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Topical review

ASSESSING THE REAL THREAT AND MITIGATING THE IMPACT OF A TERRORIST USE OF RADIOLOGICAL WEAPONS*

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Abstract. *In principle, CBRN (Chemical, Biological, Radiological and Nuclear) materials or agents could potentially be used by terrorists to construct a weapon of mass destruction in the future. This is why the European Union (EU), IAEA, NATO and other international groupings or organizations have taken relevant measures in fighting this threat. At present, it seems that especially the high-activity radioactive sources used in industry and medicine present a potential danger which has to be addressed. At the international and national levels various measures have been introduced aimed at the reduction of the risk due to radiological terrorism, including prevention – ensuring that unauthorized access to such sources is as difficult as possible, detection – having the capability to detect radioactive materials if control over them is lost, and preparedness and response – being able to efficiently respond to incidents involving high-activity radioactive materials and recover from them as quickly as possible. Nevertheless, we have to be prepared for the use of radiological weapons and be able to realistically assess the danger they present and to mitigate their impact on the population and the environment. The paper discusses the real consequences of an attack based on a typical powerful radioactive source. It has been found that the impact would be much lower than usually predicted. However, one cannot estimate the chaos and psychological effects, which may be more dangerous than the exposure of persons affected and the radioactive contamination of the areas surrounding the site.*

Key words: *CBRN, terrorism, radiological attack, prevention, detection, response*

1. INTRODUCTION

Basically, CBRN (Chemical, Biological, Radiological and Nuclear) materials may fall into the following two categories: weaponized and non-weaponized. Weaponized materials are intentionally prepared and intended for use in military or terrorist attacks. They can be delivered using conventional bombs and specific explosive materials aimed at causing not only damage by their destructive power, but especially at spreading contamination in terms of highly toxic chemical substances and biological agents as well as high-activity radioactive materials. Although, so far, one does not expect an attack using nuclear weapons, such a threat cannot be excluded in the future. On the other hand, non-weaponized materials are traditionally referred to as any dangerous goods or hazardous materials commonly used in industry, medicine and research. These materials could principally be used for terrorist and malevolent actions.

While weaponized CBRN materials and weapons meant for military purposes are reasonably well-protected from access by unauthorized persons, other dangerous substances may not always be adequately protected, especially in countries with weak regulatory control. This is particularly true in relation to high-activity radioactive sources used in a variety of applications of radiation and nuclear technologies.

It is obvious that we have to distinguish between accidental (unintentional) and intentional events. Accidental events are caused by human errors or natural or technological reasons, such as earthquakes, spills, accidental releases or leakages of radioactive materials which may be spread into surrounding areas, where they could affect exposed persons. In some cases, these persons may receive a fatal exposure.

Contrary to this, intentional incidents may include

- Criminal acts, such as the deliberate dumping, release or smuggling of radioactive materials to avoid regulatory requirements;
- Carrying out sabotage or an attack intended to release radioactive materials from nuclear power plants or other facilities or institutes where substantial quantities of these materials are produced, used or stored; and
- Direct terrorist acts using a radiological weapon that result in serious harm to persons or property for political, religious or ideological purpose.

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2. High-activity radioactive sources

Not all radioactive materials or sources are equally dangerous. The harmful impact of a radioactive substance depends largely on its activity and, to a certain extent, also on its chemical and physical properties. The activity of a radioactive element (radionuclide) corresponds to the number of decays per second occurring in the radioactive material. The process may be accompanied by one or more ionizing particles or photons emitted. This radiation includes such particles as alphas, with a short range and penetration, betas, i.e., negatively charged electrons having a range of several meters in air but only a few mm in the skin, and highly penetrating gamma radiation. In principle, gamma radiation cannot be stopped but its beam can only be attenuated (reduced) by appropriate shielding materials.

The activity, as a quantity characterizing the ability of radionuclides to emit radiation, is expressed in terms of such units as Bq (becquerel) corresponding to one decay per second or Ci (curie), an old unit related to the SI unit as follows 1 Ci = 3.7×10^{10} Bq.

In general, radioactive materials present harmful hazards to persons affected in two ways

- By the emission of penetrating radiation leading to external exposure of individuals;
- By surface skin contamination or penetration of radioactive substance through the skin; or
- By irradiation of tissues and organs in the body if the radioactive agents are inhaled or ingested by consuming contaminated food or water.

The consequences of radiation exposure are assessed by such quantities as the effective dose and RBE-weighted dose.

The effective dose is quantified in the unit of Sv (sievert) and is used only for low-level exposure, up to several hundred mSv, where only stochastic effects are expected. These effects result in an increased probability of developing cancer in an exposed individual. The probability of the effects is proportional to the exposure. The risk for an individual is rather low, 5×10^{-5} mSv^{-1} (1 to 100,000). This means that exposure of 100,000 persons to 1 mSv will result in an increase of cancer among the exposed population by 5 additional cases. However, we have to realize that the rate of spontaneous cancer (due to other initiating agents or causes) is much higher, usually at the 30% level.

The RBE-weighted dose, expressed in Gy (gray), is a measure of deterministic effects, which are caused by very high exposure (above one Gy). Such exposures can lead to acute, life-threatening injuries after an exposure period lasting anywhere from a few minutes to several hours, depending on the dose of radiation and the type (e.g. alpha, beta or gamma). The severity of these effects is related to the dose above a certain threshold for their occurrence.

Since adverse health effects are associated mainly with the activity of sources, the IAEA (International Atomic Energy Agency) developed a categorization of radioactive sources in accordance with the harm their exposure may initiate [1]. The system covers all significant radioactive sources used in industry, medicine, agriculture, research and education, taking into account their potential to cause damage to human health.

This categorization can assist regulatory bodies in establishing regulatory requirements that ensure an appropriate level of control for each authorized source. The purpose is to provide an internationally harmonized basis for risk-informed decision making. It is envisaged that the categorization system will be used by national authorities in establishing the appropriate degree of regulatory control for many activities relating to the safety and security of radioactive sources.

Table 1 presents an overview of individual categories, sources and practices characterized by the ratio A/D, where D corresponds to the so-called D-value related to the "dangerous" activity of individual radionuclides involved in relevant applications [1].

As to the potential use of radioactive sources for terrorist attacks, e.g. in a "dirty bomb", special care should be paid to the control of the radionuclides of categories 1 and 2, which include the most dangerous sources.

3. Regulatory control of powerful sources

The basic requirements for the protection of persons against exposure to ionizing radiation and for the safety of radiation sources were established in the IAEA Basic Safety Standards (BSS) [2] aimed at ensuring adequate protection against ionizing radiation and the safety of radiation sources. Similar requirements have also been set by the European Union (EU) in their own BSS [3], which are essentially compatible with the IAEA standards. The application of the BSS is based on the presumption that national infrastructures are in place to enable governments to discharge their responsibilities for radiation protection and safety.

Table 1. The categories for radioactive sources used in common practice, recommended by the IAEA

Category	Source and practice	Activity ratio (A/D)
1	Radioisotope thermonuclear generators (RTG); irradiators; teletherapy sources; field, multi-beam teletherapy (gamma knife) sources	A/D ≥1000
2	Industrial gamma radiography sources; high/medium dose rate brachytherapy sources	10≤A/D<1000
3	Fixed industrial gauges that incorporate high activity sources; well logging gauges	1≤A/D<10
4	Low dose rate brachytherapy sources (except eye plaques and permanent implants); industrial gauges that do not incorporate high activity sources; bone densitometers; static eliminators	0.01≤A/D<1
5	Low dose rate brachytherapy eye plaques and permanent implant sources; X ray fluorescence (XRF) devices; electron capture devices; Mossbauer spectrometry sources; positron emission tomography (PET) check sources	A/D < 0.01 and $A>A_e$*

A_e is exempted activity (source is outside regulatory control)

The IAEA as well as the EU are intended to assist member states in implementing the BSS requirements established in their relevant BSS by establishing and improving national regulatory infrastructure to regulate any practice involving radiation sources in medicine, industry, research, agriculture and education. These materials provide advice on the legislative basis for establishing regulatory bodies, including the effective independence of the regulatory body. The main tasks consist in implementing the functions and activities of regulatory bodies, developing regulations and guides on radiation safety, implementing a system for notification and authorization, carrying out regulatory inspections, taking necessary enforcement actions, and investigating accidents and circumstances potentially giving rise to accidents. All these regulatory procedures can ensure that all high activity radioactive sources are kept reasonably safe and secured so that their misuse for terrorist attacks could be minimized. At the same time, national regulatory authorities have adopted special programs to deal with emergency situations arising from any radiological malevolent action or the sabotage of nuclear and other facilities where high radioactive sources are produced, used or stored. This also includes repositories of high activity radioactive waste and temporary storage of spent nuclear fuel.

All radioactive sources above a certain level of activity or activity concentration have to be kept under control where the measures adopted for high activity sources should be as secure as can be achieved under the circumstances [4]. The principal arrangement as to the control of radioactive sources is illustrated in Figure 1.

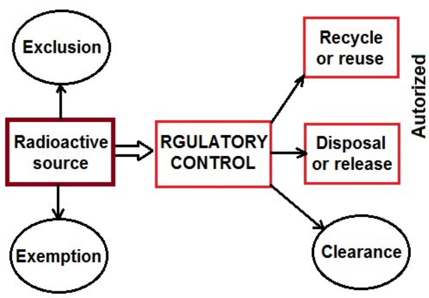

Figure 1. Options for radioactive source control

From the above figure it can be seen that not all sources have to be under regulatory control. Natural radiation sources, such as cosmic radiation on the Earth's surface or the content of radioactive potassium K-40 in our body, are essentially uncontrollable and there have been no attempts to control them. Other types of sources are so weak and contribute to such a low exposure that their control would not be justified and therefore they are exempt from such control. On the other hand, there are some sources which had been under regulatory control but, after some time, mainly because of decreased activity, they were cleared from control and can be viewed as exempted sources. All other sources have to be regulated; this includes mechanisms for their control during the whole of their life: production, use and disposal or release in quantities approved by the regulator (mainly radioactive substances in liquid and gaseous forms.

In the Czech Republic, all relevant regulatory procedures have been introduced taking into account both EU and IAEA standards. The basic legislative documents addressing this control are based on the Atomic Law [5] and specific Regulations [6] on radiation protection issued by the State Office for Nuclear Safety (SONS) [7], which is a regulator responsible for radiation protection and nuclear safety in the country, as well as for the protection against CBRN materials and agents.

4. A DIRTY BOMB AS A RADIOLOGICAL WEAPON

While for terrorists it would be difficult, at present almost impossible, to acquire nuclear weapons or a sufficient amount of highly enriched uranium (HEU) or plutonium to construct one, it would be relatively easy to obtain high activity radioactive sources at facilities lacking strict control over these sources, or terrorists can seize them when the materials are being transported. Then the construction of a dirty bomb would be quite easy (Figure 2).

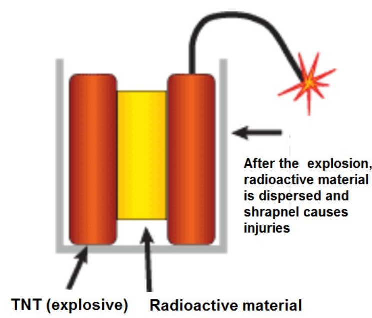

Figure 2. Principal components of the dirty bomb (based on the publication [10])

In fact, a dirty bomb is a relatively simple device designed to spread dangerous radioactive material over a wide area. A dirty bomb is much closer in power to an ordinary explosive than it is to the widespread destructive force of a nuclear bomb. This weapon, often known as a radiological dispersive bomb, is a very simple device. It is a conventional explosive, such as TNT (trinitrotoluene), packaged with radioactive material. Of course, it is a lot cruder and cheaper than a nuclear bomb, and it is a lot less effective. But it does have the combination of explosive and radiation damage. When the explosive goes off, the radioactive material spreads in a sort of dust cloud, and carried by the wind it can reach a wider area than the explosion itself.

There are a number of powerful radioactive sources used in many areas; however, not all are suitable for the construction of a dirty bomb. The most appropriate would be the following radionuclides: americium-241, californium-252, cesium-137, cobalt-60, iridium-192, polonium-210, radium-226 and strontium-90. Widely used Cs-137 is especially attractive for this purpose since it is in the form of powder. The other source frequently used, Co-60 (metallic), has to be converted into small particles by grinding.

5. Protection and measures to minimize the impact of a dirty bomb attack

The impact of an attack using a dirty bomb or radioactive dispersion device (RDD) would depend on a number of factors, including the size of the explosive, the amount and type of radioactive material used, the means of dispersal, and the weather conditions. Those closest to the RDD would be the most likely to sustain injuries due to the explosion. As radioactive material spreads, it becomes less concentrated and less harmful. Prompt detection of the type of radioactive material used will greatly assist local authorities in advising the community on protective measures, such as sheltering in place or quickly leaving the immediate area. Radiation can be readily detected with equipment already carried by many emergency responders. Subsequent decontamination of the affected area may involve considerable time and expense. There have been many measures aimed at minimizing the consequences of radiological attacks, mainly based on experiments and lessons learned from radiological accidents (e.g., [8,9]).

The immediate health effects from exposure to the low radiation levels expected from an RDD would likely be minimal. The effects of radiation exposure would be determined by such factors as

- The amount of radiation absorbed by the body;
- The type of radiation (gamma, beta, or alpha);
- The distance from the radiation to an individual;
- The means of exposure - external (by penetrating radiation) or internal (absorbed by the skin, inhaled, or ingested); and the length of time exposed.

If an explosion occurs, it may not be known immediately that radioactive material is involved. If a person is aware that he/she is near the site of a dirty bomb attack or the potential release of radioactive material, it would be desirable to

- Stay away from any obvious plume or dust cloud;
- Walk inside a building with closed doors and windows as quickly as possible and listen for information from emergency responders and authorities;
- If there is dust in the air, cover your mouth and nose with a tissue, filter, clothing or damp cloth to avoid inhaling or ingesting radioactive material;
- Remove contaminated clothing as soon as possible and place it in a sealed plastic bag; the clothing could be used later to estimate a person's exposure; and
- Gently wash the skin to remove any possible contamination, making sure that no radioactive material enters the mouth or is transferred to areas of the face where it could be easily moved to the mouth and swallowed.

If one is advised to take shelter, whether it is at home or in an office, one should

- Close all the doors and windows;
- Turn off ventilation, air conditioners, and forced air heating units that bring in fresh air from the outside. Only use units to re-circulate air that is already in the building;
- Close fireplace dampers;
- Move to an inner room;
- Keep your radio tuned to the emergency response network.

Questions such as when it is safe to leave a building or return home, what is safe to drink and when, along with how children will be cared for if they are separated from their parents, will be answered by authorities who will be making decisions on a case-by-case basis depending on the information available at the time.

6. Conclusion

Radiological terrorism is the intentional use of radioactive materials to cause physical and psychological damage to a civilian population. Terrorists seek to attack the basic sense of security and well-being of members of the general public through inflicting physical injury, loss of life, and destruction of property. Radiological terrorism by the dispersion of radiological materials results also in the contamination of the environment.

Since any excessive exposure to ionizing radiation is harmful and the decontamination of populated areas is very expensive, it may take some time before the situation returns to original conditions. There is a widespread interest in preventing radiological attacks to happen by keeping all powerful radioactive sources under strict control and, at the same time, in being prepared to respond to such an attack by efficient methods aimed at minimizing its consequences.

In order to minimize the risk due to the use of conventional radioactive sources, which may also involve the use of abandoned or "orphan" sources, it would be appropriate to replace the radionuclides at least in some applications by alternatives [11,12].

It can be concluded that the potential threat of radiological terrorism is still real and can be documented by many recent publications (e.g., [13-14).

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