclide	Estim. activity, [TBq]	Refer Date	Device Model	Package Number		Code in the Storage	Radio-nuclide	Estim. activity, [TBq]	Refer Date	Device Model	Package Number
174	^{60}Co	185	1962	Chisobalt	—		1295	^{60}Co	---	---	Chisostad	—
175	^{137}Cs	11.1	1962	Cesioterax	DA-01-015		1325	^{60}Co	370	1988	Chisostad	—
176	^{137}Cs	11.1	1962	Cesioterax	DA-01-015		1331	^{60}Co	5.2	1999	Chisostad	—
177	^{137}Cs	11.1	1962	Cesioterax	DA-01-015		1334	^{60}Co	28.5	1999	Chisostad	DA-01-019
178	^{137}Cs	11.1	1962	Cesioterax	DA-01-017		1424	^{60}Co	22.5	1999	Chisostad	—
179	^{60}Co	148	1956	Ficker	—		1432	^{60}Co	311	1981	Chisostad	—
180	^{137}Cs	11.1	1962	Cesioterax	DA-01-017		1436	^{60}Co	311	1981	Chisostad	DA-01-018
181	^{60}Co	185	1968	Gaµatron	DA-01-020		1437	^{60}Co	311	1981	Chisostad	—
337	^{60}Co	74	—	—	—		1483	^{60}Co	311	1981	Chisostad	—
353	^{60}Co	148	—	—	—		1559	^{60}Co	311	1979	Chisostad	DA-01-016
623	^{60}Co	—	—	—	—							

MANAGEMENT OPTIONS FOR DISUSED TELETHERAPY SOURCES

For disused sealed radiation sources with high activity (e.g. ^{60}Co and ^{137}Cs used for teletherapy) the only management option, except returning the source to the manufacturer, is long term interim storage (several decades) awaiting future disposal.

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

PREPARATION OF THE CONTAINER

A competent company manufactures the metallic containers, without any inside or outside corrosion and mechanical damage. Containers are then painted and marked with the package code and radioactive symbol.

CONDITIONING

The disused teletherapy source within the working shield is lifted and positioned in the center of the container (Figure I.8). In order to further secure the source, two iron bars are welded on the upper part of the container. The source in this case is not accessible unless the iron bars are cut.

After that the container is covered with the lid and locked by special screws to prevent unintentional and unauthorized opening. Closing and locking the container concludes the conditioning process, where the teletherapy source is kept retrievable it is stored safely with regard to radiation, contamination and physical safety.

FIG. I.8 Examples of some disused radioactive sources at centralized facility. Conditioning process. Controlling dose rate.

STORAGE OF TELETHERAPY SOURCES

Until a repository is available, a national interim storage facility for conditioned radioactive wastes and disused sealed sources was developed. The storage facility is located in a sparsely populated region — Managua. The facility is constructed above the original ground surface as an earth-covered mound. The estimated capacity of the storage facility is about 200 m^3.

LICENSING

The National Center for Nuclear Safety (CNSN) as the national regulatory authority is responsible for the licensing and supervision of radioactive and nuclear installations. CPHR applied to CNSN for an authorization (License) for managing the disused teletherapy units in the country. The application specifies purpose of the storage facility, suggested operational and radiation protection procedures, quantity, types and characteristics of disused teletherapy sources, safety assessment, environmental impact of the facility under normal and accident conditions, systems for record-keeping and reporting, contingency plan and description of the CPHR implemented quality assurance programme.

QUALITY ASSURANCE

A record-keeping system for tracking teletherapy sources has been established and maintained. The information is reliably stored and archived both manually and by a computerized database. This includes: source model, identification numbers (source and container), radionuclide, activity and reference date, manufacturer, former user, place of storage. This information is obtained by supplementary measurements, questioning persons and consulting documents.

Other set of data, defining the characteristics of each conditioned package is registered and kept before this package is stored for long period. Data for documentation includes: package identification number, activity content and reference date, number of sources conditioned, surface dose rate, dose rate at 1 meter, contamination level and date of measurements, date and place of conditioning, conditioning method, responsible conditioner and position of the package in store.

C. MANAGEMENT OF SHARS IN THE UNITED KINGDOM

Although there is no disposal route available for SHARS in the United Kingdom, a company, UK Nirex Ltd, has been set up by the nuclear industry, with the agreement of the Government to examine the safe, environmental and economic aspects of deep geological disposal of radioactive waste, including SHARS. Based on a research and development programme which has run since the early 1980s, Nirex has developed a specification of waste package performance and data recording requirements that addresses the range of future management options. This specification provides a firm basis for waste producers to evaluate, and develop waste packaging options which will be consistent with the needs for future storage, transport, handling and potential disposal.

Nirex assesses and endorses waste producers' plans for conditioning and packaging a number of major intermediate level waste streams. For solid wastes, such plans typically involve in-filling with cement-based grout to form a solid, monolithic block, contained in a stainless steel container, usually 500 litres.

Nirex has endorsed plans by United Kingdom Atomic Energy Authority (UKAEA) to condition the majority of its stored sources in 500 litre drums. This endorsement is subject to the packages complying with dose rate and heat output restrictions. A major consideration is the effect of localisation of nuclide inventory, such as heat generation and dose rates, particularly where many SHARS are consolidated in a single package. Therefore, SHARS in the UK are currently consolidated and held in interim storage. This will allow a period of decay prior to conditioning and packaging for potential disposal.

There is good provision for the interim storage of intermediate level radioactive wastes (ILW) in the UK (in the UK SHARS are considered to be ILW). Two main government-owned organisations operate ILW storage facilities, which are suitable for interim storage of SHARS. These are UKAEA and BNFL. The majority, of SHARS are currently stored by UKAEA.

In the UKAEA facility at Harwell (see Figure I.9), known as the Remote Handled Intermediate Level Waste Store, SHARS are stored in stainless steel cans, which are remotely placed into below ground storage tubes, each several metres deep. The cans vary in volume from 7 to 55 litres. The stainless steel cans are stacked vertically in the storage tubes below ground level, using a shielded remote handling machine. In principle, many sources can be stored in each can. However, the number of sources per can must be within activity limits set for each can. For Cs-137 and Co-60, these are normally 128 TBq per can. The UKAEA facility is equipped to recover the waste for conditioning by cementation in 500 litre drums. However, cementation of SHARS is not currently planned, for the reasons described above.

FIG. I.9. Remote Handled ILW Storage Facility (UK).

The interim storage facilities are equipped to receive pre-packaged radioactive waste for direct transfer into storage. They are not ideally suited for the handling of individual SHARS or equipment containing SHARS.

Therefore, the process of transporting SHARS to a central handling facility, and preparing them for interim storage is carried out separately as a commercially operated service. Following preparation, SHARS which have been consolidated and packaged in a commercial facility can be transferred to one of the government-owned interim storage facilities.

Although a number of companies provide services related to the various steps in preparation for disposal of sealed sources, only one organisation in the UK, Safeguard International, is able to provide a complete service for SHARS (except final disposal). The service this organisation provides within the UK is also available internationally.

Safeguard International arranges transport of SHARS to a shielded cell facility (see Figure I.10), which is capable of receiving them within the original equipment (e.g. irradiators) or in transport containers after removal from the equipment at the user's site.

FIG. I.10. SHARS handling facility.

Each source transport operation requires careful consideration of the associated risks and hazards. Detailed safety documentation is produced to identify each of the hazards, both conventional and radiological, and precautions are put in place to minimise the risks to the operators, members of the public, property and the environment.

If it can be achieved safely, the source may be transferred from its equipment at the user's premises, into a suitable transport container for delivery to the shielded facility. Typically, this method is used for many types of teletherapy equipment, which have been designed for "on-site" source exchange.

It is not always possible to remove the source from the equipment at the users' premises. This may be because the equipment was designed to be de-sourced in a shielded cell, or because insufficient technical information is available to do this safely outside a shielded cell. In such cases, it is necessary to transport the source in its operational shielding to be de-sourced on receipt at a shielded facility.

The UK approach in these cases has been to develop a Type B approved overpack (colloquially known as Transactive) which is essentially a 20 foot ISO container, manufactured in the UK to meet the IAEA standard for Type B(U) package regulatory requirements (Figure I.11). It has a payload of 6 tonnes, which far exceeds any other Type B approved container currently available. Transactive therefore enables removal of some of the older and heavier irradiation units, for which there has previously been no satisfactory transport solution.

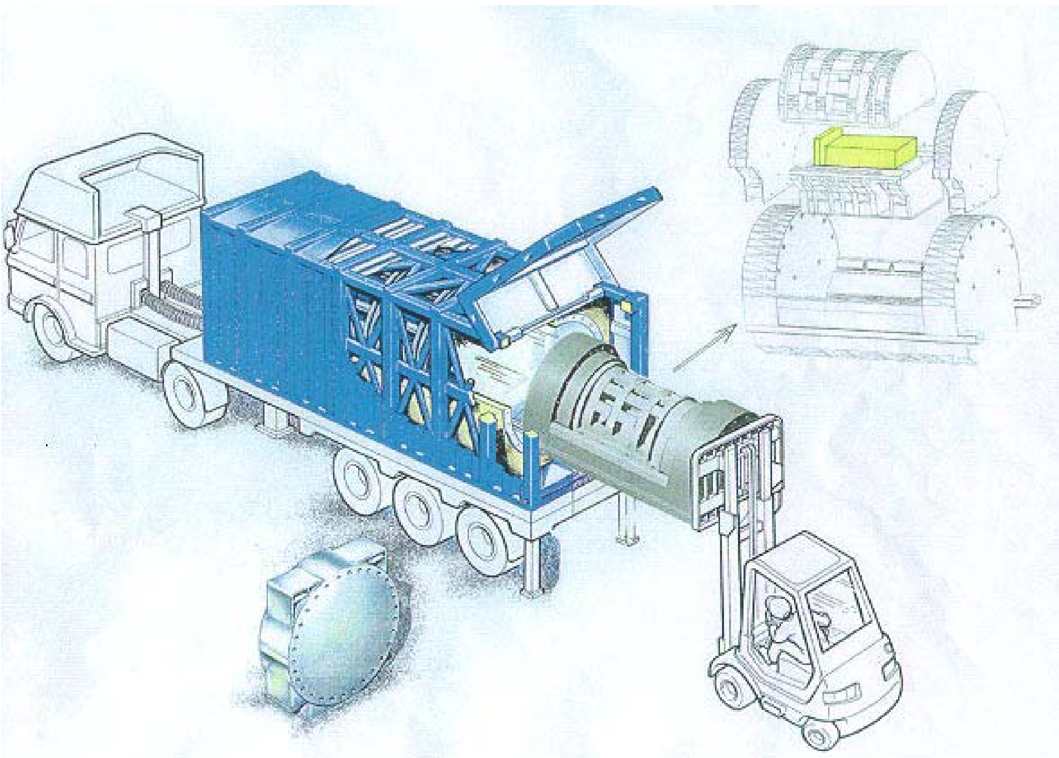


FIG. I.11. Schematic diagram of a transactive container.

D. RADIOACTIVE WASTE IN AUSTRIA

RADIOACTIVE WASTE MANAGEMENT

Primary sources of radioactive wastes in Austria are medicine, research and industry. Only low level and intermediate level waste arise from those sources. Spent fuel elements from research reactors are returned to the country of origin. No other high level waste is produced.

A department of the Austrian Research Centers (ARC), situated in Seibersdorf, south of Vienna, serves as centralized facility to collect, treat, condition and store all types of low level and intermediate level radioactive waste arising in Austria.

A number of treatment systems are available for the different tasks to be carried out. The aim of treatment and conditioning is to transform the radioactive waste into an insoluble form and the safe enclosure of it by the use of barriers to surround and isolate the waste. At the same time, it is important to reduce the volume of the raw waste by applying appropriate treatment technologies.

All activities are performed according to the requirements of the Austrian Radiation Protection Law and to specific requirements. There is a licence for interim storage of conditioned radioactive waste until 2012. During that period of time a solution for a final repository should be found.

TREATMENT SYSTEMS

Various types of waste require different methods of treatment. The following treatment systems are established at Seibersdorf:

- Incinerator (excess air): shaft type with highly efficient of gas cleaning system. Capacity: ~40kg/h for solid and liquid burnable waste

  Water treatment facility:
    chemical precipitation
    filter equipment for dewatering
    thin film dryer
    heated conical dryer
- Compactor:
    In-drum, 100 t force
    High force compactor 1200 t
- Cementation equipment
- Hot cell facility
- Intermediate storage facility:
  dry engineered storage construction, capacity: 15,000 drums of 200 litre, at present 8,500 drums are stored

Depending on the type of waste the relevant treatment technique is applied. Radium sources are encapsulated by welding them into stainless steel capsules; they are stored in lead shielding. Other sources are collected in small steel containers and stored in shielded drums, if necessary using lead.

High activated sources can be handled in the hot cell facility and can be stored in storage tubes in one of the hot cell boxes with relevant equipment. The conditioning method is cementation. Almost all conditioned radioactive waste is stored in 200 l drums, exceptions are a few 400 l drums.

TRANSPORTATION

Transportation of radioactive waste is carried out on road and rail according to the international regulation ADR/RID which are integrated into national regulations. ;the producers of radioactive waste in Austria are sending the material either directly to Seibersdorf or they take advantage of the waste collection service is offered by ARC.

DISPOSAL

At the moment there is no final repository for radioactive waste in Austria. There are plans to find a proper solution, where the repository could be installed and operated as a European task.

MANAGEMENT OF SPENT HIGH ACTIVITY RADIOACTIVE SOURCES

There are number of teletherapy units still in operation in Austrian hospitals. High activity sources (Co-60, Cs-137) of teletherapy units out of operation were either sent back to the producer or — in the absence of a relevant contract — transported to ARC for interim storage.

Such sources are stored within the hot cell facility in stainless steel cans in storage tubes suitable for interim storage of SHARS.

The cans are stacked vertically using master slave manipulators for the handling operations. It is intended to held the sources in interim storage at least until 2012, probably beyond this date. This allows a period of decay prior to conditioning for disposal.

Transport of SHARS are carried out according to the relevant transport regulation using specific transport containers which are usually provided by the producer or vendor of the source.

Since this service is not always available for several reasons, other containers meeting the requirements for the transport have to be selected.

Such alternatives are not easy to find and may turn out as a very expensive option as the following example indicates:

Example

Transport of a teletherapy head with SHARS (Co-60, ~100 TBq) from a university of the western part of Austria to ARC.

Problem

(a) the teletherapy head was stored in a cellar with difficult access
(b) no possibility for removing the source on site due to lack of equipment and narrowness of the room
(c) the certificate for the source as “special form radioactive material” was expired, no chance for revalidation
(d) the producer of the unit is no longer in the possession of a licensed transport container taking up the source
(e) no transport container available at ARC or in Austria for taking up the teletherapy head with the source

Solution

A search within the European Community for an appropriate container, able to transport the teletherapy head with the source ended up in a German container named MOSAIK. It is a type

B container having a weight of about 10 tons. The licence specifies the content and the teletherapy head type in question was included.

It was checked whether road or rail would be the best mode of transport. After careful considerations on cost comparisons and logistics involved, it was decided that the container together with the motor truck for transport on the road should be rented.

According to the transport regulations the relevant authorities in Austria and Germany were informed before the transport. Careful technical preparations for recovering the head from the cellar and for the loading were carried out before the truck arrived on the site. Before loading a number of smear tests were taken on the head and all equipment involved in order to make sure that no contamination is present. Nothing was found.

The loading operation went on very smoothly in a shorter time than expected. After unloading the teletherapy head at ARC smear test were taken again. No contamination was detected.

The following figures illustrate the operation.

FIG. I.13. Dismantled teletherapy head containing Co-60 source before loading containing into Type B container.

FIG. I.14. Teletherapy head being loaded into Type B container.

FIG. I.15. Type B container loaded with teletherapy head being closed.

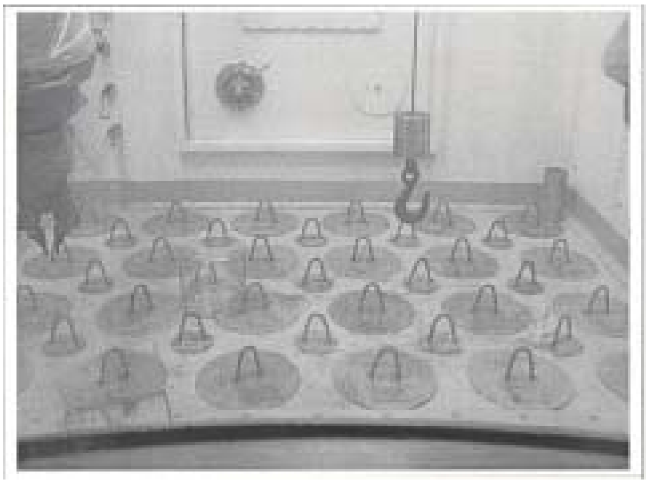


FIG. I.16. Inside hot cell, storage positions for SHARS.

E. WASTE MANAGEMENT FACILITY IN SUDAN

The Radiation Protection and Environmental Monitoring Department (RPEMD) of Sudan Atomic Energy Commission (SAEC) is responsible of management of radioactive waste in the country.

The total number of registered sources in the country stands at 453. Fifty-seven of these sources are disused and 319 radium sources were conditioned and safely stored.

The waste management facility of SAEC at Soba was constructed and commissioned on February 2000. The facility consists of a laboratory of about 5 × 8 m and on the same floor level, about 4 m apart, a small store of about 4 × 4 m. The area in-between the laboratory and store is a cementation area for concrete drum preparation.

The laboratory has two, about 3 m × 70 cm long, built-in workbenches. The walls were painted with an oil base paint. All surfaces in the laboratory can be easily cleaned in case of contamination. The facility cost about US$40,000.

The facility is being used for management and conditioning of long and intermediate level waste (LILW) mainly sealed sources (industrial, medical and research, etc.).

The facility is not suitable for conditioning of SHARS. The only option for SHARS to be managed in this facility is to be stored within its original container insider the store.

The amount of SHARS that are present in the country is shown in Table I.3.

TABLE I.3. INVENTORY OF SHARS IN SUDAN

Source	Place	Type	Activity now	Origin
Gamma cell Co-60	Faculty of Agriculture U of K	Irradiator from India	120 Ci	IAEA Project (1978)
Gamma cell Co-60	Veterinary Res. Center	Irradiator from India	150 Ci	IAEA Project (1975)
Teletherapy Unit Co-60	RICK	Teletherapy UK	700 Ci	Donation from UK

All SHARS listed above are stored at the user premises in their operational room. Several neutron sources are also collected and awaiting conditioning.

The RPEMD of SAEC collects the disused sources from users and transfers them to the waste processing facility. Registration, measurements and segregation were done inside the laboratory. The facility is equipped to recover the waste for conditioning by cementation in 200 liter drums. Sealed sources were conditioned with their shielding container. The maximum loading activity for each drum is 10 Ci.

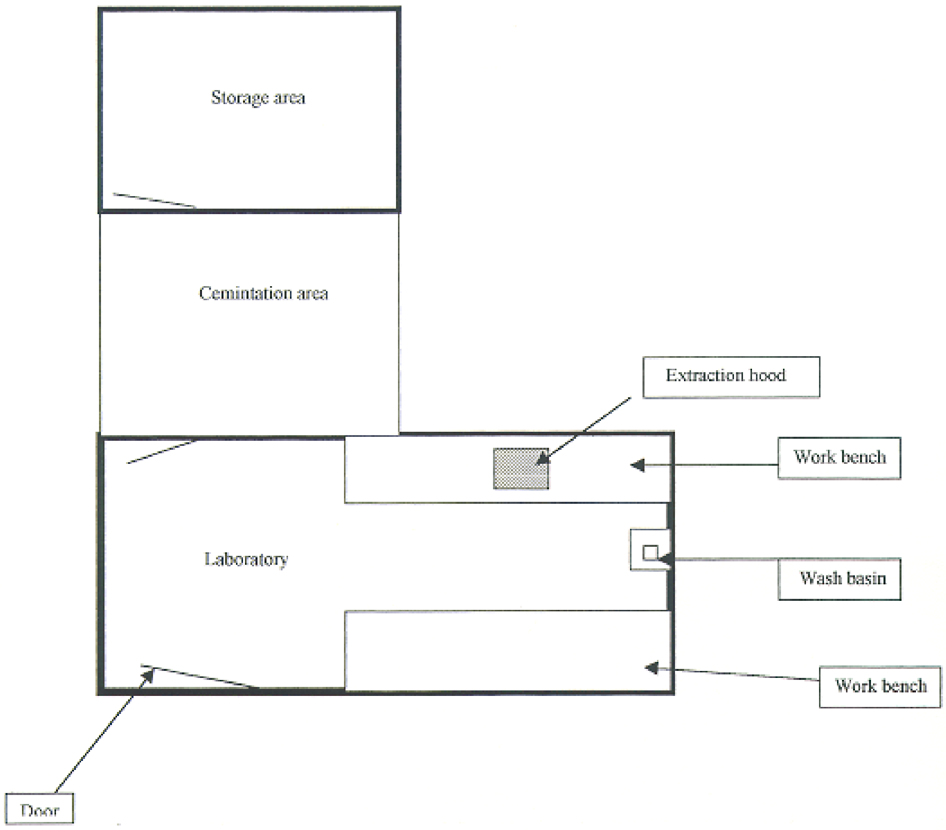


FIG. I.17. Layout of the waste management facility.

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Advisory Group Meeting
Vienna, Austria: 25–29 June 2001

Consultancy Meeting
Vienna, Austria: 2–6 October 2000, 24–28 September 2001