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Strengthening control over radioactive sources in authorized use and regaining control over orphan sources

National strategies

INTERNATIONAL ATOMIC ENERGY AGENCY

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STRENGTHENING CONTROL OVER RADIOACTIVE SOURCES IN AUTHORIZED USE AND REGAINING CONTROL OVER ORPHAN SOURCES

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FOREWORD

An orphan source is a radioactive source that poses sufficient radiological hazard to warrant regulatory control, but which is not under regulatory control because it has never been so, or because it has been abandoned, lost, misplaced, stolen or otherwise transferred without proper authorization. A vulnerable source is one, which is currently under regulatory control, but its level of control is weak. It can be regarded as a source that could easily become orphaned. In recent years, orphan sources have caused multiple fatalities or serious injuries when unknowing individuals find them. This problem, along with concern that orphan or vulnerable sources might be acquired for malevolent purposes, has led many countries to consider making concerted efforts to improve control over them. This report provides a methodology as to how to do this. It is complementary to a number of other IAEA publications related to regulatory infrastructure, emergency response, security, illicit trafficking and border monitoring, and the management of disused sources. While the focus of this TECDOC is on the development and implementation of a *remedial* national plan of action, it is expected that the development of a plan will also identify existing weaknesses in national control of sources and highlight ways to *prevent* further sources becoming orphaned.

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INTRODUCTION AND BACKGROUND

Part I

CHAPTER 1. INTRODUCTION

Chapter 1 provides some historical background information to the report as well as explaining its objectives, scope and structure.

1.1. Background of the report

Technologies that make use of radiation sources and radioactive material continue to spread around the world. They are to be found in agriculture, industry, medicine, mining, research and teaching and provide many benefits. The safety and security record of the technologies and their application is generally good. However, on occasion, a lack of appropriate controls, or circumvention of those that exist, has lead to radiological accidents [1], [2], [3], [4]. Some of these have had serious consequences, including the death of several exposed persons as well as environmental impacts and serious economic consequences. Examples can be found in the reports covering the accidents in Juarez, Mexico [5], Goiânia, Brazil [6], Tammiku, Estonia [7], Lilo, Georgia [8], Istanbul, Turkey [9], and Bangkok, Thailand [10].

1.1.1. IAEA Action Plan for the Safety and Security of Radiation Sources

The frequency of accidents in recent years prompted the IAEA, in collaboration with the European Commission (EC), INTERPOL and the World Customs Organization (WCO) to jointly sponsor an international conference on the topic in Dijon, France in September 1998 [11]. Particular concern was expressed at that conference, and since [12], [13], regarding radiation sources that have become orphaned. Orphan sources are those that are not under regulatory control and therefore are vulnerable to being found in the public domain.

To address the orphan source issues the IAEA developed and began implementing an Action Plan [14], which has since been updated and revised [15], [16]. The primary purpose of this Action Plan is to enable the IAEA to develop and implement activities that will assist Member States in maintaining and, where necessary improving the safety of radiation sources and the security of radioactive materials over their life cycle. The initiatives in the original plans were grouped according to seven topic areas that provide a logical division of tasks to be carried out by the IAEA:

- Regulatory Infrastructures
- Management of Disused Sources
- Categorization of Sources
- Response to Abnormal Events
- Information Exchange
- Education and Training
- International Undertakings

The topic on "Response to Abnormal Events" specifically included an action "to prepare guidance on national strategies and programmes for the detection and location of orphan sources and their subsequent management." This report fulfils that action.

There are two other activities in the Action Plan that have resulted in publications that are of particular relevance to this TECDOC. These are the "Categorization of radioactive sources" [17], [18], and the "Code of Conduct on the Safety and Security of Radioactive Sources" [19], and its later revision [20].

1.1.1.1. Categorization of radioactive sources

A categorization of radiation sources [17] was quickly developed because it was recognized that priority needed to be given to those radiation sources and materials that posed the most significant risks. It was seen as relevant to decisions both in a prospective sense to guide the application of the regulatory infrastructure and in a retrospective sense in developing programmes to bring orphan sources under control. Later, it was realized that there was a need to extend both the scope and applicability of the categorization to a wider range of practices and radionuclides, and to include unsealed sources. It was also recognized that a new categorization system was crucial to other high priority work initiatives being carried out by IAEA, such as the revised Code of Conduct on the Safety and Security of Radioactive Sources [20] and the preparation of guidance on the Security of Radioactive Sources [21]. Therefore, a new categorization system [18] was developed, which provides a fundamental and internationally harmonized basis for risk informed decision making by giving a relative ranking and grouping of sources and practices based on their potential hazard.

Knowing the relative hazard of radioactive sources is essential to the prioritization of efforts aimed at improving control over them. Therefore, the IAEA's categorization needs to be understood prior to attempting to develop a national strategy. In brief, it groups sources into five categories based on their potential to cause deterministic health effects in an uncontrolled environment. Categories 1, 2 and 3 are classed as dangerous, in that they can potentially cause death or a permanent injury that decreases the quality of life within a short space of time if not under proper control. Appendix I reproduces the full plain language descriptions of the categories from IAEA-TECDOC-1344 [18].

1.1.1.2. Code of conduct on the safety and security of radioactive sources

A Code of Conduct on the Safety and Security of Radioactive Sources [19] was prepared at two open-ended meetings of technical and legal experts, and was endorsed by the General Conference on 11 September 2000 in Resolution GC(44)/RES/11. Its purpose is to serve as guidance to Member States for the development and harmonization of policies, laws and regulations on the safety and security of radioactive sources. A revision of this Code was undertaken in 2002/3 to address a number of limitations and to give an increased emphasis on security of radioactive sources as well as import/export controls [20]. The revised Code of Conduct was approved by the IAEA's Board of Governors in September 2003 and endorsed by the General Conference in resolution GC(47)/RES/7B which urged each State to write to the Director General that it is "working toward following the guidance contained in the IAEA Code of Conduct on the Safety and Security of Radioactive Sources and encourages other countries to do the same". Full compliance with its provisions worldwide will largely solve problems relating to the control of radioactive sources. The development of a national strategy can be regarded as a prioritized plan towards implementation of the Code of Conduct.

1.1.2. IAEA Nuclear Security Plan of Activities

Following the terrorist attacks of 11 September 2001 in the USA, the IAEA developed a Nuclear Security Plan of Activities [22] to address issues related to protection against nuclear terrorism. One area of activity in this plan covers the security of radioactive materials other than nuclear material and has the objective of ensuring "that significant, uncontrolled radioactive sources are brought under regulatory control and properly secured". There are two major areas of work under this programme. The first aims at *preventing* further sources getting out of control by increasing their security and the second is more *remedial* and founded on the present TECDOC. The development and implementation of national strategies to improve control over radioactive sources addresses both the radiation safety problem as well as the security of vulnerable sources and the radiological terrorism threat.

1.2. Objectives

The objective of this report is to provide practical guidance to States on the development of a national strategy for improving control over radioactive sources, particularly dangerous sources (Categories 1–3). Part of this process involves the determination of the magnitude of the potential problem with orphan and vulnerable sources and indeed, whether or not a national strategy is needed. The ultimate objective is that States will use this report to develop and then implement a plan of action that will result in all significant sources being managed in a safe and secure manner.

The primary audience of the publication is the regulatory authorities of developing countries. However, all countries will find the material beneficial in that it may help them to identify weaknesses or gaps in their existing programmes of radioactive source control.

1.3. Scope

This report attempts to provide both the background *knowledge* and the *methodology* necessary for an individual or small team of responsible persons to develop a national strategy for improving control over all radioactive sources, but especially orphan and vulnerable sources. The background knowledge given in Chapter 3 is an update of the information on practices that was given in IAEA-TECDOC-804 [23], which focused on spent radioactive sources.

From a regulatory viewpoint *all* authorized sources need to be adequately controlled. However, because resources are often limited, the priority from a safety and security perspective must lie with the dangerous, higher category sources (Categories 1–3). Therefore, the efforts associated with national strategies should concentrate on these.

Nuclear material is generally outside the scope of this report except inasmuch as it is part of a radioactive source such as a radioisotopic thermoelectric generator, neutron source (PuBe) or pacemaker. Issues related to patient protection and accidental exposures from radiotherapy are also not within the scope of this report [4].

There are a number of topics that impinge on the development of a national strategy but that are adequately covered in other IAEA publications. Therefore, the publications covering the following subjects will largely be incorporated by reference:

- The radiation protection and regulatory infrastructure necessary for control of sources [24], [25], [26], [27], [28];
- Emergency preparedness and response to events involving radioactive sources [29], [30], [31], [32], [33], [34];
- Security of radioactive sources [21], [35];
- Illicit trafficking in radioactive materials and border monitoring [36], [37], [38];
- Management and disposal of disused radioactive sources [39], [40], [41], [42], [43]; and,
- Transport of radioactive material [44].

This publication focuses on establishing and assuring physical control of radioactive sources in instances where such control is not already well established. However, it is important to emphasize that a comprehensive national strategy should also include a long term vision plus practical steps to manage all sources beyond this first step of regaining control. The conditioning of spent sources and the establishment of proper facilities for this purpose, as well as the proper long term storage of conditioned sources, are all important steps in providing for the continuing safety and security of radioactive sources. The publications listed above on source conditioning should therefore also be considered when preparing a comprehensive national strategy.

1.4. Structure

After some introductory material, this report provides both the factual information and the general steps needed to develop and implement a national strategy.

1.4.1. Part I

Part I (Chapters 1–3) contains background information for those who are not already familiar with the subject. This includes:

- The need for national strategies;
- The generic causes of loss of control of sources, with specific examples;
- The common applications of radioactive sources.

1.4.2. Part II

Part II (Chapters 4–8) details the actual process for the development and implementation of a national strategy, which includes:

- assessing the problem by first gathering specific, national information;
- determining the nature and magnitude of the problem;
- developing the national strategy by evaluating, and prioritizing possible solutions;
- implementing the strategy subsequent to a high level decision; and
- evaluating the effectiveness of the plan and making changes as a result until the desired objective is achieved.

Searches for sources will be part of any national strategy and since they are of particular importance, a chapter on physical and administrative searches is also included in the report in the context of the development and implementation of the action plan.

Throughout the text, illustrative examples are given in boxes to further help the understanding of the topics under discussion. In order to assist in the free flow of the text, detailed steps and aids in the development of the strategy are provided in action summary boxes in Chapter 5 and in Appendices.

A comprehensive set of references is provided.

1.5. Definitions

In order to provide clarity with regard to the terminology used within this TECDOC, several terms are defined below. Wherever applicable, the definitions are the same as those in the IAEA's Safety Glossary and the Code of Conduct [20].

Disused source: A radioactive source, which is no longer used, and is not intended to be used, for the practice for which an authorization has been granted [20].

Illicit trafficking: Any intentional unauthorized movement or trade (particularly international) of radioactive materials (including nuclear materials) with criminal intent.

Inadvertent movement: Any unintentional unauthorized receipt, possession, use or transfer of radioactive, including nuclear, materials.

Management: The administrative and operational activities that are involved in the manufacture, supply, receipt, possession, storage, use, transfer, import, export, transport, maintenance, recycling or disposal of radioactive sources [20].

Non-proliferation: A broad term used in international agreements in relation to limiting the availability of nuclear material and thus reducing the capability for production of nuclear weapons.

Nuclear material: Plutonium except that with isotopic concentration exceeding 80% in plutonium-238; uranium-233; uranium enriched in the isotope 235 or 233; uranium containing the mixture of isotopes as occurring in nature other than in the form of ore or ore-residue; any material containing one or more of the foregoing.

Orphan source: A radioactive source which is not under regulatory control, either because it has never been under regulatory control, or because it has been abandoned, lost, misplaced, stolen or transferred without proper authorization [20].

Safety: Measures intended to minimize the likelihood of accidents involving radioactive sources and, should such an accident occur, to mitigate its consequences.

Security: Measures to prevent unauthorized access or damage to, and loss, theft or unauthorized transfer of, radioactive sources [20].

Spent source: A source that is no longer suitable for its intended purpose as a result of radioactive decay. Note that a spent source may still present a radiological hazard. Note also, that in practice, many spent sources may no longer be suitable for use because their encapsulation is past its recommended working life, or the equipment that it is in, is no longer of use.

Vulnerable source: A vulnerable radioactive source is one, which is currently under regulatory control, but for which the control is insufficient to provide assurance of long term safety and security. A vulnerable source is one that could relatively easily become orphaned.

CHAPTER 2. THE NEED FOR NATIONAL STRATEGIES

2.1. The problem

Radioactive sources that are not under good regulatory control can result in a number of undesirable consequences including human health impacts, socio-psychological impacts, political and economic impacts, as well as environmental impacts. Many countries are in the process of introducing the necessary measures to provide an appropriate level of control over them. However, for a variety of historical and economic reasons, there could already be sources in the country that are not within the regulatory system. Some of these may be known about, others may not. Therefore a strategy is needed to ascertain the likelihood and magnitude of the radioactive source control problem within a country [45] and the priorities necessary to address the problems identified. A well-developed plan for improving control over radioactive sources tailored to the national situation will ensure optimum use of resources such as time, money and personnel. It will allow these limited resources to be allocated appropriately to ensure that control is first regained over those sources presenting the highest risks.

The development of an appropriate strategy for regaining control over orphan sources requires an understanding of the mechanisms by which control of these sources can be lost. The purpose of this chapter is to summarize the root, and specific causes of the problem. In the next chapter, when the uses of radioactive sources are discussed, the potential for sources to become orphaned, and illustrative examples of loss of control are given for most of the different practices.

2.2. Causes of loss of control over radioactive sources

Fig. 2.1. illustrates some of the considerations involved in the loss of control of radioactive sources. First, loss of control can occur either inadvertently or deliberately. Intentional attempts to remove a source from regulatory control can be for purposes of damage to, or acquisition of, the source. Acquisition can be for either malevolent or financial reasons and can occur via theft, illegal or legal purchase. All of these considerations have an impact on the national strategy methodology.

Box 1: Understanding the scale of radioactive source control issues: USA data

Data from the US Nuclear Regulatory Commission in the USA [45] indicate that they have about 150,000 licensees who possess about two million devices containing radioactive sources. Of these licensees, 135,000 are general licensees for the lower categories of sources and about 20,000 are specific licensees for the higher activity sources. The latter are being used in applications such as brachytherapy, teletherapy, industrial radiography, well logging, and laboratory research. In this specifically-licenced group there are about 260,000 devices.

NRC data indicate that an average of 375 sources or devices of all kinds are reported lost or stolen each year. Although this is only about 0.02% of the total inventory, it is still approximately one source per day. However, the majority of these are very low activity sources.

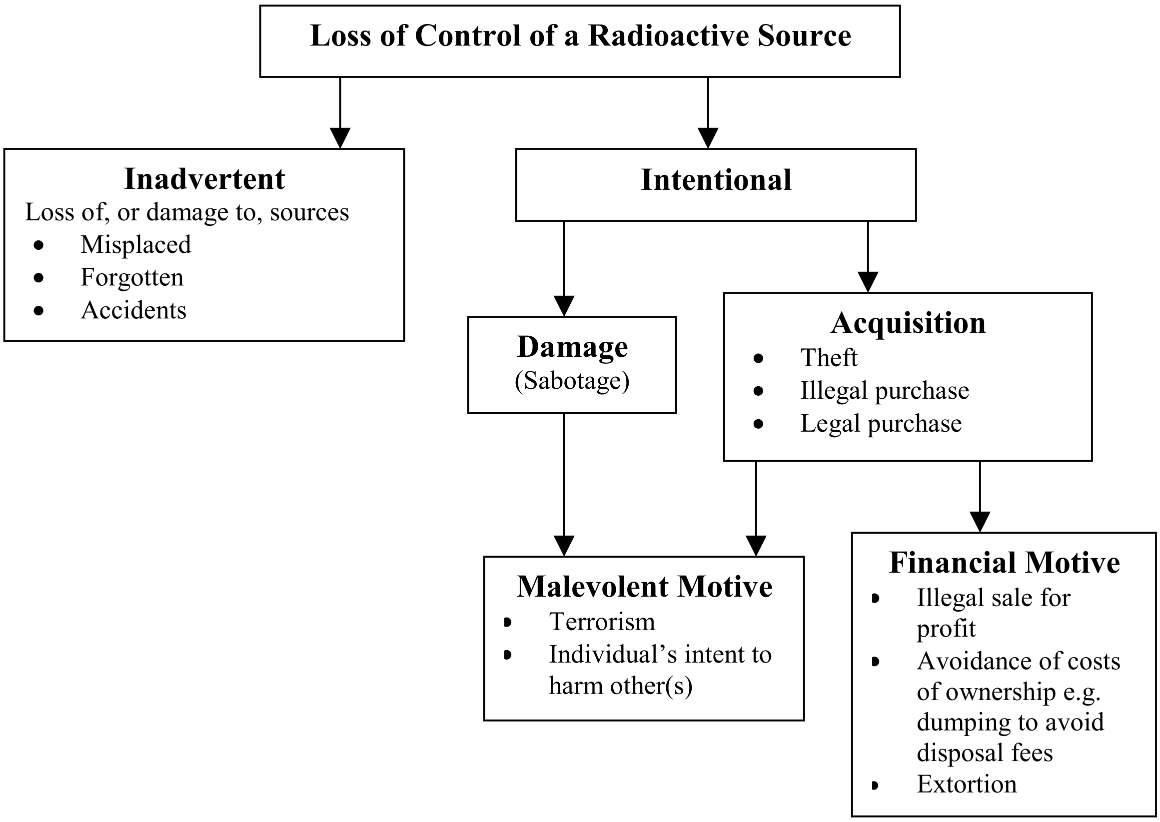

Fig. 2.1. Considerations involved in the loss of control of radioactive sources

As illustrated in Fig. 2.1., the reasons and causes for the loss of control of a source are many and varied. There may be a single catastrophic failure or more commonly a combination of contributing events. In the past, most causes have been inadvertent and largely due to negligence. However, it must be recognized that in the current climate there is an increased likelihood of sources getting out of regulatory control for deliberate financial or malevolent reasons. This includes such motivations as avoidance of disposal costs, illegal sales for profit and terrorism. A review of experience to date indicates the following main causes of loss of control.

- Mobile sources are lost or stolen while in transit.
- Sources are abandoned, either deliberately or through lack of awareness.
- Sources are stolen, either for the scrap value of the source or its container. (Sources are often perceived as having more value than they do because of the care with which they are treated.)

In addition, it must be recognized that many countries will have an "historic legacy" of sources. These are sources that were in use before radiation protection infrastructures were put in place. Whether control has been lost, or did not exist in the first place, there are some common routes for inadvertent movement of the sources within the public domain. International trade, particularly in scrap metal, provides the potential for transboundary movement of orphan sources and therefore, the consequences may not be limited to the country of origin. The listings below provide a fairly comprehensive summary of all these points.

2.2.1. *Root causes*

Some of the important root causes identified have been the lack of, or ineffective:

- regulatory bodies;
- regulations;
- regulatory enforcement;
- national radiation protection services;
- awareness or training of management and workers;
- commitment by management to safety;
- radiological protection programme in the organization.

2.2.2. *Specific causes*

A listing of the specific causes of loss of control of radioactive sources includes:

- Lack of, or inadequate:
  - prior risk assessment;
  - security during storage, transport and use;
  - radiation surveys, e.g. failure to monitor after a γ-radiography exposure;
  - supervision;
  - emergency preparedness arrangements;
  - training or qualification of personnel;
- Design or manufacturing fault;
- Inappropriate maintenance or mitigation arrangements;
- Human error;
- Deliberate avoidance of regulatory requirements;
- Abandonment;
- Catastrophic event, e.g. fire, explosion, flood;
- Theft;
- Malicious act;
- Loss of corporate knowledge, due to:
  - loss or transfer of key personnel;
  - bankruptcy;
  - long term storage of sources;
  - decommissioning of plant and facilities;
- Death of owner;
- Change in ownership of equipment or plant, especially moving from public to private ownership;
- Inhibitions to legal disposal, such as:
  - no disposal route available;
  - export not possible;
  - high costs of disposal.

Looking at the life cycle of a source can help illustrate those situations when a source might have an increased risk of loss of control. Fig. 2.2. provides an example that is appropriate for sources in an industrial plant. Good practice will follow the left hand column, but at each point, problems can arise leading to loss of control, as illustrated on the right side.

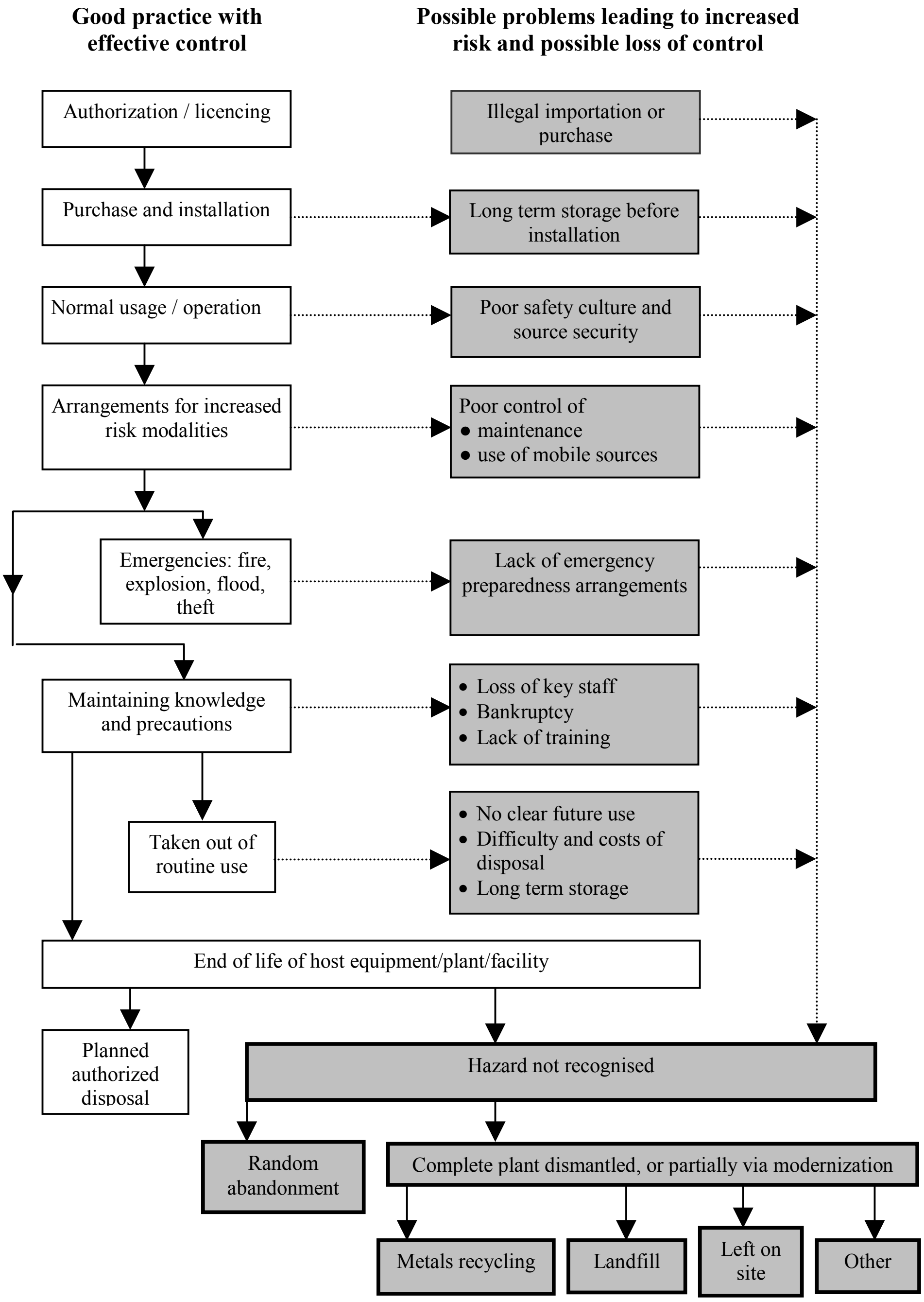

Fig. 2.2. Example of the life pattern of a source in an industrial plant.

CHAPTER 3. APPLICATIONS OF RADIOACTIVE SOURCES

Knowledge of the common applications of significant radioactive sources is an important prerequisite for the development of a national strategy. Many will be familiar with this material, but it is included here for those who are new to this topic. There are many ways of organizing this information, but because of the need to prioritize resources, it is presented here in accordance with the IAEA's Categorization of Radioactive Sources [18], with the most significant sources being introduced first. Category 5 sources are not discussed in detail because they are too small to be of significant safety or security concern. For a plain language description of the categories see Appendix I. For a summary of the main applications as well as the typical radionuclides and range of activities in use see Appendix II.

It should be remembered that sources have been used for other purposes in the past, so that historical applications also need to be considered. The following sections list the main uses, but they are not exhaustive because technology is constantly improving and because there are some applications, such as calibration, where sources of a wide range of activity are used.

The most likely ways for sources in each practice to become orphaned is discussed and then actual examples are given.

3.1. Category 1 sources

3.1.1. Radioisotopic thermoelectric generators

Application discussion: Radioisotopic thermoelectric generators (RTGs) are devices that use the decay heat of a radioisotope to produce electricity. The two radionuclides that have been most frequently used are ^{90}Sr (330 TBq – 2.5 x 10^4 TBq) and ^{238}Pu (1 – 10 TBq). The power that is typically generated can vary from a few watts to tens of kW, depending on the activity and radioisotope. There are no moving parts in these devices and, since they are designed to operate unattended for tens of years, they are ideal for supplying power to equipment in remote areas. Hence, they have been deployed fairly extensively in the Arctic regions and in space. Many of the devices were originally put in position by the military forces of the USA and the USSR for remote monitoring or for navigation purposes.

Loss of control considerations: The fact that such devices are deployed in remote regions means that they are susceptible to people moving them, acquiring them for malevolent purposes or dismantling them for the scrap value of their shielding material. In addition, changes in government and/or loss of records means that the sources can become abandoned and forgotten until re-discovered some time later. Space satellites containing RTGs have also re-entered the Earth's atmosphere causing concern for the spread of the radioactive material. Box 2 discusses an event in Georgia, which illustrates the potential problems of RTGs becoming orphaned.

Box 2: RTG accident: Georgia, 2001

In December 2001, three woodsmen found two heat-emanating ceramic objects near their campsite in the remote Inguri river valley of Georgia. Two of the woodsmen involved in the accident carried the containers on their backs and experienced nausea, vomiting, and dizziness within hours of exposure. The third carried the source attached to a wire. At a hospital in Tbilisi, Georgia, the woodsmen were diagnosed with radiation sickness and severe radiation burns, and at least two of the three were in serious condition. A Georgian team recovered the sources in early 2002 with the assistance of the IAEA. They were the unshielded, ceramic sources of two Soviet-era RTGs each containing about 30,000 Ci of ^{90}Sr. Two of the victims were treated in hospitals in Paris and Moscow for many months before recovering from severe radiation burns.

3.1.2. Irradiators

3.1.2.1. Sterilization and food preservation irradiators

Application discussion: Large scale industrial irradiator facilities are relatively few in number, and typically contain very high activity ^{60}Co and ^{137}Cs sources, in the range 0.2 to 600 PBq. Applications include the sterilization of medical products (such as sutures and gloves), preservation of foodstuffs and cross-linking of polymers to change their properties. The sources used in the irradiators vary in physical size, some being large or others being pencil-sized, with each facility containing many such sources. These sources are installed in dedicated, large, shielded enclosures that employ either a deep pool of water, or massive lead or concrete for shielding of the source when not in use.

Loss of control considerations: When the source is exposed, the dose rates inside the irradiation enclosure are very high and a lethal dose could be received in a matter of a minute or so. Therefore these facilities have many safety features, based on the principles of redundancy, diversity and independence of safety systems [46]. However, unless they are well-designed and maintained, safety systems can degrade; and, coupled with human error, accidents can happen. To date there have been five reported fatal accidents where operators were exposed in an irradiation facility:

— Bresica, Italy, 1975 [1];
— Kjeller, Norway, 1982 [1];
— San Salvador, El Salvador, 1989 [47];
— Soreq, Israel, 1990 [48];
— Nesvizh, Belarus, 1992 [49].

It should be noted that in these accidents there was no loss of control of the sources themselves. Indeed, there are no documented reports of such sources or facilities being abandoned or forgotten about. However, there have been instances involving bankruptcy where the appointed “receiver” has made staff redundant and has not known for a period of time the nature of the hazard under his responsibility. If a facility were abandoned then there would be a serious threat of a lethal exposure.

A more likely scenario would involve the loss of part of the source array. Typically the array consists of a number of source modules, with each of these being in a frame retaining 30–50 source pencils. Each pencil is about 45 cm long and 1 cm diameter and contains around 150 TBq of ^{60}Co or possibly ^{137}Cs. If irradiation facilities are not maintained, there is the potential for objects to interfere with the movement of the source array and to distort the module frames thus allowing a source pencil to fall out. This has occurred on a number of occasions (see Box 3). It provides the potential for a source pencil to fall into one of the “totes” which transports the product being irradiated out of the facility. Modern irradiators have installed monitoring systems at the product exit points to detect such a situation. These systems must, however, be maintained to be effective.

Another consideration is that from time to time a percentage of the source pencils have to be replaced due to radioactive decay. Normally, the suppliers of the sources would undertake this work, and the old sources would be put into specially designed transport containers for return. At this stage, there is the potential for transport problems to cause delays, resulting in the container being put into storage and possibly forgotten about. A scenario similar to that in the Istanbul accident involving a radiotherapy source could then develop (see Box 6).

Box 3: Irradiator accident: San Salvador, El Salvador, 1989

This accident occurred in an industrial irradiation facility containing 0.66 PBq of ^{60}Co in the form of a source rack of two modules, each containing a number of source pencils. At the time of the accident there was no relevant regulatory or radiation safety infrastructure since the country had been in a civil war for 10 years. The net effect was a degradation of the safety systems and the operators' understanding of radiation hazards. In the accident in 1989, three people gained entry to an irradiation chamber in order to free the source rack, whose movement to the safety of the water pit had been impeded by distorted product boxes. One person died and another had a leg amputated.

The problem had not been recognised for two weeks, and during this time damage to the source rack from the accident caused the source pencils to drop out. Most fell into the water pit, but one fell onto the floor of the irradiation chamber. It is pure chance that none fell into one of the product boxes that could have transferred them out of the facility. The installed monitor on the product exit, designed to detect such an event, had long since failed.

While such irradiators may become targets for sabotage, their sources are unlikely to be stolen because of their short term lethality.

3.1.2.2. Self-shielded and blood/tissue irradiators

Application discussion: There are a number of smaller irradiators that have been described variously as self-shielded irradiators, or blood/tissue irradiators. Although they are smaller, they still contain sources of high activity. In addition to sterilizing blood, tissue and seeds, they are used for gemstone coloration, insect irradiation for the sterile insect technique and research into mutation effects on agricultural products. Typically, their design includes a sample chamber with interlocked doors and the sources are moved to surround the chamber or the chamber is moved next to the sources. There is no simple way of accessing the sources themselves, and the irradiator, with perhaps some modifications, can also be the source shipping container.

While most of these irradiators are fixed, there are some devices, such as the Gamma Kolos irradiators, that were mounted on heavy trucks or on trailers and moved throughout the former Soviet Union in order to irradiate seeds as they were being planted. Most of these devices have now been removed from their vehicles and are in storage.

Loss of control considerations: Few of the fixed devices have been involved in orphan source incidents because of their robust nature and design. The major concern would be the abandonment of such devices, perhaps during times of civil unrest or as a result of bankruptcy. Changes in the research focus of institutions have also resulted in these devices being disused and neglected for a long time. There have been concerns with regard to the possible security vulnerability of some of the mobile irradiators.

3.1.3. Teletherapy devices

Application discussion: Teletherapy units are commonly found in medical institutions, such as hospitals or clinics. In this application a large source, typically ^{60}Co, but possibly ^{137}Cs, of several hundred TBq, is used, external to the body, to irradiate a tumour. The physical dimensions of the source are relatively small, and the sources are generally cylindrical (few cm in diameter by several cm long). The source is contained inside a large shielding device.

The Gamma Knife (stereotaxic radiosurgery) is a similar device but it uses a large number of sources (~200) to provide radiation beams that can be focused on a particular treatment point in the brain while minimizing doses to healthy tissue.

The facilities within which a therapy unit is located are specifically designed and include thick, shielded walls as well as other protective equipment.

Colbalt-60 sources are generally in a solid metallic form with the source capsule being made up of a number of pellets or discs. The hazard is principally from external exposure, unless the sources are subjected to significant mechanical or heat damage, as would be the case in the metals recycling industry. Then contamination and the potential for internal exposure would result. Caesium-137 teletherapy sources are usually in the form of caesium chloride in order to get the necessary high specific activity so that they can be physically small enough for treatment purposes.

Loss of control considerations: During normal usage, appropriate controls should ensure minimal risks. However if these sources are removed from their housings in an unauthorized manner they can deliver a lethal dose in a short period of time. Also since the material of the housing may be perceived as being valuable as scrap, loss of control by theft has occurred on several occasions. This has led to melting or other physical destruction of the housing with the subsequent spread of contamination, either directly or through the incorporation of the radionuclide into items manufactured from the scrap metal.

Given the massive nature of teletherapy units and the fact that they are used in an environment, such as a radiotherapy hospital, the staff of which must have knowledge of radiological protection, it is at first sight difficult to envisage these becoming orphan sources. However there are well-documented examples of this happening, leading to fatalities and serious environmental contamination.

Once the containment of a caesium chloride source is breached, the high mobility of the material causes a rapid spread of contamination (see Box 5). Thus the problem is higher from sources with chemical forms that can easily be dispersed.

Boxes 4 to 7 provide examples from accidents in Juarez, Mexico [5]; Goiânia, Brazil [6]; Istanbul, Turkey [9]; and Samut Prakarn, Thailand [10]. Some involved ^{137}Cs; others ^{60}Co.

Box 4: Teletherapy head accident: Juarez, Mexico, 1983

In 1977 a 37 GBq ^{60}Co teletherapy unit was bought from a hospital in the USA by a hospital in Juarez, Mexico. It was not imported legally and the authorities were unaware of it. The hospital did not have the resources to use it immediately and it was put into storage in a commercial facility without a clear indication of the hazards. The relevant senior staff left the hospital. In 1983 a junior member of staff who knew of its existence, but had no knowledge of the hazard, removed it to sell as scrap metal. During transport of the source it was ruptured and some small source pellets scattered along the road. The source was melted in a foundry and was only discovered when by chance, a lorry carrying contaminated products set off the alarms at the Los Alamos nuclear facility in the USA.

Some 75 people received doses between 0.25 and 7.0 Gy, 814 houses with activity in the steel reinforcing bars had to be demolished, several foundries required extensive decontamination and the waste generated amounted to 16,000 m^3 of soil and 4,500 tonnes of metal.

Box 5: Teletherapy head accident: Goiânia, Brazil, 1989

In 1987 in Goiânia, a private medical partnership specialising in radiotherapy broke up acrimoniously. No one took responsibility for a 50 TBq ^{137}Cs teletherapy unit that was left abandoned in the partially demolished building of the former clinic. After two years some local people dismantled the source and its housing and removed it for its scrap metal value. In the process the source was ruptured. The radioactive material was in the form of compacted caesium chloride, which is highly soluble and readily dispersible. For over two weeks the radioactivity was spread over parts of the city by contact contamination and resuspension. Contaminated items (and people) went to other parts of the country.

The recognition of the existence of the problem was triggered by an increasing number of health effects. Overall some 249 people were externally contaminated, 129 internally, 21 people received in excess of 1 Gy and were hospitalized, of which 10 needed specialized medical treatment with 4 of these dying. The decontamination and clean up of the environment took 6 months of intensive effort and produced 3,500 tonnes of active waste.

Box 6: Teletherapy head accident: Istanbul, Turkey, 1998

In 1993 a licenced operator loaded three spent radiotherapy sources into transport packages for their return to the original supplier in the USA. However the packages were not sent and were stored in Ankara until 1998. Two were then transported to Istanbul and stored in a general-purpose warehouse. After some time the warehouse became full and the packages were moved to empty adjoining premises. After 9 months these premises were transferred to new ownership, and the new owners not knowing the nature of the packages, sold them as scrap metal. The family of the scrap merchants broke open the source container and unwittingly exposed themselves to the unshielded 3.3 TBq ^{60}Co source. Ten people received doses between 1.0 and 3.1 Gy and showed signs of the acute radiation syndrome. Fortunately no one died.

The second source, 23.5 TBq ^{60}Co remains unaccounted for, despite an extensive search and monitoring programme.

Box 7: Teletherapy head accident: Samut Prakarn, Thailand, 2000

A company in Bangkok possessed several teletherapy devices without authorization from the Thailand Office of Atomic Energy for Peace. In the autumn of 1999, the company relocated the teletherapy heads from a warehouse it had leased to an unsecured storage location. In late January 2000, several individuals obtained access to this location and partially disassembled a teletherapy head containing 15.7 TBq of ^{60}Co. They took the unit to the residence of one of the individuals, where four people attempted to disassemble it further. Although the head displayed a radiation trefoil and warning label, the individuals did not recognize the symbol or understand the language. On 1 February 2000, two of the individuals took the partially disassembled device to a junkyard in Samut Prakarn. While a worker at the junkyard was disassembling the device using an oxyacetylene torch, the source fell out of its housing unobserved.

By the middle of February 2000, several of the individuals involved began to feel ill and sought assistance. Physicians recognized the signs and symptoms and alerted the authorities. After some searching through the scrap metal pile, the source was found and recovered. Altogether, ten people received high doses from the source. Three of those people, all workers at the junkyard, died within two months of the accident as a consequence of their exposure.

In a number of cases, there have been some common features, which are significant factors in looking at national strategies for dealing with orphan or vulnerable sources.

- There was a long term storage of the sources prior to use, or at the end of their useful life.
- The sources tended to end up in the scrap metal industry.
- Recognition of the medical effects of radiation was the trigger to discovery of an accident.

The mass of teletherapy heads means that it requires significant equipment to remove them. Hence, despite their high activity, installed sources are unlikely to be attractive targets of acquisition for malevolent purposes. However, this may not be true for such sources during transportation.

3.2. Category 2 sources

3.2.1. Industrial gamma radiography

Application discussion: Industrial radiography is in wide spread use, and has a high hazard potential [3]. The construction and maintenance of petrochemical installations, for example, will involve the use of portable radiographic sources of up to 7 TBq for testing welds in pipes and tanks. Some years ago ^{137}Cs sources were used and some of these may still exist. Currently, sources will most often be ^{192}Ir or ^{60}Co, but ^{169}Yb, ^{170}Tm or ^{75}Se may also be used.

Portable industrial radiography sources and their devices are generally small in terms of physical size, although the devices are usually heavy due to the shielding contained in them. The sources themselves are very small, less than 1 cm in diameter, and only a few cm long. They are often attached to specially designed cables for their proper operation. The portability of the devices may make them susceptible to theft or loss. The small size of the source allows for unauthorized removal by an individual, and such a source may be placed into a pocket of a garment.

Most remote-exposure radiography source containers have a general design whereby the source capsule is physically attached to a short flexible unit often known as a source assembly or a ‘source pigtail’. This is coupled, often with a spring assisted ball and socket joint, to a flexible drive cable. When not in use, the source is located in the centre of the source container. In use, a guide tube is attached to the front of the container and the source is pushed down it to the required position by winding out the drive cable.

In heavy industries such as steel foundries or fabrication plants, portable, mobile (on wheels) or fixed radiographic equipment incorporating ^{192}Ir, ^{60}Co or ^{137}Cs, may be installed in purpose built enclosures. Mobile or fixed installations incorporate heavier shielding than portable source housings and are therefore more difficult to steal and remove.

Loss of control considerations: The housings of portable sources contain several tens of kilograms of shielding material, such as depleted uranium, lead or tungsten, which may be perceived as being potentially valuable. Also relevant is the fact that the portable nature of most equipment allows it to be used almost anywhere. Often this is in remote locations or under extreme working conditions. Couple this with limited or non-existent supervision and there is a real potential for entire containers with their sources to be lost or stolen. They can end up in the metals recycling industry or remain in the public domain. These are similar problems to those for orphan teletherapy sources, and whilst the activity levels for industrial radiography are lower, they are still sufficient to produce lethal effects. Perhaps the most significant threat comes from loss of the unshielded source.

Box 8: Industrial radiography source accident: Morocco, 1984

A 1.1 TBq ^{192}Ir source became disconnected from its drive cable. It was not noticed through lack of appropriate monitoring and fell out of the guide tube. It looked like an interesting item and was picked up by a member of the public and taken home. It was out of control from March to June and as a result eight people died.

Poor maintenance, incorrect coupling, incompatible devices, obstructions or kinks in the guide tube can all lead to extreme pressures being placed on the various linkages and eventually to the source becoming decoupled from the drive cable. This poses an immediate threat to the radiographer who is required to monitor after each and every exposure to ensure the source has fully returned to the safe, shielded position. Failure to do so has led to serious exposure of the radiographer and others when the source has dropped out of the equipment unnoticed. To members of the public who find such radiography sources, they look like intriguing items and can easily be picked up and carried back to the family home, often with lethal effects as illustrated in Boxes 9 to 11. In many cases, the onset of medical symptoms is the first indication that a source has been found.

Box 9: Industrial radiography source accident: Cairo, Egypt, 2000

This was a very similar incident to the one above. A farmer picked up a 3 TBq ^{192}Ir source, thinking it valuable and took it home. On 6 May 2000 the farmer and his 9-year-old son went to their local doctor complaining of skin burns. The doctor prescribed medication for a viral or bacterial infection. The youngest son died on 5 June 2000 and the farmer on 16 June. On 26 June a blood test was done on other family members who were showing similar symptoms. The blood test showed severe depression of the white blood cell count and radiation exposure was suspected. The source was located and recovered. Other family members were hospitalized. Four men were charged with gross negligence, manslaughter, and unintentional injury because they had failed to notify authorities that the source, used to inspect natural gas pipeline welds, was not recovered after the job.

If the premises are abandoned or the equipment is otherwise left unsupervised, vandalism or other interference could lead to the same problems as those identified for teletherapy sources. The sources are still small and can easily be removed from containers.

Box 10: Industrial radiography source accident: Yanango, Peru, 1999

Whether this was a similar scenario, or the result of someone tampering with the security lock is uncertain. Recognition of a fault condition came when a processed radiography film was blank. The search for the source focused on those who had been in the area. A welder had picked it up and taken it home in his pocket. As a result of the accident he lost a leg and his wife had a more minor lesion.

The industrial radiography industry is highly competitive, with many small companies and consequently a number each year will cease functioning or become bankrupt. Under these circumstances there is an increased risk that sources could simply be abandoned.

Box 11: Theft of industrial radiography sources: India

Because of rivalry between two industrial radiography institutions, an ^{192}Ir source of activity about 0.3 TBq was stolen. A search operation, supported by a local police investigation led to the discovery of the source in a cremation ground.

A shielded container housing a 185 GBq ^{192}Ir radiography source was stolen by labourers of a garbage collection vehicle. The shielded container was sold to a scrap dealer and the source assembly was kept under the driver’s seat. The source was traced by a physical search team.

The large numbers, work environment, activity level and portability/mobility of most industrial radiography sources make them prime targets for the deliberate acquisition for malevolent purposes.

3.2.2. High/medium dose rate brachytherapy

Application discussion: Brachytherapy (therapy at short distance) is a term that is used to describe the interstitial or intra-cavity application of radioactive sources by placing them directly in the tumour (breast, prostate), in moulds (skin, rectum), or in special applicators (vagina, cervix). Brachytherapy applications are of two slightly different varieties. These are generally referred to as high dose rate (HDR) brachytherapy (Category 2) and low dose rate (LDR) brachytherapy (Category 4 or 5). Both applications use sources that may be small physically (less than 1 cm in diameter, only a few cm long), and thus are susceptible to being lost or misplaced. HDR sources, and some LDR sources, may be in the form of a long wire attached to a device (a remote afterloading device).

Historically, ^{226}Ra was used for brachytherapy. This use of radium brachytherapy sources predates the establishment of regulatory controls in many countries. This poses a separate 'legacy' problem, which is discussed later. The sources were encapsulated in platinum in either needles or tubes of a few mm in width and up to 5 cm in length. However, radon and helium buildup causes pressure inside the encapsulation and it may rupture, resulting in contamination. For this reason, ^{226}Ra was replaced by other radionuclides.

Most modern high and medium dose rate brachytherapy is performed with ^{192}Ir, but ^{60}Co and ^{137}Cs are used in places where the replacement sources might be more difficult to routinely obtain. Sources may be manufactured in different sizes and shapes, including wires or ribbons.

The application of these sources may be either manual or by remote control. Because of radiation protection problems, only low activity sources are used manually, with or without afterloading techniques. Afterloading devices may be heavy, due to the shielding for the sources when not in use, and the device may be on wheels for transport within a facility. The remote afterloading device may also contain electrical and electronic components for its operation. When using these devices, catheters are first inserted into the body and then the sources, attached to cables, are introduced by remote control. These devices typically use low activity sources of ^{137}Cs and ^{192}Ir or high activity ^{192}Ir (up to 0.4 TBq).

Brachytherapy sources are located in hospitals, clinics and similar medical institutions, and such facilities may have a large number of sources. Brachytherapy is less commonly used than teletherapy, but use of the modality is increasing.

Loss of control considerations: When not in use, brachytherapy sources are normally stored in lead shielded safes or containers, but there have been cases when the sources were improperly kept loaded in applicators in transport carts. Similarly, sources past their useful life, have been left in safes or transport containers.

Individual manual brachytherapy sources that may become orphan sources are unlikely to be life threatening, unless they are left in the patient (Box 12 [50]), but they could give rise to deterministic effects or significant contamination. The overall problem is, however, increased by the potential for such sources to be lost. A major radiotherapy unit could have several hundred brachytherapy sources that are being continually moved and manipulated. There have been many reported instances of brachytherapy sources leaving hospitals in refuse, still implanted in patients or in cadavers for cremation. However the nature of this problem was recognized a long time ago and has resulted in many countries adopting a requirement for installed radiation detectors at exit points from the facilities where brachytherapy sources are used.

If the cable of a remote afterloader breaks, the sources may become detached. Failure to recognize these problems may pose significant risks as illustrated in Box 12. These risks are similar to the ones for industrial radiography sources.

Box 12: Loss of an ^{192}Ir HDR brachytherapy source: USA, 1992 [50]

On 1 December 1992, the USNRC was informed by a cancer centre that a 0.14 TBq ^{192}Ir source from its HDR remote brachytherapy afterloader had been found when it triggered radiation alarms at a waste incinerator facility in another city. Apparently the source wire had broken off during treatment of a patient on 16 November 1992, leaving the source in the elderly patient. The patient received a serious misadministration and died on 21 November 1992 as a result. Over 90 other individuals were also exposed. Although there were some weaknesses in the design of the afterloader wire design, the breakage went unnoticed for a long time because of weaknesses in the centre's radiation safety programme, including the failure to survey patients, the afterloader or the treatment room.

An almost identical source wire failure occurred with an afterloader on 7 December 1992, but with minimal radiological consequences due to the fact that the breakage was noticed immediately.

3.2.3. Calibration facilities

Application discussion: There are a large number of radioactive sources that are used for instrument and other calibration purposes. Because they cover a wide range of radionuclides and activities, this practice cannot be assigned to any one category; however, the larger ^{60}Co and ^{137}Cs calibration sources will fall into Category 2. Other sources could fit Categories 3 and 4 and instrument check sources could be in Category 5.

Some calibration sources, especially those of higher activity, are in specifically designed, shielded and collimated devices within large shielded facilities. Others will just be individual sources that might be used for a variety of purposes within research and educational institutions. Radium-226 has been used extensively in the past for calibration purposes, and ^{226}Ra/Be and ^{238}Pu/Be sources are not uncommon for neutron instrument calibration and neutron shielding experiments.

Loss of control considerations: These are generically the same as those for teletherapy or brachytherapy devices for the larger sources within special enclosures. For individual sources in lead containers (often known as pigs), the major factors that lead to them becoming orphaned relate to neglect when the source or equipment is no longer needed, or when the responsible staff member leaves.

3.3. Category 3 sources

3.3.1. Fixed industrial gauges

Application discussion: In many industries it is necessary to measure the level, thickness, density, moisture content or presence of a material while it is being mined, manufactured or processed. Use of radioactive sources enables measurements to be made without contacting the material itself. Many different radionuclides, of a wide range of source activities, may be used. Depending upon the specific application, industrial gauges may contain relatively small quantities of radioactive material, or may contain sources with activities approaching 1 TBq. The larger activity (~100s GBq) ^{137}Cs, ^{60}Co and ^{252}Cf sources, which are used as level, conveyor, dredger, blast furnace or spinning pipe gauges are Category 3 sources, while most other thickness, moisture/density and fill-level gauges are in Category 4.

Blast furnaces that are employed in steel making, often use ^{60}Co sources to gauge the wear of the refractory lining of the bottom hearth. Spinning pipe gauges use ^{137}Cs to measure the wall thickness of pipes as they are passed through the centre of the gauge. While pipe gauges are included in this fixed gauges category, they can also be mounted on trucks. However, they can be quite heavy (~100 kg) with their lead or tungsten shielding.

Loss of control considerations: Sources in this group may be placed in locations unsuitable for continuous human presence. Consequently, they may accumulate layers of dirt, grime, grease and oil, which may cover any warning labels that are present. A facility may have a large number of these gauges. The devices generally are not large, but they may be located some distance from the radiation detector, which may have associated electrical or electronic components located within its housing. The locations of such devices or sources within a facility may not be recognized, since the devices are frequently connected to process control equipment. This lack of recognition may result in a loss of control if the facility decides to refurbish some plant or terminate operations.

These devices are usually installed permanently on the product machines and generally will be safe while in use, although care needs to be taken to guard against the problems identified in Chapter 2. The greatest problem arises at the end of the useful life of the source itself or the plant or equipment where it is installed. There are many examples of where sources have been either:

- removed from equipment and placed in storage; or
- simply left in the equipment on disused plant.

In some instances the sources have remained in this condition for a long time, and, with the passage of time, the knowledge of their existence has dissipated. In other instances, only short periods of time have been involved, but key staff has left and that part of the site has been urgently decommissioned or cleared for economic reasons. There are two dominant conclusions to these scenarios. The most likely one is that the source ends up in the metals recycling industry. Here it is relevant to note that in an industrialized country, gauge-type sources will account for a major part of the national inventory. If there is no installed monitoring in the metals recycling route, or the system is not working, the source could be melted down, resulting in the contamination of the foundry and radioactive material incorporated into manufactured articles. Significant amounts of activity might be found also in the fume and dust collection systems and the slag. Airborne discharges might also be detected at considerable distances (see Box 13 and Annex 1 to Ref. [51]).

Box 13: Source melt accident: Acerinox, Spain, 1998

On 11 June 1998, elevated levels of ^{137}Cs in the air were detected in southern France and northern Italy. Based on meteorological data and analysis, it was concluded that this was from a release somewhere in the south of Spain or north of Africa. Subsequent inquiries and investigations revealed the following sequence of events.

On 30 May 1998, an unnoticed ^{137}Cs source was melted in an electric furnace of Acerinox, a stainless steel factory located in Los Barrios, Spain. As a consequence, the vapours went out through the chimney flue, with some fraction caught in the filter system, resulting in contamination of 270 tonnes of dust already collected. On 1-2 June the dust was removed and sent to two different factories several hundred kilometres from Acerinox as part of the routine maintenance. One company received 150 tonnes that they then used in a marshland stabilization process, increasing the mass of contaminated material to 500 tonnes. The first warning of the event was on 2 June from a gate monitor that alarmed on an empty truck returning from delivering the dust. Authorities were notified of the event on 9 June and on 11 June the aforementioned elevated airborne radioactivity was measured.

The radiological consequences of this event were minimal, with six people having slight levels of ^{137}Cs contamination. However, the economic, political and social consequences were major. A rough estimate of costs include US$20 million for lost production, US$3 million for clean up operations, US$3 million for waste storage. Public alarm was also significant with major media and political pressure being exerted on the Spanish authorities.

A less likely but still relevant end point is that the source is simply left on the site, which might have been sold to another owner. Dependent on the history of the location, there might be a case for a decommissioning radiation survey of the site. Potential for loss of control of sources exists during relining of the furnace or closure of the facility (see Box 14).

Box 14: Blast furnace source event: Romania, 2001

In August 2000, a commercial company started dismantling two blast furnaces with one furnace being completed in June 2001. The decommissioning was without regulatory authorization and was stopped in 2001 when on-site inspections by the regulatory body found radiation levels of 0.5 to 400 μSv/h, with a maximum of 4 mSv/h on some debris bricks. It was determined that each furnace contained about three dozen ^{60}Co (+^{110m}Ag) small radioactive sources of activities between about 0.4 and 20 GBq installed in 1985 for wall thickness control. The consequences of the event were a significant area contaminated with ^{60}Co and a large pile of lining bricks possibly containing more sources. About a dozen workers may have been exposed but do not appear to have measurable radiation injuries.

3.3.2. Well logging gauges

Application discussion: Well logging devices are generally found in areas where exploration for water, coal, oil, or natural gas is occurring. A combination of neutron and gamma sources is used for the determination of density, porosity and moisture or hydrocarbon content of geological structures. The most usual neutron sources employed are ^{241}Am/Be of up to 800 GBq, but some use has been made of ^{239}Pu/Be and ^{226}Ra/Be. The gamma sources most frequently employed are 50–100 GBq ^{137}Cs. Smaller sources, often of radium, are still being used for reference purposes. The sources are usually contained in long (1–2 m, typically) but thin (<10 cm in diameter) devices, which also contain detectors and various electronic components. The devices are heavy, due to the ruggedness needed for the environments in which they are used.

Loss of control considerations: The housings in which the neutron sources are stored and transported are large and may appear attractive to thieves. The bulk of the shielding will normally be plastic or paraffin wax and may be thrown away as useless by a thief, leading to a potentially hazardous situation. The housings for the gamma sources will normally be shielded with depleted uranium or lead, which could be attractive for its scrap value.

The nature of the work using these sources requires that they be easily removed from their housings to be introduced into a borehole. If they were not subject to adequate control, it would be relatively simple for the source to be removed and left in a hazardous state. The potential for sources becoming orphaned are similar to those for industrial radiography. However the activities and radiation dose rates are generally lower.

Box 15: Theft of well logging sources: Nigeria, 2002

In December 2002, two ^{241}Am/Be sources used for well logging were stolen from an oil company truck while it was in transit in the southern Niger Delta region. Such sources are typically of about 0.7 TBq activity [18]. Public announcements, police efforts and increased border vigilance were all instigated in an attempt to find the sources. Health care workers were also warned to keep a look-out for anyone with prolonged nausea or skin burns. Some eight months later the sources were detected in a scrap metal shipment in Europe.

While usually of lower radioactivity than industrial radiography, the portability and use of such devices in remote field locations could make them attractive to acquisition by those with malevolent intent.

3.3.3. Pacemakers

Application discussion: During the 1970s and 1980s heart pacemakers using radioactive material as the energy source (i.e. very small RTGs) were implanted into a number of patients. The most common radionuclide used was ^{238}Pu (with a small amount of ^{241}Am as a source contaminant). One beneficial characteristic of using ^{238}Pu was that it was easy to shield and gave rise to little external dose rate.

Box 16: Melting of a pacemaker: UK, 2000

Quality assurance tests conducted in 2000 of steel from a UK foundry identified that about 140 GBq of ^{238}Pu had been melted. It is most likely that this was from a pacemaker. The foundry had sophisticated portal monitors to check incoming scrap metal for gamma emitting nuclides. However they were incapable of detecting the ^{238}Pu activity. The doses involved were negligible but the clean up and disposal costs of such an event are several million US dollars.

Loss of control considerations: It has not always been easy to keep track of patients and there may have been instances of the implanted source being cremated with the cadaver. It is also possible that sources may be discarded after autopsy and end up in recycled metals. The fact that ^{238}Pu sources are easily shielded also means that they are not easily found.

3.4. Category 4 sources

3.4.1. Low dose rate brachytherapy sources

Application discussion: Much of the general discussion of brachytherapy under Category 2 sources is also applicable here, except that the activities are lower and some different radionuclides are used. In addition to ^{137}Cs and ^{192}Ir, other radionuclides that have been used include ^{125}I, ^{198}Au and ^{252}Cf.

Loss of control considerations: These are the same as discussed earlier, except that the hazard is clearly lower with the lower activity sources. While acquisition of some Category 4 sources may still be attempted by those with malevolent intent, most of the sources are too small to cause significant harm from their radioactivity.

3.4.2. Thickness/fill-level gauges

Application discussion: Beta or low energy gamma sources are used for measuring paper, plastics and thin, light metals, with higher energy gamma sources being used in situations where steel plate is being manufactured. Industries such as breweries or soft drinks bottling plants will use low activity sources in quality control to ensure that the bottles or cans are being filled properly. Cigarette manufacturers also use sources to ensure that the proper packing density is being maintained.

Radionuclides that are typically used in these industries are ^{85}Kr, ^{90}Sr, ^{241}Am, ^{147}Pm, ^{244}Cm as well as ^{137}Cs. Activities range from 0.4 GBq to about 20 GBq.

Loss of control considerations: These are essentially the same as other fixed industrial gauges, but because they typically use less-penetrating radiations of lower activity, the potential hazards are smaller.

3.4.3. Portable gauges

Application discussion: Moisture/density devices are a type of industrial gauges that are small and portable. These devices contain the sources, detectors and electronic gear necessary for the measurement undertaken. Moisture is usually measured with a $^{241}Am/Be$ source of about 2 GBq and density measured with ^{137}Cs of about 0.4 GBq. The sources are physically small in size, typically a few cm long by a few cm in diameter, and may be located either completely within the device or at the end of a rod/handle assembly.

Moisture gauges are used in agriculture to ensure optimal watering, while combination, or density gauges are often used in road construction to ensure that the appropriate compaction is being used for the foundation materials.

Loss of control considerations: The fact that such sources are usually transported in locked boxes in vehicles means that they can be stolen as collateral theft if the vehicle itself is stolen. There appears to be some attractiveness of these devices as evidenced by the number of them that are routinely stolen. In addition, the sources are used in remote road construction sites. This, and their small size, makes them susceptible to loss of control or theft. Sometimes they are damaged by other road construction equipment and may be overlooked.

3.4.4. Bone densitometers

Application discussion: As their name implies these sources are used in devices designed to measure bone density as part of an assessment of osteoporosis. The radionuclides used are ^{109}Cd, ^{153}Gd, ^{125}I and ^{241}Am ranging from about 1 to 50 GBq. X rays are now widely used in such devices.

Loss of control considerations: Historically, there have not been any recorded events involving loss of control over sources in bone densitometers.

3.4.5. Static eliminators

Application discussion: In many industries the generation of static electricity during manufacture creates problems leading to the attraction of dust on components or a possible fire hazard. In order to minimize these problems static eliminators incorporating sources of ^{241}Am and ^{210}Po may be used. These vary in size from hand held devices of a few centimetres dimensions, to fixed installations up to several metres long and a few centimetres wide. Since the static eliminators utilize the alpha particles emitted, the source construction is fragile and will not withstand physical abuse or fire, either of which may result in spread of contamination.

Loss of control considerations: Again, there is not a lot of experience with regard to static eliminators becoming orphaned. However, there was one incident where it appears that a number of sources were deliberately gathered together and buried.

3.5. Category 5 sources

Application discussion: There are a large number and variety of Category 5 sources that are used in: X ray fluorescence, electron capture devices, Mossbauer spectrometry, positron emission tomography checking, tritium targets and smoke detectors. In addition, superficial treatment of skin and ophthalmic lesions may be carried out using ^{90}Sr/^{90}Y sources. Nasopharyngial applicators (^{90}Sr) replaced the “Crowe” radium probe in the 1970s. Permanent implants were also developed originally using ^{222}Rn and ^{198}Au seeds. Today permanent implants are done with ^{125}I, ^{106}Ru/Rh and ^{103}Pd.

Loss of control considerations: Category 5 sources are of such a low hazard that they generally do not need to be considered in a national strategy. Loss of control of such sources is more of a regulatory and administrative issue than a radiation safety or radioactive source security problem.

3.6. Special situations

3.6.1. Historical sources

Application discussion: Legacy sources are those that pre-date effective regulatory requirements and which may not have been disposed of, either at all or in an appropriate manner. The type of legacy sources will depend upon when regulatory control began to have effect within a country. The majority of legacy sources are likely to be radium (Box 18), but not exclusively (Box 17). The following list provides an indication of the types of radium sources and uses that might be found from uses in the first half of the 20th century, some of which used unsealed radioactive material.

- Medical applications, including radium brachytherapy;
- Radium luminous devices and luminizing facilities;
- Industrial radiography using radium;
- Patent medical 'curative' devices;
- Static eliminators;
- Industrial smoke detectors;
- Lightning preventers.

Loss of control considerations: If industrialization of a country and its associated use of radioactive sources started prior to the establishment of an effective regulatory infrastructure then there are likely to be a significant number of sources that are orphaned. In this case, the task becomes one of creating the initial national inventory and is discussed further in Part II, particularly Chapter 7. An initial inventory of legacy sources might be achieved by culling information from publications or records of the time, but it is also advisable to enlist the aid of those with long experience of radiation uses in the country. Care will be needed to ensure there is enough coverage of the various sectors e.g. medical, industrial, and academic uses (including nuclear research).

Box 17: Non-radium legacy orphan source: India

Not all legacy sources are radium, but depend upon when regulatory control is first established in a State. A corporate officer requested advice from the regulatory body regarding a 185 GBq ^{137}Cs that had been discovered by a member of staff to be in the corporation's possession. On investigation, it was discovered that the source had been imported by the corporate office in the early 1950s, when regulatory control in India was in its initial stages. Therefore, the source had not been placed under regulatory surveillance. The source was subsequently dealt with appropriately.

Some doctors bought their own radium brachytherapy sources and stored them at home. These could be inherited by their offspring and might only be discovered by chance. These and other radium sources have been found in bank vaults because of their value at the time (US$100,000 per gram in the 1920s). Since early radium seeds were made of thin gold tubing with the radium salt solution inside, some of these found their way into the gold recycling market. In the USA, in the 1980s a few hundred radium-contaminated gold items were recovered as part of a special campaign [52].

In some countries, radium luminizing facilities were widespread in the period from the 1930s to into the 1960s and 1970s. Many were operated by the military. The storage facilities that maintained large stocks of luminous items, as might be the case for some military facilities or early commercial airplane or clock manufacturers should not be overlooked.

Box 18: Discovery of radium luminized instrumentation: UK, 1984

In the UK in 1984 a company specializing in providing spare parts for vintage aircraft and military vehicles came to the attention of the competent authorities. The company's warehouse contained over 7,000 packing crates of spare parts and in some 2,000 of them radium, mostly in the form of luminized items, was detected. In many cases the varnish covering the luminizing compound had broken down and radium contamination was present.

The IAEA has a made focused efforts in certain regions to identify, recover and condition legacy radium sources.

3.6.2. Research and academic uses

Application discussion: Because applications of radioactive sources in teaching and research are extremely varied, they need at least a brief separate discussion. Almost any radionuclide of any activity can find a use in some research work, and therefore, such sources can belong to almost any category.

Many of the previously described medical and industrial uses can be found in universities and research institutes. Some are in modified forms to permit a wider range of operating conditions for research purposes. This can often mean a greater reliance on operating procedures rather than engineered safety solutions, and as such they provide more challenges to maintaining the safety and security of sources.

The common sources used in much research are however of low activity and/or of short half-life. Tritium (^{3}H) and ^{14}C are frequently used but they have weaker beta emissions, thereby causing less serious radiological problems when spent. Many such sources are used in electron capture, gas chromatograph, and Mossbauer spectrometry devices.

Notable exceptions are the use of large (up to 1 PBq) ^{60}Co and ^{137}Cs sources for irradiation or sterilization of materials and plants, and the use of MBq or GBq quantities of ^{241}Am/Be or ^{137}Cs for density and moisture measurement in agricultural research. Although a few irradiation facilities may be of a similar scale to an industrial one, most are of the fixed, self-shielded type that are designed to accept samples into an irradiation chamber that cannot be physically entered.

Loss of control considerations: Research work is often carried out as part of a student's thesis or under a specifically funded contract. Equipment, including radiation sources, may have been obtained specifically for a particular project. When the work is completed or the funding runs out, there may be no immediate or further use for the sources, and the person responsible may leave. In many cases the sources are put into storage, but there might not be any clear 'owner' within the organization to take responsibility. So the principal problem with research or teaching sources arises when the equipment falls into disuse and knowledgeable staff leave.

Box 19: Possible research facility source fatal accident, Estonia, 1994

The fatal radiation accident in Tammiku, Estonia in 1994 [7] involved a source originally found in scrap metal delivered to a metals recycling facility in Tallin. The source was estimated to be about 7 TBq of ^{137}Cs in an assembly that probably had been part of an irradiator, possibly in a research facility.

3.6.3. Military uses

Application discussion: In most countries military uses of radioactive sources are outside of civilian regulatory control. For this and other reasons the military uses of radioactive sources require separate consideration. They too can cover a wide range of categories. While many of the uses are similar to those found in medicine, industry and academia, there are some uses of radioactive materials that are unique to the military or use significantly larger activities than those found in comparable non-military devices. Examples of military use include:

— radioisotopic thermo-electric generators (RTGs);
— sources for simulation training for a nuclear weapons attack; and
— tritium in luminous devices (larger activities than in civil uses).

Loss of control considerations: It is probable that the military, for security reasons, have a separate inventory from the normal national inventory. Therefore it will be necessary to directly consult military authorities to assess the situation.

In addition to the normal peacetime military situations, some countries may have to consider abnormal situations. Examples are those arising from:

— the withdrawal of foreign troops from a country;
— major political changes in a country where the military command structure may have been non-functional for a while; and,
— countries or regions that have been the scene of military conflicts.

Experience has shown that all of these situations could result in sources becoming orphaned and posing a serious threat to the population. Incoming national authorities or protecting forces will need to be aware of this and develop a strategy to address the specific problems of the situation. However, it needs to be recognized that unless they have been properly addressed at the time, orphan sources can remain in the environment for a long time, and in some cases may still be there from old conflicts. Box 20 summarizes an example from Georgia following the withdrawal of the former military forces.

Box 20: Military sources accident: Lilo, Georgia, 1997 [8]

In 1992, with the break up of the former USSR, the Soviet Army abandoned its former facilities in Georgia. One of these was a training camp in Lilo, which was taken over by the Georgian Army. In October 1997, eleven soldiers developed radiation induced skin lesions. A radiation-monitoring search of the facility revealed 12 abandoned ^{137}Cs sources ranging from a few MBq to 164 GBq. These had been used by the previous occupants in Civil Defence Training; with the sources being hidden about the site and trainees having to find them. Many were still where they had been hidden. In addition, one ^{60}Co source and 200 small ^{226}Ra sources used on gun sights were also found on the site. Over six years later the soldiers are still receiving treatment for their injuries.

It should be noted that while there tends to be significant public and political concern with regard to spent depleted uranium munitions or fragments thereof, studies have shown that the radiological hazard is actually quite small [53].

Another consideration from areas of military conflicts is that the collateral damage caused by shells, bombs and other munitions may involve damage to the radiation sources themselves or the buildings in which they are housed. This can result in the abandonment of the facilities or sources, leaving them available for people to loot or scavenge.

Box 21: Sources in war affected area: Croatia, 1991-1995

Almost half of the Croatian territory was affected by war from July 1991 to September 1995. The collateral damage was significant and a number of sources were affected as shown in the table below. Most of these are Category 5 sources and below.

Application	Original number of sources	Orphan sources	
		Recovered	Burnt or lost
Smoke detectors	8,298	1,710	1,180
Lightening preventers	151	60	0
Medical	17	0	0
Industrial	103	18	24

The lightening preventers, being the most unprotected, suffered the greatest damage. Accessible dose rates were up to 3 $mSv.h^{-1}$ at 1m.

PROCESS FOR THE DEVELOPMENT AND IMPLEMENTATION OF A NATIONAL STRATEGY

Part II

CHAPTER 4. OVERVIEW

Strategies for improving control over radioactive sources need to be developed in a manner that is appropriate for the specific national situation. For example, in the case of a country with a very immature regulatory framework, the initial national strategy may consist of the creation of a national registry and the subsequent identification of, and searches for, high risk legacy orphan sources. In the case of States with an established regulatory framework, the initial national strategy may go beyond a review of legacy orphan sources, and might include:

- a comprehensive analysis of possible gaps in regulatory controls;
- the collection and disposition of high risk disused, or vulnerable sources;
- the creation and maintenance of orphan source search and recovery capacities; and,
- the installation of additional passive search capability focused on the highest risk areas within the national use of sources.

However, no country is completely isolated with respect to the movement of radioactive material. Therefore, consideration also needs to be given to the flow of radioactive material into and out of the country and the status of the regulatory control of sources in neighbouring and trading countries.

Appendix V gives a listing of some common items that have become part of specific national action plans. In every case, the development of a national strategy should provide useful insights into potential improvements in the national regulatory framework.

Fig. 4.1. provides an overview of the process of developing a national strategy and implementing a programme for improving control over radioactive sources. In essence, this consists of three phases:

(1) *Assessment:* deciding on the scope of the strategy, gathering the necessary information and determining the nature and magnitude of the problem;
(2) *Development:* identifying and prioritizing actions for solutions, and developing the plan accordingly; and,
(3) *Implementation:* obtaining the necessary commitment and resources, implementing the solutions, then evaluating the impact of the plan.

Ideally, the goal is to regain control over all orphan sources and increase the degree of control over vulnerable sources. A desirable objective in this regard would be full compliance with the International Basic Safety Standards [24], the Requirements for Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety [25] and full implementation of the Code of Conduct on the Safety and Security of Radioactive Sources [20]. However, this may not be immediately attainable. Therefore, in determining an overall strategy, the State will need to assess the benefits and detriments of various options and make judgments with regard to their priorities. Since it is most important to adequately control dangerous radioactive sources, those in Categories 1, 2 and 3 of the IAEA's Categorization of Radioactive Sources [18] should take priority. Undoubtedly budgetary and staff resource considerations will be factors in the level and rate of implementation of any national strategy.

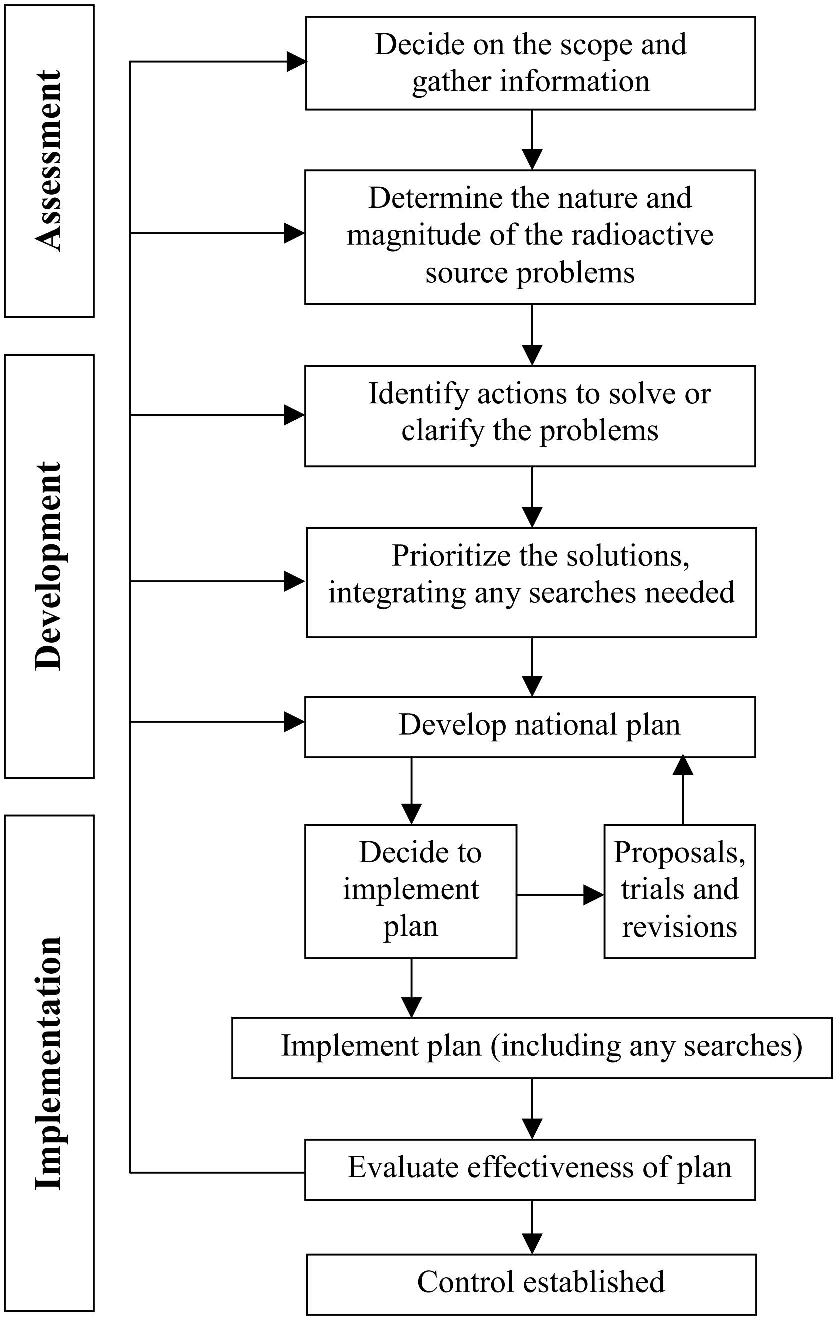

Fig. 4.1 Outline of the national strategy methodology.

CHAPTER 5. ASSESSING THE POTENTIAL PROBLEM

5.1. Assessment overview

The assessment phase of establishing a national strategy for improving control over radioactive sources involves deciding on the scope of the strategy, gathering information and then evaluating it in order to reach conclusions regarding the nature and magnitude of the problem.

Hence, the assessment phase can be divided into the following elements:

- establishing realistic expectations given the national situation (the scope);
- gathering data on all aspects of the past and current level of radioactive source control, in order to identify potential orphan and vulnerable sources; and
- performing an evaluation (gap analysis) and reaching conclusions on the need for a national strategy.

Each of these aspects is expanded upon in the next sections. This is followed by advice on how to gather and evaluate information in each of several key areas.

The assessment phase will be iterative as a State's situation changes. It is also reasonable to expect that some degree of assessment will be going on at all times. The assessment phase of this process is not intended to be the only decision making point, rather it is the point at which major decisions on the need, direction and content of the national strategy are made.

5.1.1. Deciding on the scope

Stated most simply, establishing a scope for the assessment phase consists of identifying where the subsequent data gathering phase will be focused. In most cases, the focus should be on types of sources with the potential to cause consequences above a determined threshold. Many States will choose to prioritize efforts on those sources capable of causing severe deterministic human health effects if not under control. These are Categories 1, 2 and 3 in the IAEA's Categorization of Radioactive Sources [18]. However, this is not the only possible choice. An initial national strategy focus could be based on:

- source categories (e.g. Categories 1, 2 and 3);
- source type (e.g. industrial radiography sources);
- an industrial sector where problems have been identified (e.g. scrap metal recycling);
- geographical region or area (e.g. the capital city);
- sources in use prior to a national regulatory body being established.

The scope of the assessment is likely to change with each iteration in the development of a national strategy. In some cases, the appropriate focus will be self evident. In other cases, it will be necessary to perform a careful analysis, perhaps with some preliminary data gathering, in order to determine the appropriate focus.

The importance of deciding on a scope cannot be overstated. An honest appreciation of the available resources for both the development phase and the implementation phase of the national strategy is critical to ensuring that the effort is successful. Some states may be able to devote significant effort in the development of a comprehensive national strategy that anticipates future conditions and provides the actions appropriate to those conditions. However, it is more likely that most States will only be able to devote enough resources to produce an initial national strategy that focuses on particular issues and that contains prioritized actions based on past and current conditions. These countries will perform iterative assessment phases over an extended period as the need to update the national strategy changes as the result of the completion of existing action items and of changes in conditions. Each assessment should build upon the work performed in previous assessments.

If there is a fixed budget for the national strategy effort, then there must be reasonable conservation of resources during the developmental phase to ensure that resources are available for the implementation phase of the strategy. Both the initial availability of resources and the potential availability of additional resources for the implementation phase may be affected by factors such as the national attitude toward radiological safety and the current national priorities. However, even in a country with many high priority societal needs (such as basic health care), the scope of the assessment phase needs to include at least Category 1, 2 and 3 sources. A State with greater available resources or one that perceives the control of orphan sources to be a matter of national security, may consider it appropriate to consider a broader scope of sources.

Two issues of special consideration are noted here. First, the high economic impact of melting events for sources that are not of concern from a radiological risk perspective may enter into the decision on the scope of the assessment. In developed countries, many or most recycling facilities have installed detection systems, but even the best system is not foolproof. Some States may decide that the societal benefit, relative to the cost and disruption associated with the cleanup following source melting events, justifies a broader scope of assessment than might be necessary if only human health impacts are considered. Some indication of the frequency of source melts can be seen from the listing in Appendix IV.

The second special consideration deals with the accumulation of sources that, individually, are of little radiological risk. This accumulation of sources is typically associated with the manufacture, service, or distribution of the sources, or in the waste consolidation sector. For example, in the U.S.A. a very large number of smoke detectors were found stored in a single warehouse. Searching for individual, exempt sources in devices of this type is not necessary or required, but gathering data on possible accumulations may be important for some States.

Summary - Scope

In determining the scope of the national strategy, there are multiple factors. Some of these are listed below.

1) Decide on which types of sources will be within the scope of the national strategy. As a first priority it is recommended that all dangerous sources be included; i.e. Categories 1, 2 and 3.
2) Decide whether the strategy should focus on one particular sector of use, such as the oil industry or medical uses, or whether it should be broad-based.
3) If the national strategy will cover a wide range of radioactive sources, then there should be a prioritization of efforts, beginning with Category 1 sources and moving on down to the other categories as resources allow.
4) Decide if the focus will just be on the past, or will cover current and likely future problems as well.
5) Appropriately divide available resources between development and implementation of the national strategy.
6) Determine the relative balance and priority to be made between safety, security, social, political, economic and environmental issues.

5.1.2. Gathering specific national information

The heart of the assessment phase is the gathering of data on sources, both known and unknown. The risk from orphan or vulnerable radioactive sources cannot be characterized unless information is available on what sources are likely to be in the country. Characterizing the orphan source risk involves an evaluation of both the potential for orphan sources to exist, and the potential consequences that such sources may cause. It should be clear that orphan sources in Categories 1, 2 and 3 are of primary concern because of their potential to cause severe deterministic effects. The assessment process will also address whether vulnerable sources, which are currently under control, might become orphaned in the future, and whether orphan sources might be introduced from outside the country.

There are three major aspects of gathering information that need to be addressed. These are:

- What information is needed?
- From where can this information be obtained?
- How can it be gathered?

Chapter 7 deals with the possible information sources (the where) and the methods (the how) in the larger context of searching for sources. The primary purpose of the current chapter is to address the 'what' although the other aspects are mentioned as appropriate and necessary.

While all appropriate information sources and methods should be used, personal interviews with knowledgeable regulatory staff are a good starting point and are to a certain extent assumed in the following discussion.

Fig. 5.1. illustrates the important data inputs to the information gathering and evaluation phase. Each of which is subsequently addressed in the text.

Summary – Gathering specific national information

Using all available information sources, but primarily through personnel interviews, gather data on each of the following subjects as discussed in their subsequent sections:

1) Current and past degree of regulatory control.
2) Quality of source inventory.
3) Types of use in the country.
4) Military uses and sites of conflict.
5) Legacy knowledge.
6) Intelligence on illicit trafficking.
7) Trading partners.
8) Metals recycling.
9) Disused sources.
10) Known lost and found sources.

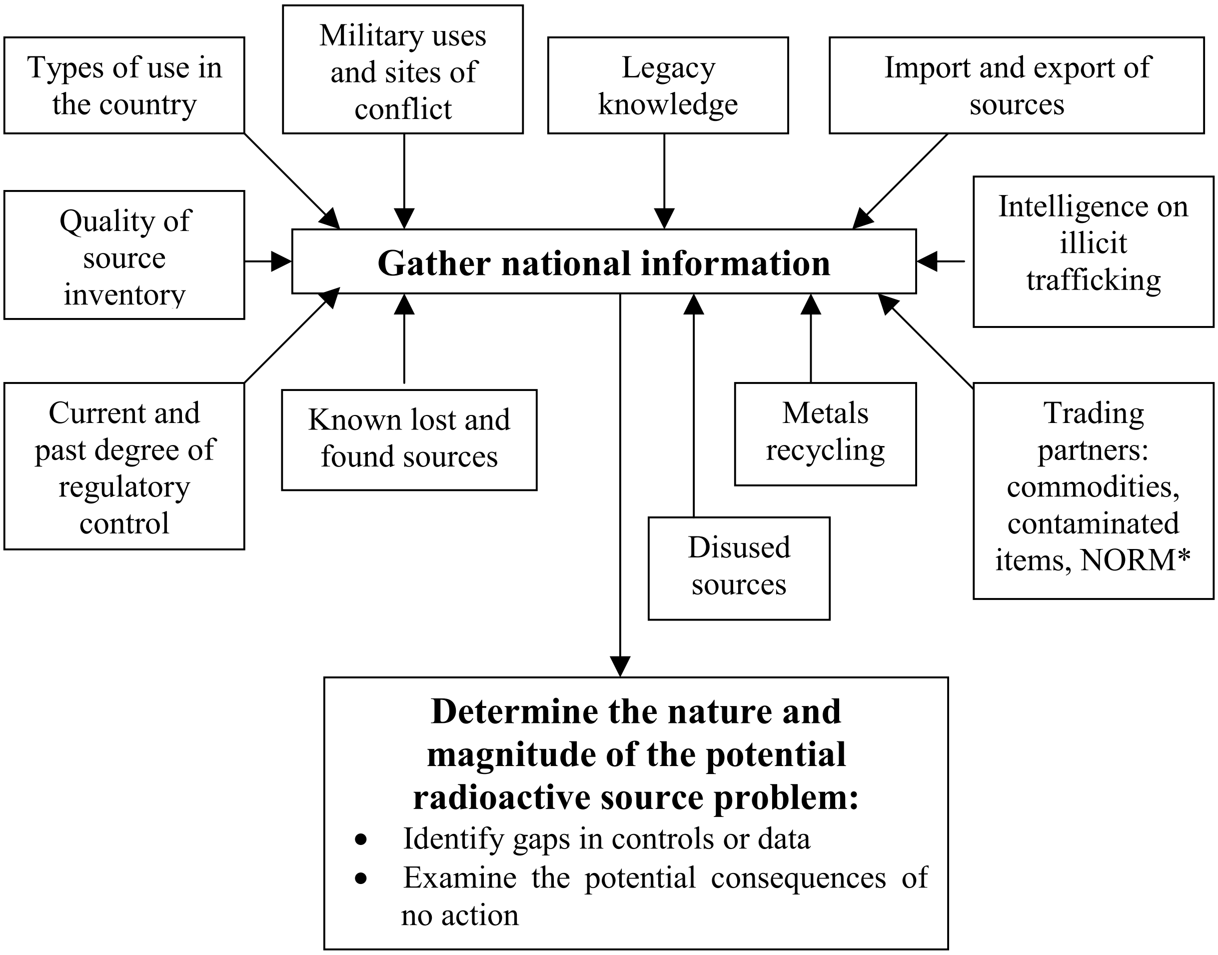

Fig. 5.1. Assessing the potential problem.

*Naturally occurring radioactive material

5.1.3. Evaluation of information gathered

While the evaluation phase is discussed separately; most of the time a large part of the evaluation will be occurring while the data gathering is taking place. As questions are being asked and answered, it will become clear where there are gaps in the information or where there are problems.

Making an evaluation of the nature and magnitude of the radioactive source control problem involves knowing how things should be in the ideal situation and comparing the actual with this ideal. The ideal situation can be characterized by a complete and thorough conformance with relevant national laws and regulations as well as international standards and guidance [24], [25], [29], [44]. The Code of Conduct for the Safety and Security of Radioactive Sources [20] is particularly useful as a model goal.

A good evaluation also involves being able to discern the significant differences from the trivial ones. The criterion for determining whether an issue is important or trivial will primarily be the potential consequences of the problem. This will in turn depend upon the category of source involved. For example, a known loss of a specific Category 1, 2 or 3 source in a city would be a problem requiring immediate action. On the other hand, failure to include all of the fixed gauges that are in a particular industrial plant within the national registry is something that needs to be remedied. However, because it is unlikely to lead to an immediate hazardous situation it has a much lower priority.

From this discussion, it is clear that the people performing a national strategy evaluation must know how radioactive source control within a country should ideally be handled and they should be experienced enough to sort and rank the discrepancies and problems found. While it is possible for the people involved in the radioactive source control programme within the country to do this, experience has shown that it is very helpful if external evaluators are involved. This is because a more objective view is obtained and blind spots are identified better.

Summary – Evaluation

The important points for a useful evaluation of the data gathered are:

1) Decide whether the data gathering and evaluation can done with internal staff, or whether external appraisers would be helpful.
2) The evaluators should be familiar with the Code of Conduct, and fully understand the requirements and guidance given in the International Basic Safety Standards, as well as other relevant IAEA standards.
3) The actual situation should be compared to these standards and guidance.
4) The important differences need to be discerned from the trivial differences.

5.2. Current and past degree of regulatory control

Any assessment of the safety and security of radioactive sources in a country must start with a review of the current and past degree of regulatory control over such materials. As radiation technologies have advanced and as radiation safety has become more complex over the years it has become necessary to have an effective radiation safety infrastructure. By definition [24] this infrastructure includes: legislation and regulation; a Regulatory Authority empowered to authorize and inspect regulated activities and to enforce the legislation and regulations; sufficient resources and adequate numbers of trained persons. The effective inspection and enforcement system is essential, together with a safety and security culture shared by all of those with responsibilities for sources, including both management and workers. The infrastructure requires clear lines of authority and responsibility, and adequate resources to operate the system at all levels. The Basic Safety Standards [24], the Requirements on infrastructure [25] and the Code of Conduct [20] provide further comprehensive guidance as to what is needed in this area.

Many countries will have used radioactive sources prior to the development of their current regulatory infrastructures. In addition, infrastructures are occasionally changed, being reviewed and brought into line with new technological, legal and political realities. Thus, for all countries, their regulatory infrastructure is continuously evolving and the probability of loss of control of sources depends not only upon their historical use of sources, but also upon the status of their regulatory infrastructure as a function of time.

As an example of the importance of the degree of regulatory control, consider a typical problem where an industrial gauge is inadvertently transferred to a scrap metal recycling plant. This is a growing problem and in the past, it has caused deaths and serious injuries as well as necessitated costly decontamination. There are many reasons why the problem exists, but basically, it involves two fundamental regulatory deficiencies:

(1) lack of effective regulatory control through notification or authorization and inspection; and,
(2) lack of regulatory requirements for, or enforcement of, security and accountability of sources.

This particular problem appears to be most acute in countries where the regulatory infrastructure is weak or essentially non-existent.

When a regulatory infrastructure review is conducted [25], [28] as part of the development of a national strategy, it is important to not only consider the regulatory requirements but also, how the regulatory authorities undertake their duties, how they are integrated and how each authority co-operates.

In looking at the past degree of regulatory control, it is necessary to examine the quality assurance arrangements of such things as authorizations, inspections and inventories that were in force since this will indicate the degree of confidence that can be placed in the operation of the regulatory infrastructure at that time.

When determining, and analyzing, the regulatory infrastructure, it is most useful when the focus is on those elements that have a direct influence on the probability of loss of control of sources and particularly those sources in the higher risk categories. These elements will include such topics as: licensing, import, possession, use and disposal of radioactive sources. Much of the information will be in regulations, with the regulatory bodies or other organizations that have specific oversight of radiation or radioactive materials. However, for other information of relevance, such as checks for competence and legitimacy of those wishing to hold and use sources, it may be necessary to look at other legislation and other regulatory or intelligence bodies.

The nature of the reviews of 'historic' and 'current' regulatory infrastructures covers essentially the same ground. However, historic reviews may be made difficult by the lack of contemporary documentation and the difficulty of finding individuals who can assist in describing the old procedures and priorities. The review of the current situation will be easier because it can use existing documentation and interviews with staff that are in relevant posts. The historic review will need to be linked to what is known of source inventories and uses at the time and this information may be difficult to establish. In the early days, for example, there might have been the possibility of contamination of land and buildings because of the spread of radium luminizing compound. However, there is far less opportunity for the loss of control of discrete sources and those conducting reviews need to be aware of these factors. The historic review will highlight the probability of loss of control of sources and the possible mechanisms; but in some areas, it may indicate an actual loss of specific sources. The current review will generate a sense of the degree of confidence regarding the safety and security of existing sources and may highlight areas that require further attention and modification.

The system of regulatory control is core to the safety and security of radioactive sources. Regulatory infrastructure in general is also the subject of several IAEA programmes, including the Model Project for Strengthening Radiation Safety Infrastructure. Typical source-related problems that these efforts and the national strategies work have identified are listed below in no particular order.

— Lack of suitable laws and regulations governing radioactive source control.
— Lack of independence of the regulatory body.

- None, or inadequate authorization, licensing, or registration process for radioactive sources.
- No specific authorization, or licensing for government-owned radioactive sources.
- Lack of, or inadequate, inspection, enforcement and follow-up.
- A licensing fee structure that encourages undesired behaviours on the part of users.
- No prioritization of regulatory efforts, with all sources being given the same amount of work regardless of their potential hazard.
- Prioritization of effort based on geographical regions, political regions, or uses rather than on the categorization of radioactive sources.

Summary – Current and past degree of regulatory control

1) Determine when the earliest laws, regulations and regulatory bodies were formed.
2) Ascertain what types of sources were first used within the country and in which practices they were applied, as well as how they were generated, purchased or imported into the country.
3) Determine how the initial licensing was begun or how the initial inventory of radioactive sources was generated.
4) Determine the current system of regulatory controls for the complete life-cycle of radioactive sources, focussing on licensing and inspection, import controls, possession, use and storage or disposal of sources.
5) Check for the possibility of these common problems:
   a) Lack of laws and regulations governing radioactive sources.
   b) Lack of independence of the regulatory body.
   c) Different regulatory bodies for different applications of sources e.g. medical vs. industrial users.
   d) Regulatory bodies with overlapping responsibilities, or conversely one aspect of sources not regulated by anyone.
   e) Radioactive sources imported and used before laws, regulations and regulatory bodies were functional.
   f) Transfer of regulatory roles, or records, with a change of governmental system or regime. This includes a loss of records, or a period of loss of regulatory control.
   g) Inadequate authorization, licensing, or registration processes.
   h) No specific authorization or licensing of *government-owned* radioactive sources.
   i) Lack of, or inadequate inspection, enforcement and follow-up.
   j) A licensing fee structure that encourages undesired behaviours on the part of users.
   k) No prioritization of regulatory efforts with regard to radioactive sources, i.e. the same amount of effort (licensing, inspection etc.) spent on Category 5 sources as on Category 1 sources.
   l) Prioritization of work based on geographical regions, political boundaries or uses rather than categories.

5.3. Quality of source inventory

The existence and the quality of a national registry of radioactive sources will be a prime indicator of the probability of there being orphan or vulnerable source problems within a country. Note that in this report, the terms ‘registry’ and ‘inventory’ are used synonymously; however, some would regard an inventory as containing more detail (such as current activity and specific current use location) than a registry. If a registry does not exist, then its creation becomes a high priority item in the national strategy. Existing information that may be available to allow the creation of a list of sources can include:

- the inventories of sources maintained by users (in some regulatory frameworks);
- the records of source manufacturers;
- the records of source distributors;

- the records of companies servicing devices that include sources;
- the records of transportation or shipping companies, including customs declarations;
- information contained in event reports and notifications;
- the information contained in user licensing records.

It is likely that radioactive source information gathered in this manner will be incomplete. For instance, the records may only identify the existence of a device but not the individual sources or sources within the device. Multiple discrete sources can be used in a single device during the lifetime of the device. Another problem with the information is that it will not necessarily indicate the likelihood of identified sources having been orphaned. In some instances, licenses are granted for the possession of up to a certain activity of a particular radionuclide and this arrangement can present some inventory problems. The licensee may have none, one or more discrete sources up to that quantity. For all of these reasons, a degree of follow-up may be necessary.

Aside from finding information contained in existing records, there are several other methods to collect data for an inventory. These are discussed in detail in Chapter 7.

Even if a national registry exists, it is quite likely that it will be incomplete. If it is incomplete, then the implication is that there are orphan sources. Therefore, an existing inventory needs to be critically examined to check its quality, reasonableness, internal consistency and likely completeness. Questions to be considered in this evaluation can include:

- Are all the likely or known applications contained within the inventory? For example, it would be unusual to find any reasonably industrialized country without some gamma radiography work being performed. Most cancer treatment centres would have at least one teletherapy device and/or brachytherapy device and any oil-producing country will have well-logging operations taking place.
- Are the radionuclides and activities given in the inventory appropriate for the application? For example, the typical activities of an AmBe neutron source and Cs source in a portable moisture/density gauge are about 2 GBq and 0.4 GBq respectively. If the inventory states something significantly different from this, then something is probably wrong. Appendix II of this report, or IAEA-TECDOC-1344 will be helpful during this check process because they provide both the typical activity and the range of activities used.
- Are all the likely companies or users of a particular application included? For example, if there are three major road construction firms in the country, and only two of them are shown as having moisture/density gauges, the reason why the third one does not have licenced gauges should be checked.

In developing a national registry, or evaluating the completeness or accuracy of an inventory, priority needs to be given to the higher category sources. For example, there should be a high degree of assurance that all Category 1 and 2 sources are included in the registry. Indeed, the Code of Conduct [20] states that "Every State should establish a national register of radioactive sources. This register should, as a minimum, include Category 1 and 2 radioactive sources". Checking that Category 4 and 5 sources are on the registry can be managed with a much lower priority over a longer time.

The other aspect with regard to the quality of the inventory relates to the type, accuracy and completeness of the information that is recorded for each of the radioactive sources. The main objectives of the inventory or register of sources for the purposes of the national strategy are to:

- ensure that the location of each source is known;
- detect whether a source is missing as soon as reasonable;
- be able to describe the source should it go missing (See Box 22);
- evaluate the possible hazard of the source in an uncontrolled environment.

While the number of data items could be expanded greatly to accommodate other regulatory purposes, for these objectives the record of each source should include as a minimum:

- sufficient information to uniquely identify the source. This should include a descriptor as well as a unique identification number;
- the radionuclide;
- the source activity and associated date;
- the category of the source;
- the form of the source material (physical and chemical);
- the current or normal location of the source;
- the person responsible for the source and contact information for that person.

Under most circumstances, the best method of generating and maintaining an inventory of radioactive sources is to use database software, rather than spreadsheet or word processing programmes, as have been used on occasion. Once set up, a source database enables searching, sorting and reporting to be much more easily accomplished. There are a number of commercially available, radioactive material inventory programmes, as well as the IAEA developed Regulatory Authority Information System (RAIS) [54], which has a source inventory module.

Box 22: Usefulness of a local photographic inventory: Sellafield, UK

Within a nuclear fuel cycle facility, a high profile is given to the security of nuclear material and fission products. Following a minor incident at British Nuclear Fuel's Sellafield plant involving the security of a conventional radioactive source, the company carried out a review of the security arrangements for such sources. They found that for over 2000 sources they had on site these arrangements needed improving, particularly in respect of keeping local inventories up to date. Although all the sources were accounted for, many were in different locations than the records showed; having been moved from one location to another for operational reasons. In locating all the sources they realised that a visual image of each source or device was important. As a result they now have a policy of having an electronic image of all their sources to supplement the inventory record and to facilitate finding a source were it to be lost.

An accurate knowledge of the radioactive sources in the country, and particularly the higher category sources, is vital to good control. The generation of a national registry is part of the national work plan required by the Model Project for Strengthening Radiation Safety Infrastructure, and required by the revised Code of Conduct [20] for at least Category 1 and 2 sources. Typical problems that are identified in this area are listed below.

- No national inventory of radioactive sources.
- Only a partial inventory of sources:
  - Only some licensees have their own inventory.
  - A local, or regional inventory only.
  - Only sources that are under one government ministry or department (such as the Health Department) are included.

- Only sources of a certain type, or used by a certain industry are included.
- Only sources acquired, or added after a certain date are included.
- No military sources are included.

— A reasonably complete inventory is present, but it is of low quality:
  - Important data fields missing.
  - Significant data missing.
  - Obviously incorrect data.
  - Out of date information.
  - Not using a computerized database, but using text or spreadsheet software.

— Multiple, individually incomplete, inventories managed by several groups or ministries.

Summary – Quality of source inventory

A comprehensive, high-quality registry of radioactive sources is essential for effective control over them. The level of effort in the generation and maintenance of such an inventory should be dependent upon the category of the sources. A national registry for at least Category 1 and 2 sources should be maintained, while authorized users should maintain an inventory of all their sources.

1) Check whether there is a national registry or inventory of radioactive sources or not? If not, then use appropriate administrative and physical search methodologies to generate an initial inventory if one does not exist (Chapter 7).

2) Evaluate the quality of any new or existing inventory, checking for:

   a) completeness of practices or applications;

   b) consistency of radionuclides and activities with practices;

   c) comprehensiveness of licensees within particular applications;

   d) clarity between possession limits and actual sources;

   e) the inclusion of the minimum data fields necessary;

   f) completeness of the data entered.

3) Determine/decide how the inventory should be maintained. Specifically designed, radioactive source inventory database software is most appropriate.

5.4. Types of use in the country

The basic process of gathering data on sources based upon their use consists of:

— knowing what types of source applications exist (See Part I);
— understanding which of these applications or industries are likely to be in use within the country;
— determining which of them are within the scope of the assessment (as decided under Section 5.1); and,
— then gathering the easily obtainable data (performing an simple administrative search as in Chapter 7).

Such a search will help to establish either that orphan sources exist or that there is some likelihood that they may exist. It may indicate that a more intensive administrative search is required.

The data gathering administrative search can be performed with the assistance of the table in Appendix III. In this table, the main applications or practices are presented by category, with Category 1 first. The industries of interest on which to concentrate the data gathering effort are also given. For instance, to determine whether any irradiation facility sources exist in a country, the staff performing the assessment could interview medical suppliers to determine how and where their supplies are sterilized. If they are sterilized using domestic radioactive sources, the staff could follow-up with those locations to determine whether they use machine generated radiation or radioactive sources. Similar inquiries could be made of suppliers or exporters of raw foods and polymerized plastic products.

To aid in this type of thinking a number of questions are given in Appendix III under the heading of "Considerations". The questions are by no means exhaustive, but provide reminders of the issues. The final component of the Appendix III table is a list of some factors that are considered to be closely associated with the likelihood of sources within each practice becoming orphaned and reflect the issues discussed in Chapter 3.

After finding that sources exist, or may exist, because of the presence of an industry, the staff performing the assessment may be able to gain additional important information without expending significant effort by determining whether any of the risk factors apply. For example, licensing records may indicate that a hospital has a ^{137}Cs teletherapy device that has been in-use for 15 years. A phone call can be made to the hospital to determine how the source replacement was handled. If the source replacement was managed completely by a well-known device manufacturer, there should be reasonable confidence that the disused source was appropriately transported and disposed of by the manufacturer. Conversely, if a new source was obtained from the manufacturer, but installed by a small, local, contractor, there may be some concern as to the fate of the old source.

In some cases, such as irradiation facilities, the staff performing the assessment will conclude, with a high level of confidence that orphan sources do or do not exist. In many other cases, staff will find that sources may be used, or may have been used, but they will be unable to reach definitive conclusions without detailed searches. On very rare occasions, the potential risk will justify the initiation of source-specific search activities. In general, however, it is envisioned that the data gathering stage of the assessment phase will only go into enough detail to determine whether a potential exists for orphan sources of a given type. If this is the case, then a further, more detailed investigation may be incorporated as part of the national action plan. For example, staff gathering data on radiography sources might find that a pipeline was built a year earlier using local companies to perform non-destructive testing, but there are no records of a licensed local radiographer company in the area. It would not normally be appropriate to pursue this issue further during the assessment phase. Rather, this could be added to a list indicating the potential for an orphan source to exist. The decision to follow-up on any specific event should be made while developing the national plan of action (Chapter 7).

Summary – Types of use in the country

1) Within the pre-determined scope of the national strategy:
   a) compare the known industries within the country with the known radioactive sources;
   b) look for anomalies, information gaps, or situations where sources may be orphaned or vulnerable;
   c) check with all applicable Government Ministries, including those involved with energy, mines, medicine, industry, and agriculture.
2) Use Appendix III to systematically examine whether or not all of the likely industries and sources have been identified.
3) Use the applicable administrative search information sources and methods given in Chapter 7.

5.5. Military uses and sites of conflict

The basic information regarding the presence of national and foreign military forces within a country or the location of sites of conflict is often common knowledge. Specific information regarding their actual, or likely use of radioactive sources, is much more difficult to obtain. However, experience has shown that military operations may result in orphan and vulnerable sources. Even in peacetime, training exercises, storage operations and the relinquishment of fixed military facilities or sites are situations that may give rise to orphan sources.

When there is conflict between military forces there are several other factors that also need to also be evaluated. These include:

— where there might be orphaning of sources due to collateral damage; for example a damaged teletherapy unit in a derelict hospital;
— where damage to buildings may allow uncontrolled access to previously restricted areas leading to looting or scavanging of materials.

In gathering relevant data, it will be necessary to determine if the national or visiting forces use, or have access to, radioactive sources, how these are stored and used and if there are inventories that would identify losses resulting in orphan sources. Detailed information on any sites of military conflict in the country should also be sought.

If it proves impossible to obtain information from the military regarding their use of radioactive sources, then as a minimum, efforts should be made via the appropriate government ministries or departments to obtain an assurance that the control of radioactive sources is at least as rigorous as that required by the civilian regulatory authority of its licencees. In addition, assurances should be sought that the military will perform its own evaluation of the orphan source potential within its areas of responsibility.

Another issue arises with regard to depleted uranium (DU). It is worth determining whether or not DU munitions were used in a conflict. This is in order to be prepared for any public relations issues rather than any significant hazard associated with DU [53].

Because the military use of radioactive sources is not usually subject to civilian control, possible problems related to their sources are likely to be unknown.

Another major problem found with geographical regions of instability, separatist, rebel or terrorist activity is that regulatory control is poor because of the unsafe situation for government staff, including inspectors.

Summary – Military uses and sites of conflict

1) Use Government inter-Departmental or Ministerial communication channels to attempt to get information regarding the military possession and use of radioactive sources during peacetime. Failing this, attempt to get assurances regarding the standard of military radioactive source control being at least equivalent to the civilian control.
2) Consider physical radiation surveys of former, or abandoned fixed military facilities and sites.
3) As soon as it is safe to do so following military conflict, consider physical surveys of non-military facilities where radioactive sources were known, or were likely to be present. Problems to check for include:
    a) High activity radioactive sources in damaged buildings;
    b) Sources from various facilities that have been gathered in one location.
4) If DU munitions were known to have been used, consider warning the public regarding picking up fragments. If a battlefield is reasonably small, consider physical surveys to collect DU fragments.

5.6. Legacy knowledge

Legacy knowledge can mean knowledge about legacy sources, but not only so. In any country, it is important to gather knowledge about the 'early days' of radioactive material use as soon as possible, and before those who were present at the time are no longer with us. What is regarded as the early days will vary significantly with each country and could range from before the 1920s through to the 1970s. While human memory is very fallible, useful information about the historical situation and the orphan source potential of early sources can still be obtained from a nation's pioneers in the field.

The earliest uses of radioactive material within the more developed countries will typically involve radium, particularly in medical and research applications. For the more recently developing countries the earliest uses are more likely to be in the medical field, and particularly cancer therapy with ^{60}Co or ^{137}Cs. In each case, universities and other research centres and institutes are likely to be some of the earliest users of radioactive sources. Therefore these are good places to begin such enquiries. Generally, the early radiation workers in any one country are fairly few and well known. However, if this is not the case, then with a relatively simple investigation it should be possible to identify the appropriate individuals. Once identified, they can be personally interviewed regarding such matters as to:

— what sources they used;
— how they were obtained;
— what they did with them;
— where the sources were stored;
— how they disposed of them;
— who their co-workers, and students were;
— what legislation, regulations or rules were in place and when;
— whether there were any 'incidents' involving the sources.

This is not an exhaustive list but provides an idea of the types of questions that might be of use in evaluating the historical potential for orphan sources. Information given should be verified by other sources whenever possible, but indications of possible orphan sources of the higher categories should be investigated further as part of the development of the national strategy.

Action Summary – Legacy knowledge

Determine whom the older, early workers were who were using radioactive sources and interview them with regard to all aspects of their use at that time. Issues to cover can include:

1) What sources were used.
2) How they were obtained.
3) What they did with them.
4) Where the sources were stored.
5) How they disposed of them.
6) The names and contact information of others who might still be alive.
7) What legislation, regulations and rules were in place and when.
8) Whether there were any incidents involving the sources.

Verify the information as far as possible and follow up on any likely orphaned sources.

5.7. Import and export of sources

Most countries will import a range of radioactive sources or devices containing them but many fewer countries will export new radioactive sources or devices. The largest import volume is likely to be for nuclear medicine uses such as ^{99m}Tc generators, which could be Category 4 sources. Again, the sources of greatest concern are those that can lead to severe deterministic effects in an uncontrolled environment (Category 1, 2 and 3 sources).

Experience has shown that failure to effectively control the import and export of radioactive sources can be a major contributor to sources becoming orphaned. The examples of the illegal import in Juarez (see Box 4) and a failed export of teletherapy sources in Istanbul (see Box 6) provide ample evidence of the consequences. These types of experiences have been one of the key drivers for strengthening import and export controls on Category 1 and 2 radioactive sources in the IAEA's revised Code of Conduct on the Safety and Security of Radioactive Sources.

Box 23: Code of Conduct: Import and export of radioactive sources [20]

23. Every State involved in the import or export of radioactive sources should take appropriate steps to ensure that transfers are undertaken in a manner consistent with the provisions of the Code and that transfers of radioactive sources in Categories 1 and 2 of Annex 1 of this Code take place only with the prior notification by the exporting State and, as appropriate, consent by the importing State in accordance with their respective laws and regulations.
24. Every State intending to authorize the import of radioactive sources in Categories 1 and 2 of Annex 1 to this Code should consent to their import only if the recipient is authorized to receive and possess the source under its national law and the State has the appropriate technical and administrative capability, resources and regulatory structure needed to ensure that the source will be managed in a manner consistent with the provisions of this Code.
25. Every State intending to authorize the export of radioactive sources in Categories 1 and 2 of Annex 1 to this Code should consent to its export only if it can satisfy itself, insofar as practicable, that the receiving State has authorized the recipient to receive and possess the source and has the appropriate technical and administrative capability, resources and regulatory structure needed to ensure that the source will be managed in a manner consistent with the provisions of this Code.
26. If the conditions in paragraphs 24 and 25 with respect to a particular import or export cannot be satisfied, that import or export may be authorized in exceptional circumstances with the consent of the importing State if an alternative arrangement has been made to ensure the source will be managed in a safe and secure manner.
27. Every State should allow for re-entry into its territory of disused radioactive sources if, in the framework of its national law, it has accepted that they be returned to a manufacturer authorized to manage the disused sources.
28. Every State which authorizes the import or export of a radioactive source should take appropriate steps to ensure that such import or export is conducted in a manner consistent with existing relevant international standards relating to the transport of radioactive materials.
29. Although not subject to the authorization procedures outlined in paragraphs 24 and 25 above, the transport of radioactive sources through the territory of a transit or transshipment state should be conducted in a manner consistent with existing relevant international standards relating to the transport of radioactive materials, in particular paying careful attention to maintaining continuity of control during international transport.

Gathering information regarding the national situation with respect to exports of *new* radioactive sources or devices should be relatively easy. There are only about half a dozen major exporting countries worldwide. If there is no capability of radioactive material production via fissile material processing, a radioisotope production reactor, a research reactor or an accelerator facility, then the only exports are likely to be the re-exportation of sources used temporarily within the country or of disused sources to the supplier or country of origin.

Determining the situation with regard to imports will first involve gathering data from the national customs organization and known users of radioactive sources. Manufacturers and suppliers are also likely to have information about sources that they have distributed. Many countries have regulatory requirements regarding the pre-authorization and licensing of imports, but these requirements are not always followed and are patchily enforced. Clearly, if all States fully adopted the revised Code of Conduct, it would be quite easy for national regulatory authorities to be aware at least of all of the Category 1 and 2 sources entering the country. In gathering the necessary data for the national strategies evaluation, the historical situation with regard to imports and exports should not be forgotten.

Sometimes more complex situations arise with regard to radioactive sources that are temporarily brought into a country, particularly by large, multi-national companies. Non-destructive testing and well logging are undertaken by multi-national enterprises with sources often being imported into a country for a short period or for a specific contract. This is particularly true for developing countries, which may not have an indigenous industrial radiography or well logging capability. These practices are often carried out under construction site conditions in remote environments. When this is coupled with the need to rely heavily on the use of procedural controls, rather than engineered safety features, it is easy to see why, for example, about 40% of all radiation accidents giving rise to clinical consequences are in industrial radiography [3]. Box 9 describes an event where the accident was caused by a source that was probably abandoned after an on-site job.

Earlier, it was identified that one of the increased generic risks is at the end of the useful life of a source. One of the important reasons has been the fact that in the past there has been no provision for the return of disused sources as well as the fact that it is often costly and difficult to dispose of them. Making provisions for the return or disposal when sources are acquired helps minimize this increased risk. Some countries make the import of a source conditional on its re-export at the end of its useful lifetime, or when the task using it is completed. Others only grant authorizations if the disposal route is already defined and planned.

The customs procedure for imports needs to be examined carefully because radioactive sources are known to have been orphaned in customs warehouses. The sources might remain unclaimed for a variety of reasons, including:

- illicit trafficking;
- inability to contact the recipient;
- abandonment because of close of business or other reasons; and,
- lack of desire or ability to pay any import duty owed.

If the package labeling does not clearly identify the radioactive nature of the contents, it is even possible for unclaimed sources to find their way into the public domain through auctions that might be conducted by customs.

Box 24: Unclaimed package containing radioactive material: India

Unclaimed, imported packages containing radioactive material have the potential to become orphan. In one incident, a fire fighter came across a heavy container containing radioactive material while fighting a fire in a lock-up storage shed of a scrap dealer. He reported the matter to the regulatory authority, and on investigation, it was found that an unclaimed package containing a nucleonic gauge source housing with 4 GBq of ^{137}Cs had been auctioned off by the Airport Authority to a scrap dealer along with other general scrap. If the fire had not taken place, and the fire fighter had not observed and reported the container, it would have gone to a small scrap shop where the shield and/or source could have been broken open exposing and contaminating many persons.

In summary, the situation with regard to the import and export of radioactive sources is complex, very variable and changing. Further guidance on the implementation of the Code of Conduct import and export controls is being developed, but some of the common problems listed below do not currently have solutions:

- The regulatory body has no knowledge of sources entering or leaving the country.
- The regulatory body has no legal authority to require users, manufacturers, distributors or importers to notify them when sources are shipped into the country.
- Companies will import sources to use for a particular job, and then re-export them again without notifying anyone.
- Even when there is a requirement for prior authorization to bring a source into a country, there is little incentive to do so, as well as poor enforcement of those discovered to be in violation of the requirement.

Summary – Import and export of sources

1) Determine if the country is an exporter of new radioactive sources or devices by looking at potential source production capabilities. If no new radioactive material is produced then the only likely exports are return of temporary imports or disused sources.
2) Gather information about imports from current users, licensing and authorization records, manufacturer or suppliers.
3) Attempt to determine if there has been a time when imports were not well controlled and sources could have been entering the country unknown to the regulatory authority.
4) Pay particular attention to sources imported temporarily for specific jobs or contracts to ensure that their import and export are well managed.
5) Determine if there are any practical provisions for the disposal or return of disused radioactive sources. If there are none, then there is a greater probability of orphan sources being present.
6) Examine customs procedures with regard to unclaimed imports to assess the likelihood of sources being left in warehouses, receiving stations and the like.
7) Most common problems are related to a lack of communication regarding sources entering or leaving the country, and include:
    a) None or little knowledge of imports or exports by the regulatory body;
    b) The regulatory body has no legal authority to require notification of importation of sources;
    c) Multinational and other companies importing and exporting sources just for a particular job without any notifications;
    d) Poor enforcement of regulations relating to import or export notifications.

5.8. Intelligence on illicit trafficking

As discussed in Chapter 2, illicit trafficking involves loss of regulatory control from *intentional* rather than *inadvertent* actions and will usually have either malevolent or financial motivations. It is clear that improving control over radioactive sources cannot be achieved unless the problem of illicit trafficking is addressed within a national strategy. In the past, most of the effort with regard to illicit trafficking in radioactive materials has been focused on nuclear materials, rather than radioactive sources. However, concern regarding the possible use of radioactive materials in dispersal devices has changed the situation.

The IAEA co-operates with Member States and other international organizations to address this issue and to harmonize policies and measures. In particular IAEA and the World Customs Organization (WCO) have signed a Memorandum of Understanding and IAEA has cooperative arrangements with the International Criminal Police Organization (ICPO-INTERPOL). These arrangements and those of the broader intelligence community provide a network that is the most important aspect of any strategy to combat criminal activities of all kinds involving radioactive sources. In co-operation with these organizations, the IAEA has published three TECDOCs on prevention [36], detection [37] and response to illicit trafficking [38] and held a major conference on the subject [55].

Gathering information that relates to illicit operations seeks to identify actual orphaned sources, as well as the probability, routes, and methods used for such activities. It relates to trafficking both within the country as well as in trans-border operations. Some understanding of the extent of illicit trafficking in a state can be obtained from studying general, worldwide data as well as country-specific data.

One general indicator of the wider problem of illicit trafficking can be found in the IAEA Illicit Trafficking Database (ITDB) [56]. As of mid-June 2002 the ITDB contains a list of 440 confirmed incidents since 1 January 1993. Several hundred additional incidents that have been reported in open sources, but not confirmed, are also tracked but not included in these statistics. The majority of the confirmed incidents involved deliberate intent to illegally acquire, smuggle, or sell nuclear or other radioactive material. However, the database also includes incidents where actions may have been inadvertent, such as accidental disposal or the detection of radioactively contaminated products.

Of the 440 confirmed incidents in the database, 284 of them involved radioactive material, other than nuclear material. In most of these cases, the radioactive material was in the form of sealed radioactive sources, but some incidents with unsealed samples, or contaminated materials, such as scrap metal have also been reported and included. By far the most common radionuclide involved in the incident reports is ^{137}Cs, followed by ^{241}Am, ^{60}Co and ^{90}Sr in roughly equal numbers.

It should be noted that the dataset is not comprehensive, in that only about 70 countries participate in the ITDB and many incidents will not have been reported to IAEA. Some States are more thorough than others in reporting incidents, and open-source information suggests that the actual number of cases is significantly larger than the number confirmed to the IAEA. Nevertheless the data does provide a useful input to the development of national strategies, and will be quite helpful to certain countries.

An important factor coming out of the more detailed data kept on each case is that most of the significant finds of nuclear material resulted from intelligence information. This indicates the importance of the law enforcement, customs and intelligence community's involvement in the efforts regarding radioactive sources as well as the radiation safety and security community. The international and national organizations of these bodies may be able to define the current situation based on their intelligence sources within the country and their wider networks.

National information to be taken into consideration or gathered, as part of the national strategies preparation will include:

- the number and nature of the bordering countries, as well as the relationship with them;
- the quality of the radioactive source control within the bordering countries;
- the nature of the borders; i.e. are they open or are they access restricted by nature or man?
- the number and type of the various ports of entry/exit via land, air, or water;
- existing border monitoring stations and their type;
- the ease of installation of border monitors;
- the national experience on the numbers and types of illicit trafficking events discovered via: intelligence, undercover operations, or existing border monitoring.

The levels of knowledge and sophistication of criminals undertaking illicit trafficking in radioactive sources can vary significantly. When the criminals have little knowledge and sophistication, the situation with regard to border monitoring is not radically different from that encountered with orphan sources. However, with increased knowledge the criminals will be able to shield the radioactive material or use routes that have no overt radiation monitoring. In the former case the shielding of the source itself may be an indicator that would cause national authorities to look closely at the real contents of an otherwise innocently appearing consignment. However, the sheer volume of consignments and vehicular movements between countries can make this akin to "searching for a needle in a haystack". This is where the sharing of intelligence information both between countries and between different agencies within a country can have a significant impact in focusing resources for detection and location. Box 25 provides an example of the internal UK arrangements and the interface with the international community.

Box 25: Arrangements for sharing information: UK

Under the umbrella of arrangements with INTERPOL regarding environmental crime, the UK has established a UK Environmental Crime Group to be the focus for actions in this area. This has three sub-groups dealing with: chemicals and wastes, endangered species and radioactive substances. It is the latter that provides the forum to act as a national focus and information exchange vehicle. The membership of the sub-group committee includes all the stakeholders from the areas of orphan sources and illicit trafficking. The members of the group are:

- Environment Agency (EA) (Chair and Secretariat)
- Scottish Environment Protection Agency (SEPA)
- Northern Ireland Environment and Heritage Service (IPRI)
- National Radiological Protection Board (NRPB)
- Health and Safety Executive (HSE)
- HM Customs and Excise
- National Criminal Intelligence Service (NCIS)
- Metropolitan Police Special Branch
- Association of Chief Police Officers (ACPO) Scotland
- Office of Civil Nuclear Security (OCNSy)
- Department of Environment, Transport and the Regions
- Department of Trade and Industry (DTI)
- UK Atomic Energy Authority (UKAEA)
- British Steel
- British Secondary Metals Association
- British Metals Federation

Thus a very broad range of interests are involved which has proved extremely useful in developing issues. The group has the responsibility for the National Response Plan for dealing with finds of orphan sources and illicit trafficking.

Combating illicit trafficking in radioactive sources requires the regulatory body to co-ordinate with law enforcement, intelligence, customs, border guards and other authorities at ports of entry. There needs to be effective communication and mutual support in each of their respective areas of expertise in order to assess the nature of illicit trafficking within their country.

Typical problems identified in this area are given below.

— There has been no communication between the various agencies regarding illicit trafficking in the country.
— No assessment has been made as to whether or not there is a national problem in this area.
— There is evidence of a significant amount of illicit trafficking.
— People in the agencies who may come into contact with illicitly trafficked radioactive materials have not had any radiation safety training and/or do not have any radiation detectors.
— When a source has been found, the regulatory body cannot, or does not, provide any technical back up for the customs, border, or law enforcement personnel.

— There is lack of border monitoring, even in those situations where there is a clear justification for it.
— Existing installed border monitoring is non-operational, inefficient or inadequate.

Summary – Intelligence on illicit trafficking

1) Gather as much data as available on illicit trafficking from general worldwide and national sources.
2) Assist in the accumulation of data by participating in the Illicit Trafficking Database [56].
3) Obtain specific information necessary for the national strategy development, including:
   a) the number and nature of bordering countries;
   b) the quality of radioactive source control within the bordering countries;
   c) the nature of the borders and especially their 'porosity';
   d) the number and type of the ports of entry/exit;
   e) existing border monitoring stations and their type;
   f) the ease of installation of border monitors;
   g) the experience on the numbers and types of illicit trafficking events discovered via intelligence, 'sting' operations, or existing border monitoring.
4) If not already a member, consider involvement in WCO, INTERPOL and similar regional organizations to share information and data on illicit trafficking.
5) Common problems identified include:
   a) No communication between law enforcement/intelligence agencies and radioactive source regulatory authorities;
   b) No comprehensive assessment of the nature or magnitude of the illicit trafficking problem;
   c) Lack of cross-training between law enforcement/intelligence agencies and radiation safety agencies;
   d) Lack of technical back-up for customs, border or law enforcement personnel;
   e) Lack of border monitoring, even in situations where it is clearly justified;
   f) Non-operational border and radiation monitoring equipment.

5.9. Trading partners

Once radioactive sources are orphaned, there is the potential for the sources themselves, or contamination arising from them, to be included in trade imports. Radioactively contaminated commodities are usually a much lesser health risk than orphan sources. However, they can be important indicators of lack of control, as well as indicators of damage to sealed source encapsulation.

Few, if any, countries would have the resources to effectively sample or monitor everything coming into, or out of, their country. Eventually decisions during the national strategy development will need to be made to focus resources on the most likely streams of commodities and to monitor for those items that pose the most significant problem. This requires knowledge of:

— the volume of imports;
— the nature of products imported and their origins;
— the entry points by land, air and water;
— the physical nature of the material, whether it is in massive bulk quantities or individual finished products;

— the point of origin of the import and the levels of control known to exist in that country or region;
— any accident/testing that may have involved the release of radioactive material and the subsequent potential contamination of land or products.

It is also worth making a clear distinction between the normal situation and one where intelligence or evidence of illicit trafficking has indicated a heightened problem from a particular geographical region or commercial sector.

Within the range of commodities imported into a country there is likely to be a small percentage that contain, or are contaminated with, naturally occurring radioactive material (NORM). Examples come from the minerals processing industries using materials such as: bastnaesite, bauzite, fluorspar, ilmenite, monazite, phospate, pyrochlore, zircon sands, oil and natural gas. The concentrations can vary widely, dependent upon the origins and degree of processing. The use of NORM may pose a chronic hazard that should be addressed within the regulatory framework, but does not pose an acute hazard, as would be the case with orphan sources. Nevertheless, in developing a national strategy the presence of NORM in imports needs to be taken into account since it will present one of the most common radioactive materials found by any checkpoint monitoring systems.

The biggest deficiency found is that national trading partner relationships have not been examined in any detail by those responsible for control of radioactive material. Hence, the regulatory body knows little about the nature of their nation's trade with other nations and the likelihood of whether commodities may be contaminated or may contain discrete sources.

Putting a scale on the magnitude of the problem or ranking them involves professional judgment but some generalizations can be made. Agricultural products coming from most regions of the world have a low probability of containing orphan sources or contamination. However, metal scrap from countries with process industries has a much higher probability of containing radioactive sources.

Summary – Trading partners

1) Gather data on:
   a) the volume of imports;
   b) the nature of products imported and their origins;
   c) the entry points by land, air and water;
   d) the physical nature of the material, whether it is in massive bulk quantities or individual finished products;
   e) the point of origin of the import and the levels of control known to exist in that country or region;
   f) any accident/testing that may have involved the release of radioactive material and the subsequent potential contamination of land or products.
2) Be aware that naturally-occurring radioactive material (NORM) may affect any detectors used to monitor commodities and plan accordingly.
3) Pay special attention to the scrap metal trade.

5.10. Metals recycling

Historically, so many orphan sources have been associated with the various phases of scrap metal recycling that it needs to be treated as a special case and information specifically gathered about the nature and magnitude of this industry in the country [51], [57], [58].

If industrial plant that used radioactive sources is decommissioned, dismantled or demolished then there is a possibility that the sources are not removed beforehand. In this way, gauging devices may still be attached to pipe work that is being removed and recycled as scrap. In addition, there is the possibility that lead or depleted uranium from a source shield may be recycled with the source still inside. Since there is a worldwide network of metals recycling, sources may be transported and imported along with the scrap metal. There have been very significant health consequences at the front end of scrap metal recycling.

Box 26: Data on radioactive material found in scrap metal: Netherlands, 1996-2000

Data from the Netherlands [58] covering 1996 to 2000 time period show that there are an average of 45 incidents per year of scrap containing radioactive material of foreign origin as well as an equal number from scrap containing radioactive materials of Dutch origin. In each case, the number of finds has been increasing significantly since 1999. However, this may be due to an increased number of detectors.

If the radioactive source is not discovered prior to its shredding or melting with the scrap metal, then the radioactivity may well cause environmental contamination, significant contamination of the plant and enormous costs associated with decontamination and lack of use [Annex 1 to Ref. [51]]. Appendix IV provides a summary of some reported source melting incidents, illustrating that this is not a rare event.

If the source is not detected before or during melting, it will be diluted and incorporated into the new metal ingots or slag. If still not detected, it will become part of the final product or waste. Again, there is the possibility of the transport and import of contaminated metal or metal products. The dose rates from contaminated metal products are generally relatively low and do not provide a significant problem in the short term. However, whenever contaminated steel is incorporated into items that people can be close to for a long period e.g. chairs, tables, or reinforcing steel bars in building structures [59], [60], [61] the accumulated doses can become significant.

Box 27: Use of contaminated steel in buildings: Taiwan [59], [60], [61]

Since late 1992, more than 100 building complexes containing public and private schools and nearly 1,000 apartments have been identified in Taiwan with elevated levels of gamma-radiation from construction steel contaminated with ^{60}Co. Due to improper handling of ^{60}Co contaminated scrap steel in late 1982 and 1983, contaminated construction materials have been widely distributed throughout the country. These contaminated construction materials have generated elevated radiation exposures to members of the public in Taiwan. As of early 1996, more than 4,000 people, including young students, have been identified as receiving more than 1mSv/y above the local background for up to 12 y.

The table in Box 28 [62] lists some examples of imported contaminated products into the USA since the early 1980s. The Juarez event (Box 4) was not an isolated incident.

Box 28: Importation of radioactively contaminated products: United States of America [62]

Item No.	Product	Contaminant	Year discovered	Country of origin
1	Steel, iron	^{60}Co	1984	Mexico
2	Steel	^{60}Co	1984	Taiwan
3	Steel	^{60}Co	1985	Brazil
4	Steel	^{60}Co	1988	Italy
5	Steel	^{60}Co	1991	India
6	Ferrophosphorus	^{60}Co	1993	Kazakhstan
7	Steel	^{60}Co	1994	Bulgaria
8	Furnace dust	^{137}Cs	1995	Canada
9	Lead	^{210}Pb ^{210}Bi ^{210}Po	1996	Brazil
10	Steel	^{60}Co	1998	Brazil

It can be seen from the previous discussion that the information that needs to be gathered with respect to metals recycling includes:

- the names and locations of the metal melting companies and their suppliers as far down the chain as reasonably possible;
- whether or not these have any radiation detectors, either installed or portable;
- the level of awareness of the potential hazard, the radiation warning symbol and the appearance of typical sources and source shields; and,
- who, if anyone, is importing or exporting metal scrap.

This is an area where use of radiation detectors at various points throughout the recycling process is almost always justified. The other need is for awareness training of those involved in the industry with regard to the appearance of the radiation warning symbol or the appearance of typical sources and shields that they might encounter.

Summary – Metals recycling

1) This is a special case. It overlaps with import/export and trading partners issues, but it can be a wholly internal issue.
2) Sources typically originate from dismantled plant or heavy metal shields with the sources still inside.
3) The hazards arise during the various phases of the cycle:
    a) Front end – high human health risk from unshielded sources
    b) Shredding or melting plant – high cost from decontamination of plant, or environmental impact from release material
    c) Back end – low acute health impact, but possible chronic exposure from contaminated ingots or products made from them.
4) Hence, gather information beginning at the top level of the recycling chain – the melting companies, then work down the chain to their larger scrap suppliers and on to the original small scrap collectors.
5) Determine who has monitoring equipment installed or who uses portable equipment.
6) Determine the level of awareness of their employees with regard to
    a) knowledge of the potential problem
    b) radiation warning sign
    c) types of likely sources and shields to be found in scrap.
7) Ensure that all the scrap metal importers and exporters are known.

5.11. Disused sources

Disused sources represent the largest pool of vulnerable and potential orphan sources. History has shown that many accidents involving orphan sources come about because sources that are no longer in use are eventually forgotten, with subsequent loss of control years later. To this end, it is beneficial from both a safety and security viewpoint for all disused sources to be identified and to undergo proper disposition.

One of the difficulties is that sources do not usually become disused abruptly, but their frequency of use decreases slowly over a period of time. In addition, licensees are discouraged from proper disposal of disused sources by the cost involved, by the bureaucracy of doing so, or by the lack of an available disposal option. Regional and national campaigns have been found useful in significantly reducing the numbers of disused sources available [63], [64].

From the foregoing discussion, it is clear that information needs to be gathered by those developing the national strategy regarding the status of at least all Category 1, 2 and 3 sources on the licensee's inventory or national registry so that appropriate decisions can be made regarding them. Generally, this will involve asking the licensee or owner of the source about its frequency of use. Examination of the source storage will also provide evidence regarding whether a source is actually being used or not and whether it is being stored securely. Gathering information about disused sources not on the inventory requires the same actions as those discussed under that heading.

> **Box 29: Improper disposal or long term storage of a disused source: India**
>
> A user of a nuclear control system did not dispose of the sources in a proper manner. Instead, he buried the shielded source containers underground for long term storage. When approached by the regulatory body during a review of his inventory, the user forgot the place of burial of the sources and could not locate them. By conducting an elaborate survey, using very sensitive survey meters, the sources were traced and dug out.

Many disused sources are vulnerable, according to the full definition of that term, in that they are orphan source precursors, and they are typically one of the largest problems. In particular, it is often found that disused sources are:

— Stored inadequately. This can apply not only to those in the possession of the former user, but also to those sources under governmental institutional control. Recovered orphan sources, or those confiscated from illicit traffickers may also be inadequately stored.
— Secured inadequately, making them relatively easy to steal.
— Not accounted for on a frequent enough basis, resulting in their loss going un-noticed for a lengthy time.
— Not declared disused, even though they have not been used for several years. This means that they are not subject to some of the controls for disused sources and are not considered for disposition.
— In a situation where they might get forgotten, especially as staff leaves.
— Unable to be disposed of, since there is no route, method, mechanism or incentive to do so.

> **Action Summary – Disused sources**
>
> Disused sources are a high priority focal point for national strategies.
>
> 1) Make efforts to determine the frequency of use of each Category 1 – 3 source.
> 2) Visit users' source storage facilities and ask which sources are still being used routinely.
> 3) Encourage users to declare sources that are very infrequently used, to be disused.
> 4) Evaluate the security of the storage of disused sources. This includes the users local storage as well as national facilities.
> 5) Typical problems found include:
>   a) Inadequately stored disused sources;
>   b) Inadequate security of disused sources;
>   c) Infrequent accounting for sources, resulting in their disappearance not being noticed soon enough;
>   d) Sources not being declared as disused, even though they have not been in use for many years;
>   e) Sources forgotten about when staff leave;
>   f) No disposition route for disused sources.

5.12. Known lost and found sources

One of the ways to quantify the size of the orphan source problem is to gather information on the rates at which sources have previously been lost or found. Historical records might be patchy, but as a minimum a system should be set up to ensure that in future all such data is collected and retained.

Although some countries may have limited data sets (e.g. the USNRC's NMED [65] and IRID [66] in the UK), very few could claim to have complete data sets. Alternative sources of data can be international databases such as the IAEA's RADEV [2] and ITDB [56], and other reports such as UNSCEAR [67]. Again these are limited data with significant under-reporting and it is unlikely that timely quantitative assessments can be made. However, when coupled with the IAEA's Categorization of Radioactive Sources, a national qualitative assessment of high, medium and low risk could be made, as discussed in the next chapter.

A lack of data on lost and found sources can be either positive or negative. On the positive side, it could mean that radioactive source control is so good that they are not being lost and found in the state. On the negative side, it could mean that there is no mechanism or encouragement to report them, or no one is looking at the problem.

Most concern in this area should be focused on any dangerous sources (Categories 1, 2 and 3) that are being lost or found. Typical problems identified in this area are listed in the summary box below.

Summary – Data on known lost and found sources

1) Gather any available data on lost and found sources from licensees, the regulatory authority, or international databases covering the country or region.
2) Explore the development of a system to ensure that all future lost and found sources are reported and records are maintained and routinely evaluated.
3) Typical problems include:
    a) No data on any lost or found sources;
    b) No attempts to search for lost sources or owners of found sources;
    c) Several sources found, which indicates that there are others;
    d) Evidence that sources were brought into the country, but no knowledge of their whereabouts;
    e) Lack of routine effort to pro-actively find unknown sources.

5.13. Security of sources

Consideration of the security of radioactive sources against the threat of their deliberate acquisition by those with malevolent intention has quite a new emphasis. Consequently, few people have evaluated the security aspects of their management of sources. Therefore, the problems in this area are:

- Lack of national guidance or regulations regarding the security of sources.
- Significant sources in all phases of their life cycle that are vulnerable in that they are inadequately secured against deliberate attempts at theft or sabotage.

The IAEA interim guidance on “Security of Radioactive Sources” [21] can be used as a starting point in this regard.

Summary – Security of sources

Few people have considered the additional security needs of high category sources. Other than the IAEA’s TECDOC-1355 there is little guidance or regulations regarding increased security needs. The major problems found are:

1) Lack of urgency, awareness or understanding as to what is needed in this regard.

2) Many radioactive sources vulnerable to theft or sabotage.

CHAPTER 6. DEVELOPING THE NATIONAL STRATEGY

6.1. Development of an action plan

The steps in the development of an action plan are:

(1) List the problems or potential issues identified during the assessment and evaluation phase.
(2) Develop actions to solve each problem, or if it is a complex situation, that make up the first steps towards a solution of the problem.
(3) Prioritize these actions and present them in a format which is suitable for the decision makers.

6.2. Development of solution actions

Once an evaluation of the current situation has been completed in accordance with Chapter 5, it is relatively simple to develop a list of actions to solve the problems identified. For example, if there were no inventory of sources, then the solution would be to begin to compile an inventory. If a disused source is in a vulnerable situation, then it needs to be made more secure. This could either mean making its current storage more secure, or transporting it to a more secure location.

Appendix V lists a number of common problems and possible solutions that have been found and proposed as part of national strategy action plans. This listing is intended to assist in the development of a simple plan of action or national strategy. However, it is provided for general guidance only and should not be regarded as a checklist. In particular, it should not preclude other creative ideas or efforts at thinking up solutions more applicable to the local situation.

6.3. Prioritization of solution actions

A much more difficult task is to *prioritize* the actions. There is usually a fairly long list of problems and possible solutions, which cannot all be done at once. There are a number of factors to consider in the prioritization process.

6.3.1. Degree of immediate hazard

One of the most important deciders of priority within the national strategy action plan is that which concerns the degree of immediate hazard. If an identified problem is likely to result in someone being killed or injured by a radioactive source, then it should be taken care of quickly and it becomes the top priority. An example of this situation would be the discovery of the loss of an industrial radiography source (Category 2).

6.3.2. Degree of potential hazard

The next consideration would be the degree of potential hazard. These are situations that if not taken care of quite quickly, could well lead to an immediate hazard. They are ‘accidents waiting to happen’. An abandoned teletherapy head (Category 1) in an area that is unsecured would be an example of this problem. This has been a common precursor to several incidents that have resulted in fatalities or severe injuries.

6.3.3. Cost of implementing the solution

The next factor that might be considered is the relative cost or ease of implementing the solution to the identified problem. The actions that can easily be taken with no additional resources should be implemented immediately. For example, if sources are being inspected, or authorized based on geographical boundaries such as provinces, the work could be re-ordered instead to be done on the basis of the source categories, dealing with Category 1 sources first, then Category 2 sources and so on.

In addressing the cost of implementing solutions, the following listing gives a likely relative ranking of cost-based prioritization:

(1) Procedural changes involving the same staff that can be implemented immediately;
(2) Procedural changes that require significant work for existing staff to develop or implement;
(3) Solutions that need new equipment to be purchased;
(4) Actions that need the hiring of additional staff to implement them;
(5) Solutions that need new facilities such as those required for long term storage or disposal.

6.3.4. Short term or long term

Once the previous factors have been taken into consideration, then the actions that can be completed sooner rather than later should receive a higher priority. It is always important to show results and begin to deal with issues as soon as possible. For example, an action to change a licensing application form to provide needed information can be accomplished much more quickly than an action to change a law or regulation and could receive a higher priority, even though neither of them require additional resources.

6.3.5. Solutions needing further work

If a solution requires further analysis, more data collection, or the development of a funding proposal, then all things being equal, it should receive a lower priority. This is not to say it is not important, but is in recognition of the fact that not everything can be done at once. As the more immediate problems are addressed, then these tasks will move up in priority. Alternatively, some of the work needed to do the analysis or collect the data can be going on as a background task during less busy moments.

6.4. Format of the national strategy action plan

Even though the contents of a national strategy are particular to that country, some guidance can be given regarding the general format.

6.4.1. Audience

While the action plan is a prioritized work plan, and therefore a publication for implementation, it also needs to be written with the decision maker in mind as its primary audience. This is because it will require a high level of commitment to implement and probably will require additional national resources, or perhaps an effort to acquire resources from donor countries or international agencies. For this reason, it is worth including some brief explanation about the types and uses of the various radioactive sources in the country as well as information about how similar sources have become orphaned or might be desirable to those with malevolent intent.

6.4.2. Content

6.4.2.1. Introduction

The introduction of the action plan needs to give the background, objectives, scope, structure and definitions used within the report.

6.4.2.2. Regulatory infrastructure for the control of radioactive sources

This chapter provides a brief summary of the regulatory history regarding the control of sources and the current regulations. It should discuss what is, and is not, covered under the existing regulations, their strengths and weaknesses, including the authorities and responsibilities given to the national regulatory body. If more than one ministry or agency is involved in the regulation of radioactive sources, then the lines of demarcation should be clear. The implications on the control of sources of the various aspects of changes in regulations should be discussed.

6.4.2.3. National data

This is the section where the specific national situation regarding each of the subjects discussed in Chapter 5 is explained. As discussed, it is useful to provide some background regarding each topic for those not familiar with the applications of radioactive sources. This will enable a decision maker reading the report, for example, to understand what radiography sources are used for, how hazardous they might be if uncontrolled, and why it is important to ensure they are accounted for properly.

6.4.2.4. Evaluation of potential radioactive source problems and proposed solutions

Each major problem identified, along with its constituent parts is summarized here, along with actions that solve, or move towards a solution of the problem. The discussion of each issue needs to be fairly detailed and specific for it to be helpful. Ideally, solutions should also be achievable within a reasonable period.

6.4.2.5. Action plan

Bearing in mind the audience, it is worth summarizing the text of the previous problem and solution chapter into a short, tabular format, which enables a brief overview of the actions, their priority and the resources necessary. This format could be similar to that of Appendix V.

6.4.2.6. Conclusion

A statement regarding the current degree of control over radioactive sources should be provided in the conclusion, along with an evaluation of the orphan source potential. A person reading the conclusion should be able to get a quick understanding as to the national status of radioactive source control.

CHAPTER 7. SEARCHING FOR SOURCES

Any national strategy is likely to involve a search for radioactive sources, and therefore, this subject is important enough to be treated here in a separate chapter. Searches for sources can primarily be divided up into non-physical (or administrative) and physical searches. The distinctive difference is that physical searches will involve the use of radiation detectors to determine the presence of sources.

Decisions with regard to whether or not to instigate a search, and its priority will depend on the reason for the search, as well as on such factors as:

- The likely potential of, and hazard from, the existence of unknown, uncontrolled sources;
- The Category of a known missing source;
- The length of time since a known source has been lost or stolen;
- The amount of information available that might be of use in a search;
- The cost of the search and financial resources available;
- The availability of qualified search personnel;
- The instrumentation available for physical searches;
- The local 'risk tolerance' of the authorities and the public.

7.1. Reasons for searches

There are several reasons for performing searches as part of the action plan, including to:

- develop an initial inventory;
- routinely check that all sources are known about;
- look for lost sources;
- investigate the causes of radiation injuries; and
- trace found sources.

7.1.1. Inventory development

Typically, searches will first need to take place when the initial national registry or inventory of radioactive sources is being developed. In many cases, sources will already be in the country because of their use prior to the introduction of the regulatory infrastructure requiring authorizations. These sources will need to be found, identified and added to the inventory.

This initial search is likely to be the most comprehensive national search ever made. It will primarily involve administrative search methods at first, but should also later involve physical searches. The scope of this search is very broad and all of the information sources and tools for administrative and physical searches discussed below will need to be used in order to develop a comprehensive first listing of radioactive sources.

7.1.2. Routine background searches for unknown sources

Once the registry is complete, there is still a need to perform certain routine non-physical and physical searches to determine if any sources have been missed, or if any have entered the country without the regulatory authority's knowledge.

Even a State that has good regulatory control over radioactive sources needs to conduct these routine administrative and physical searches. Rather than naively assuming that it knows about all sources in the country, it is preferable that a regulatory authority has a skeptical mindset, which recognizes that there are probably sources in existence that it does not know about.

A routine background search can take place as part of other work such as a normal compliance inspection, or it can be a specifically scheduled activity. Illustrative examples of how such administrative and physical searches can be incorporated into routine work activities are given later. Specifically scheduling a routine search might be done within a particular sector if there had been a series of incidents in that sector, which leads the regulatory authority to suspect that sources may have become orphaned, or that regulatory control needs to be tightened.

These routine searches are usually very broad in scope since they are essentially fulfilling the same purpose as the search to generate data for the initial inventory.

7.1.3. Specific searches for sources known to be missing

In the event of a known source, or sources, becoming misplaced, lost, or stolen then searches will probably need to take place in an attempt to find them. Usually these start with non-physical searches, but they are rapidly followed by physical searches once a search area, sector or location has been defined.

The fact that a source is missing may be discovered in a number of ways. These include:

- during an administrative search;
- a report by a user that a source was lost while being used on site;
- only a part of a consignment being received;
- a break-in to the source storage location;
- observation of some abnormal monitoring results;
- finding an empty, labelled source container;
- detection of radiation-induced health effects.

This type of search is the most focused and the most narrowly defined in scope, since it will usually be looking for a specific source in terms of radioactivity, radionuclide and physical design. This means that the risk associated with the uncontrolled source can be more precisely assessed [18]. Should the assessed risk of personnel injury be high (Category 1, 2 or 3), then this becomes an emergency and should be treated as such [30], [31], [32], [33], [34], [68]. The IAEA's emergency preparedness Requirements (§4.38, Ref. [29]) states that "Arrangements shall be made to initiate a prompt search and to issue a warning to the public in the event of a dangerous source being lost or illicitly removed and possibly been in the public domain".

7.1.4. Searching for the causes of radiation injury

Frequently the first evidence that a source might be out of control is when one or more persons exhibit symptoms similar to those of radiation injury. Once confirmed as such by a physician, there then follows a high priority investigation characterized by both administrative and physical searches.

The scope of such a search is likely to be broader than that for a specific source known to be missing, but narrower than the first two types of searches. The unknown source clearly must be of a radionuclide and activity sufficient to cause the injuries seen.

7.1.5. Tracing searches

Finally, if sources are found either intact, in pieces, or incorporated in a commodity, such as contaminated steel, then at least a non-physical search will need to be made in an attempt to trace the source, to see if there are others, and to determine if there is a gap in the control measures that needs to be corrected.

The tasks of a tracing search are to try to determine:

- the characteristics of the found source;
- if it corresponds to a known lost source;
- where it came from;
- how it came to be out of control (orphaned);
- whether there are likely to be other, similarly orphaned sources that have not yet been found; and,
- how to prevent further similar problems from ocurring.

Some of these tasks may lead to physical searches and they all will have further follow-up activities. Box 30 provides an example of national arrangements that have been in place in the UK to deal with events such as a found source [69].

Box 30: National Arrangements for Incidents Involving Radioactivity (NAIR): UK

In the UK, all users of radioactive sources have to have their own contingency plan to deal with reasonably foreseeable radiation incidents. However, there may be occasions when the established arrangements do not function satisfactorily. There will also be unforeseen incidents. The NAIR scheme provides a swift response to such events. It has been designed to provide advice and assistance to the police in incidents involving radioactivity where members of the public may require protection. As such, the police may call upon NAIR whenever they feel they have a need for radiological assistance in an incident. The arrangements have been devised around assistance to the police, since they will normally be among the first informed of any incident in a public place. The police also have the prime responsibility for protecting the public. However, other organizations such as fire and rescue services, the British Transport police and airport and docks police may all encounter incidents involving radioactivity. Whenever the public is considered at risk these organizations may also call upon NAIR assistance through the police.

Stage 1 Response

A radiation expert equipped with relatively simple monitoring and protective equipment generally provides this. The expert is often the Hospital Physicist from a local radiotherapy centre, or other hospital that uses radioactive sources. The Stage 1 respondent can quickly advise whether a radiological hazard exists and any necessary actions. However, as the experts will generally only have limited resources they are not equipped to cope with larger incidents, perhaps involving the spread of contamination. In such events the Stage 1 respondent will advise the police to initiate the Stage 2 response.

Stage 2 Response

This is provided by major nuclear establishments and will normally comprise a well-equipped team able to deal with larger incidents. In the unlikely event of an incident that could not be handled by one organisation alone, additional NAIR expertise and resources can also be mobilised either directly by the respondents or through the police.

Obtaining Assistance

NAIR assistance may be obtained by means of a 24-hour national notification telephone number. This connects to the United Kingdom Atomic Energy Authority Constabulary, Force Communications Centre, who will take details of the incident and contact the nearest Stage 1 respondent. The Stage 1 respondent will then contact the person dealing with the incident directly. Rarely, there may be major events where it is clear from the outset that a Stage 2 response is required and this can be requested.

7.2. Non-physical searches

Non-physical searches are also often called administrative searches. They are any means that do not involve the use of radiation detectors to gather information about sources that are unknown, lost, missing, stolen or found. Two keys aspects of administrative searches are determining the most useful information source, or ‘target’, and determining the best ‘tool’, or method of collecting the information from the source.

7.2.1. Information sources

An administrative search involves trying to access relevant information. In this context, the person or institution where the desired information might currently reside has been termed the ‘target’. One of the first tasks of an administrative search involves listing the potentially useful targets of the search. The use of the brainstorming technique by a group of knowledgeable individuals can be helpful in compiling a list of places to start looking for data. A listing, and brief discussion, of some typical targets follows.

7.2.1.1. Governmental authorities

These include any branch or level of government that has some authority to carry out functions related to the safety and security of radioactive sources. It can include government ministries or departments, competent authorities, regulatory authorities, regional, or local authorities. It can include those responsible for areas such as radiation safety, nuclear power, health, environment, industry, mines, agriculture, transport, education, customs and law enforcement. Particular care needs to be taken if there has been a significant change in the responsible authority at some time in the past. Transfers of authority do not always result in a commensurate transfer of applicable records and there can be points where there is a disconnect of data, as illustrated in Box 31. There can also be a problem in a federal-state system if there is no clear distinction between the responsibilities discharged at the individual state level and at the federal level. The process of going through an assessment of the orphan source problem and learning from past experience can help identify information gaps.

Box 31: Consequences of regulatory authority changes: Goiânia, Brazil

The accident in Goiânia, Brazil [6] is briefly described in Box 5 and involved a Category 1 source, namely a teletherapy unit. The National Nuclear Energy Commission (CNEN) had responsibility for licencing any new radiotherapy facility and its health physics staff. This would have included plans for the facility, radiation safety documentation, personal monitoring arrangements and contingency plans. The licences issued by CNEN are subject to a number of conditions, principally that CNEN be informed of any material change, for example, if it is desired to move or dispose of sources. Thus when the clinic was first established in 1971 all necessary controls were in place.

The subsequent inspection of such medical facilities was the responsibility of the Federal Ministry of Health until January 1976, when the responsibility was devolved under a little known decree to the State Health Secretaries. Thus the extent to which inspection and enforcement programmes existed or were implemented varied significantly. Nothing can detract from the abrogation of responsibilities by the licencees, but an inspection programme appropriate to a Category 1 source may have identified the problem before it resulted in an accident.

Following the accident a regime was introduced where licencees had to make a routine positive report on the sources under their control.

Government authorities will usually have information regarding authorizations and licenses, license applications, inspection reports, transfers of sources, and events involving sources. They should also have inventories of the sources that they have or that are under their own control.

International collaboration between governments in information searches should not be ignored since sources are always moving across borders and a neighbouring government may have the necessary information regarding a found source, for example. The possible transboundary movement of sources also makes it wise policy to communicate to neighbouring countries information regarding lost sources that are considered dangerous. In fact, States Parties to the *Convention on Early Notification on a Nuclear Accident* and the *Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency* [68] may be required to provide such information.

7.2.1.2. Non-governmental and international organizations

There are many non-governmental and international organizations that have knowledge and involvement with radioactive sources. These may include the transport modal organizations, professional organizations and societies, service organizations, technical organizations, and trade or industrial groups. The type of data they possess will vary widely, and may have restrictions in its availability or use. Nevertheless, such groups should still be approached if it is felt that they might be able to provide needed information.

The IAEA is developing an International Catalogue of Sealed Radioactive Sources and Devices [70], which amongst other things contains source and device design information. This is not an inventory of individual sources, but a database of types of sources and devices. It provides information, including drawings and photographs, where available, of the physical characteristics of several thousand sources. It also includes information with regard to source manufacturers. The database would be useful in helping to identify found radioactive sources as well as providing full information, perhaps with a photograph, for a particular source type where only partial information might be available.

7.2.1.3. Users and owners

Users and owners of sources will have some information about their current sources, but may also have documents or records of sources that they may have possessed or used earlier, that they may have installed in other facilities, or that they may have shipped or transferred to others. In addition, it is possible that they may have sources in their possession or on their premises of which they might not be aware. This can happen when those responsible for the source leave the company or transfer to a different area.

7.2.1.4. Manufacturers and suppliers

Manufacturers and suppliers of radioactive sources, by the nature of their business, keep a large number of records relating to their products. These include not only design specifications, but also sales information.

7.2.1.5. Individual workers

In addition to the official records of each of the targets discussed above, it should be recognized that the individuals who work with these groups have personal memories or records that may be of value for certain searches. While it is recognized that human memories are notoriously inaccurate, such people may be able to provide a key piece of information that points a search in a particular direction or they may provide some vital data that were not written down anywhere. Even hearsay and rumour may be of value in the source-searching context.

Sometimes individual workers will need to have assurances of anonymity or immunity from prosecution in order to encourage them to discuss aspects of source control that may not have met regulatory requirements or which may have violated such requirements. This could be the situation, for example, in trying to find out information regarding abandoned or illegally discarded sources.

7.2.1.6. Pioneers

The early pioneers of work with radioactive materials in any particular country are a very special sub-group of individual workers who should be interviewed for some types of search, especially the initial inventory search. As discussed earlier, it is especially important to tap into this resource before it disappears altogether.

7.2.1.7. Relatives, neighbours and friends

This information target is particularly important when performing a search for a source that has caused radiation injuries, especially if the injured person is incapacitated or dead. Relatives, neighbours and friends may be able to provide specific information regarding the person's possible contact with the source or the location of the source in question. They can also give general information about the habits of the injured person, as well as any others who may have been exposed. The subject needs to be addressed with some sensitivity since the nature of the event may mean that some of those interviewed may also have been exposed and need treatment. They may be exhibiting less severe symptoms and be unaware of the cause.

7.2.1.8. The public

The public at large is a target group that must be accessed with care. They can be helpful in possibly providing information about a known missing source, but they are also generally very sensitive and easily scared about matters involving radiation, or radioactive materials. For this reason, the number of times when they are targeted for information should be quite limited and probably restricted to the initial inventory development and situations where they can also be warned about the possible dangers of a known missing source.

7.2.2. Tools and methods

The 'tools', or methods used to gather data during an administrative search can be broadly grouped into three types, namely: broadcast media, records searches and interviews. The appropriate tool to use in each circumstance will be dependent on the reason for, and the extent of, the search. Each of the tools is discussed in this section with some comments about its applicability. It should be recognized that an administrative search is essentially detective work. It is an investigation, and as such, it will involve sorting information volunteered as a result of appeals, looking at official documents, and analyzing personal interviews with all persons who may be able to contribute.

7.2.2.1. Broadcast media

Newspapers, radio, television and posters are valuable assets in several types of non-physical searches. First, they can be used in the inventory development, initial search. Broadcast requests for anyone possessing radioactive material to notify the regulatory authority (with applicable contact information) can be the quickest and easiest way of gathering together a large amount of basic inventory information. The initial appeal for information will be more effective if there is no disincentive (such as initial licensing fees) to supplying the data.

The second major type of search where broadcast media are of great value is when a dangerous source (Category 1, 2 or 3) is known to be missing. A description, or photograph, of the source and the radiation trefoil warning sign, as well as the hazard involved and what to do if the source is found can be provided to a large number of people very simply and quickly. A specific example of when this is useful would be following the theft of a vehicle that happens to contain an industrial radiography source. In such cases, it is often beneficial to use the media to communicate to the public and the criminals the details and pictures of the radioactive device involved in the theft. Dissemination through the news media has often resulted in the device containing the radioactive source being dumped by the thieves, with an anonymous tip-off to the authorities as to where to find it.

During broadcast announcements related to dangerous sources, physicians can also be alerted to look out for signs and symptoms of radiation sickness as well as being given a point of contact.

7.2.2.2. Records searches

In this context, records include both hard copy and electronic records. Hard copy includes: files, 'sanitary passports', log books, index or data cards and computer printouts. Electronic records includes: text, spreadsheet and database files on the computer itself, on other computers accessed via the Internet, or on magnetic tape, removable discs or flash-memory media. The types of records to be searched include: authorizations, registrations, licenses, inspection reports, transport records, import/export permits, duty payments, customs logs, inventories, manufacturers' catalogues, purchase orders, incident reports, medical records, work orders, accountability logs and waste disposal records.

As might be imagined, searching all these records can take a lot of time and effort. Information that has been carefully archived, sorted and arranged is quicker and easier to search than that which is more random or has been improperly stored. Searches of electronic records, especially databases, can be much quicker than hard copy searches, but unless the search is well configured, important information can easily be missed. For these reasons, broad-based records searches are not performed routinely, but rather would be part of more targeted and purposeful searches looking for a particular piece of information. The tracing search related to a found source would be a good example of when a specific records search might be performed. In a focused search, much of the data is skimmed until the area of interest is approached, which is then examined in detail. The area of interest might be a particular time period, a particular type of source, or a particular industry, sector or target group.

The range and difficulty of these searches can be illustrated by thinking through what records would need to be accessed to generate a listing of entities that had purchased radioactive sources but which are now bankrupt.

Much useful information, ranging from manufacturers' catalogues of sources to news reports of incidents involving sources is available on the Internet. However, as with all Internet information, it should be used with caution. An example of the creative use of the Internet for searches (that can also be done with the Yellow Pages telephone book) is to search for companies that are performing services, or are in an industry, which typically uses radioactive sources (see Part I). For example, all the companies that are bottling, or canning beer or soft drinks in the country could be identified and located. Since many of these use fill-level gauging sources they can be visited or asked whether or not they have such sources. The companies to be searched for will be dependent upon the typical industries in the region.

7.2.2.3. Interviews

Interviews do not have to be with individuals in person, but can include telephone calls, email questions, or even the use of standardized questionnaires. The interview methodology will be found useful for all of the different search types and for most of the target groups, especially users and owners, individual workers, pioneers, relatives and friends. As with most interviews, it is best to have a standard set of questions to ask, from which branching or follow-up questions can be derived until a good understanding of the situation is achieved. This ensures that all areas of the topic are covered systematically and enables the interviewer to return to the subject if the discussion digresses too much.

Interview questions can be a very broad ranging and creative way of gathering data. For example, during a routine background search for unknown sources, a person working in a company, such as that providing an industrial radiography service, might be asked to list the company's competitors. Typically, each company is aware of others in the same field in their own country or region. If there is a competitor company that does not appear on the regulatory authority's list of licensees, then it should be visited and its management directly asked whether or not they have any radioactive sources. Physical searches might also be in order.

7.3. Physical searches

Physical searches primarily involve the development of a search plan and the deployment of radiation monitoring capabilities in the form of equipment and staff. Generally, physical searches are performed after administrative searches, but a search programme is an iterative process that flows from one logical step to the next. In certain circumstances, a physical search may well start at the same time as, or even before, an administrative search.

Physical searches can be characterized as either passive or active. Passive searches are those where the detectors are essentially stationary. They are placed in certain locations and set to alarm when a source passes close by. Active searches are those where the instruments are moved around to try to find the sources.

Radiation detectors can be classed as either stationary or mobile. Generally, stationary detectors are used for passive searches and mobile detectors for pro-active searches, but not exclusively. For example, a hand-held detector or pocket alarming dosimeter can be used for both passive and active searches.

Stationary monitors are often of the portal type, where vehicles, people, containers or other objects pass by or between radiation detectors. They can also be installed, for example, on a scrap yard grapple, over or under a conveyor belt, or just attached to a wall of a room as an area monitor.

Types of mobile instruments include:

- pocket alarming dosimeters;
- hand-held detectors;
- vehicle mounted detectors for surveys from the road;
- sensitive detectors attached to an aircraft for aerial surveys.

Most commonly, detectors used in physical searches will just measure gamma radiation, but neutrons, beta and alpha radiation are also used in particular circumstances.

The details of the types of radiation detectors for physical searches and their limitations and applications are not discussed further in this publication since they are adequately covered elsewhere [37], [51], [71].

7.3.1. Passive detection

Passive detection of radioactive sources that are not under control essentially consists of placing appropriate detectors at appropriate locations. The characteristics of the detectors to be used will clearly depend upon the type and magnitude of the sources that it is desired to find. Passive detection has its greatest application in routine background searches for unknown sources.

The most appropriate places for passive detectors are at nodal points. These are places where the flow of goods, vehicles or people is concentrated and typically includes border crossing points (ports of entry), tunnels and scrap metal recycling facilities. As discussed, the installation of passive monitoring systems at scrap metal facilities is almost always justified, whereas the case for border monitoring is more complex and needs careful evaluation.

7.3.1.1. Border monitoring

Border monitoring can have multiple functions, including passive searches for sources. The range of possible uses of border monitoring cover:

- detection of orphan sources;
- detection of illicit trafficking;
- deterrance of illicit trafficking;
- protection of border guards and customs staff;
- detection of contaminated commodities.

The relative national importance and priority of each of these will need to be factored into the decision as to whether or not to install border monitoring systems, where to install them and what types of equipment to use. Among the other factors that need to be considered are the:

- level of threat from orphan sources, illicit trafficking or contaminated commodities;
- number and type of ports of entry (border crossings, airports and sea-ports);
- resources available or obtainable;
- political and public perceptions.

For some countries, the number of border crossing points and other ports of entry can run into hundreds, and account also needs to be taken of where passenger and cargo routes separate. The practicality of covering all possible routes can be a very significant challenge. High volume ports of entry or high-risk routes clearly provide the greatest return on investments in fixed equipment. There are some situations where border monitoring makes obvious sense, and there are others where it does not. However, for the majority of cases, it is not clear-cut and requires significant analysis. If a government decided that there was a high priority in preventing orphan sources entering the country and the data showed that the majority of scrap metal came in through one or two seaports, then it would be quite sensible to install sufficient detectors of the appropriate type at those ports.

7.3.2. Pro-active searches

7.3.2.1. Searches for specific sources

The first element of any targeted search for an orphan source is the development of a systematic search plan. The search plan should specify:

- The objectives;
- The boundaries of the search (geographical or temporal);
- The radionuclide, or range of radionuclides, to be searched for;
- The limits of detection;
- The monitoring methods (hand-held, vehicle, air surveys) to be used;
- The procedures for dealing with found sources (including final disposal);
- The responsibilities of the various parties involved; and
- The provision of staff and financial resources.

Efforts to track down a source would normally start at its last known location, by performing an active search within the boundaries of the facility of interest. Investigative work (i.e. an administrative search) will need to be undertaken to retrace the sequence of events that are either known to, or may have contributed to, the loss of the source. It is important to glean information from the workers and management involved as soon as possible, before memories fade, in order to identify the potential locations or movement routes of the radioactive source.

Box 32: Brachytherapy sources lost in a hospital

Because of their small size these could be embedded in linoleum covering corridors or passages along which they, or the patients in which they were implanted, were transferred from wards to surgery. Typically lost sources might be found:

- in sinks and toilets attached to wards and their associated sewage systems;
- around hospital boundaries;
- at solid waste collection sites, septic tank wastes, incineration plants; or,
- still implanted in a patient who has left the hospital.

These all indicate the value of radiation monitoring at these locations.

If the orphan source cannot be located at the original site, then the search should be expanded to include other possible locations. Furthermore, the routes and the means of transportation connecting these locations, together with possible final destinations need to be identified and searched. If there are borders nearby, then advantage may be taken of any installed passive monitors. In any case, notification to the cognizant neighbouring authorities is appropriate and may be required under the Notification and Assistance Conventions discussed earlier [68].

Based on information from the initial search, judgments have to be made as to whether it should be extended outside of the immediate or suspected areas. If so, it may be sensible to split the search into various phases, so that there are opportunities to re-evaluate the plan, in the light of experience.

Box 33: Searching for a radiography source: Yanango, Peru

The cause and consequences of this incident are covered in Box 10. A welder and his assistant were working on a 2 m diameter pipe. At approximately 11:30 a radiographer and his assistant arrived to radiograph the repaired weld as soon as it was available. They left their radiography container close to the pipe. Due to trouble with ultrasonic testing equipment the radiographer left the site to obtain replacement equipment. At 22:00 he returned and started the radiography. When the films were developed, it was apparent that none of them had been exposed to radiation. Checks then identified that the source was not in the immediate vicinity. One potential route by which the source could have moved, was that it became disconnected from the drive cable, dropped to the ground and picked up by another worker as an interesting item. All of the personnel who had been on site that day were visited starting with those who had been near the location of the source container. When the welder's house was approached with a radiation monitor the presence of the source was evident and it was successfully recovered.

As the time between the actual loss of control of the source and its discovery increases, so does the potential for movement of the orphan source. If simple local searches do not find the source then assessments have to be made of:

- the possible scope for movement of the source;
- the scale of the searches that may be required, based on the scope of movement and the history of the source;
- the resources required to undertake such searches;
- the various end-point scenarios, including the criteria for stopping the search; and,
- the potential consequences of not finding the source.

7.3.2.2. Routine search campaigns

Routine background searches for unknown sources are generally thought of in the context of passive detection. However, they can be applied creatively to active searches. An example of how this might be done would involve regulators visiting other parts of an authorized user's premises during a routine inspection. A little additional time could be spent walking through storage areas or basements with a radiation detector switched on in order to see if there might be other unknown sources around, of which perhaps even the user is unaware.

Unless there are reasons to believe that unknown sources might be in a particular part of the country, or in a particular site, the performance of general, pro-active physical searches is not recommended. An example of when there was felt to be sufficient justification for a general pro-active search is given in Box 34.

7.4. International assistance with searches

Sometimes the situation warrants a major search programme that requires resources beyond those immediately available in the country. It was partially to address such situations that the *Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency* [68] was established. The IAEA is entrusted with the implementation of this, and has established a focal point within the Secretariat to which the IAEA's Member States, Parties to the two Conventions and relevant International Organizations can promptly and effectively direct notifications (in the case of accidents) or event reports, requests for emergency assistance, and requests for information. For this purpose and to facilitate the coordination of actions within the Secretariat, in 1986, the IAEA's Emergency Response Centre (ERC) was established and designated by the Director General to serve as a centre for management and control of the IAEA's response to nuclear accidents or radiological emergencies anywhere in the world. This Centre is located at the IAEA Headquarters in Vienna, Austria. During normal operation, this Centre is under the supervision of the Emergency Preparedness and Response Section, Division of Radiation, Transport and Waste Safety of the Department of Nuclear Safety and Security. Ref. [32] provides procedures for reporting and requesting assistance.

Box 34: Use of an aerial survey: Georgia

The IAEA has been assisting the Republic of Georgia with their radiological safety programme for several years, especially since the LILO accident [8], in which border guards were overexposed to radiation from abandoned sources. The Georgian Ministry of the Environment has begun cleaning up the territory with the help of the IAEA, which has organized training courses and provided equipment through its technical cooperation programme.

During a search carried out by the Georgian authorities, four strontium sources (among many others) were found. The activity of each was around 1,500 TBq (40,000 Ci). The IAEA supported this recovery and provided advice on how to deal with four other similar sources. The general whereabouts of these sources were known but they were not accessible before the spring because of bad weather conditions. Eventually, the four source containers were found empty. In view of the high potential for causing serious harm and the uncertainty about the whereabouts of the missing sources, the Republic of Georgia requested the IAEA to support a search. The IAEA itself requested the assistance of Member States.

Meetings in preparation for the search were held in the Republic of Georgia and in Vienna, to explore the situation and to plan a strategy. The Georgian authorities demarcated an area where they wished the search to be performed. However, the budget was not sufficient to enable this large area to be searched with the necessary detection system (equipment and personnel). As a compromise, the French participants proposed a strategy based on searching in the more heavily populated zones within the envisaged search area. In the light of the sensitivity of the detection system offered for this operation and the period of time when the detection system was to be available, the populated zones to be surveyed, and the exposure level accepted by the Georgian authorities, a compromise was reached about the level of activity above which the population was not to be overexposed. The IAEA and the Republic of Georgia accepted the strategy. The French search team used an airborne gamma mapping system called HELINUC installed on a helicopter provided by the Georgian authorities. The helicopter flight parameters were fixed in accordance with the terms of the compromise. The data (spectrum and position) were recorded in flight and processed after landing. The results of the flights of a given day were provided the same day, in the form of a map, to the IAEA representative heading the mission. The maps on which the results could be easily seen allowed decisions to be taken about the next day's activities.

During the operation the helicopter flew 81 hours with the detection system, 1200 km^2 were investigated, and a caesium source of around 100 MBq was detected in a populated area near the city of Poti. The Georgian team in charge of the recovery of the source took care of it using their local capabilities.

Follow up note: Two of the high activity strontium sources were discovered at the end of 2001 as the result of serious radiation injuries to three woodcutters. These were recovered in February 2002. Subsequently, further surface (foot, horseback, vehicle) radiological surveys were undertaken in June 2002 in an attempt to find the last two known sources.

7.5. Verification of found sources

Identification of found sources is an important part of the search process. If the search was instigated by a lost source, then it is necessary to confirm that the source found, is in fact the source for which the search was initiated. If it is a different source, then clearly it means that the search is still not complete.

If the search is non-specific, then identification of the source needs to occur as part of the investigation as discussed earlier.

The best method of identification is by the serial number if it is present and readable. Failing this, then spectrometry and appropriate dose rate measurements will enable the radionuclide and radioactivity to be determined. Measurement of physical parameters such as its size can also provide data regarding the source and its intended purpose. With such information, the IAEA's catalogue of sealed radioactive source and device designs [70] may be of value in identifying the type of source, its original purpose and manufacturer.

7.6. Criteria for stopping searches

One of the most difficult judgments to make is when to end an unsuccessful search. Such a judgment would be based on many factors, including:

- whether or not there are any useful clues or leads remaining to be investigated;
- the Category of the source;
- the likely consequences of the source being found by a member of the public;
- the half-life, activity and time since the loss;
- the likelihood of the source being in a location inaccessible to the public;
- the need for resources being used in the search to be released for other work;
- public and political pressure and level of concern.

Box 35: Example of a decision to abandon a search: India

A decayed ^{192}Ir industrial radiography source that had been packed and transported in an industrial radiography exposure device had been misplaced by the carrier and was not sent to the consignee. A detailed search revealed that the package, apparently in a good condition, had been forwarded by the cargo office to a wrong destination. Since it had not been claimed or collected by anyone, it was sent to one of the carrier's storage places. This event was followed up, but after several months of checking the various storage areas belonging to the carrier it was decided to abandon the search. The key factors in this decision were:

- The activity of the source was low to begin with and it had decayed further during the search. (The half-life of ^{192}Ir is only 74 days.)
- All records relating to the package revealed that it had not been auctioned or otherwise dispositioned.
- From the available records, it was clear that the package was in good condition and that it had not been opened.
- The source was in an industrial radiography exposure device that could be operated only by a trained person.
- Since there were many storage places belonging to the carrier, it would have taken considerable further effort, time and financial expenditure to trace the package. The dose that might result if an unauthorised individual had opened the package did not justify a continued search.

It turned out that the package was subsequently located after several months, at the original cargo office. The package had not been tampered with and the source was still intact.

Examples can be found where there is a combination of having exhausted the immediately obvious places to search, coupled with strong circumstantial evidence of an end-point that is unlikely to have serious consequences (Boxes 34, 35). However, there are other examples where the possible end-points are not reasonably well defined and the magnitude of the potential consequences could be significant, so the searches were continued (Box 37).

Box 36: Search that failed to find a source and was abandoned: UK

In May 2000 a company which makes polyester wadding for use in the bedding and furniture markets reported the loss of an 11.1 GBq ^{241}Am source, that was used for measuring the thickness of the wadding. Local searches with monitoring equipment confirmed that the source was not on the Company's premises. The source had been installed on a production machine that had been dismantled and sold to a metals recycling company in October 1999. The remaining two machines each still had their radioactive source installed, but it was noted that the source holders had almost completely lost any markings to indicate that they contained a radioactive source. It was concluded that there was a high probability that the source had gone to the metals recycling plant. Although the plant had an installed portal monitor, the low energy gamma from ^{241}Am and the shielding effect of the steel housing make it likely that it would not have been detected. There was no evidence of contamination on the scrap yard site. Those in the recycling chain who might have received the material were informed, but none reported any problems.

It was concluded that:

- the source had probably been smelted at an unknown location; and
- the potential consequences from contamination in steel arising from this (due to self shielding) were very low.
- As a result it was decided not to search further.

Box 37: Example of a decision not to abandon the search: India

A well-logging source had been stolen from a storage room. A detailed search, investigation and interrogation revealed that the stolen source had been dumped in a nearby river. Because of the weight of the probe in which the source was housed it apparently had sunk down into the sediment. Considerable efforts were made to locate the position of the probe and source under water, but these were unsuccessful. However, after an evaluation, it was decided to not abandon the search because:

- The approximate location of the source was known and the location was accessible to the public;
- It would be possible to regain control over the source, even though much effort, time and money would be involved;
- The half-life of the source was 450 years;
- The hazard involved in searching for the source was negligible.

The search was continued until the source was finally recovered.

CHAPTER 8. IMPLEMENTING THE ACTION PLAN

8.1. Deciding to proceed

Once the action plan for the national strategy has been developed, then there needs to be a definitive high level decision to implement it. Those responsible for ensuring that the control over radioactive sources is maintained and improved need the necessary authority and resources to implement the plan or else it will not happen. Should there be long term or very costly actions that need further discussion and evaluation prior to adoption, then these should be treated separately and the rest of the plan approved. It is best if the approval to move forward with the plan were given in writing by the highest appropriate authority.

8.2. Implementing

Moving ahead with the action plan is relatively straightforward once it has been approved. Implementation will be dependent on the specific nature of each of the actions. Clearly, the highest priority actions need to be addressed first.

Should the responsible authority feel that it does not have the necessary resources or expertise to implement specific tasks, then the possibilities of bilateral or international assistance should be investigated. There are a several ways of obtaining additional help, particularly with regard to higher activity sources that may be lost or vulnerable from a safety or security viewpoint. The IAEA has several mechanisms for the provision of such assistance.

8.3. Evaluating the effectiveness of the plan and updating it

Action plans by their nature become out-of-date fairly quickly if they are being implemented, since actions are being completed, or modified as they are worked on. The work itself also produces new situations, more information is gathered, resources become available or dry up, and a greater level of understanding is achieved as to what is needed in particular areas. For these and other reasons, the national strategy action plan needs to be evaluated, reviewed and revised on an annual basis. However, the review and revision process is nowhere near as much work as the development of the original plan. As the higher priority actions are completed then what were the lower priority tasks become higher priority actions in the revised plan.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Lessons Learned from Accidents in Industrial Irradiation Facilities, IAEA, Vienna (1996).

[2] WHEATLEY, J., ORTIZ-LOPEZ, P., "IAEA Radiation Events Database (RADEV)", Radiological Protection of Patients in Diagnostic and Interventional Radiology, Nuclear Medicine and Radiotherapy (Proc. Int. Conf. Malaga, 2001), IAEA-CN-85-268, IAEA, Vienna (2001).

[3] INTERNATIONAL ATOMIC ENERGY AGENGY, Lessons Learned from Accidents in Industrial Radiography, Safety Reports Series No. 7, IAEA, Vienna (1998).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Lessons Learned from Accidental Exposures in Radiotherapy, Safety Reports Series No. 17, IAEA, Vienna (2000).

[5] COMISION NACIONAL DE SEGURIDAD NUCLEAR Y SALVAGUARDIAS, Accidente por contaminacion con cobalto-60, Mexico, Rep. CNSNS-IT-001, CNSNS, Mexico City (1984).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, IAEA, Vienna (1988).

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

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

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

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Samut Prakarn, IAEA, Vienna (2002).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Radiation Sources and Security of Radioactive Materials, (Proc. Int. Conf., Dijon, 1998), IAEA, Vienna (1999).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, National Regulatory Authorities with Competencies in the Safety of Radiation Sources and the Security of Radioactive Materials, (Proc. Conf. Buenos Aires, 2000), C&S Papers Series No. 9/P, IAEA, Vienna (2001).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, International Conference on the Security of Radioactive Sources, Findings of the President of the Conference, http://www-rasanet.iaea.org/downloads/meetings/rdd_findings.pdf, IAEA, Vienna (2003).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Action Plan for the Safety of Radiation Sources and Security of Radioactive Materials, GOV/1999/46-GC(43)/10, IAEA, Vienna (1999).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Revised Action Plan for the Safety and Security of Radiation Sources, GOV/2001/29-GC(45)/12 Attachment, IAEA, Vienna (2001).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Draft Action Plan for Safety and Security of Radioactive Sources, GOV/2003/47-GC/47/7, Annex 1, IAEA, Vienna (2003).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Categorization of Radiation Sources, IAEA-TECDOC-1191, Vienna (2000).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Categorization of Radioactive Sources, IAEA-TECDOC-1344, Vienna (2003).

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, The Code of Conduct on the Safety and Security of Radioactive Sources, IAEA/CODEOC/2001, IAEA, Vienna (2001).
[20] INTERNATIONAL ATOMIC ENERGY AGENCY, Code of Conduct on the Safety and Security of Radioactive Sources, GOV/2003/49-GC(47)/9 Annex 1, IAEA, Vienna (2003).
[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Security of Radioactive Sources: Interim Guidance for Comment, IAEA-TECDOC-1355, Vienna (2003).
[22] INTERNATIONAL ATOMIC ENERGY AGENCY, Protection against Nuclear Terrorism: Specific Proposals, GOV/2002/10, IAEA, Vienna (2002).
[23] INTERNATIONAL ATOMIC ENERGY AGENCY, Methods to Identify and Locate Spent Radiation Sources, IAEA-TECDOC-804, Vienna (1995).
[24] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, NUCLEAR ENERGY AGENCY OF THE ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).
[25] INTERNATIONAL ATOMIC ENERGY AGENCY, Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety, IAEA Safety Standards Series No. GS-R-1, Vienna (2000).
[26] 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).
[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment Plans for Authorization and Inspection of Radiation Sources, IAEA-TECDOC-1113, Vienna (1999).
[28] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment by Peer Review of the Effectiveness of a Regulatory Programme for Radiation Safety, IAEA-TECDOC-1217, Vienna (2001).
[29] INTERNATIONAL ATOMIC ENERGY AGENCY, Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GS-R-2, Vienna (2002).
[30] INTERNATIONAL ATOMIC ENERGY AGENCY, Generic Procedures for Assessment and Response During a Radiological Emergency, IAEA-TECDOC-1162, Vienna (2000).
[31] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Accident/Radiological Emergency Assistance Plan, EPR-NAREAP, IAEA, Vienna (2000).
[32] INTERNATIONAL ATOMIC ENERGY AGENCY, Emergency Notification and Assistance: Technical Operations Manual, EPR-ENATOM, IAEA, Vienna (2002).
[33] INTERNATIONAL ATOMIC ENERGY AGENCY, Joint Radiation Emergency Response Plan of the International Organizations, EPR-JPLAN, IAEA (2002).
[34] INTERNATIONAL ATOMIC ENERGY AGENCY, Method for Developing Arrangements for Response to a Nuclear or Radiological Emergency, EPR-METHOD, IAEA, Vienna (2003).

[35] INTERNATIONAL ATOMIC ENERGY AGENCY, The Physical Protection of Nuclear Material and Nuclear Facilities, INFCIRC/225/Rev.4 (Corrected), IAEA, Vienna (1999).
[36] INTERNATIONAL ATOMIC ENERGY AGENCY, Prevention of the Inadvertent Movement and Illicit Trafficking of Radioactive Materials, IAEA-TECDOC-1311, Vienna (2002).
[37] INTERNATIONAL ATOMIC ENERGY AGENCY, Detection of Radioactive Materials as Borders, IAEA-TECDOC-1312, Vienna (2002).
[38] INTERNATIONAL ATOMIC ENERGY AGENCY, Response to Events Involving Inadvertent Movement and Illicit Trafficking of Radioactive Materials, IAEA-TECDOC-1313, Vienna (2002).
[39] INTERNATIONAL ATOMIC ENERGY AGENCY, Reference Design for a Centralized Spent Sealed Sources Facility, IAEA-TECDOC-806, Vienna (1995).
[40] INTERNATIONAL ATOMIC ENERGY AGENCY, Handling, Conditioning and Storage of Spent Sealed Radioactive Sources, IAEA-TECDOC-1145, Vienna (2002).
[41] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Spent High Activity Radioactive Sources, IAEA-TECDOC-1301, Vienna (2002).
[42] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Disused Long Lived Sealed Radioactive Sources (LLSRS), IAEA-TECDOC-1357, Vienna (2003).
[43] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Considerations in the Disposal of Disused Sealed Radioactive Sources in Borehole Facilities, IAEA-TECDOC-1368, Vienna (2003).
[44] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material, Safety Standards Series No. TS-R-1 (ST-1, Revised), IAEA, Vienna (2000).
[45] MESERVE, R.A., "Effective Regulatory Control of Radioactive Sources", National Regulatory Authorities with Competence in the Safety of Radiation Sources and the Security of Radioactive Materials (Proc. Int. Conf., Buenos Aires, 2000), IAEA-CN-84/2, IAEA, Vienna (2001).
[46] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Safety of Gamma and Electron Irradiation Facilities, Safety Series No. 107, IAEA, Vienna (1992).
[47] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in San Salvador, IAEA, Vienna (1990).
[48] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Soreq, IAEA, Vienna (1993).
[49] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident at the Irradiation Facility in Nesvizh, IAEA, Vienna (1996).
[50] US NUCLEAR REGULATORY COMMISSION, Loss of an Iridium-192 Source and Therapy Misadministration at Indiana Regional Cancer Center, Indiana, Pennsylvania, on November 16, 1992, NUREG-1480, USNRC, Washington, DC (1993).
[51] UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE, EUROPEAN COMMISSION, INTERNATIONAL ATOMIC ENERGY AGENCY, Report on the Improvement of the Management of Radiation Protection Aspects in the Recycling of Metal Scrap, UNECE/TRADE/278, UNECE, Geneva (2002).
[52] LUBENAU, J.O., "Unwanted Radioactive Sources in the Public Domain: A Historical Perspective", Health Physics, 76 (2), S16 (1999).

[53] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiological Conditions in Areas of Kuwait with Residues of Depleted Uranium, Radiological Assessment Reports Series, IAEA, Vienna (2003).

[54] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulatory Authority Information System (RAIS), (Computer software and instructions manual, Version 2.0), IAEA, Vienna (1999).

[55] INTERNATIONAL ATOMIC ENERGY AGENCY, Measures to Prevent, Intercept and Respond to Illicit Uses of Nuclear Material and Radioactive Sources (Proc. Conf. Stockholm, 2001), C&S Papers Series No. 12, IAEA, Vienna (2002).

[56] ANZELON, G., HAMMOND, W., NICHOLAS, M., "The IAEA's Illicit Trafficking Database Programme", Measures to Prevent, Intercept and Respond to Illicit Uses of Nuclear Material and Radioactive Sources (Proc. Conf. Stockholm, 2001), C&S Papers Series No. 12, IAEA, Vienna (2002).

[57] LUBENAU, J.O., YUSKO, J.G., "Radioactive Materials in Recycled Metals-An Update", Health Physics, 74 (3), 293-299 (1998).

[58] NETHERLANDS MINISTRY OF HOUSING, SPATIAL PLANNING AND THE ENVIRONMENT, Incidents involving radioactive substances in 1999 and 2000, Inspectorate for the Environment – South-West, Report No. 17055/185, Ministry of Housing, Spatial Planning and the Environment, The Hague (2001).

[59] CHANG, W.P., CHAN, C-C., WANG, J-D., "^{60}Co Contamination in Recycled Steel Resulting in Elevated Civilian Radiation Doses: Causes and Challenges", Health Physics, 73 (3), 465-472 (1997).

[60] HWANG, J.S., CHAN, C.C., WANG, J.D., CHANG, W.P. "Radiation Exposure Modeling for Apartment Living Spaces with Multiple Radioactive Sources", Health Physics, 74 (3), 379-386 (1998).

[61] HWANG, J.S., CHANG, J.B., CHANG, W.P. "Spread of ^{60}Co Contaminated Steel and its Legal Consequences in Taiwan", Health Physics, 81 (6), 655-660 (2001).

[62] YUSKO, J.G., Problems with Radioactive Sources in Recycled Metals, "Environmental Concepts for the Automotive Industry", SP-1542, SAE Technical Papers Series 2000-01-0667, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania (2000).

[63] US ENVIRONMENTAL PROTECTION AGENCY, Orphan Sources Initiative, Clean Materials Program, http://www.epa.gov/radiation/cleanmetals/orphan.htm

[64] CONFERENCE OF RADIATION CONTROL PROGRAM DIRECTORS, INC., A National Orphan Radioactive Material Disposition Program, http://www.crcpd.org/Special_Services.asp.

[65] US NUCLEAR REGULATORY COMMISSION, NMSS Licensee Newsletter, June-July 2001, NUREG/BR-0117, USNRC, Washington (2001).

[66] NATIONAL RADIOLOGICAL PROTECTION BOARD, HEALTH AND SAFETY EXECUTIVE, ENVIRONMENT AGENCY, IRID: Ionising Radiations Incident Database, First Review of Cases Reported and Operation of the Database, NRPB, Didcot (1999).

[67] UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION, Sources and Effects, UNSCEAR 2000 Report to the General Assembly, United Nations, New York (2000).

[68] INTERNATIONAL ATOMIC ENERGY AGENCY, Convention on Early Notification of a Nuclear Accident and Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, Adopted on 26 September 1986, at the 8th, 1986, plenary meeting, Legal Series No. 14, IAEA, Vienna (1986).

[69] NATIONAL RADIOLOGICAL PROTECTION BOARD, National Arrangements for Incidents Involving Radioactivity, Users Handbook 2000 edition, NRPB, Didcot (2000).

[70] INTERNATIONAL ATOMIC ENERGY AGENCY, International Catalogue of Sealed Radioactive Sources and Devices, IAEA, Vienna (2002).

[71] AUSTRIAN RESEARCH CENTERS SEIBERSDORF, Illicit Trafficking Radiation Detection Assessment Program, Final Report, OEFZS-G-0002, Seibersdorf (2000).

APPENDIX I. PLAIN LANGUAGE DESCRIPTION OF THE CATEGORIES (REPRODUCED FROM IAEA-TECDOC-1344)

The following is a plain language description of the categories for the purposes of public information.

Radioactive sources are used throughout the world for a wide variety of beneficial purposes in industry, medicine, agriculture, research and education. When such sources are safely managed and securely protected, the risks to workers and the public will be minimized and the benefits will outweigh the associated hazards.

If, however, a radioactive source becomes out of control and unshielded or dispersed as the result of an accident or a malevolent act, for example — persons could be exposed to radiation at dangerous levels. A radioactive source is considered to be dangerous if it could be 'life threatening' or could cause a permanent injury that would reduce the quality of life of the person exposed. Permanent injuries include burns requiring surgery and debilitating injuries to the hands, for example. An exposure is considered to be dangerous if it results in an injury to tissue or an organ that could cause death within a few years (increased cancer risks are not considered). Temporary injuries such as reddening and irritation of the skin or temporary changes to the composition of the blood are not considered to be dangerous. The extent of any such injuries will depend on many factors, including: the size of the radioactive source; how close a person is to the source and for how long; whether the source is shielded; and whether or not its radioactive material has been dispersed and caused the contamination of skin or been inhaled or ingested.

This categorization provides a relative ranking of radioactive sources in terms of their potential to cause immediate harmful health effects if the source is not safely managed or securely protected.

The following is a plain language description of the relative radiation hazards for both individual sources and dispersed radioactive material. Sources are classified into five categories: Category 1 sources are potentially the most dangerous and Category 5 sources are not dangerous.

I.1. Category 1

I.1.1. Individual sources[1]

Personally extremely dangerous: This amount of radioactive material, if not safely managed or securely protected would be likely to cause permanent injury to a person who handled it, or were otherwise in contact with it, for more than a few minutes. It would probably be fatal to be close to this amount of unshielded material for a period of a few minutes to an hour.

[1] An 'individual source' means a radioactive source that can be picked up or otherwise handled (e.g. solids such as metals, ceramics, encapsulated powder, or liquid or gas in a sealed container).

I.1.2. Dispersed radioactive material

This amount of radioactive material, if dispersed by a fire or explosion, could possibly — but would be unlikely to — permanently injure or be life threatening to persons in the immediate vicinity. There would be little or no risk of immediate health effects to persons beyond a few hundred metres away, but contaminated areas would need to be cleaned up in accordance with international standards. The size of the area to be cleaned up would depend on many factors (including the size and type of the source, whether and how it had been dispersed, and the weather). For large sources the area to be cleaned up could be a square kilometre or more.

It would be highly unlikely for a Category 1 source to contaminate a public water supply to dangerous levels, even if the radioactive material were highly soluble in water.

I.2. Category 2

I.2.1. Individual sources

Personally very dangerous: This amount of radioactive material, if not safely managed or securely protected, could cause permanent injury to a person who handled it, or were otherwise in contact with it, for a short time (minutes to hours). It could possibly be fatal to be close to this amount of unshielded radioactive material for a period of hours to days.

I.2.2. Dispersed radioactive material

This amount of radioactive material, if dispersed by a fire or explosion, could possibly — but would be very unlikely to — permanently injure or be life threatening to persons in the immediate vicinity. There would be little or no risk of immediate health effects to persons beyond a hundred metres or so away, but contaminated areas would need to be cleaned up in accordance with international standards. The size of the area to be cleaned up would depend on many factors (including the size and type of the source, whether and how it had been dispersed, and the weather), but would probably not exceed a square kilometre.

It would be virtually impossible for a Category 2 source to contaminate a public water supply to dangerous levels, even if the radioactive material were highly soluble in water.

I.3. Category 3

I.3.1. Individual sources

Personally dangerous: This amount of radioactive material, if not safely managed or securely protected, could cause permanent injury to a person who handled it, or were otherwise in contact with it, for some hours. It could possibly — although it is unlikely — be fatal to be close to this amount of unshielded radioactive material for a period of days to weeks.

I.3.2. Dispersed radioactive material

This amount of radioactive material, if dispersed by a fire or explosion, could possibly — but is extremely unlikely to — permanently injure or be life threatening to persons in the immediate vicinity. There would be little or no risk of immediate health effects to persons beyond a few metres away, but contaminated areas would need to be cleaned up in accordance with international standards. The size of the area to be cleaned up would depend on many factors (including the size and type of source, whether and how it had been dispersed, and the weather), but would probably not exceed a small fraction of a square kilometre.

It would be virtually impossible for a Category 3 source to contaminate a public water supply to dangerous levels, even if the radioactive material were highly soluble in water.

I.4. Category 4

I.4.1. Individual sources

Unlikely to be dangerous: It is very unlikely that anyone would be permanently injured by this amount of radioactive material. However, this amount of unshielded radioactive material, if not safely managed or securely protected, could possibly — although it is unlikely — temporarily injure someone who handled it or were otherwise in contact with it, or who were close to it for a period of many weeks.

I.4.2. Dispersed radioactive material

This amount of radioactive material, if dispersed by a fire or explosion, could not permanently injure persons.

I.5. Category 5

I.5.1. Individual sources

Not dangerous: No one could be permanently injured by this amount of radioactive material.

I.5.2. Dispersed radioactive material

This amount of radioactive material, if dispersed by a fire or explosion, could not permanently injure persons.

APPENDIX II. SOME PRACTICES AND RADIONUCLIDES OF INTEREST AND THEIR RANGE OF ACTIVITIES

Practice	Radionuclide		Quantity in use Ci	TBq
Category 1				
Radioisotopic thermoelectric generators (RTGs)	Sr-90	Max	6.8E+05	2.5E+04
	Sr-90	Min	9.0E+03	3.3E+02
	Sr-90	Typ	2.0E+04	7.4E+02
	Pu-238	Max	2.8E+02	1.0E+01
	Pu-238	Min	2.8E+01	1.0E+00
	Pu-238	Typ	2.8E+02	1.0E+01
Irradiators: sterilization and food preservation	Co-60	Max	1.5E+07	5.6E+05
	Co-60	Min	5.0E+03	1.9E+02
	Co-60	Typ	4.0E+06	1.5E+05
	Cs-137	Max	5.0E+06	1.9E+05
	Cs-137	Min	5.0E+03	1.9E+02
	Cs-137	Typ	3.0E+06	1.1E+05
Irradiators: self-shielded	Cs-137	Max	4.2E+04	1.6E+03
	Cs-137	Min	2.5E+03	9.3E+01
	Cs-137	Typ	1.5E+04	5.6E+02
	Co-60	Max	5.0E+04	1.9E+03
	Co-60	Min	1.5E+03	5.6E+01
	Co-60	Typ	2.5E+04	9.3E+02
Irradiators: blood/tissue	Cs-137	Max	1.2E+04	4.4E+02
	Cs-137	Min	1.0E+03	3.7E+01
	Cs-137	Typ	7.0E+03	2.6E+02
	Co-60	Max	3.0E+03	1.1E+02
	Co-60	Min	1.5E+03	5.6E+01
	Co-60	Typ	2.4E+03	8.9E+01
Multi-beam teletherapy (gamma knife)	Co-60	Max	1.0E+04	3.7E+02
	Co-60	Min	4.0E+03	1.5E+02
	Co-60	Typ	7.0E+03	2.6E+02
Teletherapy	Co-60	Max	1.5E+04	5.6E+02
	Co-60	Min	1.0E+03	3.7E+01
	Co-60	Typ	4.0E+03	1.5E+02
	Cs-137	Max	1.5E+03	5.6E+01
	Cs-137	Min	5.0E+02	1.9E+01
	Cs-137	Typ	5.0E+02	1.9E+01

Practice	Radionuclide		Quantity in use	
			Ci	TBq
		Category 2		
Industrial radiography	Co-60	Max	2.0E+02	7.4E+00
	Co-60	Min	1.1E+01	4.1E-01
	Co-60	Typ	6.0E+01	2.2E+00
	Ir-192	Max	2.0E+02	7.4E+00
	Ir-192	Min	5.0E+00	1.9E-01
	Ir-192	Typ	1.0E+02	3.7E+00
	Se-75	Max	8.0E+01	3.0E+00
	Se-75	Min	8.0E+01	3.0E+00
	Se-75	Typ	8.0E+01	3.0E+00
	Yb-169	Max	1.0E+01	3.7E-01
	Yb-169	Min	2.5E+00	9.3E-02
	Yb-169	Typ	5.0E+00	1.9E-01
	Tm-170	Max	2.0E+02	7.4E+00
	Tm-170	Min	2.0E+01	7.4E-01
	Tm-170	Typ	1.5E+02	5.6E+00
Brachytherapy - high/medium dose rate	Co-60	Max	2.0E+01	7.4E-01
	Co-60	Min	5.0E+00	1.9E-01
	Co-60	Typ	1.0E+01	3.7E-01
	Cs-137	Max	8.0E+00	3.0E-01
	Cs-137	Min	3.0E+00	1.1E-01
	Cs-137	Typ	3.0E+00	1.1E-01
	Ir-192	Max	1.2E+01	4.4E-01
	Ir-192	Min	3.0E+00	1.1E-01
	Ir-192	Typ	6.0E+00	2.2E-01
Calibration facilities	Co-60	Max	3.3E+01	1.2E+00
	Co-60	Min	5.5E-01	2.0E-02
	Co-60	Typ	2.0E+01	7.4E-01
	Cs-137	Max	3.0E+03	1.1E+02
	Cs-137	Min	1.5E+00	5.6E-02
	Cs-137	Typ	6.0E+01	2.2E+00

Practice	Radionuclide		Quantity in use Ci	TBq
		Category 3		
Level gauges	Cs-137	Max	5.0E+00	1.9E-01
	Cs-137	Min	1.0E+00	3.7E-02
	Cs-137	Typ	5.0E+00	1.9E-01
	Co-60	Max	1.0E+01	3.7E-01
	Co-60	Min	1.0E-01	3.7E-03
	Co-60	Typ	5.0E+00	1.9E-01
Calibration facilities	Am-241	Max	2.0E+01	7.4E-01
	Am-241	Min	5.0E+00	1.9E-01
	Am-241	Typ	1.0E+01	3.7E-01
Conveyor gauges	Cs-137	Max	4.0E+01	1.5E+00
	Cs-137	Min	1.0E-01	3.7E-03
	Cs-137	Typ	3.0E+00	1.1E-01
	Cf-252	Max	3.7E-02	1.4E-03
	Cf-252	Min	3.7E-02	1.4E-03
	Cf-252	Typ	3.7E-02	1.4E-03
Blast furnace gauges	Co-60	Max	2.0E+00	7.4E-02
	Co-60	Min	1.0E+00	3.7E-02
	Co-60	Typ	1.0E+00	3.7E-02
Dredger gauges	Co-60	Max	2.6E+00	9.6E-02
	Co-60	Min	2.5E-01	9.3E-03
	Co-60	Typ	7.5E-01	2.8E-02
	Cs-137	Max	1.0E+01	3.7E-01
	Cs-137	Min	2.0E-01	7.4E-03
	Cs-137	Typ	2.0E+00	7.4E-02
Spinning pipe gauges	Cs-137	Max	5.0E+00	1.9E-01
	Cs-137	Min	2.0E+00	7.4E-02
	Cs-137	Typ	2.0E+00	7.4E-02
Research reactor start-up sources	Am-241/Be	Max	5.0E+00	1.9E-01
	Am-241/Be	Min	2.0E+00	7.4E-02
	Am-241/Be	Typ	2.0E+00	7.4E-02
Well logging	Am-241/Be	Max	2.3E+01	8.5E-01
	Am-241/Be	Min	5.0E-01	1.9E-02
	Am-241/Be	Typ	2.0E+01	7.4E-01
	Cs-137	Max	2.0E+00	7.4E-02
	Cs-137	Min	1.0E+00	3.7E-02
	Cs-137	Typ	2.0E+00	7.4E-02
	Cf-252	Max	1.1E-01	4.1E-03
	Cf-252	Min	2.7E-02	1.0E-03
	Cf-252	Typ	3.0E-02	1.1E-03
Pacemakers	Pu-238	Max	8.0E+00	3.0E-01
	Pu-238	Min	2.9E+00	1.1E-01
	Pu-238	Typ	3.0E+00	1.1E-01
Calibration sources	Pu-239/Be	Max	1.0E+01	3.7E-01
	Pu-239/Be	Min	2.0E+00	7.4E-02
	Pu-239/Be	Typ	3.0E+00	1.1E-01

Practice	Radionuclide		Quantity in use	
			Ci	TBq
Category 4				
Brachytherapy - low dose rate	Cs-137	Max	7.0E-01	2.6E-02
	Cs-137	Min	1.0E-02	3.7E-04
	Cs-137	Typ	5.0E-01	1.9E-02
	Ra-226	Max	5.0E-02	1.9E-03
	Ra-226	Min	5.0E-03	1.9E-04
	Ra-226	Typ	1.5E-02	5.6E-04
	I-125	Max	4.0E-02	1.5E-03
	I-125	Min	4.0E-02	1.5E-03
	I-125	Typ	4.0E-02	1.5E-03
	Ir-192	Max	7.5E-01	2.8E-02
	Ir-192	Min	2.0E-02	7.4E-04
	Ir-192	Typ	5.0E-01	1.9E-02
	Au-198	Max	8.0E-02	3.0E-03
	Au-198	Min	8.0E-02	3.0E-03
	Au-198	Typ	8.0E-02	3.0E-03
	Cf-252	Max	8.3E-02	3.1E-03
	Cf-252	Min	8.3E-02	3.1E-03
	Cf-252	Typ	8.3E-02	3.1E-03
Thickness gauges	Kr-85	Max	1.0E+00	3.7E-02
	Kr-85	Min	5.0E-02	1.9E-03
	Kr-85	Typ	1.0E+00	3.7E-02
	Sr-90	Max	2.0E-01	7.4E-03
	Sr-90	Min	1.0E-02	3.7E-04
	Sr-90	Typ	1.0E-01	3.7E-03
	Am-241	Max	6.0E-01	2.2E-02
	Am-241	Min	3.0E-01	1.1E-02
	Am-241	Typ	6.0E-01	2.2E-02
	Pm-147	Max	5.0E-02	1.9E-03
	Pm-147	Min	5.0E-02	1.9E-03
	Pm-147	Typ	5.0E-02	1.9E-03
	Cm-244	Max	1.0E+00	3.7E-02
	Cm-244	Min	2.0E-01	7.4E-03
	Cm-244	Typ	4.0E-01	1.5E-02
Fill-level, thickness gauges	Am-241	Max	1.2E-01	4.4E-03
	Am-241	Min	1.2E-02	4.4E-04
	Am-241	Typ	6.0E-02	2.2E-03
	Cs-137	Max	6.5E-02	2.4E-03
	Cs-137	Min	5.0E-02	1.9E-03
	Cs-137	Typ	6.0E-02	2.2E-03
Calibration facilities	Sr-90	Max	2.0E+00	7.4E-02
	Sr-90	Min	2.0E+00	7.4E-02
	Sr-90	Typ	2.0E+00	7.4E-02
Moisture detectors	Am-241/Be	Max	1.0E-01	3.7E-03
	Am-241/Be	Min	5.0E-02	1.9E-03
	Am-241/Be	Typ	5.0E-02	1.9E-03

Practice	Radionuclide		Quantity in use	
			Ci	TBq
Density gauges	Cs-137	Max	1.0E-02	3.7E-04
	Cs-137	Min	8.0E-03	3.0E-04
	Cs-137	Typ	1.0E-02	3.7E-04
Moisture/density gauges	Am-241/Be	Max	1.0E-01	3.7E-03
	Am-241/Be	Min	1.0E-02	3.7E-04
	Am-241/Be	Typ	5.0E-02	1.9E-03
	Cs-137	Max	1.1E-02	4.1E-04
	Cs-137	Min	8.0E-03	3.0E-04
	Cs-137	Typ	1.0E-02	3.7E-04
	Ra-226	Max	4.0E-03	1.5E-04
	Ra-226	Min	2.0E-03	7.4E-05
	Ra-226	Typ	2.0E-03	7.4E-05
	Cf-252	Max	7.0E-05	2.6E-06
	Cf-252	Min	3.0E-05	1.1E-06
	Cf-252	Typ	6.0E-05	2.2E-06
Bone densitometry	Cd-109	Max	2.0E-02	7.4E-04
	Cd-109	Min	2.0E-02	7.4E-04
	Cd-109	Typ	2.0E-02	7.4E-04
	Gd-153	Max	1.5E+00	5.6E-02
	Gd-153	Min	2.0E-02	7.4E-04
	Gd-153	Typ	1.0E+00	3.7E-02
	I-125	Max	8.0E-01	3.0E-02
	I-125	Min	4.0E-02	1.5E-03
	I-125	Typ	5.0E-01	1.9E-02
	Am-241	Max	2.7E-01	1.0E-02
	Am-241	Min	2.7E-02	1.0E-03
	Am-241	Typ	1.4E-01	5.0E-03
Static eliminators	Am-241	Max	1.1E-01	4.1E-03
	Am-241	Min	3.0E-02	1.1E-03
	Am-241	Typ	3.0E-02	1.1E-03
	Po-210	Max	1.1E-01	4.1E-03
	Po-210	Min	3.0E-02	1.1E-03
	Po-210	Typ	3.0E-02	1.1E-03

Practice	Radionuclide		Quantity in use	
			Ci	TBq
		Category 5		
X ray fluorescence analyzers	Fe-55	Max	1.4E-01	5.0E-03
	Fe-55	Min	3.0E-03	1.1E-04
	Fe-55	Typ	2.0E-02	7.4E-04
	Cd-109	Max	1.5E-01	5.6E-03
	Cd-109	Min	3.0E-02	1.1E-03
	Cd-109	Typ	3.0E-02	1.1E-03
	Co-57	Max	4.0E-02	1.5E-03
	Co-57	Min	1.5E-02	5.6E-04
	Co-57	Typ	2.5E-02	9.3E-04
Electron capture detectors	Ni-63	Max	2.0E-02	7.4E-04
	Ni-63	Min	5.0E-03	1.9E-04
	Ni-63	Typ	1.0E-02	3.7E-04
	H-3	Max	3.0E-01	1.1E-02
	H-3	Min	5.0E-02	1.9E-03
	H-3	Typ	2.5E-01	9.3E-03
Lightning preventers	Am-241	Max	1.3E-02	4.8E-04
	Am-241	Min	1.3E-03	4.8E-05
	Am-241	Typ	1.3E-03	4.8E-05
	Ra-226	Max	8.0E-05	3.0E-06
	Ra-226	Min	7.0E-06	2.6E-07
	Ra-226	Typ	3.0E-05	1.1E-06
	H-3	Max	2.0E-01	7.4E-03
	H-3	Min	2.0E-01	7.4E-03
	H-3	Typ	2.0E-01	7.4E-03
Brachytherapy: low dose-rate - eye plaques and permanent implants	Sr-90	Max	4.0E-02	1.5E-03
	Sr-90	Min	2.0E-02	7.4E-04
	Sr-90	Typ	2.5E-02	9.3E-04
	Ru/Rh-106	Max	6.0E-04	2.2E-05
	Ru/Rh-106	Min	2.2E-04	8.1E-06
	Ru/Rh-106	Typ	6.0E-04	2.2E-05
	Pd-103	Max	3.0E-02	1.1E-03
	Pd-103	Min	3.0E-02	1.1E-03
	Pd-103	Typ	3.0E-02	1.1E-03
Tritium targets	H-3	Max	3.0E+01	1.1E+00
	H-3	Min	3.0E+00	1.1E-01
	H-3	Typ	7.0E+00	2.6E-01

APPENDIX III. ASSESSMENT CONSIDERATIONS FOR TYPES AND USES OF RADIOACTIVE SOURCES

Type of practice	Industries of interest	**Considerations** (The questions are written in the present tense, but the past also needs to be considered.)	Factors that increase the potential for sources to be orphaned or become vulnerable
		Category 1	
Radioisotopic thermoelectric generators (RTGs)	Military, space	Does the military operate any unmanned communications, navigation or monitoring equipment? Does the country participate in any space programmes? Are there severe environments with military stations? Are there remote areas without electrical service with military or governmental establishments? Is the country near the former 'Iron Curtain'?	Abandoned or unattended stations. Abandoned or unattended equipment. Conflict in the area. Radical changes in governments. Significant poor population where scavenging is common.
Irradiators: very high activity	Medical products or food sterilization, plastics	Are there transportation hubs through which new or spent irradiator source loads pass? Are there facilities that sterilize medical supplies or food? Is there a wood flooring industry making products with plastic coatings?	Bankruptcy. Failure to use major vendor in the servicing of the facility.

Type of practice	Industries of interest	**Considerations** (The questions are written in the present tense, but the past also needs to be considered.)	Factors that increase the potential for sources to be orphaned or become vulnerable
Irradiators: self-shielded, blood/tissue	Medical, gemstone, agricultural, research.	Are there any major (tertiary) hospitals in the country? Do they sterilize blood? Are there any agricultural centres where seeds are irradiated? Are there any centres for irradiating tsetse flies or mosquitoes for the sterile insect technique? Are there any research reactors? Do they calibrate high dose rate alarms/meters? Are there any significant research institutions?	Bankruptcy. Failure to use major vendor in the servicing of the device. Transfer for inappropriate disposal. Long term storage. Spent source transport. Changes in the focus of centres and institutes.
Teletherapy	Medical	Are there any oncology (cancer treatment) hospitals or clinics? Have any of the hospitals imported used medical equipment? Are there transportation hubs through which new or spent teletherapy source loads pass?	Bankruptcy. Failure to use major vendor in the servicing of the device. Transfer for inappropriate disposal. Long term storage. Spent source transport. Changes in medical personnel who had the expertise. Significant poor population where scavenging is common.

Type of practice	Industries of interest	Considerations (The questions are written in the present tense, but the past also needs to be considered.)	Factors that increase the potential for sources to be orphaned or become vulnerable
Category 2			
Industrial gamma radiography	Heavy engineering, construction, cross-country pipelines, finished/cast metal products.	Is there a heavy engineering industry? Are there any pipelines running through the country? Do any national standards require radiography non-destructive testing (NDT)?	Theft for profit (scrap). Loss in use or equipment failure. Loss in transportation (camera). Transport of source changers. Inappropriate disposal – bankruptcy or absence of economical disposal options. Malevolent use. Highly competitive industry.
High/Medium dose rate brachytherapy (HDR)	Medical	Are there any oncology (cancer treatment) hospitals or clinics? Have any of the hospitals imported used medical equipment?	Bankruptcy. Failure to use major vendor in the servicing of the device. Transfer for inappropriate disposal. Long term storage or spent source transport. Device failure. Seeds left in patients or cadavers.
Calibration facilities	Nuclear centres, universities	How or where are the higher dose rate instruments in the country calibrated? Is there a national laboratory performing nuclear standards work?	Same as for teletherapy or brachytherapy.

Type of practice	Industries of interest	Considerations (The questions are written in the present tense, but the past also needs to be considered.)	Factors that increase the potential for sources to be orphaned or become vulnerable
Category 3			
Fixed (high activity) industrial gauges: level, conveyor, blast furnace, dredger, spinning pipe gauges	Steel, mining, cement, power plants, smelting, dredging, agriculture	Are there any of the industries of interest in the country? Are there industries with large tanks or storage containers? Could industrial gauges been installed by someone who may have used radioactive sources without the owner knowing? What technology does the process control system use? What is the make and model number of the process control system? Are there trefoils or other warning labels on the process control equipment?	Sale of facility with inadequate information to the new owner. Inappropriate disposal. Dismantling of obsolete facilities and associated scrap recycling. Long term storage, or a long time between plant shut down and dismantlement. Bankruptcy. Lax licensing requirements. Limited training and high staff turnover. Malevolent use. Industrial environment obscuring trefoil warning signs.
Well logging	Drilling, oil, gas, water exploration	Are there fossil fuel resources in the country? Is there oil or water drilling taking place? Are exploratory geological surveys being performed?	Bankruptcy. Transfer for inappropriate disposal. Long term storage. Spent source transport. Malevolent use. Transitory, multi-national companies present.

Type of practice	Industries of interest	**Considerations** (The questions are written in the present tense, but the past also needs to be considered.)	Factors that increase the potential for sources to be orphaned or become vulnerable
Pacemakers	Medical, funeral homes, crematoria	Are there major hospitals where heart pacemakers were implanted? Are there likely to be persons who have had implants else who have returned to the country?	Lack of awareness of patients with implants or their relatives.
		Category 4	
Low dose rate brachytherapy	Medical	Are there any oncology (cancer treatment) hospitals or clinics? Have any of the hospitals imported used medical equipment? Were there any institutions that performed brachytherapy using radium?	Same as for HDR/MDR brachytherapy, but different radionuclides and lower activities. Improper handling. Patient excretion.
Thickness/fill-level, gauges (low activity)	Tobacco, sheet metal, paper, bottling or canning plants (beer, soft drinks)	Are there any of the industries of interest in the country? Could industrial gauges been installed by someone who may have used radioactive sources without the owner knowing? What technology does the thickness or fill control system use? Are there trefoils or other warning labels on the process control equipment?	Same as for fixed high-activity industrial gauges, but some different nuclides and lower activities.

Type of practice	**Industries of interest**	**Considerations** (The questions are written in the present tense, but the past also needs to be considered.)	**Factors that increase the potential for sources to be orphaned or become vulnerable**
Portable gauges	Construction (roads and building foundations), agriculture	Are there requirements in construction codes for compaction, or moisture content? Are modern construction techniques used? Is independent inspection used in construction or construction contracts? Are construction firms from outside the country used? Is there agricultural research in the country? Is agricultural research performed by foreign companies/institutes?	Theft, or collateral theft of vehicle containing device. Transportation accidents/events. Bankruptcy. Insecure storage when not in use. Scrap value and industrial rivalry (targeted theft). Malevolent use.
Bone densitometers	Medical, medical research	Are there health care facilities for the aged? Are there medical research facilities?	
Static eliminators	Electronics	Is there an electronics industry?	

Type of practice	Industries of interest	Considerations (The questions are written in the present tense, but the past also needs to be considered.)	Factors that increase the potential for sources to be orphaned or become vulnerable
		Category 5	
X ray fluorescence, electron capture devices	Research	Are there research centres and institutes?	Orphan source considerations for Category 5 sources are minimal because of their generally low hazard.
Lightening preventers	Building roofs.	Are there any old buildings with high steeples or antennas?	Building demolition.
Low dose-rate brachytherapy eye plaques and permanent implants, pacemakers	Medical, ophthalmic	Are there people who receive permanent radioactive implants outside the country and then return?	
Tritium targets	Research		

APPENDIX IV. A SUMMARY OF SOME REPORTED SOURCE MELTING INCIDENTS

Item No.	Year	Metal	Location	Radionuclide	Activity (GBq)
1	____[a]	Gold	NY	^{210}Ph, ^{210}Bi, ^{210}Po	Unknown
2	1983	Steel	Auburn Steel, NY	^{60}Co	930
3	1983	Iron/steel	Mexico[b]	^{60}Co	15 000
4	1983	Gold	Unknown, NY	^{241}Am	Unknown
5	1983	Steel	Taiwan[b]	^{60}Co	>740
6	1984	Steel	US Pipe & Foundry, AL	^{137}Cs	0.37—1.9
7	1985	Steel	Brazil[b]	^{60}Co	Unknown
8	1985	Steel	Tamco, CA	^{137}Cs	56
9	1987	Steel	Florida Steel, FL	^{137}Cs	0.93
10	1987	Aluminium	United Technology, IN	^{226}Ra	0.74
11	1988	Lead	ALCO Pacific, CA	^{137}Cs	0.74—0.93
12	1988	Copper	Warrington, MO	Accelerator	Unknown
13	1988	Steel	Italy[b]	^{60}Co	Unknown
14	1989	Steel	Bayou Steel, LA	^{137}Cs	19
15	1989	Steel	Cytemp, PA	Th	Unknown
16	1989	Steel	Italy	^{137}Cs	1000
17	1989	Aluminium	Russian Federation	Unknown	Unknown
18	1990	Steel	NUCOR Steel, UT	^{137}Cs	Unknown
19	1990	Aluminium	Italy	^{137}Cs	Unknown
20	1990	Steel	Ireland	^{137}Cs	3.7
21	1991	Steel	India[b]	^{60}Co	7.4—20
22	1991	Aluminium	Alcan Recycling, TN	Th	Unknown
23	1991	Aluminium	Italy	^{137}Cs	Unknown
24	1991	Copper	Italy	^{241}Am	Unknown
25	1992	Steel	Newport Steel, KY	^{137}Cs	12
26	1992	Aluminium	Reynolds, VA	^{226}Ra	Unknown
27	1992	Steel	Border Steel, TX	^{137}Cs	4.6—7.4
28	1992	Steel	Keystone Wire, IL	^{137}Cs	Unknown
29	1992	Steel	Poland	^{137}Cs	Unknown
30	1992	Copper	Estonia/Russian Federation	^{60}Co	Unknown
31	1993	Unknown	Russian Federation	^{226}Ra	Unknown
32	1993	Steel (?)	Russian Federation	^{137}Cs	Unknown
33	1993	Steel	Auburn Steel, NY	^{137}Cs	37
34	1993	Steel	Newport Steel, KY	^{137}Cs	7.4
35	1993	Steel	Chaparral Steel, TX	^{137}Cs	Unknown
36	1993	Zinc	Southern Zinc, GA	U (dep.)	Unknown
37	1993	Steel	Kazakhstan[b]	^{60}Co	0.3
38	1993	Steel	Florida Steel, FL	^{137}Cs	Unknown
39	1993	Steel	South Africa[c]	^{137}Cs	<600 Bq/g
40	1993	Steel	Italy	^{137}Cs	Unknown
41	1994	Steel	Austeel Lemont, IN	^{137}Cs	0.074
42	1994	Steel	US Pipe & Foundry,	^{137}Cs	Unknown

Item No.	Year	Metal	Location	Radionuclide	Activity (GBq)
			CA		
43	1994	Steel	Bulgaria[b]	^{60}Co	3.7
44	1995	Steel	Canada[d]	^{137}Cs	0.2—0.7
45	1995	Steel	Czech Rep.	^{60}Co	Unknown
46	1995	Steel (?)	Italy	^{137}Cs	Unknown
47	1996	Steel	Sweden	^{60}Co	87
48	1996	Steel	Austria	^{60}Co	Unknown
49	1996	Lead	Brazil[b]	^{210}Pb, ^{210}Bi, ^{210}Po	Unknown
50	1996	Aluminium	Bluegrass Recycling, KY	^{232}Th	Unknown
51	1997	Aluminium	White Salvage Co., TN	^{241}Am	Unknown
52	1997	Steel	WCI, OH	^{60}Co	0.9 (?)
53	1997	Steel	Kentucky Electric, KY	^{137}Cs	1.3
54	1997	Steel	Italy	$^{137}Cs/^{60}Co$	200/37
55	1997	Steel	Greece	^{137}Cs	11 Bq/g
56	1997	Steel	Birmingham Steel, AL	$^{137}Cs/^{241}Am$	7 Bq/g
57	1997	Steel	Brazil[b]	^{60}Co	<0.2
58	1997	Steel	Bethlehem Steel, IN	^{60}Co	0.2
59	1998	Steel	Spain	^{137}Cs	>37
60	1998	Steel	Sweden	^{192}Ir	<90

a Multiple cases reported, earliest circa 1910.

b Contaminated product exported to USA.

c Contaminated vanadium slag exported to Austria; detected in Italy.

d Contaminated by-product (electric furnace dust) exported to USA.

APPENDIX V. COMMON PROBLEMS AND POSSIBLE SOLUTIONS

The following tables provide examples of some of the common problems that are found during the national strategy assessment and evaluation phases. Ideas for possible solution actions, priorities and resources are also given. The tables are intended to assist in the development of a simple national strategy action plan. However, they are provided for general guidance only, should not be regarded as a checklist, and should not preclude other creative ideas or efforts at generating solutions more applicable to the local situation.

In any particular national strategy, each problem needs to be broken down into its constituent parts and to be specific to that state's situation. Each of the detailed problems will then have its own prioritized solution.

Problem	**Possible orphan sources:** No administrative or physical searches for orphan sources. No routine efforts to find sources that are not under regulatory control. Lack of openness to the possibility of there being sources not on the inventory.
Action	Make an initial effort to evaluate the probability of orphan sources using the administrative (and as necessary physical) search methodology. During routine inspections and surveys, ask questions and perform 'searches' using methods described.
Priority	High priority for the initial evaluation. Priority of physical searches dependent on the category of source and time since it was 'lost' from control. Routine 'searches' become part of regular tasks.
Resources	Initial effort requires significant human resources. Physical searches are typically very costly.

Problem	**Lack of, or inadequate, inventory of sources:** There is no source inventory, or if one does exist, it is not complete, does not contain the needed information, is of poor quality, or is in some other way inadequate.
Action	Develop a single database of the necessary source information using appropriate software such as RAIS. Prioritize data gathering and entry by category. Use methods discussed under administrative and physical searches to gather data about the existence of sources to enter into the database. Provide QA to ensure that all essential fields are entered correctly. Include the category of each source so that regulatory efforts can be appropriately prioritized.
Priority	Depends on the current status of the inventory. Development of a quality inventory of Category 1 and 2 sources should be a high priority. Ensuring that all Category 5 sources are accounted for will be low.
Resources	Computer and software costs are relatively small, especially if they are provided by the IAEA. Personnel effort is large if starting from scratch.

Problem	**Known disused sources:** There are known to be disused sources in one or more locations. Some of the sources are in the higher categories. Some of the sources are vulnerable in that the degree of control over them is not adequate.
Action	Develop a campaign to bring these sources under control. Start with the higher category sources and ensure that they are brought into a safe and secure situation. This may mean improving their current storage, bringing them to a central storage or disposal facility, or returning them to the supplier. If no adequate facilities exist, then a local or regional facility will need to be constructed.
Priority	The higher the category of the source and the greater its vulnerability, then the higher the priority.
Resources	The resources needed will be very dependent on the specific situation. However, they can be significant.

Problem	**No knowledge of the import (export) of sources:** Either there is no requirement for the reporting of sources entering the country, or it is not being rigorously applied or enforced.
Action	Develop, implement and enforce requirements regarding import and export of radioactive sources that at least meet those given in the Code of Conduct [20].
Priority	High.
Resources	Significant human resources over a long period if there are no laws or regulations currently in place. Lesser, but still significant effort to enforce existing reporting requirements.

Problem	**Issues with authorizations:** No authorizations or licenses issued. Application forms for authorizations are deficient. Associated fees do not encourage desired behaviour.
Action	Implement an authorization process that ensures all information necessary for the justification of the authorization is available. Ensure all data needed for the inventory is gathered at this time and that the fees and processes encourage the desired results.
Priority	High
Resources	Human resources to develop and implement a high quality authorization process.

Problem	**Border monitoring issues:** No border monitoring or inadequate monitoring. No training of law enforcement, customs, border or port authority personnel who may encounter radioactive sources. No equipment or expert support for them when radioactive materials found.
Action	Perform an analysis of the need and likely effectiveness of border monitoring for detecting orphan sources or illicit trafficking. Provide the equipment, training and support necessary based on the evaluation.
Priority	Dependent on the probability of orphan sources or illicit sources entering the country. Training and expert support for these agencies would normally be a medium to high priority.
Resources	Personnel to gather data and perform the analysis. If justified, equipment costs can be significant (portal monitors ~$100k, survey instruments ~$5k). Maintenance costs for equipment need to be built in as well.

Problem	**No consideration of source security:** Sources are being used, stored and transported with no specific consideration of the more recent security concerns.
Action	Evaluate all source security against the guidance [21] and modify as necessary. Consider the modification of source authorization conditions as they are renewed to include security provisions.
Priority	High priority for Category 1 and 2 sources. Medium for Category 3.
Resources	Security inspections can be factored into routine licensee inspections with minimal impact on staff time. Cost of security upgrades can be significant.

Problem	**Unknown disused sources:** There is evidence, or it is suspected, that there are disused sources in existence of which the regulatory authority has no awareness.
Action	Place some advertisements and announce an amnesty on the declaration and collection of radioactive sources that are no longer needed. Collect and safely secure all sources that are declared at no cost to the current possessor.
Priority	Medium.
Resources	The costs associated with the advertisements, collection, transportation and storage or disposal of the disused sources can be significant.

Problem	**Lack of scrap metal monitoring:** There is little or no monitoring in the recycled metals industry.
Action	Encourage the larger scrap metal dealers to purchase and install radiation detection equipment and to train their staff to recognize the radiation trefoil and typical containers of sources.
Priority	Medium.
Resources	Costs associated with the development of appropriate awareness training materials. Costs associated with the recovery, storage or disposal of found sources. The industry will normally pay for the installed or hand-held instrumentation once they realize the potential risks associated with orphan sources entering the scrap metal cycle.

Problem	**No prioritization of regulatory efforts:** All efforts with regard to radioactive sources are managed with an equal priority.
Action	Prioritize all regulatory efforts, such as licensing, inspection and enforcement in accordance with the source categorization. Fees and frequency of inspections for example, should be lower for the lower category sources.
Priority	This can be a lower priority effort, but it will enable existing staff to be used more effectively where the need and the risk are greater.
Resources	Minimal staff resources to re-organize the work.

Problem	**No knowledge of the military use of sources:** The regulatory authority has no responsibility or knowledge with regard to radioactive material in the military.
Action	Through appropriate government channels highlight the problems that have historically occurred with orphan sources and seek assurances from the military that their system of radioactive source control are at least as good as that applied to sources within the public domain.
Priority	Low, unless there is reason to be concerned.
Resources	Minimal, but high-level staff interaction.

Problem	**Lack of awareness of the status of sources in regions of conflict:** The presence of, or degree of control over, sources in areas of conflict or dispute is unknown.
Action	Monitor the situation and develop plans for action once it is considered safe to do so. Prioritize efforts to ensure that higher category sources are identified and secured first.
Priority	Low until action can be taken, then high.
Resources	Minimal staff resources initially for planning. Possible assistance from the military in source search and recovery.

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