The threats and challenges of a radiological emergency

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Abstract

Radiological emergencies may occur either as an accident or as a result of an intentional and malevolent use of radioactive sources. In the last few years, concerns about the potential use of radioactive materials in a "dirty bomb" or in an improvised nuclear device have increased. Although such an incident has not occurred up to now and experience in dealing with such a situation has not been acquired, there have been accidents with radioactive sources and radiation facilities that posed similar threats and challenged the capabilities of emergency responders and radiation protection infrastructures. Cases such as the deliberate poisoning of Litvinenko with ^{210}Po, the accident in Goiania with a radioactive source taken from a medical facility by metal scrappers, the Chernobyl nuclear accident, and the Balkan's syndrome related to depleted uranium, are reviewed in order to extract lessons relevant to radiological protection and radiological emergency management.

Keywords: radioactive sources, radiological emergency, radioactive contamination, dirty bomb, radiological protection.

1 Introduction to radiological emergencies

In the last decade the scenario of deliberate and malevolent irradiation of people with radioactive sources has been receiving increasing attention, especially the case-scenario of a terrorist attack using a "dirty bomb" [1]. However, many other misuses of radioactive materials may generate a radiological emergency.

There are several types of incidental uses of radioactive sources to be considered. One is the criminal act of using a radioactive source to irradiate one or several persons (e.g., there have been cases of dispute in workplaces where

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one side used a radioactive source to harm the other side). Another type is the terrorist act using a radiological dispersion device or an improvised nuclear device, or even a true nuclear weapon obtained illegally, intended to harm and scare many people and paralyze a city or a country. A radiological dispersion device (RDD), also called “dirty bomb”, would be an association of radioactive material with a means to disperse it (e.g., conventional explosive). The theft or appropriation of highly enriched uranium could lead to the production of an improvised atomic bomb to cause large scale injuries and destruction.

About the radiological or nuclear terrorist attack many specialists in security believe that today the question is no longer “if it happens” but “when and where it will happen”. Trying to foresee and to plan the response to such an emergency is usually drafted upon emergency plans to face civil disasters of another type (e.g., fire, flood, industrial accidents). Today, still some will say that there is no need to plan for such a terrorist attack, because it will never happen. Furthermore, they argue also, this type of radiological emergency never happened before and, therefore, there is no experience to prepare the response. Notwithstanding, inadvertent exposure to ionizing radiation happened already in several countries and in different times, largely by accident or negligence. Some of these cases are good proxies to extract lessons that may apply to malevolent acts using radioactive sources.

For a terrorist attack eventually not every radioactive source would be of interest to cause damage or panic [1, 2]. Nevertheless, ingested ^{210}Po was shown to be able to kill even in minute amounts. A nuclear fuel explosion was able to contaminate and compromise agriculture, meat production, and fisheries in millions of hectares. ^{137}Cs from a radiotherapy source could paralyze one large city. Even a small radioactive contamination, when amplified through the press became a big issue and did cause extreme social and political tensions replacing a true radiological emergency. Below we will see how this happened already and lessons to retain.

2 Radioactive sources

On top of nuclear power plants, there is a high number of radioactive sources in use in industry, medicine and other fields of activity in almost every country. Many amongst these sources have low activity and the radioisotopes may have relatively short half-lives which reduce the potential harm that they could cause, although some may have long half-lives and generate intense radioactivity. The strength (activity) of radioactive sources, the type of radiation emitted, and the physical-chemical form of the radioactive substance, may be the parameters to base radioactive sources ranking regarding potential biological harm (Table 1). The International Atomic Energy Agency developed a system of categorization of radioactive sources, which has been used as a basis to define safety and security measures required for radioactive sources [4].

Not every radionuclide emits intense radiation and, thus, not every radioactive source has the potential to cause a serious emergency. The most dangerous to human lives certainly are the radioisotopes with high specific activity such as plutonium, radium, and polonium. Radioisotopes such as cesium-137, or even cobalt-60 and iridium-192, all beta-gamma emitters used in hospital sources can be dangerous as well if insecure. Short-lived radionuclides, such as phosphor-32, carbon-14 or tritium (H-3), often available in research laboratories, have less harmful potential.

Radiological emergencies with some of these radioisotopes occurred already and the effects are known. The IAEA maintains a data base of the accidents with radioactive sources and a database on the cases of illicit traffic of radioactive and nuclear materials.

3 Litvinenko case: lessons from a radioactive poisoning

Mr A. Litvinenko was poisoned in London, around the 1 November 2006, with about 2 GBq of ^{210}Po (0.02 mg) mixed with his drink. The crime was directed to him, for reasons that seem related to espionage and/or political revenge. The radioactive material used was brought from abroad, and the coup was not designed to kill indiscriminate citizens or as a massive terror act. It took about three weeks for the medical doctors in the Hospital to diagnose what was killing Mr Litvinenko. He passed away about one month after the ingestion of the massive ^{210}Po dose, killed by the "radiation disease". The poisoning and the events during the following weeks revealed several weaknesses of current radiation protection system capabilities.

It was difficult to identify that he was poisoned with a radioisotope because ^{210}Po is almost a pure alpha emitter and radiation emitted is easily absorbed by a thin barrier. The dishes, kitchen tools, furniture and people in the restaurant where he was poisoned were contaminated with ^{210}Po, but it was difficult to readily identify the contamination and to monitor the large number of people (hundreds) that had been there [5].

The screening of human contamination was made by ^{210}Po bioassay in urine samples. The laboratories were not able to process in a short time the large number of samples collected. Furthermore, as ^{210}Po is also a naturally occurring radionuclide, human urine always contains some ^{210}Po and there was no criterion to decide what the normal level is, and what the threshold for dangerous concentrations is. There have been many members of the public that potentially got contaminated in places where Mr Litvinenko had been and, amongst them many were foreigners that traveled abroad before the warning given by Public Health authorities. In spite of information gaps, the international warning still did work somehow and other European countries were able to monitor ^{210}Po contamination in citizens that had been in London at the time of the events [6].

This case points out to the need for improved international coordination, for better equipment to readily identify alpha and weak beta radionuclides, and eventually to mechanisms for enhanced control of radiation sources at the border.

The criminal use of ^{210}Po with the deliberate intent to kill Mr A. Litvinenko in a directed murder seems well demonstrated, but nevertheless the act caused widespread contamination and social alarm. The deliberated dispersion of the same amount of ^{210}Po in a city centre, as part of a terrorist action, would cause

Table 1: Categories of radioactive sources and typical applications (adapted from [4]).

Category	Examples	Use	Radionuclides	Activity (TBq)
1	Irradiators Teletherapy	Sterilization of chirurgical materials Cancer therapy	Cobalt-60 Cesium-137	15 000 20
2	Industrial radiography Brachitherapy (high dose rate)	Non destructive testing Cancer therapy	Cobalt-60 Selenium-75 Iridium-192	2.2 3 3.7
3	Industrial gauges Well-logging	Process control (flow, volume, density Oil and gas prospecting	Cobalt-60 Americium-241/ Berilium	0.19 0.74
4	Brachitherapy (low dose rate) Thickness gauge	Cancer therapy Paper, plastic industries	Strontium-90 Strontium-90	0.0009 0.037
5	Level gauge Ionizer	Industry Smoke detectors	Cesium-137 Americium-241	0.002 0.00005

1 TeraBecquerel (1 TBq) = 10^{12} Bq = 1000 GBq.

probably little mortality but a much higher degree of disruption of the city life and social life; the needs for radioactivity monitoring would be much larger than in this case.

4 Goiania: lessons from a radiological accident in a city

In 1985, in Goiania, Brazil, a group of metal scrappers illegally removed from a deactivated radiotherapy hospital an equipment containing a ^{137}Cs source with 50.9 TBq (1275 Ci). They violated the source container and exposed the cesium chloride, originating the contamination of large portion of the city, including scrap yards, houses, streets, the hospital, buses, and people. About 250 people were internally or externally contaminated, of which 20 needed hospital treatment -most of them were transferred to central hospitals - and amongst these 4 died from acute radiation syndrome.

The first people-the scrappers and their families-to suffer serious health problems after exposure to the open radioactive source went to the hospital a few days later. Their symptoms were not immediately recognized as due to radiation injury. After discovery of the source and action by medical and radiation protection authorities, the intervention took more than one year to bring the situation under control, to clean up the radioactive contamination, and to ensure the radiological safety of the area.

In total, more than 112,000 people were individually monitored in whole body counters installed in the local hospital. Of 159 houses monitored, 42 required decontamination. From the clean up of the area, including houses and streets, resulted 3500 m^3 of radioactive waste equivalent to more than 275 lorry loads. A radioactive waste storage site was build near Goiania, to receive these wastes. Costs of the monitoring and cleaning operation amounted to many million dollars [7].

Lessons to retain from this accident, include the importance of the radiation protection officers and the managerial responsibility in facilities were radioactive sources are held. In addition, in every facility there is absolute need for ensuring compliance with the license conditions for radioactive sources, including frequent verification and security arrangements. Another important lesson is that people severely contaminated and needing care for radiation injury cannot receive appropriate treatment in a general hospital. These treatments are complex and require assistance from specialized medical care. Therefore, emergency plans to deal with this type of patients should foresee specialist medical care. Furthermore, contamination of a city requires trained staff and equipment readily available to carry out the radioactive monitoring.

The explosion of an RDD causing radioactive contamination did not occur yet, but the consequences in urban environment may be alike to the accident of Goiania, Brazil, and lessons should be learned from this accident.

5 Chernobyl: lessons from a nuclear accident

On 26 April 1986, during an experiment in the Chernobyl nuclear power plant, due to lack of coordination two explosions occurred in the core of the reactor destroying it and the roof of the building, and exposing the nuclear fuel. The fire that ravaged for ten days released large amounts of radioactivity that were transported by winds and dispersed over the Northern hemisphere. The accident resulted in contamination of large amounts of territory in Belarus, Ukraine, and Russia. Radioactive fallout impinged also Turkey, Poland, Sweden and UK.

Acute effects emerged soon after the accident. In 1986, 31 people, mainly fire fighters, died of radiation induced injuries, and further 19 individuals involved in urgent protection measures died after that. There has been an increase of cases of people with radiation related health problems, including thyroid cancer (4000 cases diagnosed between 1992 and 2000 in children and adolescent in Belarus, Ukraine and Russia), leukemia and solid tumors [8]. There has been more than

1.5 million hectares of agriculture and forestry land contaminated and abandoned, and there are 4.5 million people living in contaminated areas. Due to radioactive fallout, contamination with ^{90}Sr, ^{131}I and ^{137}Cs occurred outside the former USSR. In UK, restriction on sale and slaughter was placed on 4.2 million sheep. Still today, there are areas with restrictions on the movement and slaughter of sheep. Several areas of Norway were also impacted by radioactive fallout affecting cattle, reindeer and wild freshwater fish. The authorities in November 1986 adopted the ^{137}Cs intervention level of 6000Bq/kg in reindeer meat although imposing dietary intake limits, otherwise meat could not have been sold [8].

The Chernobyl accident was unprecedented and presented problems at various levels for which authorities were not fully prepared. Thousands of people were involved in cleaning operations, millions were directly affected. The radioactive contamination is an ongoing problem and will continue to be a problem for generations to come in many territories [9].

The lessons to learn are plenty.

In the immediate phase following the accident drastic actions were required. The decision to create an exclusion zone in the most contaminated area, and the decision to evacuate populations should be immediate. In such circumstances a prescriptive approach (top-down decision) where people follow what they were ordered to do, worked well. However, today it is generally accepted that the early involvement of stakeholders in the planning of emergency response is needed. Stakeholders will gain an awareness of what to expect in case of an emergency and will contribute to a higher degree of efficiency. In the later phases of the accident including rehabilitation of the territories, the top-down approach did not worked in Chernobyl. After the accident - many times said that would never happen - the problems of a centralized decision making and control were due to the lack of public trust and confidence in authorities. The public treated their information and instructions with suspicion exactly in the period that their trust was more necessary. This required restoring confidence. This took many years and it was overcome through encouraging the population to handle by themselves the radiation protection measures, such as monitoring their foods, planning what to eat, monitoring radioactivity in the cattle, advising mothers how to do the best for radiological protection of their children, modifying the use of contaminated land, and so on.

The key lesson to the scientific community was that the radiation protection professionals were unprepared for the complexity of the situation after the Chernobyl nuclear accident. Also there were no recipes to solve the problems, the existing conceptual models to deal with accidents failed or were of limited use, and the engagement of the people living in the affected areas had been neglected although it was essential to integrate radiation protection measures in their lives.

A new approach to radiation safety in nuclear emergencies with strong involvement of the population is clearly needed in order to improve the efficiency of response. This should be incorporated in emergency planning either for a nuclear accident or for a terrorist nuclear attack because the complexity of the intervention and radiation protection measures needed might be of the same scale.

6 Balkan's syndrome: lessons from the use of DU

The use of depleted uranium (DU) ammunition particularly in NATO bombings in Kosovo in the year 1999 was followed by a wave of concerns in the international press about leukemia amongst the military deployed in the Balkan region and local populations. According to news reports and breaking of TV journals, the entire region was contaminated with radioactive materials, soldiers were poisoned by radiation, and cases of leukemia deaths amongst peace keeping forces were increasing. Human life in those territories was described as seriously threatened by the heavy contamination with depleted uranium and other radionuclides present in ammunition made of high activity radioactive waste. Soon an expression was coined to designate the depleted uranium related health injuries: "Balkan's syndrome"

Several countries and international organizations from the UN system performed scientific missions to the Balkans in order to assess the radioactive and chemical contamination caused by the DU ammunition [10].

Without making any judgment about the war and the use of DU ammunition, and strictly on scientific grounds, the scientific teams produced independent reports on the DU issue that were largely in agreement. Actually, DU ammunition had been used and debris was found in several sites. The projectiles analyzed contained very small amounts (traces) of ^{236}U and sometimes of $^{239+240}$Pu (artificial radionuclides), indicating that DU was at least in part from reprocessed spent fuel. However, the amounts of those artificial radionuclides were minor and could not be considered as high activity radioactive waste. Moreover, the presence of DU in the Balkan's environment was confined to bombed sites, and not widespread in the environment. Soils and water resources sampled across the region were not contaminated and contained natural uranium in normal concentrations only [10]. Therefore agriculture and drinking water were not contaminated. Thorough analyses of foods, aerosols, and humans (through bioassay of uranium in urine samples) it was concluded that there was no significant DU contamination and the environment and society were not threatened by radioactive and toxic contamination with DU. The outcome of these reports was clear.

The "Balkan's syndrome" finally was not a truly radiation related disease and, in face of the low DU concentrations found, it was considered unlikely to be a toxic effect of depleted uranium. The misunderstanding and fear about the heavily contaminated Balkan region (does not matter here if it was a true concern or a creation of political propaganda), dissipated rapidly.

The rapid action of some institutes to investigate the DU issue and to help implementing radiation protection measures was instrumental to clarify the situation. Probably this action and the public scientific reports avoided the panic and social disruption that could afflict the Balkan region if the DU fear had continued, regardless if the risk was real or believed as real. The lesson to learn is that rapid action to investigate the radiation risk and good communication with the public are essential.

7 Radiation protection: improvements needed

The implementation of lessons learnt from these cases is necessary. Nowadays, countries discuss and enhance their national radiation security measures and probably it is now the right time to improve or build trustful relationship between radiation protection professionals, government officials, civil protection and other emergency responders, including international information exchange and cooperation networks.

The duties of radiation protection authorities will remain primarily in the field of controlling radiation sources and radiation doses in peaceful applications, therefore in the field of occupational and environmental control of radioactivity and radiations. Nevertheless, accidents and malevolent uses of radiation require more and more attention and in the framework of civil protection and response to disasters, radiation protection will be more often called upon to act in the field of its expertise, i.e. radiation safety.

At the national level it seems absolutely necessary that competent authorities, laws and regulations are in place as prescribed in the International Basic Safety Standards of the IAEA and of the European Union. [10,11] This includes legal mechanisms for licensing radiation facilities and radioactive sources, mechanisms for inspection, and services for recording occupational radiation doses of workers and environmental radioactivity monitoring. An inventory of radioactive sources and mechanisms of verification is needed also, as well as emergency planning for accidents with radiation sources. However, this is not sufficient.

There is also a need for the competent authority to be staffed with trained and sufficient personnel enabling them to fulfill their duties. In this respect at the European level there is a decrease in trained staff that is posing a problem of lack of qualified human resources nearly everywhere. As revealed by the accidents with international incidence described above, there is no adequate international networking to respond in an efficient manner to radiological threats.

Today many countries have plans to develop further the nuclear industry. This brings about more sites to monitor and extended duties to ensure radiation safety. Furthermore, there is the increased need for safety, security and control of risk of radioactive sources misuse and, at the present the society does want to be kept informed and to be part in the decisions.

The right and timely question is: are the current radiation protection infrastructures prepared?

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