Strategies and procedures for recovery and safe management of orphan radioactive sources discovered by military forces during peacekeeping operations

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Abstract

The subject of discovery and safe management of “orphan” radioactive sources recently aroused great interest due to its relevance in terms of protection of population and environment. The European Community issued a specific Directive (Council Directive 2003/122/EURATOM) in order to keep the national institutions prepared to manage the risk of radioactive exposure from such sources. When military units are deployed in peacekeeping operations, orphan sources could easily be discovered: the lack of rules and enforcement in a post conflict environment makes easier - compared to peaceful and developed areas - to lose control over radioactive sources used in medical, industrial and research settlements. This work suggests a strategy for the management of orphan radioactive sources, with the aim of ensuring protection of military personnel during recovery missions that could possibly be performed during peacekeeping operations. Operating procedures to be followed by specialised military teams are described. A simple method, based on radioprotection principles, is proposed in order to choose between two possible strategies: the “on site” conditioning of the source and the transport to a safe site. Finally, medical aspects related to possible accidental exposures, occurred before being aware of the presence of the orphan source, are investigated.

Keywords: orphan radioactive sources, radioprotection, accidental exposures

1 Introduction

Sealed radioactive sources have been used globally in a wide range of applications in medicine, industry and research for more than a century. Various activities are being implemented to improve the management of sealed radioactive sources in order to ensure that they are manufactured, handled, employed, reused, transported, stored and disposed of in a technically safe manner. Legal requirements arising from existing legislation at national and international level ensure a strict control from the time the sources are manufactured to the time they are placed in a suitable installation for their long-term storage or disposal. Despite the existence of this regulatory framework, experience shows that full control of high activity sources may however get lost. According to the definition provided by Council Directive 2003/122/EURATOM, “orphan source” means a sealed source which is not under regulatory control, either because it has never been under regulatory control or because it has been abandoned, lost, misplaced, stolen or transferred, without proper notification of the competent authority, to a new holder or without informing the recipient. Orphan sources pose a potential risk to health, safety and security, since such material could possibly be used by terrorists to assemble radiological dispersion devices. The existence of orphan sources - according to Council Directive - requires specific initiatives to be undertaken. In particular, it is necessary to provide specific training and information to everybody dealing with high activity sources and to people who may accidentally deal with orphan sources.
A post conflict environment is often characterized by a general weakness of regulatory control and law enforcement, so it may happen that soldiers deployed in post conflict areas discover high activity sources abandoned without any type of control. This type of findings has already occurred during recent peacekeeping operations, mainly on the occasion of recognition of abandoned industrial sites and hospitals.

In the following table are listed radionuclides and source activities typically used in common industrial and medical applications.

Table 1.1: Radionuclides and source activities typically used in common industrial and medical applications.

<table>
<thead>
<tr>
<th>Application</th>
<th>Radionuclide</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gammagrafy</td>
<td>$^{60}$Co</td>
<td>$10^{11}-10^{12}$ Bq</td>
</tr>
<tr>
<td>Gammagrafy</td>
<td>$^{137}$Cs</td>
<td>$10^{11}-10^{12}$ Bq</td>
</tr>
<tr>
<td>Gammagrafy</td>
<td>$^{192}$Ir</td>
<td>$10^{11}-10^{12}$ Bq</td>
</tr>
<tr>
<td>Industrial radiometry</td>
<td>$^{60}$Co</td>
<td>$10^7$ Bq</td>
</tr>
<tr>
<td>Industrial radiometry</td>
<td>$^{137}$Cs</td>
<td>$10^8$ Bq</td>
</tr>
<tr>
<td>Industrial radiometry</td>
<td>$^{241}$Am</td>
<td>$10^2-10^{10}$ Bq</td>
</tr>
<tr>
<td>Industrial radiometry</td>
<td>$^{147}$Pm</td>
<td>$10^2-10^{10}$ Bq</td>
</tr>
<tr>
<td>Industrial radiometry</td>
<td>$^{90}$Sr</td>
<td>$10^2-10^{10}$ Bq</td>
</tr>
<tr>
<td>Smoke detection</td>
<td>$^{241}$Am</td>
<td>$10^2-10^6$ Bq</td>
</tr>
<tr>
<td>Radiotherapy</td>
<td>$^{60}$Co</td>
<td>$10^2-10^{11}$ Bq</td>
</tr>
<tr>
<td>Radiotherapy</td>
<td>$^{137}$Cs</td>
<td>$10^2-10^{11}$ Bq</td>
</tr>
</tbody>
</table>

2 Safe management of orphan sources

2.1 Teams involved in the management activity

The discovery of an orphan source could typically happen during specific missions of NBRC teams that are requested to check the presence of radioactive material in a site, but can happen during any military mission by any soldier carrying a radiation meter accidentally or voluntarily switched on. Before getting aware of the radiological risk, accidental exposures may occur.

After the discovery of the source, it is mandatory to immediately move away and to carefully plan the recovery mission with particular reference to radioprotection planning.

If the competent civilian authority of the Host Nation cannot assume control, a specialized military unit must be called upon (typically taken from NBC Units).

From trained and controlled personnel, two teams will be formed: the first response team and the management team. The first response team will:

1. delimit the hazardous area;
2. perform the first monitoring;
3. shield the source with field expedients.

The management team will:

1. complete the monitoring;
2. provide a sufficient shielding;
3. complete the safe conditioning on site and/or the transport of the source to a safe site.

The procedure proposed in this work is compatible with the organization and standing operating procedures followed by the Italian Army, but can be easily adapted and customized in order to be implemented by other military NBC Units. In particular, each country has its own NBC team composition: the required teams for orphan sources management will be preferably those already existent in the NBC Unit, but can be also possibly formed from available personnel to answer the specific need.
2.2 Planning and carrying out the mission of the first response team

One of the main tasks of the first response team is to delimit the hazardous area. This delimitation should take into account the risks of external exposure and, if applicable, internal contamination by incorporation of radionuclides. If there are not indications on the activity of the source and on the possible presence of dispersed contamination yet, the delimitation of the area will be based on experience and existing operational practices. As a first approximation, the limit could be placed on a circumference of radius of 30-40 meters centred on the location of the source. This limit has to be redefined on the base of the outcome of monitoring.

The simplest way to define the limit of the danger area is based on the measure of the external exposure. If only external exposure is present, it is sufficient to place the limit where the dose rate is five times the natural background (therefore, typically, 1 µSv/h). If a dispersed contamination is present, at this limit the airborne contamination could deliver a dose much higher than the dose from external exposure. Therefore it will be necessary to evaluate the presence of radioactive aerosol at the boundary of the danger area.

This danger area not only will be considered inaccessible to the general population, which will be kept, if possible, even at higher distance from the place of the discovery, but mainly will be regarded as a reference area for the mission of the team, in which:

- a radioprotection planning is mandatory;
- everybody must bring dosimeters;
- in case of actual or suspected presence of dispersed contamination, the complete individual protective equipment must be worn and control and decontamination measures are mandatory for equipment and personnel that leave the area.

After placing appropriate indications at the boundary of the danger area, the first response team locates and marks the orphan sources.

In general, sources used in medical and industrial applications irradiate only in a specific direction. The team has to find that direction of main irradiation and to place a preliminary shield using appropriate material (preferably metal) found directly on site.

After characterizing the radiation field from the shielded source, the first response team will leave the area.

2.3 Planning and carrying out the mission of the management team

After the mission of the first response team a decision has to be taken between two options: safe conditioning and securing the source on site or transporting it to a safe and secure site.

The choice has to be done on the base of a simple calculation of the collective dose delivered to the personnel involved in the recovery activity, taking into account that the mission of the military teams will end when the source is transferred to the competent civilian authority. The option to be chosen will obviously be the one involving the lowest collective dose.

In the case of the conditioning on site, the management team will: 1. place a semi-permanent shield on the source; 2. characterize the radiation field from the shielded source.

In this first case the collective dose $S_1$ is given by:

$$S_1 = n_{ps} \frac{dH_{ps}}{dt} t_{ps} + n_c \frac{dH_c}{dt} t_c$$

where:

- $n_{ps}$ is the number of people placing the semi-permanent shield on the source;
- $dH_{ps}/dt$ is the dose rate at the location of the operators placing the semi-permanent shield;
- $t_{ps}$ is the time required to place the semi-permanent shield;
- $n_c$ is the number of people charged of the on-site control of the source;
- $dH_c/dt$ is the dose rate at the location of the operators charged of the control of the source;
- $t_c$ is the time of the control activity until the arrival of the competent civilian authority.
If it has been decided to transport the source to a safe and secure site, the management team will: 1. place a transportable shield on the source; 2. characterize the radiation field from the shielded source; 3. transport the source to the new site.

In this last case the collective dose $S_2$ is given by:

$$S_2 = n_{ts} \frac{dH}{dt} t_{ts} + n_t \frac{dH}{dt} t_t$$

where:

$n_{ts}$ is the number of people placing the transportable shield on the source;
$dH_{ts}/dt$ is the dose rate at the location of the operators placing the transportable shield;
$t_{ts}$ is the time required to place the transportable shield;
$n_t$ is the number of people transporting the source;
$dH_{t}/dt$ is the dose rate at the location of the operators transporting the source;
$t_t$ is the duration of transport.

Before conditioning or transporting the source, the management team will perform a provisional identification of the radionuclide, checking and confirming indications on source labels, if present. Nuclide identification can be achieved using a portable low resolution spectrometer with scintillation probe.

The source activity $A$ can be estimated using a radiation monitor placed at known distance $d$ from the centre of the source using the formula:

$$A = \frac{d^2}{\Gamma} \frac{dH}{dt}$$

where:

$\Gamma$ is a tabulated constant, specific for the radionuclide;
$d$ is the distance from the centre of the source;
$dH/dt$ is the measured dose rate.

3 Radioprotection for First Responders and the Management Team

All the members of the teams are classified as professionally exposed workers and are therefore submitted to physical and medical surveillance of the radioprotection according to the law. They have to be prepared to get protected from internal contamination (complete protective equipment with mask) if necessary. They also have to be equipped with individual dosimeters (film badge or TLD), as well as with “direct reading” dosimeters with dose alarm and dose rate alarm set up.

Before entering the danger area a radioprotection planning must be carried out, defining the maximum value of dose from external exposure for the specific mission and the time limit for the permanence in the danger area, according to dose rate values known or estimated. The reference limits must always be in accordance to those established by the ICRP recommendations. A reasonable proposal on dose alarm threshold, provided that 20 mSv is the annual dose limit for professionally exposed workers, is 1 mSv per recovery mission. A suggestion to derive the dose rate threshold from the dose threshold is summarized in table 3.1. The factor 10 in the formula accounts for the hypothesis of permanence of 10% of mission time close to “hot spots” in the danger area. The activation of the dose rate alarm will not end the mission: it will be only a danger indicator that can be used to modulate the development of the activity (people should move away from the source). If the time limit is reached or the dose alarm is activated, the mission will be terminated and will be redefined on the base of the received alarm and the radiation measures already performed; in particular, the time of the mission will be modified and a turn-over of personnel will be established.

Table 3.1: Dose and dose rate alarm thresholds for first response team and management team.

<table>
<thead>
<tr>
<th>Dose threshold (mSv)</th>
<th>Dose rate threshold (mSv/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mSv</td>
<td>$10 \cdot \frac{\text{dose threshold (1 mSv)}}{\text{mission time limit (1 h)}} = 10 \text{ mSv/h}$</td>
</tr>
</tbody>
</table>
4. Medical aspects involved in accidental exposure to radiation from orphan sources

Before getting aware of the presence of orphan radioactive sources, accidental exposures may occur if somebody stays and works close to an orphan source, unaware of the risk posed by the radioactive emission. The dose received depends on the time of exposure and the level of dose rate (function of the type and activity of the source, the distance of the exposed individual and the possible shielding interposed).

The first step before any medical response is the assessment of the dose received by the irradiated individual: since probably there aren’t any dosimetric instrumental indications, the dose will be evaluated by a reconstruction of the accident and/or by evaluating the symptoms and diagnostics evidences, including possible biodosimetric parameters. Recording this background information should be regarded as an integral part of the initial medical handling of the patients and is very helpful for the preliminary assessment of the seriousness of the situation.

Means of estimating dose without dosimeters have been developed, such as electron spin resonance analysis of exposed clothes, cotton fibres or other substances. These techniques can augment the well established cytogenetic dosimetry assays. The clothes of exposed persons should be kept for this purpose.

The high activity of the sources commonly used in some medical therapeutic applications makes possible the occurrence of severe accidents with relevant deterministic health effects, including death. The dose rate from gamma rays at 1 meter from an unshielded $^{60}$Co source of $10^{13}$ Bq, widely used in cancer radiotherapy, is 3.7 Sv/h. The exposure of the whole body for several hours in such high radiation field implies the delivery of an almost certain lethal dose.

Depending on the severity of the accident, the level of medical aid to persons irradiated or contaminated will include the following:

(a) First aid provided at the place of the accident (without a physician or nurse necessarily in attendance);

(b) Initial medical examination (triage will be required if large numbers of persons are exposed), detailed clinical and laboratory investigations and medical treatment in a hospital;

(c) Complete examination and treatment in a specialized radiation medical centre, when there is evidence of serious irradiation or internal contamination.

Given the type of accident considered in this work, we will focus the attention on the health effects of external irradiation with gamma rays. The following table summarizes the possible consequences of accidental external exposures and the appropriate medical treatments.

*Table 4.1: Possible consequences of accidental external exposures and appropriate medical treatments.*

<table>
<thead>
<tr>
<th>Type of external exposure</th>
<th>Possible consequences</th>
<th>Treatment at a military field hospital or at a general civilian hospital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localized exposure (most often to hands)</td>
<td>Localized erythema with possible development of blisters, ulceration and necrosis</td>
<td>Clinical observation and treatment</td>
</tr>
<tr>
<td>Total or partial body exposure with minimal and delayed clinical signs</td>
<td>No clinical manifestation for several hours following exposure Not life threatening Minimal haematological changes</td>
<td>Clinical observation and symptomatic treatment Haematological investigations</td>
</tr>
<tr>
<td>Total or partial body exposure with early prodromal signs</td>
<td>Acute radiation syndrome of mild or severe degree depending on dose</td>
<td>Specialized treatment Full blood count and HLA typing before transfer to a specialized centre</td>
</tr>
<tr>
<td>Heavy total or partial body exposure with radiation burns</td>
<td>Severe combined injuries Life threatening</td>
<td>Treatment of life threatening conditions Treatment as above and early transfer to a specialized centre</td>
</tr>
</tbody>
</table>

Trained first aid workers may be called upon to conduct resuscitation. Paramedical or ambulance personnel are required to transport the patient to a reception area, which may be a military field hospital or a general civilian hospital.
Once the patient arrives at the reception area, the trained staff establishes the general condition of the patient and performs any necessary treatment of the exposed persons. A full haematological, pathological and biochemical laboratory service is necessary. The first priority at the reception area is the treatment of life threatening injuries (shock, bleeding, thermal burns, fractures, etc.) by whichever type of specialist is appropriate for the condition. The medical staff dealing with patients transferred from the reception area to the specialized centre will complete the diagnostic investigation and will plan the appropriate treatment. Specialists appropriate for the particular type of syndrome of the radiation illness (bone marrow, gastrointestinal, central nervous system or radiation burns) may be required.

5 Conclusions

Military Units deployed in Peacekeeping Operations have to be prepared to manage the risk posed by orphan sources. Suitable procedures of recovery and safe management have to be established in order to protect the force, the civilian population and the environment from the radiological threats posed by such dangerous material. Radioprotection principles and indications from scientific research can provide useful guidelines and decision tools, in order to identify the best strategies of risk management. Finally, pre-planned medical procedures must be established in order to deal with accidental exposures.

References