Radiation applications and waste management: Taking the final steps

Countries are receiving practical guidance and support for safely managing radioactive sources after their beneficial use

by C. Bergman and B.G. Pettersson

Reported radiation accidents have caused about 20 fatalities among innocent members of the public due to improper handling and storage of spent radiation sources. Against this background, the IAEA has developed a range of services for assisting countries interested in building effective systems for the safe control, management, and disposal of these sources.

This article focuses on nuclear applications that involve the use of sealed radiation sources. It highlights common applications of sealed sources and discusses principles and techniques for safely managing them after use.

Applications of sealed radiation sources

Sealed radiation sources of various types and activities are in widespread use in virtually all IAEA Member States and the use is increasing. The largest diversity of radionuclides and activity is found in industrial applications.

In the medical field, both the number of nuclides and the activity range is more limited. Research applications can involve almost any radionuclide, the activity of which is usually in the lower range. The notable exception is radiation sources in irradiators for research related to biology.

Radiation sources in industry. A large proportion of radiation sources are used for process or quality control. Typical examples are industrial radiography and industrial gauges.

The purpose of radiography is to detect any imperfection, voids, or alien material in the sample being investigated. Radiography techniques are used in the construction industry, mainly for checking the quality of welds, and in the steel industry for verifying the quality of manufactured items such as piping and cast iron. The principal nuclides used are cobalt-60 and iridium-192.

Radiography units comprise a housing for shielding purposes and a mechanism to bring the source into the exposure position. Units used in the construction industry are portable, while those used in the steel industry are of fixed types, often installed in specially built enclosures.

Industrial gauges broadly include units for determining the thickness, density, or moisture content of a particular material during or immediately after production or for monitoring levels in vessels or tanks. Beta sources (strontium-90 and krypton-85) are used for thickness/density measurements of paper, plastics, and thin, light metals. Gamma sources (caesium-137 and iridium-192) are needed for the more dense materials such as steel plates. Caesium-137 and cobalt-60 are commonly used in level gauges.

More specialized gauges for determining the density, porosity, and moisture or hydrocarbon content of geological structures or building material use americium-241/beryllium and caesium-137.

High-activity cobalt-60 and caesium-137 sources are used in specially designed facilities for sterilization of gloves, syringes, and similar medical products. They also have applications in the preservation of foodstuffs.

Radiation sources in medicine. The two principal applications of radiation sources in medicine are brachytherapy and teletherapy. Brachytherapy is a term used to describe the interstitial or intracavitary application of radioactive sources by placing them directly in, or very near, the tumour. The application may be done manually or by remote control.

When brachytherapy started, only radium-226 was in use. Replacement programmes have made the vast majority of the radium sources redundant, but limited use of radium still occurs. Current applications mainly involve the use of

Messrs Bergman and Pettersson are staff members of the IAEA's Division of Nuclear Fuel Cycle and Waste Management.

caesium-137, cobalt-60, and iridium-192. Additional applications include superficial treatment of skin and ophthalmic lesions (strontium-90).

In teletherapy, high-activity cobalt-60 or caesium-137 sources are used. The sources are invariably mounted in specially designed shielded housings and used in shielded enclosures.

Radiation sources in research. Applications of sealed radiation sources in research are highly varied. Almost any radionuclide can find a use in research work. Many of the radiation sources are of low activity and/or of short half-life.

The notable exceptions include high-activity sources for biological research. Cobalt-60 and caesium-137 sources are used for irradiation or sterilization of materials and plants, and americium241/beryllium or caesium-137 sources are used for density and moisture measurements in agricultural research. Additionally, radium-226 and radium-226/beryllium sources may still be in use for instrument calibration purposes or in university training programmes. *(See tables.)*

Waste management principles

The primary reason for the hazards of radioactive material is its inherent characteristic of emitting ionizing radiation. That characteristic is independent of whether the material, the radiation sources, is in use or not. A radiation source, no longer to be used and for that reason considered as radioactive waste, is therefore as potentially dangerous as the corresponding source still in use. The fact that a radiation source in use is often considered as a valuable resource makes the owner more apt to exercise control of it than if the source is spent and thus represents a negative resource (cost for disposal). This fact, and that there is no interest to save it for future use, often makes a spent radiation source more dangerous than one in use.

The primary objective of radioactive waste management is to implement an effective control, management, and disposal system that ensures the safety of people and of the environment. The control, which must have a firm base in a national regulation and enforcement system, needs to cover every source of significant risk from cradle to grave.

To meet requests from Member States on this subject, the IAEA's Waste Management Section is finalizing a radiation source database package. It consists of a database which can be operated on modern personal computers and includes an operating manual. After proper testing, the package will be offered to all Member States as a tool for keeping track of their sealed radiation sources. The prime target group is national regulatory bodies. It also can be used by individual organizations, such as a national waste management body, which have a large number of radiation sources.

Radiation sources in industry

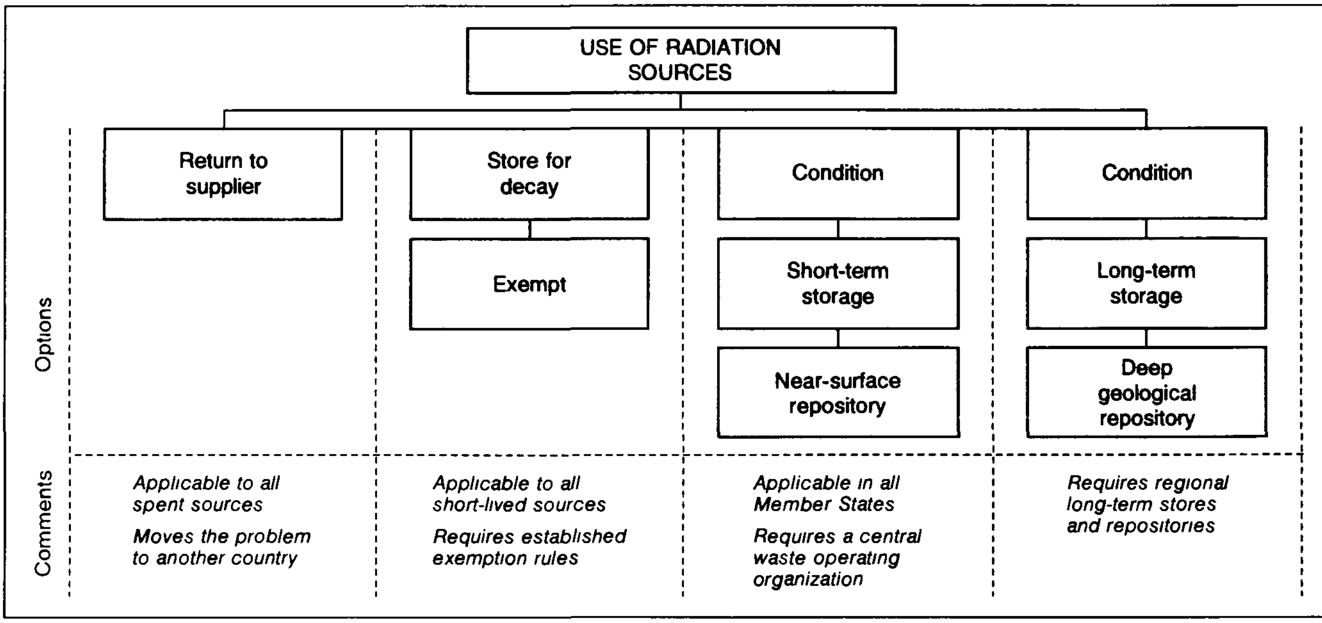
Application	Radionuclide	Source activity
Industrial radiography	Iridium-192	0.1 - 5 TBq
	Cobalt-60	0.1 - 5 TBq
Well logging	Americium-241/Beryllium	1 - 800 GBq
	Caesium-137	1 - 100 GBq
Moisture detector	Americium-241/Beryllium	0.1 - 2 GBq
Conveyor gauge	Caesium-137	0.1 - 40 GBq
Density gauge	Caesium-137	1 - 20 GBq
	Americium-241	1 - 10 GBq
Level gauge	Caesium-137	0.1 - 20 GBq
	Cobalt-60	0.1 - 10 GBq
Thickness gauge	Krypton-85	0.1 - 50 GBq
	Strontium-90	0.1 - 4 GBq
Static eliminators	Americium-241	1 - 4 GBq
	Polonium-210	1 - 4 GBq
Lightning preventers	Americium-241	50 - 500 MBq
Sterilization and food preservation	Cobalt-60 Caesium-137	0.1 - 400 PBq 0.1 - 400 PBq
Calibration facilities	Cobalt-60	1 - 100 TBq
	Caesium-137	1 - 100 TBq

Radiation sources in medicine

Application	Radionuclide	Source activity
Manual brachytherapy	Caesium-137	50 - 500 MBq
	Radium-226	30 - 300 MBq
	Cobalt-60	50 - 500 MBq
	Strontium-90	50 - 1500 MBq
Remote after-loading brachytherapy	Cobalt-60 Caesium-137	about 10 GBq 0.03-10 MBq
	Iridium-192	about 400 GBq
Teletherapy	Cobalt-60	50 - 1000 TBq
	Caesium-137	500 TBq

Radiation sources in research

Application	Radionuclide	Source activity
Calibration sources	Many different ones	less than 0.1 GBq
Calibration facilities	Caesium-137	less than 100 TBq
	Cobalt-60	less than 100 TBq
	Californium-252	less than 10 GBq
Irradiators	Cobalt-60	less than 1000 TBq
	Caesium-137	less than 1000 TBq



Options for waste management of radiation sources

To meet the waste management objective, it is necessary to have a complete system for collection, transport, treatment, conditioning, storage, and final disposal of radiation sources that is adapted to national needs. It is outside the scope of this article to go into the technical details on how the different steps can be implemented, but the different approaches for the final steps will be elaborated.

There are four ways in which the final step in waste management can be taken. *(See figure.)* These are (1) return of the spent radiation source to the supplier; (2) storage to allow time for decay and subsequent exemption from regulatory control; (3) conditioning, storage, and disposal in a near surface repository; and (4) conditioning, storage for a long period of time, and disposal in a deep geological repository.

Return to supplier. A simplified procedure may be described as follows: *The waste producer sends the sealed source back to the supplier as soon as it is no longer to be used. Information is given to the regulatory body. Approval and/or a license might be required for the transport and export based on national legislation.*

Sealed radiation sources represent a special problem because of their small sizes and often high dose rates on the surface. Additionally, they frequently appear in countries which do not have a waste management infrastructure suitable for managing the disposal of the sources. The producer of a radiation source often has the best possibilities to safely store the radiation sources it produces. Furthermore, the producer may have the possibility to refurbish a spent source by re-encapsulation of the source for reuse. (Such operations can normally not be done by the user).

Through the IAEA's Waste Management Advisory Programme (WAMAP), advice on the return-to-supplier option is provided to national authorities which do not have full waste management capabilities, especially in developing countries. As a result, national legislation today often requires a clause in every purchase contract for sealed radiation sources that permits the buyer to return it to the supplier when it no longer is of any use.

The option to return a spent radiation source to the supplier should, however, only be used when it is the optimal solution; it is no final solution since it only moves the problem from one country to another. In countries having excellent possibilities for final disposal of spent sources, there is no need to use the option since in these cases it will increase rather than decrease the total risk from the radioactive waste.

Exemption from regulatory control after storage for decay. A simplified procedure may be: *The waste producer places the waste in a suitable decay store and keeps it there under proper surveillance until it has reached levels for exemption (clearance), at which time it is removed and disposed of as if it were not radioactive.*

The inherent characteristics of radionuclides to decay, and eventually to result in stable nuclides, makes it attractive to store radioactive waste until the established exemption level has been reached. Although a very useful option, there are prerequisites to be met and limitations to its applicability.

Half-lives of the radionuclides in the waste must be short to allow the exemption level to be reached in a reasonable time, at most a few years. In practice, the half-life must thus not exceed one or at most a few months. For example, with a half-life of one month, the activity will be reduced by a factor of 4000 in one year and 16 million in 2 years.

In order to be able to practice this option, it is necessary to have exemption levels established by the national regulatory body. There are no international derived exemption levels. However, there has been agreement on the basic principles for exemption, and the IAEA is now preparing appropriate guidance.

The main advantage with this option is that it can be done by every waste producer, avoiding unnecessary transport of radioactive materials. If properly applied, the option also prevents storage of unnecessarily large quantities of radioactive waste, since the wastes which have reached exemption levels can be removed.

To implement the option successfully, there needs to be an operational system of waste segregation to ensure that the short-lived waste is properly separated from the long-lived wastes. Radionuclides having the longest half-lives in a waste package will determine the storage time required for decay.

Although suitable for almost all radioactive waste generated in diagnostic nuclear medicine, this option has only limited application for sealed radiation sources.

Short-term storage followed by near surface disposal. A simplified procedure may be: *The waste producer transports (before or after conditioning) the waste to a national central waste processing and storage facility for subsequent disposal in a near-surface repository.*

Radioactive wastes with half-lives below the order of 30 years can normally, after being properly conditioned, be disposed of in a shallow land repository. Establishment and operation of these repositories is technically mature and there is no major disagreement among experts on the acceptability of the concept, provided that proper limitations and conditions are given for the waste and the repository. There might still be disagreement among politicians, people requiring "no risks" and those who, for whatever reasons, are against nuclear energy.

Almost every country can, in principle, establish a near-surface repository on its territory for disposing of short-lived waste generated in the country. Since the quantities would be small, it is normally not justified to have more than one, or very few, repositories in a country. The cost for a repository for small quantities of short-lived waste is not unacceptable even for small countries, since simple solutions will be adequate for a small waste producer.

Radioactive waste for such storage or disposal needs to be properly conditioned. These operations often can not be done by every waste producer, but rather by a central waste operating organization. The IAEA has developed a generic description of a waste treatment and storage facility, intended for a country having a nuclear research centre with a research reactor. The package includes detailed descriptions of the facility and the equipment used, lay-out drawings, and a generic safety assessment of the facility. The package was recently made available to IAEA Member States, and has already been used for new central waste management and storage facilities. A similar design package for conditioning and interim storage of spent radiation sources has recently been completed and will be made available to Member States in 1994.

To implement the option, a country has to establish a central waste processing and storage facility at which the waste can be stored until disposal in a near-surface repository. The country will, sooner or later, have to establish such a repository for its short-lived radioactive wastes.

Long-term storage followed by deep geological disposal. A simplified procedure may be: *The waste producer transports (before or after conditioning) the waste to a national central waste processing and storage facility. If required, the waste is later transported to a regional store for long-term storage awaiting deep geological disposal.*

There is waste from nuclear applications which is not suitable for near-surface disposal owing to its long half-life and activity. These wastes notably include sealed sources containing radium-226 and americium-241. As discussed in the IAEA's 1991 report *The Nature and Magnitude of the Problem of Spent Radiation Sources* (IAEA TECDOC-620), it is expected that those radiation sources should be disposed of in deep geological repositories.

Establishment of a deep geological repository is extremely expensive. The cost can not be borne by countries having only sealed radiation sources for deep geological disposal. A country having nuclear power must, on the other hand, establish such a repository. Since the activity of the sealed radiation sources is negligible in comparison to what exists in spent fuel or high-level waste, one suggested solution is to dispose of the long-lived sealed sources, including those from foreign countries, along with the high-level waste from the nuclear power reactors.

The co-disposal of sealed sources from one country with high-level wastes in another country will require international or bilateral agreements. Although there is no urgency in having such agreements, considering that deep geological repositories will not be established until well into the next century, it might still be wise to initiate the process, which most likely will be both difficult and time consuming.

Until the availability of deep geological repositories, interim stores for the conditioned waste are needed which can be safely operated for many decades. Considering that the volumes are very small and the requirements for interim stores are high, it is also desirable to find regional solutions for the long-term storage of conditioned long-lived sealed sources. The IAEA has initiated a process for establishing such a regional approach.

Much national legislation today prohibits import of radioactive waste for disposal and there are political statements to the effect that "all countries shall take care of and dispose of their own waste". The background of those requirements and statements, however, is the fear of having the large quantities of radioactive waste from the nuclear power plants and not the small quantities of radioactive waste from, for example, medical applications.

The final steps in managing long-lived spent radiation sources are not yet at hand. Before they can be taken, decisions will be required on the need for regional long-term stores and international or bilateral agreements on the co-disposal of sealed sources and high-level wastes from nuclear power reactors.

The range of radiation applications includes radiography, typically used in the airline and steel industries for reasons of safety and quality control.
(Credits: Tech/Ops; Dahlström, Bildhuset Sweden)

Challenges ahead

It is possible today to manage, on a national basis, all radioactive waste generated from nuclear applications with the exception of a few long-lived sealed radiation sources which require international solutions. If it actually can be accomplished in a country is a question of the availability of national expertise and resources. The IAEA is assisting its Member States to give them that possibility. However, there is still a long way to go before most Member States will have been able to establish an appropriate national waste management infrastructure. ❐