IAEA Safety Standards
for protecting people and the environment

National Strategy for Regaining Control over Orphan Sources and Improving Control over Vulnerable Sources

Specific Safety Guide
No. SSG-19

IAEA
International Atomic Energy Agency

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Information on the IAEA's safety standards programme is available at the IAEA Internet site

http://www-ns.iaea.org/standards/

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at PO Box 100, 1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to Official.Mail@iaea.org.

OTHER SAFETY RELATED PUBLICATIONS

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Reports on safety and protection in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

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NATIONAL STRATEGY FOR REGAINING CONTROL OVER ORPHAN SOURCES AND IMPROVING CONTROL OVER VULNERABLE SOURCES

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

IAEA SAFETY STANDARDS SERIES No. SSG-19

NATIONAL STRATEGY FOR REGAINING CONTROL OVER ORPHAN SOURCES AND IMPROVING CONTROL OVER VULNERABLE SOURCES

SPECIFIC SAFETY GUIDE

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Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
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FOREWORD

by Yukiya Amano
Director General

The IAEA's Statute authorizes the Agency to "establish or adopt… standards of safety for protection of health and minimization of danger to life and property" — standards that the IAEA must use in its own operations, and which States can apply by means of their regulatory provisions for nuclear and radiation safety. The IAEA does this in consultation with the competent organs of the United Nations and with the specialized agencies concerned. A comprehensive set of high quality standards under regular review is a key element of a stable and sustainable global safety regime, as is the IAEA's assistance in their application.

The IAEA commenced its safety standards programme in 1958. The emphasis placed on quality, fitness for purpose and continuous improvement has led to the widespread use of the IAEA standards throughout the world. The Safety Standards Series now includes unified Fundamental Safety Principles, which represent an international consensus on what must constitute a high level of protection and safety. With the strong support of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its standards.

Standards are only effective if they are properly applied in practice. The IAEA's safety services encompass design, siting and engineering safety, operational safety, radiation safety, safe transport of radioactive material and safe management of radioactive waste, as well as governmental organization, regulatory matters and safety culture in organizations. These safety services assist Member States in the application of the standards and enable valuable experience and insights to be shared.

Regulating safety is a national responsibility, and many States have decided to adopt the IAEA's standards for use in their national regulations. For parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by regulatory bodies and operators around the world to enhance safety in nuclear power generation and in nuclear applications in medicine, industry, agriculture and research.

Safety is not an end in itself but a prerequisite for the purpose of the protection of people in all States and of the environment — now and in the future. The risks associated with ionizing radiation must be assessed and controlled without unduly limiting the contribution of nuclear energy to equitable and sustainable development. Governments, regulatory bodies and operators everywhere must ensure that nuclear material and radiation sources are used beneficially, safely and ethically. The IAEA safety standards are designed to facilitate this, and I encourage all Member States to make use of them.

THE IAEA SAFETY STANDARDS

BACKGROUND

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety.

Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.

States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations.

International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade.

A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions.

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

Safety measures and security measures[1] have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Fig. 1).

Safety Fundamentals

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered ‘overarching’ requirements, are expressed

[1] See also publications issued in the IAEA Nuclear Security Series.

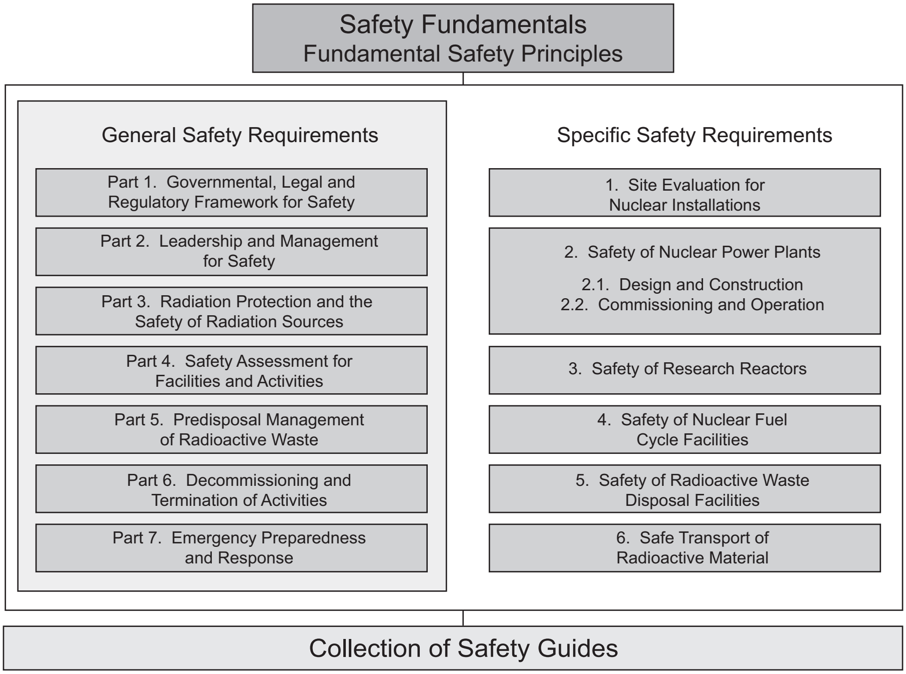

FIG. 1. The long term structure of the IAEA Safety Standards Series.

as ‘shall’ statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

The IAEA safety standards are applicable, as relevant, throughout the entire lifetime of all facilities and activities — existing and new — utilized for peaceful purposes and to protective actions to reduce existing radiation risks. They can be used by States as a reference for their national regulations in respect of facilities and activities.

The IAEA's Statute makes the safety standards binding on the IAEA in relation to its own operations and also on States in relation to IAEA assisted operations.

The IAEA safety standards also form the basis for the IAEA's safety review services, and they are used by the IAEA in support of competence building, including the development of educational curricula and training courses.

International conventions contain requirements similar to those in the IAEA safety standards and make them binding on contracting parties. The IAEA safety standards, supplemented by international conventions, industry standards and detailed national requirements, establish a consistent basis for protecting people and the environment. There will also be some special aspects of safety that need to be assessed at the national level. For example, many of the IAEA safety standards, in particular those addressing aspects of safety in planning or design, are intended to apply primarily to new facilities and activities. The requirements established in the IAEA safety standards might not be fully met at some existing facilities that were built to earlier standards. The way in which IAEA safety standards are to be applied to such facilities is a decision for individual States.

The scientific considerations underlying the IAEA safety standards provide an objective basis for decisions concerning safety; however, decision makers must also make informed judgements and must determine how best to balance the benefits of an action or an activity against the associated radiation risks and any other detrimental impacts to which it gives rise.

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and four safety standards committees, for nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

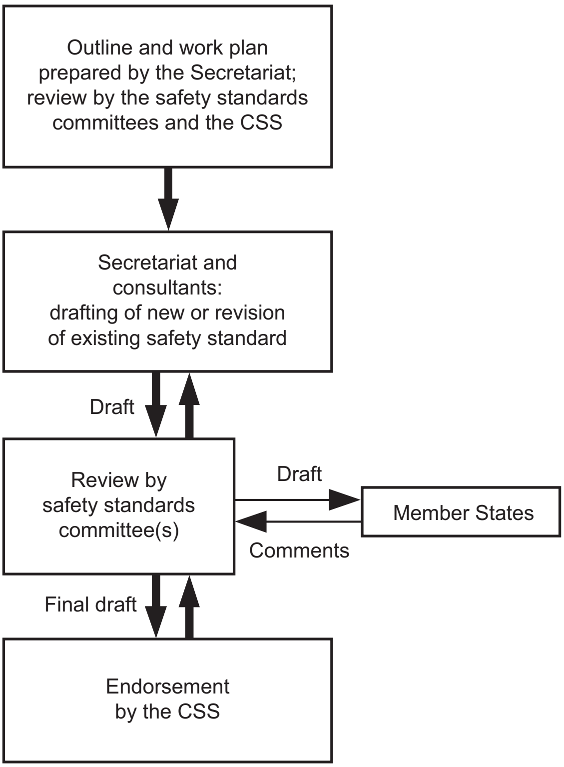

FIG. 2. The process for developing a new safety standard or revising an existing standard.

All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards. It articulates the mandate of the IAEA, the vision for the future application of the safety standards, policies and strategies, and corresponding functions and responsibilities.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP), are taken into account in developing the IAEA safety standards. Some safety standards are developed in cooperation with other bodies in the United Nations system or other specialized agencies, including the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as defined in the IAEA Safety Glossary (see http://www-ns.iaea.org/standards/safety-glossary.htm). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

The background and context of each standard in the IAEA Safety Standards Series and its objective, scope and structure are explained in Section 1, Introduction, of each publication.

Material for which there is no appropriate place in the body text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the body text, or describes methods of calculation, procedures or limits and conditions) may be presented in appendices or annexes.

An appendix, if included, is considered to form an integral part of the safety standard. Material in an appendix has the same status as the body text, and the IAEA assumes authorship of it. Annexes and footnotes to the main text, if included, are used to provide practical examples or additional information or explanation. Annexes and footnotes are not integral parts of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material under other authorship may be presented in annexes to the safety standards. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. Technologies that make use of radioactive sources are used in many practices around the world. Radioactive sources are used in agriculture, industry, medicine, mining, research and education, and they provide many benefits. The safety record of these technologies with regard to the radioactive sources that they employ has generally been good. However, occasionally a lack of appropriate controls, or circumvention of those that exist, has led to sources becoming orphaned or vulnerable — resulting in serious radiological accidents — as well as to harmful environmental, social and economic impacts [1–6].

1.2. An orphan source is 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 otherwise transferred without proper authorization. A vulnerable source is a radioactive source for which the control is inadequate to provide assurance of long term safety and security, such that it could be relatively easily be acquired by unauthorized persons [7]. The series of accidents involving such sources initiated international concerns, and the attacks of 11 September 2001 raised further concerns that such sources might be acquired and used for malicious purposes. These concerns have led many States to address issues relating to the control of radioactive sources and the IAEA to initiate a programme of work on the safety and security of radioactive sources. Progress on these efforts can be traced through the proceedings of a series of IAEA international conferences on the subject [8–11].

1.3. The Safety Fundamentals publication, Fundamental Safety Principles [12], establishes the fundamental safety objective and ten fundamental safety principles. The fundamental safety objective, “to protect people and the environment from harmful effects of ionizing radiation”, applies to all circumstances that give rise to radiation risks[1]. Principle 7 states that "People and the environment, present and future, must be protected against radiation risks." Requirements designed to protect people and the environment from harmful effects of ionizing radiation, and that are relevant to establishing and maintaining control over radioactive sources, are established in the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (the BSS) [13] (under revision) and in the Safety Requirements publication Governmental, Legal and Regulatory Framework for Safety [14]. In particular:

— Requirement 9 of Ref. [14] requires States to establish a "system for protective actions to reduce undue radiation risks associated with unregulated sources". Paragraph 2.25 elaborates on this requirement: "Where unacceptable radiation risks arise as a consequence of an accident, a discontinued practice, or inadequate control over a radioactive source or a natural source, the government shall designate organizations to be responsible for making the necessary arrangements for the protection of workers, the public and the environment. The organization taking the protective action shall have access to the resources necessary to fulfill its function."
— Paragraph 2.11 of Ref. [13] requires that "The legal person responsible for any sealed source, unsealed source or radiation generator shall, unless the source is exempted, apply to the Regulatory Authority for an authorization which shall take the form of either a registration or a licence."
— Paragraph 2.34 of Ref. [13] requires, in part, that "Sources shall be kept secure so as to prevent theft or damage and to prevent any unauthorized legal person from carrying out any of the actions specified in the General Obligations for practices of the Standards (see paras 2.7–2.9 of Ref. [13]), by ensuring that:

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[1] The term 'radiation risks' is used in a general sense to refer to:
— Detrimental health effects of radiation exposure (including the likelihood of such effects occurring).
— Any other safety related risks (including those to ecosystems in the environment) that might arise as a direct consequence of:
  • Exposure to radiation;
  • The presence of radioactive material (including radioactive waste) or its release to the environment;
  • A loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation.

"(a) control of a source not be relinquished without compliance with all relevant requirements specified in the registration or licence and without immediate communication to the Regulatory Authority, and when applicable to the relevant Sponsoring Organization, of information regarding any decontrolled, lost, stolen or missing source;

"(b) a source not be transferred unless the receiver possesses a valid authorization".

— Paragraph 3.10 of Ref. [13] requires that "The relevant Intervening Organizations shall prepare a general plan or plans for co-ordinating and implementing the actions required for supporting protective actions under the emergency plans of registrants and licensees, as well as for other situations that may require prompt intervention. This includes situations involving such sources of exposure as sources illegally brought into the country, falling satellites equipped with sources or radioactive materials released in accidents beyond national borders."

1.4. The Code of Conduct on the Safety and Security of Radioactive Sources (Code of Conduct) [15], which is a voluntary undertaking intended to help national authorities to ensure that radioactive sources are used within an appropriate framework of radiation safety and security, sets out measures for achieving and maintaining a high level of safety and security of radioactive sources that may pose a significant risk. Basic Principle 7 of Ref. [15] states that "Every State should, in order to protect individuals, society and the environment, take the appropriate measures necessary to ensure: …. (a) that the radioactive sources within its territory, or under its jurisdiction or control, are safely managed and securely protected during their useful lives and at the end of their useful lives". Basic Principle 8 of Ref. [15] states that "Every State should have in place an effective national legislative and regulatory system of control over the management and protection of radioactive sources. Such a system should: …. (b) minimize the likelihood of a loss of control; (c) include national strategies for gaining or regaining control over orphan sources".

1.5. This Safety Guide provides recommendations on a methodology for establishing a national strategy for regaining such control over orphan sources and for improving control over vulnerable sources. A well developed strategy tailored to the national situation will allow optimum use of resources to ensure that control is first regained over the most dangerous sources. It is assumed that the responsibility for developing and implementing the activities described in this Safety Guide will be assigned by the government to an appropriate body or bodies, such as the regulatory body; technical support organizations; government ministries, agencies or other bodies responsible for specific areas such as health, environment, industry, metal recycling, mines, and agriculture; regional or local authorities; law enforcement agencies, including customs and border authorities; intelligence organizations; and scientific and research institutes. It is assumed that the assigned body or bodies will coordinate and liaise with other relevant organizations as necessary to ensure proper implementation of the strategy.

1.6. This Safety Guide is complemented by IAEA safety standards and related IAEA publications on regulatory infrastructure, emergency response, security, illicit trafficking and border monitoring, and the management of disused sources [14, 18, 22, 25, 29, 42–44, 48]. While the focus of this Safety Guide is on the development and implementation of a national strategy for remedial action, it is expected that the development of such a strategy will also identify existing weaknesses in national control of sources and will highlight ways to prevent further sources becoming orphaned.

1.7. The terms used in this publication have the meanings ascribed to them in the IAEA Safety Glossary [7], where applicable.

OBJECTIVE

1.8. The objective of this Safety Guide is to provide a methodology for establishing a national strategy for regaining control over orphan sources and improving control over vulnerable sources in order to meet the safety requirements established in the relevant IAEA safety standards [13, 14]. This Safety Guide provides recommendations and guidance on how to assess systematically the national situation, and then how to develop and implement a prioritized national strategy to achieve these goals.

SCOPE

1.9. This Safety Guide describes actions that should be taken by governments and governmental bodies to establish a national strategy for regaining control over orphan sources and improving control over vulnerable sources. It recommends the application of a graded approach in accordance with the category of the source [16].

1.10. Nuclear material, as defined in the Convention on the Physical Protection of Nuclear Material [17], is outside the scope of this Safety Guide, except for the case of radioactive sources incorporating ^{239}Pu. Similarly, radioactive sources used in military applications are outside of the scope of this Safety Guide. However, radioactive sources formerly used in military applications that may have been abandoned are within the scope.

STRUCTURE

1.11. Each of the three main phases of the methodology for developing a national strategy is dealt with in a separate section. Section 2 provides recommendations on the assessment process. This covers deciding on the scope of the strategy, gathering the necessary information, and determining the nature and magnitude of the problem. Section 3 provides recommendations on development of the strategy, covering identification and prioritization of actions for solutions. Section 4 provides recommendations on implementation of the strategy and includes: obtaining the necessary commitment and resources, implementing the solutions, and then evaluating the impact of the strategy. Appendix I provides an example of the format and content of an action plan for the national strategy; Appendix II provides more information regarding searching for sources. Annex I provides examples from various Member States of the causes of loss of control over radioactive sources, while Annex II outlines some common problems that have been found with control of radioactive sources and solutions.

2. ASSESSMENT OF THE PROBLEM

OVERVIEW

2.1. The following steps should be carried out in the assessment phase of the development of a national strategy for regaining control over orphan sources and improving control over vulnerable sources:

— Deciding on the scope of the strategy;
— Gathering specific information on all aspects of the past and current degree of regulatory control of radioactive sources;
— Identifying problems and potential issues (gap analysis).

These three points are expanded upon in paras 2.2–2.12. This is followed by recommendations on how to gather and evaluate information systematically in each of several key areas.

2.2. The assessment will be iterative as a State's situation changes, and some degree of assessment will be continual. Some decision making will be necessary as part of the assessment, particularly in deciding on the scope of the assessment, in dealing with identified hazards that require urgent action and in modifying the assessment in the light of experience. However, the primary function of the assessment is to collect data on the current situation so that they can be assessed and proposals for improvement can be made.

Deciding on the scope

2.3. The scope of the assessment should be established in order to identify where the subsequent data gathering will be focused. In most cases, the focus should be at least on those sources capable of causing severe deterministic human health effects if not under control. Such sources are in Categories 1, 2 and 3 according to the Safety Guide on Categorization of Radioactive Sources [16], and include aggregations of smaller sources, which may be categorized in accordance with their aggregate activity ratios. However, this is not the only possible choice of focus. The scope of an initial national strategy could be focused on one or more of the following:

- A particular type of source or use of sources (e.g. mobile uses of radioactive sources, including industrial radiography sources; this may be considered appropriate because of the frequency of accidents associated with loss of control of such sources);
- A particular industrial sector where problems have been identified (e.g. scrap metal collection and recycling; this may be considered appropriate because of the frequency of events and the high economic and societal costs associated with unintentionally melting a source);
- A particular geographical region or area (either because of the region's national importance or because in the past fewer resources were devoted to regulatory control in the region);
- A particular aspect of control of radioactive sources such as import or export of radioactive sources;
- Sources in use prior to a national control system being established;
- Industrial sectors that are vulnerable to economic downturn and other market factors, which could lead to a sudden cessation of the use of a particular type of source;
- A sector of use that is critical to the national economy.

In addition, information from national bodies that conduct threat assessments may indicate particular types of radioactive sources that might be vulnerable and requiring attention under a national strategy.

2.4. The scope of the assessment is likely to change with each iteration in the development of a national strategy. While the appropriate focus may be self-evident, in some cases a careful analysis should be performed, perhaps with some preliminary data gathering, in order to determine the appropriate focus. Irrespective of the focus chosen, the delineation of the scope and the underlying reasoning should be recorded appropriately.

2.5. The importance of deciding on an appropriate scope cannot be overstated. An honest evaluation of the available resources should be carried out for both the development and the implementation of the national strategy as this is critical to ensuring that the effort is successful. Some States may be able to devote significant effort to the development of a comprehensive national strategy. However, it is likely that many States will have a limited number of suitably trained staff that can be diverted from their normal activities. Under these circumstances, the resources available should be devoted to producing an initial national strategy that focuses on specific issues and that sets out prioritized actions determined on the basis of past and current conditions. Such States should perform the assessment in an iterative manner, over an extended period, as the national strategy will need to be updated following the completion of existing action items and as a result of changes in conditions. Each assessment should build upon the work performed in previous assessments.

2.6. Once the scope of the assessment has been delineated, a programme of work should be drawn up with clear responsibilities and timescales for tasks.

Gathering specific national information

2.7. As part of the assessment, data should be gathered on sources, both those known to be present in the State and those potentially present in the State. The risk from orphan sources or vulnerable sources cannot be characterized unless information is available on what sources are likely to exist within the State. Characterization of the risk associated with orphan sources should involve an evaluation of both the potential for orphan sources to exist and the potential consequences that such sources may cause. The assessment process should also address whether vulnerable sources, although currently under control, might become orphaned in the future, and whether orphan sources might be introduced into the State from another State.

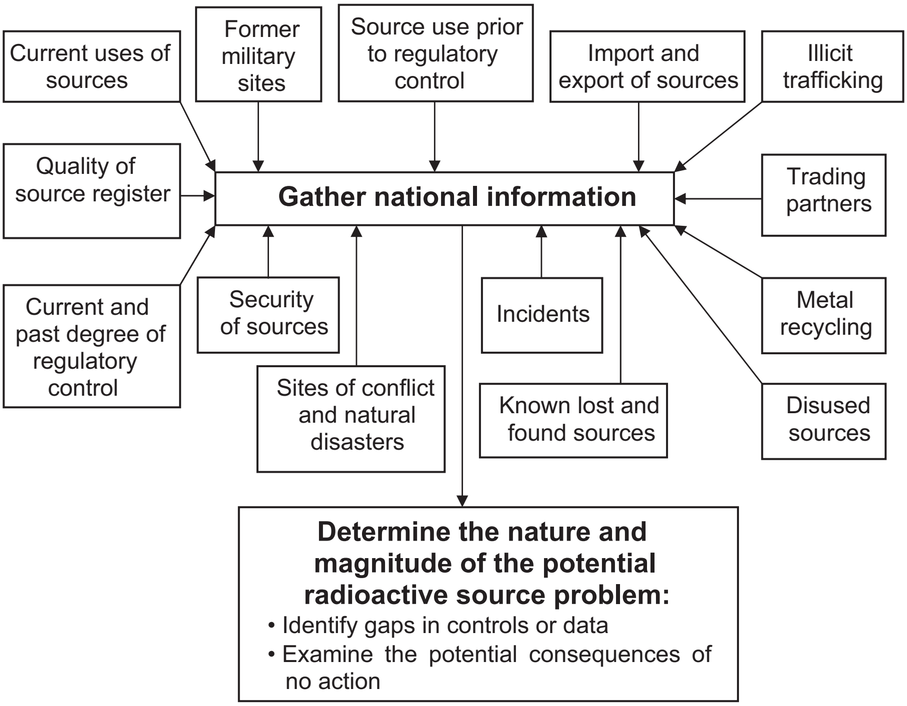

FIG. 1. Assesing the problem.

2.8. Three major aspects of gathering information should be addressed, as follows:

— *What* information is necessary?
— From *where* can this information be obtained?
— *How* can it be gathered?

The primary purpose of Section 2 of this Safety Guide is to provide recommendations on *what* information is necessary. Appendix II provides guidance on the possible sources of information (the *where*) and the methods (the *how*) in the larger context of searching for sources.

Figure 1 illustrates the important data inputs to the information gathering and evaluation phase, each of which is addressed in sequence in Section 2 of this Safety Guide.

Identifying problems and potential issues

2.9. Problems and potential issues should be identified while the data gathering is taking place. As questions are asked and answered, it will become clear where there are gaps in information or where there are problems.

2.10. An evaluation of the nature and magnitude of problems associated with control of radioactive sources should be made by comparing the actual situation with the ideal situation. The ideal situation can be characterized as complete and thorough conformance with relevant national laws and regulations as well as international standards and guidance [12–14, 18–25]. The Code of Conduct on the Safety and Security of Radioactive Sources [15] as well as its supplemental Guidance on the Import and Export of Radioactive Sources [26] are particularly useful in this regard because they provide basic principles and guidelines that are specific to radioactive sources.

2.11. As part of the evaluation process, it should be determined whether deviations from standards that are identified require immediate action. The criteria for this determination should be set on the basis of the potential consequences of the problem. This will primarily depend upon the category of source involved. For example, the loss of a particular Category 1, 2 or 3 source in a city would require immediate action. On the other hand, failure to include on the national register all the fixed gauges present in a particular industrial plant would be something that needs to be remedied; however, because it would be unlikely to lead to an immediate hazardous situation it would have a lower priority.

2.12. The individuals who are assigned to develop a national strategy should know how radioactive source control within a State is required to be handled and they should be sufficiently experienced to prioritize the discrepancies and problems found. If such experts are not available within a State, a peer review mission should be requested in order to obtain assistance.

CURRENT AND PAST DEGREE OF REGULATORY CONTROL

2.13. The assessment of the national situation should begin with a review of the current and past degree of regulatory control over radioactive sources. Reference [14] establishes requirements in respect of an effective regulatory infrastructure, which includes: legislation and regulation; a regulatory body empowered to authorize and inspect regulated activities and to enforce the legislation and regulations; and sufficient resources and adequate numbers of trained persons. Further requirements on regulatory infrastructure are established in Ref. [13] and guidance is provided in the Code of Conduct [15].

2.14. When analysing the regulatory infrastructure, the focus should be placed on those elements of the regulatory infrastructure that have a direct influence on the probability of loss of control of sources, particularly those in the higher risk categories. A partial list of such elements includes the licensing, inspection, import, export, possession, use and disposal of sources.

2.15. Radioactive sources will have been in use in many States prior to the development of the current regulatory infrastructure. In addition, regulatory infrastructures often change. Thus, the probability of loss of control of a source depends not only upon its historical use, but also upon the status of the regulatory infrastructure in the past.

2.16. The quality of authorizations and inventories in place, and the frequency and quality of inspections in the past should be examined since these will indicate the level of confidence that can be placed in the regulatory control over sources at that time.

2.17. A review of regulatory control in the past may be difficult because of a lack of contemporary documentation and difficulties in finding individuals who can assist in describing former procedures and priorities. The historical review should attempt to discover what was known of source inventories and uses at the time, but this information may be difficult to establish. This historical review should be used to highlight actual and probable losses of control of sources and the possible causes. The review of the current infrastructure will generate a sense of the level of confidence in the safety and security of existing sources and may highlight areas that require further attention and modification.

2.18. Typical problems or issues relating to deficiencies in control are the following:

- — A lack of appropriate laws and regulations governing control of radioactive sources;
- — A lack of effective independence of the regulatory body in the conduct of its activities;
- — A regulatory body with insufficient resources and inadequate numbers of trained persons;

— An inadequate process for authorization, licensing or registration of radioactive sources;
— A non-existent, incomplete or poorly maintained national register of sources (see paras 2.19–2.24);
— No specific authorization or licensing of government owned radioactive sources;
— Inadequate inspection, enforcement and follow-up;
— A lack of sanctions and deterrence measures;
— A licensing fee structure that encourages undesired behaviour on the part of users, for example, imposing high licensing fees on users who simply possess a disused source may result in individuals not requesting authorizations for such sources;
— Prioritization of resources on the basis of geographical regions, political regions or use, rather than on categories of sources.

QUALITY OF THE SOURCE REGISTER

2.19. The existence of a national register of radioactive sources and its quality should be carefully examined, since this will be a prime indicator of whether problems involving orphan or vulnerable sources may be expected. If a source register does not exist or appears incomplete, its establishment and completion should be given a high priority in the national strategy that is subsequently developed. The following sources of information should be searched to assist in the creation or completion of a source register:

— Inventory records of sources maintained by users or others who may be storing sources;
— Records of source manufacturers, distributors and service providers;
— Records of transport or shipping companies, including customs declarations;
— Inspection reports from any authority that may have inspected a particular facility for any reason;
— Event reports and notifications;
— Licensing records, including notifications and original requests for authorization.

2.20. Aside from finding information contained in existing records, there are other methods of collecting data for a source register. Several of these are discussed in detail in Appendix II.

2.21. Even if a national source register exists, it may well be incomplete, which may imply the presence of orphan sources in the State. Therefore, an existing source register should be critically examined to verify its quality, reasonableness and internal consistency. Questions to be considered in this evaluation should include:

— Are all the types of sources used in all the likely or known industrial and medical activities within the State reflected in the register?
— Are the radionuclides and activities identified appropriate for the application of the source? (Table 2 of Appendix I in Ref. [16], which provides the typical range of activities used in various applications, may prove helpful in this review.)
— Are all likely companies or users of a particular practice included in the register?

2.22. In developing a national source register, or in evaluating the completeness or accuracy of a register, priority should be given to ensuring that dangerous sources (Category 1, 2, and 3 sources) are brought under control, although it is recognized that resources are often limited. Sources in lower categories should be dealt with after higher activity sources have been brought under control. However, where data on lower category sources are available or found, they should be recorded in the source register at the same time as data on any dangerous sources. The Code of Conduct [15] also provides guidance in this respect: "Every State should establish a national register of radioactive sources. This register should, as a minimum, include Category 1 and 2 radioactive sources as described in Annex 1 to this Code" (Basic Principle 11).

2.23. For each source in the register, the following information, as a minimum, should be recorded:

— The operating organization authorized to possess the source and associated device, including contact information;
— The authorized use of the source and associated device;
— The unique identification of the source (manufacturer, model number, serial number, and date of manufacture);
— The unique identification of the associated device (manufacturer, model number and serial number);
— The location of the source and/or associated device (installed location or location of authorized use);
— The radionuclide, the source activity and the date on which the activity was measured;

— The category of the source;
— The form of the radioactive material (physical and chemical), including its special form status (see Ref. [19]);
— A record of where the source was received from or transferred to;
— The date the source and/or associated device was entered into the register;
— The planned disposition of the source, including, as applicable, the planned date of its return to its supplier or its transfer to a waste facility.

2.24. A register of radioactive sources should be generated and maintained using database software, rather than spreadsheet or word processing programmes, to enable searching and sorting of data and the generation of reports. There are a number of commercially available programs for maintaining inventories of radioactive material (registers); the Regulatory Authority Information System (RAIS) developed by the IAEA [27], which includes a module for developing and maintaining a source register, may also be used.

CURRENT USES OF SOURCES

2.25. Detailed information should be gathered on the current uses of radioactive sources in the State and the organizations using them. This is fundamental to developing and maintaining a national source register and to identifying possible orphan sources or vulnerable sources.

2.26. The basic process of gathering data on sources based upon their use consists of the following steps:

— Becoming knowledgeable about the various types of source applications commonly in existence (Table 2 of Appendix I in Ref. [16] provides examples of practices using radioactive sources);
— Determining which of these applications or industries are likely to be in use within the State;
— Determining which of them are within the scope of the assessment (as decided in accordance with the recommendations provided in paras 2.3–2.6);
— Gathering user data that are easily obtainable (i.e. conducting an administrative search, as described in detail in Appendix II).

2.27. Such a search will help to establish whether orphan sources exist or whether there is some likelihood that they may exist. The results of such a search may also indicate that more intensive administrative searches and/or physical searches are warranted.

2.28. Such an administrative search for the purposes of data gathering can be conducted with the help of the information provided in Annex I. In Annex I, typical applications or practices are presented by category of the sources used, starting with practices using Category 1 sources. The industries of interest on which to concentrate the data gathering efforts are also given, along with considerations regarding loss of control that should be taken into account when reviewing each practice using radioactive sources.

2.29. In some cases, such as for irradiation facilities, those performing the assessment will be able to conclude, with a high level of confidence, that orphan sources either do or do not exist. In many other cases, those performing the assessment will determine that sources may be in use, or may have been used, but they will be unable to reach definitive conclusions without further detailed searches. On very rare occasions, the potential risk uncovered by the assessment may justify the immediate initiation of source specific search activities. In general, however, the data gathering stage of the assessment should go into only enough detail to determine whether there is the potential for orphan sources of a certain type to exist. If it is determined that orphan sources of a given type may exist, a further, more detailed investigation should be incorporated as part of the national strategy action plan.

FORMER MILITARY SITES

2.30. While military uses of radioactive sources are specifically excluded from the scope of the Code of Conduct [15] and of this Safety Guide, sources within this sector can become and have become orphan sources, often by being abandoned. Therefore, former military sites should be assessed by means of physical and administrative searches (see Appendix II) to ensure that there are no sources that have been lost or abandoned in these areas. This task will be made easier if information can be obtained from the relevant military authorities regarding what sources have been used, where they were used, and their final disposition.

SOURCES IN USE PRIOR TO THE APPLICATION OF REGULATORY CONTROL

2.31. An assessment should be performed to determine what sources were in use before adequate regulatory control was applied within the State, and whether any of these sources are still not under regulatory control.

2.32. In many States, sources may have been used prior to the establishment of effective regulatory requirements and may not have been disposed of appropriately. Therefore, information should be gathered about the ‘early days’ of radioactive material use as soon as possible, while individuals who were present at the time are still alive. What is regarded as the early days will vary significantly for different States and could range from before the 1920s to the 1990s. Although human memory is very fallible, useful information about the historical situation and the potential for orphan sources to exist can still be obtained from individuals who were the first to work in the various fields of application of radioactive sources (‘pioneers’).

2.33. The earliest uses of radioactive material within more developed States will typically involve radium, particularly in medical and research applications. For developing States, the earliest uses are more likely to be in the medical field, and particularly in cancer therapy using ^{60}Co or ^{137}Cs. In any case, universities and other research centres and institutes are likely to represent some of the earliest users of radioactive sources. Therefore, these are good places to begin enquiries as to the use of sources prior to the application of regulatory control. Once pioneers in the early use of radioactive sources are identified, they should be interviewed regarding:

- The type and number of sources they used, and their typical activities;
- How the sources were obtained and from whom;
- What the sources were used for;
- Details about any incidents involving the sources;
- Where the sources were stored;
- How the sources were disposed of;
- Who their co-workers and/or students were;
- What legislation, regulations or rules were in place and when such rules were established.

2.34. The list in para. 2.33 is not exhaustive, but it provides an indication of the types of questions that might be of use in evaluating the potential for orphan sources to exist. Information provided in the course of such interviews should be verified by other sources of information wherever possible, but indications of the possible existence of orphan sources in higher categories should be investigated further as part of the development of the national strategy.

2.35. Other individuals who are likely to have relevant information are those who were involved in developing and enforcing regulations. Here it is recognized that regulatory control and its application will have evolved over time. One possible source of information that may lead to the discovery of orphan sources where control was lost in the distant past is records from repositories of radioactive waste. If available, such records should be reviewed for information about the original owners of sources or organizations from which the sources came. Such information should be used to develop further information about current possession of radioactive sources and may indicate the existence of orphan sources.

IMPORT AND EXPORT OF SOURCES

2.36. National practice in the import and export of radioactive sources should be assessed. Experience has shown that failure to control effectively the import and export of radioactive sources can be a major contributor to sources becoming orphaned. Most States import a range of radioactive sources or devices containing them, but only a limited number of States export new radioactive sources or devices.

2.37. Many States have made a political commitment to the Code of Conduct on the Safety and Security of Radioactive Sources [15] and its supplemental Guidance on the Import and Export of Radioactive Sources [26]. Irrespective of whether a political commitment has been made, all States should strive to meet the principles of the Code and to implement the Guidance. However, it is recognized that it will take time for most States to become fully compliant. Therefore, a review of the current and past status of import and export practices should be conducted as an important part of the assessment of the national situation. In particular, large, multinational companies that import sources for temporary use for non-destructive testing or well logging should be questioned, as in the past problems have arisen concerning lack of notification to national authorities of the import of such sources.

2.38. Gathering information on the export of new radioactive sources or devices will generally be relatively easy. There are only a few States that are major exporters of sources. If there is no capability for manufacture of radioactive sources in the State, it is likely that the only export of sources will be the re-export of sources that had been imported for temporary use within the State or of disused sources to the supplier or State of origin.

2.39. To determine the situation with regard to the import of radioactive sources, data should first be gathered from customs authorities and from known users of radioactive sources. Manufacturers and suppliers of sources are also likely to have information about sources that they have distributed. Although many States have established regulatory requirements for the pre-authorization and licensing of imports, these requirements are sometimes not met or enforced.

2.40. In the past, radioactive sources have become orphaned in customs warehouses. For this reason customs procedures for imports should be examined carefully. Radioactive sources might remain unclaimed from customs for a variety of reasons, including:

- Non-conformity with the customs import manifests;
- Suspected illicit trafficking of radioactive material;
- Inability to contact the recipient;
- Abandonment of the source because of reasons such as cessation of business, bankruptcy, or because the source has decayed to the point where it has no commercial value;
- Lack of desire or ability on the part of the recipient to pay any import duty owed;
- Lack of desire or ability on the part of the recipient to pay for management and disposal of a disused source.

2.41. Reference [19] establishes international requirements for the labelling of packages containing radioactive material. If a package label does not identify clearly that a package contains radioactive material, it is possible that unclaimed sources may enter the public domain through auctions later conducted by customs authorities.

ILLICIT TRAFFICKING

2.42. The occurrence of incidents of illicit trafficking of radioactive material and other events such as seizures of radioactive material being trafficked, the theft or loss of sources, the unauthorized movement or disposal of sources, or recoveries of radioactive sources is symptomatic of weaknesses and vulnerabilities in regulatory control and in security systems. The collection and assessment of information about such events can provide valuable indications of which sources may be at risk of becoming orphaned, where such sources may be located and which sources or facilities are not under regulatory control, and may also indicate generic problems in the legislative and regulatory framework. Information should also be gathered on illicit trafficking and other unauthorized acts in neighbouring States and further afield.

2.43. The IAEA's Illicit Trafficking Database (ITDB) is an information system for the collection and dissemination of information on incidents of illicit trafficking and other events such as thefts and losses of radioactive material, unauthorized movement and disposal of material, and recoveries of radioactive material [28]. The ITDB is unique in that information on incidents falling within its scope is provided by the States themselves. Information on such events is also collected from open sources, and verification, or otherwise, is sought from the States involved. Each State participating in the ITDB programme appoints a national point of contact, who has access to the information in the ITDB and will therefore be a useful resource in the assessment phase. Participation in the ITDB programme is voluntary, but States that are not members should consider joining as part of their national strategy for regaining control over orphan sources and improving control over vulnerable sources.

2.44. An important factor that may be identified from detailed data stored in the ITDB is that most of the significant recoveries of nuclear material have resulted from the gathering and analysis of intelligence information. This indicates the importance of involving law enforcement agencies, customs authorities and intelligence agencies in efforts relating to the gathering of information on radioactive sources. International and national law enforcement agencies, customs authorities and intelligence agencies should be consulted in the assessment phase, because they may be able to provide relevant, current information based on information gathered from intelligence sources within the State and from wider networks.

2.45. The following information should be taken into consideration or gathered, as part of the preparation for development of a national strategy:

- — The number and nature of neighbouring States, as well as the political relationship with them;
- — The quality of the regulatory control of radioactive sources in neighbouring States;

— The nature of borders with neighbouring States; i.e. are the borders open or is access to neighbouring States restricted by natural barriers or because of the political situation?
— The number and type of the various ports of entry and exit via land, air or water;
— Radiation detection capabilities at national borders and other relevant locations;
— Estimates of the ease of installation of additional border monitoring equipment;
— Records of illicit trafficking events uncovered via law enforcement or intelligence operations, or existing border monitoring.

2.46. Cooperation should be established between the regulatory body, law enforcement agencies, intelligence organizations, customs authorities, border guards and other authorities at ports of entry to the State. Effective communication and mutual assistance are necessary between such organizations in each of their respective areas of expertise in order to properly assess the extent of illicit trafficking within their State.

2.47. Typical problems that may arise in the collection and assessment of information on the illicit trafficking of radioactive sources are given in the following:

— There has been no communication between the various relevant organizations in relation to a harmonized approach to combating illicit trafficking in the State;
— Information concerning illicit trafficking events has not been provided to or by relevant law enforcement agencies;
— No assessment has been made as to whether or not illicit trafficking is a problem in the State;
— There is evidence of a significant amount of illicit trafficking in the State;
— Personnel who may come into contact with illicitly trafficked radioactive material have not been provided with training in the detection and identification of radioactive material and/or are not in possession of appropriate radiation detectors;
— There is no cooperation or agreements between the various organizations that provide technical support to customs and border authorities or law enforcement agencies;
— There is a lack of border monitoring, even in situations where it would be clearly justified;

— Existing border monitoring equipment is non-operational, inefficient or inadequate.

TRADING PARTNERS

2.48. The potential for imported materials to contain orphan sources should be assessed. If radioactive sources are lost from regulatory control, there is the possibility that the sources themselves may become mixed with other commodities, or that such commodities may become contaminated. Contaminated commodities usually present a much lesser health risk than orphan sources themselves. However, the existence of contaminated commodities can be an important indicator of a lack of regulatory control.

2.49. Few, if any, States have the resources to sample or monitor effectively all goods entering or leaving the State. Therefore, decisions should be made during the development phase of the national strategy to focus resources on the streams of commodities that are most likely to contain sources or to be contaminated and to monitor for those items that may pose the most significant risk. Usually, resources should be focused on imports for the metal recycling industry, as in the past events have occurred in this sector. The flow of these goods (and others that may be identified as being of interest) should be assessed to determine whether the trade is restricted to a limited number of ports, in order to limit the locations where monitoring programmes may need to be considered. Decisions on establishing arrangements for monitoring are complex; however, guidance is provided in Appendix II and Ref. [29].

2.50. In developing a national strategy, the potential for the presence of radionuclides of natural origin in imports should be assessed since these will represent some of the most common radionuclides detected by border monitoring systems. Materials containing radionuclides of natural origin may come from the industries processing minerals such as: bastnaesite, bauxite, fluorspar, ilmenite, monazite, phosphate, pyrochlore, zircon sands, oil and natural gas. Concentrations can vary widely, depending upon the origin of the material and the degree of processing. The use of materials containing radionuclides of natural origin may pose a chronic hazard that should be addressed within the regulatory framework, but does not normally pose an acute hazard.

RECYCLING OF METALS

2.51. In the past there have been significant health and economic consequences caused by orphan sources contained in scrap metal in various phases of recycling. Therefore, scrap metal recycling should be treated as a special case and information should be gathered about the nature and magnitude of this industry in the State [30–33].

2.52. If a facility in which radioactive sources were used is decommissioned, dismantled or demolished, there is a possibility that the sources will not have been removed before this takes place. For example, gauging devices in an industrial plant may still be attached to piping that is being removed for recycling as scrap metal. In addition, there is the possibility that lead, tungsten or depleted uranium from a source shield may be sent for recycling while the source is still contained inside the shield. As scrap metal may be transported worldwide for recycling, it may happen that sources are transported and imported along with the scrap metal.

2.53. If a radioactive source is not discovered prior to its shredding or melting along with the scrap metal, the consequent release of radioactive material may lead to environmental contamination, significant contamination of the plant and enormous costs associated with decontamination activities (see Annex 1 of Ref. [30]).

2.54. If the source is not detected before or during melting, it may be vaporized or diluted and incorporated into the new metal ingots or slag. If still not detected, the radioactive material will become part of the final product or waste. Contaminated metal or metal products may themselves be transported or imported. Dose rates from contaminated metal products are generally relatively low and do not pose a significant problem in the short term. However, if contaminated steel is incorporated into items that people can be close to for a long period of time, e.g. chairs, tables or reinforcing steel bars in building structures [34–36], accumulated doses can become significant.

2.55. Information should be gathered on scrap metal dealers and others involved in the metal recycling industry. Scrap metal dealers and representatives of industries involved in metal recycling should be made aware of the risks posed by orphan sources. Also, provisions for the monitoring of scrap metal for contamination and for the presence of radioactive sources should be considered for inclusion in the national strategy. Acceptance criteria and other action levels should be set before such provisions are implemented.

2.56. Information that should be gathered with respect to metal recycling includes:

- — The names and locations of the metal processing companies in the State and their suppliers, as far down the supply chain as reasonably possible;
- — Whether these companies have any radiation detectors, either stationary or mobile;
- — The level of awareness among staff of such companies of the potential hazard, the radiation warning symbol and the visual appearance of typical sources and source shields;
- — Whether arrangements are in place for dealing with sources found in scrap metal;
- — Which companies, if any, are importing or exporting scrap metal.

2.57. The use of radiation detectors at various points throughout the metal recycling process is almost always justified. Provisions for dealing with found sources should also be made. Individuals involved in the metal recycling industry should be trained with regard to the visual appearance of the radiation warning symbol and of typical sources and source shields that they might encounter. The IAEA has produced an information tool kit that may be useful in this regard [37]. Further recommendations on dealing with orphan sources in the metal recycling and production industries are provided in Ref. [38].

DISUSED SOURCES

2.58. Disused sources represent the largest pool of potential orphan sources, and therefore special attention should be paid to assessing the scale of the problem. Historically, many accidents involving orphan sources came about because sources that were no longer in use were eventually forgotten, with subsequent loss of control some years later. Therefore, an attempt should be made to identify all disused sources in the State and ensure that they undergo proper disposition.

2.59. Information should be gathered on the status of at least all Category 1, 2 and 3 sources in each operating organization’s inventory or the national register of sources, so that an assessment can be made as to whether the sources are disused or not. Generally, this will involve asking the licensee or owner of the source about the frequency of use. An examination of provisions made for storage of sources will also provide evidence as to whether a source is actually being used and whether it is being stored securely.

2.60. Guidance is provided in Appendix II on conducting searches in order to gather information on disused sources not listed in any inventory or in the national register of sources.

2.61. Operating organizations should be encouraged to maintain awareness of and anticipate the likely end of the useful life of a source. This will enable them to make appropriate management and budgetary provision for disposal of the source and will reduce the probability of disused sources being stored at user facilities for extended periods of time. The following aspects should be monitored for each source:

- — Recommended working life;
- — Compliance with approval certificates for special form radioactive material, which could affect the ability of the operating organization to transfer the source at the end of its period of use [19];
- — The availability of authorized transport packaging, especially when specific packaging is required to transport a source [19];
- — Results of leak tests.

2.62. Operating organizations should be encouraged through various means, such as the imposition of increased licence fees or regulatory requirements, to return disused sources to their manufacturer, or to ship them to disposal facilities, centralized storage facilities, or other authorized recipients where their continued control can be assured. In some States, the import of a source is conditional on its re-export at the end of its useful lifetime, or when the task for which it is imported is completed. In other States authorizations are granted only if the disposal route for the source is already specified and planned. In some States routine reauthorization of sources is required, with an appropriate fee; this has been found to be beneficial in encouraging users to decide whether or not the sources are still really needed. Regional and national campaigns to recover orphan sources have significantly reduced the numbers of disused sources available [39].

2.63. It is often found that disused sources are:

- — Stored inadequately (this can apply not only to disused sources in the possession of a former user, but also to disused 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 the loss of a source going undetected for some time.

— Not declared disused, even though they have not been used for several years (this means that such sources are not subject to regulatory requirements for disused sources and are not considered for disposition).
— In a situation where they might be forgotten, especially when staff leave due to retirement, job changes or other reasons.
— Unable to be disposed of, as there is no route, method, mechanism or incentive in place to do so.

KNOWN LOST AND FOUND SOURCES

2.64. Information should be gathered on radioactive sources that have previously been lost or found in order to help quantify the extent of the orphan source problem. The greatest effort in this area should be devoted to Category 1, 2 and 3 sources. Data on lost and found sources from other States can also help identify areas where problems may arise.

2.65. Although historical records might be incomplete, a system should be set up to ensure that in the future all data on lost and found sources are collected and retained. Some States maintain databases (for example, the Nuclear Materials Events Database maintained by the United States Nuclear Regulatory Commission [40]), and international organizations also maintain databases and records in other forms [28, 29, 41]. The data contained in these information sources are limited, with significant under-reporting, and it is unlikely that timely quantitative assessments can be made. However, when used together with the information in Ref. [16], a qualitative assessment of high, medium and low risk sources could be made.

2.66. A lack of data on lost and found sources can be either a positive or negative indicator. On the positive side, it could mean that the control of radioactive sources 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 the loss or finding of sources, or that no one is aware that sources are lost.

2.67. Typical problems include the following:

— No data are kept on any lost or found sources;
— No attempts have been made to search for lost sources or the owners of found sources;
— Several sources have been found, which indicates that other sources remain lost;

— There is evidence that sources were brought into the State, but there is no knowledge of their current whereabouts;
— There is a lack of routine effort to search actively for sources;
— No requirement has been established to notify relevant governmental bodies of lost, missing and found sources.

INCIDENTS

2.68. While much can be learned from reviewing past incidents, including accidents involving radioactive sources, the focus in the context of the development of a national strategy should be placed on how the sources involved became orphaned.

2.69. The following steps should be considered in reviewing incidents involving radioactive sources:

— A list of past incidents involving radioactive sources should be drawn up.
— If an event involved properly licensed or authorized sources, then, while there might be radiation safety or regulatory lessons to be learned, these are unlikely to be of use in finding orphan sources; therefore, events that involved orphan or vulnerable sources should be selected and efforts focused on these.
— The process by which the radioactive source was lost from regulatory control (orphaned) should be determined and the sequence of events should be analysed to determine the primary cause.
— If events involving orphan sources have occurred, it should be determined if there are commonalities.
— Existing records and data should be reviewed to determine whether other sources may have followed a similar flawed process leading to their becoming orphaned, but have not yet resulted in an incident.
— Where appropriate, review of information should be followed up with interviews or site visits to confirm or disprove the existence of other sources.

2.70. Clearly a review of incidents involving radioactive sources has significant potential overlap with reviews of disused sources and known lost and found sources; however, it will provide a distinctively separate starting point for an investigation.

SITES OF CONFLICT AND NATURAL DISASTERS

2.71. Social upheavals resulting from armed conflicts and natural disasters such as floods, hurricanes and earthquakes can lead to the normal mechanisms of regulatory control of sources being removed or becoming severely degraded. Therefore, as soon as possible following such disruptive events, the potential for new orphan and vulnerable sources should be assessed.

2.72. Questions that should be asked following such events include:

- What sources were in the area previously and where were they located?
- What is the extent of damage sustained by facilities using and storing sources?
- Could there be vulnerable or orphan sources as a consequence of collateral war damage, for example, a damaged teletherapy unit in a derelict hospital?
- Could damage to buildings allow uncontrolled access to previously restricted areas, thereby making looting or scavanging of radioactive material possible?
- Have facilities containing radioactive sources been abandoned by authorized persons or has the oversight by these individuals been reduced?
- Has normal regulatory control been affected?
- Does a threat assessment indicate an increased desire by individuals to illegally acquire radioactive sources?

2.73. All these types of events warrant the inclusion of administrative and physical searches for radioactive sources in the national strategy (see Appendix II).

SECURITY OF SOURCES

2.74. As part of the assessment, the current status and implementation of security requirements for radioactive sources should be reviewed.

2.75. Historically, many States had no specific regulatory requirements regarding the application of security measures to radioactive sources other than those based primarily on safety considerations. Since the attacks of 11 September 2001, however, new measures for the security of radioactive sources have been developed [42]. However, not all States have yet implemented security measures that reflect the current threat environment.

2.76. Potential problems in the area of security of sources are the following:

— Lack of coordination among all national organizations with responsibilities in the field of security;
— Lack of a national legal framework, regulatory requirements or guidance regarding the security of sources;
— Inadequate application of national safety and security requirements at facilities using radioactive sources.

3. DEVELOPMENT OF THE NATIONAL STRATEGY

OVERVIEW

3.1. The following steps should be carried out in the development phase of a national strategy for regaining control over orphan sources and improving control over vulnerable sources:

— Listing the problems or potential issues identified in the assessment phase;
— Developing actions that will solve each problem, or, if it is a complex situation, identifying the first steps towards a solution of the problem;
— Prioritizing these actions and presenting them in a format that is suitable for review by decision makers;
— Identifying the various agencies involved and achieving agreement on assignment of responsibilities for the actions.

3.2. While the action plan is a prioritized work plan, and is therefore a document for implementation, it should be written with decision makers in mind as its primary audience. This is because a high level of commitment and, probably, additional national resources will be necessary to implement the action plan; further resources from donor States or international agencies may also be necessary.

DEVELOPMENT OF SOLUTIONS

3.3. Some problems identified in the assessment phase may be sufficiently minor or immediate that they should be handled before development of a formal national strategy. Minor problems should be dealt with quickly by the relevant government body within their normal scope of activities. Such minor problems and their solutions should be recorded, both to ensure that lessons are learned from the process and to assemble data that may indicate a more systemic problem.

3.4. Similarly, problems that present an immediate danger should be dealt with immediately by the relevant government body. Such problems and the actions carried out to mitigate them should also be recorded. Thus, there may be some overlap between the phases of assessment, development and implementation. However, the main part of the assessment phase will involve identification of problems and issues that necessitate a national strategy to address them.

3.5. Once the assessment of the current situation has been completed, a list should be developed of actions to be taken to solve the problems identified. For example, if there is no register of sources in the State, a solution would be to begin to establish one. Annex II lists examples of a number of common problems and possible solutions that have been found and proposed as part of the national strategy action plan in various States.

3.6. For some problems, there may be several possible solutions. For example, if a disused source is in a vulnerable situation, it should be made more secure [42]. This could involve making its current storage more secure, transporting it to a more secure location or permanently disposing of it.

3.7. It is sometimes difficult to determine the amount of detail with which to present solutions in the action plan. The appropriate amount of detail should be determined in accordance with the process for obtaining agreement on the national strategy by decision makers. Therefore, the decision makers should be identified at an early stage and the level of detail of the action plan should be adjusted to meet their needs.

PRIORITIZATION OF ACTIONS

3.8. The actions developed should be prioritized. Typically there will be a long list of problems and possible solutions, which cannot all be accomplished at once. Paragraphs 3.9–3.14 provide recommendations on a number of factors that should be considered in the prioritization process.

Degree of immediate hazard

3.9. If a problem identified presents an immediate hazard and is likely to result in a radioactive source causing death or injury, that problem should become the top priority. As stated in para. 3.4, such problems should be addressed before development of a formal national strategy, but should still be approached in a carefully planned manner. An example of such a situation is the discovery of the loss of an industrial radiography source (Category 2), requiring immediate action to locate and secure it.

Degree of potential hazard

3.10. The next consideration should be the degree of potential hazard. These are situations that, if not taken care of quite quickly, could present an immediate hazard. They are 'accidents waiting to happen'. A teletherapy head (Category 1) left in an area that is unsecured is an example of such a problem. Similar situations have been common precursors to several incidents that have resulted in fatalities or serious injuries.

Cost of implementing the solution

3.11. The relative cost or ease of implementing the solution to an identified problem should be considered in the prioritization of actions. Actions that can be taken easily with no additional resources should be implemented immediately. For example, if a regulatory body is undertaking inspection or authorization of sources on the basis of geographical boundaries such as provinces, the work should instead be organized on the basis of source categories, thereby dealing with Category 1 sources first, or on the basis of information from national threat assessments.

3.12. The following listing provides a possible ranking of solutions according to their cost:

(1) Procedural changes that existing staff can implement immediately;
(2) Procedural changes that require significant work for existing staff to develop or implement;
(3) Solutions that require the purchase of new equipment or vehicles;
(4) Solutions that require the hiring of additional staff;
(5) Solutions that require the construction of new facilities, such as facilities for long term storage or disposal of disused sources.

Speed of implementation

3.13. The speed of implementation of a solution should be considered in the prioritization process. Some solutions can be achieved more quickly than others. For example, an action to change a licence application form to require the provision of additional information can be accomplished much more quickly than an action to amend a law or regulation.

3.14. Initially, resources should be allocated to implement solutions having a short timescale and low cost. This has the value of showing results and maintaining the momentum of improvement. However, solutions with longer timescales may have a higher importance and impact and may have milestones that need to be met within a specified time. Further analysis, more data collection, or the development of a funding or policy proposal may be necessary for such solutions.

Format of the national strategy document

3.15. Appendix I provides an example of the format of the national strategy document and its content; however, this should be adapted to meet the specific national situation.

4. IMPLEMENTATION OF THE NATIONAL STRATEGY

OVERVIEW

4.1. The following steps should be carried out in the implementation phase of a national strategy for regaining control over orphan sources and improving control over vulnerable sources:

- — Deciding to proceed;
- — Implementing the action plan;
- — Evaluating the effectiveness of the action plan and updating it accordingly.

DECIDING TO PROCEED

4.2. Once the action plan for the national strategy has been developed, the decision to implement it should be made by the highest appropriate authority. The decision should be formally recorded. Those responsible for ensuring that the control over radioactive sources is maintained and improved should be granted the necessary authority and resources to implement the plan; otherwise the plan will not be effective. If there are long term or very costly actions that need further discussion and evaluation prior to their adoption, these should be treated separately and the rest of the plan should be submitted for approval.

IMPLEMENTING THE ACTION PLAN

4.3. Moving ahead with the action plan will generally be relatively straightforward once it has been approved. Implementation will be dependent on the specific nature of each of the actions. However, actions with the highest priority should be addressed first.

4.4. If a State does not have the necessary resources or expertise to implement specific tasks, the possibilities for obtaining bilateral or international assistance should be investigated. There are several ways of obtaining additional assistance, particularly with regard to higher category sources that may be lost or vulnerable. The IAEA has several mechanisms for the provision of such assistance, for example through its technical cooperation programme.

EVALUATING THE EFFECTIVENESS OF THE ACTION PLAN AND UPDATING IT

4.5. The national strategy action plan should be evaluated, reviewed and revised on an annual basis. As the higher priority actions are completed, those tasks that had had lower priority should be given a higher priority in the revised action plans. The work itself will also lead to changes in the situation as more information is gathered, resources become available or dry up, and a greater level of understanding is achieved.

4.6. The successful implementation of a national strategy will result in orphan sources being brought under regulatory control and the control over vulnerable sources being improved. Therefore, the evaluation of the effectiveness of the action plan and its updating can also be considered an evaluation of the system of regulatory control over radioactive sources.

Appendix I

FORMAT AND CONTENT OF A NATIONAL STRATEGY DOCUMENT

I.1. Even though a national strategy, and hence the contents of the national strategy document, will be specific to each State, this appendix provides some guidance regarding the general format and content.

INTRODUCTION

I.2. The introduction of the national strategy document should provide the background, objectives, scope and structure of the document and should set out definitions of terms used in it. While the action plan is a prioritized work plan, and is therefore a document for implementation, it should be written with decision makers in mind as its primary audience. This is because a high level of commitment and, probably, additional national resources will be necessary to implement the action plan; further resources from donor States or international agencies may also be necessary. For this reason, a brief explanation of the types and uses of the various radioactive sources in the State should be included in the introduction, as well as information about how similar sources have become orphaned or been targets of theft.

NATIONAL INFRASTRUCTURE FOR THE CONTROL OF RADIOACTIVE SOURCES

I.3. This section of the national strategy document should provide a brief summary of the historical situation regarding the national infrastructure for control of sources and the current requirements. It should set out the scope of coverage of the existing mechanisms for control of sources and their strengths and weaknesses, and should include the authorities and responsibilities granted to various national body(ies) in this respect. If more than one authority has responsibility for the control of radioactive sources, their various responsibilities, and the coordination and liaison between the authorities, should be clearly set out in this section. The implications of any proposed changes in national requirements for the control of sources should be addressed.

DATA FROM THE ASSESSMENT

I.4. The national assessment of each of the key areas covered in Section 2 of this Safety Guide should be described in this section of the national strategy document. Background information on each key area should be provided for the benefit of readers who may be unfamiliar with the applications of radioactive sources. This will enable a decision maker to understand, for example, the uses of radiography sources, how hazardous they might be if uncontrolled, and why it is important to ensure they are controlled properly.

EVALUATION OF PROBLEMS AND PROPOSED SOLUTIONS

I.5. Each problem that has been identified and its constituent parts should be described, along with actions that solve, or move towards a solution, of the problem. The description of each problem and its proposed solution should be fairly detailed and specific for it to be helpful.

ACTION PLAN

I.6. In order to assist decision makers, the text of the previous section describing each problem and its solution should be summarized in a short, tabular format, comprising the following aspects:

(a) A clear statement of the problem identified;
(b) The action to be taken to address the problem;
(c) The priority for the action;
(d) The resources necessary;
(e) The allocation of responsibility;
(f) The timescale for implementation.

The format used for each action plan could be an expanded version of the examples set out in Annex II.

CONCLUSION

I.7. A statement regarding the current level of control over radioactive sources should be provided in the conclusion to the national strategy document, along with an evaluation of the potential for orphan sources to exist. The reader should be able to gain a quick understanding of the national situation with regard to control of radioactive sources and the importance of implementing the national strategy.

Appendix II

SEARCHING FOR SOURCES

II.1. The national strategy should involve some type of search for radioactive sources. This appendix provides detailed guidance on methodologies for conducting such searches. Searches may be administrative or physical searches. A physical search will involve attempts to identify radioactive sources both visually and with the use of radiation detectors. An administrative search may identify evidence of a lost source and lead to a physical search for the source. Administrative searches are also used to prioritize physical searches.

II.2. There are several reasons for conducting searches as part of a national strategy, including the following:

- To develop an initial register of sources;
- To check routinely that all sources are accounted for, and so allow the register to be updated;
- To investigate the causes of radiation injuries;
- To look for specific lost sources.

II.3. The fact that a source is missing may be discovered in a number of ways. These include the following:

- The results of an administrative search;
- A report by a user that a source has been lost or stolen;
- Only a part of a consignment being received;
- A break-in to a storage location for sources;
- Observation of abnormal monitoring results;
- Finding an empty, labelled source container;
- Detection of radiation induced health effects.

II.4. The decisions as to whether to initiate a search, and its priority, will depend on the reason for the search, as well as on such factors as:

- The likely potential hazard from suspected, uncontrolled sources;
- The category of a source known to be missing;
- The length of time since a source was lost or stolen;
- The amount of information available that might be of use in searching;
- The projected cost of the search and the financial resources available;

— The future development plans for an area in which an orphan source is suspected to be present;
— The availability of qualified search personnel;
— The instrumentation available for physical searches;
— The ‘risk tolerance’ of the local authorities and the nearby population (e.g. whether the potential presence of an orphan source in a public place would be tolerable).

II.5. If the risk of injury to individuals is determined to be high (for example, in the case of a lost Category 1, 2 or 3 source), this becomes an emergency and should be treated as such [43–47]. “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 being in the public domain” (para. 4.38 of Ref [18]).

ADMINISTRATIVE SEARCHES

II.6. In an administrative search, information is gathered without the use of radiation detection equipment or visual searches about sources that are known or suspected to be lost, missing or stolen. Two key aspects of administrative searches are determining the most useful source of information and determining the best method of collecting the information from that source.

Sources of information

II.7. One of the first tasks of an administrative search involves listing the persons or institutions where the desired information might currently reside. A listing, and brief discussion, of some typical information sources follows.

Government authorities

II.8. This includes any branch or level of government that has some authority to carry out functions relating to the safety and security of radioactive sources. It can include government ministries or departments, competent authorities, regulatory bodies, or regional or local authorities. It can include those responsible for areas such as radiation safety, nuclear power, health, the environment, industry, mines, agriculture, transport, education, customs and law enforcement. Particular care should be taken if there has been a significant change in the authorities and responsibilities at some time in the past. The transfer of authority does not always result in a commensurate transfer of applicable records, as illustrated in Box II.1.

There can also be gaps in regulatory control in States with a federal system of government if there is no clear distinction between the responsibilities discharged at the State level and at the federal level. The process of assessing an orphan source problem and learning from past experience can help identify gaps in information.

Box II.1. Consequences of a change in the regulatory authority: Goiânia, Brazil

The accident in Goiânia, Brazil [2], in 1987 involved a Category 1 source, namely a teletherapy unit. The National Nuclear Energy Commission (CNEN) had responsibility for the licensing of any new radiotherapy facility and its health physics staff. This 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 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 from state to state. Although the prime responsibility for safety was with the licensee, an inspection programme appropriate to a Category 1 source might have identified the problem before it resulted in an accident.

Following the accident, a system was introduced whereby licensees were required to make routine reports on the sources under their control.

II.9. Government authorities will usually have information regarding current and past authorizations and licences, licence applications and inspection reports, and regarding recent and historical transfers of sources and events involving sources. They will also have inventories of the sources in their possession or that are under their own control.

II.10. The need for international collaboration between governments in conducting information searches should be considered, since sources may be moved across borders and the government of a neighbouring State may have the necessary information regarding a found source, for example. Owing to the possible transboundary movement of sources, information regarding lost sources that are considered dangerous should be provided to neighbouring States. States Parties to the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency [47] may be required to provide such information.

Non-governmental and international organizations

II.11. There are many non-governmental and international organizations that have knowledge of and are involved with radioactive sources. These may include the various transport modal organizations, professional organizations and societies, technical support organizations, and trade associations or industry groups. The types of data they possess will vary widely, and there may be restrictions on their availability or use. Nevertheless, such organizations should still be approached if it is considered that they might be able to provide necessary information.

II.12. The IAEA has developed an International Catalogue of Sealed Radioactive Sources and Devices (ICSRS) for use by Member States. The ICSRS is a collection of technical information and specifications on radioactive sources, devices, manufacturers and distributors. While not comprehensive, the ICSRS contained over 20 000 entries in 2010 for sources and devices, and is constantly being expanded. Access to the ICSRS is granted on a case by case basis and requires the agreement of the Member State government authority. However, a manual [48] provides a more manageable and publicly available summary of the catalogue. Its purpose is to help identify commonly used radioactive sources and devices and packages containing radioactive material. The level of detail in the manual is consistent with the need to minimize the dissemination of information to those who might use it for malicious purposes.

II.13. In addition to the IAEA's source catalogue and the manual [48], a communications tool kit with fact sheets and booklets [37] has been published to assist in the initial identification of radioactive sources and devices and packages containing radioactive material by non-specialist individuals and organizations that may come into contact with them by accident or in the course of their normal work.

Users and owners

II.14. Users and owners of sources will have some information about their current sources, but may also have documents or records of sources that they possessed or used in the past, which may now be located in other facilities, or which may have been shipped or transferred to others. In addition, it is possible that there may be sources in their possession or on their premises of which they are not aware. This can happen when the individuals responsible for the source leave due to retirement, job changes or another reason. Users of sources may also know of other users of similar radioactive sources or devices in their industry or field of practice.

Manufacturers and suppliers

II.15. Manufacturers and suppliers of radioactive sources, by the nature of their business, will be in possession of a large number of records relating to their products. These will include not only design specifications but also the locations where sources have been shipped or installed.

Waste storage and disposal records

II.16. Old records from waste storage or disposal facilities should be checked and compared to current information about users of radioactive sources. A search of historical records of the organizations that contributed sources to the national radioactive waste storage facility or disposal facility (if such a facility exists) should be conducted. Comparison of this list with the current list of organizations that are known to use radioactive sources will provide an indication of organizations that may be in possession of sources that are not registered.

Individual workers

II.17. In addition to the official records described in paras II.8–II.16, it should be recognized that the individuals who work in these organizations have personal memories or may be in possession of personal records that could be of value for certain searches. Although human memory is fallible, such people may be able to provide a key piece of information that would indicate the possible presence of a source for which there are no written records. Even hearsay and rumour may be of value in the context of searching for sources.

II.18. Sometimes individual workers will need to be provided with 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 case, for example, in trying to ascertain information about abandoned or illegally discarded sources.

Pioneers

II.19. Individuals who were the first to work with radioactive material in any particular State are a very special subgroup of individual workers who should be interviewed for some types of searches, especially a search with the aim of initially developing a source register. It is especially important to tap into this information resource before such individuals die.

Relatives, neighbours and friends

II.20. This information resource is particularly important when conducting a search for a source that has caused radiation injuries, especially if the injured person is incapacitated or has died. Relatives, neighbours and friends may be able to provide specific information regarding the person's contact with the source or the location of the source in question. They can also provide general information about the habits of the injured or deceased person, as well as about any others who may have been exposed. This subject needs to be addressed with some sensitivity since those interviewed may also have been exposed and may need treatment. They may be exhibiting less severe symptoms and may be unaware of the cause.

The public

II.21. The general public is a target group that must be approached with care. Although members of the public may be helpful in providing information about a source known to be missing, some individuals may be easily scared about matters involving radiation or radioactive material. For this reason, the number of times that members of the public are asked for information should be limited; such questioning should be restricted to the initial development of the source register and to situations where the public can also be warned about the possible dangers of a source known to be missing.

Methods

II.22. The methods used to gather data in an administrative search can be grouped into three broad types, namely: appeals for information using the media, searches of records and interviews. The appropriate method to use in each circumstance will be dependent on the reason for, and the extent of, the search. Each of the methods is discussed in this section with some comments about its applicability. An administrative search is an investigation, and as such, it will involve sorting information volunteered as a result of appeals, looking at official documents and analysing personal interviews with all persons who may be able to contribute.

The media

II.23. Newspapers, radio, television and posters are valuable assets in conducting administrative searches. They are particularly useful in the search for information for initial development of a source register. Appeals through the media for anyone possessing radioactive material to notify the regulatory body or other appropriate governmental body (with applicable contact information) can be the quickest and easiest way of gathering a large amount of basic information for development of a source register. The initial appeal for information will be more effective if there is no disincentive to supplying the data (such as a requirement to pay licensing fees).

II.24. The media are also of great value 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 information on 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 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 to the thieves the details and pictures of the radioactive device stolen. Dissemination of information through the news media about a device containing a radioactive source has sometimes resulted in the device being abandoned by the thieves, with an anonymous ‘tip-off’ to the authorities as to where to find it.

II.25. Media announcements on missing dangerous sources can also be used to alert physicians to signs and symptoms of radiation sickness and provide them with a point of contact.

Searches of records

II.26. In this context, records include both hard copy and electronic records. Hard copy records include: files, ‘sanitary passports’[2], log books, index or data cards and computer printouts. Electronic records include: text, spreadsheet and database files stored on the hard drive of a particular computer or on other computers accessible via the Internet, or on magnetic tape, removable discs or flash memory media. The types of records to be searched include: authorizations,

[2] Formal documents issued in States of the former USSR as part of the authorization process for facilities and activities involving any regulated hazard, including radioactive sources.

registrations, licences, inspection reports, transport records, import and export permits, records of duty payments, customs logs, inventories, manufacturers' catalogues, purchase orders, incident reports, medical records, dosimeter records, work orders and records of disposal of radioactive waste.

II.27. Searching many records can take a lot of time and effort. For these reasons, such broad searches of records are generally not conducted routinely, but rather are typically part of targeted and purposeful searches for a particular piece of information. In a focused search, typically, much of the data is skimmed until the area of interest is approached, and this 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.

II.28. 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 information found on the Internet, it should be used with caution. An example of the creative use of the Internet for searches (which can also be done with the yellow pages of the telephone directory) is to search for companies that are performing services or are in an industry that typically uses radioactive sources. For example, all the companies that are bottling or canning beer or soft drinks in the State could be identified and located. Since many of these will use sources in fill level gauges, it may be appropriate to visit such companies or ask them whether or not they have such sources. The companies to be questioned as part of this search will be dependent upon the typical industries in the region.

Interviews

II.29. Interviews can be conducted by telephone, email, or even by the use of standardized questionnaires. It will generally be necessary to conduct interviews as part of all searches in order to obtain information from most of the target groups, especially users and owners, individual workers, pioneers in the fields of application of radioactive sources, relatives and friends. A standard set of questions should be developed for all interviews; these questions may then be followed by questions that are specific to the target group or search until a good understanding of the situation is achieved.

II.30. Interviews can be used in a very broad and creative way to gather data. For example, during a routine background search for sources, a person working in a company performing industrial radiography might be asked to list the company's competitors. Typically, each company will be aware of others in the same field in the same State or region. If there is a competitor company that does not appear on the regulatory body's list of licensees, it should be visited and its management should be questioned directly as to whether they are in possession of radioactive sources. Physical searches might also be necessary in such situations.

PHYSICAL SEARCHES

II.31. A physical search primarily involves the development of a search plan, after which a search team of one or more persons goes to physically locate radioactive sources both visually and using radiation detectors. Generally, a physical search is conducted following an administrative search. However, a search programme is an iterative process and, in certain circumstances, a physical search may start at the same time as, or even before, an administrative search. Because search teams may encounter radioactive sources, the need for radiation protection measures for these individuals should be considered.

II.32. Physical searches can be characterized as either passive or active. Passive searches are those where the search team and detectors are essentially stationary. Detectors are placed in certain locations and an alarm is set to actuate when a source passes close by. Active searches are those where search teams use mobile instruments and move to the sources they are attempting to find.

II.33. Radiation detectors can be classed similarly as either stationary or mobile. Generally, stationary detectors are used for passive searches and mobile detectors for active searches, but not exclusively. For example, a hand-held radiation detector can be used for both passive and active searches.

II.34. Stationary radiation detectors are often of the portal type, past which or through which vehicles, people, containers or other objects pass. Stationary radiation detectors can also be installed, for example, on a scrapyard grapple, above or beneath a conveyor belt, or attached to a wall as a radiation room monitor.

II.35. Types of mobile radiation detectors include:

— Pocket dosimeters with an alarm function;
— Hand-held detectors;
— Vehicle mounted detectors for surveys from the road;
— Sensitive detectors attached to an aircraft for aerial surveys.

II.36. Most commonly, detectors used in physical searches are used to measure only gamma radiation, but neutrons, beta radiation and alpha radiation are also measured in particular circumstances.

II.37. Further details on the types of radiation detectors used for physical searches and their limitations and applications are provided in Refs [30, 49].

II.38. Search teams conducting active and passive physical searches, and those who may be called to respond when radiation is detected, should be trained in the use of radiation detection equipment and should be provided with basic training in radiation safety covering, at a minimum, the importance of optimizing radiation protection and keeping doses below established dose limits and reference levels. The training should cover how to use the detection equipment properly, effective search strategies, the appearance of individual sources and of the shielded containers or devices that may contain them [48], and appropriate actions to be taken if sources are found.

Passive searches

II.39. In passive searches for radioactive sources that are not under control, appropriate detectors are placed at appropriate locations. The characteristics of the detectors to be used will depend on the type and activity of the sources being searched for. Passive detection is most widely applied in routine background searches for sources.

II.40. The most appropriate location for a passive radiation detector is at a nodal point. These are places where the flow of goods, vehicles or people is concentrated, and typically include border crossings (and other ports of entry), tunnels and scrap metal recycling facilities. The installation of monitoring systems for passive searches at scrap metal facilities is almost always justified (see para. 2.57), whereas the case for carrying out border monitoring is more complex and needs careful evaluation.

Border monitoring

II.41. Border monitoring can have multiple uses, including for conducting passive searches for sources [29, 49]. Border monitoring is normally within the purview of organizations other than the regulatory body, such as customs authorities, border guards and authorities of ports. The range of possible uses of border monitoring includes the following:

— Detection of orphan sources;
— Detection of illicit trafficking;
— Deterrence of illicit trafficking;
— Radiation protection of border guards and customs personnel;
— Detection of contaminated commodities.

II.42. The relative national importance and priority of each of these uses should be taken into account in deciding whether or not to install border monitoring systems, where to install them and what types of equipment to use. Among other factors that should be taken into account are the following:

— The level of threat from orphan sources, illicit trafficking or contaminated commodities;
— The number and type of ports of entry to the State (border crossings, ports and airports);
— Resources available or obtainable;
— Political and public perceptions of border monitoring.

II.43. In some States, there may be hundreds of border crossings and other ports of entry; account should also be taken of where passenger and cargo routes separate. The practicality of covering all possible routes can be a very significant challenge. Installation of stationary detectors at ports of entry through which high volumes of cargo pass, or on high risk routes, will clearly provide the greatest return on investment. There are some situations in which it is clear that border monitoring should be carried out, and others in which it is not so clear. If a high priority has been given to preventing orphan sources entering the State and data have indicated that a majority of scrap metal enters the State through one or two particular ports, consideration should be given to installing sufficient detectors of the appropriate type at these ports. However, to address these concerns, a threat assessment should be conducted and a strategy developed on how to establish radiation monitoring capability at borders.

Active searches

Searches for specific sources

II.44. 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 of the search;
— The boundaries of the search (geographical or temporal);

— The radionuclide, or range of radionuclides, to be searched for;
— The limits of the detection capabilities of the equipment;
— Monitoring methods (hand-held detectors, vehicle mounted detectors or aerial surveys) to be used;
— Procedures for dealing with a found source (including for ensuring radiation protection and the safe transport, interim storage and disposal of the source, and, if criminal activity is suspected, for ensuring that forensic aspects are addressed [50]);
— Responsibilities and mechanisms for coordination of the various parties involved in the search;
— The provision of human and financial resources;
— Criteria for stopping the search (see paras II.52 and II.53).

II.45. Efforts to track down a source will normally start at its last known location, by conducting an active search within the boundaries of the facility of interest. An administrative search should be undertaken to trace the sequence of events that is known to have contributed to, or may have contributed to, the loss of the source. Information should be gathered from the workers and management involved as soon as possible, before memories fade, in order to identify possible locations (see Box II.2) or routes of movement of the radioactive source.

Box II.2. Brachytherapy sources lost in a hospital

Because of their small size, brachytherapy sources can become embedded in linoleum covering corridors or passages along which the sources, or the patients in which the sources were implanted, are transferred from wards to surgery. Typically, lost brachytherapy 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 and incineration plants;
— Still implanted in a patient who has left the hospital.

II.46. If the orphan source cannot be located at the original site, the search should be expanded to include other possible locations (Box II.3). Furthermore, the routes and the means of transport connecting these locations, together with possible final destinations, need to be identified and searched. If there are borders nearby, advantage may be taken of any installed passive monitors. In any case, notification to the cognizant authorities of neighbouring States is appropriate and may be required of States Parties to the Early Notification and Assistance Conventions [47].

Box II.3. Searching for a radiography source: Yanango, Peru [51]

In 1999, a welder and his assistant carried out repairs on a 2 m diameter pipe. At approximately 11:30 a radiographer and his assistant arrived to make a radiograph of the repaired weld as soon as it was available. They left their radiography container close to the pipe. Owing to difficulties with ultrasonic testing equipment, the radiographer left the site to obtain replacement equipment. At 22:00, he returned and commenced the radiography. When the films were developed, it was apparent that none of them had been exposed to radiation. Checks then determined that the source was not in the immediate vicinity of the pipe. One potential route by which the source could have moved was that it became disconnected from the drive cable, dropped to the ground and was 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.

II.47. If the search has been initiated by observation of radiation induced health effects, investigative interviews with those affected should provide useful information on where to start the search.

II.48. Based on information from the initial search, a decision should be made as to whether the search should be extended beyond the immediate area or initially suspected location of the source. If so, consideration should be given to splitting the search into phases, so that there are opportunities to re-evaluate the search plan in the light of experience.

II.49. As time passes following the actual loss of control of the source, the potential for movement of the orphan source increases. If simple local searches do not locate the source, an assessment should be made of the following:

- — The possible scope of movement of the source;
- — The scale of the searches that may be necessary, based on the scope for movement and the history of the source;
- — The resources necessary to conduct such searches;
- — The various end-point scenarios, including criteria for stopping the search (see paras II.52 and II.53);
- — The potential consequences of not finding the source.

Routine search campaigns

II.50. Routine searches for sources are generally passive searches. However, routine searches can also be conducted in an active manner. An example of how this might be done is as follows: In the course of a routine inspection of an authorized user's premises, some additional time could be spent walking through storage areas or basements with a radiation detector in order to see if there might be other sources present, of which perhaps even the user is unaware.

II.51. Unless there are reasons to believe that sources might be present in a particular part of the State, or on a particular site, the conduct of general, active physical searches is not recommended. Typically, such searches are very expensive, especially if large numbers of personnel or aerial surveys are used. In addition, experience has shown that they are not particularly successful at finding sources. An example of when there was felt to be sufficient justification for a general, active physical search is given in Box II.4.

Box II.4. Use of an aerial survey: Georgia

The IAEA has been assisting Georgia with its radiological safety programme for several years, especially since the accident in Lilo in 1997, in which border guards sustained radiation related injuries that resulted from exposure to radiation from abandoned sources [4]. The Georgian Ministry of the Environment began 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 for orphan sources carried out by the Georgian authorities in 1998, four strontium sources (among many others) were discovered. The activity of each was around 1500 TBq (40 000 Ci).

In consideration of the possibility that more dangerous orphan sources may be present in the country, Georgia requested the IAEA to support a search for these sources. Meetings in preparation for the search were held in Georgia and in Vienna, to explore the situation and to plan a strategy. The Georgian authorities demarcated an area in which 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 in the project 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 exposed. The IAEA and 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 searched, 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 caesium source took care of it using their local capabilities.

Two additional high activity strontium sources were discovered at the end of 2001 as the result of serious radiation injuries to three woodcutters. These sources were recovered in February 2002. Subsequently, further surface radiological surveys (on foot, horseback, and vehicle) were undertaken in June 2002 to search for two more orphan strontium sources that were thought to be present in the State.

CRITERIA FOR STOPPING A SEARCH

II.52. One of the most difficult decisions to make is when to end an unsuccessful search. Such a decision will 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 and activity of the source and the time elapsed since its 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 levels of concern.

II.53. In cases in the past (see Boxes II.5 and II.6), there has been a combination of having exhausted the immediately obvious places to search, coupled with strong circumstantial evidence that serious consequences would be unlikely. However, there are other cases where the possible end-points were not well defined and the magnitude of the potential consequences could be significant, so the search was continued (see Box II.7).

Box II.5. 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 the wrong destination. Since it had not been claimed or collected by anyone, it was sent to one of the carrier's storage areas. 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 following:

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

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.

Box II.6. A search that failed to find a source and was abandoned: United Kingdom

In May 2000, a company that 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. Searches of the vicinity using 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 metal recycling company in October 1999. The remaining two machines each still had their radioactive sources installed, but it was noted that the markings on these source holders to indicate that they contained a radioactive source were almost completely gone. It was concluded that there was a high probability that the source had gone to the metal recycling plant. Although the plant had an installed portal type radiation detector, the low energy gamma radiation from ^{241}Am and the shielding effect of the steel housing made it likely that it would not have been detected. There was no evidence of contamination on the scrapyard site. Individuals and companies in the recycling industry 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;
— Most of the ^{241}Am would have been in the slag and therefore significantly self-shielded;
— The potential radiological consequences to workers and the public were very low;
— The search should be discontinued.

Box II.7. Example of a decision not to abandon a 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 had apparently 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.

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Annex I

CAUSES OF LOSS OF CONTROL OVER RADIOACTIVE SOURCES

OVERVIEW OF THE CAUSES OF LOSS OF CONTROL

I–1. In preparing a national strategy it is useful to review both the root causes and the specific causes of loss of control of radioactive sources as well as typical events that have occurred in specific practices. 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, 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.

I–2. In addition, many States will have a 'historical legacy' of sources. These are sources that were in use before a regulatory infrastructure was put in place. Irrespective of whether control has been lost, or did not exist in the first place, there are some common routes for inadvertent movement of a source 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 State of origin.

Root causes

I–3. Some of the important root causes that have contributed to a loss of control of sources have been a lack of, or ineffective:

— Government support to the regulatory body;
— Government commitment to international recommendations on the safety and security of radioactive sources;
— Regulatory bodies;
— Regulatory requirements;
— Regulatory inspection and enforcement;
— National source register;
— Awareness or training of management and workers;
— Commitment by management to safety and control of sources;
— Radiation protection programme in the organization.

Specific causes

I–4. A listing of the specific causes of loss of control of radioactive sources that would apply to most applications includes:

- A lack of, or inadequate:
  - Prior risk assessment;
  - Knowledge of safety and security requirements;
  - Security in storage, transport and use of sources;
  - Radiation surveys, e.g. failure to monitor after a gamma radiography exposure;
  - Supervision of workers;
  - Emergency preparedness arrangements;
  - Training or qualification of personnel.
- Inappropriate arrangments for maintenance or for mitigation of consequences of accidents;
- Deliberate avoidance of regulatory requirements, including import or export provisions;
- Abandonment;
- A catastrophic event, e.g. fire, explosion, flood, civil unrest;
- Theft;
- Loss of corporate knowledge, owing to:
  - Loss or transfer of key personnel;
  - Bankruptcy;
  - Long term storage of sources;
  - Decommissioning of a plant or facility.
- Death of the owner;
- Change in ownership of equipment or plant, especially a change from public to private ownership;
- Transfer of a source for inappropriate disposal;
- Obstacles to legal disposal, such as:
  - No disposal route available;
  - Export not possible;
  - High costs of disposal.

I–5. Consideration of the life of a source can help illustrate those situations where a source might have an increased risk of loss of control. Figure I–1 provides an example that is appropriate for a source in an industrial plant. Good practice will follow the path along the left side, but at each point problems can arise leading to loss of control, as illustrated on the right side.

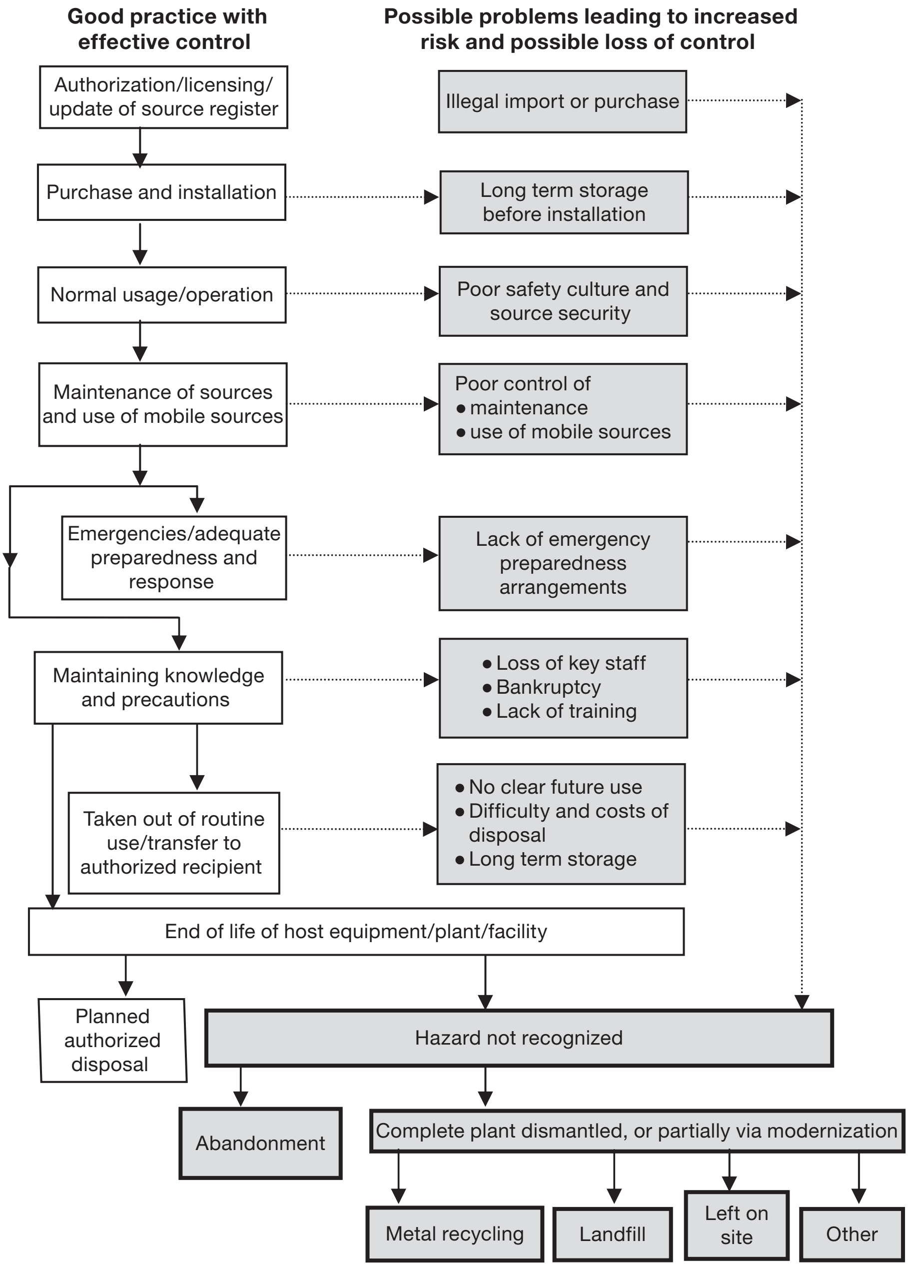

FIG. I–1. *Example of the life of a source in an industrial plant.*

LOSS OF CONTROL IN SPECIFIC PRACTICES

I–6. This section provides a brief summary of particular practices that use sources of different categories, and a discussion of considerations relating to loss of control that are specific to that practice. The most likely ways for sources in each practice to become orphaned are discussed and examples of actual occurrences are provided. Category 5 sources are not discussed in detail because they are too small to be of significant safety concern. Nevertheless it is important to underline that any material designated as being subject to regulatory control because of its radioactivity needs to be regulated applying a graded approach. For a summary of the main applications as well as the typical radionuclides and range of activities in use, see Table 2 of Appendix I of Ref. [I–1].

I–7. Sources have been used for other purposes in the past, so historical applications also need to be considered. The following sections list the main uses of various sources, 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 activities are used.

Category 1 sources

Radioisotope thermoelectric generators

I–8. *Application.* Radioisotope thermoelectric generators (RTGs) are devices that use the decay heat of a radioisotope to produce electricity. The two radionuclides that have been used most frequently are ^{90}Sr (330 –2.5 $\times 10^4$ TBq) and ^{238}Pu (1 –10 TBq). The power that is typically generated can vary from a few watts to tens of kilowatts, 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 former USSR for remote monitoring or for navigation purposes.

I–9. *Possible causes of loss of control.* The fact that such devices are deployed in remote regions at facilities that are often unattended means that they are susceptible to people moving them, acquiring them for illegal purposes or dismantling them for the scrap value of their shielding material. In addition, a change in government and/or a loss of records may mean that such sources can become abandoned and forgotten until rediscovered some time later. Space satellites containing RTGs have also reentered the Earth's atmosphere, causing concern about the spread of the radioactive material. Box I–1 discusses an event in Georgia that illustrates the potential problems of RTGs becoming orphaned.

Box I–1. RTG accident: Georgia, 2001

In December 2001, three woodsmen found two heat-emanating ceramic objects near their camp site in the remote Inguri River valley of Georgia. Two of the woodsmen 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 a serious condition. A Georgian team recovered the sources in early 2002 with the assistance of the IAEA. The sources were 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.

Commercial irradiators

I–10. *Application.* Large scale commercial irradiation facilities are relatively few in number and typically contain very high activity ^{60}Co and ^{137}Cs sources, in the range of 0.2–600 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, with others being pencil sized, and each facility typically contains many such sources. The 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.

I–11. *Possible causes of loss of control.* 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 seconds. Therefore these facilities have many safety features, which are based on the principles of defence in depth, diversity and independence of safety systems [I–2]. However, unless they are well designed and maintained, safety systems can degrade; and, coupled with human error, accidents can happen. There are no documented reports of such sources or irradiators 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 an irradiator were abandoned, there would be a serious threat of a lethal exposure.

I–12. A more likely scenario would involve the loss of individual sources from the source rack. Typically the source rack consists of a number of source modules, with each of these set in a frame retaining 30–50 source pencils. Each pencil is about 45 cm long and 1 cm in 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 rack and to distort the module frames, thus allowing a source pencil to fall out. This has occurred on a number of occasions (see Box I–2) [I–3]. It provides the potential for a source pencil to fall into one of the 'totes' that transport the product being irradiated out of the facility. Modern irradiators have source shoulders installed to separate the sources from the totes and monitoring systems at the product exit points to detect such a situation. However, these systems need to be maintained to be effective.

Box I–2. 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 ten years. The net effect was a degradation of the safety systems and of the operators' understanding of radiation hazards. In the accident, three people entered 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.

The problem had not been recognized for two weeks, and during this time damage to the source rack had 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. One of those who entered the chamber later died and another had to have one leg amputated.

I–13. Another consideration is that from time to time a number 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 I–5).

Self-shielded irradiators and blood/tissue irradiators

I–14. *Application.* There are a number of smaller irradiators described variously as self-shielded irradiators, or blood/tissue irradiators, that are used in hospitals and clinics. Although they are smaller than commercial irradiators, they still contain sources of high activity. In addition to sterilizing blood, tissue and seeds, they are used for gemstone coloration, insect irradiation as part of insect eradication programmes and research into mutation effects on agricultural products. Typically, such irradiators include 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 once they have been installed in the irradiator. In some cases the irradiator, with some minor modifications, is also used as the source shipping container.

I–15. While most of these irradiators are fixed in a permanent position, there are some devices, such as ‘Gamma Kolos’ irradiators, which were mounted on heavy trucks or on trailers and transported around 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.

I–16. *Possible causes of loss of control.* Few of the fixed devices have been involved in orphan source incidents, in part 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 possible security vulnerability of some mobile irradiators.

Teletherapy devices

I–17. *Application.* Teletherapy units are commonly found in medical institutions such as hospitals or clinics for use in cancer treatment. 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 portions of a patient’s body, particularly a tumour. The physical dimensions of such sources are relatively small, and they are generally cylindrical (a few centimetres in diameter by several centimetres long). The source is contained inside a large shielding device.

I–18. The ‘gamma knife’ (for stereotactic radiosurgery) is a similar device, but it uses a large number of sources (about 200) to provide radiation beams that can be focused on a particular treatment point in the brain while minimizing doses to healthy tissue.

I–19. The facilities within which such radiotherapy units are located are specifically designed and include thick, shielded walls as well as other protective equipment.

I–20. Cobalt-60 sources generally comprise a number of solid metallic pellets or discs within a stainless steel source capsule. 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 metal recycling industry. Then, contamination and the potential for internal exposure would result.

I–21. The radioactive material in ^{137}Cs teletherapy devices is usually in the form of caesium chloride, which has the necessary high specific activity so that the devices can be physically small enough for treatment purposes.

I–22. *Possible causes of loss of control.* In normal usage, appropriate controls will 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. In addition, as 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 incorporation of the radionuclide into items manufactured from the scrap metal.

I–23. Given the massive nature of teletherapy units and the fact that they are used in an environment such as a radiotherapy clinic, the staff of which must have knowledge of radiation 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.

I–24. Once the containment of a caesium chloride source is breached, the high mobility of the material causes a rapid spread of contamination (see Box I–4).

I–25. Boxes I–3 to I–6 provide examples from accidents in Juarez, Mexico [I–4], Goiânia, Brazil [I–5], Istanbul, Turkey [I–6] and Samut Prakarn, Thailand [I–7]. Some involved ^{137}Cs, others ^{60}Co.

Box I–3. Teletherapy head accident: Goiânia, Brazil, 1989

In 1987 in Goiânia, a private medical partnership specializing 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.

Recognition of the existence of the problem was triggered by an increasing number of health effects. Overall some 249 people were externally contaminated and 129 internally. Twenty-one people received doses in excess of 1 Gy and were hospitalized, of which ten needed specialized medical treatment with four of these dying. The decontamination and cleanup of the environment took six months of intensive effort and produced 3500 tonnes of radioactive waste.

Box I–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 were 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 radioactive material 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 4500 tonnes of metal.

Box I–5. Teletherapy head accident: Istanbul, Turkey, 1998

In 1993, a licensed 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 nine 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 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 I–6. Teletherapy head accident: Samut Prakarn, Thailand, 2000

A company in Bangkok possessed several teletherapy devices without authorization from the country's Office of Atomic Energy for Peace. In late 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.

I–26. In a number of cases there have been some common features, which are significant factors in determining national strategies for dealing with orphan or vulnerable sources.

- There was 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 health effects of radiation was the trigger to the discovery of the accident.

Category 2 sources

Industrial gamma radiography

I–27. *Application.* Industrial radiography is in widespread use, and has a high hazard potential [I–8]. The construction and maintenance of petrochemical installations, for example, involves 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, ^{192}Ir or ^{60}Co sources are most often used, but ^{169}Yb, ^{170}Tm or ^{75}Se may also be used.

I–28. Devices containing industrial radiography sources are generally small in terms of physical size, although they are usually heavy owing to the shielding contained in them. The sources themselves are very small, less than 1 cm in diameter, and only a few centimetres long. They are often attached to specially designed cables for their proper operation. The portability of these devices may make them susceptible to theft or loss.

I–29. Most remote exposure radiography devices have a general design whereby the source capsule is physically attached to a short flexible cable, often known as the source assembly or ‘source pigtail’. This is coupled, often by means of 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 exposure device. 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.

I–30. 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 or remove.

I–31. *Possible causes of loss of control.* The housings of radiographic exposure devices and source changers contain several tens of kilograms of shielding material, such as depleted uranium, lead or tungsten, which may be perceived as being valuable. Also relevant is the fact that the portable nature of most equipment allows it to be used almost anywhere. Often such devices are transported to temporary work sites in remote locations or sites with extreme working conditions. Coupled with this there may be limited or non-existent supervision in place and so there is a real potential for entire containers with their sources to be lost or stolen at temporary work sites. Sources are also at risk of being lost while being transported to temporary work sites. They can end up in the metal recycling industry or remain in the public domain. These are similar problems to those of orphan teletherapy sources, and while 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.

I–32. 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 survey after each exposure to ensure thatthe 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, such sources may 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 I–7 [I–8], I–8 and I–9 [I–9]. In many cases, the onset of medical symptoms is unfortunately the first indication that a radioactive source has been found.

Box I–7. Industrial radiography source accident: Morocco, 1984

A 1.1 TBq ^{192}Ir source became disconnected from its drive cable. Owing to a lack of appropriate monitoring, it was not noticed 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.

Box I–8. Industrial radiography source accident: Cairo, Egypt, 2000

A farmer picked up a 3 TBq ^{192}Ir source, thinking it was 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, had not been recovered after the job.

Box I–9. Industrial radiography source accident: Yanango, Peru, 1999

It is uncertain whether this accident was the result of someone tampering with a security lock. 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 minor lesion.

I–33. 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.

I–34. 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.

I–35. The large numbers, work environment, activity level and portability/mobility of most industrial radiography sources make them prime targets for theft (Box I–10).

Box I–10. Theft of an industrial radiography source: India

A shielded container housing a 185 GBq ^{192}Ir radiography source of activity about 0.3 TBq 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. A search operation, supported by a local police investigation, led to the discovery of the source in a cremation ground. The source was traced by a physical search team.

High/medium dose rate brachytherapy

I–36. *Application.* Brachytherapy 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 centimetres 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).

I–37. Historically, ^{226}Ra was used for brachytherapy. This use of radium brachytherapy sources predates the establishment of regulatory controls in many States. The sources were encapsulated in platinum in either needles or tubes of a few millimetres in width and up to 5 cm in length. However, buildup of radon and helium gases causes pressure inside the encapsulation and it may rupture, resulting in contamination. For this reason, ^{226}Ra was replaced by other radionuclides.

I–38. 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 obtain routinely. Sources may be manufactured in different sizes and shapes, including as wires or ribbons.

I–39. The application of these sources may be either manual or by remote control. For reasons of radiation protection, only low activity sources are used manually, with or without afterloading techniques. Afterloading devices may be heavy, owing 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, a catheter is first inserted into the body and then the source, attached to a cable, is 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).

I–40. 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 its use is increasing.

I–41. *Possible causes of loss of control.* 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.

I–42. Individual manual brachytherapy sources that may become orphan sources are unlikely to be life threatening, 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 facility could have several hundred brachytherapy sources that are being continually moved and manipulated. There have been many reported instances of brachytherapy sources being discarded in normal waste, and remaining unknowingly in patients who have been released from hospital, or in cadavers. However the nature of this problem was recognized a long time ago and has resulted in many States adopting a requirement for radiation detectors to be installed at exit points from the facilities where brachytherapy sources are used.

I–43. If the cable of a remote afterloader breaks, the source may become detached. Failure to recognize these problems may pose significant risks, as illustrated in Box I–11 [I–10]. The risks are similar to those for industrial radiography sources.

Box I–11. Loss of an ^{192}Ir HDR brachytherapy source: USA, 1992

On 1 December 1992, the United States Nuclear Regulatory Commission was informed by a cancer centre that a 0.14 TBq ^{192}Ir source lost 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 high dose 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, 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 owing to the fact that the breakage was noticed immediately.

Calibration facilities

I–44. *Application.* There are a large number of radioactive sources that are used for instrument calibration 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 typically fall into Category 2. Other sources could fit Categories 3 and 4, and instrument check sources could be in Category 5.

I–45. Some calibration sources, especially those of higher activity, are located in specifically designed, shielded and collimated devices within large shielded facilities. Others are just 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 in neutron instrument calibration and neutron shielding experiments.

I–46. *Possible causes of loss of control.* For large calibration sources within special enclosures, the causes of loss of control are generally the same as those for teletherapy or brachytherapy devices. 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 necessary, or when the responsible staff member leaves.

Category 3 sources

Fixed industrial gauges

I–47. *Application.* 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 coming into contact with 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. Larger activity (about 100 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.

I–48. Blast furnaces that are employed in steelmaking 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 the category of fixed gauges, they can also be mounted on trucks. However, they can be quite heavy (about 100 kg) owing to their lead or tungsten shielding.

I–49. *Possible causes of loss of control.* 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. Generally, the devices are not large, but they may be located at some distance from the radiation detector, which may have associated electrical or electronic components within its housing. The locations of such devices or sources within a facility may not be recognized, since the devices may be connected to innocuous looking process control equipment. This lack of recognition may result in a loss of control if the facility decides to refurbish a plant or terminate operations (Boxes I–12, I–13).

Box I–12. Source melt accident: Los Barrios, Spain, 1998

On 11 June 1998, elevated levels of ^{137}Cs in the air were detected in southern France and northern Italy. On the basis of meteorological data and analysis, it was concluded that this was due to a release somewhere in the south of Spain or northern 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 Los Barrios as part of routine maintenance. One company received 150 tonnes that was 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 sounded an alarm 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 includes US$20 million for lost production, $3 million for cleanup operations and $3 million for waste storage. Public alarm was also significant, with major media involvement and political pressure being exerted on the Spanish authorities.

Box I–13. Blast furnace source event: Romania, 2001

In August 2000, a commercial company started dismantling two blast furnaces, with the dismantling of one furnace being completed in June 2001. The decommissioning was carried out 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 (with ^{110m}Ag) small radioactive sources of activities between about 0.4 and 20 GBq, which had been 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 did not appear to have measurable radiation injuries.

I–50. These devices are usually installed permanently on product machines and generally will be safe while in use. 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 where sources have been either removed from equipment and placed in storage, or simply left on the equipment in a disused plant.

I–51. In some instances, sources have remained in this condition for a long time, and, with the passage of time, knowledge of their existence has been lost. In other instances, only short periods of time have been involved, but key staff left the organization and that part of the site was urgently decommissioned or cleared for economic reasons.

Well logging gauges

I–52. *Application.* Well logging devices are generally found in areas where exploration for water, coal, oil or natural gas is under way. 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, owing to the robustness necessary for the environments in which they are used.

I–53. *Possible causes of loss of control.* The housings in which 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 gamma sources will normally be shielded with depleted uranium or lead, which could be attractive for its scrap value (Box I–14) [I–11].

Box I–14. 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. 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.

I–54. 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 such sources to become orphaned is similar to that for industrial radiography sources. However, the activities and radiation dose rates are generally lower.

I–55. While they are usually of lower radioactivity than industrial radiography sources, the portability and use of such devices in remote field locations could make them susceptible to loss or theft.

Pacemakers

I–56. *Application.* 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. However, it is also difficult to detect if the source becomes orphaned (Box I–15).

Box I–15. Melting of a pacemaker: United Kingdom, 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 cleanup and disposal costs of such an event are several million dollars.

I–57. *Possible causes of loss of control.* 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 such a source may be discarded following an autopsy and May end up in recycled metals. The fact that ^{238}Pu sources are easily shielded also means that they are not easily found.

Category 4 sources

Low dose rate brachytherapy sources

I–58. *Application.* 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.

I–59. *Possible causes of loss of control.* These are the same as discussed earlier, except that the hazard is clearly lower with the lower activity sources.

Category 4 sources are normally too small to cause significant harm from their radioactivity.

Thickness gauges and fill-level gauges

I–60. *Application.* 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.

I–61. Radionuclides that are typically used in these industries are ^{85}Kr, ^{90}Sr, ^{241}Am, ^{147}Pm and ^{244}Cm as well as ^{137}Cs. Activities range from 0.4 GBq to about 20 GBq.

I–62. *Possible causes of loss of control.* These are essentially the same as for other fixed industrial gauges, but because thickness gauges and fill-level gauges typically use less penetrating radiation of lower activity, the potential hazards are smaller.

Portable gauges

I–63. *Application.* Portable moisture or density gauges 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 is measured with ^{137}Cs of about 0.4 GBq. The sources are physically small in size, typically a few cm long by a few centimetres in diameter, and may be located either completely within the device or at the end of a rod and handle assembly.

I–64. Moisture gauges are used in agriculture to ensure optimal watering, while combination gauges or density gauges are often used in road construction to ensure that the appropriate compaction is being used for the foundation materials.

I–65. *Possible causes of loss of control.* 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.

Bone densitometers

I–66. *Application.* 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.

I–67. *Possible causes of loss of control.* Historically, there have not been any recorded events involving loss of control over sources in bone densitometers.

Static eliminators

I–68. *Application.* In many industries the generation of static electricity in manufacturing creates problems leading to the attraction of dust to 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 static eliminators emit alpha particles, the source construction is fragile and will not withstand physical abuse or fire, either of which may result in a spread of contamination.

I–69. *Possible causes of loss of control.* Again, there is not a lot of experience with regard to static eliminators becoming orphaned. However, there was one incident in which it appears that a number of sources were deliberately gathered together and buried.

Category 5 sources

I–70. *Application.* There are a large number and variety of Category 5 sources that are used in: X ray fluorescence, electron capture devices, Mössbauer spectroscopy, 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. Nasopharyngeal applicators (^{90}Sr) replaced the 'Crowe' radium probe in the 1970s. In addition, permanent implants of radioactive seeds were developed originally using ^{222}Rn and ^{198}Au seeds. Today permanent implants use ^{125}I, ^{106}Ru/Rh and ^{103}Pd.

I–71. *Possible causes of loss of control.* Category 5 sources are of such a low hazard that they generally do not need to be considered in a national strategy. However, they still need to be subject to regulatory controls.

Special situations

Legacy sources

I–72. *Application.* 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 present will depend upon when regulatory control began to have effect within a State. The majority of legacy sources are likely to be radium (Box I–17), but not exclusively (Box I–16). The following list provides an indication of the types of radium sources and uses of sources in the first half of the 20th century, some of which involved unsealed radioactive material:

— Medical applications, including radium brachytherapy;
— Radium luminous devices and luminizing facilities;
— Industrial radiography using radium;
— Patented fake medical devices;
— Static eliminators;
— Industrial smoke detectors;
— Lightning protection systems.

Box I–16. Non-radium legacy orphan source: India

Not all legacy sources are radium, but rather this depends upon when regulatory control is first established in a State. A manager from a corporation requested advice from the regulatory body regarding a 185 GBq ^{137}Cs source 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 control. The source was subsequently dealt with appropriately.

Box I–17. Discovery of radium luminized instrumentation: United Kingdom, 1984

In the United Kingdom 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 7000 packing crates of spare parts, and in some 2000 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.

I–73. *Possible causes of loss of control.* If industrialization of a State and the 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 legacy sources that have been orphaned. In this case, the task becomes one of creating the initial national register. Care will be necessary to ensure there is enough coverage of the various sectors, e.g. medical, industrial and academic uses (including nuclear research).

I–74. Some doctors bought their own radium brachytherapy sources and stored them at home. These could be inherited by other individuals and might only be discovered by chance. These and other radium sources have been found in bank vaults, where they were sometimes stored because of their value at the time ($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 [I–12].

I–75. In some States, radium luminizing facilities were widespread in the period from the 1930s into the 1960s and 1970s. Many were operated by the military. 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, may also need to be investigated.

Research and academic uses

I–76. *Application.* Applications of radioactive sources in teaching and research are extremely varied. Almost any radionuclide of any activity can find a use in some research work, and therefore, such sources can belong to almost any category.

I–77. Many of the medical and industrial uses described above can be found in universities and research institutes. Some sources 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 therefore such uses provide more challenges to maintaining the safety and security of sources.

I–78. 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 weak beta emissions, thereby causing less serious radiological problems should control be lost. Many such sources are used in electron capture, gas chromatography and Mössbauer spectroscopy devices.

I–79. 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 industrial facilities, most devices are of the fixed, self-shielded type that are designed to accept samples into an irradiation chamber that cannot be physically entered.

I–80. *Possible causes of loss of control.* 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 the organization. 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 I–18).

Box I–18. Fatal accident possibly due to a source from a research facility: Estonia, 1994

A fatal radiation accident in Tammiku, Estonia, in 1994 [I–13] involved a source originally found in scrap metal delivered to a metal 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.

Former military sites and sites of conflict

I–81. *Application.* The military uses of radioactive sources are outside the scope of this Safety Guide. However, some understanding of typical military use is beneficial in that sometimes military sites are abandoned or returned to civilian use. Typical examples of military applications have included:

— Radioisotope thermoelectric generators (RTGs);
— Sources for simulation training for a nuclear weapons attack;
— Calibration sources;
— Radium and tritium in luminous devices (larger activities than in civil uses).

I–82. *Possible causes of loss of control.* Situations may arise from:

— The withdrawal of foreign troops from a State;
— Major political changes in a State where the military command structure may have been non-functional for a while;
— States or regions that have been the scene of military conflicts.

I–83. Experience has shown that all of these situations could result in sources becoming orphaned and posing a serious threat to the population. Unless source control has 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 I–19).

Box I–19. 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	8298	1710	1180
Lightning protection systems	151	60	0
Medical	17	0	0
Industrial	103	18	24

The lightning protection systems, being the most unprotected, suffered the greatest damage.

Accessible dose rates were up to 3 mSv/h at 1 m from the source.

Box I–20. Military sources accident: Lilo, Georgia, 1997

In 1992, with the break up of the former USSR, the Soviet Army abandoned its facilities in Georgia. One of these was a training camp in Lilo, which was taken over by the Georgian Army. In October 1997, 11 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.

I–84. Another consideration from areas of military conflicts is that the collateral damage caused by shells, bombs and other munitions may involve damage to radiation sources themselves or to 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.

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Annex II

COMMON PROBLEMS AND POSSIBLE SOLUTIONS IDENTIFIED IN IAEA MISSIONS TO ASSIST IN DEVELOPING NATIONAL STRATEGIES

II–1. The IAEA conducted several missions between 2002 and 2005 to provide assistance to States in drafting national strategies for regaining control over orphan sources. The following tables present generic examples of some of the common problems that were identified in the assessment and development phases of these missions. Ideas for possible actions, priorities and resources are also provided. The tables are intended to assist in the development of a simple national strategy action plan. However, they are provided for general guidance only, and are not meant to be regarded as a checklist, nor preclude other creative ideas or efforts for generating solutions more applicable to the local situation.

II–1. In any particular national strategy, each problem needs to be broken down into its constituent parts and dealt with in a manner 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 have been undertaken. There are no routine efforts to find sources that are not under regulatory control. There is a lack of openness to the possibility of there being sources not on the register.
Action	Make an initial effort to evaluate the probability of orphan sources being present using the administrative searches (and as necessary physical searches). In routine inspections and surveys, ask questions and conduct searches using methods described in this Safety Guide.
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' need to become part of regular tasks.
Resources	Initial effort requires significant human resources. Physical searches are typically very costly.

Problem	**Issues with authorizations:** No authorizations or licences have been or are being issued. Application forms for authorizations are deficient. Associated fees do not encourage desired behaviour. There is no requirement to notify the regulatory body or other relevant governmental bodies of the loss of sources.
Action	Implement an authorization process that ensures that all information necessary for the justification of the authorization is available. Ensure that all data necessary for the register are gathered at this time and that the fees and processes encourage the desired results. Revise rules or regulations to require notification of lost sources.
Priority	High
Resources	Human resources to develop and implement a high quality authorization process.

Problem	**Surveys not performed of businesses that were known to have possessed sources**: In particular, surveys have not been performed of facilities where the ultimate disposition of sources is unknown. Some facilities are now abandoned or have become bankrupt.
Action	Gain authorization to conduct physical searches in relevant facilities. Establish a procedure whereby all facilities are routinely contacted so that if a facility does cease operations, this is known about.
Priority	May be high or low for facilities that have already ceased operations, depending on the sources they had possessed. Low for the establishment of new procedures for conducting surveys.
Resources	Personnel time to gain the necessary authorizations. Some staff time to develop and implement routine checking procedures.

Problem	**Known disused sources:** There are sources in one or more locations that are known to be disused. 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, a local or regional facility will need to be constructed.
Priority	The higher the category of the source and the greater its vulnerability, the higher the priority.
Resources	The resources necessary will depend greatly on the specific situation. However, they can be significant.

Problem	**No adequate temporary or permanent location to store or dispose of disused sources:** There is no national radioactive waste disposal facility or interim source storage facility.
Action	Create a safe and secure temporary source storage facility. Begin the process of designing, funding and building a permanent storage or disposal facility, such as a borehole disposal facility.
Priority	High for a temporary storage facility. Medium for a permanent storage facility or disposal facility.
Resources	Costs vary a lot for the temporary storage facility, depending on how much a particular location must be modified. For example, a freight container inside a fenced area has been used for such a temporary storage facility at relatively cheap cost. A permanent facility is much more expensive, but disposal of sources in a borehole disposal facility is feasible and not as expensive as construction of a more generic national waste disposal site.

Problem	**No knowledge of the import (or export) of sources:** Either there is no requirement for the reporting of sources entering the State, or it is not being rigorously applied or enforced.
Action	Develop, implement and enforce requirements regarding the import and export of radioactive sources that at least meet the guidelines provided in the Code of Conduct on the Safety and Security of Radioactive Sources.
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	**Border monitoring issues:** There is no border monitoring or inadequate monitoring. There is no training of law enforcement, customs, border or port authority personnel who may encounter radioactive sources. There is no equipment or expert support for such personnel when radioactive material is found.
Action	Perform an analysis of the need for border monitoring and its likely effectiveness in detecting orphan sources or illicit trafficking. Provide the equipment, training and support necessary on the basis of the evaluation.
Priority	Dependent on the probability of orphan sources or illicit sources entering the State. Training and expert support for border monitoring personnel will normally be of medium to high priority.
Resources	Personnel to gather data and perform the analysis. Costs of any necessary equipment can be significant (portal monitors cost about \$100 000, a set of radiation monitoring equipment costs about \$70 000). Consideration also needs to be given to maintenance costs for equipment.

Problem	**No notification of police and other law enforcement agencies regarding illicit trafficking issues:** There is a lack of communication between customs officials, the regulatory body and law enforcement agencies, particularly when sources are stolen, lost or found.
Action	Establish memoranda of understanding (MOUs) between the relevant agencies. Conduct joint training sessions so personnel can get to know each other and discuss common issues.
Priority	High to medium, depending on the severity of the problem.
Resources	Personnel time to develop and agree on the MOUs. Significant time and cost for the development of joint training courses and release time for staff to attend such courses.

Problem	**No consideration of the security of sources:** Sources are being used, stored and transported with no specific consideration given to security concerns.
Action	Evaluate the security of all sources against the guidance, 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 priority for Category 3.
Resources	Security inspections can be factored into routine inspections of licensees with minimal impact on staff time. The cost of security upgrades can be significant.

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

Problem	**Lack of scrap metal monitoring:** There is little or no monitoring being conducted in the metal recycling industry.
Action	Encourage large 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 training materials to raise awareness. Costs associated with the recovery, storage or disposal of found sources. The industry will normally pay for installed or hand-held instrumentation once the potential risks associated with orphan sources entering the scrap metal cycle are recognized.

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Priority	Medium.
Resources	Costs associated with the development of appropriate training materials to raise awareness. Costs associated with the recovery, storage or disposal of found sources. The industry will normally pay for installed or hand-held instrumentation once the potential risks associated with orphan sources entering the scrap metal cycle are recognized.

Problem	**No awareness campaigns for metal recycling facilities:** There is no effort to inform scrap metal dealers of the possibility of orphan sources or ofwhat they look like.
Action	Send out a letter to each metal recycling facility informing them of the issue and enclosing leaflets from the IAEA's information toolkit on scrap metal.
Priority	Medium
Resources	Time to draft and mail a letter. Mailing costs. Use of free IAEA publications.

CONTRIBUTORS TO DRAFTING AND REVIEW

Cain, C.	Nuclear Regulatory Commission, United States of America
Croft, J.	Health Protection Agency, United Kingdom
Dodd, B.	BD Consulting, United States of America
Kutkov, V.	International Atomic Energy Agency
Reber, E.	International Atomic Energy Agency
Zeleke, A.	National Radiation Protection Authority, Ethiopia
Zombori, P.	International Atomic Energy Agency

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