STATUS AND TRENDS OF THE MANAGEMENT OF DISUSED SEALED RADIOACTIVE SOURCES

M. Al-Mughrabi, J. Balla
Division of Nuclear Fuel Cycle and Waste Technology
Nuclear Energy Department, IAEA

ABSTRACT

Sealed radioactive sources have been used widely in health, industry, agriculture and geological exploration over the last six decades. The large number of the sealed sources, many of them of high activity, generates certain risk for the users and the public. The risk depends on whether the source is in operation or disused and also different country by country where the source is operating or stored. For a long time the control of the sealed sources was not and in many cases still not well established in many countries although almost all the countries of the world have established their own regulatory organizations. In many countries the managing of sealed radioactive sources is far from the necessary level due to the lack of funds, professional expertise or existence of technical and logistical requirements.

The history of the accidents caused by sealed radioactive sources in the last decades shows that on the average 30 incidents and 2-3 accidents happen and 1-3 people die per year where radioactive sources were involved. In many cases serious radiation injuries occur as well. It can be said that the sealed sources cause the majority of human death in the nuclear industry. Due to the complete lack of control or the non-perfect control in the sixties and the seventies many disused sealed sources slipped out of control and were lost. The accidents and the human death/injury incidents that occurred warned the international professional community dealing with radioactive sources that immediate actions were needed. Several countries and the IAEA recognized this need and reasonable developments were performed.

IAEA has strengthened the work on the SRS management giving direct assistance for member and non –member states and providing training for the persons involved in the management of disused sealed radioactive sources. The IAEA's activity to drive the development of new technologies and to propose these technologies for the safe management of disused sealed radioactive sources–especially in developing countries- is an important tool to minimize the risk generated by disused sources.

INTRODUCTION

Nuclear technology has useful applications in various fields especially in medicine, agriculture, industry and geological explorations. In order to use the useful radiation in a less restrictive manner and with acceptable safety conditions, the radioactive material is encapsulated to prevent any possibility of the radioactive material from finding its way to the environment. This makes the material in the form of a sealed source of radiation. To provide a biological shield and control the radiation field where and when needed the source of radiation is placed in a shield with certain safety measures. Such sources became common tools from the early days of the nuclear age. The management of these sealed radioactive sources (SRS), once they are no longer in use, was not up to the acceptable standards of today. This had led, over the years, to a large number of sources being poorly managed or outside control.

The substantial technological development and the higher quality assurance requirements have led to an increase in the number of SRS utilized in various disciplines. While radiation safety standards and radiation protection guidelines have been developed and applied in the nuclear facilities, the sealed sources being used outside such facilities did not receive the same attention and were not, in many cases, dealt with in the correct manner. This is particularly true when they were no longer in use. As a result many sources were abandoned, stored inappropriately or disposed of in the wrong fashion. Their specific and total activity as well as former manufacturing procedures were indications of the potential danger looming around the corner.[1]. As their numbers grew so did the risk involved. From 1953 to 1986, 23 deaths and 155 cases of significant exposure from solely sealed sources were reported. These, however, were mainly isolated cases during normal utilization of SRSs and affected a limited number of people involved. The real turning point was reached in 1987 when a teletherapy source was abandoned at the old premises of a clinic in Gioania, Brazil which resulted in an accident that caused fatal injuries, over exposure and a wide spread contamination over a large area. It has also demonstrated the potential economic, social, medical and environmental damage that can be inflicted if such sources are mistreated.[2]

Consequently, the area of SRS received more attention and a programme on the international level was planned to provide technical know-how, further guidelines and in some cases direct assistance where deemed useful. The programme was launched in 1990 by the International Atomic Energy Agency (IAEA) and included among other things assessment of the magnitude of the problem [3]. Technical manuals aiming at providing step-by-step guidance to dealing with SRS handing, conditioning and disposal were also developed.[4-9] Safety Standards and guidelines on the subject were issued to help regulatory bodies deal with the problem.[10-15]

However, accidents continued to occur and due to the sources involved having higher activities the injuries and fatalities went on the rise also [16]. In this paper, the international status of SRS management will be presented and the trend of management will be will be highlighted. Several areas of importance for the proper management of sources will be discussed.

Source Status

A disused SRS [17] is a source that is not in active use. If no further use of the sources is expected the user should consider the source as disused and take necessary actions to declare it as such. It is important to emphasize that a source declared by a user as disused may still be used by a different user, supplier or manufacturer in the future. Reasons for disuse can vary from too weak of activity, obsolete equipment, damage to the source or use of alternative technology to stop of the practice due to change in priorities or field of activity. Defining the source status is very important to the management of the source, especially that sources tend to get much less attention once no longer in use. Experience has shown that it is not always easy to define exactly when a source should be considered as disused. Sources in transition from being used to disused could pose special problems. And may be more difficult to deal with. For example:

- Sources that are 'temporarily out of use for operational reasons;
- Sources that may be used by another user for a different application;

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

Such sources are usually kept in a temporary store, their status is not very clear and their control slowly slips away. While management of a source applies for the whole lifetime of a source whether in use or use has ceased. The management of the source we are concerned with here is the source that is no longer in use. The terms "spent", "orphaned" and "disused" are used among others to mean that the source is no longer utilized for the intended purpose. Sources that are addressed in this paper are all sealed sources that are not in active use.

Infrastructure and Legacy

Countries lacking radiation protection and proper waste management infrastructure may not recognize the risks from disused radioactive sources. Some other developed countries, with extensive use of SRS, may underestimate the risks involved with these sources and may not have full control of their radioactive sources, even though they have adequate legislation, radiation protection and waste management infrastructure. While the number of sources in a developing country is relatively small the probability of an accident is high due to the lack of the required infrastructure. The sheer number of sources in developed countries is quite large and hence the risk is not negligible even though the probability of an accident is quite small (as an example, the NRC receives about 300 reports of lost, stolen or abandoned radioactive sources and devices per year). Other countries do not give high enough priority to the problem because there are larger and more urgent issues taking the available resources. In summary, it cannot be over emphasized that the risk of an accident with a sealed source is real and not a negligible one. [a]

Disused sealed sources, in best actual conditions, are stored in locations that are, in many cases, irregularly visited. Unless there is a conditioning campaign or an inspection of the sources, disused sources are not dealt with frequently. If no proper management system is put in place, this nature makes them more susceptible to being forgotten and ignored. This increases the risk of an accident and needs to be given top priority in source control. Disused sealed sources are frequently found somewhere in the world outside any control.

The IAEA maintains Illicit Trafficking Database (ITDB), which records information on incidents involving illicit trafficking in nuclear and other radioactive materials both authoritative, i.e. confirmed by States, and that obtained from open media sources, which is yet to be confirmed by States involved. Between 1993 and 2003, the ITDB recorded a total of 323 confirmed incidents [18] involving illicit trafficking [b] in radioactive sources, which amounts to an average of 30 cases per year. A considerable share of these incidents involved discoveries of uncontrolled radioactive sources, i.e. orphan sources. The ITDB statistics is based on information from a little over 80 Member States of the Agency. There is also a considerable number of incidents pending confirmation which allegedly involved unauthorized activities involving radioactive sources.

Figure 1 below shows that the number of confirmed incidents involving illicit trafficking in radioactive sources has been on the increase since 1996 (with the exception of 2002) with the highest number recorded in 2003. In 2004, this upward trend is continuing with the number of such cases expected to be higher than in 2003.

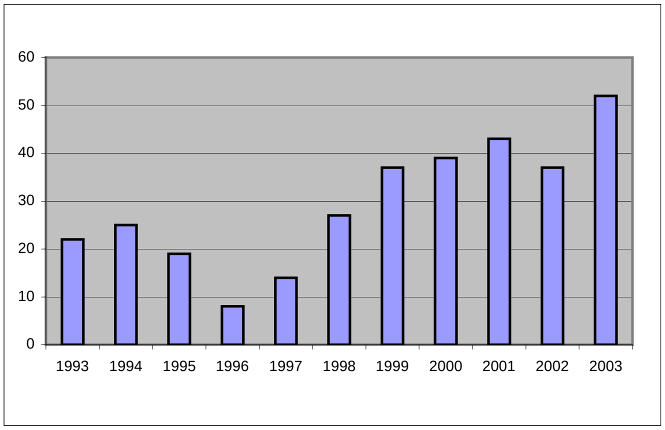

Fig. 1. Confirmed incidents involving illicit trafficking in radioactive sources, 1993-2003

Figure 2 and Figure 3 show distribution of the sources involved in confirmed trafficking incidents according to their activity level and the radioisotope involved. The most of the radioactive sources involved in confirmed trafficking incidents have had activity levels too low to be of serious radiological concern (Figure 2). These sources fall under Categories 4 and 5 of the IAEA Categorization of Radioactive Sources [19]. About 40 incidents were confirmed to the ITDB between 1993 and 2003, which involved radioactive sources falling under Categories 1-3. Some of these cases could be deadly. It is to be mentioned that a considerable number of incidents have involved radioactive sources with unidentified activity levels and/or applications.

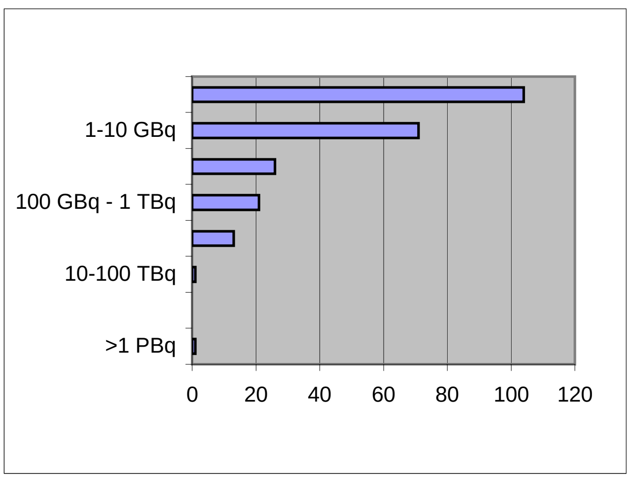

Fig. 2. Confirmed trafficking in radioactive sources, by activity level, 1993-2003

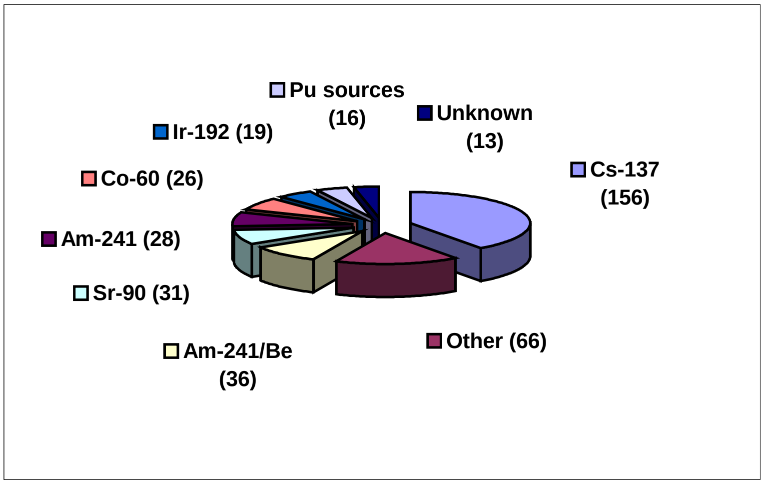

Fig. 3. Confirmed incidents with radioactive sources, by radioisotope involved, 1993-2003

Proper management and source control became into actual being relatively recently even in developed countries. Most developing countries still do not have the personnel and the facilities required to deal with the SRS problem effectively and efficiently. Over the first four decades of utilization of Nuclear Energy source control and security was not well established. Source management was vaguely defined and poorly implemented over a long time in most countries. This had led to sources with considerable radioactivity piling up in many countries. Many of these sources were manufactured to lower technology standards which make them susceptible to leakage and damage. Furthermore, most of these sources were shipped world wide in shipping containers that no longer are licensed for transport or shipped in their working shield utilizing special arrangement. In some cases, the source is fit to the equipment with no intention of exchanging it with another one. Since any conditioning operation will involve transport in most cases this has limited the choices with regard to conditioning and rendering such sources safe. Some sources have a depleted uranium shield making not only the source but dealing with the original shield as a problem also.

Source Inventory and Status

Accurate information on the numbers of sealed sources in use worldwide is not accessible. An estimate of source numbers was made by IAEA in early nineties based on data available in TECDOC 620 "Nature and magnitude of the problem of spent radiation sources" [20]**.** This included information on high activity sources such as commercial irradiators and teletherapy devices. There is some evidence today that the figures may have been an underestimation. Information accessed in 1999 from the web site of a major supplier of radiation therapy equipment indicates that 2500 units have been installed by one company alone. The company has encapsulated over 5000 sources and over 1600 PBq (over 40 million Ci) over the past five decades and installed over 2500 cobalt-60 radiation therapy units in more than 50 countries. This provides a clear indication of the magnitude of the legacy of source utilization over several decades.

While it is recognizable that even where full good control has been practiced for a long time source inventory is still well below the actual number of sources. Such countries, however, give a good hint to source inventory worldwide. Taking the US as an example, over 170 000 licenses authorizing the use of nuclear material have been issued. There are over 1200 manufacturers and distributors of Sealed Radioactive Sources or equipment with approximately 3500 active products and well over 1500 products that are no longer manufactured. Nearly 2 million devices containing radioactive sources (e.g. measuring gauging and controlling devices) have been used under general license in the United States alone [21].

On a worldwide level, it is also important to observe that the source inventories are quite dynamic. Especially in cases when many of the current sources are manufactured using Ir-192 with a 74 days half-life. Almost all of these sources are frequently replaced on a regular basis. Such sources have a useful life of several months but need to be managed as waste for a period of 2-3 years. Furthermore, numerous process control installations in the oil, textile, paper and other industries utilize sources in equipment and installation without clear indications of the presence of the sealed source. Many users in least developing countries are still not required to have a license due to lack of regulations. Hence, many of these sources are not available for accountancy. It is believed that the number of sealed sources worldwide that should be under regulatory control is around ten to fifteen millions.

It is important to note here that many of the world stock of sealed sources are relatively low activity sources for process control, brachytherapy or calibration purposes. Many others are for non-destructive testing with several half-lives elapsed since their use has been stopped. A considerable number of these sources have been taken by the manufacturers for replacement with new sources. This limits the number of sources that are posing a real threat and are responsible for most of the accidents. This number is believed to be in the order of several hundred thousands worldwide [22]. Figure 4 gives an impression of the degree of difficulties involved in dealing with the various types of sources as waste.

Teletherapy sources are common sources used in Oncology Departments for cancer treatment. Their use started in the early fifties and many of the earlier designs used Cs-137 without the option of source replacements. Later the manufacturers supplied the new machines with Co-60 sources. Almost all countries have several tens of teletherapy heads that are no longer in use. In many cases such sources are stored in unacceptable conditions. Their security is much in question and their treatment as normal scrap is too probable. Most accidents have occurred when such equipment was mixed with normal metal waste and mistaken for a valuable scrap.

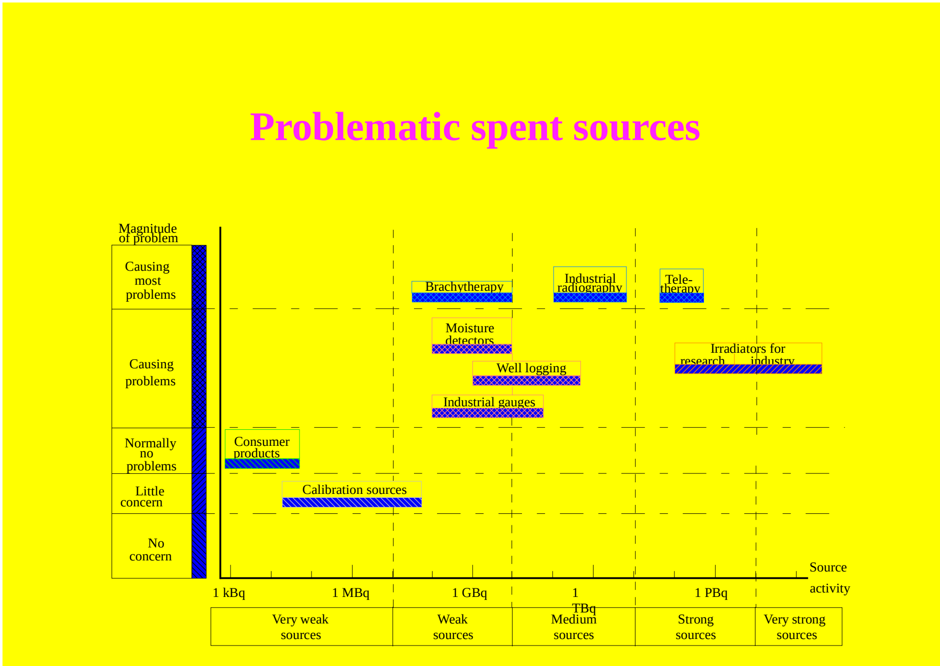

Fig. 4. Degree of difficulty within various types of sources

Radiography equipment being widely used for non-destructive testing is very common equipment that has caused many accidents in the past. Their mobility and use outside a specialized facility makes them a potential danger. Blood irradiators and other irradiators for scientific research also pose a special problem due to the size and activity involved. The second category above while easier to handle and deal with, their size or application makes their displacement very easy (e.g. brachytherapy sources). These sources are widely spread in almost all countries; especially radium sources that where used for brachytherapy for most of the fifties, sixties and seventies. The number of radium needles alone is estimated to be several hundred thousands. 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.

Large industrial irradiators usually have, by design, good security measures in place. During normal operation of these facilities the sources are safely protected although in some cases the safety rules had been over ridden and the consequences were grave (most of these events were caused by the inadequate actions of the staff involved). Irradiators that are no longer in use still require a good deal of attention. Pool type irradiators need to maintain the water quality and water level, dry storage irradiators require regular control against source leakage.

National Infrastructure

There is no national infrastructure that only deals with sealed radioactive sources. Naturally, the existing infrastructure in a given country deals with the radioactive waste issues including SRS. This infrastructure varies in diversity and complexity from one country to another. At one end of the spectrum are developed countries to the other extreme with a very limited nuclear application. This wide spectrum makes it impractical to give specific description for individual countries.

For practical reasons the IAEA classification of member states (Figure 4) is used to cover the infrastructure status on an international level [23]. It is worth mentioning here that while the categorization tried to cover all countries in a practical manner, some countries may fall below extent of class A in regard to nuclear activity within the country and others may go beyond class D at the other end. Some other countries, while they may have a nuclear fuel cycle related facility, may not have either power reactors or research reactors. Their infrastructure maybe very similar to class A or B if you take the facility connected to the fuel cycle out of the over all picture of such country's infrastructure. This description is solely intended to give an idea on the situation on a global level.

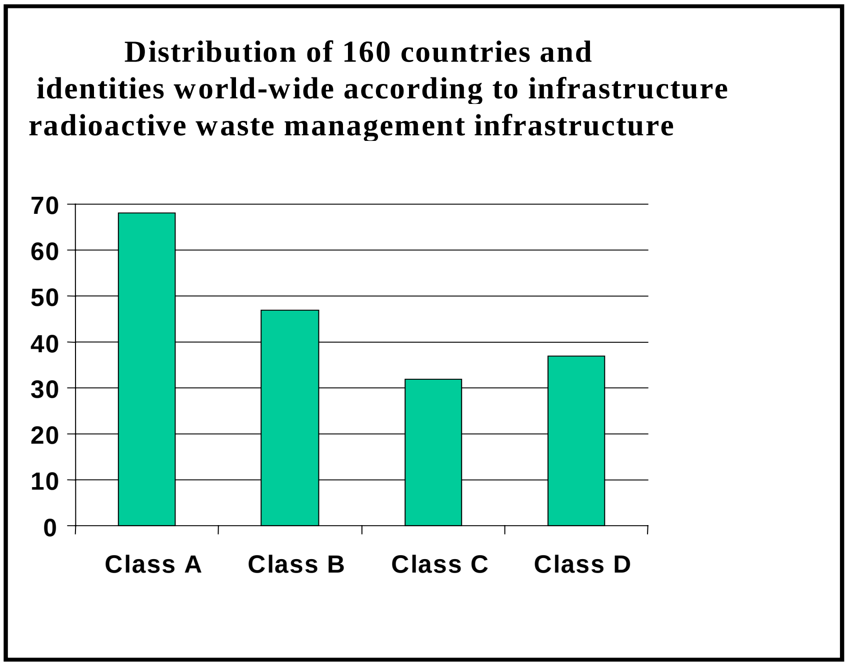

Fig. 4. Distribution of countries

National Programmes

It is generally presumed that a national infrastructure to enable a national government to delegate its responsibilities for radiation protection, safety and waste management is in place. This in many countries is not the case. There is also a misunderstanding between the functions to be covered and the administrative and technical requirements to cover them. While the infrastructure generally covers the following:

- 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.

In actual fact most of the countries in Class A and B lack the above. It is only recently with IAEA assistance that legislations are being implemented. The draw back is that many countries still lack the required technical infrastructure for third and forth points above. In Class C countries, while many have the infrastructure, we find that the emphasis is on the utilization technology and waste management takes a secondary priority. This results in many of the countries of C and D classes with less funds being provided than are actually needed to take care of sources in an effective and efficient way.

National infrastructures must also provide facilities and services that are essential 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 disused SRS and
- detection of any build-up or transport of radioactive substances in the country.

In most cases we may only find services with regard to dosimetry and general waste management in a broad sense in limited cases. The infrastructure required maybe very simple or maybe more elaborate depending on the extent, type, amount and nature of waste involved. Developing countries on one hand have only a limited number of sources but lack the required infrastructure. Even the limited requirements to deal with the situation are still, in many cases, beyond their capabilities.

A common problem in most developing countries is dealing with high activity and long-lived intermediate activity sources. This problem is not within the technical capabilities of most of these countries. Furthermore, the building of such capabilities is a long-term objective that may be too difficult to build in the time frame required to deal with many sources; sources with treatment already overdue. This makes regional and inter-regional co-operation a vital component of any future solution.

On the other hand, most developed countries have all the capabilities to deal with the problem from regulatory and waste operational aspects. This, however, still falls short of taking care of the problem. The multi-dimensional nature and the under estimation of the associated problems in developed countries contribute to a worsening situation. As a result we still see sources getting out of control and getting involved in incidents/accidents. Probably one of the best infrastructures for waste management and record keeping exists in the United States of America. According to some existing databases [c] in the US there is, on average, 2 accidental cases of melting of radioactive material in the USA per year. On the worldwide level, conditions are maybe even worse. Contaminated products that make it through foundries, manufacturers and exporters worldwide and eventually get detected by the US customs alone average one case every two years. Close co-operation between developed and developing countries involving regional and international organizations is an important component for a global solution of the problem.

International Programmes

Problems related to sealed radioactive sources had been under consideration within the Agency since the mid eighties. Following the high profile accident in Brazil in 1987 the subject received more attention. By 1990 the Agency had a resolution from its General Conference to review and assess both the magnitude and the nature of the problems associated with sealed sources. It concluded that infrastructure for the management of SRS in most developing countries is poor. It also reported on the initiation of an action plan to assist developing countries with the management issues. The report also hinted on attempts to seek regional and inter-regional solutions to long-term storage and disposal problems. The latter proved to be too difficult due to socio-political reasons. The technical manuals along with many training courses offered on the subject, while providing useful information, fell short of rectifying the situation. A series of Demonstration of Pre-disposal Waste Management Methods and Procedures providing on-the-job training for experts from developing countries were implemented. The programme proved to be very successful for giving a real experience and required skill for experts from the developing countries. A new technical programme for these demonstrations with emphasis on quality management of radioactive waste has been developed and implemented over the last few years (2001-2004).

For some sources requiring special skills, complicated procedures, stringent quality assurance or specialized tools, the Agency resorted to directing its programme to provide hands-on-assistance. Over fifty recovery and conditioning operations have been carried out in Developing Countries. Spent SRS containing Radium-226, Cobalt-60, Cesium-137 and Amerecium-241 were dealt with. The first prototype operation to recover and condition neutron sources was conducted with the cooperation of Las Alamos National Laboratory and the Nuclear Energy Corporation of South Africa in November 2004, paving the way to deal with such sources on a worldwide basis.

The Agency also continued to sponsor international meetings and information exchange on the subject. This formed a major input to the IAEA General Conference and resulted in a number of actions to be implemented by the Agency.

The primary objectives were to enable the Agency to develop and implement activities that will assist Member States, and where necessary, to improve the safety and security of radioactive sources. Considerations are given to fostering safety culture and training of staff that are using such sources. Among others, the following tasks were accomplished in 2004:

- Developing an international database on missing and found “orphan sources”.
- Fully developing and maintaining the international database on unusual radiation events and making it available to Member States;
- Developing of a database (catalogue) for sources, transport containers and devices containing sources,
- Development of a Radioactive Waste Management Database to help Developing Countries keep complete and reliable records of their waste inventories including spent SRSs.

The action plan [d] had been the subject of review and enhancement to concentrate on several very important aspects to enhance the safety and security of sealed sources. Apart from the action plan the Agency has several activities that are related and directly contribute to the safety of sealed sources.

Technical Difficulties

While national and international programmes are contributing to the solution of the sealed radioactive sealed sources problem, several situations still pose a real challenge to source management.

Personnel qualifications and infrastructure

For handling and conditioning of sealed sources, in most of the cases, some infrastructure would be required. Building a large infrastructure to simply deal with few sources per year may not be justifiable. This may make a regional activity to deal with such a problem more effective and financially viable. This, however, does not undermine the real need for qualified personnel to manage the radioactive waste in a given country.

Transport containers

Many sources that have been mentioned are high activity sources that require a special container if they are to be transported. Transport is essential to deliver the sources to a facility where they can be treated, conditioned for either reuse or long-term storage. While these containers are designed and manufactured for the same requirements (ST-1), we see different designs being developed in different Member States and large sums of money being spent on the licensing procedures. So far all containers are licensed for use within a country or few countries at the most. The possibility of using a container with a flexible source size and geometry on a regional or international level can tremendously change the options including return of sources to suppliers.

Some of the earlier sources have been manufactured under different specifications and in many cases the sources were designed without the possibility of unloading from the source holder. If the only solution possible is to transport the source to a facility with the required infrastructure then it is necessary to use a large transport container that can take the source and its shield. Such a container involves a large cost. Formalities for getting required permission will still be required. International co-operation may be instrumental in easing the process and substantially reducing the cost involved.

Bare source manipulation

Many sources are being manipulated in the field, usually between the transport containers and the working shields. A special transport container is usually used for this purpose. Many of these are no longer licensed for transport but are very useful in manipulating the source for further management procedures. Information about the availability of such containers and the possibility of their retention for such utilization may be very useful, especially for sources that have been accumulated over the last several decades.

For proper conditioning of sources with no Special Form Certificate, bare source manipulation may be inevitable. This capability will also contribute significantly to handling sources that either have been found accidentally outside their shield, sources involved in an accident or sources that have been hampered with making their biological shield weak or ineffective. The design of a mobile installation to provide for such technical capabilities has been initiated in 2002 and is expected to be operational in 2005.

International Approach

Given the magnitude of the problem, it is important that any solution be in the context of a comprehensive international approach, rather than an isolated national or regional action. Because the issues involved are complex and multi-faceted, national infrastructures will perform better if there is an effective and recognized international mechanism on these issues. The set up of an international circular, for example, for information on mishaps or incidents or accidents would be very useful. This will not only disseminate the information but also keep all parties involved in the technology of dealing with such sources informed of the latest. This mechanism, if set up, would prove indispensable in steering the whole community in the right direction for any future overall management strategies. Locally qualified experts would also find the required support to continue such a job through international contacts. Such a system would also ensure the mechanism to provide advice on how best to fulfill regulatory requirements according to the latest findings and with close consideration of local conditions.

Source manufacturers, equipment suppliers and other relevant international organizations are important stakeholders that have become more involved in recent years. This has already helped with the issue of return of sources to suppliers and in co-operating with Interpol, Europol and World Customs Organization (WCO). Cooperation with some source manufacturers had made a profound effect on a number of urgent cases. A total of 30 000 Curie has been returned to suppliers in the 2003-04 period.

The approach selected by the IAEA to put solutions into place is the use of a Model Project. Under this project modality a "Country Programme Frameworks" is set up to identify priorities and thematic planning that singles out the most significant technical solutions that can be implemented across several countries. Milestones are set to measure progress towards overall objectives. This mechanism has proven to be instrumental in solving many problems in many countries.

The inter-regional projects INT/4/131 and AFRA-4-015 have been the primary projects within IAEA to deal with the waste issue in general and with sealed sources in particular in this context. Under the project an action plan is set up to address individual needs with regard to waste management of the participating Member State. The action plan identifies the main activities to address the deficiencies or difficulties in the infrastructure or the source status in a country, and is introduced as one step. Each activity is dealt with as a project identifying the IAEA and the Member States responsibilities. Prior to the execution of the work plan for a given Member State a formal approval from the Member State is required. A number of procedures and methods have been developed for dealing with similar conditions. Apart from individual activities in different countries, INT/4/131 was the main tool to implement the pre-disposal demonstration of waste management methods and procedure for the radium conditioning. The former provides on-the-job training for experts from developing countries to condition radioactive waste including SRS. The latter provides hands-on assistance to condition all radium sources in a given country in one conditioning campaign. Within the same project other sources such as Co-60 and Cs-137 teletherapy and industrial sources have been conditioned in special cases. This approach is resorted to in cases where the sources pose too much risk. Both programmes are expected to move further to deal with more complicated and wider scopes. The first programme has been developed to become “Practice Oriented Training on Quality Management of Radioactive Waste” and the second is being developed to deal with Spent High Activity Radioactive Sources (SHARS) and Long Lived Sealed Radioactive Sources (LLSRS). Technical documents on these subjects have been published by the IAEA and technical procedures for high activity sources and neutron sources have been drafted, and in some cases, tested for use in recovery and conditioning operations to be conducted in the near future.

CONCLUSIONS

- The SRS number is very large and the number of disused SRS with high risk is alarming.
- Infrastructure for waste management is still poor and unacceptable in many countries.
- Old sources pose a special problem that, if not dealt with in due time, may become too late to solve in an efficient way.
- Neither national nor international programmes can solve the problem alone. A strong link between national and international programmes is an effective way to deal with the problem in the long run.
- Some technical problems need innovative solutions. This involves the large number of sources without valid special form certificates where their original transport arrangements are no longer approved by transport regulations. The technical development of a mobile Sealed Radioactive Source Conditioning installation will provide the required technical capability to address this issue in developing countries worldwide.
- Ignoring the problem of disused SRS has grave uncalculated risk. This risk only increases by time. Experts dealing with these sources will also have a more difficult job and a higher risk if the problem is not tackled expeditiously.

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FOOTNOTES

[a] Especially because the real number of uncontrolled sources is much higher than data available. In several countries of the world sources go missing with no trace or evidence.

[b] An illicit trafficking incident for the purpose of reporting to the ITDB is a situation that involves unauthorized acquisition, provision, possession, use, transfer, or disposal of nuclear material and other radioactive material, whether intentional or unintentional and with or without crossing international borders, including unsuccessful or thwarted attempts. It also includes incidents involving loss of control and discovery of uncontrolled radioactive materials, e.g. ‘orphan’ sources.

[c] Database maintained by James Yusko, CHP, Pennsylvania Department of Environmental Protection. Note that not all cases may involve an SRS.

[d] IAEA General Conference Resolution, GC(43)/RES/10