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Management for the prevention of accidents from disused sealed radioactive sources

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FOREWORD

The use of sealed radioactive sources is widespread in different fields and various activities. The type and characteristics of sources also vary according to the application, manufacturer and time of manufacturing. Accordingly, sealed radioactive sources can be found in a variety of shapes, forms and outside appearance. In some cases these sources are manufactured as an integral part of equipment. Furthermore, the high standard imposed on the manufacturing of such sources has given them the special and, in some cases, attractive look which could be mistaken for them being a valuable object. These factors have contributed in one form or another to accidents involving sealed sources.

A number of accidents have caught the attention of the public in recent years. The infrastructure required for safe management in many Member States is still not fully satisfactory. Loss of control and mismanagement of such sources has significantly contributed to many of the accidents, which took place worldwide.

The IAEA has issued several technical publications on the various activities related to proper management of sealed radiation sources, as well as publications on establishment of the required infrastructure. Concise practical information on how to recognise sealed sources, how to avoid injuries from such sources and what essential tasks should be fulfilled to avoid accidents with sealed sources was still missing. The intention of this publication is to collect the most relevant material that directly contribute to the reduction of risk of accidents involving such sources.

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EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

Sealed radioactive sources (SRS) are used worldwide in medicine, research, agriculture and industry, in mobile as well as stationary devices. The International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources [1] defines a sealed source as “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 wear for which the source was designed, also under foreseeable mishaps”. The activity of such sources varies from a few kilobecquerel in consumer products to petabecquerel in facilities for irradiation, sterilization and radiotherapy; the former are relatively harmless whereas the latter may be lethal even during very brief exposure. A SRS consists of a radioactive material that is encapsulated in a strong metal housing, typically stainless steel, to ensure containment of the radioactive material even under extreme conditions. However, old SRS were not manufactured to current standards and therefore have increased risk of mishap. Note that radiation sources such as X ray units or ion accelerators do not fall under such definition and are not the subject of this report.

According to IAEA information, [2] a large number of SRSs exist throughout the world both in developed and developing countries. SRS have a great variety of uses and their total number worldwide is not known for certain but believed to be in the order of millions.

Sealed radioactive sources need to be kept under regulatory control during their entire life time until they are safely disposed of or have decayed to accepted clearance levels [3]. SRS that are no longer in use present significant risks both in developed and in developing countries. In the former a large number of SRSs are under good control, while in the latter the control may be poor. However, it is worth noting that not only the adequacy of control but it is also the number of sources that influence the risk.

When a SRS is no longer in use and no further use is foreseen it should be considered and dealt with as a spent radioactive source. In addition, a source may be taken out of service temporarily or indefinitely. The source in this case is out of use (“disused”) but not considered spent. Such radioactive sources represent special risks and could create situations prone to accidents. Sources that are not in active use and have not being declared as spent are considered as disused SRS.

Any unintended radiological event, including operating errors, equipment failures or other mishaps, the consequences or potential consequences of which are not negligible from the point of view of radiation protection or safety are defined as accident [1].

Over the last 20 years there have been on average more than two reported accidents annually with spent or disused radioactive sources each exposing a number of people. The real number of accidents is probably much higher. Considering uncertainties involved in reported accidents, the trend seems to be towards fewer accidents per year, but an increase in the number of over exposed people. Accidents with disused or spent radioactive sources normally give rise to large individual exposures and on average have caused the deaths of two or three persons per accident. In one incident a lost source caused the death of eight persons [4].

Accidents with severe consequences are usually given extensive publicity, and in spite of their adverse effects, they provide for an increased awareness of the risks associated with radiation sources, especially SRS. Since the risk concept has so many dimensions it is not possible to make a detailed analysis of the risk perceived. The emphasis in this report will, however, be on the factors that affect the risk and on the technical and administrative measures that could be taken to reduce the accident probability or limit the accident consequences.

In addition to people being hurt, accidents involving SRS can inflict a considerable mental effect on workers and the public at large and can result in significant cost. If a source were to be discovered in the public domain, it can expose individuals to radiation (although perhaps not with lethal or severe consequences); it can become ruptured and contaminate both individuals and a local environment; or it can be improperly transferred to a metal recycling plant or an unauthorized disposal facility, such as a landfill. If a source were to be transferred to a metal recycling plant, in addition to the potential consequences of exposure and contamination, the source can be melted, contaminating either the product or the by-products of the remelting facility. The costs from such an event can run in millions of dollars. The consequences and total cost of an accident depend largely on the accident scenario and time span between initiation and discovery of the accident. If the accident is not immediately recognised or if responding action is delayed, increased exposure of individuals and/or spread of contamination can result.

Improper waste management with lack of regulatory control, inadequate radiation protection measures and improper waste handling makes the probability of an accident more likely.

1.2. OBJECTIVE

The objective of this report is to provide advice to SRS users, radioactive waste operators, and other concerned public sectors on the measures to be taken to reduce the risk of accidents associated with disused or spent SRS. The report also explains policies as well as technical and administrative procedures to minimize the risk of accidents and to mitigate the consequences should an accident occur. The report emphasizes areas of high risk in handling disused or spent SRS in any form and condition to help save health, life and financial resources.

1.3. SCOPE

The report defines spent and disused SRS, identifies and analyses the possible causes of accidents with such SRS and assesses the potential risks involved. The report, in particular, highlights the periods of highest risk in the lifetime of the SRS. It outlines the responsibilities associated with spent/disused SRS on the national, regulatory and waste management levels. The report, however, does not cover SRS exempted from Regulatory Control, unsealed radioactive material or radiation generators.

This report covers accident scenarios that may occur during periods of transition between the active use of the SRS and once the source has been declared spent. It also covers possible accidents due to improper waste management activities when the source is declared as spent. In doing so, the report emphasises the importance of proper management as the key factor in reducing the risk of accidents involving a SRS. The transition period is an important management period during which the responsibility for the source should be well defined. The report provides concise recommendations for risk reduction and only refers to other documents wherever necessary for detailed explanation. Regulatory aspects are covered to the extent required to make all parties concerned with disused or spent SRS aware of the regulatory role and requirements.

Emergency plans and preparedness measures associated with SRS are highlighted. This part is included to emphasize areas that are important to reduce consequences if an accident does occur.

2. WHEN A SEALED RADIATION SOURCE IS CONSIDERED "DISUSED"

The terms "spent" and "disused" are used in this document to mean that the source is no longer utilized for the intended purpose. The following definitions and explanations are provided to give a better appreciation of the actual situation with sources rather than to define precise terminology. Sources that are addressed in this document are all sealed sources that are not in active use. Figures 1 and 2 show typical sealed sources in their shield and bare sources respectively.

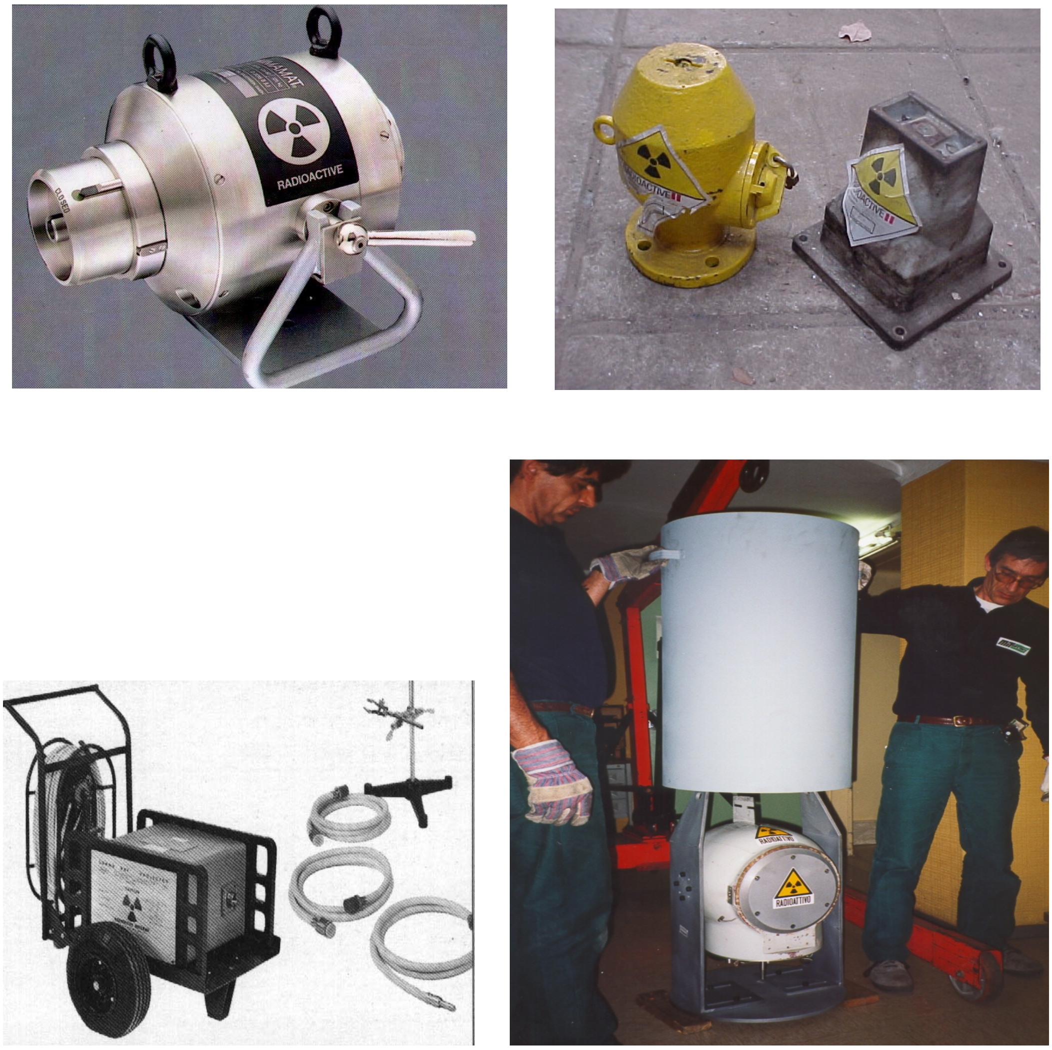


Fig. 1. Typical sealed sources for different applications
(all sources are in their working shields).*
**To a layman, some sources may give the idea of a fast-profit object and this has resulted in many radiation accidents with severe consequences.*

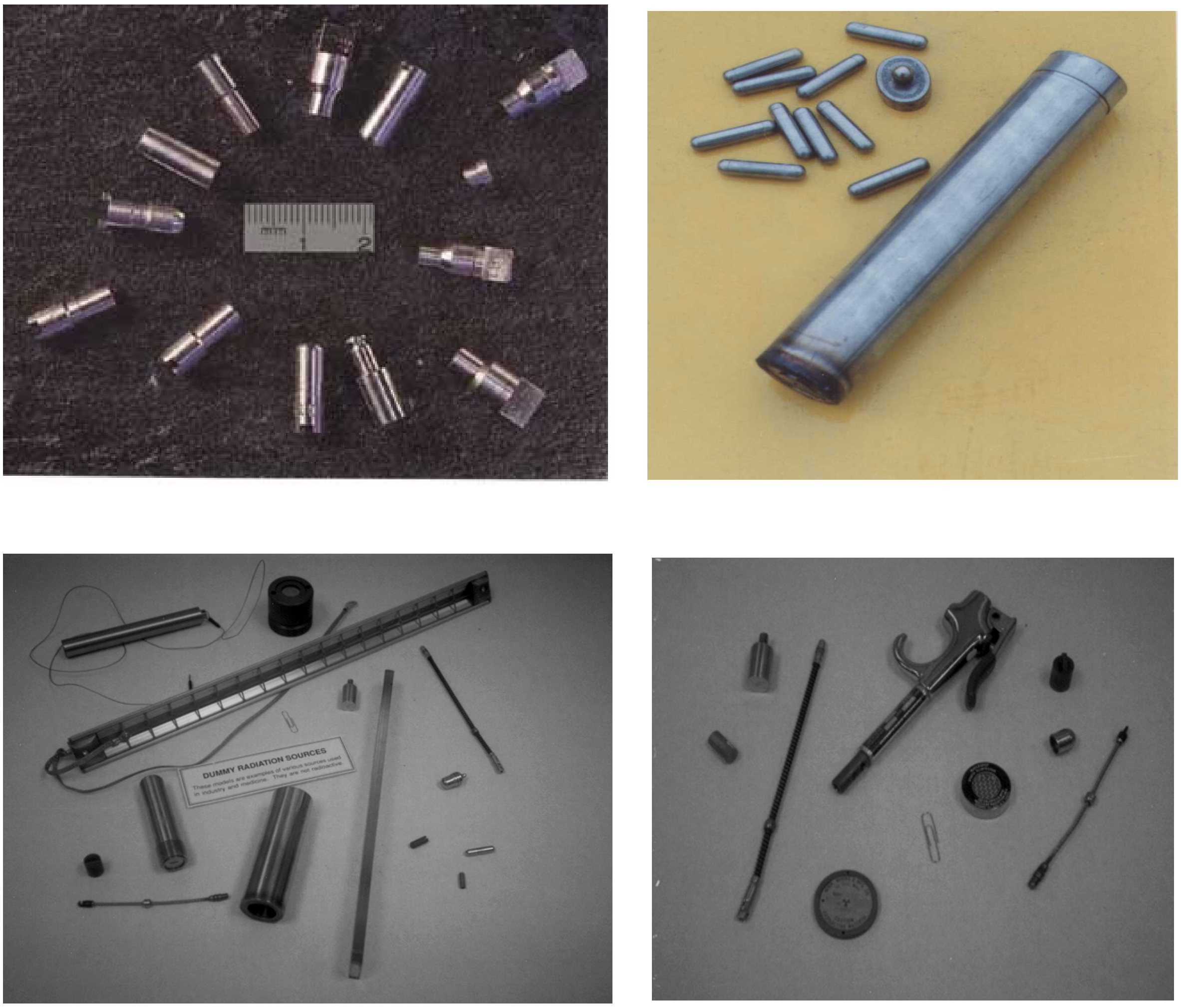


FIG. 2. Bare sources (This is the actual radioactive component in its encapsulated form. Such sources must never be handled by hand, short contact with such sources can cause severe injury and can result in finger or hand amputation).

2.1. REASONS FOR A SRS DISUSE

A disused SRS is a source that is not in active use. If no further use of the source is expected the user should consider the source as spent and take necessary actions to declare it as such. It is important to emphasise that a source declared by one user as spent may still be used by a different user, supplier or manufacturer in the future. The following are some of the main reasons for a source to be considered as disused or spent.

2.1.1. Decay

For all sealed radioactive sources there is a minimum activity content below which the source is no longer useful for its specified purpose. In most applications the source needs to be replaced when the activity has decreased by a factor of two or slightly more. Industrial radiography sources containing ^{192}Ir, which has a half-life of only 74 days, usually become spent because of decay two or three months after purchase, while ^{60}Co sources used for either industrial radiography or teletherapy need to be replaced every 5–10 years. Although the sources may not be useful, they may be still highly radioactive, posing a potential danger to people and the environment even after several half-lives have elapsed.

2.1.2. Leaking or damaged source

Sealed radioactive sources need to be leak tested at intervals recommended by the manufacturer and/or as required by the national regulatory authority. This testing must only be carried out by persons who have been trained. Guidance on leak test methods is given by ISO [5].

Leaking sources should be considered as spent, and immediately taken out of service and handled as radioactive waste. For instance, old radium sources encapsulated in platinum or glass ampoules may leak due to the increased pressure resulting from gaseous buildup of ^{226}Ra decay products. If a source is physically damaged, (e.g. bent, corroded, cracked or badly scratched, etc.) (Fig. 3) it should also be considered as spent and removed from service for long term storage or disposal.

FIG. 3. Damaged, abandoned or lost sources may look like normal scrap. The only way of knowing is through radiation detection and record keeping and record updating.

2.1.3. Obsolete equipment

All equipment will in time reach the end of its useful life. While the source may still be of adequate strength, the equipment may no longer be serviceable (e.g. moisture/density gauge with old electronics). The associated source needs to be considered as a disused/spent radioactive source.

2.1.4. Alternative technology

A sealed radioactive source is usually made for a specific function. The function may be to treat a tumour, assess the quality of a weld, measure the density of a product in a pipe, the moisture in the soil, or the level of material in a tank. The source provides the ionizing radiation required by the system. Even if the source still gives the required radiation output, the system may be taken out of use because other ways to achieve the desired results have been developed. The alternative way might possibly use a different type of source that is easier to work with or manage as waste later on[1]. The alternative technique may also use a more stable chemical compound[2], a lower level of radiation, use a radiation-generator (X ray machine) instead of radioactive material, or may be a technique not using ionizing radiation at all.

2.1.5. Changes in priorities

SRS is considered disused/spent if the experiment or a programme using a specific SRS is completed or terminated. For instance, recent changes in the former USSR and Eastern European countries have brought about extensive economic restructuring and many facilities have changed their business direction. Other enterprises worldwide also may change their field of interest or terminate their research programme resulting in sources that are no longer needed. These sources have to be considered as disused/spent sources and taken over by another properly authorized organisation for re-use, conditioning or disposal.

2.1.6. Lost, stolen, unknown sources

Lost or stolen sources constitute a serious loss of regulatory control and can lead to serious consequences to public health and the environment. Immediate action (e.g. notification, search) is required. When the source is found, it must be checked and leak-tested before being returned to use. In addition, devices discovered by a third party and identified as being radioactive but cannot be traced to the authorized entity[3] are best considered as disused/spent SRS.

2.2. SOURCES IN TRANSITION (FROM ACTIVE TO DISUSED)

Experience has shown that it is not always easy to define exactly when a source should be considered as spent. Sources in transition from being used to spent could pose special problems. For example:

- *Sources that are 'temporarily out of use';*

For example a ^{60}Co source that has been used for level gauging. In time its activity becomes too low for the proper operation of the equipment. Such a source may be replaced and may be returned to the producer who may store it for future use. Such sources, after undergoing integrity testing may be used again. During the time between the end of its first use and the beginning of its second use the source is “temporarily out of use.” Another example would be a source that still has the required activity but the electronic support systems are out of date or old and accordingly need better/new components.

[1] e.g. ^{137}Cs instead of ^{226}Ra for radiotherapy and ^{192}Ir instead of ^{137}Cs for industrial radiography
[2] e.g. ceramic ^{137}Cs instead of CsCl
[3] BSS uses “Legal Person” to denote the entity responsible for the source.

- *Sources that may be used by another user for a different application;*

A ^{137}Cs source that has been used in a hospital for interstitial treatment is a typical example. When the hospital switches to using ^{192}Ir the ^{137}Cs may be given to a nearby university for use as calibration source. Two users are involved in this case and the time between applications is the transition period. The first user considers it “spent” whereas for the second user the source is “in use”.

- *Sources that are taken out of service but not declared as waste.*

Radium sources used in the past for medical purposes that have been replaced by a shorter lived and more chemically stable radionuclides e.g. ^{137}Cs. They may have not been declared as spent for several reasons: for example, physicians may not want to abandon the traditional treatment with radium sources because of their long standing experience with them or physicians may want to keep them for backup should the replacement sources not be available. Some sources are actually owned by private clinics, and hence ownership is an important issue in declaring the sources as waste. Such sources may be stored for several decades in containers, some of which may be in poor condition. In some instances, the high cost of proper disposal or the lack of proper disposition options may be a deterrent to disposing of the sources properly, and result in sources being stored, often for an indefinite period. Because they are in storage and not used, accountability for the sources may deteriorate, or unauthorized removal or theft may occur.

To ensure that a source status is clearly understood, it is preferable that these sources are called *disused* sealed radioactive sources. For the purpose of this document the term disused source will refer to all sources that are not in active use, including spent sealed radioactive sources that have not been formally declared as waste.

3. RISKS ASSOCIATED WITH DISUSED SEALED RADIOACTIVE SOURCES

3.1. RISK DEFINITION

Risk involves complex concepts related to the fundamentals of existence for individuals, organisations and societies and can be associated with any type of human endeavour. If a risky challenge is accepted, it is because the benefits, either in personal satisfaction or in a tangible outcome, are judged to be worth the risk. For a disaster, risk is a measure of the harmful consequence disaster might do. In the nuclear field, the emphasis on discussing risk is on reducing harmful consequences, while maintaining or maximizing the benefits to society of using ionizing radiation. Two ways exist for risk assessment and analysis, namely probabilistic and deterministic approaches. The former approach will be adopted for this discussion.

Several technical definitions of risk have been cited in the literature. However, the term "risk" is associated with several different meanings:

- the probability of an event occurring (e.g. the probability of being exposed to ionizing radiation from a radioactive source);
- the consequence of an event once it has occurred (e.g. the probability of developing cancer as a result of a given radiation exposure or the severity of injury manifested due to a radiation exposure); and
- the product of the event probability and its consequences.

In radiation protection normally the third meaning of risk is used, although it has created and still does create problems because of the different ways in which the words may be understood. In general terms, risk due to radiation exposure is defined as a ‘multi-attribute quantity expressing hazard, danger or chance of harmful or injurious consequences associated with actual or potential exposure. It relates to quantities such as the probability that specific deleterious conditions may arise and the magnitude and character of their consequences [6,7]. This definition provides a good basis for the risk analysis. In this TECDOC, the descriptions and recommendations adopt a qualitative rather than a quantitative character.

3.2. FEATURES INFLUENCING THE RISK OF DISUSED SOURCES

In the case of disused SRS, the consequence of an accident could consist of one or more of the following:

- radiation injuries (e.g. erythema, tissue damage, amputation and even death) due to excessive exposure of individuals (see Fig. 4);
- contamination of material or the environment due to the breaching of the encapsulation and dispersion of the radioactive content of the SRS (destruction of the encapsulation, melting down with scrap, etc.);
- Internal and/or external contamination of individuals;
- Economic losses due to medical treatment, accident related radiation surveillance, decontamination, dismantling, waste management and disposal, as well as costs due to loss of production capacity, monetary compensation to over exposed individuals, social expenses and the loss of use of the source itself.
- Each accident scenario is associated with a specific probability, which is a function of the characteristics of the source, environmental factors and the actions of the persons involved.

The International Basis Safety Standards — Security of Sources — specifies the safety requirements for the security of sources. These are:

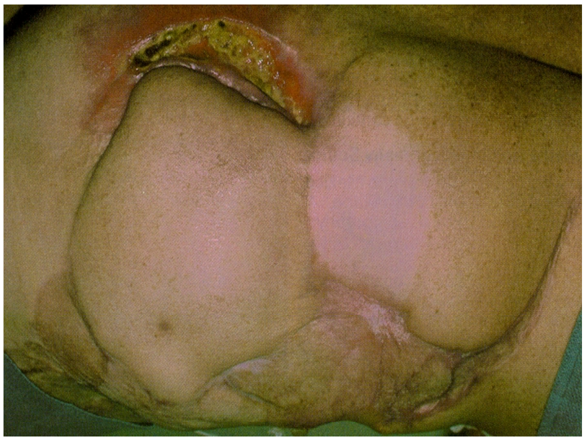
> “Sources shall be kept secure so as to prevent theft or damage and to prevent any unauthorised legal person from carrying out any of the actions specified in the General Obligations for practices of the Standards, by ensuring that:
>
> (a) a control of a source not be relinquished without compliance with all relevant requirements specified in the registration or licence and without immediate communication to the Regulatory Authority, and when applicable to the relevant Sponsoring Organization, of information regarding any decontrolled, lost, stolen or missing source;
>
> (b) a source not be transferred unless the receiver possesses a valid authorization; and
>
> (c) a periodic inventory of movable sources be conducted at appropriate intervals to confirm that they are in their assigned locations and are secure.”

Non-compliance with these requirements is the major cause of accidents. Accidents are difficult to predict, but the following factors increase the probability of occurrence:

Radiation burn on the buttock of a worker 31 days after he put an iridium source in his back pocket.

A skin flap has been sewn over the wound to close it (50 days after the accident).

Six months after the accident



A second skin flap has been added 19 months after the accident. But the wound has still not healed

Fig.4. Radiation injuries may look initially like a normal wound; complication later on is quite different from the normal wound. In many cases such injuries lead to amputation.

(photos are curtesy of USNRC)

NOTE: Reproduction of Figure 4 is prohibited. Permission to publish these photographs was obtained for this manual only.

- ineffective regulatory control (authorization, inspection and enforcement); and
- lack of management commitment to the safety and security of disused sources which results in:
  - lack of planning and clear guidelines to implement proper management for disused sources including provision for transfer of ownership,
  - lack of inventory and accountability of disused sources,

– lack of funds to implement safety requirements related to storage, decommissioning, conditioning, and disposal of disused and spent sources,

– poor safety culture with deviations from written management procedures and relevant radiation protection guidelines,

– improper maintenance or handling of equipment leading to failure and malfunction,

– lack of proper planning of scheduled work, and

– poor management of sources and record keeping.

The potential hazard from SRS also depends on their characteristics [4], i.e. half-life, activity and design.

3.2.1. Half-life

Radioactive sources containing long lived radionuclides, such as ^{241}Am or ^{226}Ra, will still be potentially dangerous after thousands of years. Conversely, short lived radioisotopes become safe in a far shorter time. The decay of 10 half-lives decreases the activity by a factor of about 1000. A teletherapy source with an initial activity of 100 TBq ^{60}Co will decay to a safer level after 100 years, while a ^{137}Cs source of the same activity requires 600 years and an ^{192}Ir radiography source only four years, to decay to the same level of activity.

3.2.2. Activity

The risk consequences of an accident with SRS is directly proportional to its activity. For a α or a β emitting source, the damage caused by the handling of a kBq source would be undetectable but a similar source of TBq strength could have fatal implications **(note this assumes β and/or γ sources only)**.

3.2.3. Source design

There are a number of factors of source design that impact directly on the risk of accident.

3.2.3.1. Geometry

Many applications of radioactive sources require that the activity be concentrated into a very small volume so as to produce "point sources" or approximate line sources. To achieve these properties, the sources are made as small or as thin as possible, with a material of high specific activity. The volume of radioactive material is usually of the order of a cubic centimetre or a few cubic millimetres, which results in the source having very small physical dimensions even though the overall volume is increased by encapsulation and shielding. Because of their small dimensions, there is a high risk that they can be lost or misplaced. The high specific activity could result in serious radiation injuries, especially if the bare sources are directly handled (Fig. 4).

3.2.3.2. Encapsulation

Most commercially produced sources are currently manufactured and tested to internationally agreed standards [8]. The materials used for encapsulation are chosen to afford the greatest degree of containment, but are dependent on the type of nuclide, e.g. a few millimetres thick stainless steel for weak γ sources, thin beryllium windows for β emitters and

α sources require such thin materials that special processes have to be employed in the manufacture. Both β and α sources are easily damaged. The encapsulation of neutron sources requires materials that are not activated by neutron emission. Precious metals used for encapsulating radium sources have been stolen for their monetary value and have become a cause for accidents [9]. The compatibility of the source material with that of the equipment in which it may be required to move can cause chemical or physical reaction that may result in the source being damaged.

3.2.3.3. Chemical/physical form

The consequence of a ruptured source is dependent on its chemical and physical form. Limited dispersal of the material occurs when it is a metal and in an insoluble form (e.g. ^{60}Co or ^{192}Ir). A modern ^{137}Cs source is in ceramic form in contrast to its previous form of a caesium chloride salt, which is not only soluble in water but is also hygroscopic. A leaking ^{226}Ra source for example can cause extensive contamination due to its physical form, namely a powder (e.g. $^{226}RaCl_2$ or $^{226}RaSO_4$).

3.2.3.4. Effects of decay

The decay products of some radioisotopes can have a damaging effect on the encapsulation of a SRS and can cause, or increase the consequences, of an accident. For example, the complete decay of a radium atom is accompanied by the generation of 5 atoms of helium and thus causes the encapsulating container to become pressurized with the eventual possibility of rupture [10]. The sudden release of such pressure would also enlarge the area of contamination.

3.2.3.5. Type of radiation

The impact of an accident depends on the type of radiation associated with the source. When ionizing radiation imparts energy to living tissue, damage is done. The larger the amount of energy imported, the larger the damage. It is, therefore, the transfer or deposition of energy to living tissue that determines the extent of the damage to living tissue and, hence, the injury. The ionization of tissue can also take place as a direct consequence, as is the case with alpha and beta radiation or indirectly, as is the case with gamma rays and neutrons. While alpha radiation has a high specific ionization characteristic, its penetration is very small. Gamma radiation and neutron beam ionization characteristics depend on their energy.

Neutron sources (e.g. Am/Be, Ra/Be, PuBe) require particularly careful handling as neutrons emitted by these sources represent a more dangerous type of radiation. Moreover, when absorbed by the surrounding medium, neutrons can induce artificial radioactivity.

3.3. RISKS OF DISUSED SRS

Countries lacking radiation protection and proper waste management infrastructure may not recognize the risks from disused radioactive sources. Some developed countries that use SRS extensively may underestimate the risks involved and, thus, may not have full control of their radioactive sources, even though they have adequate legislation, radiation protection and waste management infrastructure. Other countries do not give high enough priority to the problem because there are larger or more urgent issues demanding all of the available resources. Even if the hazards are recognized, there can be an increase in risk resulting from disused SRS. Disused sealed sources are usually stored in locations that are, in many cases, irregularly visited. This makes them more susceptible to being forgotten and ignored, which increases the risk of an accident. Disused sealed sources are frequently found in unexpected locations and outside any control [11]. Some of these cases can be deadly.

Lost sources are a worldwide problem since; on the one hand, a large number of radioactive sources are being used in developed countries. Thus even if there is a small probability of failure of regulatory control or of management procedures, the total number of sources that may be mislaid becomes large. On the other hand, in countries having a small number of sources but with inadequate regulatory control and lack of a proper management system, there is a high probability of loss or mistreatment and consequently the number of sources that may cause an accident also becomes large.

The number of disused sources in a given country does not influence the consequences of an individual accident, but increases the likelihood that an accident will occur. The degree of regulatory control and its effectiveness also influence the probability of an accident. The consequences of such accident are governed by the characteristics of the source (source design, activity, chemical form etc.), the way the accident develops, the people involved and the countermeasures taken.

Also, the time factor of the loss has to be taken into account. The later that control over the disused SRS is re-established, the higher is the risk of an accident. During this period, the SRS could be mechanically damaged, possibly resulting in contamination of the environment with more people exposed. Technical defects of a SRS device (e.g. SRS jammed in an unshielded position, SRS with a damaged shield etc.) are a potential danger and increase the consequences of an accident.

Experience gained from dealing with actual accidents with disused SRS shows that risk of accidents with SRS increases when:

- sources are taken out of everyday use and stored indefinitely at the user's facility; and
- sources are physically transferred to another user without transferring information and responsibility.

When there is a shift in responsibility either within the same institution (from the former operator to a person in charge of temporary storage) or from one institution (old owner) to another (new owner), any information gap between the two is an important source of new risks.

If control over the stored (disused) SRS is loosened or even abandoned, there is a high risk of loss, theft, or misappropriation. The most severe accidents with SRS have happened when disused SRS ended up in the hands of laymen who unaware that they were dealing with radioactive material (e.g. the Turkey and Tammiku accidents) [13, 14]. A new dimension to the potential hazard of disused sources is the possibility that they may be intentionally stolen for malicious use or illicit trafficking. This possibility heightens the need for proper security measures for *all* radiation sources.

Once the source is declared as spent SRS and conditioned, the risk of improper handling, theft, loss of control, etc., decreases and control over the spent SRS is facilitated. However, even a conditioned source should not be perceived as risk free.

In the IAEA database on illicit trafficking [15] of radioactive and nuclear material, 304 cases of illegal trafficking of such material were registered between 1993 and mid–1998; 134 of these cases were associated with sealed radioactive sources.

– Examples of accidents/incidents involving spent/disused SRS

Very often spent/disused SRS and their containers are taken by laymen as valuable scrap. Such situations can prove to be very dangerous. The Goiana accident in Brazil demonstrates an accident resulting from the neglect of a ^{137}Cs teletherapy unit [16]. This happened when a private radiotherapy institute in Goiania, Brazil, moved to new premises, leaving behind a ^{137}Cs teletherapy unit without notifying the licensing authority as required under the terms of the institute's authorization. The former premises were subsequently partly demolished. As a result, the teletherapy unit became insecure. Two people entered the premises and, not knowing what the unit was, but thinking it might have some scrap value, removed the source assembly from the radiation head of the machine. They took it home and the source capsule was ruptured. The remnants of the source assembly were sold to a scrap yard owner. Fourteen (14) people were seriously radiologically injured, of whom four died with the others surviving after extensive treatment. One hundred and twelve thousand persons had to be radiometrically monitored, of whom 249 were contaminated either internally or externally. Severe environmental contamination occurred. Remediation of the contaminated area resulted in a final total volume of stored waste of 3500 m^3. International co-operation was essential to mitigate the consequences. The direct costs of the decontamination operation and the construction of the two big concrete vaults now hold the waste is estimated to be US$ 15 million.

Another accident involving disused sealed sources happened in Georgia in 1997 [12] where eleven military servicemen were found to have developed radiation-induced skin disease. The major cause of the accident was the improper and unauthorized abandonment of twelve ^{137}Cs radioactive sources previously used by the army.

In the United States and Canada, information collected between 1983 and June 1997 [17] reveal 244 incidents of SRS, devices containing SRS, or other alloys containing radioactive materials being found in recycled metal scrap. The cost of decontamination, waste disposal, and mill shutdowns for U.S. metal mills that actually inadvertently melted radioactive materials averaged about $10 000 000 per accident. Worldwide, there have been a total of 67 instances[4] where radioactive materials were unintentionally melted in the course of recycling metal scrap [17]. In the United Sates alone, where regulations for controlling radioactive sources are particularly restrictive and the authorities are particularly efficient, there are still some 200 reports of lost, stolen or abandoned radioactive sources received by the US NRC annually [11][5]. These are examples of the risks encountered with neglect, loss or theft of SRS.

4. PRACTICAL STEPS TO MINIMIZE RISK

Risk reduction specifically connected to SRS may be summarized as follows.

- There is a need for good and safe design of both sources and of facilities that take into account the requirements for the entire lifetime of the source. If sources are imported, a safety assessment taking into account the source design, and the prevailing local conditions, is advisable; thus ensuring that the source is "fit for purpose".
- Labels and logos for a SRS should not only be on the apparatus or shielding container, but, if technically possible, on the SRS itself, so that it can be recognized as a dangerous object even when detached or removed from its housing. The size of the source is very important in this case. For very small sources, it may be not feasible or practical to have such

[4] As of the year 2000.

[5] From a source population estimated at 2 000 000. The loss rate is therefore ~ 1×10^{-4} per year with a "retention" rate of 99.99%, but even this loss rate may be considered too high.

information on the sources. For larger sources, this may be very instrumental in recognizing a lost source. The presence of the trefoil symbol alone, however, is not satisfactory to convey the hazard of the source; it needs to be accompanied by a caution or danger warning in the appropriate language. Some radiological accidents have occurred despite the presence of the trefoil symbol, because individuals did not understand the meaning of the symbol.

- High standards of training and retraining of personnel should be maintained.
- A record and control system, demonstrating inventory, control and accountability of *all* sources should be maintained.
- Physical security during use, transport and storage should be provided.
- Spent sources should be conditioned.
- All personnel equipment and vehicles going into and out of the facility should be monitored.
- Proper and efficient disposal of the sources should be undertaken once no further use is anticipated, in a licensed repository if it exists or the sources should be transferred to an authorized recipient.
- An emergency plan for dealing with all conceivable accidents in the facility should be established and training undertaken.
- Records and identifying lost sources should be updated and campaigns for locating them conducted. Such a campaign must be conducted in a very proper way in order not to cause an accident. The IAEA Technical Document on Methods to Identify And Locate Spent Radiation Sources should be consulted for advice [18].

4.1. AT THE NATIONAL LEVEL

The international basic safety standards (BSS) [1] are intended to place requirements on those persons (registrants or licensees) legally authorized to conduct practices that cause radiation exposure or to intervene in order to reduce existing exposures. These legal persons have the prime responsibility for applying the Standards. National Governments, however, have responsibility for the enforcement of regulations, generally through a system that includes a Regulatory Authority. In addition, National Governments generally provide for certain essential services for radiation protection, safety, waste management and accident response. The Standards are based therefore on the presumption that a national infrastructure is in place enabling the Government to discharge its responsibilities for radiation protection, safety and waste management.

Risk reduction for disused SRS is an integral part of the existence of this infrastructure which in general covers and contains:

- legislation and regulations;
- Regulatory Authority empowered to authorize and inspect regulated activities and to enforce the legislation and regulations;
- specialized enterprises for handling, storing, conditioning and possibly disposing of radioactive waste including disused SRS;
- sufficient resources; and
- adequate numbers of trained personnel.

National infrastructures must also provide facilities and services that are essential for radiation protection, waste management and safety in normal, as well as emergency conditions. Such facilities and services include those needed for:

- intervention, particularly during accidents and emergencies;
- personal dosimetry and environmental measurements;
- calibration and inter-comparison for radiation measuring equipment;
- collection, conditioning and storage facilities of radioactive wastes including spent SRS; and.
- detection of any buildup or transport of radioactive substances in the country (see Fig. 5).

To fulfil these requirements, the operator charged with rendering safe the sealed sources should establish and maintain a facility that meets the given requirements (see Section 5.4).

Use of SRS and the equipment containing the SRS should be in compliance with pertinent regulations and should be subject to the system of notification, authorization, inspection and enforcement. It is important that SRS should never fall outside regulatory control during their life whether in use, disused or designated as spent.

Guidance on the system of notification, authorization, inspection and enforcement, as well as safety assessment plans can be found in the IAEA documents on Organization and Implementation of a National Regulatory Infrastructure Governing Protection Against Ionizing Radiation and the Safety of Radiation Sources and the document on Safety Assessment Plans for Authorization and Inspection of Radiation Sources respectively [19, 20]. It is important to understand that even the best laws and regulations cannot alone guarantee the proper radiation safety and accident minimization if no adequate measures are taken to enforce them.

A professional and well established national waste management organization is needed in order to ensure compliance with national regulation and so reduce the risk of accidents. Risk reduction in the area of sealed radioactive sources can only be ensured by having a set of radiation protection and waste management activities that are based on clear principles. Observation of such principles, consideration of criteria and guidelines laid down for proper waste management in general and for SRS in particular are the only guarantee for global measures to reduce risk associated with SRS. The basic requirements for establishing a proper waste management system on the national level are documented in “Establishing a National System for Radioactive Waste Management”, Safety Series No. 111-S-1 [3]. For proper establishment of such infrastructure the principles of radioactive waste management as provided in Safety Series No. 111-F should be closely observed [21].

4.2. AT THE REGULATORY LEVEL

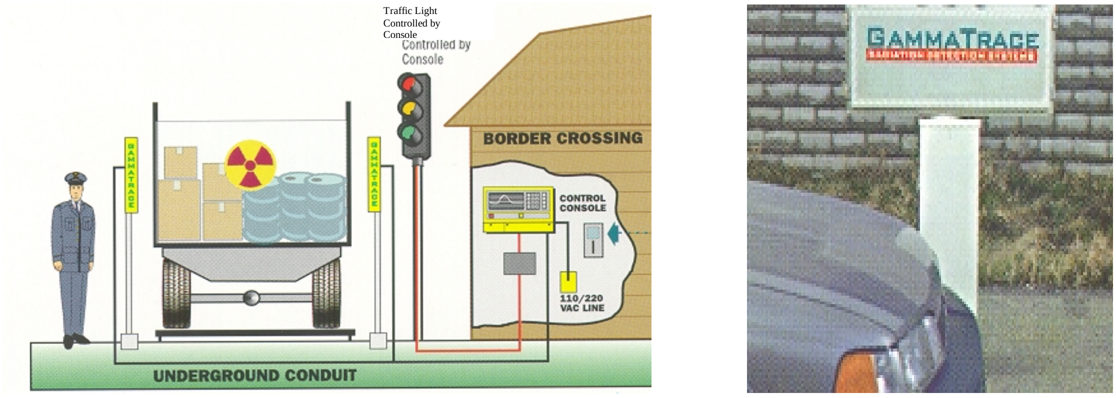
For practices involving SRS, regulations should require prior safety assessment by the user (i.e. the waste generator or the waste operator), and independent assessment, of all aspects of design, use and disposal of SRS (i.e. from cradle to grave). This will include accident scenarios and risk evaluation. The authorization issued by the regulator will include requirements that the user/waste operator comply with conditions which enhance safety and reduce the risk of accidents.

Border Crossing

Cargo Area

Airports

Transboundary Railway Lines



Facility Entrance

Fig. 5. It is important to have on line radiation monitoring equipment at sensitive points. (photos are courtesy of Barringer Europe SARL)

These conditions include:

- regular and documented inventory checks;
- accountability of sources;
- periodic contamination and leak testing;

- security of sources, including control of source movements and conditions for authorized transfer of ownership;
- compliance with relevant safety standards, when waste packages are prepared (allowable surface dose, labelling of source, full records, etc.);
- written safe operational procedures including emergency plans; and
- personnel and facility monitoring.

The regulatory authority needs to institute a system of registration for all radioactive sources present in its territory making it possible to identify SRS users, source details and status. The wide variety of uses of radiation sources and radioactive materials necessitates the development of some form of categorization so that the controls to be applied will be commensurate with the radiological risks that the sources and materials present [22]. Account would need to be taken of the radionuclide, its activity, the physical characteristics and the design of the source and its container and conditions of use. The Regulatory Authority should also consider having an inventory of all radiation sources within its boundaries, and not confine registration for radioactive material sources, depending on the legislative authorization.

4.3. AT THE LEVEL OF THE USER

Once the necessary prerequisites are met, the user organization responsible for possession and use of SRS and equipment with SRS is required to obtain from the Regulatory Authority any authorizations necessary for their acquisition, storage, use and disposal. The user is primarily responsible for applying safety standards in accordance with legislation and authorizations and must comply with any condition established by the Authorizing Authority. The management structure will vary with the size and complexity of the organization. However, the user is required to establish clear lines of responsibility and accountability for the SRS throughout their operational lifetime within its organization, including safe disposal. The main responsibilities follow.

- The management makes a commitment to safety, to keeping doses as low as reasonably achievable (ALARA), and has in place a radiation protection and safety programme.
- The management develops and implements a quality assurance programme for radiation protection, which defines the responsibilities at all levels and which details the requirements for safe operation, radiation monitoring, equipment and maintenance, as well as personnel qualification and training. The quality assurance programme should be based on recognized national or international standards. Internal inspections or audits must be performed routinely and documented. Deviations noted or identified by the internal inspections or audits must be tracked and corrected promptly.
- There are written safe operational procedures including those for emergency situations. All procedures need to be fully understood by the authorized or proximal personnel.
- The operational staff should be well trained. The training should be repeated at regular intervals. Records on the training and the staff performance should be maintained. It is also important that the users are well aquatinted with the design of the SRS and have full knowledge on the operation of the equipment.
- The user is responsible for regularly testing the safety functions of equipment as required. A formal programme of maintenance and testing needs to be set up in a well documented fashion.

- The user carries out a regular and periodical inventory check for all sources in his position. Any discrepancy should be investigated immediately.
- The user ensures that SRS are stored and disposed of in accordance with the requirements of the Regulatory Authority and other applicable standards such as IAEA's Radioactive Waste Safety programme [3, 23].
- All devices and containers of SRS must have the required signs, labels and warning plates, ensuring that they are visible and clear from any obstructions (Fig. 6, 7). Warning texts on the plates and labels need to be in the local language, as well as in the manufacturer's language if appropriate. The use of only the internationally approved symbols (e.g., the trefoil) is not sufficient as many ordinary people do not understand their meaning. Devices should also carry warning or cautionary labels, if the source inside can cause deterministic effects from short term exposure.
- The user organization must have written and practised emergency procedures.

To minimize the risk with sealed radioactive sources the following, while not exhaustive, are some practical points for users to consider.

- Sealed sources should always have safety features to keep the sources in a safe position, by an interlock mechanism if feasible. Do not allow the safety devices or interlock to be overridden.

*)

FIG. 6. Packages prepared for storage or transport must have proper labeling on them. It is preferable to have warning labels in the local language also. (Note container type A or B label also).

(photo is courtesy of Indermühle Logistics, Switzerland)*

- Minimize human factors to the greatest extent possible. Install technically reliable, autonomous gauges that cannot be easily dismounted or overridden at all critical points.
- Should the SRS device become jammed in the unshielded position, it should be considered a radiation incident, and be properly reported and solved in co-operation with qualified experts. If proper operation of the jammed SRS cannot be restored, the whole installation must be taken out of use and the relevant SRS considered as disused SRS and dealt with as such.
- If a SRS is considered disused, the user must report the fact to the Regulatory Authority and its future decided in co-operation with them.
- Whenever possible, the user needs to conclude a contract with the SRS supplier for the return of the disused SRS. Alternatively, a similar agreement should be in place with an appropriate national waste operator prior to the source procurement.
- It is important that approved procedures are rehearsed and exercised in "cold run" prior to commencement of the actual operation.

*)

*)

Fig. 7. Vehicles used for transporting sealed radioactive sources must be labelled accordingly with the proper marking. Transported sources must be well secured in their position during transport and should be as far away as possible from the driver. Dose rates at difference external points and at the driver position must be checked and documented.

(photos are courtesy of Indermühle Logistics, Switzerland)*

- For temporary storage within the current user's premises, the SRS must be labelled at all times (e.g. DANGEROUS RADIOACTIVE MATERIAL). Sources should never be taken out of their original shield except for good reason and only by competent personnel. Moreover, approved, written technical procedures and adequate precautionary signs in a suitable handling facility must be provided.
- Temporary storage facilities are to be kept under proper surveillance. Adequate security measures need to be taken and unauthorized access must be prevented. Temporary storage period should be defined and adhered to. Any extension should be for a good reason and should be for a well defined period of time.
- It is highly recommended that transport of the spent SRS to the authorized recipient (manufacturer/waste operator) occurs as soon as possible.
- Sources should not be transferred from one user to another directly. Only the regulatory body is authorised to licence further use.
- Mobile sources should be kept under lock and key whenever not in use. Such sources should not be left in the transport vehicle for an extended period or overnight. While a source is being transported, the vehicle should never be left unattended. This period is particularly risky with regard to loss of control over the SRS.

4.4. AT THE LEVEL OF A WASTE OPERATOR

The waste management organization is responsible for the safe operation of the waste management facility, where spent SRS are handled, conditioned, stored and/or disposed. The waste management organization has to comply with the legal requirement established by regulations and needs to comply with any conditions laid down in the authorization. The waste operator deals with a large number and type of sources from various activities in the country and hence needs to have an extensive in-house experience in dealing with different sources and should have his facility well equipped to deal with all expected sources. It should be mentioned here that the regulatory requirements and guidelines mentioned under the user level applies for the waste operator as well. The infrastructure of the facility and qualification of the personal in the waste operator case, however, are more elaborate. Components that are related to risk reduction, at the waste operator level, can be summarized as follows:

- Full familiarity with the design and characteristics of the sources brought to the facility for conditioning or storage. This implies good documentation and technical description of all types of sources imported into the country;
- Trained and experienced staff (initial and periodical training including radiation protection, operating procedures, practical aspects of health care and safety, waste characteristics, regulatory requirements, quality control procedures, requirements for documentation);
- Licensing (including fulfilment of all requirements of the competent authority);
- Quality assurance programme (including i.e. written procedures, surveillance, programme, security measures, emergency planning); and
- Regular auditing (internal and/or external).

FIG. 8. When handling a bare source or extracting it from its shield, manipulators and suitable shields must always be used. The extent of the shield varies according to the source activity, and its chemical and physical form.

Sources taken out of service are usually stored for some time at the temporary storage of the user and only later transferred to the waste operator. Good management practices for spent SRS are perceived as the main tool to reduce the risk of accidents. The source management programme should provide for the capability to characterize sources (e.g. determine: kind of nuclide, type of radiation used, source design, activity, physical and chemical form). The infrastructure should provide for proper handling according to source characteristics, see Fig. 8 (removing from or putting in a container, relocation, inspection or testing, disassembling the part of equipment containing a source), conditioning (process required to produce a waste package for the intended operation, i.e. transport, storage or disposal) and safe storage (placement in a facility for isolation, environmental protection and human control).

While disposal is not an available option in many countries, participation in preparatory work should be part of the activities of the waste operator. Disposal of a SRS in its final destination with reasonable assurance for safety, without intention of retrieval and without reliance on long term surveillance and maintenance, reduces the risk to an absolute minimum. It is important, here, to point out that documentation of all sources is vital for future reference. Documentation of sources should include comprehensive information on spent/disused SRS and should include a register for spent SRS which has been stored, conditioned or disposed. Essential information on conditioned sources should be on the Package and should be intended for long term (see Fig. 9). Records go beyond that to include information on training, procedures, as well as actions taken that change the physical, administrative or legal status of the SRS.

A detailed description of the management of spent sealed sources is provided in the IAEA technical report on “Handling, Conditioning and Storing of Spent Radioactive Sources” [24]. In this respect, the waste operator needs a well equipped facility to handle, condition and store safely conditioned, as well as unconditioned waste. Depending on the national inventory and the intended manipulation and conditioning procedures adopted, funds are also very important to maintain the required standards adopted and to enforce guidelines. The operator also needs to have access to the national registry of SRS for planning of future needs and for supporting users in the event of an accident.

Spent or disused radioactive sources are often temporarily stored at their last place of, e.g. hospitals, research institutes or industry, and may be required to be transported to the original supplier or to the place of conditioning and finally to an interim storage or a final disposal site. Such transports are to be carried out in accordance with the national transport regulations, which may be based on recommendations from the IAEA [25]. Ideally, conditioning for interim storage is carried out such that it complies with transport regulations and/or acceptance criteria for a repository will be demonstrated. Approved transport containers should always be used to transport bare small sources (see Fig. 10). For high activity sources a special transport container must be used (Fig. 11). The waste operator facility, in order to address the above requirements, should comply with the requirements and guidelines set forth by the regulatory body. In particular in order to reduce risk, the facility should demonstrate:

- source accountability comprising of a registry system that ensures retrievability of all essential information on all sources in the facility or handled by the facility and information on all operations carried out;
- a monitoring system in all areas at the facility where sources are manipulated in any, way including all facility access points;

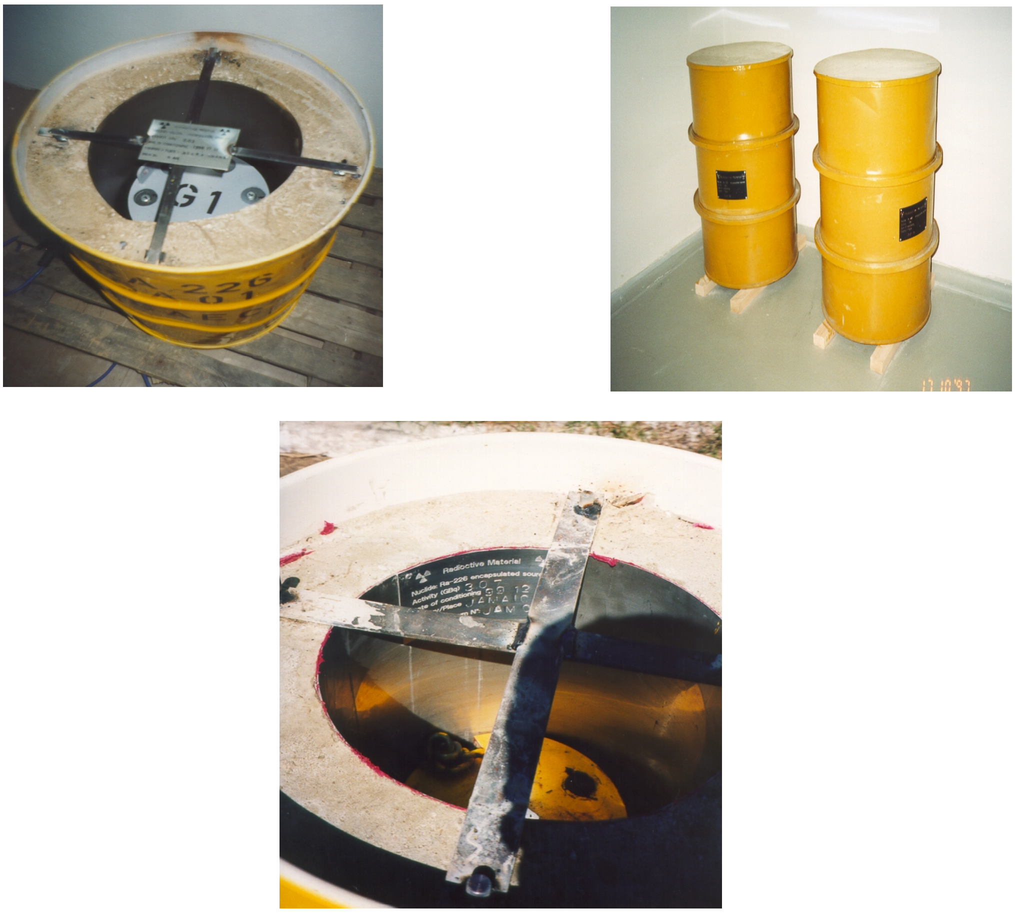


Fig. 9. Conditioned sources for long term storage. The engraved metal tags fixed within the drum and on the outer surface of the drum will withstand the long term effects of the environment.

- approved procedures by the regulatory body for all intended purposes;
- facility emergency procedures which include records of all incidents/accidents and full records of accumulative doses by all workers; and
- dissemination of information on waste management, radiation protection and safety provided by the regulatory body and other collaborating institutes.

4.5. AT THE LEVEL OF THE INDIVIDUAL

While the infrastructure described above is essential for risk reduction, accidents take place even in countries with such a system. This is mainly due to the fact that individuals working directly with sealed sources or working for establishments dealing with sealed sources may take a course of action that either intentionally or unintentionally leads to an accident. This shows that individual actions are important in minimizing the risk involved. Accidents happen when:

- proper procedures are violated, as a result of rushing to finish a job, working when tired or under stress poor communication or poor training;
- undue pressures emphasizing output, rather than safety, take precedence;
- working with or on a source and it is left temporary unattended and exposed (e.g. to take care of unexpected business matters near by);

Fig. 10. For small sources, depending on the source size, geometry, and activity, a special container should be used for transport.

- not conducting sufficient radiation surveillance during and after a job;
- sources are left with no security locks in place;
- sources go missing, not reported and/or no action taken;
- transport vehicles left unattended during a rest or lunch break on the road;
- evidence of tampering with locks on storage areas goes unreported;
- training on newly received radiation detection equipment is not given, but use commences in a vague or unfamiliar way;
- failure to maintain all related equipment in good working order leads to workers adopting unsafe practices (Technical workers need to have a programme developed by the management to prevent simplification of rules for daily practices.);
- a worker attempts to solve an unusual problem so as to be seen as taken an initiative; there is a lack of information or interest about previous accidents and thus no lessons learned.

The following useful advice will minimize the risks to those who find an SRS.

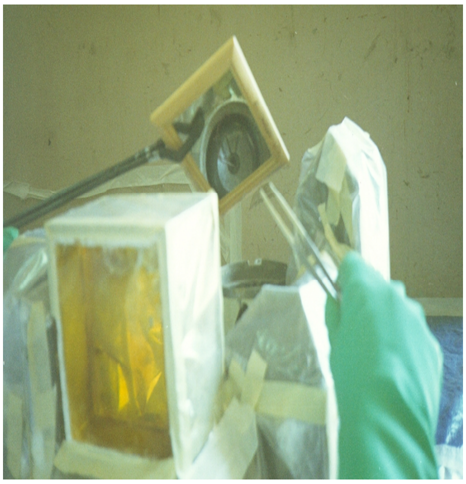
- Never pick up an attractive strange metal object and keep it. Any equipment that may look valuable may be lethal if it contains a SRS.
- When working with SRS sources do conduct periodical radiation surveys of the working place.
- Never handle a bare source with your hands (Fig. 12, 13).

Fig. 11. For large sources (in the order of TBq), special transport containers, tools and lifting cranes may be required. With such sources, handling must only be carried out once written and approved procedures in place.

(photos are courtesy of Indermühle Logistics, Switzerland)

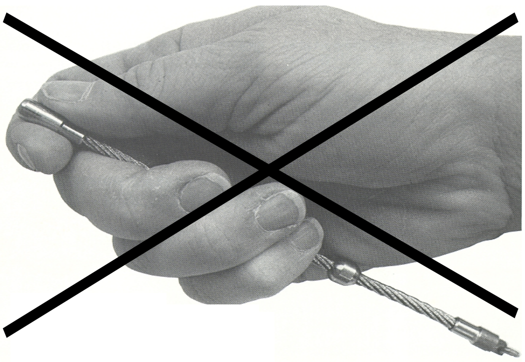
- Always check on exposure rate and check for any contamination before handling a source (Fig. 14, 15).
- When entering an area where SRS sources are expected, always have a tested and working radiation monitor with you.
- Be sure that you know how to use radiation detection equipment and that you have been trained in its use.
- Be particularly careful with disused SRS and especially those that may show visible damage.
- When working on a source, make sure that its locking mechanism is in order and that the source is in the shielded position by conducting a radiation survey.
- Never violate regulations or guidelines or defined working procedures.

- When working with a SRS make sure that the area around the source is isolated and full control on this area is established
- Radiation sources should not be left unattended. Rooms containing radioactive sources must always be kept under lock and key (see Fig. 16).
- While working with sources use an electronic pocket dosimeter and periodically check your radiation exposure.
- Place warning signs in the local language when sources are handled, stored or used.
- As much as possible, use distance and shielding as protection mechanisms.



A.

B.



*C. *)*

Fig. 12. Never look directly to a bare source or handle it with your own hands, even momentarily. Bare sources should be observed through lead glass with sufficient shielding capability. Alternatively, sources can be observed behind a lead shield while utilizing a mirror.

**) The source in C. is a dummy source.*

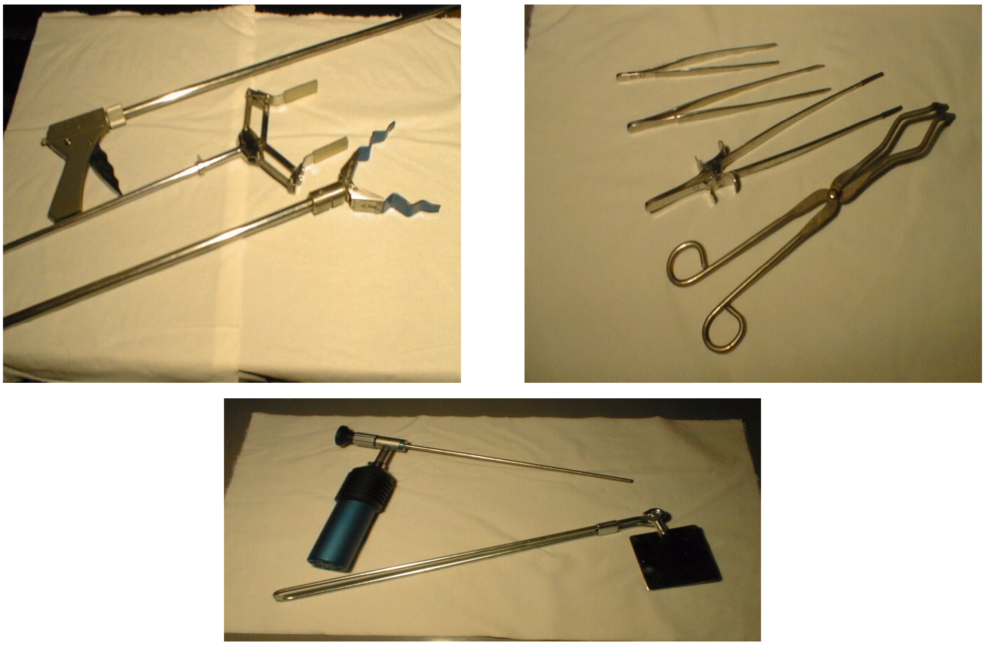


FIG. 13. If small sources (in the order of MBq) are being handled outside their shield, they should always be handled with suitable tools.

*)

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FIG. 14. Sources handled within their shields or packages must always be checked for surface dose rate and dose rate at 1 meter distance. Radiation beam pathway must be checked carefully to confirm shutter closure.

(photos are courtesy of Indermühle Logistics, Switzerland)*

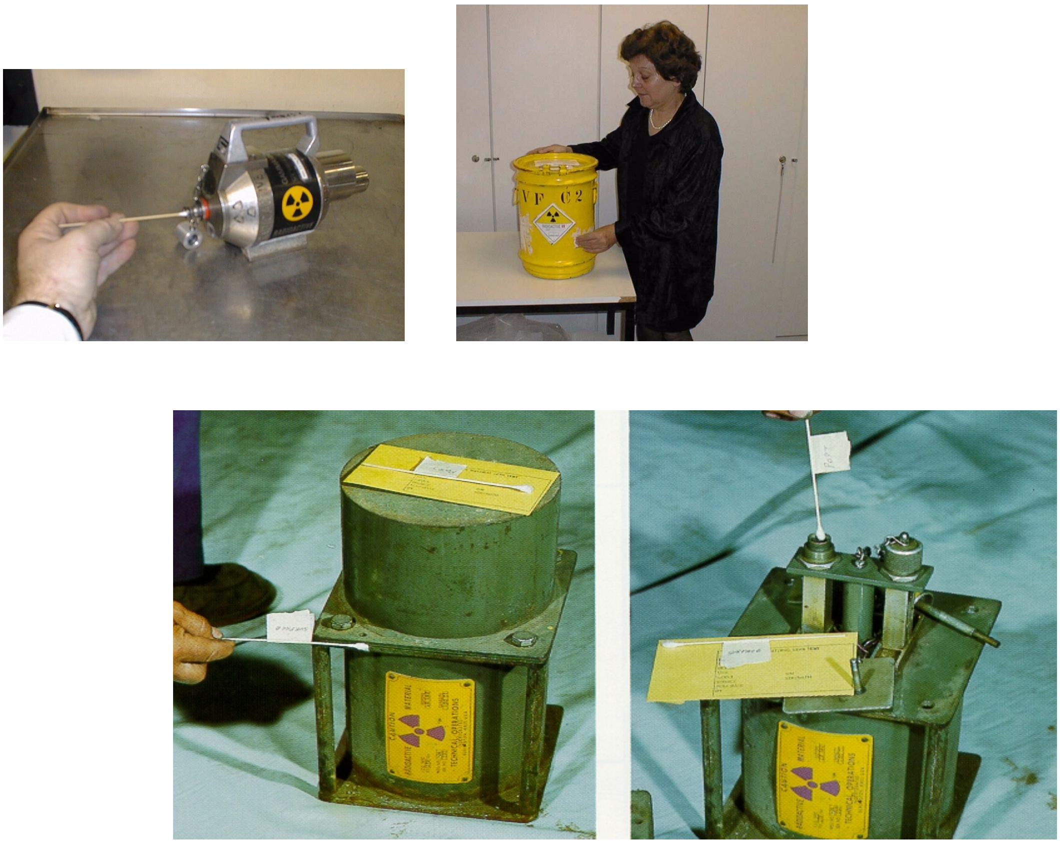


FIG. 15. Prior to handling a source within its shield, smeer tests for contamination control should be carried out.

Fig. 16. Storage places for sealed sources must have a good degree of physical security. Only authorized personnel should have access to these stores.

Time

- You can effectively reduce your exposure by spending the minimum time near a source that you are working on or with.
- Manipulation of a bare source should be carried out in a minimum time and only after several exercises with a dummy source.
- Emergency procedures should be well defined if intended procedures fail.

Distance

- Don't stay in the vicinity of a source longer than necessary.
- Stay as far away from a sources as you can.
- Never travel with a source in the passenger compartment of your vehicle.
- Manipulate a source from as far a distance as possible using proper equipment (tongs).

Shield

- Use shielding material between you and a source effectively.
- If a bare source needs to be transferred or manipulated, a shielding pot can be used to minimize exposure.
- Utilize proper shields (thickness, type, geometry) when handling a bare source. Different types of radiation require different materials for shielding materials.

Taking into account the expected time required to manipulate a source, the distance foreseen for the manipulation and any possible shield used, expected exposure dose rate and accumulative dose should be calculated prior to commencement of any operation. Such an expected dose should be well within the permissible level.

5. ACCIDENT MANAGEMENT

5.1. EMERGENCY PLANNING AND PREPAREDNESS

Experience has shown that advance emergency planning and preparedness are essential in order to respond effectively and mitigate the consequences of an accident. Analysis of possible accident scenarios and their magnitude and consequences ensures the best protective measures to be taken, and preparations of the various personnel and organizations that might be called upon to respond efficiently to the emergency. This plan should include intervention levels. The organization responsible for implementing the emergency plans needs to be provided with suitable training in radiological protection and source recovery procedures.

Emergency planning and preparedness has the following major components: identification of potential accident situation, evaluation of identified accident situations, preparation of emergency response plan, training and exercises. The basic obligations, responsibilities and requirements for emergency situations are established in Safety Series No. 91 and No 87 [26,27]. Advice and guidance on developing and implementing emergency plans are also provided in SS No.91. A step by step method for developing integrated user, local and national emergency response capability are detailed in [28 and 29.].

The topics covered in the emergency plan include:

- information flowchart (whom to notify);
- the allocated tasks and responsibilities of authorities and organisations involved;

- identification of the emergency response team (team manager, radiological and industrial safety manager, instrumentation specialist, public relations, media contact, and persons trained in relevant technical and medical disciplines);
- measurements to be made and equipment to be used to identify, locate and recover the source (e.g. remote handling tongs, measuring instruments, shielding containers);
- radiation protection measures (using radiation warning signs, ropes, overalls, shoe covers, gloves, respirators, etc.);
- decontamination (e.g. equipment, chemical and procedures);
- post accident assessment and monitoring;
- temporary storage arrangement;
- transport to an authorised storage facility;
- final handling, possible conditioning and storage of the involved sources and any contaminated material (i.e. post accident waste management);
- co-ordination of public information activities.

All the organizations responsible for management of spent SRS have to develop capabilities needed to implement the emergency response plan. This entails training of staff to deal with emergency situations, including training in handling emergency equipment and how to follow written procedures.

Once a response capability has been developed, drills and exercises need to be conducted periodically. These drills and exercises not only provide training, but also test the response and the training of emergency personnel and identify deficiencies for improvement. Periodic check of all names and telephone numbers in the emergency procedures for validity and emergency equipment for adequacy is recommended.

The involved organizations, according to the level of responsibility, are also designated to keep liaison with emergency services (police, fire and medical), qualified experts and other bodies that are assigned in the procedures. The purpose of this liaison is to ensure that all parties understand the hazards and are aware of the requirements of the emergency procedures and any responsibilities for action. In the event of an accident, it is the duty of the owner of the disused SRS or the waste operator (i.e. the entity in possession of the source) to promptly initiate the emergency response and coordinate the response of the emergency services with other bodies, as well as to inform the Regulatory Authority.

In an emergency response, a generic response scheme designates responsible “persons” under three specific titles: response initiator, emergency manager, and radiological assessor.

- Response initiator-first responder on scene

  This is the person who initiates the response and performs immediate actions to mitigate the effect of the accident.

- Emergency manager

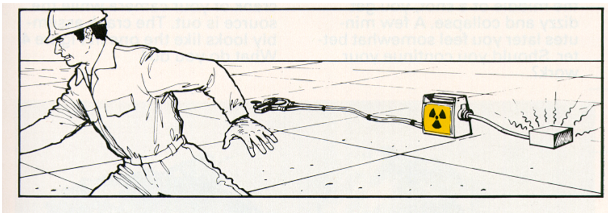
  The emergency manager (EM) is in charge of the overall emergency response and manages the priorities and the protection of the public and emergency workers. The EM ensures that all appropriate resources have been activated.

- Radiological assessor

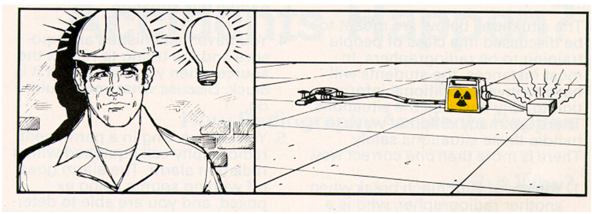
  The radiological assessor is responsible for radiation surveys, dose assessment, contamination control, radiation protection support to emergency workers and the formulation of protective action recommendations. The radiological assessor also initiates and, in many cases, carries out source recovery, cleanup and decontamination.

  This position is normally held by the radiation protection officer (RPO) or a hired qualified expert.

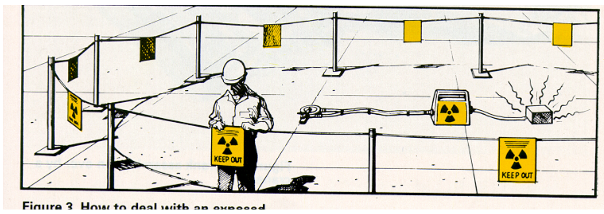
For example, in industrial radiography, the response initiator is most likely to be the radiographer himself (Fig. 17), while the emergency manager may be the operating organisation manager or a designated senior staff. In the case of a lost source the EM may be an appointed member of the local government. The EM depending on the size of accident may be designated to be the primary spokesperson with the media. In small organizations, the radiographer may be the RPO and EM.



Move away from source at once



Calm down and think



Establish controlled area

Call for help

FIG. 17. How to deal with an exposed source

To respond to an emergency adequately, it is suggested that the following minimum resources be made available by the responsible organization.

Radiation survey instruments:

- High range survey instruments, preferably with an extendible probe;
- Low range survey instrument;
- Contamination monitor or probe; and
- Check source for low range survey instruments.

Personal protective equipment:

- Self reading dosimeters for each team member;
- Permanent dosimeters for each team member;
- Protective overalls, overshoes and gloves; and
- First aid kit.

Communication equipment:

- Portable radio communications.

Supplies:

- Appropriate shielding (sufficient to significantly attenuate the radiation, for example, at least two bags of lead shot, i.e. 5 kg each for ^{192}Ir and 10 kg each for ^{60}Co or lead bricks or slabs);
- Tongs at least 1 m long suitable for safely handling the source assembly;
- A shielded container;
- Appropriate hand tools;
- Radiation warning labels and signs;
- Plastic for preventing contamination of instruments and isolation of contaminated objects; and
- Log book.

Supporting documentation:

- Equipment operations manuals;
- Response co-ordination procedures;
- Procedures for conducting monitoring; and
- Procedures for personal radiation protection.

5.2. ACCIDENT ASSESSMENT

An accident involving a disused SRS is assessed by estimating its severity in terms of the geographical extent and level of contamination and magnitude of radiation exposure to persons. The exposure pathways have to be determined for setting up emergency response actions.

Emergency response to accidents associated with disused SRS depends on the particular circumstances. In the case of an operational malfunction, the consequences of an accident are usually limited to a single room or building, with only few personnel involved and no direct risk of overexposure to the public. This allows the emergency response team more time for detailed planning of source recovery and to select the most efficient protective measures for team members. In the case where the impact of an accident exceeds the borders of a facility (lost, abandoned, stolen or “unknown” source), the highest priority would address the immediate control of the affected area in order to minimise the number of people who might be exposed or contaminated. A rapid assessment of the radiological situation should be made. In the case of the rupture of the source encapsulation, immediate steps are required to prevent the spreading of contamination. Typical tasks involve the following:

- gather information by interviewing involved parties (potential instigators and affected people);
- performing a preliminary radiological measurements;
- identify perimeter of affected area;
- identify the source causing the accident and its disposition (strength, status, etc.); and
- identify any aggravating and complicating factors.

5.3. EMERGENCY RESPONSE ACTIONS

If an accident with a radioactive source has occurred, emergency response actions [4] may be taken to:

- determine the actual disposition of the radioactive source;
- prevent access to the area;
- identify strategies, procedures and tools to regain control of the source;
- rehearse adopted procedures for source recovery and containment;
- regain control of the radioactive source in order to restore the normal situation;
- arrange for medical assistance, if necessary;
- notify all relevant parties and organizations including IAEA Emergency Response Unit;
- implement appropriate radiation protection measures to reduce risk to the health of the public and members of the emergency response team; and
- identification of waste management procedure to be carried out to remediate any post accident conditions that pose a danger to staff or the general public (management of the sources as spent, collection of any secondary waste, decontamination of affected area, conditioning of the resulted waste).

5.4. FEEDBACK FROM OPERATING EXPERIENCE

It has to be ensured that all reasonable steps are taken to assess exposure incurred by members of the public and/or radiation workers as a consequence of an accident, and results of assessments be made available to the public. Comprehensive records are required to be maintained and updated constantly.

One of the most effective ways to prevent or mitigate consequences of similar accidents is to ensure that information significant to protection and safety on both normal and abnormal operations is identified, collected, evaluated, and made available to all relevant parties concerned with radiation protection and safety. All accidents involving unplanned potential or actual radiation exposure are to be investigated by the operating organization (waste operators and waste generators). Relevant parties to receive the report of the investigation include the

Regulatory Authorities, manufacturers, and similar licensees. Relevant information covers, for example, descriptions of accidents, doses associated with accidents, maintenance records of facilities and equipment, corrective actions taken, and recommendations made including those intended to prevent similar accidents in the future.

Periodic publication of review of collected information at the national level by the Regulatory Authority, addressing the lessons learned, improvement of operating procedures, management strategy, manufacture and regulatory procedures are essential. Moreover, these reviews should be prepared with the objective to foster safety culture amongst those responsible for radiation protection and safety in the industry.

REFERENCES

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

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Nature and Magnitude of the Problem of Spent Radiation Sources, IAEA-TECDOC-620, Vienna (1991).

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

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

[5] ISO 9978: SEALED RADIOACTIVE SOURCES - Leak Test Methods.

[6] KUNREUTHER, HOWARD, ERYL V. LEY, The Risk Analysis Controversy: An Institutional Perspective, Berlin (1982).

[7] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Protection from Potential Exposure: A Conceptual Framework, Oxford (1993).

[8] ISO 2919: 1999 RADIATION PROTECTION — SEALED RADIOACTIVE SOURCES — General requirements and classification.

[9] LUBENAU, J. O., YUSKO, J. G., Radioactive Material In Recycled Metal, Update, Health Physics V 68, N4 (APR 1995).

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

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Timely Action, Strengthening Radiation Safety and Security, Abel J. Gonzalez, IAEA Bulletin 41/3/1999 (September 1999) Vienna, Austria.

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiological Accident in Lilo, IAEA, Vienna (2000)

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiological Accident in Istanbul, IAEA, Vienna (2000).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiological Accident in Tammiku, IAEA, Vienna (1998).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, "Database for Illicit Trafficking of Nuclear Material and Other Radioactive Sources", Division of Safeguards Information Technology, Department of Safeguards, IAEA, Vienna.

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiania, STI/PUB/815, IAEA, Vienna (1988).

[17] LUBENAU, J.O., YUSKO, J.G., Radioactive Material In Recycled Metal Update, Health Physics, V 74, N3 (MAR), 293–299 (1998).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Methods to Identify And Locate Spent Radiation Sources, IAEA-TECDOC-804, IAEA, Vienna (1995).
[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Organization and Implementation of a National Regulatory Infrastructure Governing Protection Against Ionizing Radiation and the Safety of Radiation Sources, IAEA-TECDOC-1067, Vienna (1999).
[20] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment Plans for Authorization and Inspection of Radiation Sources, IAEA TECDOC-1113, Vienna (1999).
[21] INTERNATIONAL ATOMIC ENERGY AGENCY, The Principles of Radioactive Waste Management, Safety Series No. 111-F, IAEA, Vienna (1995).
[22] INTERNTIONAL ATOMIC ENERGY AGENCY, Categorization of Radiation Sources, IAEA-TECDOC-1191, Vienna (2000).
[23] INTERNATIONAL ATOMIC ENERGY AGENCY, Classification of Radioactive Waste, Safety Series No. 111-G-1.1, IAEA, Vienna (1994).
[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Handling Conditioning and Storage of Spent Radioactive Sources, IAEA-TECDOC-1145, Vienna (2000).
[25] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material—1996 Edition, Safety Standards Series No. ST-1, IAEA, Vienna (1996).
[26] INTERNATIONAL ATOMIC ENERGY AGENCY, Emergency Planning and Preparedness for Accidents Involving Radioactive Materials Used In Medicine, Industry, Research and Teaching, Safety Series 91, IAEA, Vienna (1989).
[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Emergency Response Planning and Preparedness for Transport Accidents Involving Radioactive Material, Safety Series 87, IAEA, Vienna (1988).
[28] INTERNATIONAL ATOMIC ENERGY AGENCY, Method for the Development of Emergency Response Preparedness for Nuclear or Radiological Accidents, IAEA-TECDOC-953, Vienna (1997).
[29] INTERNATIONAL ATOMIC ENERGY AGENCY, Generic Procedures for Assessment and Response during a Radiological Emergency, IAEA-TECDOC-1162, Vienna (2000).

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