

Radiation Terrorism – The Medical Challenge

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Abstract

Ionizing radiation can cause acute as well as chronic and late illnesses, and is a well-known health hazard. Its use by terrorists and nations in the form of a non-conventional weapon is no longer impossible. The release of radioactive materials with the accompanying contamination and radiation has the potential of causing serious medical problems. In analyzing the different radiologic terrorism scenarios, a scheme is proposed for the triage and evacuation of injured, contaminated and non-contaminated casualties from the scene itself as well as from the periphery. Knowledge, plans and drills will lessen the impact of those potential attacks and prepare us to respond to such events.

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The terrorist attack on 11 September 2001 in the United States and the use of anthrax spores via mail soon thereafter raised again the fear that terrorists will use weapons of mass destruction. Chemical and biologic warfare weapons have been developed and stockpiled by many nations, and it is believed that terrorists could use them, as they did in the sarin attack on a Tokyo subway in 1995. Nuclear weapons, on the other hand, are considered more complex to develop, and obtaining fissile materials needed to build them is problematic. Nowadays, various publications claim that terrorist groups as well as Iraq may have assembled a type of radioactive bomb, also known as the “dirty bomb” or a radiation dispersal device, that is relatively easy to construct [1,2]. Terrorists could also carry out potential mass destruction without sophisticated weaponry, by targeting nuclear facilities using conventional bombs or hijacked aircraft. Apart from the physical damage, such a scenario could have a considerable impact on the public’s imagination and fear. To reduce the effect of those potential attacks and provide care for its victims, it is imperative that the community as a whole – and the medical community in particular – have the knowledge of the various signs and symptoms of exposure to radiation and radioactive contamination, as well as a planned response once such an attack has occurred. In this article we provide some basic information of radiation types, biologic damage, clinical appearance, and general concepts of radiation event planning, focusing on the medical community’s response.

Ionizing radiation

Ionizing radiation is a form of energy classified into alpha, beta, neutrons, gamma and X-rays. The first three are particulate and the last two are electromagnetic waves. Alpha particles are helium nuclei made up of two protons and two neutrons. These are relatively heavy particles characterized by a high amount of energy but with very short range and low penetration (blocked by the skin and even by a sheet of paper). Therefore, alpha particles can pose a health hazard, mainly if internalized but also to the region immediately adjacent to their physical location. Beta particles are fast electrons that can penetrate a few centimeters of tissue. The typical lesion on the skin, called “beta burn,” is much like a thermal burn but evolves more slowly. Beta-emitting materials also constitute a significant internal hazard. The range and penetration of gamma and X-rays, on the other hand, are infinite and their damage depends on their energy. Because of its high penetrability, gamma radiation can result in total body exposure.

Radioactive materials are non-stable elements characterized by emission of one or some of the above types of radiation. Iodine-131, for example, is a radioactive isotope of iodine that emits beta and gamma radiation with specific energy and for a known period, called the half-life. The half-life of a radioactive isotope is the time needed for the material to lose half of its radioactivity. The intensity of radioactive radiation from a point source diminishes, like that of light and noise, depending on the square of the distance from the radioactive source. The amount of energy absorbed in an object depends on the intensity of the source, proximity to it, the type of energy, the duration of exposure, the type of medium in between (shielding, for example), and the material from which the object is made.

Biologic effects of ionizing radiation

When radiation interacts with atoms, energy is deposited resulting in ionization (electron excitation). There are two modes of action in the cell: direct and indirect. The radiation may directly hit a particularly sensitive atom or molecule in the cell. When repair mechanisms are exhausted, the cell either dies or is severely damaged leading to malfunction. The radiation can also damage a cell indirectly by creation of unstable, toxic hyperoxide molecules, which in turn can damage sensitive molecules and afflict subcellular

structures. Non-ionizing radiation, such as radiowave or microwave, does not exert the above effects and is not discussed here.

Ionizing radiation exerts two kinds of effects on the cell. The first is cell death. This can lead to acute or subacute injury, depending on the cell turnover rate of the affected tissue – the higher the cell turnover the more sensitive the tissue to radiation. Therefore, the most sensitive organ system is the hematopoietic, followed by the gastrointestinal [3,4]. The second effect is changes in cellular function, which occur at lower radiation doses than those that cause cell death. These changes are stochastic in nature (randomly acquired, as opposed to deterministic) and are responsible for cancerous changes that occur after exposure to ionizing radiation. These are the late carcinogenic effects of radiation, manifested by an increase in the incidence of certain types of cancer in a population of people exposed to radiation, e.g., survivors of the atomic bomb and patients after therapeutic irradiation [5,6].

There are several possible routes whereby humans may be exposed to ionizing radiation. The first is external radiation. This is usually the case with a radioactive source that emits gamma, X-rays or neutrons, which have a long range, e.g., medical imaging. The exposure in this case will cease when the source or the exposed individual has been removed or shielded with radiation-absorbing material. The other route is contamination, where deposition of radioisotopes on the skin can cause beta burns. The major hazard of external contamination of clothing and skin is that it might be internalized into the body. Internal contamination can occur when radioactive material is internalized via ingestion, inhalation or through open wounds, or deliberately via therapeutic injection. This type of exposure will continue for as long as the radioactive material has not decayed or been excreted from the body.

Gray (1 joule per kilogram, SI units) is a measure of dose: the amount of energy deposited per gram of matter by ionizing radiation. It replaces the former radiation-absorbed dose (rad) unit. One Gray (Gy) equals 100 rad.

Exposure of human beings to ionizing radiation is part of normal life: We are exposed continuously to natural background radiation from radioactive elements in the ground and from cosmic radiation. The damage from radiation is a consequence of the amount of exposure. Lacking the capability for total prevention, the principle of protecting human beings from radiation is termed ALARA: As Low As Reasonably Achievable, taking into consideration economic and social factors. The ALARA principle demands that exposure be justified. ALARA techniques include limiting the period of exposure (time), keeping away from the radioactive source as possible (distance), placing radio-protective material between the individual and the source (shielding), and using protective equipment.

Clinical radiation injury

Acute radiation syndrome represents the death of cells after whole-body exposure to ionizing radiation. Without appropriate medical care, the median lethal dose of radiation, the LD_{50/60} (defined as the

dose that will kill 50% of the exposed persons within a period of 60 days), is estimated to be 3.5 Gy. With appropriate medical intensive care the LD_{50/60} will rise to 5–6 Gy.

ARS varies with individual radiation sensitivity, type of radiation, and the radiation dose absorbed. The prodromal phase is manifested by gastrointestinal symptoms (nausea and vomiting), headache, erythema, elevated core body temperature, and malaise. The higher the level of exposure the earlier the onset of symptoms. Those symptoms can last for a few days.

Following the prodromal phase the patient is relatively symptom free. This is called the latent phase and can last between 2 and 6 weeks, depending on the radiation dose. The higher the dose the shorter the latent phase [4,7].

The third and crucial phase is the manifest illness. The clinical symptoms in this phase are associated with the organ system injured, such as bone marrow, gastrointestinal, and neurovascular. Table 1 summarizes the pathophysiologic appearance at each level of exposure.

Local radiation injury is more common than ARS. Certain tissues can become the specific targets of radiation from either an external or internal source. Thyroid is the target organ for iodine-131, which is present in huge amounts in nuclear reactor accidents as well as in atomic bomb fallout. The lung is particularly sensitive to external radiation with acute (pneumonitis) as well as chronic (fibrosis) consequences. The skin and the deep dermal tissues can suffer severe damage from beta burns, even to the degree of limb loss.

An early evaluation of the absorbed dose is essential for determining the clinical management. One can use clinical dosimetry by assessing the time elapsed from exposure to the beginning of prodromal symptoms, or blood count can be used as dosimetry – the earlier the drop in lymphocyte count the higher the exposure level.

Medical care should include isolation, fluid and electrolytes replacement, anti-emetics, anti-infection (microbial, viral and fungal) therapy, bone marrow stimulants, bone marrow transplantation, and psychological support [4].

Table 1. Clinical syndrome and survival expectancy

| Dose range (Gy) | Prodromal effects | Manifest illness | Survival |
|-----------------|--------------------------------------|---|-----------------------------------|
| 0.5–1.0 | Mild (up to 48 hours) | Slight decrease in blood cell count | Almost certain |
| 1.0–3.5 | Mild to moderate (Up to 24 hours) | Mild to severe bone marrow damage | Probable (>90%) to possible |
| 3.5–7.5 | Severe (? hours) | Pancytopenia, mild to moderate intestinal damage | Death within 2–6 weeks |
| 7.5–10.0 | Severe (a few hours) | Combined gastrointestinal and bone marrow damage | Death within 1–3 weeks |
| >10.0 | Severe (minutes) | Gastrointestinal, neuro- and cardiovascular damage | Death within 2–12 days |

Source: Data from references 3,4.

ARS = acute radiation syndrome

Radiation also has stochastic effects leading to carcinogenesis. These effects are manifested by an increase in the incidence of certain types of cancer in a population exposed to radiation, such as atomic bomb survivors and patients after therapeutic irradiation [5,6]. Based on statistical probability, it is known that an exposure dose of less than 1.0 Gy can lead to functional changes, which after a latency period of several years may show up as radiation-induced tumors. Some radioisotopes have affinity to specific target organs – e.g., radioactive iodine to thyroid, plutonium to bone – and as such they are presumed to be carcinogenic to those organs but not to other remote organs.

Radiation incident scenarios

The International Atomic Energy Agency is concerned that terrorists could carry out potential attacks by targeting nuclear facilities using bombs or hijacked commercial airliners, or by dispersal of radioactive materials with or without the use of conventional explosive devices [1].

The radiation dispersal device is a bomb that contains radioactive material in addition to conventional explosives, with the intent to disperse the material and cause contamination and radiation. Possible sources of radioactive materials include spent reactor fuel, commercially produced and purchased radioisotopes (i.e., Cobalt 60 for medical uses), and low level radioactive waste from laboratory and medical procedures.

The second scenario is that of an intentional crash of a large commercial airliner into a nuclear facility. Although nuclear power plants are not designed to withstand such a crash, it will not cause a nuclear explosion. However, it could damage the outer layer of the facility or even rupture the reactor core, which in turn can cause release of the fission product found in reactor fuel rods. Post-destruction winds will determine the fallout pattern. Most of the fallout in this case will be of radioactive iodine [2].

Whatever the scenario, the outcomes are similar, although not on the same scale. People in the close vicinity can be harmed by direct body trauma, external radiation and contamination through open wounds and inhalation, while external and internal contamination can occur in people downwind and in the periphery. The contamination of a large area will prohibit entry to people without protective gear and will thus preclude normal life in these areas. Of course, the psychological ramifications of the true or even suspected presence of a hazardous material that cannot be seen or smelled can be extreme. Any dispersal pattern will produce small areas of relatively high contamination and larger areas with lower contamination. In no circumstance is a radiation dispersal device expected to produce an area with the hazard of immediate lethality unless there are accompanying trauma injuries resulting from the conventional explosives. Trauma injury and radiation injury may have synergistic effects. However, in dealing with a combined injury, the conventional trauma injury is always given first priority.

The response

Several countermeasures are useful in preparation for a radiation incident. Of course, prevention is always best. Preventing terrorists from gaining access to the technologies and radioactive materials

should be the highest priority component of the new global battle against terrorism. There must be an international effort to strengthen the physical protection of radioactive materials. In fact, this is currently a major endeavor of the International Atomic Energy Agency, besides its efforts to improve safety and security of nuclear reactors against terrorist attacks from the ground and from the air.

Non-medical measures

- *Detection of environmental radiation and delineation of area contamination.* This can be done with the aid of radiation meters and people skilled in using them. Detection meters should be brought on site to measure the direct radiation as well as sampling the air both on site and downwind for radioactive contamination. Monitoring from aircraft and helicopters may be necessary, the results of which will dictate area restrictions. Face-masks can be used as effective protecting devices in contaminated areas, and sheltering of the population at risk is warranted. Evacuation of people from the epicenter can significantly reduce their exposure to radiation.
- *Clean-up and decontamination of affected areas.* Due to the long half-life of some radioactive isotopes, this mandates physical removal of the contamination. This can be a very complicated and source-consuming operation, as was clearly seen in the Goiania and Chernobyl accidents [8]. Foods and dairy products may have to be monitored and appropriate restrictions on their consumption implemented.
- *Nuclear facility emergency response plans.* All nuclear facilities should have an emergency response plan to enable the mitigation of impact on the public in the event of release of radioisotopes from its reactors. Evacuation of people from the immediate vicinity and the supply of potassium-iodide tablets to the public in the periphery of the facility are the mainstays of the plan.
- *Public information plan.* This is always an essential part of any contingency plan for mass casualty disaster [9]. The contents of the information should be adequate for the severity of the situation, and scientific information that is easily understood should be given to the public. Physicians and physicists well instructed by public relations personnel should serve as spokespeople. It should be emphasized that restoring public confidence after such an event is likely to be very difficult and is a real challenge.

Medical measures

- *Triage.* This is particularly important for people coming from the center of the incident. Trauma injuries are always more risky than radiation exposure and should be given first priority. Decontamination of people found to be externally contaminated should be undertaken only if the patient is medically stable. A triage post in the vicinity of “point zero” should be established and manned by emergency response services. Trauma victims or people showing signs and symptoms of acute radiation syndrome should be evacuated to the nearest trauma center. The appropriate location for others is a separate public facility

(known as the evacuation center) that will assist in preserving hospital resources for the acutely ill and injured [10].

- *Decontamination.* The major danger of external contamination of clothing and skin is that it might be internalized into the body. People suspected of being contaminated should be monitored by detection meters. If found to be contaminated they should be undressed and washed, usually with soap and water, and monitored until they are found to be clean. This will be done both in the hospital for the severely injured and in the evacuation center for the others. The external contamination of victims poses some risk for the medical personnel, but it can easily be mitigated by adhering to the standard precautions used in routine medical practice and by decontaminating the patient once his or her medical condition stabilizes.
- *Diagnosis.* In all likelihood the evacuation center will contain hundreds to thousands of casualties. It should have decontamination facilities as well as showers and dressing rooms, and will serve as a temporary hostel for the evacuated casualties until it is decided whether to hospitalize them because of suspected ARS or send them home after proper registration and medical examination. The diagnosis of radiation exposure will be made using clinical criteria and laboratory tests. A complete blood count will be used to detect lymphopenia, the first and major sign of radiation exposure. In order to detect low levels of exposure, more sophisticated tests are needed such as cytogenetic analysis to reveal chromosomal abnormalities [11].
- *Hospital.* At the hospital, triage should be quick and effective. It should be performed by the senior, most experienced medical officer on scene. He/she should determine whether a trauma injury requires immediate hospital treatment or whether only radioactive contamination is involved, in which case the victim will be sent to the evacuation center after decontamination. These decisions will eliminate crowding the emergency department with casualties who do not need hospitalization at this stage. Thus, the triage will reserve the medical attention for those casualties who will die unless they receive the appropriate trauma care, in contrast to those contaminated or even those at risk of developing ARS in the near future. The emergency department and hospitals should be familiar with the plans and the care of radiation victims. Optimally, every major city should designate at least one hospital for this scenario. Those hospitals should have their own plans for such an event, designated areas with decontamination facilities to receive contaminated casualties, and protective gear for the medical and non-medical personnel.
- *Medical therapy.* This includes decorporation of internal contamination and treating ARS. Some specific radioactive materials can be eliminated by chelation, dilution or excretion. This can be achieved by various agents available against specific radioisotopes. Early start of therapy is important to prevent the radioactive element from being incorporated into target tissues. If the isotope half-life is long then the therapy might also be effective if continued for a prolonged period. The treatment of ARS is in the intensive care setting and includes supportive care,

hematopoietic growth factors, and bone marrow or stem-cell transplantation [12,13].

- *Follow-up.* A follow-up plan for the exposed population should be established. People exposed to ionizing radiation are at increased risk for cancer. Thyroid cancer in those exposed to radioactive iodine during a nuclear reactor accident or atomic bomb explosion is the typical example. However, since other radioactive isotopes do not have such a clear association with a specific type of cancer, a general follow-up may not prove to be effective for the early detection of all kinds of malignant diseases.
- *Medical records.* Since most of the radiation-induced biologic damage, except for ARS, will not show up before months or even years after the exposure, it is mandatory that all the casualties from the scene be medically evaluated and documented. Those records should include demographic data, the exact place of the victim at the moment of the event, contamination survey results if available, treatment if given, signs and symptoms pointing to ARS, and blood count if done. The records should be kept for the future medical follow-up of those casualties in case ARS will develop in the subsequent days, or for cancer screening programs in the years to come.

Fortunately, a radiation dispersal device has never been used. Nevertheless, radioactive materials have been used for terrorist purposes, the most serious event occurring in 1995 when Chechen guerrillas hid cases of radioactive cesium in a park in Moscow. The Russian authorities took severe precautions, sending emergency search teams around the city with Geiger meters. Another incident involved the Russian mafia, which allegedly killed a Moscow businessman by leaving gamma ray-emitting pellets in his office. In 1996, three men attempted to kill local Republican Party officials in Long Island by placing radium in the victims' cars, food and even in their toothpaste. The International Atomic Energy Agency reports 380 incidents of radiologic trafficking since 1993. Customs officials seized 10 lead-lined radioactive containers on the border between Uzbekistan and Kazakhstan, and it is possible that Bin Laden's al-Qaida was the potential end-user [1]. In addition, several radiation accidents have occurred in the past that might provide a clue as to what can happen when radioactive materials are dispersed. The most well known is the Chernobyl accident, which serves as a model both for a nuclear reactor accident and for the scenario of a plane crashing into a nuclear facility. Much less known is the Goiania incident in 1985, which exemplified radiation dispersal and also demonstrates how a response can be effectively implemented.

The Goiania accident [7,8]

At the end of 1985 a private radiotherapy institute in Goiania, Brazil, moved to new premises, leaving in place a cesium-137 teletherapy unit without notifying the authorities. The former premises were subsequently partly demolished. Two people entered the premises and, not knowing what the unit was but thinking it might have some scrap value, removed the source assembly from the radiation head of the machine, took it home and tried to dismantle it. In the attempt the source capsule was ruptured. The radioactive source was in the form of cesium chloride salt, which is highly soluble and

readily dispersible. Contamination of the environment ensued, with one result being the external irradiation and internal contamination of several people. The remnants of the assembly were sold for scrap to a junkyard owner who noticed that the material glowed green in the dark. He showed it to friends and relatives and distributed fragments of the source to several families. For 5 days a number of people experienced gastrointestinal symptoms arising from their exposure to radiation from the source powder. One of them connected the illness with the material and reported the incident to the public health authorities.

The response was impressive. Several sites were monitored and identified as being contaminated, and residents in the area were evacuated. The authorities set up a triage site in a large stadium and notified the public. Twenty people were identified as needing hospital treatment. In total, 112,000 people were monitored of whom 249 were found to be contaminated either internally or externally. Some suffered very high internal and external contamination because of the way they handled the cesium chloride powder, such as eating with contaminated hands. Four people died; the total radiation dose they absorbed was estimated by cytogenetic analysis to be 4.5 Gy to over 6 Gy.

Blood samples from exposed persons were analyzed by cytogenetic methods to estimate the radiation dose absorbed. Urine and fecal samples were collected daily from people with internal contamination to assess the internal radioactive burden and the efficacy of the agent Prussian blue in promoting decorporation of cesium. The authorities set up a whole-body counter to assist with the bioassay program.

The environment was severely contaminated in the accident. The actions taken to clean up the contamination can be divided into two phases: The primary objective was to establish control over sites where high radiation doses could induce non-stochastic effects, and this took 3 days. Sixty-seven square kilometers of urban areas of Goiania were monitored for 2 days. Eighty-five houses were found to have significant contamination, and the residents were evacuated. Water, soil and fruits were also monitored. Subsequently (the second phase), several houses had to be demolished and the soil removed. The final total volume of waste removed in 3 years was 3,500 cubic meters, or more than 275 lorry loads.

The response to the Goiania accident demonstrates several critical elements of any contingency plan for any type of radiation incident:

- Medical triage
- Setting up an evacuation center to monitor, decontaminate and register the population exposed
- Environmental monitoring and clean-up
- Hospital treatment of the severely exposed
- Effective dissemination of information to the public.

Implementing these elements is therefore feasible and results in appropriate medical care and restoration of normal life.

Conclusion

The threat of radiologic terrorism by terrorists or nations is no longer as remote as it was in the past. Awareness of the true hazards posed by such weapons is imperative, especially among the

medical community. Medical and paramedical personnel are not familiar with all aspects of nuclear, biologic and chemical terrorism in general, and radiation casualties care in particular. They should be taught and trained how to respond to such incidents.

Planning for radiologic scenarios is essential and not too difficult. Planning ahead for nuclear facility accidents can form the basis for radiologic terrorism preparedness. The planned response should be checked by drills. Knowledge and exercises will reduce the fear of radiation and help the community as a whole to cope with such an event should it occur.

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