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Methods to identify and locate spent radiation sources

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FOREWORD

In 1991, the International Atomic Energy Agency initiated the Spent Radiation Sources Programme to assist developing countries in their effort to improve the management of spent radiation sources. The programme is organized with the aim of providing guidance to Member States to prevent potential accidents with spent radiation sources. The programme focuses on both the strengthening of national radioactive waste management infrastructures and human resources, and on providing tools and methodology advice on operational aspects of the safe management of spent radiation sources.

An important aspect of the Spent Radiation Sources Programme is its aim towards providing practical advice capable of ready implementation by any Member State. Both this manual and a design package for a standardized facility for the conditioning and interim storage of spent radiation sources, have been prepared to provide such practical advice. In both cases requirements on equipment and general technology sophistication have been kept to a minimum.

The objective of this manual is to provide essential guidance to Member States with nuclear applications involving the use of a wide range of sealed radiation sources on the practical task of physically locating spent radiation sources not properly accounted for. Advice is also provided to render the located source safe on location, but ensuing activities, such as off-site transport and conditioning of the source, are outside the scope of the manual. In this regard, reference is made to the IAEA's series of technical documents entitled 'Technical manuals for the management of low and intermediate level wastes generated at small nuclear research centres and by radioisotope users in medicine, research and industry'.

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EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

Sealed radioactive sources have been used for a variety of medical, industrial and research applications almost since the isolation of radium by the Curies in 1898. Since the 1950s the choice of radionuclides available has increased with the advent of particle accelerators and nuclear reactors. These sources have been widely used throughout the developed and developing world. In many countries the infrastructure exists to account for radioactive material by, for example, a system of licensing, legislative requirements on the user to keep appropriate records and perhaps to report to the authorities on a periodic basis or, in the case of imported items, customs clearance procedures. In other countries there may be no, or inadequate, formal arrangements to account for sources.

Incidents or accidents have happened when radiation sources have been lost, stolen or discarded. Since 1962, reported accidents with sealed radiation sources have resulted in 21 fatalities among members of the general public (Table I) [1]. Moreover, significant expenditure has been involved for the monitoring and clean-up costs associated with the accidents. Some reported cases are listed in Table II [2].

Additional information on the nature and the magnitude of the spent radiation sources problem can be found in the IAEA-TECDOC-620 [1].

In 1991, the IAEA initiated the Spent Radiation Sources Programme, the aim of which is to provide direct and indirect assistance to developing Member States in the safe management of spent radiation sources. The main component parts of this programme include training opportunities on the safe management of spent sources, practical tools for maintaining inventory records for sealed sources, and a standardized design of a facility for the conditioning and interim storage of spent sealed sources.

This report, being part of the Spent Radiation Sources Programme, provides advice on methodology to locate and identify spent sources that are not appropriately accounted for.

TABLE I. REPORTED FATAL RADIATION ACCIDENTS WITH SEALED SOURCES AMONG MEMBERS OF THE PUBLIC
(accidents caused by X rays, accelerators, medical treatment, and reactors or critical assemblies are not included)

Year	Location	Sealed radiation source	Fatalities
1962	Mexico City, Mexico	Lost radiography source	4
1963	China	Seed irradiator	2
1978	Algeria	Lost radiography source	1
1984	Morocco	Lost radiography source	8
1987	Goiânia, Brazil	Stolen teletherapy source	4
1992	China	Co-60 irradiator source	2
			21

TABLE II. REPORTED COST ESTIMATES OF CLEAN-UP

Radionuclide	Quantity	Incident	Cost (US $)
Cobalt-60	> 37 TBq	Rupture of source capsules	Several million
Americium-241	9.3 GBq	Rupture of well logging source	> 1 000 000
Caesium-137	740 GBq	Rupture of well logging source	> 600 000
Cobalt-60	0.93-11 TBq	Melted source in furnace	> 2 200 000
Caesium-137	37 GBq	Melted source in furnace	> 450 000
Caesium-137	370-1850 MBq	Ruptured gauge in scrap	> 50 000 to 500 000
Caesium-137	55 GBq	Melted source in furnace	> 1 000 000
Cobalt-60	15 TBq	Products contaminated	> 35 000 000
Caesium-137	50 TBq	Rupture of source	> 3 000 000

1.2. PURPOSE

The purpose of this publication is to provide guidance on the task of locating spent sealed radiation sources of various types in situations where records of inventory of sources were not adequately maintained, or have been lost in the course of time. A "spent radiation source" means a source which is no longer in use and for which no further use is foreseen.

The report firstly addresses the task of identifying the range of spent radiation sources that need to be located and safely managed as radioactive waste. Secondly, it addresses the task of physically locating these sources. Additionally, the purpose is to advise on the immediate action that needs to be taken once a source, or sources, have been located.

1.3. SCOPE

The guidance is aimed predominantly at developing Member States, but may be of interest also to developed Member States. It is directed to the national Waste Management and/or Radiation Protection Competent Authority, or, in the absence thereof, to the Government Department responsible for radiation health and safety matters. The guidance is not intended to carry any legal or juridical significance; for example it is not intended for the enforcement of laws and regulations.

This report provides advice for the purpose of locating spent sealed radiation sources irrespective of in what application the radiation source was used during its operational lifetime. It is limited to locating spent *sealed* sources, meaning that locating radioactive material in the form of un-sealed sources or widespread contamination is outside the scope, although the possibility of an originally sealed source becoming damaged and leaking radioactive material, has been taken into account.

Advice on immediate action to be taken once a source has been located focuses on rendering the source safe on the location where it was found. Safety arrangements discussed are adequate only for the limited period of time that reasonably may be required to plan and carry out collection and transfer of the source to a facility suitable for conditioning, immobilization or long term storage.

Appropriate staff skills related to operational radiation protection activities, including the proper use of radiation monitoring instruments, are required when spent sources are to be located. It is outside the scope of this publication to provide detailed guidance on training necessary to achieve these skills. However, Annexes III–V address basic concepts of radiation protection and the monitoring of external radiation and surface contamination. Additional information on operational radiation protection can be obtained from the series of Practical Radiation Safety Manuals published by the IAEA [3].

2. APPROACH TO THE PROBLEM

2.1. THE PROBLEM

The basis for advice given in this report is the consideration that documentary evidence of the existence, location and condition of a sealed radiation source may not be readily available or is incomplete.

Information on the identity and other characteristics of the spent radiation sources, or of applications in which they were used, is essential for a successful search. This first aspect of the problem involves the *identification* of types or groups of spent sources that need to be collected for safe management. The second aspect of the problem concerns collecting and assessing information necessary to safely *locate* the spent sources.

The following three situations related to spent sealed sources are considered in the report:

Individual sources and their locations unknown

In this case, there would be no, or insufficient, documentary evidence readily available regarding existence, location or condition of the spent sources.

Location of identified source not known

For sources of known identity that may have been misplaced or stolen, information on source characteristics and on equipment the source is installed in is usually available but information on source location is missing.

Source location known

Following early establishment of control of access to the source location, the remaining task is to render the source safe on location until collection and off-site transport can be completed.

2.2. STRATEGY

A strategy to identify and locate spent sealed sources and, as necessary, render them safe on location, must be established. The strategy must take into account an assessment, however incomplete, of the expected range and quantity of spent sources to be located, as well as the availability of qualified personnel and equipment to support the search effort.

In terms of strategy, identification of spent radiation sources is understood to imply collecting, verifying and assessing information on the range or types of sources that require efforts to be located and safely managed as radioactive waste. Similarly, the operational task

STRATEGY

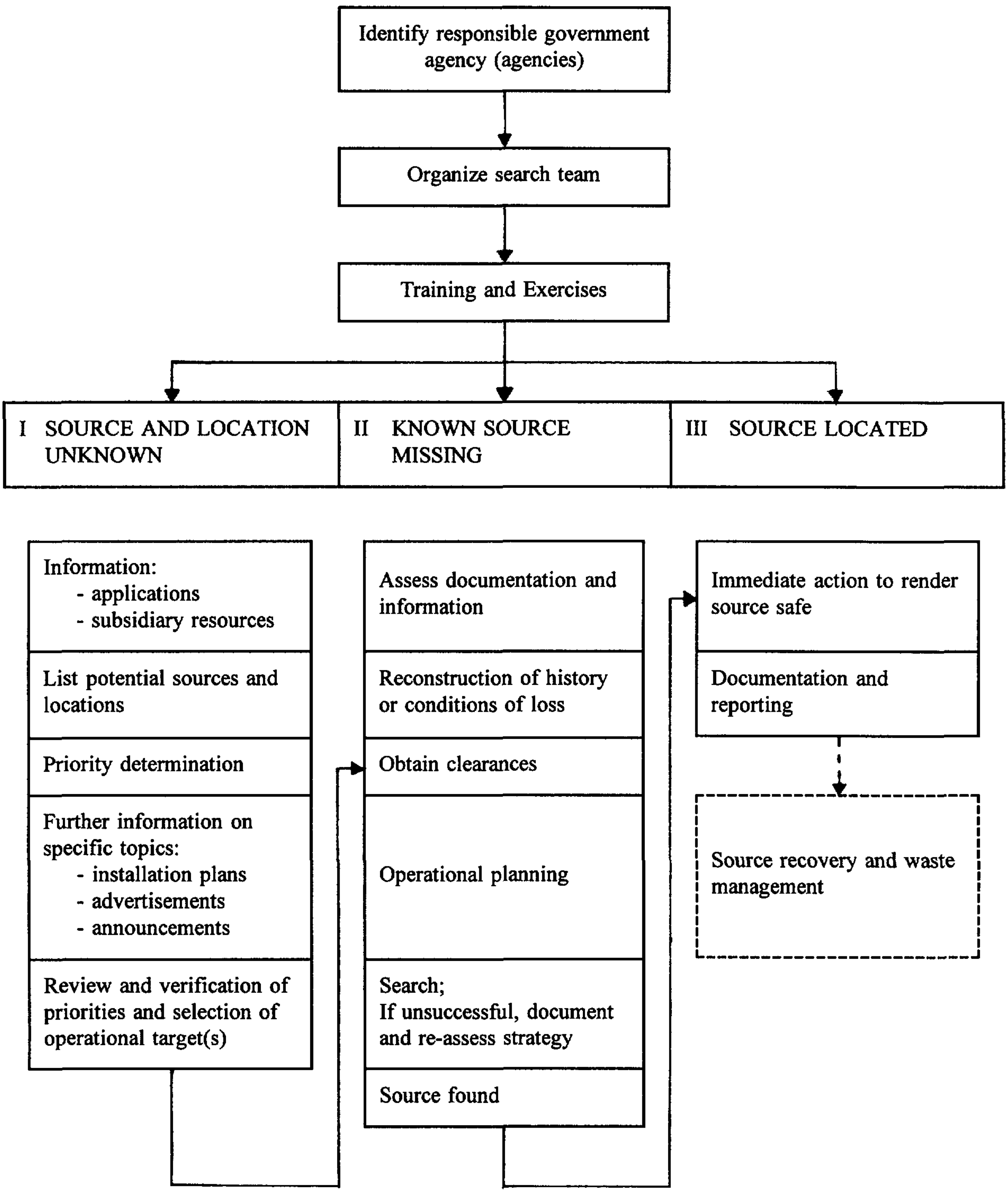


FIG. 1. Strategy to identify and locate spent sealed radiation sources.

of locating spent radiation sources should be based on a strategy first to collect, verify and assess information on locations (confirmed or likely) and second to assign priorities for the search efforts.

In many countries the task of identifying and searching for spent sources may extend over one or more years. It may be sensible for the strategy to include provisions for continuity of staff allocated to these activities during this extended period.

Where there are several governmental agencies responsible for radioactive waste management and radiation protection matters, or otherwise involved in the control of radiation sources (e.g. Ministries of Agriculture, Commerce, Energy, Health, Industry, Research, etc), it is recommended that the effort be jointly undertaken and appropriately coordinated.

Figure 1 is a flow diagram providing suggestions on how to develop a search strategy for spent sealed sources. Associated action is discussed in detail later in the report.

The most general case would be characterized by recognized awareness of the existence of unknown numbers of spent sources, in combination with no immediately accessible documentary evidence of the existence, location and condition of these sources. Lack of immediate access to documentary evidence means that the evidence may exist, at least to a limited extent, but is not readily available, or has not been compiled in a form suitable for the current purpose.

For countries where a system of accountancy and control of radiation sources has been fully operational only for a limited number of years, general information on spent radiation sources potentially in existence needs first to be established. Although such a system would adequately account for sources currently in use, it is possible that spent sources, in particular sources that became spent a long time ago, have not been tracked and accounted for. By combining the results of a review of past and ongoing medical, industrial and research activities in the country with the summary of historical and current applications of sealed radiation sources provided in Section 3, information on the range of radiation sources in previous and current use can be established. This information can also be used to determine which applications, both present and past, are the most important.

For countries with a longer tradition of an operational radiation sources accountancy and control system the part of the summary provided in Section 3 that covers the historical applications of radiation sources may be the one of most relevance.

Section 3 also discusses scenarios which may lead to loss of control of radiation sources; e.g. inadvertent transfer to an unsuitable or even unsafe location. Sources of information and the potential locations where sources may have been used are discussed in detail in Section 4.

In most situations, some basic information is likely to be available on current and past uses of radiation sources. For example, in many countries radium has been, and possibly still is, used for brachytherapy purposes. At least the hospital(s) using radium is likely to be known. Also, there may be a nuclear research centre, or past industrial development, which are obvious potential locations of radiation sources or of information about such locations. Common to these situations is that detailed information may be in existence but is not readily available in a coherent form or with adequate precision.

Based on this information a tentative inventory of relevant possible spent sources and their likely locations can be drawn up. In many cases information on any potential or confirmed location will be general only; perhaps limited to addresses or buildings. It is usually more important to ensure reasonable completeness regarding the source inventory, because action priority for the ensuing work will in most cases be based on the range of sources identified in the initial effort. Detailed information about source locations inside buildings or on premises is not necessary at this stage.

When only the general location of a source, e.g. a building, is known, it is necessary to explore additional information resources for more data on exact location. Such additional resources include e.g. building layout charts and current or former employees, and are further discussed in Section 5.

Wherever possible, information obtained from different sources should be compared and checked to verify consistency and completeness. Information from different sources may be conflicting or confusing. In this case, each source and corresponding information should be recorded and efforts should be undertaken to eliminate the uncertainties. Any remaining unclarified points need to be taken into account in the planning of physical searches.

Before a physical search is started, it must be ensured that adequate radiation protection measures can be taken during and after completion of the search. Operational planning of each search project needs to be done, including estimations of personal radiation doses expected to be received. Also administrative clearances may be required to e.g. enter a building or cordon off an area otherwise freely accessible by the public. See Section 5 for additional details.

There may be situations where evidence points to the probable existence of a source, or sources, in an area or building but a physical search fails to confirm this. This is addressed in Section 5.

Parts of this general strategy can be used in cases where a known source is lost or misplaced. The starting point in the flow chart will then normally be the middle column in Figure 1. Although the source is known, it must be ensured that all relevant information on source characteristics is available. As necessary, additional information must be sought, which may bring the starting point back to the first column.

Efforts to track the source would usually start at the last known location, concentrating on conditions and sequence of events immediately before control was lost. A course of action must be developed depending on actual circumstances (source lost in transit, time span since control was lost, stolen source, etc). Resources for tracking include owner/user of source, shipping companies or agents, police or customs officials and the general public.

The final starting point in the flow chart is when a source has been located; either as the result of a physical search, or because a report about a discovered source is received. Then action must be taken to render the source safe. Details of this action will depend on conditions prevailing at the site and the time required to transfer the source to a suitable facility for handling and conditioning. Immediate action following the locating of a source is discussed in Section 6.

It is important to note that this strategy does not consider an emergency situation arising during normal operations, where, for example, a radiography source has become detached from its cable or housing as the result of mechanical failure or improper handling, or when equipment containing a source falls from a truck. While such incidents require immediate response, they are outside the scope of the strategy discussed here and should be addressed in contingency plans prepared by the source user or transporter.

In the special case of the presence of a source having been discovered and reported, some period of time will elapse before a specialist team is available on location. It is therefore essential that persons on-site be advised on what to do, and more importantly, what not to do. Available information about conditions at the location where the source was found should be sought from the person(s) that provided the report. Presence on-site of the police is in many cases the quickest way to ensure that persons are kept away from the source. Suitable advice may have to be provided to the local police.

2.3. SEARCH PRIORITY

The top priority should be to locate and make safe those sources which are capable of delivering a high radiation dose to persons in the vicinity or even to cause radiation injury. Sources likely to cause most problems normally need to be located with the highest priority. Figure 2 provides general background information for the establishment of priorities. Using this approach one would develop the following search priorities, listed from highest to lowest:

Irradiator sources; teletherapy, industrial radiography, brachytherapy and well logging sources; moisture and density gauges and industrial gauges.

These are the sources that could cause radiation injury to a single person or a population due to extended gamma exposure. Factors that may affect priority include, but are not limited to, radiotoxicity of the radionuclide, available information on its chemical and physical form, solubility, dispersibility, and mechanical integrity of the device containing the sealed source. The real hazard posed by large gamma emitting sources will be less than indicated by Figure 2 if they remain within properly engineered shielded enclosures. A source that is identified as having poor mechanical integrity (such as radium sources) or as being leaking, should be treated with higher priority because of the associated higher risk of internal exposure.

In the listing of priorities above, irradiator sources are indicated as having the highest priority because of the associated high radiation injury potential in cases where the irradiation plant has been closed without complete removal of the sources. The high priority applies firstly to verification of source removal status and, as necessary, to locating, rendering safe on-site and eventual collection of the sources for safe management.

It is also necessary, however, that the actual inventory be assessed in the light of local or current conditions. As an example, consider a situation where the information available indicates that there is a hospital where radium has been used in the past for brachytherapy and there are also factories where industrial gauges have been installed. On the basis of the priorities indicated above, locating the radium sources would take precedence because of the higher hazard associated with radium. If, however, further information was available which showed that a factory or factories were to be demolished or the use changed without positive evidence that the installed gauges had been removed, top priority should be given to location of these gauges.

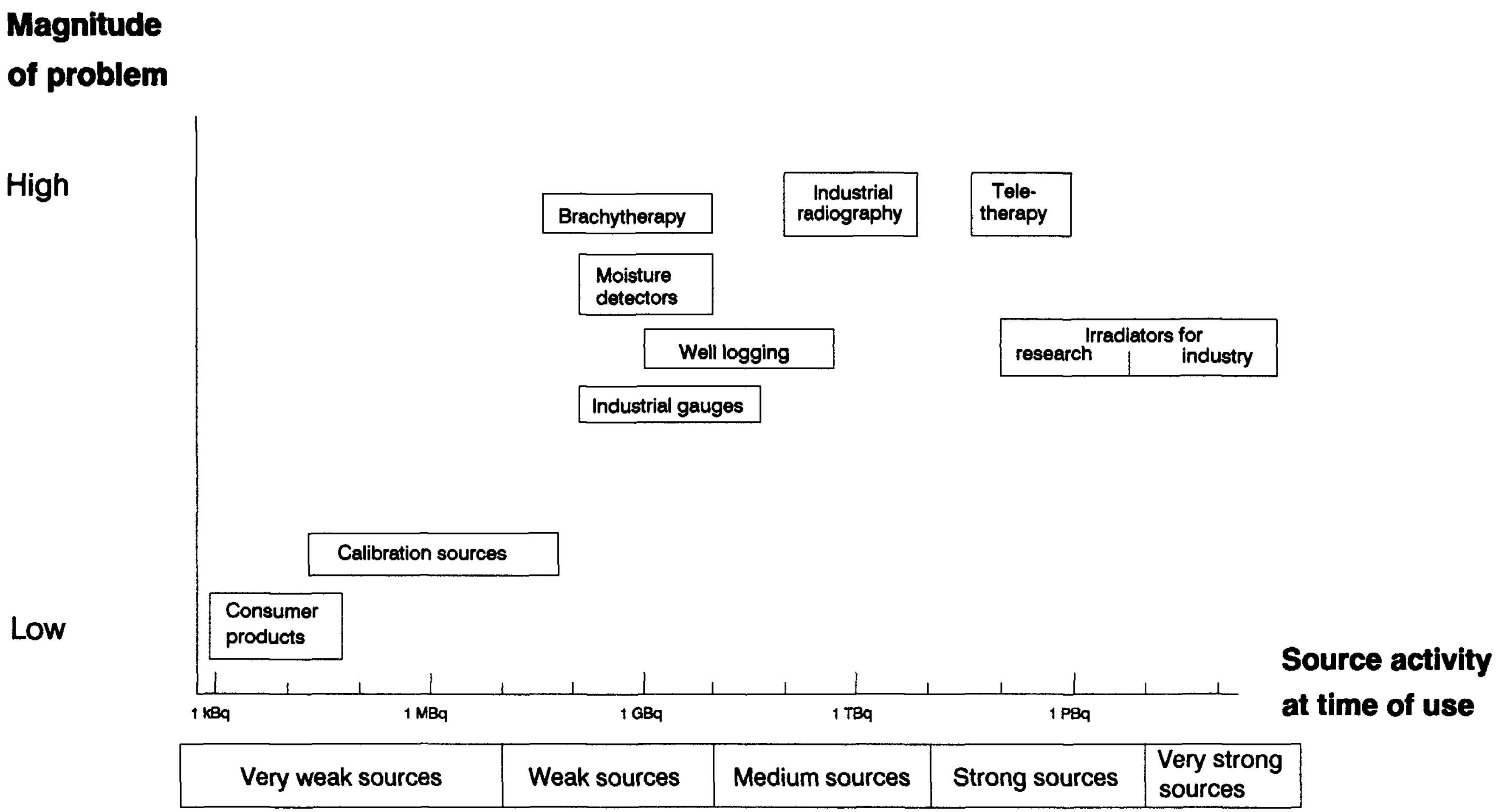


FIG. 2. Activity ranges for some important applications of sealed sources and magnitude of problems caused.

3. INFORMATION RESOURCES FOR DEVELOPING SPENT RADIATION SOURCES INVENTORY

3.1. OVERVIEW

The number of spent radiation sources around the world is not known exactly. An estimate made by the IAEA's Secretariat suggests that the number of such sources in developing countries may be as high as 30 000 [1].

This section summarizes the historical and current applications of sealed radiation sources. The purpose is to assist implementing the strategy element concerned with *identifying* the range or types of radiation sources not accounted for that have become spent. It also provides a basis for assigning priorities for implementing search efforts aiming at *locating* the sources. Information resources for developing details on physical locations are discussed in Section 4. Additionally, the summary may assist in identifying individual applications that engage radiation sources not adequately accounted for.

In an overview manner, Section 3.2 illustrates the increasing diversification of radiation sources from 1900 to the current time. For the time periods shown, typical radionuclide applications are broadly indicated. Generic pointers to potential facilities where radiation sources may have been used are included. Sections 3.3, 3.4 and 3.5 provide more detailed information on radiation sources used in medicine, industry and research.

A comprehensive review of current uses of radiation sources in industry, medicine, research and training is presented in IAEA Safety Series No. 102 [4].

It is useful at the outset to analyse the history of medical, industrial and research activities in the country with the aim of identifying both discontinued and ongoing operations using radioactive materials. The need for an iterative approach, involving the reassessing of information, is emphasized. The final result of this analysis is likely to be limited to a list of radiation source applications - information providing details of types of sources and their locations will probably be infrequent. However, in many cases it will be possible to decide those applications of radiation sources which can be disregarded or given low priority.

The physical and radiological characteristics of selected radiation sources are given in Annex I.

3.2. HISTORY OF USE OF RADIATION SOURCES

3.2.1. From 1900 to about 1950

Radionuclide: ^{226}Ra

Usage: Medical and research

Existing and former hospitals, government and private clinics, university and other research laboratories.

Older institutes that were operating during this period, particularly during the period 1930–1950, are the most likely places where spent radium sources may be located, but more modern institutes could have received such sources from older institutes or medical practitioners may have brought sources from other practices. Radium was often perceived to be valuable and may be retained in homes or safety deposits by the families of deceased medical practitioners. Older research facilities, where ^{226}Ra may have been used, are other possible locations. Typical activities for medical radium needles and tubes range from a few mg to a few tens of mg (equivalent to a few tens to a few hundreds of MBq).

3.2.2. From about 1950 to about 1960/1970

Radionuclides: ^{60}Co, ^{90}Sr, ^{137}Cs, ^{226}Ra

Usage: Medical

Cobalt-60 became the most commonly used radionuclide during the period, although ^{137}Cs has been used. Large teletherapy devices could be found in existing or former medical facilities. Brachytherapy devices using ^{137}Cs, ^{226}Ra, ^{60}Co or ^{90}Sr may also be found.

Where radium sources have been replaced they may have been relegated to a subsidiary store, donated to another hospital, project or country, disposed of in a controlled or uncontrolled manner or simply forgotten about.

Usage: Industrial

Radiation sources have been used in gauges, irradiation facilities and industrial radiography devices. These might be found in existing or abandoned industrial operations, mine sites, former oil exploration sites, shipyards, etc.

Usage: Research and development

Radium was commonly used for various purposes such as instrument calibration. Radium-226/beryllium neutron sources were also used during this period. These radium sources tended to be of higher activities than medical radium sources, e.g. $^{226}Ra/Be$ sources can exceed 500 mg (20 GBq) of radium and some sources greater than 1000 mg (40 GBq) have been used.

3.2.3. From about 1960/1970 to present

In this period the variety of radiation sources used in medicine and industry has become very large. This also corresponds to the period when some form of regulatory control or documentation of radiation sources became more common. Thus, in many countries records of radiation source type and location (or at least the original location) may exist. However, in many developing countries, regulatory infrastructures do not exist, and even where infrastructures do exist, foreign industrial companies may bring sources into the country unknown to the authorities as part of a larger industrial process and later abandon or lose these sources. Special attention has to be paid to dumps and scrap yards and possibly also to second hand dealers.

3.3. SOURCES IN MEDICINE

3.3.1. Radium sources

Of special interest are radium sources. Radium-226 is alpha emitting, long lived and the sources are widely spread. The *identified* quantity of radium in developing countries is about 122 g, corresponding to 4.5 TBq. For a mean quantity of 8 mg per source, that corresponds to approximately 15 000 sources. The *total* quantity of radium in developing countries, however, is estimated to be 200–250 g (the total for the whole world is estimated at a few kg) [1].

3.3.2. Manual and afterloading brachytherapy

Brachytherapy (therapy at short distance) is a term that is used to describe the interstitial or intracavitary application of radioactive sources by placing them directly in the tumour (breast, prostate), in moulds (skin, rectum), or in special applicators (vagina, cervix).

Historically, ^{226}Ra was used encapsulated in platinum in either needles or tubes of a few mm in width and up to 5 cm in length. Radon build-up causes pressure inside the encapsulation and may rupture it, resulting not only in ^{222}Rn leaking, but radium salt as well. For this reason, ^{226}Ra was replaced mainly by ^{137}Cs, but also by ^{60}Co and more recently by other radionuclides including ^{192}Ir and ^{252}Cf. Sources may be manufactured in different sizes and shapes and may be sold assembled in ribbons. The application of these sources may be done manually or by remote control.

TABLE III. RADIATION SOURCES IN MEDICINE

Application	Radionuclide	Half-life	Source activity[a]	Comments
Bone densitometry	^{241}Am	433 a	1-10 GBq	Mobile units
	^{153}Gd	242 d	1-40 GBq	
	^{125}I	60 d	1-10 GBq	
Manual brachytherapy	^{137}Cs	30 a	50-500 MBq	Small portable sources
	^{226}Ra	1600 a	30-300 MBq	
	^{60}Co	5.3 a	50-500 MBq	
	^{90}Sr	29 a	50-1500 MBq	
	^{103}Pd	17 d	50-1500 MBq	
	^{125}I	60 d	50-1500 MBq	
	^{192}Ir	74 d	200-1500 MBq	
	^{131}I	8 d	50-1500 MBq	
	^{198}Au	2.7 d	50-1500 MBq	
	^{252}Cf	2.6 a	50-1500 KBq	
Remote afterloading brachytherapy	^{60}Co	5.3 a	≈ 10 GBq	Mobile units
	^{137}Cs	30 a	0.03-10 MBq	
	^{192}Ir	74 d	≈ 400 GBq	
Teletherapy	^{60}Co	5.3 a	50-1000 TBq	Fixed installations
	^{137}Cs	30 a	500 TBq	
Blood irradiation	^{137}Cs	30 a	2-100 TBq	Fixed installations

[a]A table for the conversion of activity given in SI units to the old unit (curie) is given in Annex VI.

Because of radiation protection problems, only low activity sources are used manually, with or without afterloading techniques. In between treatments sources should be stored in lead shielded safes or containers, but they may (improperly) be kept loaded in applicators in transport carts. There are a variety of applicators, i.e. Manchester, Fletcher, Burnett, etc. Once spent, the sources may be left in the safes or transport containers.

Superficial treatment of skin and ophthalmic lesions may be carried out using $^{90}Sr/^{90}Y$ sources. Nasopharyngial applicators (^{90}Sr) replaced the "Crowe" radium probe in the 1970s.

Permanent implants were also developed, originally using ^{222}Rn and ^{198}Au "seeds". Today permanent implants are done with ^{125}I and ^{103}Pd. Because of the relatively short half-life, these are unlikely to cause problems as spent sources.

In recent times afterloading brachytherapy devices have been developed. When using these devices, plastic catheters are first inserted into the body and then the sources, attached to cables, are introduced by remote control. These devices use low activity sources of ^{137}Cs and ^{192}Ir or high activity ^{192}Ir (up to 0.4 TBq). If the cable breaks, the sources may become detached. Failure to recognize these problems may pose significant risks [5].

The sources which superseded the use of radium have much shorter half-lives (Table III) and may have been discarded because the radioactive decay has rendered them unsuitable for the intended purpose. They may, however, have sufficient residual activity to be radiologically hazardous if inadequately controlled.

3.3.3. Teletherapy

The other principal medical application is teletherapy, where a large source, typically ^{60}Co but possibly ^{137}Cs of several hundred TBq, is used, external to the body, to irradiate a tumour. These sources are invariably mounted in heavily shielded housings of steel, lead or depleted uranium and used in shielded enclosures, normally of brick or concrete of about one metre thickness. If these sources are removed from their housings in an unauthorized manner they will deliver a lethal dose in a short period of time. Since the material of the housing may be perceived as being valuable as scrap, theft leading to melting or other physical destruction of the housing has resulted in the spread of contamination, either directly or through the incorporation of the radionuclide into items manufactured from the scrap metal [6].

3.4. SOURCES IN INDUSTRY

There are many industrial applications of sealed radioactive sources (Table IV). The extent to which they will be found in both developed and developing countries will depend upon the degree and type of industrialization.

3.4.1. Industrial radiography

Industrial radiography is in wide use, and has a high hazard potential. The construction of, for example, petrochemical installations will involve the use of portable radiographic sources of up to 5 TBq for testing of welds in pipes and tanks. Some years ago ^{137}Cs sources were used, some of which may still exist. Currently, sources will most often be ^{192}Ir or ^{60}Co, but ^{169}Yb or ^{170}Tm may also be used. The housings for these portable sources contain several

TABLE IV. RADIATION SOURCES IN INDUSTRY

Application	Radionuclide	Half-life	Source activity[a]	Comments
Industrial radiography	^{192}Ir ^{60}Co (^{137}Cs, ^{170}Tm, ^{169}Yb)	74 d 5.3 a	0.1-5 TBq 0.1-5 TBq	Often portable units
Well logging	$^{241}Am/Be$ ^{137}Cs (^{252}Cf)	433 a 30 a	1-800 GBq 1-100 GBq	Portable units
Moisture detector	$^{241}Am/Be$ ^{137}Cs (^{252}Cf, $^{226}Ra/Be$)	433 a 30 a	0.1-2 GBq 400 MBq	Portable units to measure moisture content/density. Normally contains both a neutron and gamma emitter
Conveyor gauge	^{137}Cs	30 a	0.1-40 GBq	Fixed installations to measure density of coal, silt or ores
Density gauge	^{137}Cs ^{241}Am	30 a 433 a	1-20 GBq 1-10 GBq	Fixed installations to measure density of materials in a constant volume
Level gauge	^{137}Cs ^{60}Co (^{241}Am)	30 a 5.3 a	0.1-20 GBq 0.1-10 GBq	Fixed installations to measure level of materials in tanks, silos or packages
Thickness gauge	^{85}Kr ^{90}Sr (^{14}C, ^{147}Pm, ^{241}Am)	10.8 a 29 a	0.1-50 GBq 0.1-4 GBq	Fixed installations to measure thickness of papers, plastic or similar materials
Static eliminators	^{241}Am ^{210}Po (^{226}Ra)	433 a 138 d	1-4 GBq 1-4 GBq	Fixed installations and portable units
Lightning preventers	^{241}Am (^{226}Ra)	433 a	50-500 MBq	Fixed installations
Electron capture detectors	^{63}Ni ^{3}H	100 a 12 a	200-500 MBq 1-7.4 GBq	Fixed or portable equipment
X ray fluorescence analyser	^{55}Fe ^{109}Cd (^{238}Pu, ^{241}Am, ^{57}Co)	2.7 a 463 d	0.1-5 GBq 1-8 Gbq	Often portable units to analyse alloys by stimulating fluorescence X rays

TABLE IV. (cont.)

Application	Radionuclide	Half-life	Source activity[a]	Comments
Sterilization and food preservation	^{60}Co ^{137}Cs	5.3 a 30 a	0.1-400 PBq 0.1-400 PBq	Fixed installations (individual source activity up to 600 TBq)
Calibration facilities	^{60}Co ^{137}Cs	5.3 a 30 a	1-100 TBq	Fixed installations
Smoke detectors	^{241}Am (^{239}Pu)	433 a	0.02-3 MBq	Fixed (easily removed)
Dredgers	^{60}Co ^{137}Cs	5.3 a 30 a	1-100 GBq 1-100 GBq	Fixed installations for silt density measurements
Blast furnace control	^{60}Co	5.3 a	2 GBq	Fixed

[a]A table for the conversion of activity given in SI units to the old unit (curie) is given in Annex VI.

tens of kilograms of shielding material, such as depleted uranium, lead or tungsten, which may be perceived as potentially valuable. Most housings are designed so that the source may be easily exposed during normal operation, and removed for periodic replacement. Theft of the housing and removal, destruction or uncontrolled disposal of the source may give rise to similar problems as for teletherapy sources.

In heavy industries such as steel foundries or fabrication, portable, mobile, or fixed radiographic equipment incorporating ^{192}Ir, ^{60}Co or ^{137}Cs, may be installed in purpose built enclosures. Mobile or fixed installations incorporate heavier shielding than portable source housings and are therefore more difficult to steal and transport. If the premises are abandoned or the equipment is otherwise left unsupervised, vandalism or other interference could lead to the problems identified for teletherapy sources.

3.4.2. Field applications

In oil exploration, mining industry and construction work, neutron and gamma sources are used for the determination of density, porosity and moisture or hydrocarbon content of geological structures or building materials. The most usual neutron sources employed are $^{241}Am/Be$ of up to 800 GBq, but some use has been made of $^{239}Pu/Be$ or $^{226}Ra/Be$. 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 housings in which the neutron sources are stored and transported are large and may appear attractive to thieves, the bulk of the shielding will normally be plastics or paraffin wax and may be thrown away as useless by a thief, leading to a potentially hazardous situation. The housings for the gamma sources will normally be shielded with lead or depleted uranium, which may be attractive for its scrap value.

The nature of the work which is done with these sources requires that they be easily removed from their housings to be introduced into a borehole. If they are not subject to adequate control, it would be relatively simple for the source to be removed and left in a hazardous state.

3.4.3. Industrial gauges

In many industries it is necessary to measure the thickness, density or moisture content of a material while it is being made. Use of radioactive sources enables non-contact measurement to be made. Many different radionuclides, of a wide range of source strengths, may be used. Beta sources are used for measuring paper, plastics and thin light metals, whilst gamma sources may be used in situations where steel plate is being manufactured or the density of coal, rock or oil well fluids is to be determined. Similar sources may be used in other industries to measure the level of material in a vessel or tank, normally using ^{137}Cs. Neutron sources, normally $^{241}Am/Be$, may be used to measure the moisture content of coke or coal prior to loading furnaces.

These devices are usually installed permanently on the product machines and will be safe while in use. If the plant is scrapped without the gauges being removed and either disposed of, or stored in an authorized manner, it is possible that the sources could be melted down and incorporated into manufactured articles. Experience has shown that contamination may be found in the dust or fume collection system or slag resulting from the melt process.

3.4.4. Electrostatic eliminators

In many industries the generation of static electricity during manufacture creates problems leading to attraction of dust or possible fire hazard. In order to minimize these problems static eliminators incorporating sources of ^{241}Am, ^{226}Ra 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. Since the eliminators utilize the alpha particles emitted, the source construction is fragile and will not withstand physical abuse or fire, either of which may result in spread of contamination.

3.4.5. Thickness gauges — electronics industry

The electronics industries use small sources to measure the thickness of plating of precious metals on circuit boards or electrical contacts. These will be relatively easy to lose or mislay, but, other than from prolonged very close skin contact, present little hazard.

3.4.6. Blast furnace control

Where blast furnaces are employed in steel making, ^{60}Co sources are often used to gauge the wear of the refractory lining of the bottom hearth. Potential of loss of control of sources exists during relining of the furnace or closure of the facility.

3.4.7. Industrial irradiators

Very large (several TBq) ^{60}Co and ^{137}Cs sources are used for the irradiation sterilization of medical products, such as sutures and gloves, and for food preservation. These sources are installed in dedicated enclosures which employ either a deep pool of water or massive lead or concrete for shielding purposes. These facilities are normally designed to prevent anyone having access to the vicinity of the sources — there have however been instances of operators defeating the interlock systems and entering the enclosure whilst the sources are exposed. It is unlikely that such an installation would be abandoned or forgotten about, but if this were to happen the consequences could be very serious.

3.5. SOURCES IN RESEARCH

Applications of radioactive sources in research are very varied. Almost any radionuclide can find a use in some research work. Use of radium sources for calibration purposes has been extensive, and may still continue. Radium-226/beryllium and plutonium-238/beryllium sources have been used in university training programmes.

Research work is often carried out in project form; e.g. thesis work and under a contract. Equipment, including radiation sources, may have been obtained specifically for the project. When the work is completed, there may be no further use for the sources, which then remain as spent.

The sources used in much research are however of low activity and/or of short half-life, or, in the case of tritium (^{3}H) and ^{14}C having weaker beta emissions, cause less serious radiological problems when spent (Table V).

TABLE V. RADIATION SOURCES IN RESEARCH

Application	Radionuclide	Half-life	Source activity[a]	Comments
Calibration sources	Many different		< 0.1 GBq	Small portable sources
Electron capture detector	^{3}H ^{63}Ni	12.3 a 100 a	1-50 GBq 200-500 MBq	Can be used in portable units and in gas chromatograph detectors
Irradiators	^{60}Co (^{137}Cs)	5.3 a	1-1000 TBq	Fixed installations
Calibration facilities	^{137}Cs ^{60}Co ^{252}Cf ($^{241}Am/Be$ $^{238}Pu/Be$)	30 a 5.3 a 2.6 a	<100 TBq <100 TBq <10 GBq	Fixed installations
Tritium targets	^{3}H	12 a	1-10 TBq	Fixed installations for neutron production

[a]A table for the conversion of activity given in SI units to the old unit (curie) is given in Annex VI.

Notable exceptions are the use of large (up to 1 TBq) ^{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. The former sources can deliver a lethal dose in a short period of time, if the sources are removed from the shielding. There are normally engineered safeguards to prevent this happening but the efficacy of these must depend upon the adequacy and regularity of maintenance procedures. The moisture and density sources are designed to be portable and in many instances to be removed from the housings. They may therefore become easily lost, stolen or mislaid.

A series of illustrations of typical devices containing radiation sources and the sources themselves is given in Annex II. It is not practicable to give a complete inventory of the many types of equipment which has been manufactured for use in medicine, industry and research. The illustrations are intended to give guidance to the main visual indicators which may be of value during the search.

4. INFORMATION RESOURCES FOR DEVELOPING DATA ON LOCATIONS OF SPENT RADIATION SOURCES

4.1. INTRODUCTION

The initial review of nuclear applications discussed in Section 3, aimed at identifying the range of spent radiation sources in need of being located for safe waste management purposes, is likely to have generated limited only information about the physical location of those sources. Information resources useful for establishing the more detailed data necessary for the location of individual radiation sources are discussed in this section.

The list of resources suggested is not necessarily complete, nor will every entry apply in situations prevailing in any given country. The main intention with the examples is to illustrate that, often, indirect, or seemingly unrelated, sources of information need to be explored. The need for an iterative approach in the exploration also needs to be emphasized; reassessing information can prove particularly useful when, at the later stage, more precise questions can be asked.

4.2. DOCUMENTARY AND OTHER INFORMATION

4.2.1. Medical sources

It may be useful to consider a wide range of information for the location of radiation sources used in medicine. These may include:

- existing or former hospitals which carried out radiotherapy; records may be found in the department concerned, or in administrative files;
- records of inventory of radiation sources centrally kept; e.g. ministry of health, emergency organizations or agency responsible for radiation control;
- customs records; a license, or report, may have been required for the radioactive source, or for reasons of high value of the equipment in which the source was installed;
- records of import of sources into the country from major suppliers;
- records from organizations or government departments responsible for procuring radiation sources locally or from abroad;
- sales records of suppliers;

- records of inter-government cooperation programmes resulting in donation of equipment;
- technical cooperation agreements between the national government and international organizations or other governments;
- contracts made between nationals of the country and people in organizations in other countries where they received training or made exchange visits;
- discussions with older staff members who may have recollections of sources and equipment previously used in the establishment;
- papers in professional or scientific journals (published in the country or abroad) recording work involving radiation sources;
- national radioactive waste services - access to their records may indicate an intention to return a source that never arrived, the existence of obsolete facilities for nuclear applications not realized and details of individuals involved with old sources in the past;
- IAEA Directory of Teletherapy Facilities High-Energy Radiotherapy Centres [7];
- anecdotal information regarding donations and source usage.

It may be useful to advertise in professional journals or write individually to radiologists seeking their cooperation. A specimen letter/advertisement is given as Annex VII.

4.2.2. Industrial sources

There is a wide variety of industrial uses of radiation sources, and this will mean that attempting to locate possible spent sources will be a complex task. Spent sources may exist both on operating sites and those which have ceased to be used. Avenues of enquiry include (in addition to many of those listed for medical sources):

- construction projects often carried out by third country organizations where radiography sources may have been abandoned rather than being repatriated to the country of origin;
- industrial plants where level, thickness and density gauges may have been installed;
- oil exploration and mine sites where borehole probes may have been used and subsequently abandoned;
- scrap dealers; equipment containing radiation sources could have inadvertently been sold as scrap;
- discussions with persons previously employed in any of these industries, particularly where the sites have subsequently been abandoned for any reason.

It may be useful to provide scrap dealers with information on characteristics of housings for radiation sources to enable them to identify such items and report when they are passed on [8–10]. A sample poster providing this information is shown in Annex VIII.

4.2.3. Research sources

The number of institutes carrying out research and development will often be smaller than the possible sites of industrial operation. Many of the lines of enquiry suggested for locating spent medical and industrial sources will also be relevant in this area. There may also be:

- joint research projects carried out between universities in several countries which involve the transfer of sources between the institutes;
- donations of sources from overseas institutes for particular research projects

5. PRACTICAL ASPECTS OF SEARCH PROCEDURES

5.1. GENERAL

A physical search should be started only when there is reasonable assurance that all available documentary or other information sources have been fully explored and a trained search team has been formed. An essential input for the planning effort is an assessment of completeness, accuracy and reliability of the data extracted from the information sources. Any doubts, assessed incompleteness, or conflicting pieces of information must be identified at the information investigation stage in order that it can be properly taken into account when planning searches.

The search for a source or sources should consider a combination of indicators such as:

(1) the appearance of elevated dose rates;
(2) nuclear related signs — e.g. hazard warning signs or trefoil or names of manufacturers of nuclear equipment;
(3) the presence of dense material for no evident structural purpose — for example lead, concrete or depleted uranium;
(4) housings or containers such as those shown in Annex II;
(5) evidence of contamination.

Any combination of the above could occur. It should also be remembered that in the search, material used originally for shielding may be moved, leading to significantly higher dose rates.

Advice given in this section pertains to searches carried out for the purpose of locating spent radiation sources and rendering them safe. Although certain items of the advice may be applicable in emergency situations involving radiation sources, it is important to recognize that for emergency situations additional and in some aspects, different, advice applies. IAEA Safety Series No. 91 [11], Emergency Planning and Preparedness for Accidents Involving Radioactive Materials Used in Medicine, Industry, Research and Training, should be consulted for advice on emergency preparedness.

5.2. PLANNING

5.2.1. Administrative clearances

The first step in the location of a spent source is to define the general area where the search will be conducted. The next step is to contact the current owners and occupants of the area in order to solicit their cooperation. This may require administrative clearances within the government if the area is in the public domain (e.g. a hospital owned or operated by local or national government), or careful negotiations with owners, managers and occupants if the areas to be surveyed are privately owned. Although undesirable, clearance may have to be obtained by government decree if a reasonable agreement with a private owner cannot be reached. Information on the purpose of the search and its possible consequences must be provided in writing to the party from which clearance is requested. Similarly, any permit or consents required to conduct the investigation should be obtained in writing.

Information should also be provided to persons occupying or otherwise using the premises to be searched. This is necessary for safety and radiation protection reasons, and also in order to solicit any necessary assistance from them.

Administrative clearances may have to be obtained for the members of the survey team as well. This is particularly important if the National Authority responsible for the search contracts a non-governmental agency or non-governmental individuals to do the work.

These administrative requirements may be necessary to avoid legal complications such as litigation or disputes about allocation of responsibility. This may in particular be of importance should the search result in discovering conditions which may call for drastic actions such as evacuation of persons or demolition of buildings or plant.

5.2.2. Organization of the search team

Spent sources will often have to be searched for at several different places, and the total search effort will therefore be extended over time. Advice provided here focuses on such situations, although details apply also in cases where one, or a few only, sources need to be searched for.

Recognizing the campaign nature of a comprehensive search effort, it is preferable to maintain the same search team for each of the search campaigns. This will ensure personnel continuity, will enable proper attention to feed back and will make methodological fine tuning based on experience more attainable. From the radiological protection point of view staff experience usually leads to lower individual and collective doses for the team.

The search team should be organized around a technical unit composed of individuals trained in radiation physics and in radiation protection, with professionally recognized expertise. Such specialists may be found in hospitals, universities, and especially in radiation protection services if these exist. Where appropriate, consideration should be given to recruiting suitable specialists from abroad.

A headquarters for the search team should be established for the whole series of search campaigns. Such a focal point may be established at the office of the co-ordinating government department or agency.

The search team should be headed by a search manager who is responsible for the operation and takes the decisions. He or she should be assisted by a safety officer, an instrumentation specialist and a communications officer (see Fig. 3). Depending on details of the individual search effort, additional expertise or support may have to be provided for by adding one or more persons to the team. The functions identified above may be undertaken by separate individuals or several tasks can be allocated to one person. It is important, however, that the search manager and the safety officer are separate persons.

Additional experts, advisors or search team members may be required for certain search campaigns. Details of additional support needed depend on the type and level of expertise in the regular search team, the assessed risks associated with the source to be searched for and particular aspects of the individual search. In many cases, a guide well acquainted with the premises and/or plant operation can provide valuable assistance. It may also be helpful to include in the search team a well known local functionary, e.g. a social worker or teacher, to assist in the communication with local residents.

Search Manager [responsible for the operation]

- Safety Officer [radiological and general safety]
- Instrumentation Specialist [appropriateness, maintenance and testing of instruments]
- Communications Officer [contact with headquarters, authorities, news media and the public]
- (Other experts)
- Technical unit
    - Persons trained in
        - radiation physics
        - radiation protection
        - recognition of devices, equipment and sources
    - Local Guide
    - ...

FIG. 3. Search team.

The search team should be organized to operate in accordance with established plans delineating tasks, responsibilities and report channels. Written instructions on radiation protection aspects are also essential.

It is strongly suggested that the members of the search team meet periodically to ensure "team spirit", check the adequacy of the available instrumentation and equipment to be used for the search, and to discuss the situation regarding compliance with laws and regulations. It may be useful for the search team to be involved periodically in simulated exercises designed to test their preparedness and ability to work as a team. All members of the search team must be prepared to communicate professionally with the local members of the public as the occasion demands.

It must be understood that an improperly trained, inexperienced or undisciplined team could make the situation worse.

5.2.3. Instrumentation and equipment

Several considerations apply when selecting radiation measuring instruments for a search. While general purpose instruments would normally be used, depending on the radiation emitted, specialized instruments may also be required (Annex IV).

Most sources of radiological significance will have associated beta or gamma emissions. These can be detected with unsophisticated equipment such as an end window or a thin walled G–M tube monitor. Scintillation monitors, if available, are preferred because of their shorter response times. A very useful addition would be the fitting of the monitor with audible output so that the operator would not need to watch the meter constantly.

This basic equipment is not suitable, or not reliable, if the source is an alpha or neutron emitter, or if a beta source is positioned in a shielded housing. Instruments sensitive to alpha or neutron radiation may be required depending on particulars of the search plan originating from assessment of what sources are to be searched for and, in addition, what other sources could reasonably be expected to be encountered.

From the monitoring point of view, shielded alpha or beta sources are the most difficult to detect. For beta sources, in the absence of measurable levels of Bremsstrahlung, an end window G–M tube monitor is probably best suited, provided safe opening of the shield can be arranged and the taking of measurements can start at several metres distance, to avoid saturation of the G–M counter.

The location of neutron sources will not always require access to a neutron monitor. Some gamma or X ray emissions associated with ^{226}Ra–Be and ^{241}Am–Be neutron sources can be detected by using a G–M tube or thin crystal scintillation monitor. This indirect detection technique will, however, introduce uncertainties caused partly by the low energy of the photons (^{241}Am–Be) and partly by the shielding itself. It may also lead to a significant underestimation of the risks involved.

For the basic equipment (G–M tube or scintillation detector) at least two types of instruments should be available; one with lower and one with higher sensitivity. The high sensitivity monitor would often be more suitable for identifying the general area where a source is located. Changing to a less sensitive detector would then enable closer approach and pinpointing the location.

Where several sources of widely differing activity need to be located in the same area, a collimated monitor with defined angular response may be particularly useful.

Locating high activity sources, such as teletherapy sources, known or suspected to be partly or wholly unshielded, require special considerations. Because of the high radiation field, normal or readily available equipment may saturate and resulting readings will be unreliable. To limit personal exposure, a high dose rate instrument with a telescopic arm would be necessary.

More specialized equipment for locating sources and for nuclide identification include instruments designed for geological exploration (capable of measuring variations in natural background around 0.1 μSv/h, but unsuitable for nuclide identification) and gamma spectrometers. Availability of such equipment in immediate association with the search is beneficial, but normally not necessary. The one exception to note would be if a large area (of the order of several square kilometres or more) needs to be surveyed. In this case, a geological survey instrument or a large collimated scintillation detector mounted in a small aircraft will enable a rapid survey to be made.

Alpha, beta and low energy X and gamma ray contamination monitors are recommended for checking contamination in case of damage and subsequent leakage of the radiation source (Annex V). For the purpose of more detailed assessment of contamination, soil samples or wipe tests may have to be taken. Suitable plastic containers and PVC wrapping should be provided. Self-adhesive labels are necessary for identifying samples taken.

Ancillary equipment for topographic work such as measuring ropes, sticks, and, possibly, theodolytes need to be provided. When the area in which a spent source is located has been identified, it may be necessary to prevent access by erecting barriers. Barrier materials may comprise ropes, tapes, supports or purpose designed extending barriers. Warning signs should also be available which can be placed around the barriers.

When a source is located it may be possible to handle it remotely using tongs or grabs (see also Section 6). Such remote handling tools of length 1–1½ m should be part of the equipment available to the search team. If precise details are available of the physical size and activity of the source which is being sought, a shielded container into which it can be placed when located will be of use.

For the purposes of radiological safety, protective clothing is needed, as are gloves, overshoes, respirators, and plastic bags to contain contaminated items. Details of protective equipment should be decided upon at the planning stage; it is often prudent to allow a safety margin to account for unforseen events.

5.2.4. Topographical information

Survey of wide open spaces would normally be conducted only if there is firm information to indicate the existence of abandoned or derelict plant where radiation sources have been used or of deliberate disposal in pits or refuse dumps.

Whenever a search is to be performed out of doors and over a large area, it is necessary to have access to suitable maps. Any existing old maps should be consulted for information on sites that no longer exist. Updated maps are also needed to provide information on current characteristics of the area to be searched.

Large scale geographical maps are preferable, but plans and sketches may be used. The best suitable scale of the survey map will depend on the survey method, which could be by foot, by car or from the air. Electronic positioning systems such as radiogeodesical, Doppler and cosmic navigation systems can help to determine the position of a vehicle or an airplane with an error less than 50 m.

When searches are performed indoors, building and floor lay out drawings are needed. In the absence of copies of the original drawings, hand made charts providing similar information need to be developed. It is desirable to consult with persons having worked in the part of the building subjected to the search to check the information prior to a search commencing.

Similarly, for searches in factories and other industrial premises, site plans or lay out drawings should be used. In this case, plans showing details of plant where source containing equipment was installed are particularly helpful.

5.3. METHODOLOGY

5.3.1. Safety precautions for personnel

The individuals composing the survey team need to have adequate knowledge of radiation protection and safety and must have been properly instructed in the operational aspects of the search task (Annex III) [3, 14]. Safety precautions must include the possibility of contamination and high radiation fields.

Prior to the actual search process, the methodology to be implemented needs to be thoroughly explained and discussed. Special attention is needed with regard to potentially leaking sources and in cases where high activity sources will, or could, be encountered. The team should do at least one trial run to verify performance efficiency. Contingency plans in case of unexpected findings need to be developed and be available in written form.

All members of the search team must wear an integrating type of personal dosimeter and, if possible, a direct reading instrument with audible output [12]. Responsibility of the team safety officer includes the personal dosimetry of the team members. Based on the radiation levels encountered, the safety officer should advise the search manager on methods for optimizing the protection, such as limiting the number of surveyors in a specific area or reducing the survey time [13]. The safety officer should also establish operational dose limits for the whole procedure. Should such limits be closely approached, or exceeded, work procedures should be reassessed and optimization criteria reconsidered.

Where there is a contamination risk, the safety officer should advise the team members on the additional precautions to be taken, such as the use of gloves, boots, overshoes and/or protective clothing. During the survey, the team members should be regularly checked for contamination. It may be necessary that such contamination checks are done in an area of low background [15].

Should the situation prove to be posing significant risks, either due to the presence of unforseen high dose rates or gross amounts of contamination, it is the responsibility of the safety officer to advise the search manager to discontinue the search. It may then be necessary to reconsider the search strategy or seek assistance from experts from other organizations or other countries to permit the search to be continued in a safe manner.

In all cases, the radiation protection regulations established by the National Authority or, in their absence, the requirements of the current edition of Basic Safety Standards for Radiation Protection, IAEA Safety Series No. 9 [14], should be observed.

5.3.2. Instrument calibration and checks

All radiation monitoring instruments used in the search should be calibrated and a calibration certificate should be available. Instrument functional checks should be made twice per day before and after the work, using check sources. Background measurements should be made at a place where radiation levels can be considered normal.

5.3.3. Practical hints for locating spent sources

It is important for the search team to be aware, whenever possible, of the physical appearance of the sources for which they are searching and associated shielding and equipment and not to rely only on measurements. Typical source housings for a range of equipment are illustrated in Annex II and further information on current techniques can be gained from IAEA Safety Series No. 102 [4]. Other indicators of the possible location of sources are mentioned previously (see Section 5.1). When targeting specific areas for a search where it is known or suspected that sources could be located, the following lines of approach may be considered.

Medical sources

When a hospital has been identified where radioactive sources may have been used, search efforts should be concentrated on the radiotherapy department and other units related to it. Shielded safes or storage areas are the most likely locations.

Due to their small size, ^{137}Cs, radium and ^{60}Co sources may have been embedded in or under linoleum covering corridors or passage ways connecting patients' wards and surgery departments, or in dedicated patients wards.

Potential locations for brachytherapy sources include: sinks/toilets attached to wards and their associated sewage system, hospital laundries, solid waste collection sites and septic wastes, incineration plants, hospital grounds and garbage dumps.

Radium sources may still be kept in homes or safety deposit boxes of former physicians or their families.

Teletherapy units may be located in stores or basements, buried in hospital grounds or in disused radiotherapy enclosures.

Industrial sources

Equipment containing sealed sources used in industry is often designed to be portable. It would normally be expected that dedicated areas would be set aside on sites where such sources are used. When work on these sites ceases, it is possible that the warning signs indicating these areas may not be maintained. Company archives may contain information which will enable the number of sources and original locations of areas on a site to be identified. If site plans can be obtained, the original location of these areas may be found. It may also be possible to locate these areas from the recollections of persons previously employed there. If these areas cannot be located, the whole site will have to be surveyed visually and with appropriate monitoring instruments.

Equipment for industrial radiography is a special example of devices designed to be mobile. If the equipment was used only within the same industrial facility, advice given above applies. If, on the other hand, the radiography equipment had been used at several different sites, e.g. to check pipe welds during construction of some process plant, normal practice would be to return the equipment to the radiography company storage facility once any site project was completed. Companies still in operation would be able to provide information on current storage facilities, and they are likely to possess information on location of such facilities even if abandoned several years ago.

Former employees, or even old telephone directories, may provide assistance in locating possible storage facilities if the company no longer exists. Persons familiar with the immediate area at such addresses may be able to provide additional information.

Other industrial sources are normally installed on parts of the plant to monitor product manufacture. When such a plant ceases to operate it is normally expected that the sources, in their housings, would be removed to a dedicated store prior to ultimate disposal. Efforts to locate these stores as indicated above may therefore be rewarding.

If the industrial site has been abandoned without the sources having been removed from the plant, site plans, possibly retained by the fire department or the public body which licensed or registered construction, may indicate the original locations of the sources. Persons who previously worked in the abandoned plant or persons working in similar plants in the country may be able to indicate the most suitable places to search.

Portable sources used in borehole probes for oil exploration may have been used at a large number of well sites, many of which may have been abandoned as dry wells. Some method of sealing the source in place may have been used. If it is confirmed that this was done, continuing search may be unrewarding.

No indication of the borehole site may be visible on the ground. Government departments responsible for licensing exploration should be able to provide map references of all sites where boreholes were drilled and which company carried out the work.

Research sources

Most spent sources in research institutes would normally be expected to be located in a dedicated storage area. There may however be many separate storage areas in a typical institute. Archives or administration records may enable some or all of the storage areas to be identified. It is unlikely that the location of all these areas will be indicated in records or on plans of the institute; it may therefore be necessary to endeavour to find out from present and former employees the most suitable locations to search for spent sources. In the absence of information from records or employees, persons working in similar institutes in the country may be able to recognize equipment and suggest possible areas to search.

5.3.4. Survey procedure

Characteristics of the area, factory site or building identified for the search and the operation carried out there, need to be analysed before search operations are started. This is important in particular with regard to what visual indicators to look for. When surveying a process industry factory site, a typical indicator would be gauge housings. For sites and localities long ago abandoned or showing obvious signs of disorder or dilapidation, visual indicators may become more difficult to employ but nevertheless need to be kept constantly in mind.

Before an out-of-doors search is started, suitable maps or plans should be available as discussed in Section 5.2.4. It is necessary to relate these maps to some visual marks on the area covered. All points with enhanced radiation levels should be referred to such visual marks.

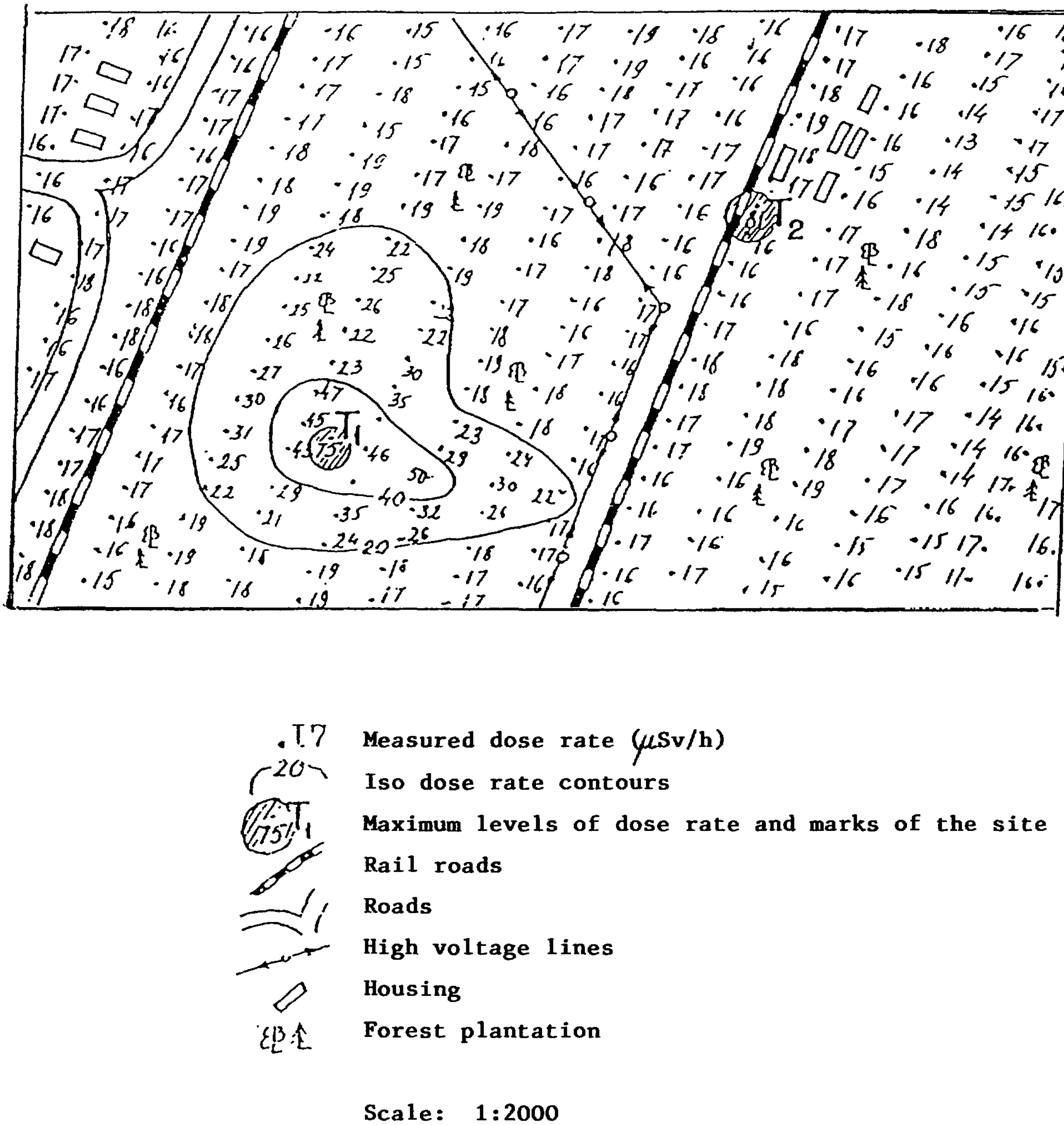


FIG. 4. Example of a marked-up survey map from a gamma survey conducted by foot.

If a large area survey is necessary, monitoring by aeroplane, helicopter or car can be considered. A search on foot will always complete the survey.

The planned routes of the survey and the results of visual observations and dose rate measurement should be entered on the survey map, which becomes the basic document of the search. When an elevated dose rate level is found, the complete dose rate distribution around the spot needs to be determined by scanning the area with a series of parallel routes. An example of a resulting survey map is given in Figure 4.

Elevated dose rate levels could be due to either sealed sources or areas of high natural background. Normally, those due to sealed sources will be more localized and may give rise to a more rapidly changing dose rate distribution unless the source has leaked and given rise to widespread contamination (see also Section 6.3).

As more refined measurements are made, using finer and finer grids on the survey map, the radiation anomaly can eventually be located. Normally measurements will be made at a height of 50–100 cm above ground level. Where an anomaly is indicated, measurement close to the ground would enable the position of the anomaly, which may indicate a buried source, to be better defined.

Similar procedures should be carried out when surveying limited areas or parts of factory sites or buildings. Measurements and observations should be made along a prescribed route and the results recorded on a map or plan of the area. When monitoring within a building, the survey team must be aware that sources could be on various levels above or below that on which they are working. Where an increasing dose rate is encountered, collimated detectors may be of use to indicate the probable direction of the source.

The search manager may decide that identification of the radionuclide is of prime importance. In that case, a portable gamma spectrometer can indicate whether the source is ^{226}Ra, ^{60}Co, ^{137}Cs, ^{192}Ir or some other gamma emitting nuclide. Interpretation of the results from such an instrument may require a specialist.

The survey team must take care when approaching a radiation anomaly that appropriate monitoring equipment is used; for example using a telescopic detector to avoid approaching too close to a high output source.

There may be circumstances where a telescopic detector will still be insufficient to keep doses within the operational limit established, in which case the monitoring must cease and the procedures discussed in Section 6.2 must be followed.

5.3.5. Failure to locate suspected source

It is possible that an area, where it is suspected that a source may be located, can be searched both visually and with monitoring instruments and the position of the source cannot be identified. In such a case there may be several reasons for this and the search manager needs to make a judgement on how to proceed.

If the source being sought is a gamma emitter, it may be shielded or buried to an extent that the gamma radiation is not detectable; a beta source may have easily attenuated emissions or be in a closed housing, so that detection is not possible unless a detector is placed very close to the source; an alpha source cannot be detected unless unshielded.

It may therefore be necessary to consider current and future use of the area. If an undetected source remains in the area, the search manager should consider whether it is likely to be disturbed and create an unsafe situation in the future or if there is a high probability that it will remain undisturbed and therefore be safe for the foreseeable future.

Follow-up actions must be considered, examples being:

- sampling and measurement of ground water,
- permanent warning signs,
- establishment of a monitoring programme,
- record possible lost source location in public land records,
- providing information to the general public.

6. IMMEDIATE ACTIONS FOLLOWING THE LOCATION OF A SPENT SEALED SOURCE

6.1. GENERAL

The most immediate action to be taken once a spent source has been located is to ensure that members of the public in the vicinity are adequately protected. In some circumstances, for example where a high activity unshielded gamma source is encountered, the only immediate action which can be taken may be to isolate the source within a barriered area where access is made impossible and erect warning signs to advise of the danger. In other circumstances it may be possible to take steps to shield the source or place it in a suitable container prior to removing it from the area. In attempting to make the source safe, the search team should not put itself into an unsafe situation. Dose rate mapping of the area should be done in a way which does not endanger the measurement team, and any unsafe area for the public must be declared. Barriers with warning signs must be arranged, patrolling the perimeter needs to be considered. In all cases the appropriate authorities should be informed.

6.2. UNDAMAGED SOURCES

If the radiation level close to the source is too high to approach to a distance where it can be safely handled with tongs, grabs or other means, expert advice on future action needs to be sought immediately. For example, an unshielded ^{60}Co source of 500 TBq gives a dose rate of about 3 Sv/min at 1 m. In no case must such a source be approached.

Sources of intermediate activity (for example a typical ^{137}Cs source of 2 TBq, which gives a dose rate of about 3 mSv/min at 1 m), produce dose rates such that they can be placed in a suitable shielded container using appropriate equipment for remote handling of the source. On no account should the source be directly handled - tongs, grabs or other remote means should always be employed. If there is no shielded container available, then temporary shielding can be used to reduce the potential hazard. Care must be exercised to ensure that there are no gaps in the shielding through which radiation could escape. Care must also be taken to make sure that the use of such shielding does not create more problems than it cures; do not shovel dirt on to the source and later find that it is impossible to separate the source from the dirt! If there are metal plates or pipes, lead or building bricks or concrete blocks available, then they can be piled around the source until the radiation dose rate has been reduced to an acceptable level. If such materials are not available, bags of soil or sand may be used. Exceptionally, a pit could be dug in the ground, the source put into it and a lid put over the top. Efforts should be made to ensure that the pit will not be filled with water, the sides will not collapse and that the lid is secure so that the source is not likely to be stolen.

Difficulties may arise if sources are found in areas which cannot be evacuated or from which people can only be moved for a short time. It should be possible, by using enough temporary shielding, to reduce to a minimum the extent of the area from which people have to be excluded. Warning signs must be placed and the finding reported to the appropriate authority.

6.3. LEAKING SOURCES AND CONTAMINATION RISK

If the sources remain in their housings, the housings apparently are undamaged and the shutters are closed, the only remaining hazard could be contamination from a leaking source. The existence of contamination can best be assessed by someone with the necessary training and experience [15].

If, in the absence of a full assessment, it is suspected that a source may be damaged, the leakage can be contained by, for example, wrapping the housing in plastic sheeting, or putting it in a rubbish bin or oil drum and sealing the lid.

If the source has been leaking, there may be contamination in the area where the housing was found. To avert this being spread into other areas, people should be prevented from entering the area unnecessarily until the situation has been assessed by someone with the appropriate technical knowledge.

It is possible that a source found out of its shielding will have been damaged and be leaking. It is important that this is recognized and the precautions mentioned above are taken. Unless the people carrying out the recovery operation have the necessary expertise to assess and deal with a leaking source and any residual contamination, no one should be allowed back into the area until an expert assessment of the situation has been made.

It is important that any means employed to clean up the contamination adequately contains the activity. It is dangerous, for example, to hose down the area and divert the contamination into the nearest drain. The contamination, together with any items such as wipes used to decontaminate surfaces, must be collected together for disposal in an appropriate manner.

6.4. TEMPORARY SAFE CONFINEMENT FOR THE SOURCE

When the sources have been rendered safe it will be necessary to review the size and construction of the safe area for the public. Until more permanent arrangements can be made, adequate security must be provided to prevent unauthorized access to the vicinity of the source, removal of any part of the source or the temporary shielding. This may be carried out in a manner similar to establishing the initial delineation, such as cordoning off the area, locking doors, displaying warning signs, patrolling the area, etc.

These measures should adequately deal with the situation at the site where the source has been initially located. For source recovery and waste management action, arrangements will need to be made for transport to an appropriate facility. If for this transport it is necessary to use the public domain, the provisions of the relevant transport regulations should be applied [16]. If the source is to be transported out of the country it is necessary to use certified transport containers. A written record of the method of packing should accompany the container, to help safe unpacking.

For advice on handling, conditioning and disposal of spent sealed sources see IAEA-TECDOC-548 [17].

7. FINAL REPORT

A final report, to be submitted to the relevant national authority, should be prepared by the search team. It should at least contain the following information:

1. The summary of all the information which prompted the decision to start the search for the radiation source (e.g. history of usage, documentary evidence, discussions with former and current employees).

2. Plans of the search, including location of the survey, list of available instruments and equipment and maps.

3. Summary of data collected by the survey team entered on the survey maps such as visual observations, dose rate results, soil sample positions and levels of contamination, with information about instruments, calibration and testing.

4. Description of the source or sources found, with available information about their activity, nature, condition of containment and shielding.

5. Description of the immediate actions taken to render the source(s) located safe.

6. Description of the arrangements taken to provide radiation protection for the search team, and summary information on doses incurred by the search team (extract from dose records) and members of the general public (estimates).

7. Recommendations regarding actions necessary for final management of the source(s).

8. Information on the experience gained by the search team.

In cases where a search has been unsuccessful, a report should also be submitted to the relevant national authority. Such a report should cover items 1- 3, 6 and 8 above.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Nature and Magnitude of the Problem of Spent Radiation Sources, IAEA-TECDOC-620, Vienna (1991).

[2] LUBENAU, J.O., Nussbaumer, D.A., Radioactive Contamination of Manufactured Products, Health Physics **51** 4 (1986) 409–425

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Practical Radiation Safety Manuals, IAEA, Vienna (1992 and 1993).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Recommendations for the Safe Use and Regulation of Radiation Sources in Industry, Medicine, Research and Teaching, Safety Series No. 102, IAEA, Vienna (1990).

[5] US NUCLEAR REGULATORY COMMISSION, Loss of an Iridium-192 Source and Therapy Misadministration at Indiana Regional Cancer Center, NUREG-1480 (1993).

[6] COMISIÓN NACIONAL DE SEGURIDAD NUCLEAR Y SALVAGUARDIAS, Secretaria de Energia, Minas e Industria Paraestatal, México, Accidente por Contaminación con Cobalto-60, México, CNSNS-IT-01 (1984).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Directory of High-Energy Radiotherapy Centres, 1976 Edition, IAEA, Vienna (1976).

[8] US NUCLEAR REGULATORY COMMISSION, "Hazardous Scrap - Beware!" (poster) NUREG/BR-0108 (1986).

[9] COMISIÓN NACIONAL DE SEGURIDAD NUCLEAR Y SALVAGUARDIAS, "¡Cuidado con la chatarra!", Mexico scrap metal dealer poster.

[10] INSTITUTE OF SCRAP RECYCLING INDUSTRIES, INC., Radioactivity in the Scrap Recycling Process, Washington (1993).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Emergency Planning and Preparedness for Accidents Involving Radioactive Materials Used in Medicine, Industry, Research and Teaching, Safety Series No. 91, IAEA, Vienna (1989).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Basic Principles for Occupational Radiation Monitoring, Safety Series No. 84, IAEA, Vienna (1987).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Operational Radiation Protection, A Guide to Optimization, Safety Series No. 101, IAEA, Vienna (1990).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Basic Safety Standards for Radiation Protection, Safety Series No. 9, 1982 Edition, jointly sponsored by IAEA, ILO, NEA(OECD), WHO; IAEA, Vienna (1982).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Monitoring of Radioactive Contamination on Surfaces, Technical Reports Series No.120, IAEA, Vienna (1971).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material, 1985 Edition (As Amended 1990), Safety Series No. 6, IAEA, Vienna (1990).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Handling, Conditioning and Disposal of Spent Sealed Sources, IAEA-TECDOC-548, Vienna (1990).

Annex I
CHARACTERISTICS OF SELECTED RADIONUCLIDES USED IN SEALED RADIATION SOURCES

Radium-226 is part of the decay chain of ^{238}U. Radium decays with alpha emission to ^{222}Rn, a noble gas with a half-life of 3.6 days. Before the decay chain ends with the stable isotope ^{206}Pb, it has generated a further eight radionuclides of which four are alpha emitters. Each decaying ^{226}Ra atom thus gives rise to five alpha particles. During the decay many high as well as low energy gamma quanta and beta particles are also emitted. In a radium source there are always not only ^{226}Ra but also its daughter products. Radium-226 is a very radiotoxic radionuclide with a correspondingly low annual limit of intake (ALI). A simplified scheme for the ^{238}U series, which includes ^{226}Ra, is shown in Figure I-1. Some important characteristics of ^{226}Ra are given in Table I-1.

Radium is an alkaline earth metal. It is very reactive and reacts even with nitrogen. In radiation sources radium is therefore always used in the form of salts, which may be bromides, chlorides, sulphates or carbonates. All are soluble in water in amounts which can give rise to radiological problems. These salts may easily be dispersed as powder if the source encapsulation is damaged. This is one reason why radium is not regarded as an ideal radionuclide for use in sealed sources.

In the body radium behaves like calcium, which means it concentrates in the bone where it has a very long biological half-life.

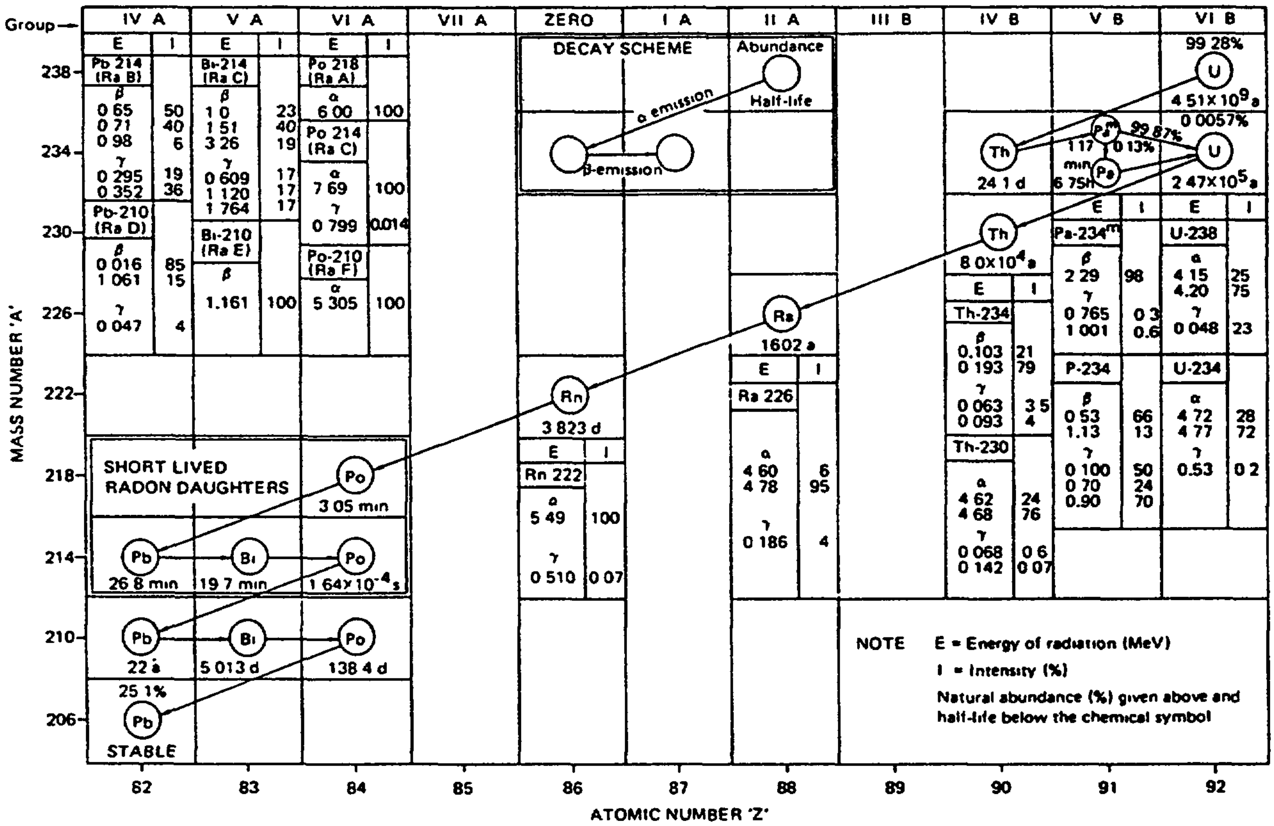


FIG. I-1. A simplified scheme for the ^{238}U decay series, which includes ^{226}Ra [I-2].

TABLE I-1. CHARACTERISTICS OF FIVE RADIONUCLIDES OFTEN USED IN SEALED RADIATION SOURCES

Characteristics	Radionuclide						
	^{60}Co	^{137}Cs	^{192}Ir	^{226}Ra	^{241}Am	^{90}Sr (^{90}Y)	^{125}I
Half-life	5.27 a	30 a	74 d	1600 a	433 a	29 a	60 d
Principal							
- alpha energy [MeV]	-	-	-	[a]	5.86	-	-
- max beta energy [MeV]	0.31	1.2	0.67	[a]	-	0.55 (2.3)	-
- gamma energy [MeV]	1.17 1.32	0.66	0.32 0.47	[a]	0.06	-	0.03
Gamma constant [μSv/h GBq at 1 m]	360	86	140	220	4	3.5 (Bremss.)	39
Dose rate at 1 cm from a 1 MBq source[b] [mSv/h]	2.5	0.6	0.9	1.7	[c]	[d]	[d]
Half value layer (HVL) of lead [mm]	12	6	5.5	14	0.2	(10)	0.02
ALI(oral) [Bq]	7×10^6	4×10^6	4×10^7	7×10^4	5×10^4	1×10^6	1×10^6
ALI(inhalation) [Bq]	1×10^6	6×10^6	8×10^6	2×10^4	2×10^2	1×10^5	2×10^6

[a] In the decay chain there are alpha energies up to 7.7 MeV, beta energies up to 2.8 MeV and main gamma energies up to 2.4 MeV.

[b] Dose rate calculated for a point source encapsulated in 0.8 mm stainless steel. An addition of 35-45% is made to take into account electron production in the encapsulation [I-2].

[c] Dose rate is very dependent on encapsulation, which may include a thin window. At short distances the dose rates can be very high from alpha radiation, but not at larger distances.

[d] Dose rate is very dependent on type of construction.

The decay of each atom of ^{226}Ra yields five helium atoms formed from the alpha particles emitted in the decay chain. This generates overpressure in a sealed radium source (about 0.2 atmospheres per year for one gram of radium and a free volume of 1 cm^3) and facilitates the spread of contamination if it starts leaking. If there is water of crystallization in the source, the alpha particles emitted in the decay chain decompose it to oxygen and hydrogen, which further increases the overpressure. Leaking radium sources have always been a major radiation protection problem. In the early days there were explosions of large standard ^{226}Ra sources encapsulated in glass, and explosive ruptures of metal sealed sources have also been reported. This characteristic of ^{226}Ra is another reason why it is regarded as unsatisfactory from the point of view of radiation protection.

Cobalt-60 is produced by neutron bombardment of natural cobalt. If pure cobalt is used as target material, ^{60}Co will be produced almost free of other radionuclides. It decays by emission of beta particles and two gamma quanta (1.17 and 1.33 MeV) to a stable nickel isotope. The half-life is 5.27 years. Important characteristics of ^{60}Co are shown in Table I-1.

In sealed radiation sources, metallic cobalt is always used since this gives the highest specific activity to the source. Usually it is in the form of thin discs or small cylindrical pellets. The metal is stable in air, but a thin layer of oxide forms on its surface and this could cause contamination if unprotected cobalt is handled. For this reason the cobalt used in radiation sources is nickel plated before activation.

Cobalt metal is not soluble in water. If cobalt in a soluble form is taken up by the body it is evenly distributed, with the exception of the liver where four times higher concentration may be reached.

Caesium-137 is a fission product produced in reactor fuel. It must be purified chemically from other elements before it can be used in a radiation source. Its half-life is 30 years and the decay mode is beta and gamma. The gamma energy is low (0.66 MeV) in comparison to that of ^{60}Co, which implies that less shielding is required, but since the gamma output is also lower, higher activity is needed to achieve the same dose rate. The radiation output achievable from a sealed source is however limited by self absorption within the source. Important characteristics of ^{137}Cs are shown in Table I-1.

Caesium is an alkaline metal similar to potassium and sodium. It is very reactive and can only be used as a salt in sealed radiation sources. Caesium chloride has often been used. Today ^{137}Cs sources are also prepared in ceramic form, making the radionuclide virtually insoluble in water. This technique is used only for weak sources, however, because it results in a drastic reduction of specific activity. When taken up by the body, the highest concentrations are reached in muscle tissue.

Iridium-192 is produced by neutron irradiation of metallic iridium. It has a short half-life, only 74 days, which makes all iridium sources harmless within five years. It decays via emission of beta particles and gamma quanta to stable platinum and osmium isotopes. The decay scheme includes many different gamma quanta with energies up to about 0.5 MeV. Important characteristics of ^{192}Ir are shown in Table I-1. Iridium is a noble metal which is not oxidized in air or dissolved in water, which are excellent characteristics for a sealed radiation source.

Americium-241 is a transuranic element, produced in uranium by neutron bombardment. Like ^{137}Cs, it is a by-product of nuclear power production. Its half-life is 433 years and it decays by alpha emission to a long-lived neptunium isotope with a half-life of 2 million years. Important characteristics of ^{241}Am are shown in Table I-1.

Americium has chemical characteristics similar to the rare earth metals, indicating that as metal it is not in a stable form. Normally, oxides are used in sources. For neutron sources fine oxide powder is mixed with beryllium powder. Most sources contain Am-Be in powder or pellet form; a small number contain Am-Be in sintered form. When used as a low energy gamma source the stainless steel capsule has a thin closure in one direction to allow the quanta to be emitted without undue attenuation. In the human body the element is concentrated in bone and liver, and small intakes give high committed dose.

Strontium-90 is a fission product produced in reactor fuel. Sources will most often be prepared by purification from processing of the fission products. The form of the source will be an oxide or titanate. For medical applications, for example superficial and ophthalmic treatment, the strontium compound will be contained in a silver plate and screened with 0.1 mm palladium coated silver. For other applications the strontium compound may be incorporated in a ceramic, glass bead or rolled silver foil.

The high energy beta activity of the daughter product, yttrium-90 (which has a half-life of 62 h), results in the emission of high energy bremsstrahlung which may require heavy shielding for high strength sources. Some characteristics of $^{90}Sr/^{90}Y$ are shown in Table I-1.

When taken into the body much of the $^{90}Sr/^{90}Y$ will be deposited in bone. Depending upon whether the intake is by inhalation or ingestion, some deposition in the lungs or the lymph glands may also occur.

Iodine-125 is normally produced as the result of alpha irradiation of antimony according to the reaction ^{123}Sb (α, 2n) ^{125}I. It has a short half-life of 60 days. It decays by electron capture resulting in the emission of low energy X rays of 27 and 35 keV.

Iodine-235 sources used for brachytherapy would typically consist of iodine-125 adsorbed onto a silver rod or an ion exchange resin bead, welded into a thin titanium capsule. When used for industrial purposes, the sources would typically take the form of an active resin bead enclosed in a stainless steel capsule with a thin titanium window. This construction would normally be expected to result in a fine collimated radiation beam. Principal characteristics of ^{125}I are given in Table I-1.

Because the source is constructed of active material absorbed onto a substrate, should the encapsulation become damaged some of the radioiodine may become volatilized.

When taken into the body, isotopes of iodine concentrate preferentially in the thyroid. If uptake of radioiodine is suspected, deposition in the thyroid can be minimized by administration of stable iodide up to a few hours after the intake.

Further details on the above and other radionuclides can be found in Refs[I-1] to [I-4].

REFERENCES TO ANNEX I

[I-1] MOLINARI, J., SNODGRASS, W.J.,"The chemistry and radiochemistry of radium and the other elements of the uranium and thorium natural decay series", The Environmental Behaviour of Radium, Vol. 1, Technical Reports Series No. 310, IAEA, Vienna (1990).

[I-2] NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS, Protection Against Radiation from Brachytherapy Sources, NCRP Report No. 40, Washington (1972).

[I-3] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Limits for Intakes of Radionuclides by Workers, ICRP Publication 30, Pergamon Press, Oxford and New York (1979) (and later supplements).

[I-4] WANG, Y. (Ed.), Handbook of Radioactive Nuclides, The Chemical Rubber Co. (1969).

Annex II
ILLUSTRATIONS OF SOURCES AND EQUIPMENT WITH INSTALLED SOURCES

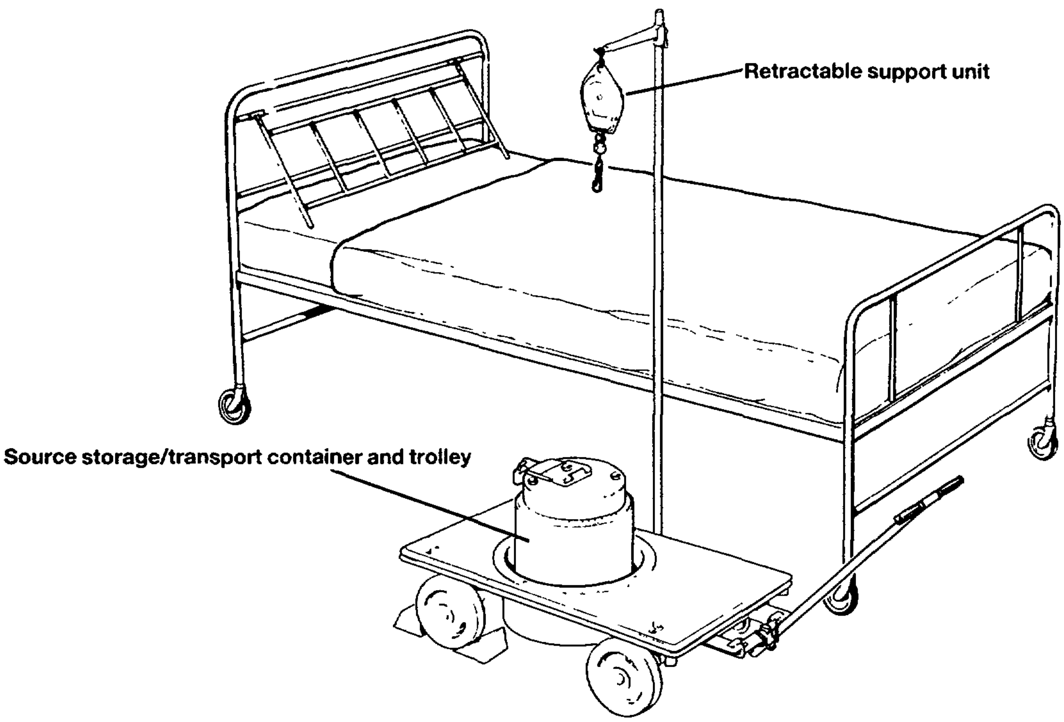
This annex provides illustrations for the purpose of facilitating visual recognition of devices or housings used to contain radiation sources. Only a limited number of illustrations depicting radiation sources have been included, because location of unshielded sources is deemed to depend on radiation measurement rather than on visual recognition. It must also be borne in mind that shapes and sizes of radiation sources vary considerably.

The illustrations focus on general or typical design characteristics and do not attempt to cover all design variations.

Brachytherapy

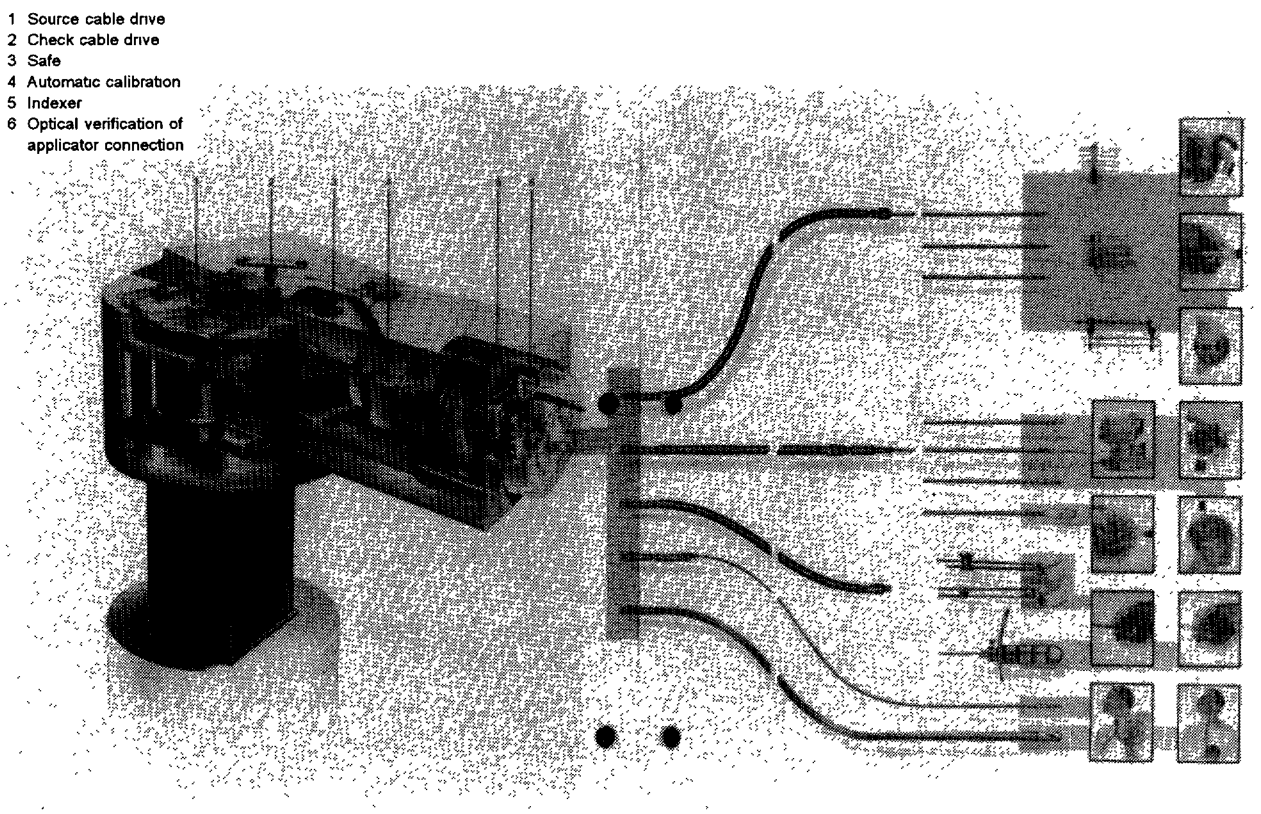
There are many different types of brachytherapy devices depending upon the treatment which is to be given.

Manual afterloading systems usually consist of a lead shielded source transfer pot either mounted on a trolley or carried by a handle to the patient's bedside. An example of these systems is given in the illustration below. The source mountings will vary considerably and it is not possible to illustrate a typical source.



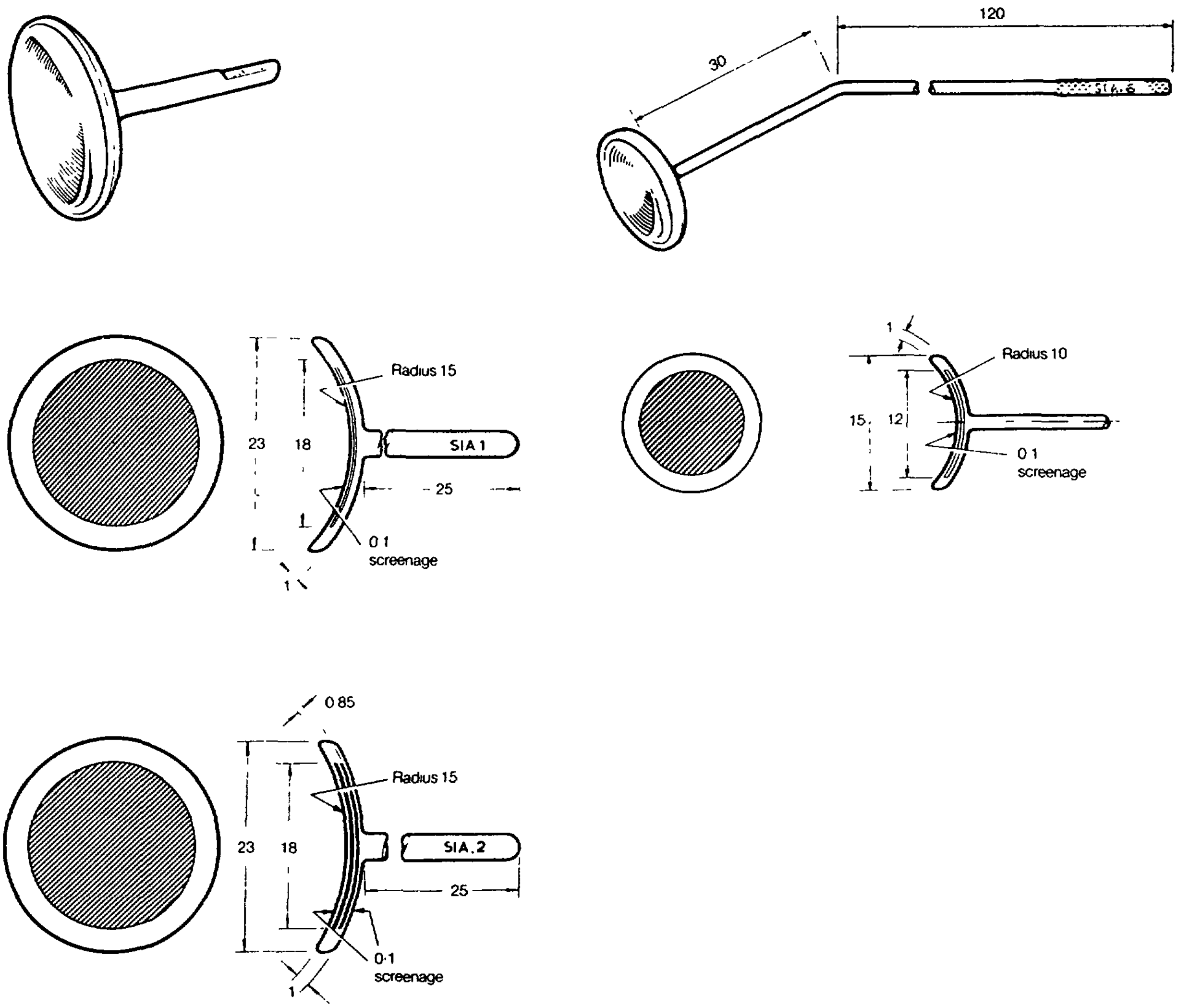
Shielded iridium-192 source handling system.
The retractable support unit is designed to take the weight of the handling gun and allow it to be moved from the storage/transport container to the implant. The source storage/transport container can hold up to 50 iridium-192 wire source assemblies. Prior to source implant it can be positioned next to the patient's bed.

Remote afterloading systems consist of similar shielding devices with facilities for remotely projecting sources along guide tubes into the body of the patient. The size, shape and construction of these shields varies markedly depending upon the type of sources to be used, the manufacturer and the year of manufacture. It is not therefore practicable to illustrate typical remote after loading equipment. The illustration below indicates the general principles used.



System layout and applicators

Devices are available for treatment of skin lesions and the eyes. These devices vary in size and shape depending upon their purpose. Typical devices are illustrated below.

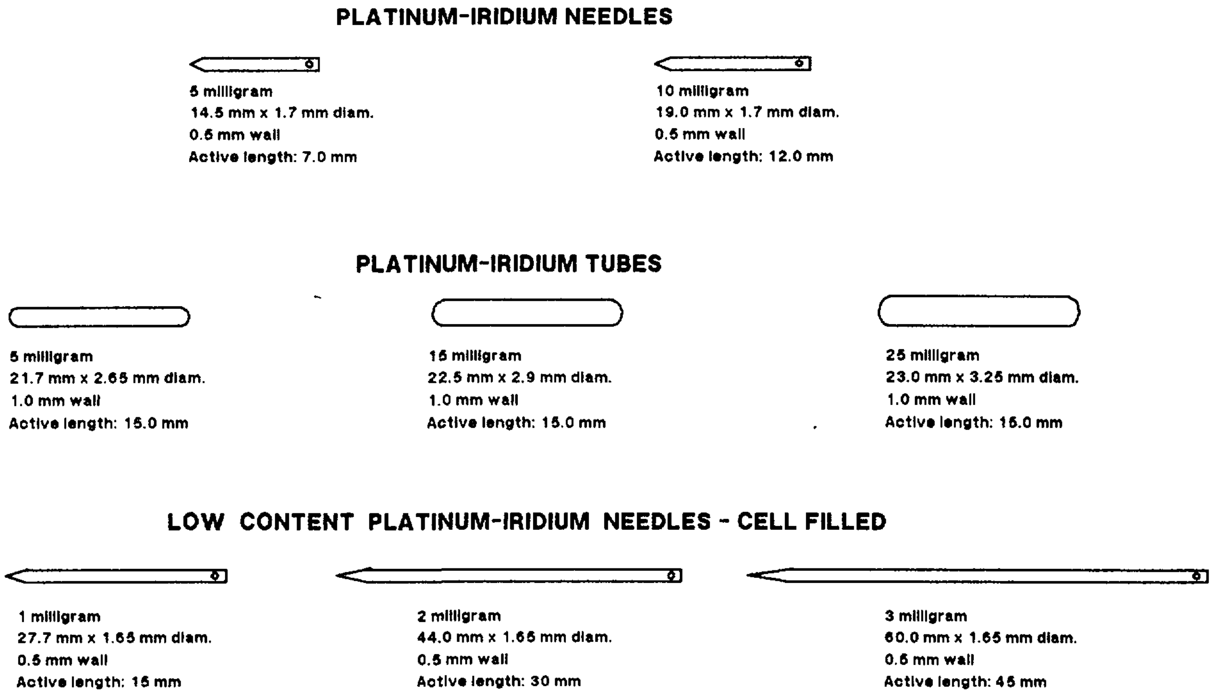


Superficial treatments: curved ophthalmic applicators.
These applicators contain a strontium-90 compound incorporated in rolled silver sheet.

Radium sources store

Radium sources and other brachytherapy sources would normally be stored in a safe similar to that illustrated here, although they may also be found in places not normally recognized as source stores. The sources themselves may have the appearance illustrated below.

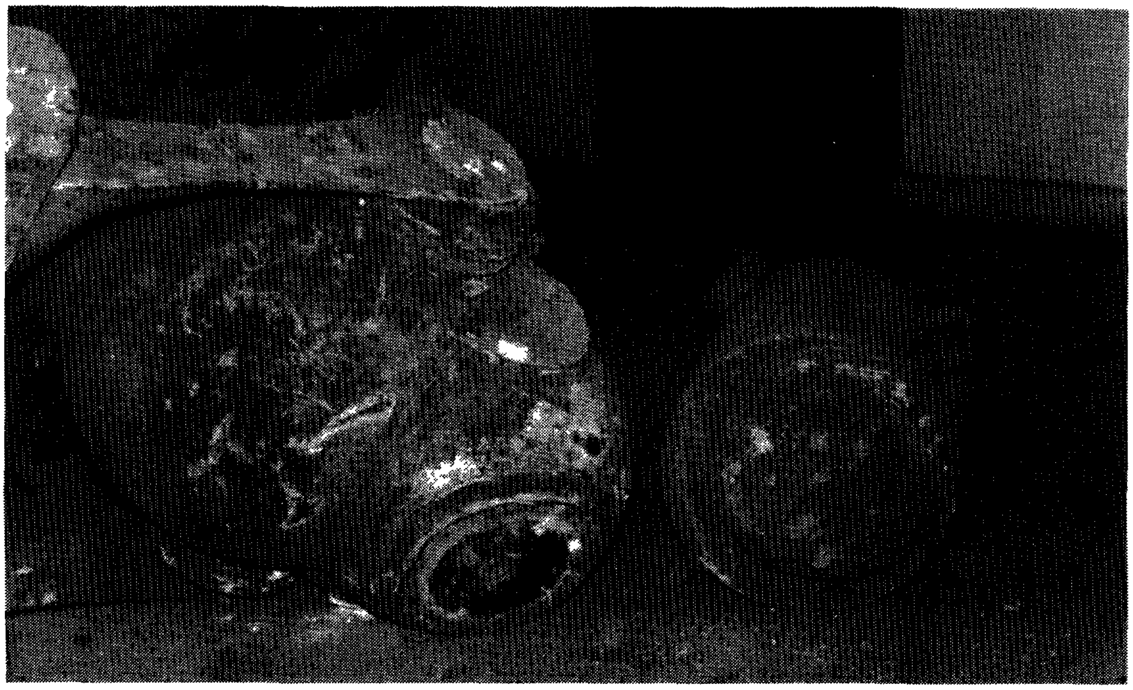
Radium store

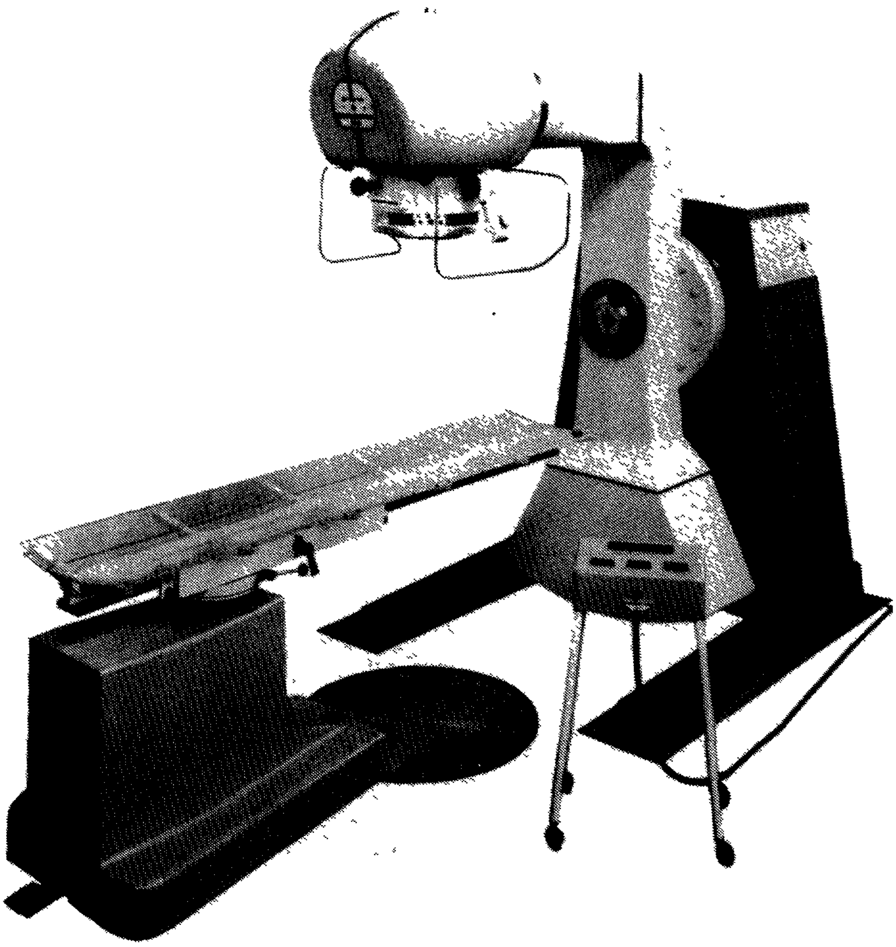


Examples of radium brachytherapy sources

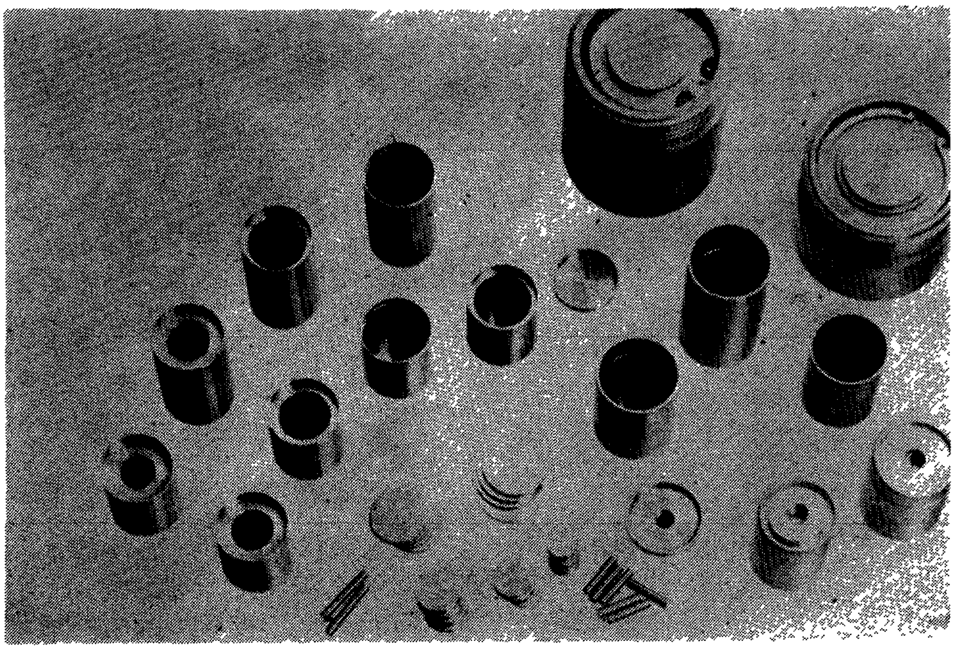
Teletherapy source housings

Teletherapy source housings are characterized by large amounts of shielding, when in use mounted on a counterbalanced arm. When the sources are spent the housings may be dismounted from the counterbalance mechanism.





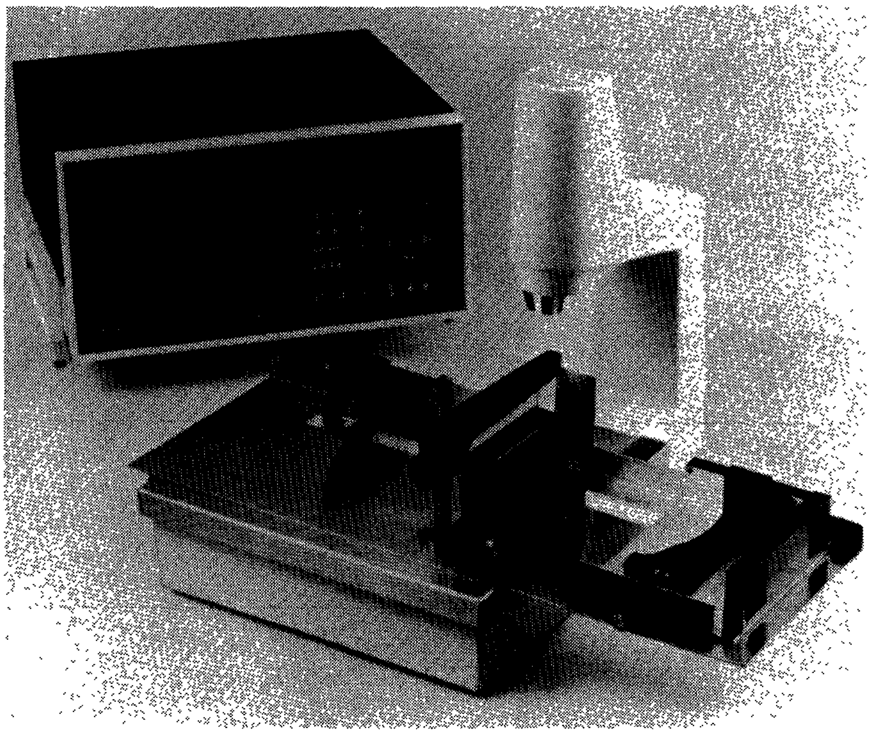
Cobalt-60 teletherapy equipment



Components for fabricating cobalt sources for teletherapy

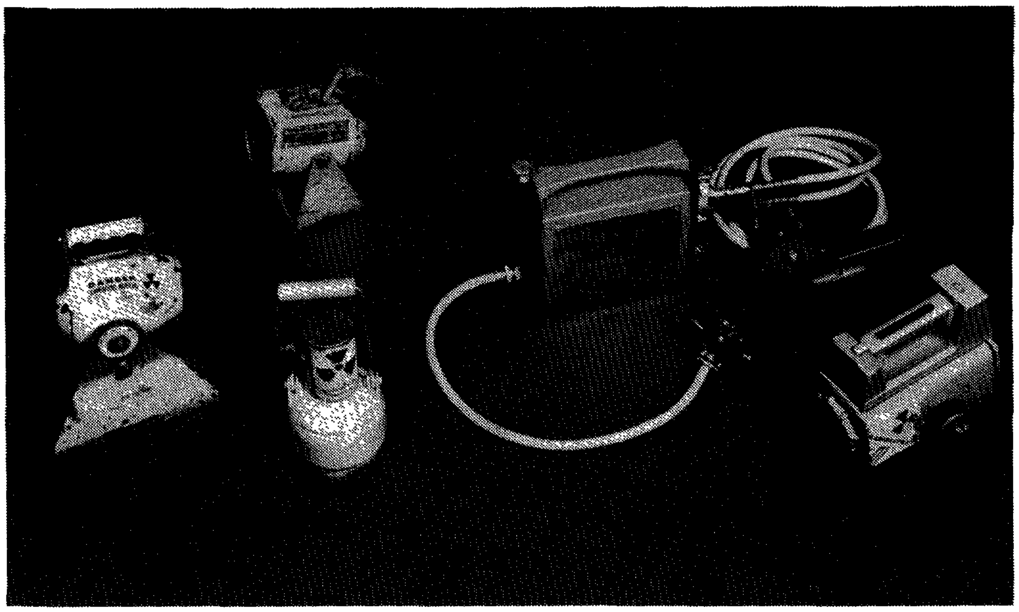
Bone densitometers

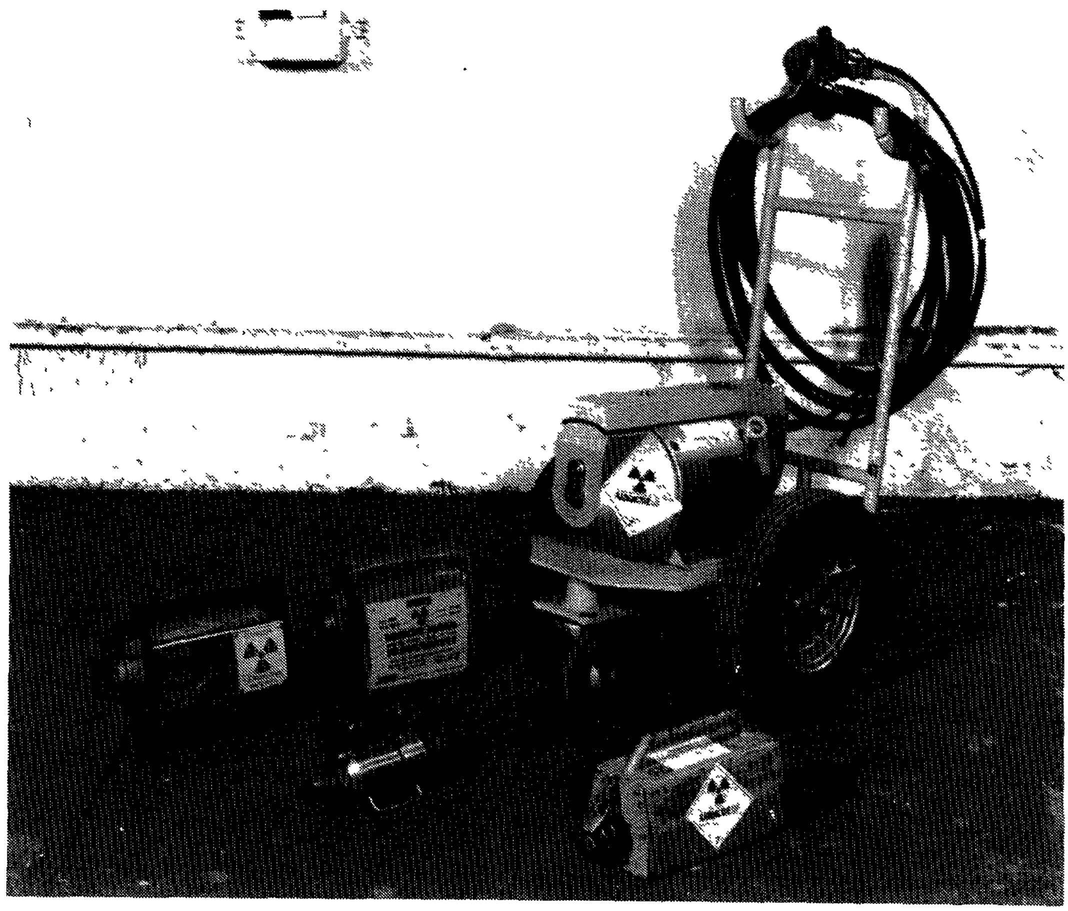
The source housing is attached to a fixture and the unit is portable.

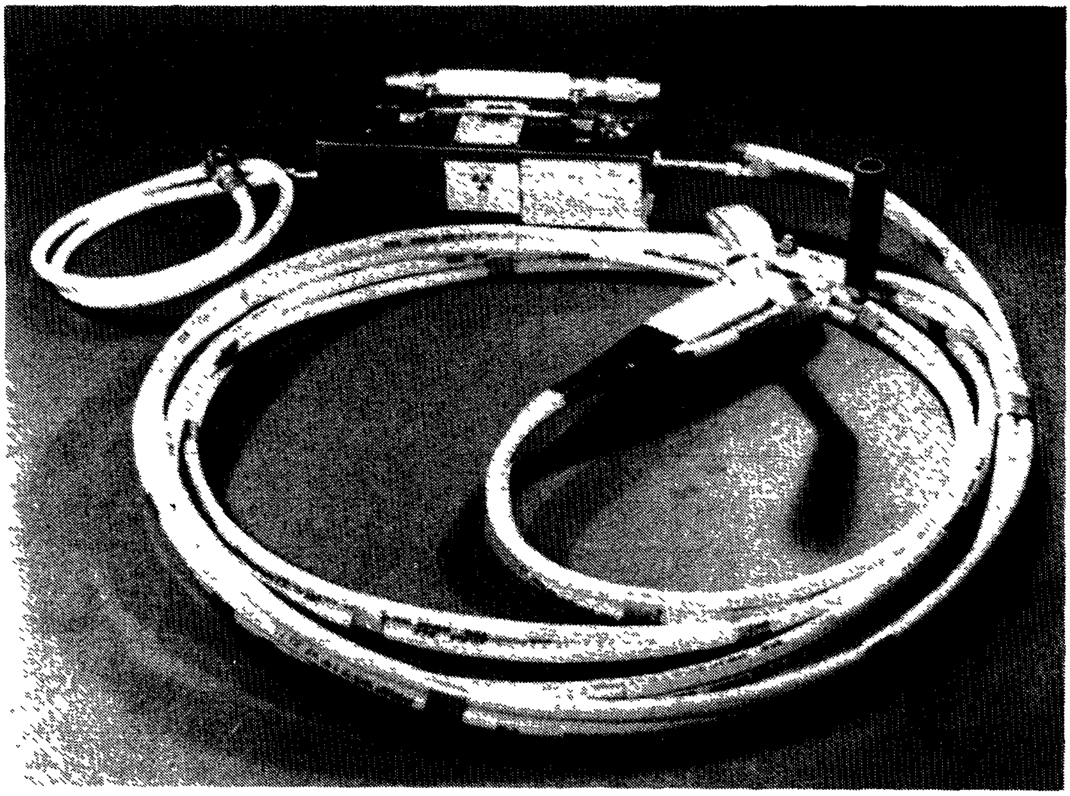


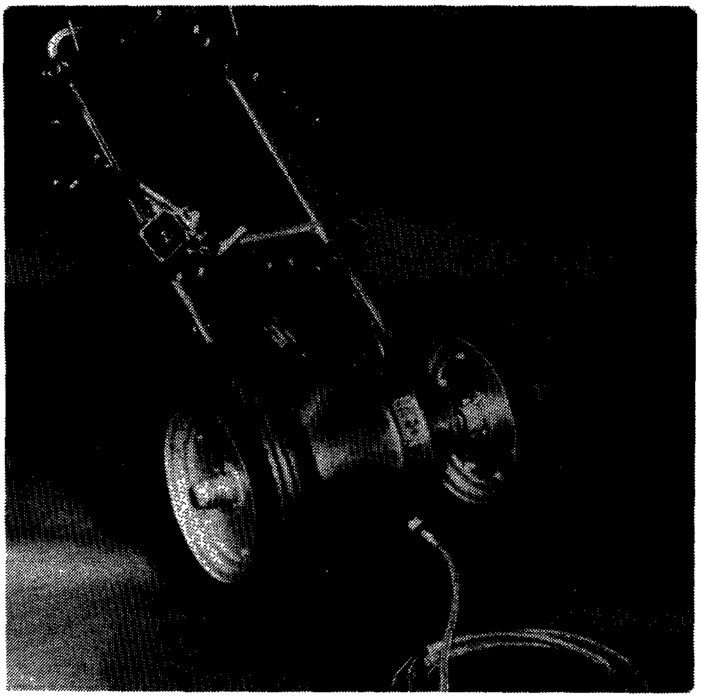
Industrial radiography

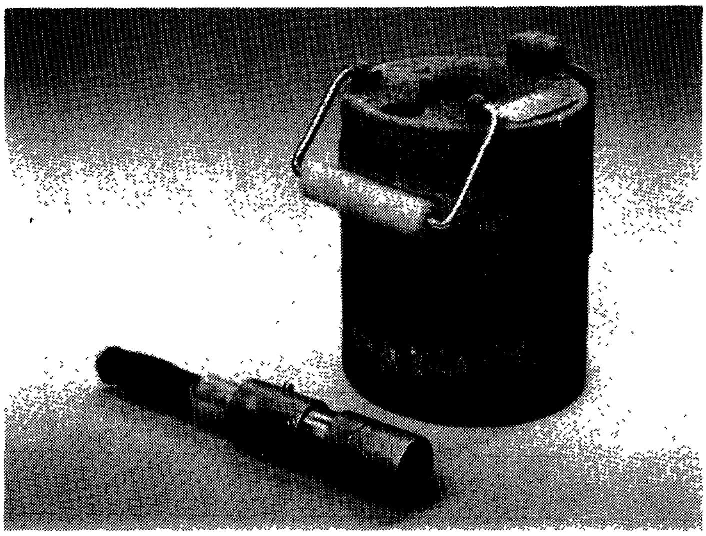
Source housings for industrial radiography vary depending upon the radionuclide contained and the purpose for which they are manufactured. They may be portable, mounted on wheels, designed so that the source is always contained within the shielding or designed so that the source can be moved from the shielding either remotely or manually. A selection of the different types of equipment is illustrated here.

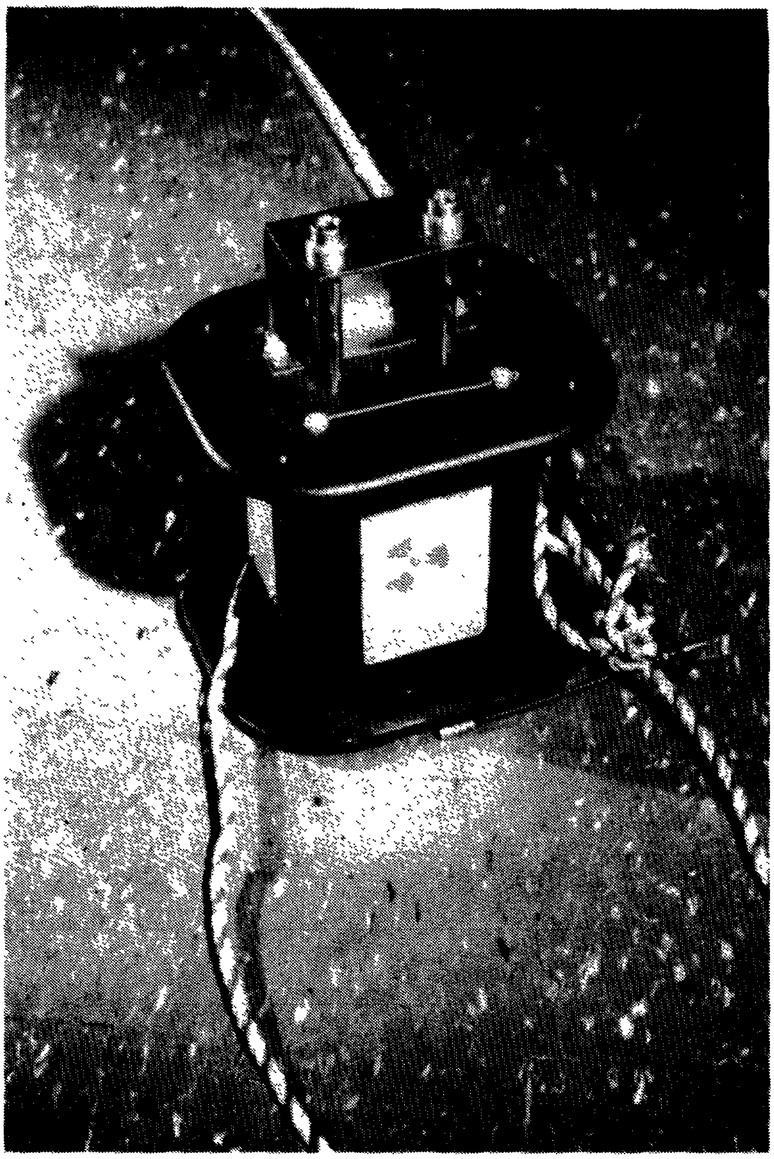


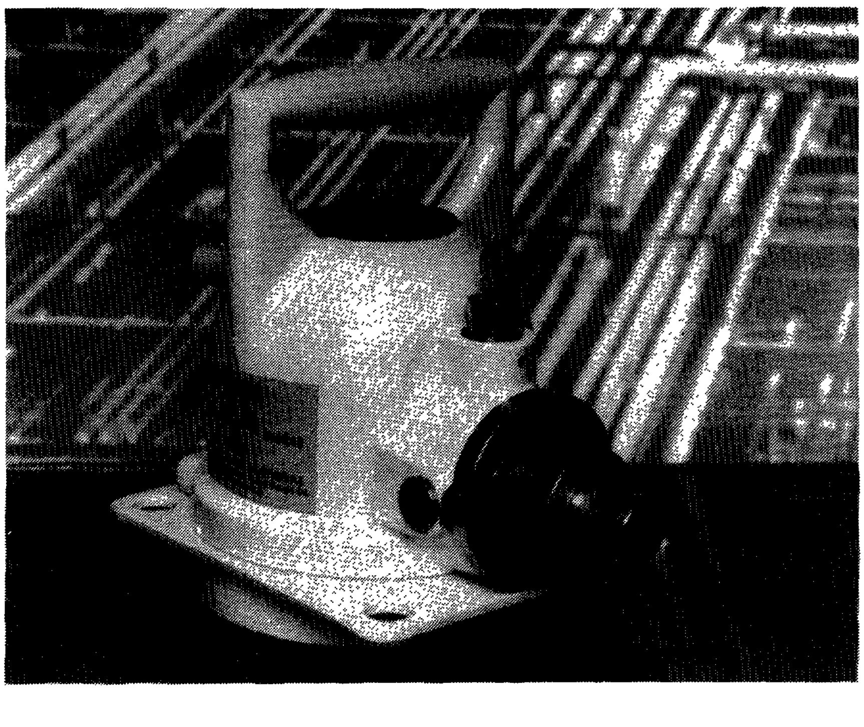








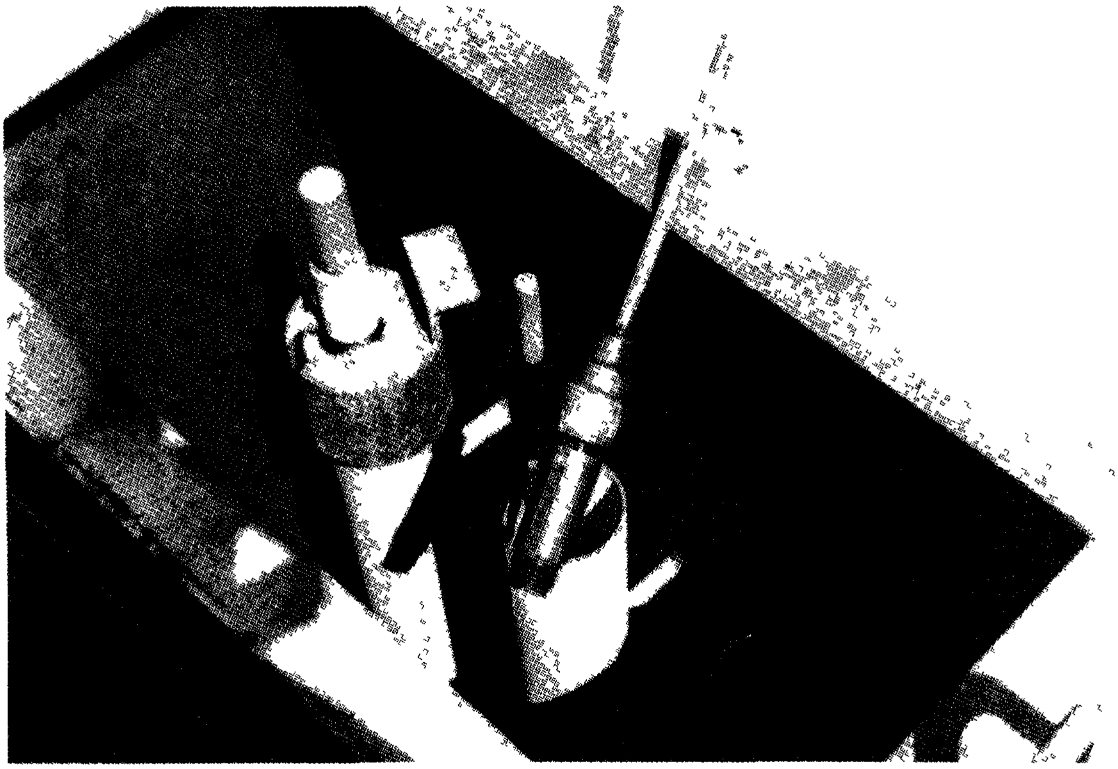




Gamma ray pipeline crawler
Self-propelled, battery operated and remote controlled

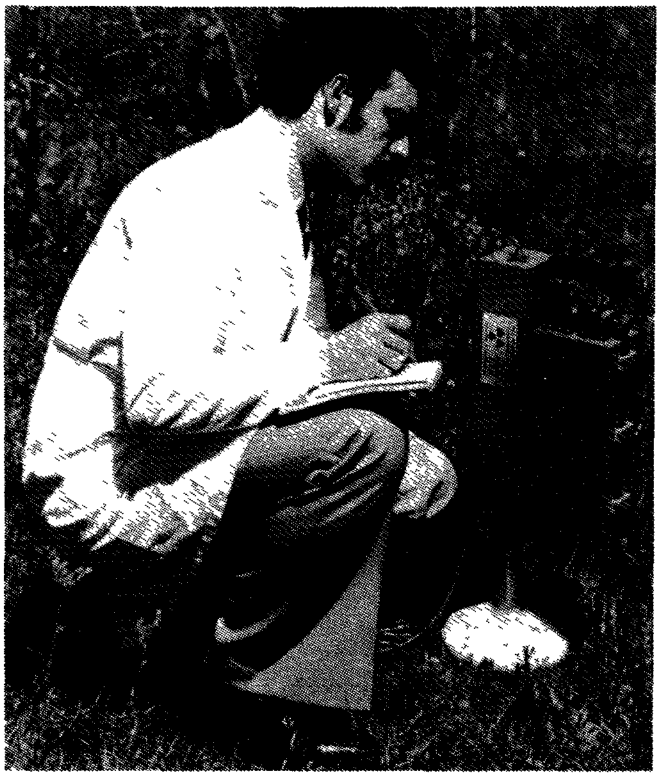
Borehole probes

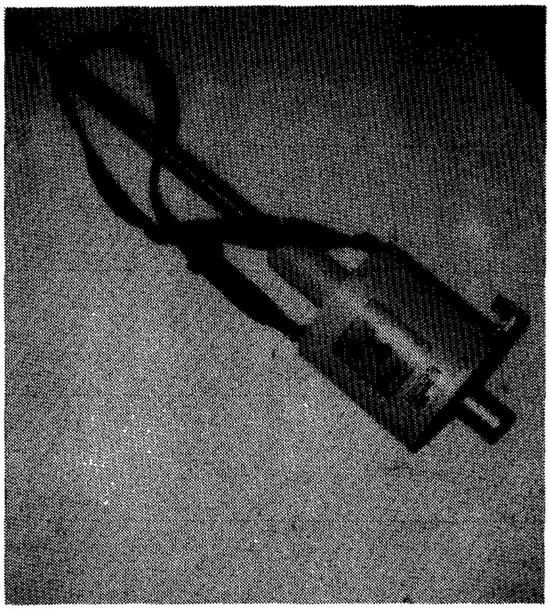
These sources, which may be gamma or neutron emitters are normally transported in the containers illustrated. When in use the sources will be removed from the transport containers and mounted in tools which are lowered into the borehole.

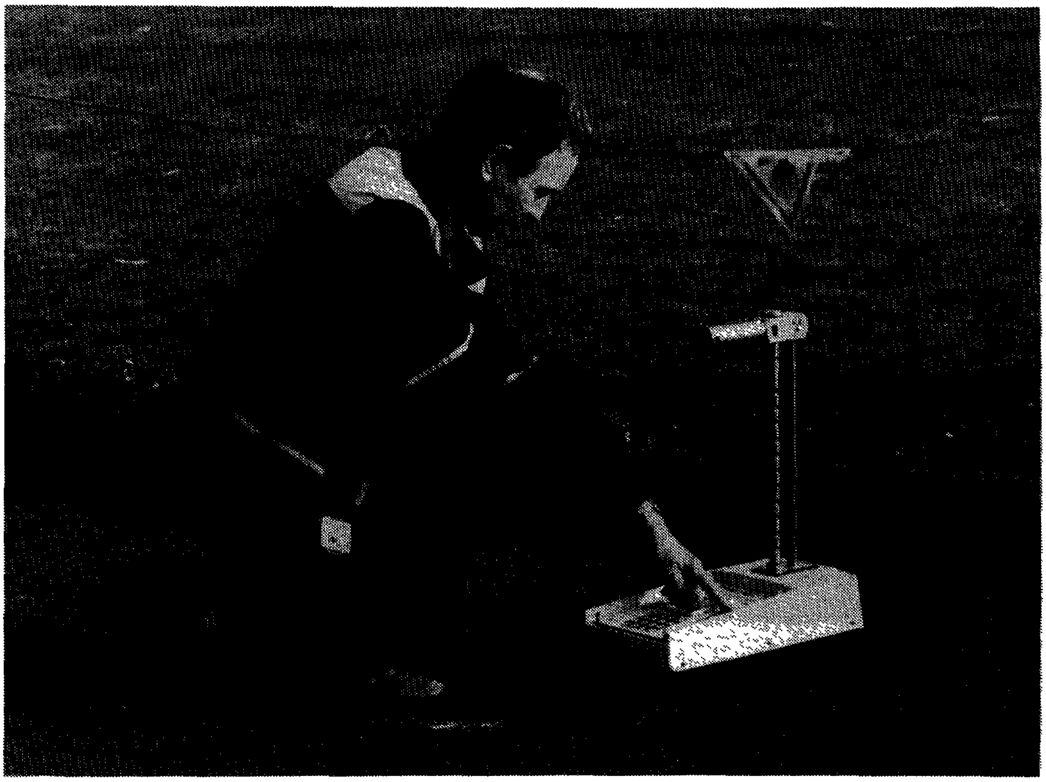


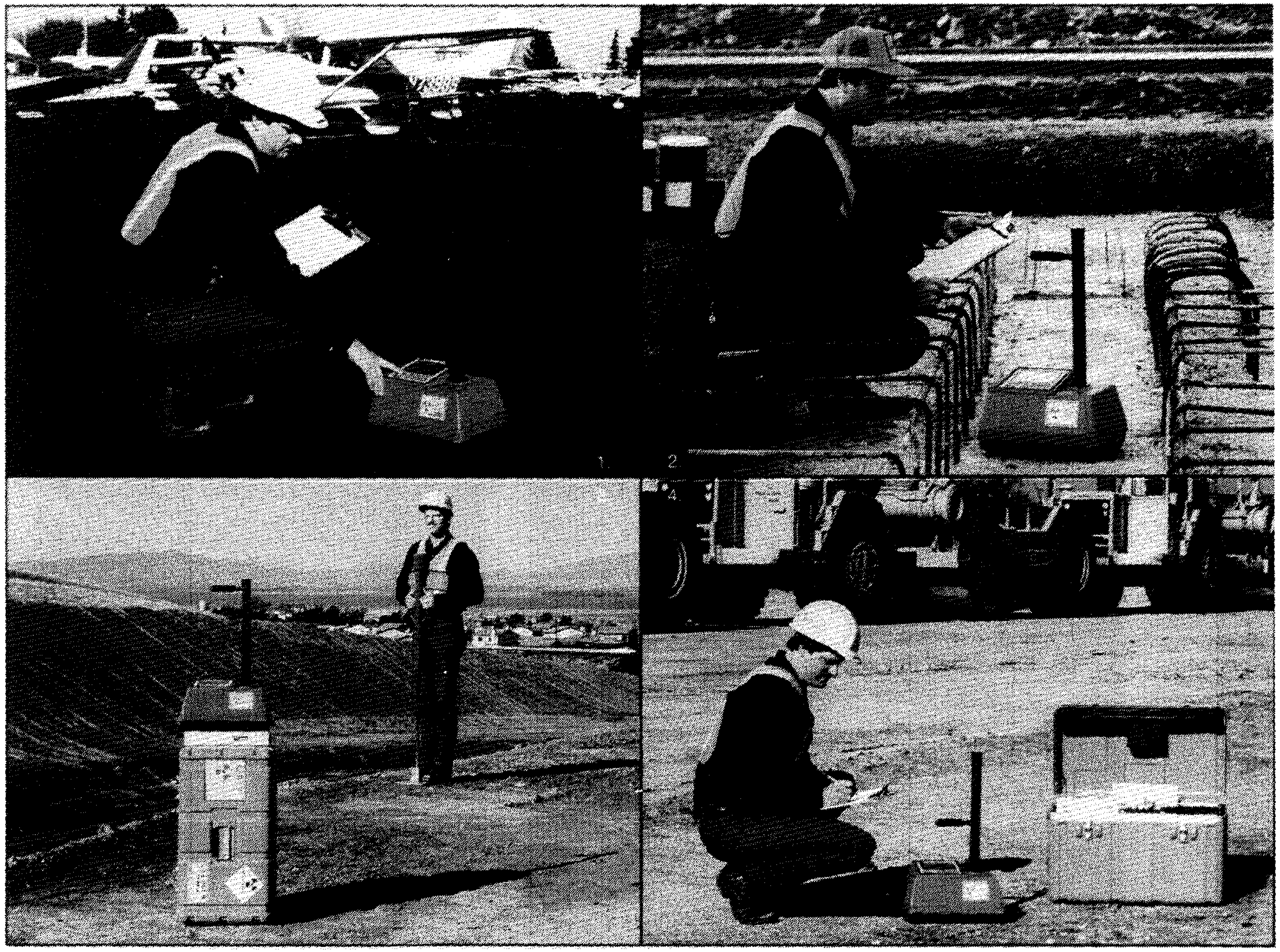
Moisture and density probes

In these devices the sources are normally retained within the body of the instrument although it is sometimes possible to lower a source probe into a shallow hole. The equipment may contain neutron or gamma or both neutron and gamma emitting sources.





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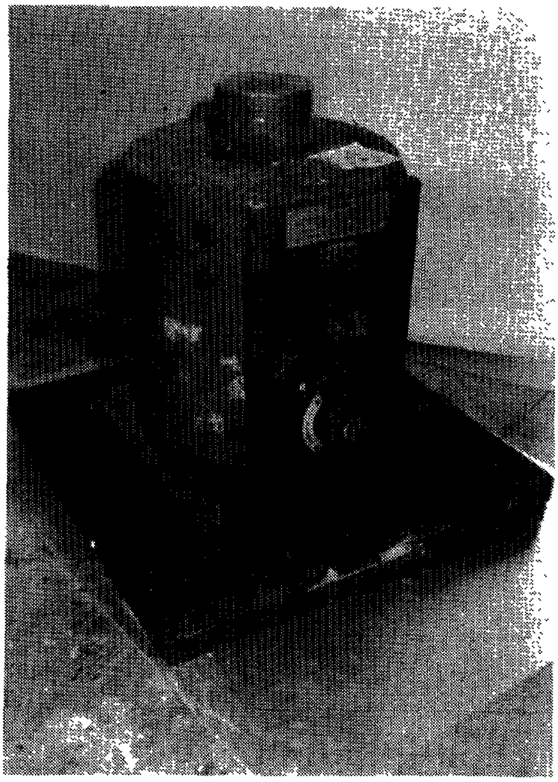
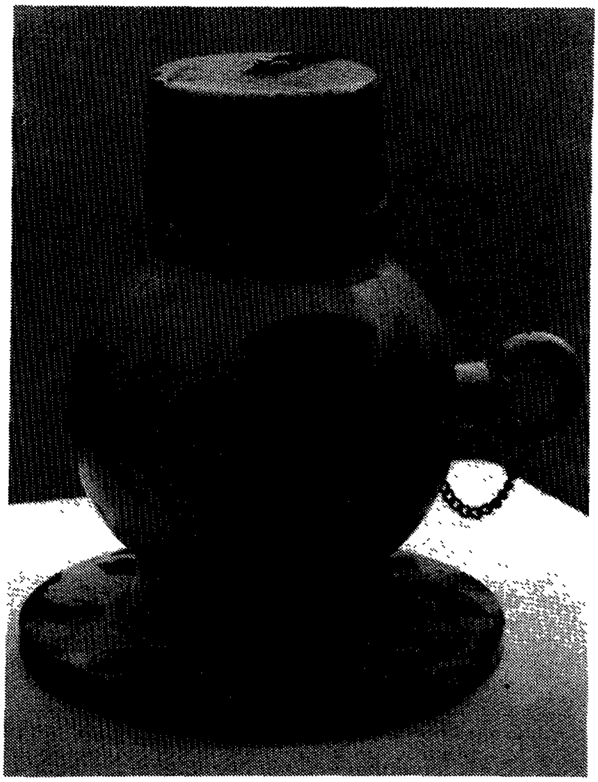
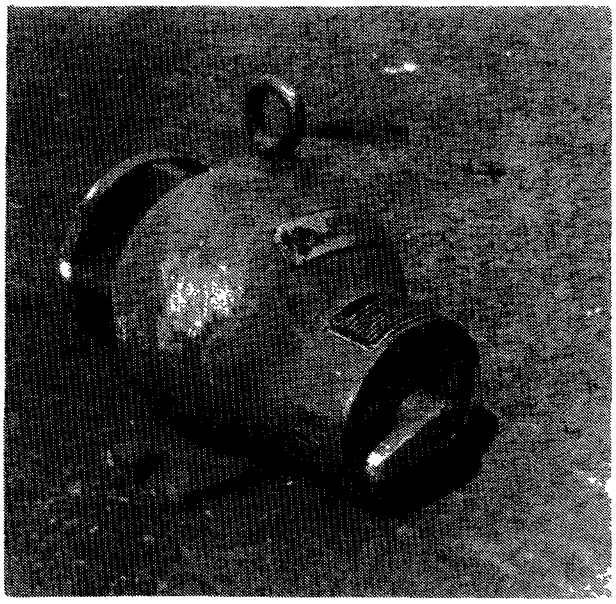
Industrial gauges

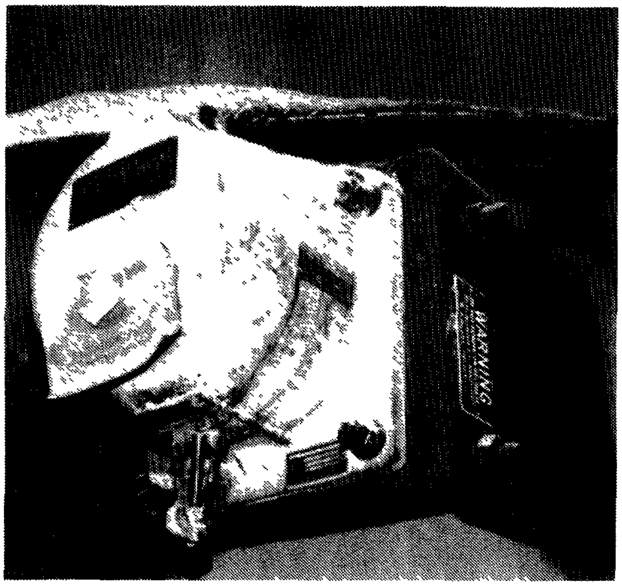
Level gauges

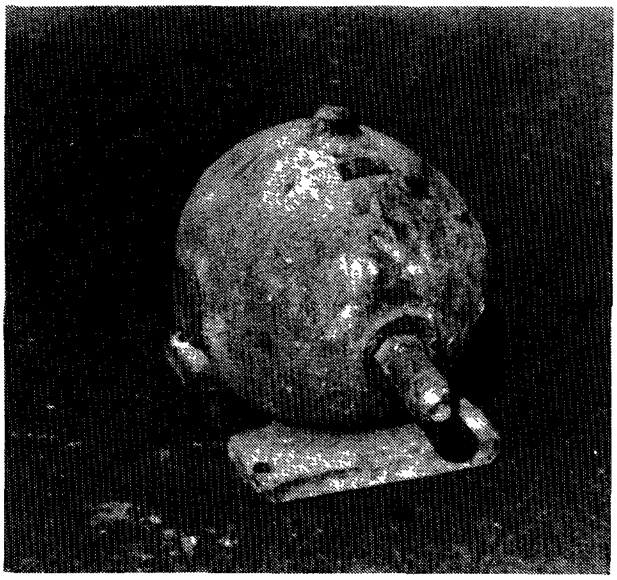
These will normally be mounted on tanks or hoppers to measure the level of material within the vessel. They vary in size and shape and may or may not have recognizable markings on them. There will normally be a handle or other method of opening and closing a shutter over the source.





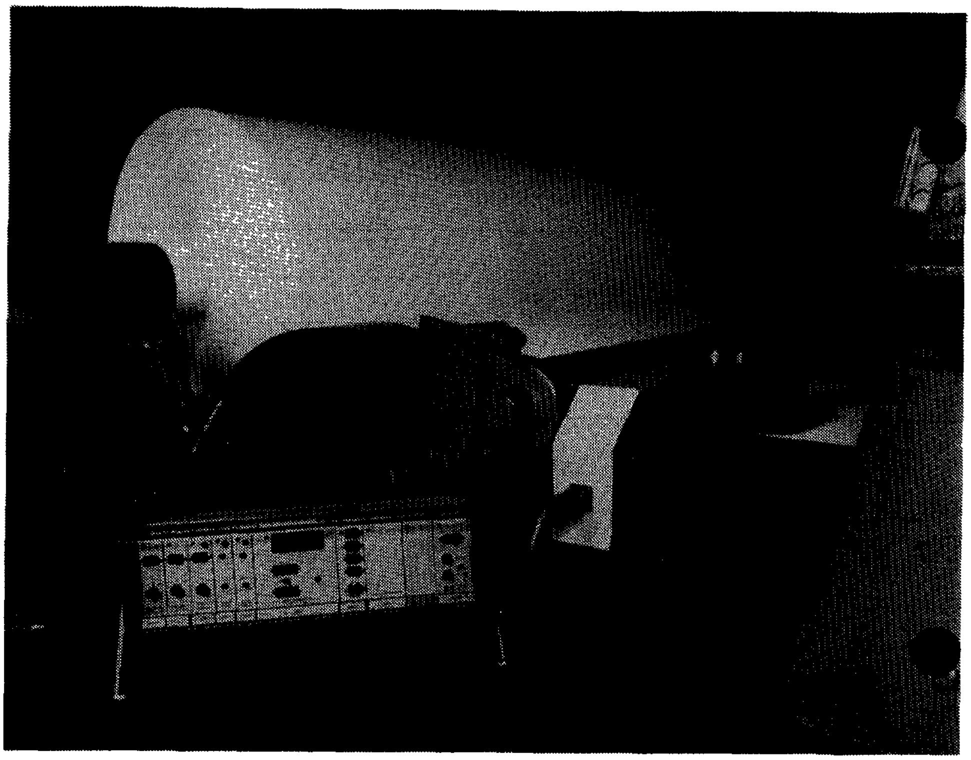



WARNING



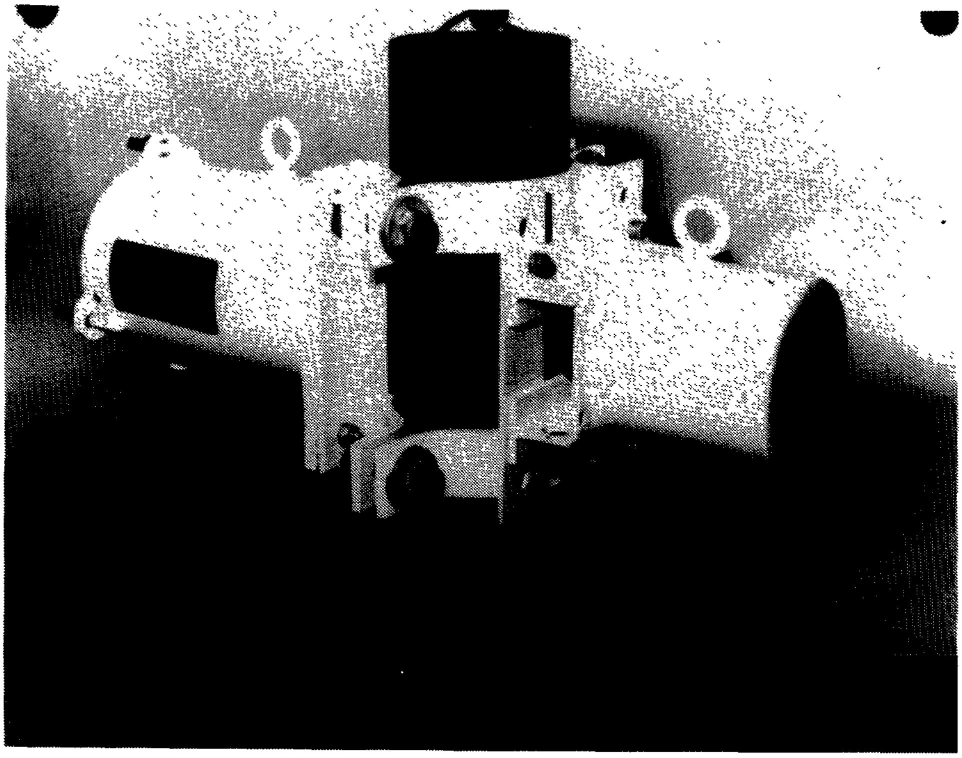
Thickness/density gauges

These will often be mounted on machines to measure the thickness or density of paper, plastics or sheet metal during manufacture. They may be designed to scan the whole width of the material or just to measure at a fixed position.



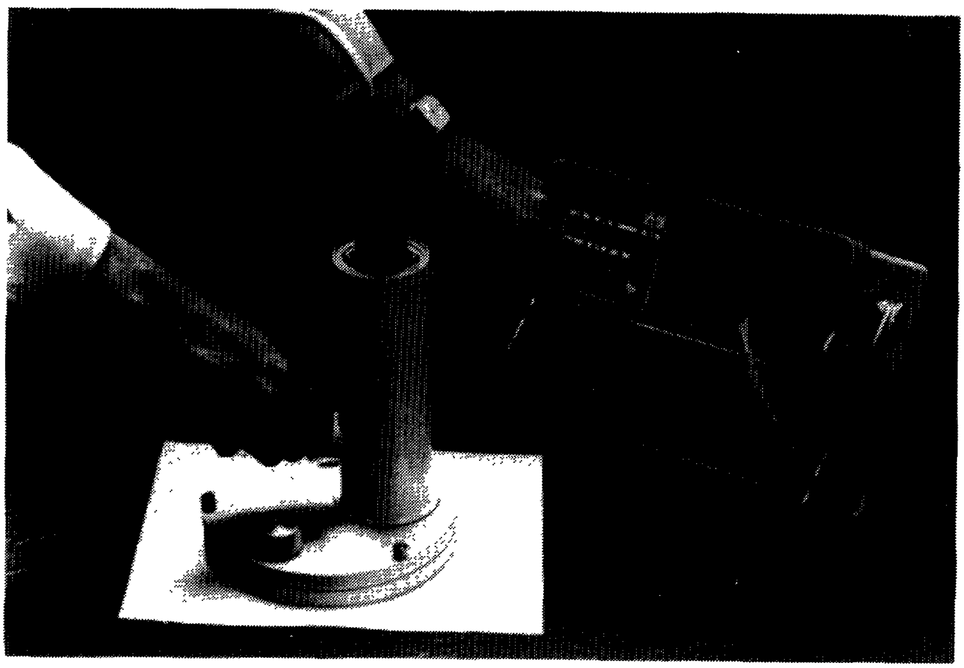
Fluid density gauges

These gauges will be fixed to or mounted on pipes through which fluids are pumped. They will normally consist of a source housing at one side of the pipe and a detector at the other both mounted on a locating frame.



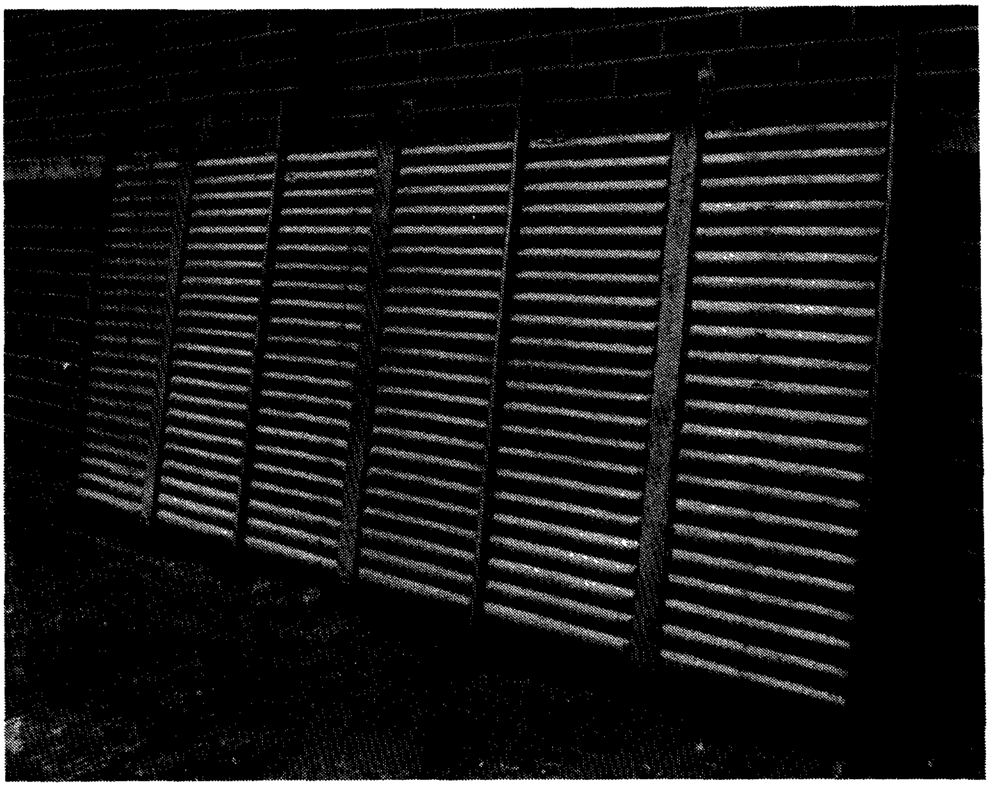
Hand held gauges

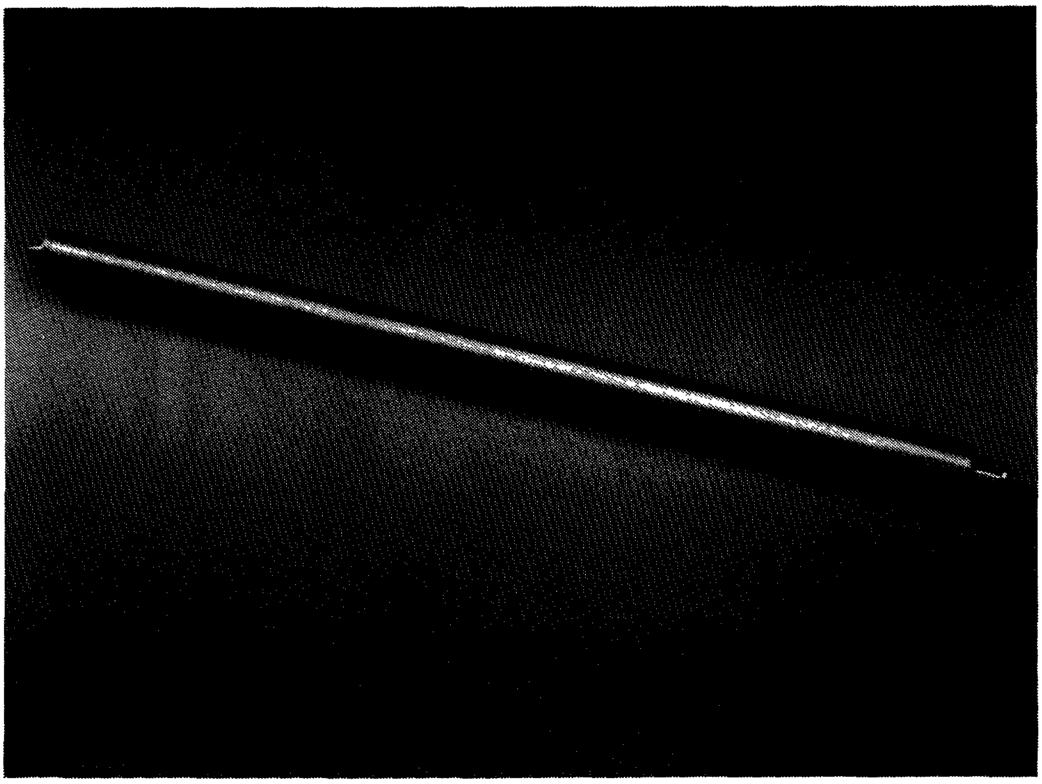
These gauges may use the technique of backscatter or X ray fluorescence to measure the nature or thickness of materials. They normally incorporate low strength sources only.



Industrial irradiators

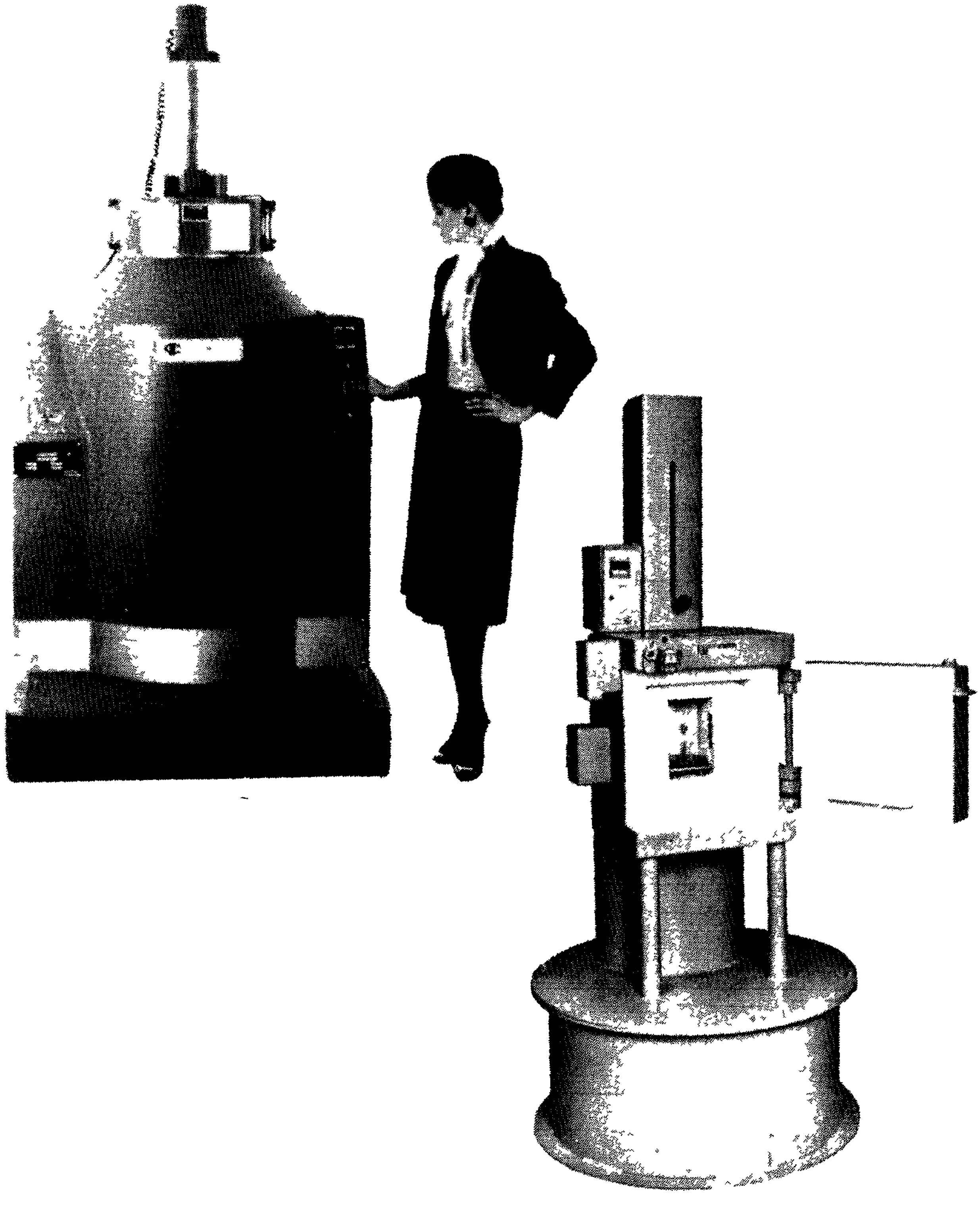
These installations contain very large sources, normally ^{60}Co, shielded by water or extensive concrete. The illustration is of a source rack from a water shielded installation and one of the sources from the rack.





Research irradiators

These may be self-contained, as illustrated here, where the sources are shielded by the construction of the equipment. They may also, like industrial irradiators, be installed in an enclosure which incorporates massive shielding.



Annex III
RADIOLOGICAL PROTECTION

Standards of radiological protection incorporated into national and international legislation and codes of practice are based upon the Recommendations of the International Commission on Radiological Protection (ICRP). The latest publication, No. 60 in 1990 [III-1], is currently being incorporated into the legislation of many countries and the IAEA Safety Series No. 9 [III-2].

ICRP Publication No. 60 recommends that:

(a) any use of ionizing radiation should be justified and show a net benefit over any alternative method not using ionizing radiation;
(b) doses to persons using or affected by the use of ionizing radiation should be kept as low as reasonably achievable. The planning, information and decisions which constitute this dose limitation is termed "optimization".

It is also recommended in ICRP Publication 60 that occupational whole body doses should not exceed 50 mSv in any year or 100 mSv in any five year period. In some countries the flexibility implied by averaging over a five year period is considered unnecessary and in these circumstances an annual limit of 20 mSv is proposed. For members of the public, the annual whole body dose should not exceed 1 mSv. In special circumstances, a higher value could be allowed in a single year, provided that the average dose over five years does not exceed 1 mSv per year. These dose limits apply to the sum of doses from external exposure and from radionuclides taken into the body.

When a particular operation, involving exposure to ionizing radiation, has been justified, the procedures to be followed must take into account the optimization of protection and safety measures. In the context of this report, this means to keep the magnitude of individual doses, the number of persons exposed and the probability of exposure as low as reasonably achievable consistent with the operation. In doing so, prevailing economic and social factors, and other societal and socio-economic considerations need to be taken into account.

Consideration may also need to be given to the optimization of external exposure between and within groups of workers or between workers and the general public. For example, where spent sources are located in areas to which the public have access, rendering them safe may involve significant exposure to workers while saving the exposure of the public. Optimization of the exposures may indicate that the increased exposure to workers is justified. For example, in the Ciudad Juarez accident involving a 185 TBq teletherapy ^{60}Co source, the loaded truck used to transport the source to the junk yard was found by the search team parked on a street. The decision made was to remove the truck immediately in order to protect the population. This resulted in a whole body dose to a person of 10 mSv and a dose to his hands of 36 mSv.

In other situations where, for example, spent sources are located in a suitably secure store in a working factory or hospital, the continuing small dose to workers by these sources remaining in the store may be more acceptable than the larger dose to a recovery team in removing them from the store and rendering them safe at another location. This of course assumes that the continuing security of the store can be guaranteed until the sources are recovered. It will also be necessary to consider possible changes to operations on the site and radioactive decay of the sources when deciding if removal or continued storage is appropriate.

Decisions also need to be made as to whether persons involved should have their radiation exposure individually measured. The guidance given by ICRP is that where specific working procedures will be necessary to limit the exposure of a group of workers, measurement of individual doses would be appropriate.

When searching for spent sources it is necessary to have a strategy or working procedure to ensure that persons involved are aware of the hazards to which they may be exposed and the means to minimize these hazards. It is therefore appropriate that, in accordance with ICRP recommendations, their exposure should be individually measured, preferably by means of an integrating dosemeter such as a film or TLD badge. Where there is a possibility that radioactive contamination may be taken into the body, means should be instituted to measure the contribution which this gives to the total dose.

Written procedures should be prepared for each search operation which takes into account the sources which are to be sought and the radiations which these sources emit. They should then specify the type of instrument(s) which can detect these radiations and should be used during the search. The written procedures should also address the likelihood of radioactive contamination being present, and the means to be provided to prevent or limit the intake of the contamination by the search teams.

It will often be appropriate to indicate dose rates which, if exceeded, require the search to be suspended, the area isolated or other action to be taken. Typically, if dose rates in excess of 7.5 μSv/h are measured, the area should be cordoned off to prevent unauthorized access and a strategy produced to further localize the source or sources which give rise to this dose rate.

Guidance should also be given in the written instructions about the maximum dose which anyone should receive when finally locating and making a source safe. Although this is an intervention where the ICRP system of dose limitation is not strictly relevant, it is unlikely that an individual dose exceeding the dose limit could be justified when searching for spent sources and rendering them safe. In practice it is probably justifiable to limit individual doses to 10 mSv. This would permit, for example, 9 minutes at 1 m from an unshielded ^{137}Cs source of 740 GBq or 1 minute at 1 m from an unshielded source of 1.7 TBq of ^{60}Co.

If the sources when found are not intact, some contribution to the dose received by members of the search team may be from internally deposited radionuclides.

When radioactive material is taken into the body, through the mouth, nose, skin or wounds, some will remain in the body and some will be excreted. The fraction remaining within the body and the time for which it remains will depend upon many factors including:

(a) the solubility of the material;
(b) its chemical form;
(c) the metabolic function of organs of the body; and
(d) the radioactive half-life.

Soluble salts of radium for example may behave like calcium in the body and become part of the bone in the skeleton. Caesium salts may be incorporated into muscle tissue. Because of the relatively faster turnover of muscle cells, caesium will normally be excreted from the body with a half time of the order of 50–70 days. Radium incorporated into bone tissue will be excreted at a much slower rate.

While radioactive material is within the body it is delivering a radiation dose to individual organs and an equivalent dose to the whole body. This dose must be calculated and aggregated with the external dose for comparison with dose limits. The calculation of the internal dose is difficult and may require:

(a) collection of excreta — urine, faeces, sweat, breath, etc., depending upon the radionuclide, its chemical form and mode of entry into the body; or
(b) direct measurement of penetrating gamma radiation by detectors external to the body.

Assumptions then have to be made about the metabolism of the material, its residence time within the body and with a knowledge or assumption of the time of intake, the dose calculation can be made.

Taking into account the requirement to keep doses as low as reasonably achievable, it is necessary to optimize total doses by taking appropriate precautions. Where there is the possibility of a damaged source leading to surface contamination the written instructions should require protective clothing to be worn and work to be carried out in such a manner as to avoid creating an airborne hazard. When an airborne hazard cannot be avoided it may be appropriate to wear respiratory protection. It is accepted that wearing respiratory protection will normally result in longer working time to complete a task. If the external dose rates are very high it may be necessary to strike a balance between higher external doses from wearing respiratory protection and lower external doses plus some internal dose by wearing no or lower standard respiratory protection. In these circumstances it may be necessary to run dust samples in the working area to assess the magnitude of the airborne hazard before allowing work to be carried out.

REFERENCES TO ANNEX III

[III-1] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1990 Recommendations of the International Commission on Radiological Protection, Publication 60, Pergamon Press, Oxford and New York (1991).
[III-2] INTERNATIONAL ATOMIC ENERGY AGENC, Basic Safety Standards for Radiation Protection - 1982 Edition, Safety Series No. 9, jointly sponsored by IAEA, ILO, NEA(OECD), WHO; IAEA, Vienna (1982).

Annex IV
RADIATION MONITORS

Several of the most widely used types of radiation monitors are based on the effects produced when a charged particle passes through a gas. Other, more recently developed detectors are based on light emission or ionization in solid state materials.

Features of radiation monitoring instruments

Factors which affect the choice of radiation monitoring instruments for any particular application include:

- The type and energy of radiation to be measured
- Dose, dose rate or contamination measurement
- Sensitivity and range of measurements required
- Ruggedness
- Battery availability and life expectancy
- Response in ambient temperature, humidity, light, magnetic fields and under radiofrequency exposure
- Overload performance
- Speed with which the instrument responds
- Size, mass and portability
- Availability and cost of maintenance
- Ease of decontamination
- Possibility to increase the measuring distance using a telescopic detector
- Illuminated display and audible output
- Logarithmic/linear analogue scales or digital displays and ease of use
- Position of scale on instrument and scale readability.

Ionization chambers

Ion chambers are the simplest of all gasfilled detectors. Their normal operation is based on the collection of all the charges created by ionization within the gas through the application of an electric field. The term "ionization chamber" has come to be used exclusively for the type of detector in which ion pairs are collected from gases.

Measurement of the "ionization current" or "ion current" is the basic principle of the ion chamber.

Portable ion chambers of many designs are commonly used as survey instruments for radiation monitoring purposes. They typically consist of a closed air volume of several hundred cm^3 from which the ion current is measured using a battery-powered electrometer circuit. These instruments give relatively accurate measurements of the exposure from gamma rays. Figure IV-1 shows an energy response curve for two such instruments, and illustrates the drop-off in sensitivity due to window attenuation for gamma ray energies which are less than 50–100 keV.

Many of the common applications of ion chambers take advantage of their long term stability. Typical operating characteristics can remain stable within $\pm 0.1\%$ over several years, eliminating the need for frequent calibration.

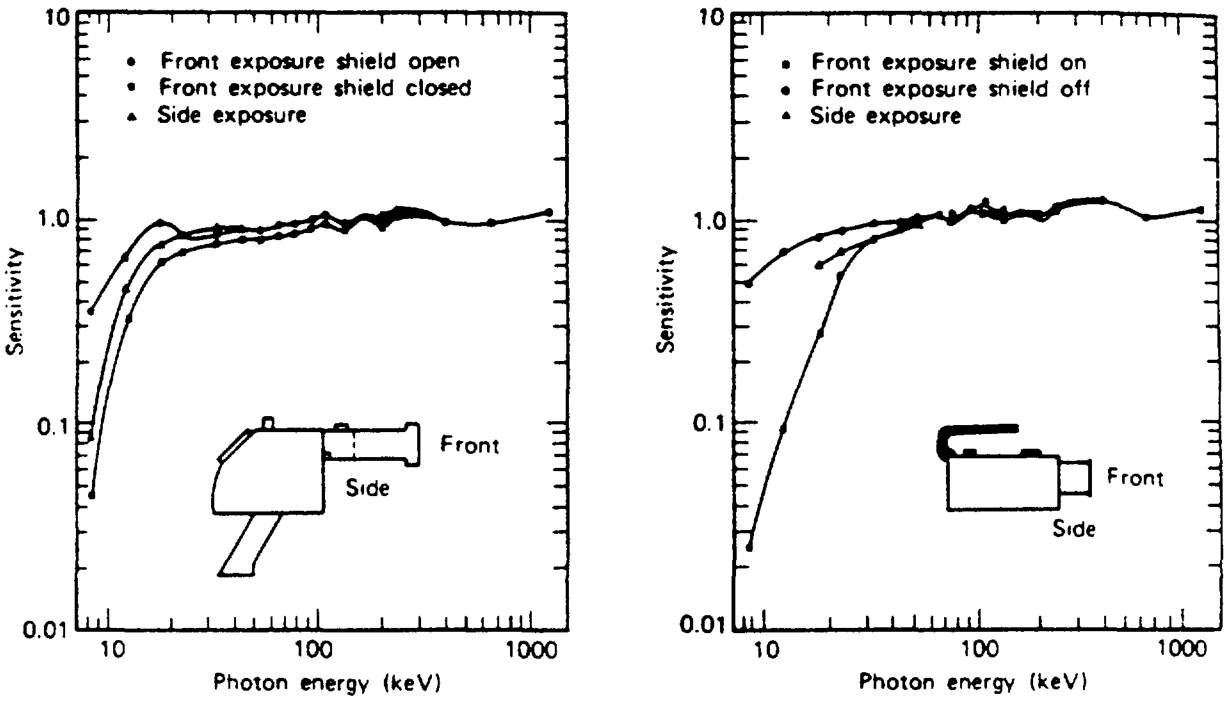


FIG. IV-1. Energy response curve of two different gamma ray survey meters.

Ionization chamber instruments may be useful for searching for spent sources because of the good energy response which enables them to detect both beta and gamma ray emissions. High humidity can affect the performance of this type of monitor. At low dose rates the response time is slow and this will be a consideration when needing to survey large areas. Many ionization chamber instruments are fragile and therefore not suited for field operations. Monitors based on ionization chambers are not suitable for contamination monitoring.

Proportional counters

The proportional counter is a type of gas-filled detector which is most commonly operated in the pulse mode and relies on the phenomenon of "gas multiplication" to amplify the charge generated in the gas. Pulses are considerably larger than the pulses that are integrated to current in an ion chamber.

Gas-filled proportional counters can be useful for alpha, beta and gamma surface contamination monitoring because they can be built with a large detection area and can have a very low background. Some of them need a continuous supply of counting gas.

An integrating type of proportional chamber can be operated in the same way as an ionization chamber, measuring exposure. The sensitivity is much higher and response time of such an instrument is shorter than that of an ionization chamber. The inherent stability is somewhat lower because the multiplication factor depends on the value of the high voltage and the precision with which it can be maintained. This type of instrument can be useful for survey in larger areas.

The Geiger-Mueller (G-M) counter is probably the best known radiation detector. It is widely used because it is simple in principle, inexpensive, easy to maintain and operate, sensitive and reliable as a detector of ionizing radiation. It is particularly useful for radiation protection surveys.

Simply constructed, a G-M counter is a type of gas-filled detector, where any incident particle that ionizes at least one molecule of the gas will initiate a succession of ionizations and discharges in the counter, resulting in a signal of about 1 volt.

If exposed to dose rates much higher than they are designed to measure some G-M counters will cease to function properly and give an indication well below the actual dose rate and, in many cases, the indication even drops to zero. This phenomenon is termed saturation. Special circuits may ensure that a full reading is maintained under these circumstances but, depending on the counter and the currently selected dose rate range the actual dose rate range may be considerably higher than the full reading shown on the scale.

The response of a G-M tube to radiation varies widely; typically being 6–15 times more sensitive to X radiation of ~ 60 keV than to X radiation below ~ 20 keV or gamma radiation above ~ 120 keV. An energy compensated G-M tube is designed with a special shield which modifies this response so that it is essentially the same for all energies above about 40 keV; see Figure IV-2.

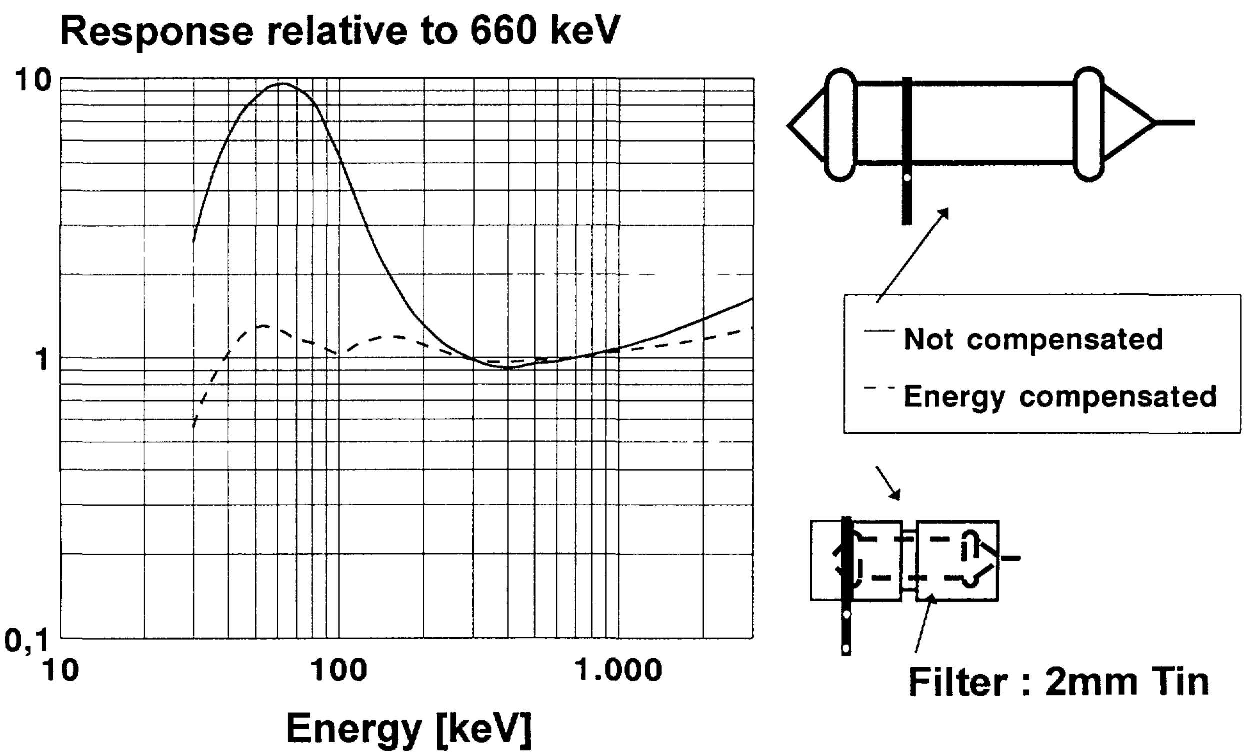


FIG. IV-2. Typical energy response for Geiger-Mueller counters.

Two of the more popular G–M tubes, the "end-window" and "pancake" detectors are in wide use throughout the industry for monitoring (see Figure IV-3). The "pancake" G–M tube has a several order of magnitude range extending from a few μGy/h to over 1.0×10^4 μGy/h. The end-window G–M tube has a very thin covering to allow alpha or low energy ß particles to penetrate the window into the gas. Gamma rays can penetrate the counter from any direction.

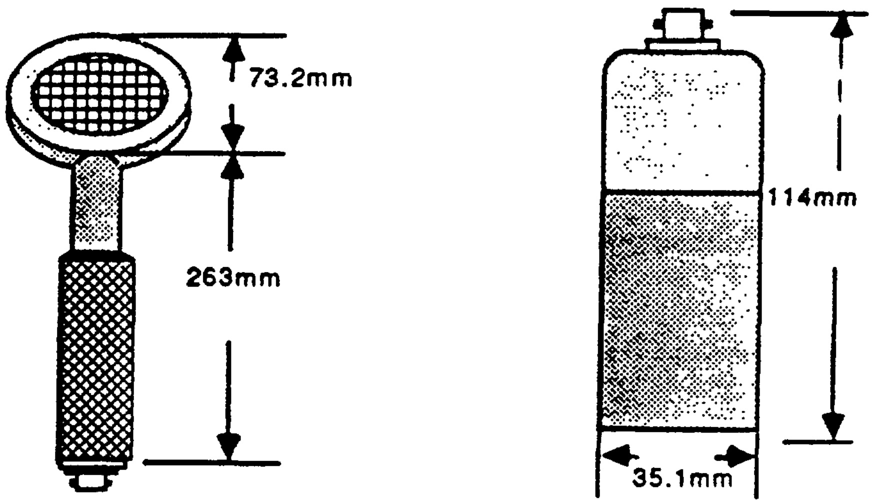


FIG. IV-3. "Pancake" and "end-window" Geiger-Mueller tubes.

G–M counters are versatile and may be of use in searching for spent sources provided that the limitations to their use are recognized. Users must be aware of the possibility of errors resulting from saturation when exposed to higher dose rates and the inability of energy compensated G–M tubes to measure X and gamma radiations below an energy of about 40 keV, or beta radiation.

Some G–M probes may be sensitive to light of high intensity.

Scintillation detectors and photomultipliers

When an energetic charged particle slows down in a scintillator, a fraction of the energy it imparts to the atoms is converted into light photons. The greater the amount of energy imparted by a particle to the scintillator, the greater the number of light photons produced and the more intense the light signal produced in the scintillator. The light emitted from the scintillator as a result of absorption of energy from the ionizing particle is converted to an electrical signal in a photomultiplier tube (see Figure IV-4).

Scintillators of different types of materials, are available in various shapes and sizes. The larger and heavier scintillators are used to detect gamma ray photons, because of their higher detection efficiency. Thin plastic scintillators are well suited for beta contamination measurement.

Many scintillation counter designs are available for field use with the photomultiplier protected by a shock absorber and the scintillation crystal suitably encapsulated.

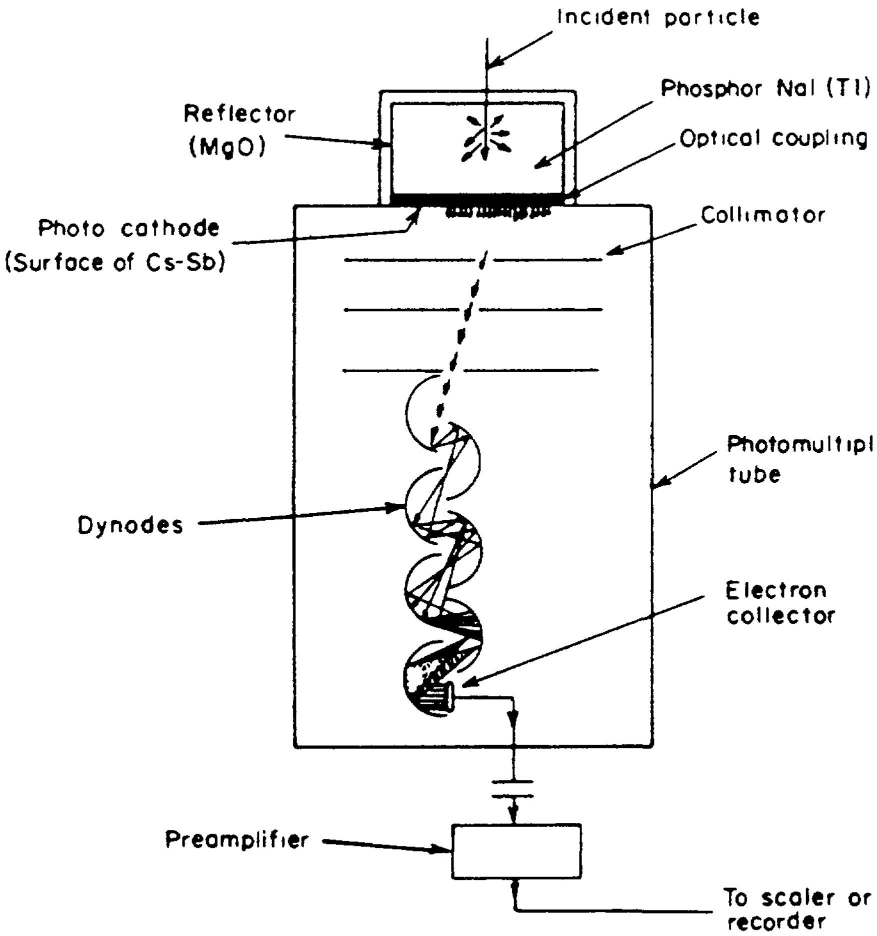


FIG. IV-4. Scintillation crystal-photomultiplier tube radiation detector.

Scintillation detectors and the associated ratemeters typically have a fast response time, which renders them very useful for searching for spent sources in a variety of situations.

Neutron monitors

Neutron monitors are exclusively used for neutron dose or dose rate measurement. A typical design of a neutron monitoring instrument is as follows. The proportional counter incorporating BF_3 or ^3He is surrounded by a cylindrical or spherical polyethylene moderator to thermalize incident fast neutrons. Between the moderator and the proportional counter a perforated cadmium or boron plastic sheath is inserted for the purpose of modifying the energy response according to neutron quality factors, thus enabling direct measurement of dose equivalent rates.

Spectrometers

Spectrometers are used to identify nuclides and are based on the fact that the pulse height at the output of sodium iodide (NaI) and semi-conductor detectors is related to the energy of the interacting particle or radiation. This pulse height can then be analyzed electronically.

The simplest form of gamma-spectrometer is a NaI detector with a single channel analyzer. This improves detection limits for a given nuclide in an environment with increased background and is useful for larger surveys if it is known which nuclide is being searched for.

More elaborate portable and "laboratory type" spectrometers exist which incorporate multichannel analyzers. These spectrometers can use NaI detector with high detection efficiency but low resolution (8%) or semi-conductor detectors, such as lithium drifted or pure germanium with high resolution (0.5%) but lower detection efficiency. The semi-conductor detector needs cooling to -170°C with liquid nitrogen or with an electrical cooling unit.

Alpha-spectrometers are for laboratory use. They consist of a multichannel analyzer and surface barrier, diffused junction or passivated implanted planar silicon detector. Each detector is mounted in a vacuum chamber together with the sample to be measured.

Performance checks

In addition to periodic (usually annual) calibration of survey meters, routine performance checks should also be conducted. Items such as instrument response after warm-up, battery condition, probe condition, background readings, response to a radiation test source, and various scale operations should be checked before each use. If any one of these checks fails, or seems to give inaccurate readings, the instrument should not be used until assessed by a competent person and re-calibrated.

BIBLIOGRAPHY

INTERNATIONAL ATOMIC ENERGY AGENCY, Guidelines on Calibration of Neutron Measuring Devices, Technical Reports Series No. 285, IAEA, Vienna (1988).

INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook on Calibration of Radiation Protection Monitoring Instruments, Technical Reports Series No. 133, IAEA Vienna (1971).

INTERNATIONAL ATOMIC ENERGY AGENCY, High Dose Measurements in Industrial Radiation Processing, Technical Reports Series No. 205, IAEA, Vienna (1981).

KNOLL, GLENN F., Radiation Detection and Measurement, John Wiley and Sons, New York (1979).

Annex V
SURFACE CONTAMINATION

The hazard from a contaminated surface is difficult to evaluate. From damaged sealed sources the most probable mechanism of intake of the contamination is by transfer from the surface to the hands and then from the hands to the mouth to be swallowed. Some of the contamination may be dispersed into the air and subsequently inhaled. Contamination on body surfaces or wounds may also be hazardous if not detected and removed. Further information on decontamination controls and methods can be found in IAEA Safety Series No. 91, Emergency Planning and Preparedness for Accidents Involving Radioactive Materials Used in Medicine, Industry, Research and Teaching [V-1].

Monitoring for contamination

Ideally, a contamination monitor designed and calibrated for the contaminants to be measured should be used. This could imply a requirement to have a range of monitors available and to select the one, or ones, suitable. In situations addressed in this report such diversity of monitors may, however, not always be available. Where monitor availability restrictions apply, it is particularly important to recognise what contaminants cannot be detected. It is important therefore that contamination monitors are calibrated against standard reference sources with different energies so that the response to the radionuclides known or suspected of causing the contamination can be determined.

The most widely used monitor for beta-gamma contamination is the end-window Geiger-Mueller tube. A doubling of the background counting rate might be considered as a positive indication of contamination. Plastic scintillators are also used for beta contamination monitoring. Combinations of plastic scintillators and zinc sulphate (ZnS) scintillators can be used to measure both beta and alpha contamination.

A suitable monitor for alpha contamination is one employing a proportional flow counter with a very thin window for the detector. A supply of suitable gas must be available. Another useful monitor for alpha contamination is one with a ZnS scintillator. The background of this type is virtually zero, because it has almost no sensitivity for beta or gamma radiation.

Monitoring for contamination is done by slowly moving the detector over the surfaces [V-2]. In order to avoid damage to the detector, or its protective foil, it is necessary to maintain a clearance between the detector and the surface. A protective grille or mesh with small openings will prevent objects from damaging the foil, and can keep the detector at its normal calibration distance from the surface (typically 0.5 cm). This mesh reduces the efficiency by a factor of about two, but it makes the detector much more robust.

It is very useful to have an audible signal, such as from a loudspeaker, because small increases of radiation above the background are detected most easily by listening to the clicks. It is also easier to pay attention to the surface being monitored if the meter does not have to be watched.

A range of factors that could influence the measurement of contamination must be considered; e.g. curvature of surface, degree of surface porosity, 'self absorption' of radiation within thick contamination, a wet surface potentially masking radiation from alpha and low energy beta emitters.

For monitoring loose contamination, a wipe test is normally performed. Alcohol moistened wipes will usually remove contamination more efficiently. A piece of filter paper is wiped over a predetermined area (usually approximately 100 cm^2) and then counted with a shielded end-window or pancake G-M detector, gas proportional, liquid scintillation detector; or returned to a laboratory for assessment. It is normally assumed that only about 10% of the loose contamination transfers to the wipe.

Wipe test with proper analysis (windowless proportional counter or liquid scintillation) may be used to assess contamination by alpha and low energy beta emitters, which may be difficult to detect with the monitor(s) normally available, to monitor for contamination in places which are inaccessible to an instrument and to obtain a measurement in the presence of high background radiation.

Personnel contamination and decontamination

When hands, body surfaces, clothing, or shoes become contaminated, steps should be taken as soon as possible to remove loose contamination.

The following procedures are recommended:

If personnel contamination is suspected, first identify contaminated areas with a survey meter. Care must be exercised to prevent contamination on the body from spreading or from getting into open wounds. Do not use decontamination methods that will spread localized material or increase penetration of the contaminant into the body (such as by abrasion of the skin). Washing with a mild soap and water is usually the best initial approach. Decontamination of wounds should be accomplished under the supervision of a physician.

Irrigate any wounds profusely with lukewarm water, and clean with a swab. Follow with mild soap or detergent and water (and gentle scrubbing with a soft brush, if needed). Avoid the use of highly alkaline soaps (may result in fixation of contaminant) or organic solvents (may increase skin penetration by contaminant).

The procedure for skin decontamination includes the following steps:

(a) Wet hands and apply mild soap.
(b) Work up good lather, keep lather wet.
(c) Work lather into contaminated area by rubbing gently for at least 3 minutes. Apply water frequently.
(d) Rinse thoroughly with lukewarm water (limiting water to contaminated areas).
(e) Repeat above procedures several times, gently scrubbing residual contaminated areas with a soft brush, if necessary.

When monitoring of hands indicates that the tips of the fingers are contaminated, clipping the fingernails may remove most of the residual activity after washing. When other measures still leave residual contamination on the hands, it may be worthwhile to wear a rubber glove for a day or so. The induced sweating has been reported as very effective in certain instances.

Personnel contamination must be reported to the search team manager. Expert advice should be sought if decontamination efforts as described above are unsuccessful or if internal contamination is suspected.

REFERENCES TO ANNEX V

[V-1] INTERNATIONAL ATOMIC ENERGY AGENCY, Emergency Planning and Preparedness for Accidents Involving Radioactive Materials Used in Medicine, Industry, Research and Teaching, Safety Series No. 91, IAEA, Vienna (1989).

[V-2] INTERNATIONAL ATOMIC ENERGY AGENCY, Monitoring of Radioactive Contamination on Surfaces, Technical Reports Series No. 120, IAEA (1971).

Annex VI
ACTIVITY CONVERSION TABLES

Curie to becquerel

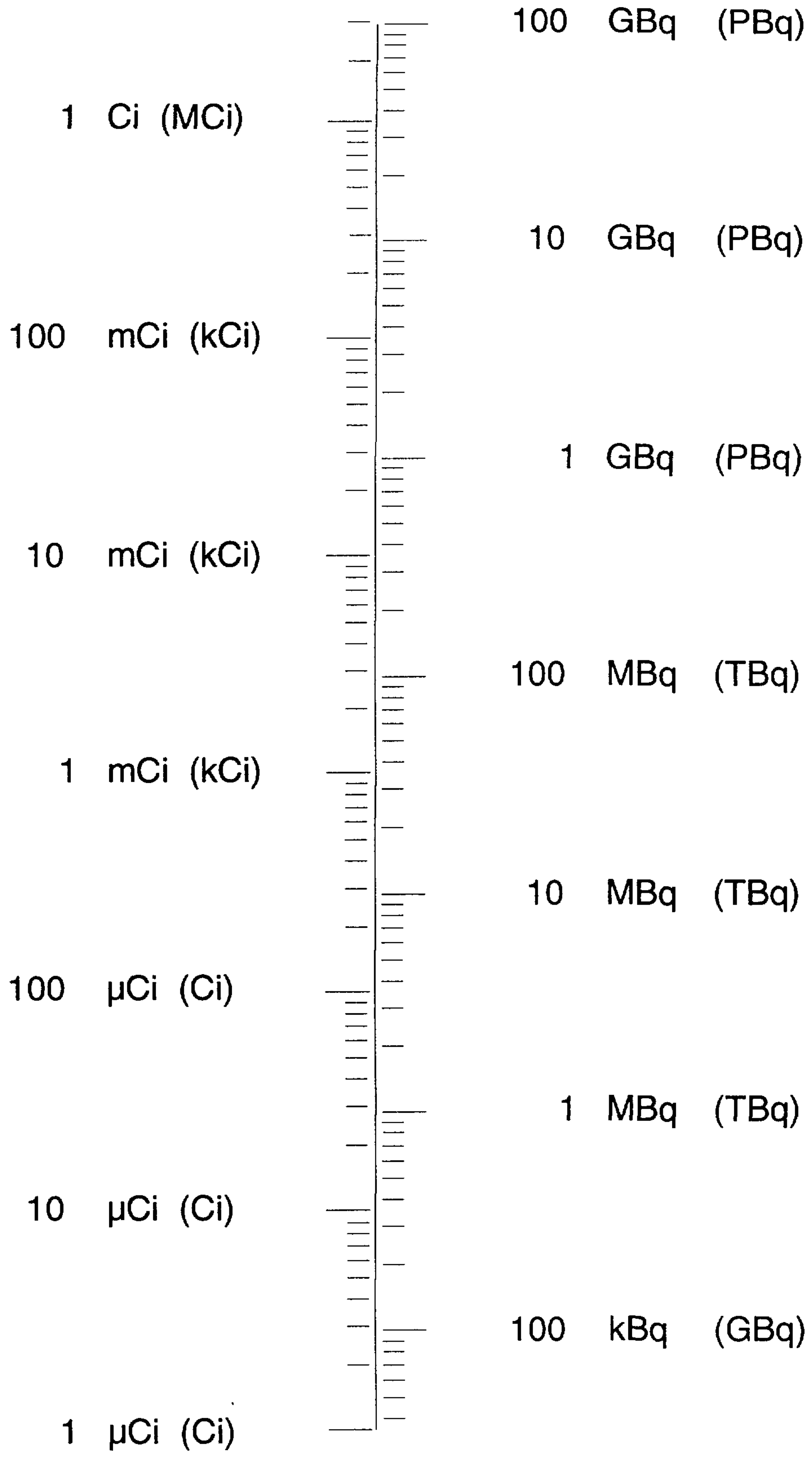
1 mCi	=	37	MBq
2 mCi	=	74	MBq
3 mCi	=	111	MBq
4 mCi	=	148	MBq
5 mCi	=	185	MBq
6 mCi	=	222	MBq
7 mCi	=	259	MBq
8 mCi	=	296	MBq
9 mCi	=	333	MBq
10 mCi	=	370	MBq
100 mCi	=	3.7	GBq
1 Ci	=	37	GBq
10 Ci	=	370	GBq
100 Ci	=	3.7	TBq
1 kCi	=	37	TBq
10 kCi	=	370	TBq
100 kCi	=	3.7	PBq

Becquerel to curie

1 MBq	=	27	μCi
2 MBq	=	54	μCi
3 MBq	=	81	μCi
4 MBq	=	108	μCi
5 MBq	=	135	μCi
6 MBq	=	162	μCi
7 MBq	=	189	μCi
8 MBq	=	216	μCi
9 MBq	=	243	μCi
10 MBq	=	270	μCi
100 MBq	=	2.7	mCi
1 GBq	=	27	mCi
10 GBq	=	270	mCi
100 GBq	=	2.7	Ci
1 TBq	=	27	Ci
10 TBq	=	270	Ci
100 TBq	=	2.7	kCi

Multiplying factors and SI units prefixes:

Multiplying factor	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a



Becquerel–curie conversion nomogram.

Annex VII
SUGGESTED TEXT FOR ANNOUNCEMENT IN PROFESSIONAL NATIONAL JOURNALS

ATTENTION RADIOLOGISTS AND RADIOTHERAPISTS

Radium in the form of needles, tubes and plaques have been used for several decades for the treatment of superficial and intracavitary tumors. These sources are normally 2 to 6 cm long and 2 mm in diameter. Because of constant use and build-up of pressure due to gaseous radon-222 daughter product, the platinum-iridium encapsulation may rupture and radium salt can leak causing contamination of the clinical premises. Efforts are underway to withdraw the use of radium and substitute it with less hazardous sources such as cobalt-60, caesium-137, etc. As the half-life of radium is very long, 1600 years, and its radiotoxicity is very high, any lost or unused sources lying in hospital premises and with private practitioners will pose health problems for generations to come.

In order to trace and collect such unused sources for disposal in a controlled manner, radiologists and radiotherapists who handled radium in the past are approached through this announcement for information on locations of use – hospitals, private clinics, etc. An appeal is made to the medical community to send the full address of institutions or individuals to the address given below.

The national programme to regulate handling of radioactive substances came into force after many of the radium sources had been introduced into medical practice. Individuals possessing radium can therefore freely disclose the information sought. This is a national effort to remove the potential hazard, perhaps permanently, and your cooperation is solicited.

National Competent Authority

U.S. NUCLEAR
REGULATORY
COMMISSION

HAZARDOUS SCRAP-BEWARE!

NOTICE

The devices pictured may contain radioactive material. If you see such devices, notice radioactive warning markings on a piece of scrap, or if you otherwise think the material is radioactive, set it aside It must not be processed Keep time spent near it to a minimum Immediately contact the U.S. Nuclear Regulatory Commission or your State radiation control office for more information

BACKGROUND

Since 1983 rad oactive material has been accidentally processed with steel scrap three times at U S steel m lls Sim lar ncidents have also occurred at foreign steel m lls

In these cases shielded devices contain ng radioactive material *found their way nto scrap handling facilities were later processed* along with normal scrap at steel foundr es and converted to various steel products This resulted in widespread contamination of the production facility and equipment and possible radiation exposure of workers The contaminated steel products could also have been hazardous to members of the publ c

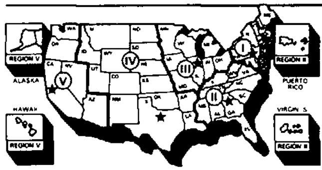
The chances of such incidents n this country are small Most radioactive materials are regulated by the U S Nuclear Regulatory Commission or by State radiation control programs

Users are subject to strict regulatory requ rements for accountability and proper transfers or disposal Therefore the chances of accidental disposa of such a device in scrap s remote Yet the possibility still exists when scrap s processed

The steel ndustry s now explor ng and testing methods to check ncom ng scrap mater al for ao oactivity Until practical controls are established you should be alert to the possible presence of devices wh ch may conta n radioactive sources Familiarize yourself with the types of mark ngs that appear on the various devices such as the three bladed radiation warning symbol and the terms used to describe the adioactive materials most commonly used in these devices This poster illustrates typical devices which could turn up n scrap material and which could contain a radioactive substance

WHERE TO GET HELP

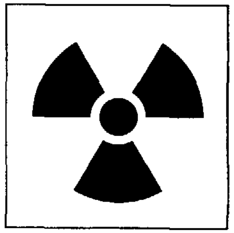
UNITED STATES NUCLEAR REGULATORY COMMISSION REGIONAL OFFICE LOCATIONS



REGION	ADDRESS	TELEPHONE
I	631 Park Avenue King of Prussia PA 19406	215 337 6000
II	101 Marietta St N W Suite 3100 Atlanta GA 30323	404 331 4503
III	799 Roosevelt Road Glen Ellyn IL 60137	312 790-5500
IV	611 Ryan Plaza Drive Suite 1000 Arlington TX 76011	817 860-8100
V	1450 Maria Lane Suite 210 Walnut Creek CA 94596	415 943 3700

Radiation Warning Symbol

This symbol appears on containers or devices which hold radioactive substances Its color is reddish purple (magenta) or black on a yellow background Its size may vary



Nature and Quantity of Radioactive Material

These terms are normally used in association with the Radiation Warning Symbol to indicate the nature of the radioactive material and its quantity Certain other markings describing the type of container may also appear

Cobalt 60 (^{60}Co) Iridium 192 (^{192}Ir) Cesium 137 (^{137}Cs) Radium 226 (^{226}Ra)	DOT Type A or B CDN/XXXX/B USA/XXXX/B
Curie (Ci) Millicurie (mCi) Becquerel (Bq) Gigabecquerel (GBq)	

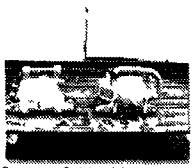
UNITED STATES NUCLEAR REGULATORY COMMISSION
OFFICE OF STATE PROGRAMS
WASHINGTON DC 20555

FIGURES AND CAPTIONS COURTESY OF THE ATOMIC ENERGY CONTROL BOARD GOVERNMENT OF CANADA

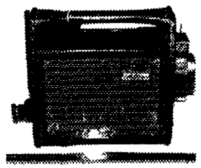
Typical devices that may contain radioactive materials

Radiography Cameras

Portable

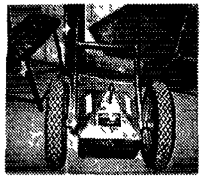


Description	Oval shaped aluminum or steel shell with integrated carrying handle and a round hose connector at each end
Size	Approx 8" × 12" (20 cm × 30 cm)
Weight	Approx 56 lb (25 kg)
Color	Variable often metallic gray



Description	Lunch-box appearance Steel shell with integrated carrying handle and a round hose connector at each end
Size	Approx 12" × 8" × 6" (30 cm × 20 cm × 15 cm)
Weight	Approx 45 lb (20 kg)
Color	Variable often orange

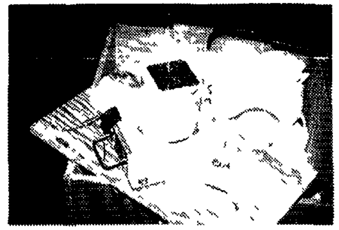
Movable



Description	Oval or irregular shaped steel shell possibly with wheel and lifting mounts on each side Most have a l fting eye on the top
Size	Approx 24 × 20" × 18" 60 cm × 50 cm × 45 cm)
Weight	600-3000 lb (300-1300 kg)
Color	Variable usually metallic gray

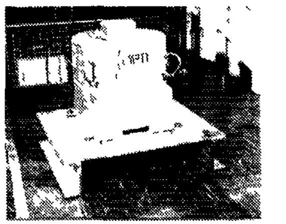
Description	Flat oval-shaped steel shell with short protruding rod attachments at opposite sides Usually has a lifting eye
Size	Approx 24 (60 cm) in diameter and 12" (30 cm) thick
Weight	Approx 450 lb (200 kg)
Color	Variable often red

Gauges

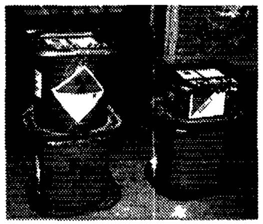


Description	Steel cylindrical or bell shaped container mounted on a square base
Size	Cylinder approx 8" (20 cm) in diameter and 12" (30 cm) long
Weight	56-225 lb (25-100 kg)
Color	Variable could be corroded

Transportation Containers

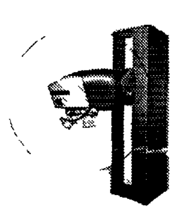


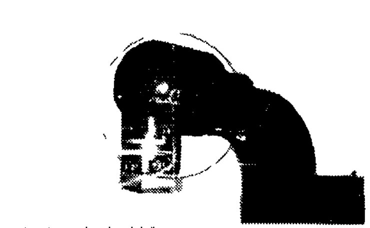
Description	Steel container normally cylindrical Could be mounted on a steel pallet
Size	Approx 20-40" (0 5-1 m) in diameter and 3-4 (0 9-1 2 m) high
Weight	1200-2200 lb (500-1000 kg)
Color	Variable often green



Description	Steel container normally cylindrical May have lifting handles
Size	Approx 8-15 (20-40 cm) in diameter and 12 24 (30-60 cm) high
Weight	56-300 lb (25-125 kg)
Color	Variable

Cancer Therapy Machines





Description	Irregular oval shaped steel shell with a cone shaped hole on one side
Size	Usually about 4 × 3' × 2' (1 2 m 1 m × 0 6 m)
Weight	2000-4000 lb (900-1800 kg)
Color	Variable many models dark green or brown

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Consultants Meetings

Vienna, Austria, 22–26 June 1992
Vienna, Austria, 19–23 April 1993
Vienna, Austria, 6–8 December 1993
Vienna, Austria, 25–29 July 1994

Advisory Group Meetings

Vienna, Austria, 2–6 November 1992
Vienna, Austria, 7–11 June 1993

QUESTIONNAIRE ON IAEA-TECDOCs

It would greatly assist the International Atomic Energy Agency in its analysis of the effectiveness of its Technical Document programme if you could kindly answer the following questions and return the form to the address shown below. Your co-operation is greatly appreciated.

Title: **Methods to identify and locate spent radiation sources**
Number: **IAEA-TECDOC-804**

1. How did you obtain this TECDOC?

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