CURRENT PRACTICES IN INDIA FOR MANAGEMENT OF DISUSED RADIATION SOURCES

N. K. Bansal, K. Raj, S. Kumar
Nuclear Recycle Group
Bhabha Atomic Research Centre, Bombay, Mumbai – 400 085, India

Abstract

In India, the various isotopes are being used all over the country in large numbers in hospitals, industries and research institutions. In hospitals, these are mainly used for radiotherapy and diagnostic investigations. Some of the industries using radiation sources are steel, paper, petroleum, cement, fertiliser, metal refineries and thermal power stations. Radiation sources are also used in various electronic instruments and radiography. Research institutions normally use radiotracers and irradiators for studying materials. Some sources are used for calibration of nucleonic instruments.

The majority of these isotopes are produced in India and few are imported. Dedicated facilities are existing for converting these isotopes, into usable form and shape. These radiation sources are supplied by Board of Radiation & Isotope Technology (BRIT) or routed through BRIT if imported from another country. To keep a proper inventory and control over the use of these radioisotopes all relevant information pertaining to these sources are available with Atomic Energy Regulatory Authority (AERB), AERB also provides guidance with respect to the management of sources.

Sources are normally sealed in stainless steel capsule or impregnated in materials with adequate mechanical strength and are loaded in the respective gadgets. These gadgets with good locking mechanism can be unloaded only by authorised persons specially trained for such works, with special tools and usually in hot cell. Such facility is available in Bhabha Atomic Research Centre (BARC) at Trombay and Kalpakkam. Strength of source varies from instrument to instrument and depends upon the operational requirements. Normally level and thickness gauges are loaded with 37-MBq to 370-MBq of Co-60. However for higher material thickness measurement, sources with strength up to 111-GBq are used. Teletherapy units with 78-TBq of Co-60 and 40-TBq of Co-60 are in use.

The source is replenished with new source and the depleted sources are sent as solid waste. Some of the depleted sources may be suitable for other kind of applications and are put to reuse. Due to failure or malfunctioning of gauge's mechanism, nucleonic gauges as such become un-serviceable and such gauges are also treated as solid wastes.

Small sources are packed in container with sufficient shielding. For example, radium needles used in hospitals are placed in SS capsules and impregnated in wax; the capsule is then loaded in lead transport cask. The transport cask is again packed in a wooden crate with all information about the source. The wooden crate is labelled with radiation symbol, sender's and consigner's address etc. The sources from equipment like radiography unit and nuclear gauge are not decasked at user's premises but are packed in wooden crate or metal container having all information and labelled as mentioned earlier. The necessary radiation shielding is provided to keep the contact dose on the package as low as 0.01 to 0.02 mGy/hr. The package is sent by railway or by road preferably on door–to–door delivery basis, to avoid repeated handling, misplacing, pilferage and delay in transport.

The radioactive sources loaded in radiography units or in gauges are decasked and relocated in small steel container. The void between source and the container is filled with cement grout. If required this processing is carried out in shielded glow box having remote handling facilities. At BARC Trombay, in

Western India, a Radioactive Solid Management Site (RSMS) is in operation for last more than three decades to meet the requirements of proper disposal of radioactive solid waste. Other facility is in operation at Centralised Waste Management Facilities (CWMF) at Kalpakkam in Southern part of the country. The solid radioactive waste is disposed/ stored in engineered facilities depending upon the type and activity of isotopes present as well as the radiation field on the surface. Low and intermediate level radioactive waste contaminated with isotopes having half life less 30 years is disposed in shallow ground in engineered facility like reinforced concrete trench. If solid waste contains significant amount of transuranic isotopes or having radiation field of more than 500-mGy/hr, such consignments are stored in retrievable manner in tile hole. Tile hole is a cylindrical concrete lined steel container and about 4-m. deep below ground. Its outer surface is also concrete lined and provided with cement-based water proofing treatment. The filled tile hole is sealed at top with concrete and finally water proofed.

The experience in management of disused radiation sources in the country has been quite safe and satisfactory. One of the important feature is that no financial charges are levied on the radioisotope user with respect to management of disused sources and the Department of Atomic Energy is providing all services including guidance and consultancy for their safe use and disposal.

INTRODUCTION

In India, sealed radioactive sources have been used for many decades and have enabled unique application not possible by other means. These radioactive sources are used in hospitals, industries, agriculture and research institutions. Smoke detectors, moisture meters, radiographic equipment and well logging devices are a few examples of their broad use. In hospitals, these are mainly used for radiotherapy and diagnostic investigations. Radiation sources are also used in medicine and various electronic instruments. Research institutions normally use radiotracers and irradiators for studying materials. Some sources are used for calibration of nucleonic instruments. These radioactive sources may lead to radiological accidents if not properly managed. There are large numbers of sealed radioactive sources in use countrywide. Due to the limited operational lifetime of sealed radioactive sources, many of them are no longer in use and require safe management.

Isotopes Production and Supply

The majority of isotopes used in radiation sources are produced in India and a few are imported. The details of commonly used radiation sources are presented in Table I.

Dedicated facilities are existing for converting these isotopes into usable form and shape. These radiation sources are supplied by Board of Radiation & Isotope Technology (BRIT). To keep a proper inventory and control over the use of these radioisotopes, all relevant information like radionuclide, type of radiation, activity, half life, energy, dose conversion factors, physical condition and chemical and physical form etc. are available with Atomic Energy Regulatory Board (AERB), which is the centralised regulatory authority in India. Personnel from AERB regularly visit the users located all over the country at their premises and assess the condition of these sources. Accordingly, the user is advised with respect to the management of sources. BRIT also supplies various radiation sources to other countries.

Table I Commonly used radiation sources in India

Radionuclide	Half-life	Source Activity	Application
Am-241	433-a	1 – 10GBq.	Smoke detector, thickness gauge
Co-60	5.29-a	Up to 1000 TBq.	Irradiator, gauging
Cs-137	30-a	Up to 500 TBq.	Irradiator, gauging, well logging
Fe-55	2.6-a	Up to 5 GBq.	Thickness gauge, moisture detector
Gd-153	244-d	1- 40 GBq.	Bone densitometry, nuclear medicine
H-3	12.3-a	1- 10 TBq	Tracer, electron capture detector
I-125	60-d	1- 10 GBq	Bone densitometry, nuclear medicine
Ir-192	74-d	200-1500 MBq.	Brachytherapy
Kr-85	10.7 a	1- 100 GBq	Thickness gauge, well logging
Mo-99	67-h	1- 100 GBq	Nuclear medicine
Pm-147	2.6-a	< 4 MBq.	Calibration sources, thickness gauge
Po-210	138-d	Up to 20 GBq.	Static eliminators
Ra-226	1600-a	Up to 10 MBq	Brachytherapy, calibration sources
Sr-90	28-a	50-1500 MBq	Brachytherapy, gauging
Tc-99	6-h	Up to 100 GBq	Clinical measurements, biological research
Tl-201	3-d	Up to 200 MBq	Clinical measurements
Ni-63	100 a	Up to 50 GBq.	Research in pesticide residue analysis
Am-241-Be	433-a	Up to 5 GBq	Oil exploration, geological survey

Types of Source and Source Characterisation

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

Alpha sources

Beta sources

Gamma sources

Neutron sources

Other sources for special use.

These sealed radioactive sources are utilised for various applications and strength of the source varies from instrument to instrument which depends upon the operational requirements. Normally the sources of the order of 37 MBq to 370 MBq. of Co^{60} are used in level and thickness gauges. Sources of the order of 100 TBq. are used country wide for teletherapy in radiology. Sources in the TBq - PBq. range are used in research irradiators and sources of PBq. are used for sterilisation and food irradiation.

Sources are normally sealed in stainless steel capsule or impregnated in materials with adequate mechanical strength and are loaded in gadget. These gadgets with good locking mechanism can only be unloaded by authorised persons specially trained for such works, with special tools and have theoretical and practical knowledge to deal with the wide range of sources. Such facility is available in Bhabha Atomic Research Centre (BARC) at Trombay.

Data with respect to disposal of disused / spent sources is gathered, including the source and device manufacturer, model number, serial number, nuclide, activity and manufacturing date. Design specifications and procedures for loading and unloading of sources from the apparatus are also obtained. This facilitates the planning of handling, conditioning and storage operations and increases the quality of the technical information retained in record.

Temporary Storage and Packing

The radionuclides which have been most commonly used to produce radioactive sources are ^{60}Co, ^{137}Cs, ^{241}Am and ^{192}Ir . These sources are replenished with new sources as time passes due to the limited operational lifetime. Such depleted sources are treated as solid waste. Due to failure or malfunctioning of gauge's mechanism, nucleonic gauges become un-serviceable and such gauges are also treated as solid wastes. Temporary storage takes place when a radioactive source is stored as a solid waste as an interim measure after being taken out of service.

Such sources are decommissioned from their locations along with the working shield and made safe for temporary storage with-in the control of the user premises. At this stage, care is taken to avoid separation of the sources from its shield and no attempt is permitted to disable any interlocking system or safety feature. Transfer of the source from its location to temporary storage is done according to approved procedure by trained personnel only.

Some of the depleted sources may be suitable for other kind of application. The established policy is to encourage the recycling or reuse of depleted radioactive sources wherever possible. They are put to reuse depending upon the commercial demand for the recycled product.

Sources of short half-lives are allowed to decay during temporary storage at user's premises. Temporary storage is also beneficial to wait for sufficient numbers of depleted sources, so that all accumulated sources, similar in nature, can be sent for long term storage or disposal in a single consignment. This helps in reduction of transportation cost. Different stages in the management system are:

Temporary storage at user's premises

Transport to waste management site

Reuse or treatment and conditioning

Disposal

Authorisation Procedure

Radioisotope user informs Atomic Energy Regulatory Board (AERB) about the need to dispose the source. AERB gets all the relevant information about the source like radionuclide, type of radiation, activity, half-life, energy, dose conversion factors and chemical and physical form etc. from user in a standard proforma, as per Annexure, along with all documents and drawings. This information is also provided to Waste Management Division (WMD) of BARC and a formal concurrence is obtained by AERB from WMD for disposal. Personnel from Radiation Safety Division (RSD) of AERB visit the user and after inspecting the gadget, advise them about the proper requirement of packaging for safe transportation. AERB ensures that these sources are properly packed, labelled and marked as per the regulation of the safe transport of radioactive material. Transport permission is accorded by AERB to the user for the transport of disused sources under intimation to WMD.

Packaging for Transportation to a Conditioning Facility

Sources to be transported to the conditioning / long term storage facility are packed to meet transport regulation. Depending on shape, size, geometry, activity content and radiation field suitable transport containers, shielded casks and over packs are used where construction of working shield is not directly suitable for transport. Small sources are packed in suitable container with sufficient shielding. For example, radium needles used in hospitals are placed in stainless steel capsules and impregnated in wax. The capsule is then loaded in lead shielded transport cask. The transport cask is again packed in a wooden crate with all information about the source. The wooden crate is labelled with radiation symbol, sender’s and consigner’s (RSD/BARC) address etc. The sources from equipment like radiography unit and nucleonic gauges are not decasked at user’s premises but are packed in wooden crates or metal containers having all the information and labelled as mentioned earlier. The necessary radiation shielding is provided to keep the contact dose on the package less than 2 mGy/hr.

All these packages are transported by rail or road preferably on door delivery basis, to avoid repeated handling, misplacing, pilferage and delay in transport of the package. The sender intimates RSD about the mode of transport, transporting agency and date of dispatch of the package. At the receiving end at BARC, package is inspected for any external damage. The package is opened by trained personnel to verify the content of the package with the document earlier provided by user/sender.

Short Term Storage Facility

Radioactive Solid Waste Management Site (RSMS) at Trombay and Centralised Waste Management Facility (CWMF) at Kalpakkam are part of Indian programme for disposal of low and intermediate level waste from other activities of nuclear fuel cycle. All the depleted sources from western, northern and eastern part of the country, received from different users, are stored in short term storage facility at RSMS. Similarly, CWMF takes care of the requirements of disposal of used spent sources from southern part of the country.

Short Term Storage area is a designated and operated as controlled area having all required tools and monitoring equipment where entry is restricted. Radiation and contamination level is regularly measured by competent authority of Radiation Hazards Control (RHC) Section as a part of the monitoring program to detect leaking sources or defective shields and packages. Checking the effectiveness of the ventilation is also a part of the surveillance. Recommended safety measures are also taken while handling. These measures are listed in Table II.

Table II Recommended safety measures during handling based on type of radiation

Feature	**Alpha**	**Beta**	**Gamma**	**Neutron**
Shield	Paper, Halogen free Plastic	Metal foil	Heavy metal, concrete	Light materials, Cd, B or Li-containing alloys, Combined shielding.
Removal from Equipment	Glove Box	Remote Handling	Remote Handling	Remote Handling

Volume Reduction

The storage of radioactive materials is usually expensive and, therefore, volume reduction is carried out. Volume reduction for disused radioactive sources is achieved by the removal of the sources from the original device/container and grouping them together with similar sources at the time of conditioning.

Conditioning and Disposal

The conditioning is done to produce a waste package in solid form intended for long-term storage and disposal. The purpose of conditioning of disused radioactive source is to create a safe and reasonable isolation from the environment.

The radioactive sources loaded in radiography units or in gauges are decasked and relocated in small steel container. The void between source and the container is filled with cement sand grout. Some times this processing is carried out in shielded glove box having remote handling facilities. ^{226}Ra sources are embedded in wax in stainless steel container. Such processing helps in preventing the leaching of the radioactivity to the environment. This also decreases the radiation dose rate at surface of container, making it suitable and safe for handling and disposal. In the case of high dose on these packages, the same are transported to disposal sites in casks of varying shielding.

At RSMS the solid radioactive waste is conditioned and disposed in engineered facilities depending upon the isotopes present, the total activity content and the radiation field on the surface of the waste package. Complete records are maintained at WMD after receipt of these sources. Similar conditioning and disposal procedures are followed at CWMF also.

Normally all radioactive sources are disposed in tile holes as the radiation field and the activity content of these sources are moderately high. Tile hole is a cylindrical concrete lined steel container with top open and about 4 m. deep. Its outer surface is also concrete lined and provided with water proofing treatment. The void between the containers placed inside are filled with cement grout. The tile hole filled in such a way is sealed at top with concrete and finally water proofed. The contact dose on such sealed facility is kept less than 0.01 mGy/hr. A sketch of tile hole is shown in Fig. 1.

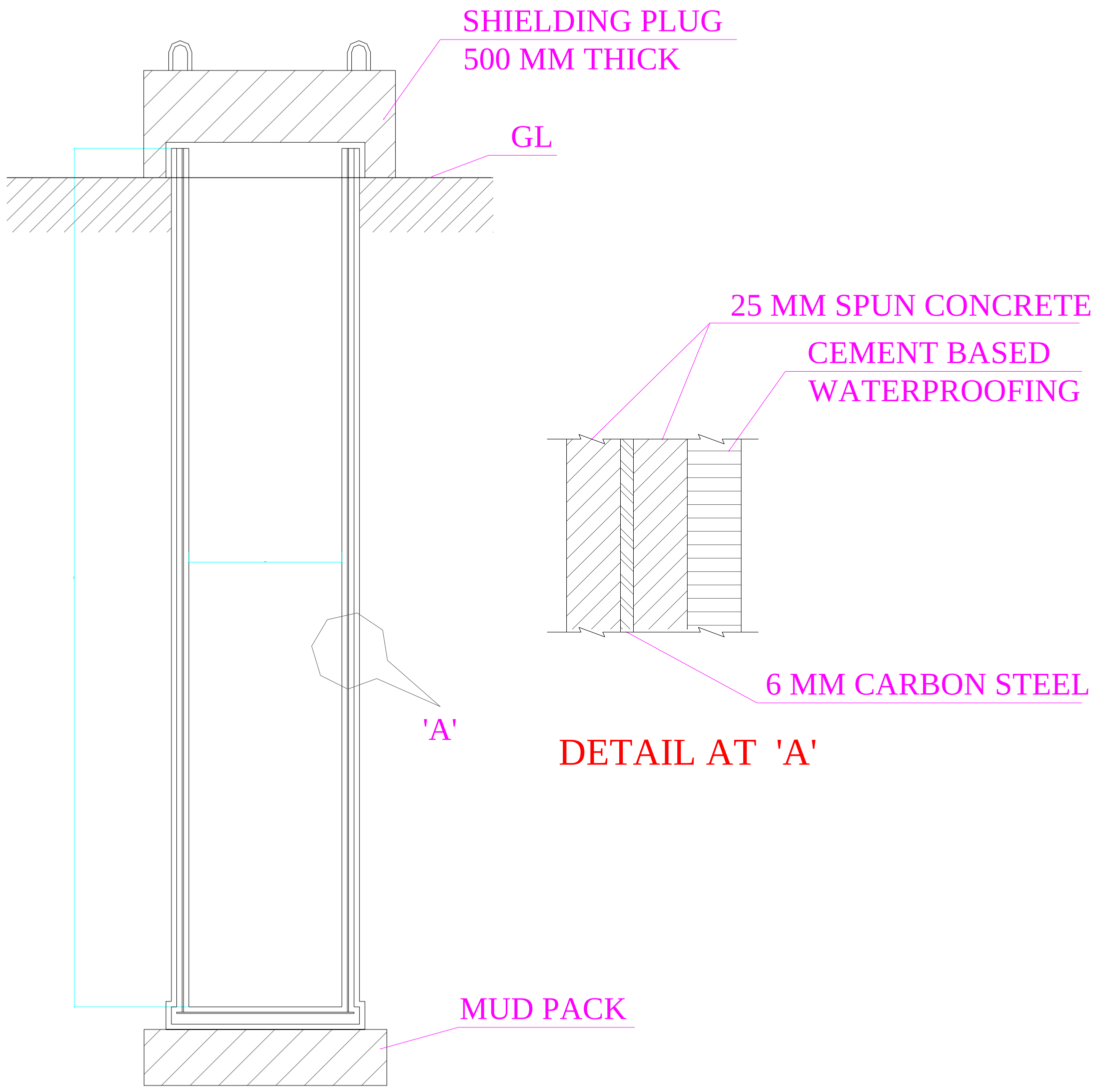

Fig. 1 Tile hole with shielding plug

On an average 85 and 10 nos of spent radiation sources mainly of ^{60}Co , ^{137}Cs and ^{192}Ir associated with 1600 GBq and 200 GBq of activity are disposed at RSMS and CWMF respectively, per annum. The current practice is not to dispose neutron sources with high alpha activity and these are being stored. Only those sources which have alpha activity of 4000 Bq/g or less are being disposed.

A Case Study

A large numbers of spent radiation sources in pencil form of ^{60}Co, from various irradiation facilities, containing about 18.5 TBq each of activity are presently being stored in tile holes. These sources having 670 TBq of activity are being stored under water and regular monitoring of temperature indicates a rise of about $10^{o}C$ above ambient temperature. As a case study for disposal of such heat generating spent sources, work was undertaken for development of a suitable cement matrix to provide better heat dissipation, thermal stability, monolithic mass and shielding. Considering the geometry of spent sources and the tile holes and uniform distribution of activity, a maximum temperature of $90^{o}C$ is likely to generate in the system. Experiments were also planned considering a heat input of 400 W at a point source in the matrix. The heat input is equivalent of 900TBq of ^{60}Co compared to 670 TBq of activity stored.

To simulate the field conditions, a metallic heater was embedded in the matrix on laboratory scale. Various matrices such as cement : sand; cement : sand: iron filling; cement: sand : iron powder were evaluated for heat dissipation and strength. A centre line temperature of $90\ ^{O}C$ was maintained and temperature recorded at various distances. The study indicated that addition of iron fillings as an ingredient in the cement matrix helps in better heat dissipation and improvement in compressive strength of conditioned product. It was concluded that a modified cement matrix (cement : sand : iron filling = 5 : 12 : 3) is having appropriate characteristic for the intended work.

Based on the optimised composition, 200 litre scale experiments (Fig. 2) were performed by simulating the actual conditions. In one experiment, a constant temperature of $90^{o}C$ was maintained at the centre of the matrix by embedding a suitable electric heater. In another experiment a constant wattage of 400 W was maintained and temperatures at various points were recorded continuously for a month. The equilibrium temperatures are given in Table III. Core drill samples were taken after heating for one month and these were evaluated for compressive strengths. No adverse effect was observed on the matrix. With a view to study the effect of prolonged heating, the experiments were continued for another six months. The core drill samples were taken after this period and tested for compressive strength.

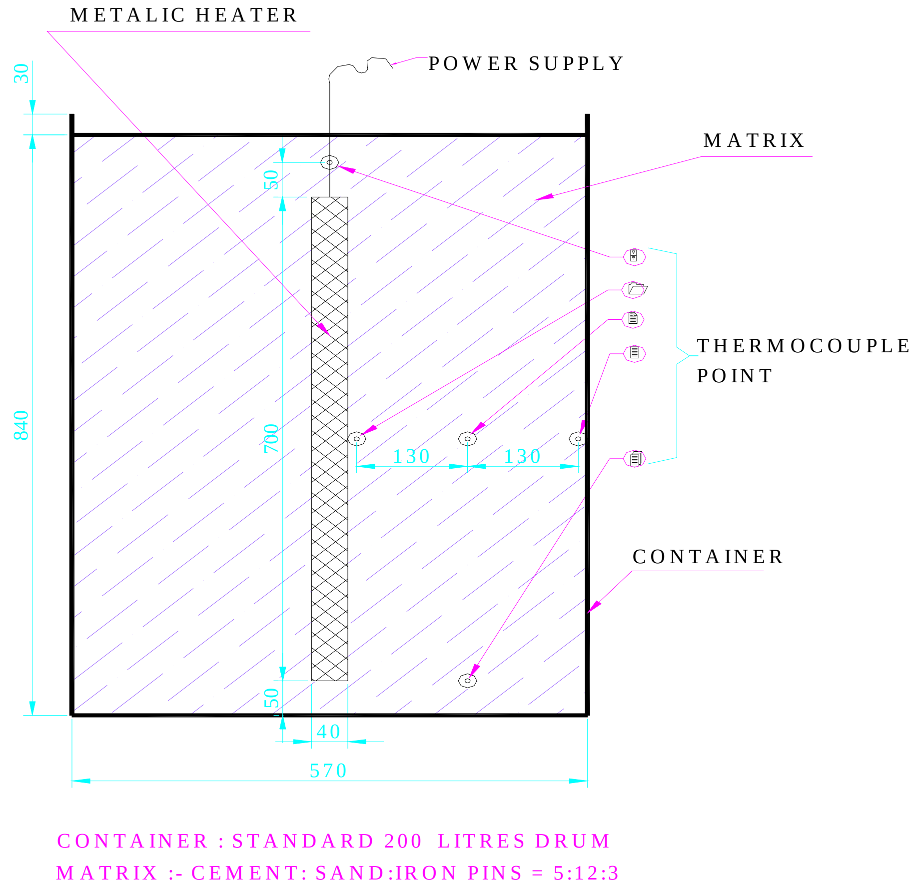

Fig. 2 Experimental set-up for studying cement matrix at elevated temperatures

Table II Equilibrium temperatures at different locations

Location No.	Equilibrium temperature, ^{o}C	
	Set-I (Constant temperature, 90^{o}C)	Set-II (Constant power, 400 W)
1.	90	315
2.	55	105
3.	44	63
4.	48	74
5.	39	53

The results of compressive strength for various temperatures at the two intervals of heating are given in Table IV. It is observed that by increasing the temperature up to 80 ^{o}C, compressive strength increases. This may be due to loss of loose water and getting a better matrix. After 100 ^{O}C, there are chances of decomposition of hydrated compounds of all silicates of calcium, aluminium and iron present in cement matrix by loosing water of hydration and, thereby, compressive strength is likely to get affected. By prolonged heating, the curing is continued till the maximum strength is achieved and may remain constant. The compressive strength, 68 kg/cm^2 at 300 ^{O}C, the peak temperature is well above the acceptable value of 50 Kg/cm^2 for disposal in NSDF.

Table IV Studies on compressive strength with respect to temperature

Temp. ^{o}C	Compressive strength of matrix Kg/cm^2	
	After one month heating	After seven months heating
40	66	148
80	124	173
150	120	125
200	107	80
300	-	68

The compressive strength and equilibrium temperature results have established that the matrix (cement: sand: iron fillings = 5 : 12 : 3) can be successfully employed for the immobilisation of these sources.

CONCLUSION

Spent radiation sources are being used in India on a very large scale all over the country for various applications. After their useful life, majority of these are conditioned and stored/disposed at near surface disposal facilities located at Trombay and Kalpakkam. The transportation and disposal is authorised by Atomic Energy Regulatory Board which is the national competent authority. Valuable experience exists in all aspects of management of spent radiation sources. The case study described in the paper pertains to management of ^{60}Co sources with high specific activity used in irradiation facilities including development of suitable matrix. One of the important feature of management of spent radiation sources in India is that no financial charges are levied on the radioisotope users for storage/disposal of disused sources and Bhabha Atomic Research Centre is providing all services including guidance and consultancy for their safe use and disposal.

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