IAEA-TECDOC-1312

Detection of radioactive materials at borders

Jointly sponsored by IAEA, WCO,EUROPOL and INTERPOL

INTERNATIONAL ATOMIC ENERGY AGENCY IAEA

September 2002

The originating Section of this publication in the IAEA was:

Radiation Safety Section
International Atomic Energy Agency
Wagramer Strasse 5
P.O. Box 100
A-1400 Vienna, Austria

DETECTION OF RADIOACTIVE MATERIALS AT BORDERS
IAEA, VIENNA, 2002
IAEA-TECDOC-1312
ISBN 92–0–116102–6
ISSN 1011–4289

Printed by the IAEA in Austria
September 2002

FOREWORD

By international agreements, the movement of all radioactive materials within and between States should be subject to high standards of regulatory, administrative, safety and engineering controls to ensure that such movements are conducted in a safe and secure manner. In the case of nuclear materials, there are additional requirements for physical protection and accountability to ensure against threats of nuclear proliferation and to safeguard against any attempts at diversion.

The results of the terrorist attacks of September 2001 emphasized the requirement for enhanced control and security of nuclear and radioactive materials. In this regard, measures are being taken to increase the global levels of physical protection and security for nuclear materials. In like manner, efforts are underway to enhance the safety and security of radioactive sources so prevalent in many industries and health care facilities. It follows that detection of radioactive materials (nuclear material and radioactive sources) at borders is an essential component of an overall strategy to insure that such materials do not fall into the hands of terrorist groups and those criminal organizations that would supply them. Shipments of radioactive materials warrant the attention of law enforcement and regulatory agencies to ascertain legality, and to prevent diversion and illicit trafficking.

Experience in many parts of the world continues to prove that movements of radioactive materials outside of the regulatory and legal frameworks continue to occur. Such movements may be either deliberate or inadvertent. Deliberate, illegal movements of radioactive materials, including nuclear material, for terrorist, political or illegal profit is generally understood to be illicit trafficking. The more common movements outside of regulatory control are inadvertent in nature. An example of an inadvertent movement might be the transport of steel contaminated by a melted radioactive source that was lost from proper controls. Such a shipment may present health and safety threats to the personnel involved as well as to the general public.

States have the responsibility for combating illicit trafficking and inadvertent movements of radioactive materials. The IAEA co-operates with Member States and other international organizations in joint efforts to prevent incidents of illicit trafficking and inadvertent movements and to harmonize policies and measures by the provision of relevant advice through technical assistance and documents. As an example, the IAEA and the World Customs Organization (WCO) maintain a Memorandum of Understanding (MOU) (1998) to promote co-operation at the international level in order to improve the control of radioactive materials. At the time of the drafting of this report, a similar MOU between the IAEA and the International Criminal Police Organization (INTERPOL) is pending.

There are a number of measures that must be undertaken by States to combat the illicit trafficking and inadvertent movements of radioactive materials. These measures are, generally, shared between the regulatory and law enforcement agencies as part of a State's national arrangements. One of these measures is the subject of this Technical Document (TECDOC), namely the detection of radioactive materials at borders. While effective detection involves many components of regulatory and law enforcement strategies, the major focus of this publication is on radiation detection and in particular, the instrumentation necessary for such purposes. Its intent is to assist Member State organizations in effectively detecting radioactive materials crossing their borders, whether importations, exportations, or shipments in transit.

This is the second of a group of three TECDOCs on inadvertent movement and illicit trafficking of radioactive materials that are co-sponsored by WCO, EUROPOL and INTERPOL. The first is entitled "Prevention of the Inadvertent Movement and Illicit Trafficking of Radioactive Materials" (IAEA-TECDOC-1311), and the third "Response to Events Involving the Inadvertent Movement or Illicit Trafficking of Radioactive Materials" (IAEA-TECDOC-1313). The IAEA officer responsible for these publications was B. Dodd of the Division of Radiation and Waste Safety.

CONTENTS

1. INTRODUCTION

1.1. Illicit trafficking

The IAEA glossary definition at the time of writing is: "Illicit trafficking is the receipt, possession, use, transfer or disposal of radioactive material without authorization". This definition is much broader than the term as police, customs and other law enforcement bodies generally understand it. In view of this, and the diverse professional interest of the three co-sponsors of this TECDOC, it is important to provide some amplification of the term illicit trafficking to ensure its correct application.

In the context of this TECDOC, the term should not be interpreted as covering all unauthorized events involving radioactive materials, irrespective of type and cause, since most of these may only be administrative offences and matters for the national nuclear or radiological regulatory authority, rather than for law enforcement.

The interests of the co-sponsoring organizations all include criminal activities (such as breaches of national and international law) and it is this dimension that underlies the purpose of this definition, this TECDOC and its companions [1, 2].

Criminal activities under consideration include:

— subversive activities, such as breaches of proliferation controls (as they are subversive to international will);
— other actual or potential malevolent acts intended to cause harm to people or the environment;
— illegal gain, such as profits from the sale of the radioactive material;
— avoiding prescribed costs of disposal, or relevant taxes;
— violation of transport regulations.

Experience of some Member States has shown that many cases where radioactive materials have been shown to have been moved illegally across international borders have been due to inadvertent movements, rather than those with true criminal intent. An example of this is when radioactive materials have been moved across international borders mixed with scrap metal [3, 4]. For this reason, instances where loss of control has occurred unintentionally, and the material is then found in another country can be usefully included in the discussion. In reality, it is only after such cases have been discovered and investigated can they be distinguished from cases with clear criminal intent. The problems of radiation safety, and harm to people, property and the environment are identical in both categories of incident.

To summarize, this TECDOC uses the term "illicit trafficking" to mean any intentional unauthorized movement or trade (particularly international) of radioactive materials (including nuclear materials) with criminal intent. This use of the term is consistent with that used by police, customs and other law enforcement bodies involved in combating trafficking in firearms, people, motor vehicles and drugs.

1.2. Background

It should be noted that since nuclear materials are also radioactive, in this publication the term "radioactive materials" includes nuclear materials. "Radioactive materials" is used simply to avoid repetitious use of the phrase “nuclear, and other radioactive materials”. It is recognized that nuclear materials will be of prime interest from an illicit trafficking viewpoint.

Radioactive materials are used throughout the world for a wide variety of beneficial purposes, in industry, medicine, research, defense and education. The radiological risks associated with such use need to be restricted and protected against by the application of appropriate radiation safety standards. Similarly the proliferation risks associated with the use of nuclear materials also need to be controlled and managed by standards, agreements and conventions.

National regulatory systems consistent with the IAEA standards and guidance [5–8] would be expected to ensure that effective control of radioactive materials is maintained. This is particularly true for all States that have implemented the Code of Conduct [9] and entered into safeguards agreements. Nevertheless, control can be lost for a variety of reasons. For example, a user of radioactive materials may not follow the procedures required by regulations. Loss of control can also result from deficiencies in the infrastructure itself or from inadequate physical security. In addition to negligence, there may also be deliberate diversion of radioactive materials. This can be to avoid the costs of waste disposal or in the belief that the materials have value, as a commercial or military commodity. Terrorists may also attempt to acquire radioactive materials. Because of the issues associated with the proliferation of nuclear weapons, and terrorism there is a particular concern in this regard with materials that are used in nuclear power and nuclear weapons programmes.

Some Member States have chosen to place radiation detectors at some of their border crossings to try to detect radioactive materials that are illicitly brought into the country as well as to find any orphan[1] sources that may be inadvertently transported. The operational issues relevant to the use of radiological instrumentation for such purposes are the subject of this TECDOC. Discussion of prevention and response to inadvertent movement and illicit trafficking of radioactive materials can be found in the companion TECDOCs [1, 2].

The IAEA and the Austrian Government jointly sponsored a pilot study of the practicalities of border monitoring instruments. This was called the Illicit Trafficking Radiation Detection Assessment Program (ITRAP) [10], and the results of this study were considered in the writing of this TECDOC. In particular, the study was useful in developing performance characteristics for monitoring instruments. Those given in this TECDOC are based on the ITRAP report, but some adjustments have been made taking into consideration input from other experts. The performance characteristics should be regarded as providing guidance only, and *should not be taken as IAEA requirements or standards.*

1.3. Incidence of illicit trafficking and inadvertent movement of radioactive materials

In 1995 the IAEA started a programme to combat illicit trafficking in nuclear and other radioactive materials, which included the development and maintenance of an international database on trafficking incidents [11]. Because of the original broad definition of illicit trafficking, this is called the Illicit Trafficking Database (ITDB) although many incidents that are included in it are more inadvertent movement rather than illicit trafficking. As of the time of the last full report (December 2001), the database contained 399 confirmed incidents, which have been reported since 1993. There are 69 Member States participating in the illicit

---

[1] Orphan source: A source which poses sufficient radiological hazard to warrant regulatory control, but which is not under regulatory control because it has never been so, or because it has been abandoned, lost, misplaced, stolen or otherwise transferred without proper authorization.

trafficking database programme. About 90% of the incidents in the database involve radioactive sources, or low-enriched, natural and depleted uranium. The remainder involve plutonium and high-enriched uranium, and these usually involve some form of criminal intent to bypass non-proliferation safeguards as well as extensive radiation protection requirements. About 19 of these incidents involve important quantities of material. It is likely that there are more incidents occurring worldwide than are reported in the IAEA database.

A related problem of increasing importance is associated with the cross-border movement of metallurgical scrap. Today metal scrap for recycling is transported all over the world, often without a clear reference to its origin. Occasionally, such metal scrap shipments have included radioactive materials and sealed radioactive sources. One study of this problem in the USA [12] identified over 2300 instances where abnormal radiation levels were found in shipments of metals for recycling. About 11% of those instances involved sealed radiation sources or devices. While most of the discoveries of abnormal radioactivity were due to surface contamination by naturally occurring radioactive materials (NORM), other radioactive materials, orphan sources and devices, create a risk of radiation exposure to workers and the public. Some 50 cases have also led to inadvertent meltings of radioactive materials by those recycling facilities. Such incidents may disperse radioactive material over a wider area, and cause serious social and economic consequences. Examples include very high clean-up and disposal costs, lost production-time and litigation.

To prevent contaminated metals from being recycled, scrap processors and metal smelting facilities in some countries have installed radiation detection systems. Whilst there are some similarities in the equipment used, the measurement conditions at border crossings are quite different from those in scrap yards and metal production plants. At borders, the large volume of traffic means that the time for detection and initial response is limited to a few seconds and that repeated checks of the same vehicle are usually impractical. In addition, border monitoring not only has to cover transport by road freight vehicles and rail cars but also by passenger vehicles and pedestrians. Furthermore, where illicit trafficking in nuclear materials needs to be detected at borders, neutron measurement is also required whereas this would not generally be considered necessary at scrap yards and metal production plants.

1.4. Scope

For customs, police and other law enforcement bodies, the term detection has a much broader connotation than for those involved with radiation safety. For the former, detection includes activities such as intelligence, risk assessment, seizure and investigation while for the latter it usually just involves the use of an instrument or device to determine the presence and level of radiation. This report addresses the radiation detection aspects only. It covers the issue of detecting radioactive materials that may be being illicitly trafficked or inadvertently moved. As such, it addresses in general terms the capabilities of detection, and outlines methods for such detection. Further, although the term borders is used repeatedly in this publication, it is meant to apply not only to international land borders, but also to maritime ports, airports, and similar locations where goods or individuals may enter or leave a State.

This publication does not address the issue of detection of radioactive materials at recycling facilities, although it is recognized that transboundary movement of metals for recycling occurs, and that monitoring of the metals for recycling may take place at the borders of a State or at a recycling plant.

This publication does not address authorized trans-boundary shipment of radioactive materials. This activity is governed by rules and regulations and other guidance already in existence to address the safe transport of radioactive materials [13].

This publication does not address the measures which regulatory authorities, and the legal persons whom they authorize to possess and use radiation sources, should undertake to ensure the safety and security of radioactive or nuclear materials. These are described elsewhere (see Refs [5–8]).

1.5. Objective

The purpose of this publication is to provide guidance for Member States for use by customs, police or other law enforcement bodies on the radiation monitoring of vehicles, people and commodities at border crossing facilities as a countermeasure to illicit trafficking and also to find inadvertent movement of radioactive materials. Such monitoring may be one component of efforts towards finding radioactive materials that have been lost from control and which may enter a Member State.

2. THE PROCESS OF DETECTION

The process leading to decisions regarding the setting up of systems for the detection of inadvertent movement or illicit trafficking of radioactive materials at borders and the use of such equipment has the following main steps:

(1) strategic evaluation of the need for border monitoring;

(2) selection of instruments;

(3) installation, acceptance testing and calibration, setting up a maintenance plan and training of users and technical support staff;

(4) determination of investigation levels and instrument alarm settings;

(5) evaluation of alarms and appropriate response, by verification and localization of the radioactive material; and

(6) evaluation of any radioactive materials found.

This in essence provides the outline for this publication. The actions or measures to be taken when monitoring discloses an event involving inadvertent movement or illicit trafficking of radioactive materials is dealt with in the third TECDOC of this series [2].

3. STRATEGIC EVALUATION OF THE NEED FOR BORDER MONITORING

This TECDOC primarily covers radiation detection at borders from a technical and operational viewpoint. A Member State’s decision as to whether, when or where to establish radiation detection at its borders should be the result of the development of a comprehensive national strategy for regaining control over radioactive materials. Guidance on the design and implementation of such a national strategy is under development as part of the IAEA Action Plan for the Safety and Security of Radioactive Materials.

One of the key factors in the development of a national strategy is the threat analysis. By evaluating historical, political, social, economic and geographic factors a State can come to a reasonable assessment as to the potential, or threat of illicit trafficking or inadvertent movement of radioactive materials across its borders. For some countries, at certain border locations, monitoring may be regarded as a worthwhile component of their overall strategy. For others, the potential problem is so low that it would not be considered sufficiently cost-beneficial to implement border monitoring. Other considerations favouring installation of border monitors include deterrence and public safety.

Should it be determined that border monitoring is needed, the results of the strategic analysis will also help in the determination of the types of instruments to be used and where they should be deployed. This is because it will help define what is being sought. The monitoring process will be most effective if it is conducted at locations that have the greatest potential for identifying and intercepting illicit trafficking or inadvertent movement of radioactive material. In general terms, these are control points or nodal points where the flow of people, movement or freight converges. These locations may already be control points for other purposes, such as for weigh bridges, or customs.

4. SELECTION OF INSTRUMENTS

4.1. Introduction

This section offers guidance on the selection of instrumentation for deployment at borders[2], and also offers guidance on their use under field conditions where there are operational constraints. It should be noted that the advice refers to radiological detection of radioactive materials, and does not focus on radiological protection issues that need to be considered if radioactive materials are detected. The protection of the individuals involved is a prime consideration; however, experience has shown that the number of events involving hazardous radiation levels is small.

There are some important points that need to be emphasized at the beginning. Firstly, in order for radioactive material to be detected, the radiation that it emits must first penetrate any container, package, vehicle or person that it is in. Practically, this means that if the radioactive material emits only alpha radiation, low energy beta radiation and/or low energy gamma radiation it may not be detected. Furthermore, knowledgeable persons may be able to deliberately shield radioactive material such that the radiation levels outside the container are below detectable levels. Under these circumstance there may be a need for additional information such as other methods of screening, intelligence information or observation.

Secondly, not all instruments detect all types and energies of radiation and therefore decisions have to be made as to what radioactive materials might be expected and what it is desired to detect. For example, significant neutron sources do not exist as naturally occurring radioactive materials and they are not used in radiopharmaceuticals. The detection of neutron radiation can, therefore, be used as an indication of the presence of nuclear materials (although neutron sources are used in some nucleonic gauging systems). For this reason, neutron detectors are recommended where there is a need to detect illicit trafficking in nuclear material.

---

[2] As stated earlier, “borders” is meant to include all locations where goods or individuals may enter a State.

Instrument users should be aware of the following technical and practical reasons why radioactive materials may not be detected.

- The radiation level at the instrument is too low to be detected because the source is of low radioactivity, is shielded or is too far away.
- The instrument response time characteristics may be too slow for the speed at which the instrument and the source pass each other.
- The instrument might need re-calibration to ensure it has the correct response.
- The instrument might not be functional at the time.

The advice included within this report addresses most of these issues; therefore, following it will maximize the probability of detecting radioactive materials at borders.

4.2. Types of instruments

Instruments for detecting radioactive materials at borders can be divided into three categories.

(1) *Pocket-type instruments* are small, lightweight instruments used to detect the presence of radioactive materials and to inform the user about radiation levels.

(2) *Hand-held instruments* usually have greater sensitivity and can be used to detect, locate or (for some types of instrument) identify radioactive materials. Such instruments may also be useful for making more accurate dose rate measurements in order to determine radiation safety requirements.

(3) *Fixed, installed, automatic instruments* are designed to be used at checkpoints such as those at road and rail border crossings, airports or seaports. Such instruments can provide high sensitivity monitoring of a continuous flow of persons, vehicles, luggage, packages, and cargo, whilst minimizing interference with the flow of traffic.

Each of these will be discussed in detail.

4.3. Purpose of instruments

There are several uses of radiation detection instruments that are relevant to this publication. Each of these will be a factor in the selection of an appropriate instrument. The purposes can be summarized as:

(1) *Detection:* An instrument is only needed to give an alarm if a certain radiation level is exceeded.

(2) *Verification:* Once an alarm has been given it is necessary to verify whether or not it is genuine. Use of a different instrument is one way of doing this.

(3) *Assessment and localization:* A real alarm necessitates searching for and localizing the origin of the radiation. As this is done it is important to make a radiological assessment for radiation safety purposes as well as to determine the appropriate level of response .

(4) *Identification:* Determination of the radiation type and energy will often enable the radionuclide to be identified. This will help in categorizing the nature of the event and further response.

4.3.1. Detection

Once a decision has been made to perform border monitoring, as well as where and how to perform it, the next step is to select the appropriate instrument.

Where the traffic of goods, vehicles or people can be funnelled into narrow confines known as nodal points, fixed, installed, automatic instruments are the preferred option.

Pocket-type and hand-held instruments are particularly useful where operations are conducted in widely dispersed areas such as airports or seaports. For example, pocket-type instruments can be issued to and worn by every law enforcement officer on duty.

Hand-held instruments provide greater sensitivity of detection compared to pocket-type instruments, but they are heavier and usually more expensive. Hand-held instruments are mostly used for detection in targeted search situations of specified consignments. For example, they would be chosen: (a) when a suspicion of illicit trafficking already exists based on intelligence reports; (b) to localize a source; (c) to measure the dose rate; or (d) to identify the radionuclide.

4.3.2. Verification

Each detection needs to be verified to exclude false alarms. Verification involves repeating the measurement process to confirm the initial indication of a radiation field. For pocket-type and hand-held instruments, this would normally involve repeating the examination of the vehicle or person. For fixed, installed instruments, it may mean that the vehicle needs to be re-circulated through the installation to obtain a repeat measurement. When re-circulation is not practicable, a different type of instrument may need to be used.

4.3.3. Assessment and localization

After the detection of radioactive material has been verified, the origin of the radiation signal needs to be localized. For this purpose pocket-type or hand-held instruments are needed. At this point a radiological safety assessment will be required in order to ensure the safety of the officers and the public. In addition, the radiological assessment will determine whether the response should be operational, tactical or strategic [2]. To do this, instruments with dose rate indication are essential.

4.3.4. Identification

Once the origin of the signal is located, it is necessary to identify the specific radionuclide involved. This is because it impacts the safety considerations, as well as the subsequent scale of response to the discovery of the radioactive material. Identification of the radionuclide helps to categorize the nature of the event as inadvertent movement, illicit trafficking or an innocent alarm. It may also provide some information about the former use and ownership of the material, although this type of analysis is best done later at a laboratory for seized material. These data may be used later for enforcement purposes by the national regulatory authority.

Primary identification at border crossings typically requires special hand-held instruments to measure gamma ray energies to identify the radionuclide. This is known as gamma spectroscopy. If such equipment is not available, additional expert assistance may be necessary.

Today there is a user-driven trend to combine the above-mentioned tasks (localization, dose rate measurement and radionuclide identification) into a single hand-held instrument using multiple radiation detectors.

4.3.5. Guidance on instruments

The rest of this section offers guidance on the selection of each of the three types of instrumentation discussed. Guidance is also given on their use under field conditions where there may be operational constraints.

As discussed in the introduction, performance characteristics for each type of instrument should be regarded as providing guidance only, and *should not be taken as IAEA requirements or standards.* In addition, it should be recognized that such parameters are always a compromise between the ideal and the practical. As technology improves, then the performance characteristics may also be changed to reflect these improvements.

4.4. Pocket-type instruments

4.4.1. Application

The technology for detecting radioactive materials has developed rapidly in recent years. Advances in the miniaturization of low power electronics have made possible the development of a new class of compact gamma and neutron detectors. These detectors, which are similar in size to a message pager, can be worn on a belt or carried in a pocket for hands-free operation. Some such detectors can be used in ‘silent mode’ to warn the operator to the presence of radioactive materials, without alerting other persons in the proximity. Pocket-type instruments are ideally suited for use by individual officers and first responders to a radiation alarm because of their small size. In addition, they do not require extensive training to operate.

Since these instruments are relatively inexpensive and small enough to be worn on the uniform, it may be feasible for each individual officer to be routinely equipped with such an instrument while on duty. They have low power consumption so that they may be used continuously. Another advantage of them is their inherent mobility, which allows closer approach to a suspected radiation source, when it is safe to do so.

The use of pocket-type radiation detectors worn by many personnel in the course of their regular duties, can represent a ‘moving curtain’ that can be very flexible compared to fixed, installed instruments and thus cover a wide variety of possible traffic routes.

4.4.2. General characteristics

Although pocket-type instruments can be made with one of several different types of radiation detector, only those that employ scintillation detectors are sensitive enough for this application. The instrument’s display should provide a simple, luminescent indication, which is proportional to the dose rate. This clearly indicates to the user any changes in radiation levels and can be used as a search tool for locating radiation sources.

The best instruments of this type are maintenance free, of rugged construction, weather resistant and battery operated with adequate operation time. It is recommended that the alarm threshold is pre-set before issue to field officers, to correctly account for the local natural background radiation. However, some instruments now measure the background automatically upon start-up and store it for reference.

Design details vary, but pocket-type instruments may have a variety of additional features. Some types are able to produce three types of alarms: visual (light), audible (tone), and vibrating (silent, for covert operation). Some instruments feature an audible tone that changes as a function of dose rate.

4.4.3. Operation, calibration, and testing

A pocket-type instrument would normally be worn on the body, in a pocket, or on a belt. Useful self-testing features would verify proper electronics operation of the instrument (including battery status) before each period of use. A pocket-type instrument should also be checked, on a daily basis if possible, to verify its continued ability to detect radiation. This may be done by placing the instrument near a small radioactive check source and observing its response to the radiation.

It is inevitable that false alarms, i.e. alarms without radioactive materials present, will occur occasionally due to the fluctuations in background. When the alarm threshold is set appropriately, i.e. about three times natural background level, false alarms rates not exceeding one or two per working shift may be reasonable to expect.

Pocket-type instruments may be triggered by innocent radiation sources occasionally. This is because many common objects and materials contain small quantities of naturally occurring radioactive material such as thorium or uranium (see Annex I).

Like most radiation detectors, it is recommended that pocket-type instruments be calibrated once a year (or as required by the national regulatory authority), by a qualified individual or maintenance facility.

4.4.4. Minimum performance recommendations

As mentioned previously, the performance characteristics for each type of instrument should be regarded as providing guidance only, and *should not be taken as IAEA requirements or standards.* Furthermore, it should be noted that the conditions given in this section are not operational settings, but criteria against which performance tests can be made.

4.4.4.1. Sensitivity to gamma radiation

At a mean indication of 0.2 $\mu Sv \cdot h^{-1}$, an alarm should be triggered when the dose rate is increased by 0.1 $\mu Sv \cdot h^{-1}$ for a duration of 1 second. The probability of detecting this alarm condition should be 99%, i.e. no more than 100 failures in 10 000 exposures. The instrument should fulfil these performance characteristics in a continuous, incident gamma energy range from 60 keV to 1.33 MeV (tested with ^{241}Am, ^{137}Cs and ^{60}Co).

4.4.4.2. Alarm setting

The system should provide adjustable threshold levels for the alarm.

4.4.4.3. Dose rate indication

If the instrument provides a dose rate indication, the uncertainty should be within ±50%, when calibrated with ^{137}Cs.

4.4.4.4. *False alarm rate*

The false alarm rate should be less than 1 in a 12-hour period for background dose rates of up to 0.2 $\mu Sv \cdot h^{-1}$.

4.4.4.5. *Environmental conditions*

The instrument should meet the performance characteristics listed above in a temperature range of –15°C to +45°C and a relative humidity of at least 95%, in non-condensing conditions.

4.4.4.6. *Battery life*

The battery life should be greater than 800 hours under no alarm conditions for instruments with non-rechargeable batteries and greater than 12 hours for units with rechargeable batteries. Under alarm conditions the battery lifetime should be greater than 3 hours.

4.4.4.7. *Drop test*

Instruments should meet the performance characteristics after a 0.7 m test-drop on every face onto concrete.

4.5. Hand-held instruments

4.5.1. Application

Hand-held radiation monitors may take different forms and utilize different detectors and electronics. Those most recently developed are small, battery-powered, instruments that contain microprocessors. As technology advances additional capabilities will no doubt continue to emerge.

Hand-held monitors can be used to effectively search pedestrians, packages, cargo, and motor vehicles, with a great deal of flexibility. Training in proper use and interpretation of readings is of vital importance, and the training must be repeated periodically.

Hand-held instruments are available to detect all types of radiation, including neutrons. Some such instruments can detect more than one type of radiation (e.g. gamma and neutron). Hand-held instruments usually have the capability of measuring dose rates, and can therefore be used for radiation safety purposes.

Some sophisticated hand-held instruments can also be used to identify radionuclides.

4.5.2. Operation, calibration, and testing

Hand-held monitors can be used as either the primary search (detection) device or a secondary search device (validation) for fixed, installed instruments. It is essential that the instrument be equipped with an audible dose rate indicator or alarm to enable the user to perform the search without watching the meter.

For search applications a hand-held instrument should weigh less than 2 kg and have a comfortable carrying handle. The probability of detection can be improved if the user moves the instrument closer to any radioactive material that is present. Also, an instrument is more likely to detect radiation when it is moved reasonably slowly over the area to be scanned.

However, moving too slowly means that a survey takes longer, and so there is a compromise between speed and sensitivity. Instruments are available that can make measurements over a short time scale (less than 1 second), so that they can be used to quickly scan the surfaces of packages, pedestrians, vehicles, and cargo. To enable the location of the radiation source to be determined, the alarm indication should either automatically reset itself, or the frequency of the alarm tone should rise with increasing dose rate.

It is recommended that a hand-held instrument be checked, on a daily basis if possible, to verify its continued ability to detect radiation. This may be done by placing the instrument near a small radioactive check source and observing its response. Like most radiation detectors, it is recommended that it be calibrated once a year by a qualified individual or maintenance facility. Most of the combined hand-held radionuclide identifiers use a low activity gamma source to stabilize the energy scale. This is essential to achieve a good performance with regard to radionuclide identification.

4.5.3. Minimum performance recommendations

As mentioned previously, the performance characteristics for each type of instrument should be regarded as providing guidance only, and *should not be taken as IAEA requirements or standards.* Furthermore, it should be noted that the conditions given in this section are not operational settings, but criteria against which performance tests can be made.

4.5.3.1. Sensitivity to gamma radiation

At a mean indication of 0.2 $\mu Sv \cdot h^{-1}$, an alarm should be triggered when the dose rate is increased by 0.05 $\mu Sv \cdot h^{-1}$ for a period of 1 second. The probability of detecting this alarm condition should be 99%, i.e. no more than 100 failures in 10 000 exposure. This performance characteristic should be fulfilled in a continuous, incident gamma energy range from 60 keV to 1.33 MeV (tested with ^{241}Am, ^{137}Cs and ^{60}Co).

4.5.3.2. Audible indication rate for gamma radiation

The audible indication rate (the beep rate) at the specified background conditions should be not more than 1 beep per minute during 12 hours of operation, i.e. not more than 100 beeps in at least 100 minutes.

4.5.3.3. Sensitivity to neutron radiation

For instruments that have a neutron detection capability, the detector should alarm when exposed to a neutron flux emitted from a ^{252}Cf source of 0.01 μg (approximately 20 000 $n \cdot s^{-1}$) for a duration of 10 seconds, at 0.25 m distance, when the gamma radiation is shielded to less than 1%. The probability of detecting this alarm condition should be 99 %, i.e. no more than 100 failures in 10 000 exposures. The neutron dose rate corresponding to these irradiation conditions is about 2 $\mu Sv \cdot h^{-1}$.

4.5.3.4. False alarm rate for neutron radiation

The false alarm rate should be less than 6 in a 1-hour period.

4.5.3.5. Dose rate indication

If the instrument indicates dose rate, it should be capable of measuring at least up to 10 $mSv \cdot h^{-1}$ within an uncertainty of less than $\pm 30\%$, when calibrated for ^{137}Cs.

4.5.3.6. *Over-range indication*

The instrument should provide an over-range indication or continuous alarm at dose rates that are beyond its range.

4.5.3.7. *Environmental conditions*

The instrument should meet the performance characteristics listed above in a temperature range of –15°C to +45°C and a relative humidity of at least 95%, in non-condensing conditions.

4.5.3.8. *Battery life*

It is recommended that the battery life should be greater than 40 hours under no alarm conditions for instruments with non-rechargeable batteries and greater than 12 hours for units with rechargeable batteries. Under alarm conditions, the battery life should be greater than 3 hours. It is desirable that there be an indicator on battery condition.

4.6. Fixed, installed instruments

4.6.1. Application

Modern, fixed, installed radiation monitors are designed to automatically detect the presence of radioactive material being carried by pedestrians or transported in vehicles. The monitoring systems do this by measuring the radiation level (gamma or neutron) taken while a person or vehicle occupies the detection area, and comparing this level to the background radiation level that is measured and updated while the detection area is unoccupied. Continuous measurement of the background radiation level and adjustment of the alarm threshold enables a constant, statistical false alarm rate to be maintained. It follows that suitable occupancy sensors are needed, so that the instrument knows when to monitor the pedestrians or vehicles as they pass through and when to monitor background radiation levels.

4.6.2. Installation and operation, calibration and testing

Fixed, installed radiation monitors are often known as portal monitors and typically consist of an array of detectors in one or two vertical pillars with associated electronics. Because instrument sensitivity is strongly dependent upon distance, it is important to get the person or vehicle as close as practically possible to the detector array. Therefore, highest effectiveness is achieved if the monitors are installed such that all the pedestrians, vehicles, and cargo traffic are forced to pass close by, or between monitors. Careful consideration should, therefore, be given to selecting the optimum location to install fixed radiation portal monitors so they can be most effective.

The effectiveness of a fixed, installed instrument is also strongly dependent on its ability to measure the radiation intensity over the search area of interest. Therefore, when installing the monitor, it is important that the detector is positioned so that it has an unobstructed view of the search area. However, the instrument must also be protected from mechanical damage.

Alarm indications should be clearly visible to the officers manning the inspection point and officers responding to alarms will need to be trained in the appropriate response procedures [2].

Portal monitors need to be calibrated and tested periodically to ensure optimum performance. Automatic portal monitors should be checked daily with small radioactive sources to verify they can detect radiation intensity increases.

4.6.2.1. Pedestrian monitors

Pedestrian monitors may be installed as single or dual pillar monitors. Barriers should be installed to restrict the pedestrian traffic so that each person passes within 1.0 metre of the monitor. Where pedestrian traffic corridors are larger than 1.5 metres, dual pillars should be installed. It is important that the detector is placed away from heavy doors, which can cause excess false alarms. This is because shielding by the doors may lead to increased fluctuations in the radiation background. Also, it is important that the occupancy sensor be positioned so that it is only triggered when the instrument is occupied and not by individuals walking in the vicinity of the monitor.

The possible presence of shielding in luggage and packages may mean that the monitors are most effective when they are used in combination with metal detection systems (such as X ray machines), which can be used to easily identify the presence of shielding material.

4.6.2.2. Vehicle monitors

The use of fixed, installed radiation monitors to detect radiation sources in vehicles is complicated by the inherent shielding of the vehicle structure and its components. While standard truck-bed monitors can be effective in detecting abnormal radiation levels in shipments of metals for recycling, they are much less effective in detecting radioactive materials when that material is purposely concealed. Monitors specially designed to detect radioactive sources that may be being illicitly trafficked are more effective than truck-bed monitors, because they typically have detectors to view all areas above and below vehicles as well as the sides.

As discussed earlier, the sensitivity of detectors is dependent upon the closeness of the detector and source as well as the slowness with which they pass each other. For passenger vehicles, one-pillar monitors are acceptable if the maximum passage width is limited to a maximum of 3 m. For large trucks and buses, two pillars are required and the maximum recommended distance between pillars is 6 metres, dependent on the maximum width of the vehicle to be scanned. It is important that barriers, which do not obstruct the view of the monitor, are installed to protect the monitor from being damaged by vehicles.

Since the sensitivity of the monitor is also strongly dependent on monitoring time, the instrument needs to be placed where the speed of the vehicle is controlled and reduced. Instruments vary in their capabilities, but it is recommended that the speed of the vehicle does not exceed 8 $km \cdot h^{-1}$ and that the vehicle is not allowed to stop while passing through the monitor. It is recommended that the occupancy sensor is positioned so that it is only triggered when the monitoring system is occupied and not by other traffic in the vicinity.

4.6.3. Minimum performance recommendations

As mentioned previously, the performance characteristics for each type of instrument should be regarded as providing guidance only, and *should not be taken as IAEA requirements or standards*. Furthermore, it should be noted that the conditions given in this section are not operational settings, but criteria against which performance tests can be made.

4.6.3.1. *Sensitivity to gamma radiation*

It is recommended that at a mean indication of 0.2 $\mu Sv \cdot h^{-1}$, an alarm should be triggered when the dose rate is increased by 0.1 $\mu Sv \cdot h^{-1}$ for a period of 1 second. The probability of detecting this alarm condition should be 99.9%, i.e. no more than 10 failures in 10 000 exposures. This requirement should be fulfilled in a continuous radiation field, with the incident gamma radiation ranging from 60 keV to 1.33 MeV (tested with ^{241}Am, ^{137}Cs and ^{60}Co).

4.6.3.2. *Sensitivity to neutron radiation*

For instruments that have a neutron detection capability, the detector should alarm when exposed to a neutron flux emitted from a ^{252}Cf source of 0.01 μg (approximately 20 000 $n \cdot s^{-1}$) for a duration of 5 seconds, at 2 m distance, when the gamma radiation is shielded to less than 1%. The probability of detecting this alarm condition should be 99.9 %, i.e. no more than 10 failures in 10 000 exposures. The neutron dose rate corresponding to these irradiation conditions is about 0.05 $\mu Sv \cdot h^{-1}$.

4.6.3.3. *Search region*

The volume in which efficiency of detection is maintained will vary according to the instrument. The following is a description of the geometrical region in which the performance characteristics for the given alarm levels should be applicable.

(a) Pedestrian monitor:

- (i) Vertical: 0 to 1.8 m;
- (ii) Horizontal, parallel to the direction of movement: 0 to 1.5 m;
- (iii) Normal walking speed of 1.2 $m \cdot s^{-1}$.

(b) Car monitor (one pillar):

- (i) Vertical: 0 to 2 m;
- (ii) Horizontal, parallel to the direction of movement: up to 4 m;
- (iii) Speed up to 8 $km \cdot h^{-1}$.

(c) Truck and bus monitor (two pillars):

- (i) Vertical: 0.7 to 4 m;
- (ii) Horizontal, parallel to the direction of movement: up to 3 m (6 m between the two pillars);
- (iii) Speed up to 8 $km \cdot h^{-1}$.

4.6.3.4. *False alarm rate*

The false alarm rate during operation should be less than 1 per day for background dose rates of up to 0.2 $\mu Sv \cdot h^{-1}$. If a high occupancy rate of say, 10 000 occupancies per day were expected, this would mean ensuring not more than 1 false alarm in 10 000, for which the recommended testing requirement is not more than 4 false alarms in 40 000 occupancies.

4.6.3.5. *Operational availability*

Installed equipment should be available at least 99% of the time, i.e. less than 4 days out of service per year.

4.6.3.6. Environmental conditions

The system should be weather proofed and designed for outdoor operation. A desirable working temperature range would be –15°C to +45°C. However, this will be dependent on conditions at the installed location and lower temperatures down to –35°C may be necessary.

5. INVESTIGATION LEVELS AND INSTRUMENT ALARM SETTINGS

5.1. Nominal investigation level vs. instrument alarm setting

The nominal investigation level is defined here as that radiation level which is selected as the trigger for further investigation. This needs to be distinguished from the instrument alarm threshold. For example, assume that it is decided to investigate any time the dose rate exceeds 0.2 $\mu Sv\cdot h^{-1}$ (say this is at point A in Fig. 1). Setting the actual instrument's alarm at this point (A) would mean that half of the time such a dose rate is encountered it would not cause an alarm (i.e. 50% failure rate) because of the statistical nature of radioactive decay. Therefore, to reduce the failure rate to something more acceptable, the alarm threshold needs to be set at some lower value (say at C in Fig. 1).

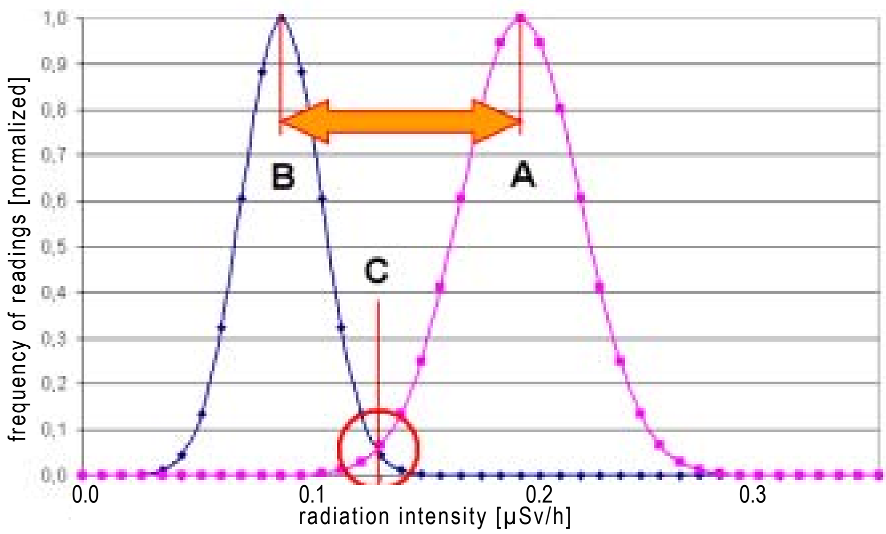


FIG. 1. Overlapping signals from background and a radiation source; frequency of instrument readings at background (left peak) and exposure conditions (right peak).

However, the background dose rate also has an interfering effect, since if the desired investigation level (A) is too close to the background dose rate (B in Fig. 1), there will be an unacceptable number of false alarms due to the background radiation. It can be seen from this that the determination of the nominal investigation level and the instrument alarm threshold setting are not trivial. A brief discussion of this follows for those who wish to know further details.

5.2. Determination of an instrument alarm threshold

The selection of a particular investigation level means that the alarm threshold of a monitoring instrument has to be set appropriately. The alarm threshold can be expressed in terms of multiples of background, or as a multiple of the standard deviation of the background count rate. Since the relationship between background dose rate and its standard deviation depends on the detection sensitivity of the instrument and the actual value of the background, a generally applicable investigation level cannot be derived.

Similarly, because of unknown factors such as the amount of shielding and the energy of the radiation, it is not possible to set an investigation level in order to detect a certain quantity of radioactivity. Therefore, it becomes reasonable to set the level at a value that is as sensitive as possible without causing too many false alarms. On this basis, recommendations for an optimum investigation level can be derived from results obtained from the large scale pilot study on border monitoring systems conducted by the Austrian Research Centers and the IAEA [10].

A compromise must be reached in establishing a practical alarm threshold so that radioactive materials being inadvertently moved or illicitly trafficked can be detected, yet provide an acceptably low nuisance alarm rate. Legally transported radioactive materials will also trigger the alarms, but the subsequent investigation should disclose this and allow continued movement of the individual or goods.

As discussed, the instrument alarm threshold must be set considerably below the nominal investigation level chosen to allow for statistical variations. To achieve a 99.9% detection probability, assuming the idealized case of Gaussian distribution, the instrument threshold has to be set at least at 3 σ below the desired level in order to catch all those events that fall statistically on the ‘low side’. On the other hand, the instrument setting must stay safely away from values too close to background. For a false alarm rate of 1 in 10 000 the instrument alarm threshold must be set at least 4 σ higher than average background for systems under Gaussian assumptions (3 σ for a false alarm rate of 1 in 1000).

Results from the ITRAP field tests [10] for truck monitoring indicate that an investigation level of at least 1.2 times natural background (at a normal background level of approximately 0.070 $\mu Sv \cdot h^{-1}$), is needed to meet the performance characteristics for the false alarm rate given earlier.

If the investigation level is raised to 1.4 times background, in addition to fulfilling the false alarm rate requirements, the frequency of innocent alarms can be decreased by approximately a factor of ten. For example, a truck lane handling some 1000 trucks per day would see innocent alarms reduced from 10 per day to 1 per day, corresponding to a reduction in innocent alarm rate from 1% per truck to 0.1% per truck. With this increase of the investigation level the required sensitivity of detection for real illicit trafficking incidents will still be obtained. For instance an unshielded radiation source of 3.7 MBq ^{137}Cs should trigger an alarm under the worst-case conditions for all properly installed and calibrated fixed, monitors.

For monitoring of pedestrians or cars, where it is expected that innocent alarms would be caused by medical radionuclides only, a lower investigation level of 1.2 times natural background can be used because the innocent alarms are likely to be less frequent.

With some assumptions, it is possible to convert the recommended investigation levels from multiples of background to multiples of the standard deviation. For a typical detector system with 1000 cps at background conditions, fulfilling the performance characteristics stated earlier, means that a nominal investigation level value of 1.2 times background would correspond to about 7 standard deviations. A value of 1.4 times background corresponds to approximately 14 standard deviations under this condition.

Specialist personnel involved in the selection and installation of this type of equipment are advised to consider these issues in the local context, and thereby satisfy themselves that appropriate instrument alarm settings have been made to achieve an investigation level that is practical under local conditions. Inevitably, once a unit has been in operation for a while some adjustments to the alarm settings will need to be made based on operational experience.

As discussed earlier, once an alarm has been signified the next tasks are to:

— verify that the alarm is caused by an actual increase in the radiation level;
— localize the source of the radiation, if present;
— identify the radioactive material and evaluate the situation.

Each of these steps is discussed in more detail in subsequent sections.

6. VERIFICATION OF ALARMS

6.1. Types of alarm

There are three main types of alarms of primary interest:

— false alarms;
— innocent alarms;
— real alarms.

6.1.1. False alarms

The normal, statistical fluctuations of the background radiation intensities can cause false alarms. They can also be caused by nearby radio-frequency interference, but this should not be a problem with modern, well-designed instruments.

6.1.2. Innocent alarms

For the purpose of this TECDOC, innocent alarms are those that result from an actual increase in radiation level, but for reasons that are *not* due to inadvertent movement or illicit trafficking of radioactive materials. There are a multitude of potential causes for innocent alarms and a detailed listing is given under several categories in Annex I. It is expected that the majority of actual alarms at borders will be innocent alarms resulting from the presence of medical radionuclides administered to patients, naturally occurring radioactive materials (NORM), and legal shipments of radioactive materials.

As an example, in airline passenger or pedestrian border crossing environments, the most common radioactive sources likely to be encountered are people who have recently received radionuclides for medical diagnosis or treatment. Although the radioactive agents used (e.g., iodine for thyroid treatment, or thallium for heart stress tests) are generally short-lived, residual radioactive materials may be detectable for days or weeks after the medical procedure. There is a significant probability of encountering such patients among the travelling public.

Measurement conditions at borders are essentially different from those in nuclear facilities, recycling or disposal facilities. Large traffic volumes crossing major borders limit the time available for detection and multiple checks are usually impractical. Even high activity radioactive sources in shielding containers may not be detected at borders without unloading the vehicle, and such a procedure is not routinely practicable. Highly sensitive monitoring systems necessarily cause more frequent false alarms or innocent alarms due to such sources as naturally occurring radioactivity in fertilizers or in scale deposited in pipes used in the oil industry. The ITRAP study [10] identified four categories of transported goods that caused innocent alarms, with the highest frequency of 10 alarms per day coming from industrial products and raw material.

The relevant authorities of States determine the limits of allowable activity concentrations, for naturally occurring substances. Frequent innocent or false alarms at a border or other high traffic volume monitoring location would render the monitoring system useless in practice. Therefore a compromise between excessive false alarm rate and unacceptably low sensitivity has to be made.

6.1.3. Real alarms

The final category of alarms, real alarms are defined here as being ones that: (a) are caused by an actual increase in the radiation intensity; and (b) result from the inadvertent movement or illicit trafficking of radioactive materials. Making the latter determination normally involves further evaluation of the situation.

6.2. Alarm verification by monitoring

Verifying an initial alarm usually involves repeating the measurement under the same conditions and/or using another instrument. A similar response is a good indication that there is a real increase in radiation levels.

6.2.1. Pocket-type and hand-held instruments

Once a radioactive emitter has been detected, the same or a different instrument can also be used for verification. If an alarm is triggered again, verification is clear, and further investigation is required.

6.2.2. Monitoring of pedestrians and their luggage

A pedestrian causing a portal monitor alarm to be triggered can be passed through the monitor a second time to see if the alarm recurs. If the alarm recurs, it is recommended that the person be separated from any items being carried and that further investigations are made.

A radiation dose rate survey of the person and the person's belongings using a hand-held or pocket-type instrument should be undertaken. Advice on the significance of radiation levels and on search techniques are given in the next sections.

If the source of the radiation is determined to be located in one of the carried items, consideration may be given to X raying the item to determine whether significant gamma shielding is present or not. However, if local assessment suggests that there is a significant probability of trafficking associated with terrorist activity, consideration should be given to other potential hazards. In particular, there may be the possibility of explosive devices being detonated by the action of the X radiation.

When the source of the radiation has been located, it is useful to identify its energy and thereby determine the radionuclide(s) involved.

6.2.3. Monitoring of vehicles

When the passage of a vehicle through a fixed, installed radiation monitor results in an alarm condition, it will normally be necessary to remove the vehicle from the flow of traffic for further investigation.

Remembering the possibility that the alarm could be caused by residual medical radionuclides, it is useful to ensure that the driver and passengers are removed from the vehicle and scanned separately. At this point a radiation dose rate survey of the individuals and the vehicle can be performed, but it would also be important to identify the isotope(s). Advice on the significance of radiation levels and on search techniques are given in the next sections.

As already mentioned, for truck traffic and cargo containers the most frequent alarms will be innocent alarms caused by large quantities of naturally occurring radioactive material. For example, large shipments of fertilizer, agricultural produce, tobacco products, some ores, porcelain, and timber have been known to cause alarms. However, it should be noted that these radiation signatures are uniformly distributed through the load and therefore, are different from the usually more localized signature of individual sources or trafficked radioactive material.

7. RADIOLOGICAL CONDITIONS AND RESPONSE LEVELS

In general, the level of response needed to a real alarm will be dependent upon the radiological conditions found [2]. Most situations encountered will involve little or no hazard and can be handled by non-radiation safety specialists. This is termed an operational level response.

It is recommended that the response be upgraded to the tactical level involving radiation safety professionals if any of the following situations are found:

- radiation level greater than 0.1 $mSv \cdot h^{-1}$ at a distance of 1 m from a surface or object;
- the confirmed detection of neutron radiation;
- detection of nuclear material with a hand-held isotope identifier; or
- uncontrolled contamination indicated by loose, spilled or leaking radioactive materials.

The value of 0.1 $mSv \cdot h^{-1}$ at 1 m has been selected in view of the fact that this is the limit for legal transport of radioactive materials as detailed in the IAEA “Regulations for the Safe Transport of Radioactive Material”, IAEA Safety Requirements No ST-1 [13].

Further escalation to a rare, strategic level response would depend upon the magnitude and severity of the radiological situation. This would likely involve the activation of a national or district emergency response plan.

The recommended response measures to be applied when radioactive materials have been detected, are described in more detail in the companion TECDOC, "Response to Events Involving Inadvertent Movement or Illicit Trafficking of Radioactive Materials" [2].

8. LOCALIZATION OF RADIOACTIVE MATERIAL

8.1. General search preparation

Normally the verification of an alarm, the searching for the radioactive material and performing a cursory radiological assessment are one continuous process even though they are discussed separately in this publication. Each of them involves a survey with a portable instrument. It should be noted that only the general principles of searching are described since individual instruments vary in their features.

Because the presence of radiation is not detectable by human senses, it is important to check the operability of any instrument before its use. Manufacturer's suggested procedures should be followed. Typically they will involve a battery check and a response check to a small radioactive source. In addition, the average background radiation level needs to be noted. All of this preparation is best undertaken away from the intended search area. Initial functional checks, and background measurement are reliable only if they are performed in a representative normal background. This is especially important for some modern instruments that measure the ambient background level and automatically adjust alarm thresholds. These checks would normally only take 10 to 30 seconds, and the search may then be started.

Regardless of the portable search instrument used, including pocket-type instruments, the effectiveness of the procedure depends on the quality of the search technique. Different techniques are recommended below for searching pedestrians, packages, vehicles, or cargo.

When searching, automated instruments may occasionally indicate very brief signals above the alarm threshold. This is because instruments of this type continuously measure the radiation field in very short counting-time intervals. Most of the measured values are near the background level, but a few may exceed the alarm threshold due to statistical effects of counting. Therefore, single alarms during the scanning process are not significant. Significant alarms are those that are multiple and reproducible.

To conduct a thorough, effective search, the monitor must be scanned over the surface of the individual, package, or vehicle. When the instrument detects a radiation level that is significantly above background, it will indicate this in some way, depending on its design features. Many modern instruments alarm with a series of beeps. This allows the user to concentrate on the search instead of watching the meter.

It is important that during scanning the instrument is maintained at a close distance to the surface (approximately 5 to 10 cm) without making contact. In addition, instruments are typically more sensitive if they are moved slowly over an area. However, there is a trade-off with the length of time that a survey might take. A reasonable guide would be to move the detector, or its probe at about 20 $cm \cdot s^{-1}$.

The nearer a monitor is to a radioactive source the greater the radiation intensity and the easier it is to find the material. To localise the radioactive material, the user should follow the direction of increasing intensity (more frequent beeps) until the maximum level is found. A rapidly varying dose rate as the instrument is moved would be an indicator of an individual radiation source or partially shielded radiation. On the other hand, a small change in an elevated reading would indicate a larger volume of material such as a naturally radioactive bulk ore shipment.

8.2. Pedestrian search

It is recommended that a pedestrian carrying bags or packages be separated from these items before searching so that they may be searched independently.

To perform a reasonable radiation search of an individual, will typically take about 20 to 30 seconds. This is enough time to search the individual's front, back and sides if the speed and distance guide given above is used.

The following systematic search pattern is recommended. Starting near one foot, continue up one side of the body to the head, then scan down the other side. Then ask the individual to make a quarter turn and repeat the pattern on the front and back. A scan from head to foot will take about 4–5 seconds. Hence, each up and down scan will take about 8–10 seconds. Turning takes a few more seconds, giving a total of about 20 seconds. These timings are considered to be the minimum, but will enable a reasonable search when a large number of people need to be scanned.

8.3. Package and cargo search

It is important that the items people commonly carry, such as briefcases, purses, packages and luggage are searched as a separate procedure from the search of the individual. This will help to ensure that a systematic and complete search is achieved. Each item is best searched by passing the monitor over its surface at a rate similar to that used on people.

Where legal powers allow law enforcement officers to do so, it is useful to ask the person to open large items for a visual search. It is recommended that bulky, heavy objects be assessed and searched if it is considered that they may be shielding radioactive material.

If a package is sealed and cannot be opened for a visual search, a slower external search of all accessible sides with the instrument will increase the probability of detecting any radioactive material that may be inside.

Law enforcement officers need to think broadly about all risks when searching for nuclear or other radioactive material. For example, a package may contain explosives or other hazardous materials and may need to be handled with appropriate caution.

8.4. Motor vehicle search

Motor vehicles are more challenging to search than people or packages. The search is a much longer procedure due to the materials and complexity of the structure of the vehicle, as well as the need to search people in the vehicle and any items carried as separate searches.

Although instrumentation is essential in these searches, it is important to remember that a visual search is also a key part of the process. Large, heavy containers merit very careful scans with the monitor because they may be shielding radioactive material contained within. More careful scans usually means moving the instrument probe slower and keeping it closer to the object of interest.

In addition, large heavy structures can shield the path of gamma rays and block their passage, just as objects in the path of light create a shadow. It follows that it is important to look for shields that are in the path of any radiation that may be originating from behind the item, rather than within it. Effective materials to shield against gamma radiation include thick metal, brick and concrete, whereas neutron radiation can be shielded by substantial quantities of polythene, plastic, fuel or water.

8.4.1. Search of personnel and their effects

It is recommended that the occupants are searched as well as the vehicle. A systematic and complete search of the occupants can only be achieved if the occupants disembark from the vehicle, and stand away from it, and the procedure described earlier is followed. Similarly, belongings such as briefcases, purses or packages need to be surveyed as before.

8.4.2. Hood area search

A search under the vehicle's hood can be achieved by moving the monitor close to all surfaces that can be reached, including the hood itself.

8.4.3. Trunk and interior search

A search of the vehicle's trunk and interior can be performed if a systematic approach is taken. Enter through each door and search around every object and surface within reach. Scan unlikely places, such as the dashboard, sun-visor, headliner area, floor, and under the seats. Search the space behind the rear seat. Search the cargo areas in trucks. Areas that cannot be reached on the inside may be able to be searched from outside the vehicle.

It may be useful to note that glass is a less effective shield than metal for lower energy radiations, and so it could be more appropriate to search at windows than part of the metal structure. It is recommended that the aim should be to keep the monitor within 10 cm of every surface. Extra time taken when searching a vehicle improves the probability of detecting any radioactive material that may be present.

8.4.4. Exterior search

It is recommended that a search of the outside of a vehicle includes checking under frame rails and bumpers as well as the wheel wells in front and behind the tires.

8.4.5. Truck beds

It is recommended that the bed of trucks is searched, even if it appears to be empty. This is because a container of radioactive material may be attached to the under-surface.

8.4.6. Large trucks

Large vehicles such as step vans, flatbed trucks, dump trucks, garbage trucks, and many other large trucks present a particular challenge. In fact, the ITRAP study even concluded that detailed searching of large trucks with hand-held instruments is not practical. It recommended a more sophisticated fixed installation system for such search purposes. Nevertheless a hand-held instrument search of some areas of the vehicle can still be achieved. It is helpful to have a stepladder or step-stool to reach high places. Alternatively, a detector could have its cable extended and then be attached to the end of a long pole. A search of accessible spaces can be augmented by a search of the exterior of any inaccessible spaces.

9. EVALUATION OF RADIOACTIVE MATERIALS FOUND

9.1. General

A further step in the evaluation of the nature of an alarm involves the identification of the specific radionuclides that are found. The identification of a gamma emitting radionuclide, using a combined hand-held device, normally follows after the confirmation of an alarm, localization of the source and a dose rate measurement. Identification of the radionuclide will help in the assessment as to whether the alarm is an innocent alarm. For example, if the radioactive material is identified as one that is often used for medical treatment, it is less likely to be an illicit trafficking event.

Radionuclide identification is just one part of the evaluation of the nature of the radioactive materials and the determination as to whether they are part of an inadvertent movement or illicit trafficking incident. Interviews with the personnel involved, and an examination of documentation are complementary activities that will be part of the investigation as to whether there is criminal intent. These topics will not be discussed further, since they are a normal part of customs and law enforcement activities and are outside of the scope of this report.

However, it is worth being alert to the possibility of illicit material being transported along with, or in, a legal shipment of radioactive material. If a commodity causes an alarm, and is found be one that is known to be rich in a naturally occurring radionuclide, such as ^{40}K or ^{232}Th, it may be helpful to assess other information related to the consignment. For example, a vehicle carrying bananas or tobacco (rich in ^{40}K), which gives a positive alarm, might be assessed for the possibility of it carrying illicitly trafficked radioactive materials in addition to its legitimate cargo.

9.2. Radionuclide identification devices

Modern radionuclide identification devices typically measure the gamma-ray spectrum and identify the radionuclide from that. They are hand-held, battery powered instruments that may be used in the field by non-experts. If such a device cannot be provided for routine use in the field, it may be considered appropriate to obtain expert technical support with more comprehensive, and less portable, equipment.

The technology associated with radionuclide identification is improving continually, and it is not possible to predict what improvements may emerge in the near future. However, whichever radionuclide identification device is used, it is likely that the analysis will take significantly longer than the time-scale of a typical search process. Modern portable instruments may take minutes rather than hours. However, if these are not available, specialist support may involve the deployment of larger instruments that would normally be laboratory based and accordingly take several hours. This is because of the extended set-up times needed for laboratory type-instruments that may have to be used in the field (e.g. calibration), as well as the time taken for the data to be collected and analyzed. Alternatively, the radioactive material of interest could be transported to a laboratory after any radiological safety issues have been considered, including meeting applicable transport regulations.

9.3. Performance characteristics for radionuclide identification

9.3.1. Radionuclides of interest

Most of the radionuclides likely to be encountered at borders can be identified by instruments capable of identifying spectra consisting of gamma ray energy peaks between 60 keV and at least 1.33 MeV. The radionuclides of greatest interest and those most likely to be encountered are listed below in increasing isotopic number:

(1) Nuclear materials: ^{233}U, ^{235}U, ^{239}Pu;

(2) Medical radionuclides: ^{18}F, ^{67}Ga, ^{99m}Tc, ^{111}In, ^{123}I, ^{125}I, ^{131}I, ^{133}Xe, ^{192}Ir, ^{201}Tl;

(3) Naturally occurring radioactive materials (NORM): ^{40}K, ^{226}Ra, ^{232}Th, ^{238}U;

(4) Industrial radionuclides: ^{57}Co, ^{60}Co, ^{133}Ba, ^{137}Cs, ^{192}Ir, ^{226}Ra, ^{241}Am.

Radionuclide identification devices should be capable of identifying all radionuclides listed above.

Since the probability of observing particular radionuclides at different types of border crossings, such as land borders, airports and seaports varies, it is useful to be aware that:

— For pedestrian border crossings and airports, medical radionuclides from recently discharged patients are the most likely to be encountered. These radioactive materials can either be localized, or distributed throughout the body.

— Naturally occurring radionuclides such as ^{40}K, ^{226}Ra, ^{232}Th and ^{238}U are most likely to be detected when large quantities of materials are transported, i.e. at seaports, trains, and truck traffic at land borders.

9.3.2. Testing

After calibration the following radionuclides, producing a gamma radiation dose rate at detector of about 0.5 μSv h^{-1} above background with and without shielding, should be identified:

— unshielded, in less than 3 min: ^{111}In, ^{99m}Tc, ^{201}Tl, ^{67}Ga, ^{133}Xe, ^{125}I, ^{123}I, ^{131}I, ^{192}Ir, ^{18}F;

— behind 3 mm steel shielding, in less than 20 min.: ^{235}U, ^{238}U, ^{57}Co, ^{241}Am, ^{237}Np;

— behind 5 mm steel shielding, in less than 20 min.: ^{239}Pu, ^{233}U, ^{133}Ba, ^{40}K, ^{226}Ra, ^{232}Th, ^{137}Cs, ^{60}Co, ^{192}Ir.

It is desirable that combinations of radionuclides, such as $^{137}Cs + {}^{239}Pu$, $^{131}I + {}^{235}U$, $^{57}Co + {}^{235}U$, $^{133}Ba + {}^{239}Pu$, each producing a gamma radiation dose rate at detector of about 0.5 μSv·h^{-1} above background, can be identified.

9.4. Practical considerations when selecting an instrument

The usefulness of an instrument depends on several factors:

- The user interface (dial, lights, screen) should be large and easy to read under various lighting conditions.
- The best practical, field instruments are those that incorporate a very limited number of buttons, knobs and keystrokes (for navigation of any software).
- A good menu structure of any software is one that is simple and intuitively easy to follow.
- A detailed gamma spectrum is not normally required to be shown, although it may be helpful if this is available at a deeper level of the menu for diagnostics by an expert user.
- Messages which the instrument provides as its output are most useful if they have a high certainty shown by constancy of display. Indication of more than one choice for a single radionuclide is not helpful under field conditions.
- If a radionuclide cannot be identified unambiguously, clear messages such as “not identified” or extended measurement required, are more useful than a wrong identification.
- The higher the processing speed of the software used in the instrument, the more rapidly the analysis results become available for prompt field use. When a gamma spectrum is measured to identify radionuclides, there are two different time periods of relevance. One is the measurement time needed to collect the gamma spectrum. This time depends upon the activity of the source, energy of the gamma lines, presence of shielding and distance from the source. This time may range from tenths of seconds to about 10 minutes. After completion of the measurement, the gamma spectrum is processed to determine the radionuclides present. The time needed for this is usually less than 30 seconds.
- The possibility of storing spectra in a non-volatile memory and transfering them to a computer or over a remote link for expert review can be useful. This is especially so if problems cannot be resolved on the spot.
- In many ways the instrumentation for border monitoring is still in its infancy, and more development work is needed to improve its ease of use and ruggedness.

Annex I
RADIOACTIVE MATERIALS AND RADIONUCLIDES OF INTEREST

This annex provides some useful tables of radioactive materials and radionuclides of interest to those involved with border monitoring

A.I.1. Causes of innocent alarms

As discussed in the main text and illustrated in Fig. 1, the main reasons for innocent alarms of border monitoring systems are medical applications of radioactive materials as well as legal shipments of radioactive materials such as naturally occurring radioactive materials (NORM), consumer products, and labelled radionuclides.

A.I.1.1. Medical radionuclides

Table I gives those medical radionuclides which are most likely to be encountered.

Table I. Most common medical radionuclides

Gallium-67	Iodine-129
Technetium-99m	Iodine-131
Indium-111	Xenon-133
Iodine-123	Thallium-201
Iodine-125	

A.I.1.2. Naturally occurring radioactive materials (NORM)

The most frequently naturally occurring radionuclides are ^{40}K, natural U (^{238}U, ^{226}Ra) and natural Th (^{232}Th). The latter two may also be in equilibrium with their daughter products.

Table II. Frequently observed materials containing naturally occurring radionuclides

Substance	Approximate activity concentration in Bq.kg^{-1}		
	K-40	**Ra-226**	**Th-232**
Fertilizers	40–8000	20–1000	20–30
Granite	600–4000	30–500	40–70
Adobe	300–2000	20–90	32–200
Slate	500–1000	30–70	40–70
Sandstone	40–1000	20–70	20–70
Marble	40–200	20–30	20
Feldspar	2000–4000	40–100	70–200
Monazite sand	40–70	30–1000	50–3000
Concrete	150–500	40	40

Additional substances containing naturally occurring radioactive materials are:

- Thoriated tungsten welding electrodes.
- Dental ceramics.
- Irradiated gem stones (natural base material containing artificial radionuclides).
- Camera lenses.
- Polishing powder.

— Thoriated glasses.
— Coloured ceramic glazes.
— Incandescent gas mantles.
— Bananas, marihuana (containing K-40).

It should be noted that uranium which has been depleted in ^{235}U, and is therefore mostly ^{238}U, is often used as a radiation shield for source containers because of its high density.

A.I.1.3. Radionuclides frequently used in industry and research

Table III. Radionuclides frequently used in industry and research

Sodium-22	Yttrium-90	Barium-133
Phosphorus-32	Technetium-99	*Caesium-137
Calcium-47	Technetium-99m	Promethium-147
Cobalt-58	Ruthenium-106	Gadolinium-153
*Cobalt-60	Palladium-103	*Iridium-192
Gallium-67	Indium-111	Mercury-197
Selenium-75	Iodine-123	Thallium-201
Krypton-81m	Iodine-125	Radon-222
Yttrium-88	Iodine-129	*Radium-226
Strontium-89	Iodine-131	Plutonium-238
*Strontium-90	Xenon-133	*Californium-252

* Although these radioactive materials are also used in medicine, they are used principally for radiation *therapy*, and should not be found when individuals are monitored. If, however, these radioactive materials are identified and verified in individuals, it is recommended that this is immediately investigated.

A.I.2. Radioactive materials involved in incidents reported to the IAEA database

These data have been derived from the IAEA database on illicit trafficking incidents (as of the last full report 31 December 2000).

Table IV. Nuclear materials in the illicit trafficking database

Element	**Material description**	
	Material type	**Mass range***
Uranium	natural	0.1 g–82 kg
	depleted	0.1 g–100 kg
	low enriched	4.11 g–149.8 kg
	high enriched	0.17 g–2.972 kg
Plutonium	total	0.05 mg–363 g
Thorium	various chemical forms	0.3 kg–1400 kg

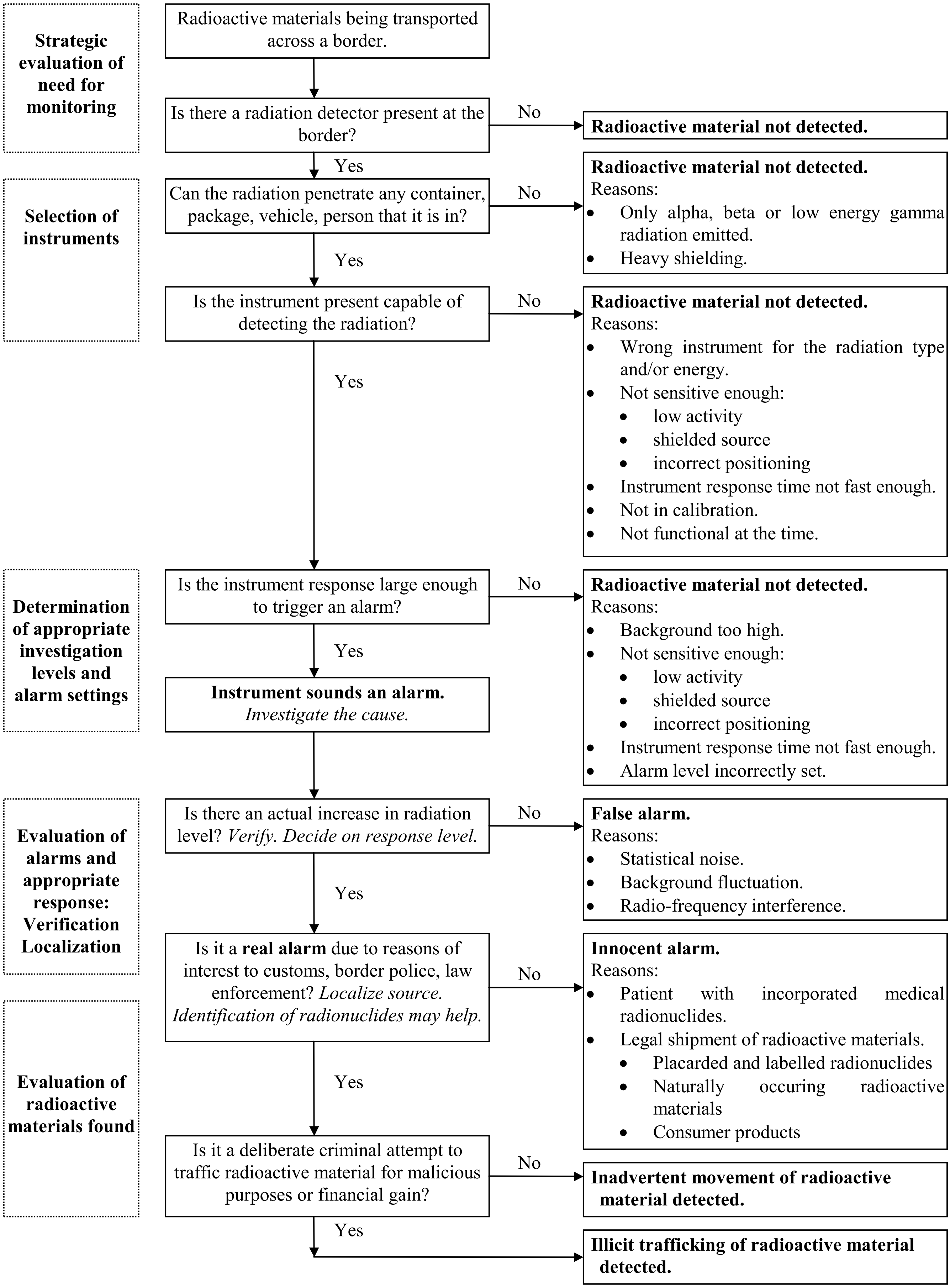
*The lowest and highest mass value of all seized materials.

Table V. Other radionuclides of interest in the illicit trafficking database

Radionuclide	Type of radiation	Activity /Neutron flux range*
Americium-241	a, g	3.7×10^4 Bq – 2.0×10^{10} Bq
Cadmium-109	g	1.85 × 105 Bq – 3.7 × 108 Bq
Caesium-137	b, g	1.85 × 105 Bq – 3.1 × 1012 Bq
Californium-252	a, g, n	3.3 × 106 $n.s^{-1}$ – 1.3 × 107 n.s-1
Cobalt-60	b, g	3.34 × 102 Bq – 3.26 × 1013 Bq
Iridium-192	G	9.25 × 104 Bq – 2.94 × 1012 Bq
Krypton-85	b, g	1.85 × 105 Bq – 1.85 × 107 Bq
Lead-210	a, b, g	1.0 × 104 Bq
Strontium-90	B	1.8 × 103 Bq – 2.6 × 1011 Bq
Radium-226	a, b	7.1 × 103 Bq – 5.0 × 108 Bq
Technetium-99m	b, g	5.9 × 109 Bq – 1.4 × 1011 Bq

* The lowest and highest activity of all seized sources.

Annex II
FLOWCHART SHOWING THE PROCESS LEADING TO DETECTION OF INADVERTENT MOVEMENT OR ILLICIT TRAFFICKING



REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Prevention of the Inadvertent Movement and Illicit Trafficking of Radioactive Materials, IAEA-TECDOC-1311, Vienna (2001).
[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Response to Events Involving Inadvertent Movement and Illicit Trafficking of Radioactive Materials, IAEA-TECDOC-1313, Vienna (2001).
[3] UNITED STATES NUCLEAR REGULATORY COMMISSION, Lost Iridium-192 Source Resulting in the Death of Eight Persons in Morocco, Information Notice No. 85-57, USNRC, Washington (1985).
[4] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, IAEA, Vienna (1988).
[5] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, NUCLEAR ENERGY AGENCY OF THE ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).
[6] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, NUCLEAR ENERGY AGENCY OF THE ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, Radiation Protection and the Safety of Radiation Sources, Safety Series No. 120, IAEA, Vienna (1996).
[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety, Safety Standards Series No. GS-R-1, IAEA, Vienna (2000).
[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Organization and Implementation of a National Regulatory Infrastructure Governing Protection Against Ionizing Radiation and the Safety of Radiation Sources, IAEA-TECDOC-1067, Vienna (1999).
[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Code of Conduct on the Safety and Security of Radioactive Sources, IAEA/CODEC/2001, IAEA, Vienna (2001).
[10] AUSTRIAN RESEARCH CENTERS SEIBERSDORF, Illicit Trafficking Radiation Detection Assessment Program, Final Report, OEFZS-G-0002, Seibersdorf (2000).
[11] ANZELON, G., HAMMOND, W., NICHOLAS, M., "The IAEA's Illicit Trafficking Database Programme", Measures to Prevent, Intercept and Respond to Illicit Uses of Nuclear Material and Radioactive Sources (Proc. Conf. Stockholm, 2001), C&S Papers Series No. 12, IAEA, Vienna (2002).
[12] LUBENAU, J.O., YUSKO, J.G., Radioactive materials in recycled metals: an update, Health Phys. **74** 3 (1998).
[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material, Safety Standards Series No. ST-1, IAEA, Vienna (1996).

GLOSSARY

The following definitions apply for the purposes of the present publication:

Control of radioactive materials

The act of maintaining cognizant supervision by proper authorities over the production, use, storage, transport and disposal of radioactive materials.

Illicit trafficking

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

Inadvertent movement

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

Non-proliferation

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

Nuclear material

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

Orphan source

A source which poses sufficient radiological hazard to warrant regulatory control, but which is not under regulatory control because it has never been so, or because it has been abandoned, lost, misplaced, stolen or otherwise transferred without proper authorization.

Physical protection

Measures for the protection of nuclear material or authorized facilities designed to prevent unauthorized access or removal of fissile material or sabotage with regard to safeguards, as, for example, in the Convention on the Physical Protection of Nuclear Material.

Radioactive materials

Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity.

Radioactive waste

Material, whatever its physical form, remaining from practices or interventions and for which no further use is foreseen (i) that contains or is contaminated with radioactive substances and has an activity or activity concentration higher than the level from regulatory requirements, and (ii) exposure to which is not excluded from the Standards.

Safeguards

A verification system within the framework of international non-proliferation policy, applied to the peaceful uses of nuclear energy and intended to maintain stringent control over nuclear material.

CONTRIBUTORS TO DRAFTING AND REVIEW

Andrasi, A.	KFKI Atomic Energy Research Institute, Hungary
Aygün, A.	Customs Administration, Turkey
Beck, P.	Research Centre Seibersdorf, Austria
Becker, D.	Bundesamt für Strahlenschutz, Germany
Betko, I.	Customs Administration, Slovak Republic
Ciani, V.	European Commission, Belgium
Cunningham, J.	Pennant Security Consultants Ltd, United Kingdom
Dodd, B.	International Atomic Energy Agency
Duftschmid, K.E.	International Atomic Energy Agency
Englefield, C.	Environment Agency, United Kingdom
Gayral, J.P.	Commissariat à l'Energie Atomique, France
Geysels, F.	Programme Environnement, Service Général d'Appui Policier, Belgium
Golder, F.	KFKI Atomic Energy Research Institute, Hungary
Hagberg, N.	Swedish Radiation Protection Institute, Sweden
Hohenberg, J.K.	Federal Ministry for Agriculture, Austria
Hort, M	RC Plzen, Czech Republic
Jurina, V.	Ministry of Health Protection, Slovak Republic
Karakaya, M.	General Directorate of Security, Turkey
Klastersky, K.	NCB Interpol Prague, Czech Republic
Kolobov, I	Ministry of Fuel and Energy, Ukraine
Kravchenko, N.	State of Customs Committee of the Russian Federation
Kümbül, A.	Customs Administration, Turkey
Maher, L.	Exploranium, Ltd, Canada
Maiorano, N.	National Europol Unit, Italy
Maroto, R.	ICPO (INTERPOL), France
Meehan, W.	International Atomic Energy Agency
Mellwig, R.	World Customs Organization, Belgium
Menga, A.	Service Opérationnel pour l'Ecologie de L'Arme des Carabiniers, Italy
Miklush, D.I.	International Atomic Energy Agency
Molnár, K.	Atomic Energy Authority, Hungary
Montmayeul, J.P.	Commissariat à l'Energie Atomique, France

Nilsson, A.	International Atomic Energy Agency
Okyar, B.	Atomic Energy Authority, Turkey
Ortiz López, P.	International Atomic Energy Agency
Osborne, R.V.	Private consultant, Canada
Paaladino, N.	Triestes's Anti Fraud Team, Italy
Raggetti, N.	Colonel Des Carabiniers, Italy
Rakshit, S.	Customs Administration, Finland
Rostek, H.J.	Zollkriminalamt, Germany
Saka, E.	World Customs Organization, Belgium
Samiei, M.	International Atomic Energy Agency
Schmitzer, C.	Research Centre Seibersdorf, Austria
Sedlácek, J.	State Office for Nuclear Safety, Czech Republic
Sloover, J. de	Customs Administration, Belgium
Smagala, G.	Central Laboratory for Radiological Protection, Poland
Smith, D.	US Customs Service, United States of America
Solomin, A.	National Central Bureau (INTERPOL), Russian Federation
Stavrov. A.	Polimaster, Belarus
Stefulova, A.	Nuclear Regulatory Authority, Slovak Republic
Strand, J.	Customs Administration, Norway
Sudakou, I.	Nuclear and Radiation Safety Regulation Comm., Belarus
Thomson, J.	Pennant Security Consultants Ltd, United Kingdom
Tikkinen, J.	Radiation & Nuclear Safety Authority, Finland
Todorova, B.Z.	Bulgarian Customs Service, Bulgaria
Vadala, G.	Corps Forestier de l'Etat, Italy
Valle, A.D.	Departamento de Aduanas e Impuestos, Spain
Weil, L.	International Atomic Energy Agency
Weiss, B.	International Atomic Energy Agency
Willuhn, K.	Bundesamt für Strahlenschutz, Germany
Wrixon, A.D.	International Atomic Energy Agency
Wynne, B.	Permanent Mission of the United Kingdom to the IAEA
York, R.L.	Los Alamos National Laboratory, United States of America
Yusko, J.	International Atomic Energy Agency