CME Article

Scenario of a dirty bomb in an urban environment and acute management of radiation poisoning and injuries

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ABSTRACT

In the new security environment, there is a clear and present danger of terrorists using non-conventional weapons to inflict maximum psychological and economic damage on their targets. This article examines two scenarios of radiation contamination and injury, one accidental in nature leading to environmental contamination, and another of deliberate intent resulting in injury and death. This article also discusses the management of injury from radiological dispersion devices or dirty bombs, with emphasis on the immediate aftermath as well as strategy recommendations.

Keywords: dirty bombs, non-conventional weapons, radiological dispersion devices, radiation injuries

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SCENARIO ONE: GIOANIA CONTAMINATION 1987[1]

Goiania city (population 800,000) is the capital of the Goias state in southern central Brazil. On September 18, 1987, a lead canister containing 1,400 curies of caesium-137 (consisting of 93 g of CsCl powder) was opened after being found by scavengers in an abandoned radiotherapy treatment centre. A junkyard worker pried open the lead canister to reveal a glowing blue dust (radioactive caesium-137). The caesium was later parcelled out to friends and family, spreading the contamination from the junkyard to homes around the city, although within a localised area. This led to the second largest nuclear incident after Chernobyl, which occurred barely a year prior to this incident.

On September 28, 1987, a member of the junkyard worker's family reported symptoms of vomiting, lethargy and diarrhoea to a community health clinic, and acute radiation poisoning was correctly diagnosed with the help of a Goianian physicist. The Brazilian Nuclear Energy Commission was informed of a serious radiological accident. The International Atomic Energy Commission (IAEC) sent a team of doctors and physicists to aid the Brazilian government. 244 persons were found to be contaminated, with 54 persons seriously afflicted enough to be hospitalised for further tests or treatment. 34 were treated and released. 100,000 people (10% of the population) were checked using Geiger counters with the city's soccer stadium as a venue. There were four fatalities (two men, a woman and a child) and widespread contamination of downtown Goiania and external exposure to members of the public.

An immediate contamination survey in the residences was initiated. Four main foci of contamination were identified: three junkyards and one residence. Up to 85 residences were found to have significant levels of contamination and a decision was made to destroy the most contaminated sites for burial. The destroyed radioactive building materials and waste were stored in 4,500 metals drums of 200 L each and reinforced with concrete shielding and buried at a decontamination site 30 km outside the city. The decontamination effort took three months to complete. The immediate social and economic aftermath was a crippling of all transport communication and trade in agricultural produce with the outside world, when the severity of the incident was announced, especially coming so soon after Chernobyl. The incident led to the tightening of the various national regulatory legislations regarding orphaned radiotherapy sources.

SCENARIO TWO: LONDON POLONIUM POISONING 2006[2]

A 44-year old, caucasian man had a meal with an associate in a central London sushi restaurant on November 1, 2006. A few hours later, he complained of feeling sick and was admitted to a district general hospital in Barnet, North London. His condition deteriorated and he was transferred to a tertiary hospital, the University College Hospital, on November 17, 2006. He was initially reported to be suffering from suspected thallium poisoning on November 19, 2006. The national police investigated possible foul play and poisoning on November 20, 2006. The possibility of radioactive thallium was cited

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Table I. Properties of radioisotopes.

Radionuclide	Physical half-life	Radioactivity emissions	Use
Caesium-137 (Cs-137)	30 years	1.5 ×106 Ci gamma photons	Food irradiator
Cobalt-60 (Co-60)	5 years	1.5 ×103 Ci gamma photons	Cancer therapy
Plutonium-239 (Pu-239)	24,000 years	6 × 102 Ci gamma photons	Nuclear weapon
Polonium-210 (Po-210)	138 days	4.5 × 103 Ci alpha particles	Electrostatic machines
Strontium-90 (Sr-90)	20 years	0.1 Ci beta particles	Eye therapy device
Americium-241 (Am-241)	432 years	0.000005 Ci alpha particles, gamma photons	Smoke detectors

on November 21, 2006. The patient continued to deteriorate, became critically ill on November 22, 2006, and died on November 23, 2006. Thallium poisoning was ruled out. The diagnosis of polonium-210 poisoning was made on November 24, 2006 after specialist tests. In the aftermath, 14 locations in central London were investigated for radioactive contamination, with the closing of some locations. A health alert was issued for passengers who had been on certain British Airways (BA) flights to contact the relevant authorities because of possible exposure to radiation.

INTRODUCTION

A radiological dispersion device (RDD) or dirty bomb is created by combining radioactive material with conventional explosives, leading to a double effect of a physical blast injury and the psychological fear of lingering radiation contamination on the environment. In a nuclear detonation, most of the injuries will be inflicted by the immediate blast, while the firestorm and radiation contribute mainly to long-term carcinogenesis. In a RDD attack, although most of the death and injuries will be caused by the blast trauma, the radioactive contamination can also be significant, depending on the amount and type of radioactive material used. Probable radioisotopes include Cs-137, Sr-90, Co-60, Am-241 and Pu-239 (Table I). These isotopes, with the exception of Pu-239 and Po-210, are widely and readily available from industrial and medical applications. They are gamma emitters with an appreciable range of irradiation and relatively long half-lives.

The Gioania contamination incident in 1987, albeit an accident, has become the textbook example of how to manage widespread environment contamination resulting from a possible RDD. Firstly, only a small amount of Cs-137 was required to wreak havoc and panic among the population, with the implications of the disruption of social and economic activity. The radioactive material was a powder, thus enabling widespread aerosol dispersal and integration of the particulates in the topsoil. This required the condemnation of the junkyard building, and the disposal of contaminated topsoil and 'hot' wreckage material into reinforced cement-lined oil drums, which were then buried in a specialised decontamination burial mound. The long half-life of Cs-137 (30 years) also required a strategy of secure unperturbed disposal of radioactive material for at least five half-lives, or about 150 years. This strategy of wreck and disposal would present particular difficulties if the terrorists were to target buildings of significant national, historical, cultural or economic value in order to inflict the most collateral damage. If the half-life is short, like Po-210 used in the London incident, and the contamination occurs in an important commercial area, a strategy of quarantine for the contaminated areas until the level of radioactivity decreases to safe levels, is appropriate.

The second lesson is that the actual number of casualties from a radiation incident is usually small and confined to the victims exposed directly and immediately. This is due to factors related to the dose, intensity and nature of the radioactive isotopes. In the Gioania incident, there were four fatalities among those receiving the highest doses and up to another 22 patients who were immediate family and friends of those most adversely affected, developing significant radiation sickness symptoms and bone marrow depression. The then pioneering work of bone marrow transplants and intensive supportive treatment in the intensive care unit team enabled the survival of those poisoned with a moderate level of radiation. In the second example, there was one fatality with poisoning and the contamination of his wife, his associate and a waitress serving at the restaurant. The risk of contamination to the general public was extremely small in this case because Po-210 is an alpha-emitter, with a short range of action which is easily shielded. However, the "worried well" of the general population had fears of being inadvertently contaminated or irradiated, despite the low radiation risk. These fears had to be allayed. In

Gioania, a significant number of the population (10%) was screened in the city stadium using survey meters. A smaller number of those people with significant contamination was picked up on initial screening, then had more accurate dosimeters used on them. For the London incident, up to 33,000 passengers on 221 BA flights were contacted about possible contamination. Only a smaller number of around 200 passengers were asked for a urine sample for dosimetry and only 24 passengers were referred on to specialist clinics for further management.

In incidents like these, there is great public interest and general worry regarding exposure to radiation. Psychiatric counselling for victims, and health advisories by radiation experts for the general public, are essential to prevent widespread panic. A well-executed media campaign, coordinated with security officials' statements, will allay widespread fear. The propagation of fear is one of the prime objectives of terrorists using a RDD. Appropriate triage of the "worried well" and decontamination, plus further inpatient treatment of those with significant contamination, will conserve scarce hospital resources for patients most seriously injured and in particular need of specialist radiation injury treatment.

IN THE AFTERMATH OF A RDD: AN ALL-HAZARDS APPROACH

One of the most critical periods to tide over is the first 24 to 48 hours after the occurrence of a blast incident. Multi-agency coordination between the security personnel, like police, army, bomb disposal experts as well as health workers/rescuers, is essential. Regular simulation exercises of RDD scenarios, in preparation of the actual event, are essential to foster multi-agency coordination. This has to be done in anticipation of incompatible inter-agency communication systems, unclear chain of command, overlapping responsibilities and the chaotic aftermath of an actual terrorist attack. An all-hazards strategy will include securing and isolating the blast area. Specialist HazMat (hazardous materials) teams like the army's chemical, radiation, biological and explosives division have to confirm radiological emission and exclude chemical, biological and secondary explosions before evacuating those critically injured for hospital management. Decontamination of those not critically injured but contaminated with radioactive material on their bodies has to be conducted on the spot to prevent further spread of the radioactive material. These individuals may otherwise, in the confusing aftermath, try to make their way home on public transport. A fast-acting team is necessary to ensure help is made available at the earliest time to treat, offer psychological counselling and decontaminate victims. The authorities should also be aware of the possibility of a delayed secondary blast, with the initial blast used as a decoy to lure rescue workers and members of the public in for a more widespread contamination. The primary aim of the use of the RDD by terroists is after all, to maximise its potential for contamination. The all-hazard approach serves as a contigency against this threat, and the protection of rescue personnel at the scene with barrier suits mitigates against chemical and radiological contamination. These HazMat suits prevent the inhalation of aerosolised radioactive particles, accidental ingestion and contact with open wounds and mucosal membranes.

Initial rescue steps will involve physicists to detect the level of radioactivity and identify the possible radioisotopes involved in the RDD attack. This has implications on appropriate shielding, medical treatment and deployment of personnel. Sometimes, the identity of the isotope is readily identifiable because of the particular characteristic spectrum of the gamma photons emitted matching the expected radioisotope deployed. However, an isotopic mix can also be used with varying gamma energies to confound even experts. There are specific specialist detectors for specific radioactive particles or emissions, and incorrect detectors used will give only a false all-clear situation (Fig. 1). In the London incident, the short-range alpha particles from Po-210 were not immediately detectable using the standard gamma-detectors commonly available in hospital radiotherapy departments. This delayed the actual diagnosis until specialist equipment from the national radiological response centre was made available. With scant information available, it took astute clinical observation of the symptoms experienced by the patient and strong inferences of the patient's background before an exotic method of radiation poisoning was suspected. Unfortunately, the delay of the true diagnosis also led to the deterioration of the patient.

A decontamination centre with support of mobile response/decontamination units will be set up close to the site. Fig. 2 shows an arrow for patient movement through contaminated and cleans areas of a decontamination centre. The decontamination target for safe working levels is about twice above the normal background radiation level. Measures like changing into new clothes can remove up to 95% of radioactive contamination and washing patients with copious amounts of water will remove residual radiation to safe working levels. The collection of the radioactive effluent waste water is mandated by national regulations and to prevent environmental

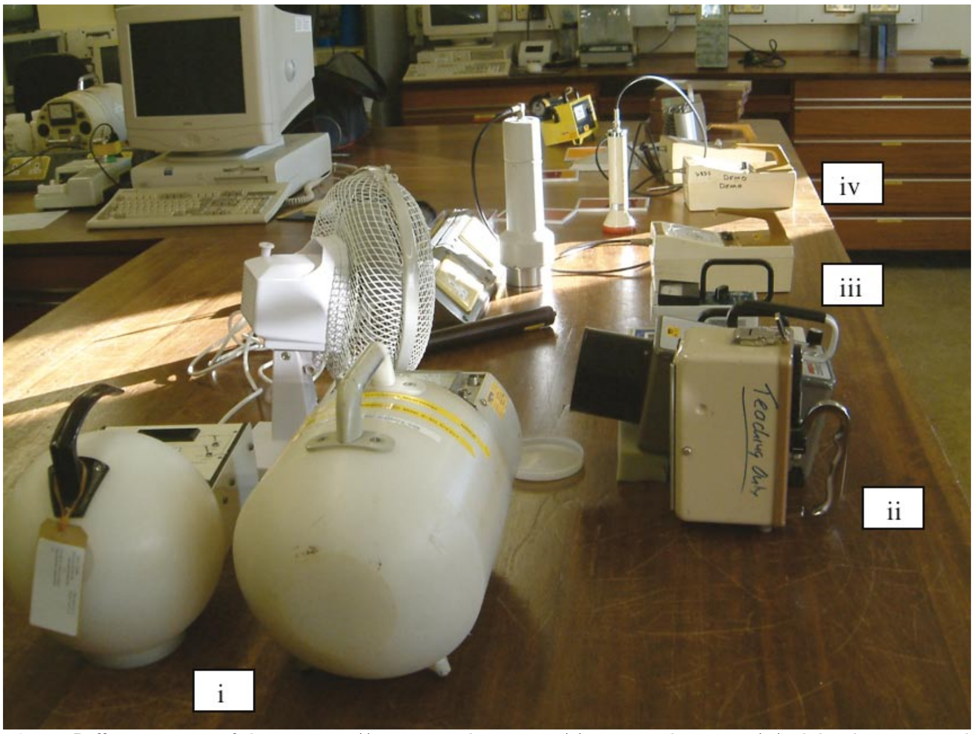

Fig. 1 Different types of dosimeters: (i) neutron detectors; (ii) gamma detector; (iii) alpha detector; and (iv) beta detector.

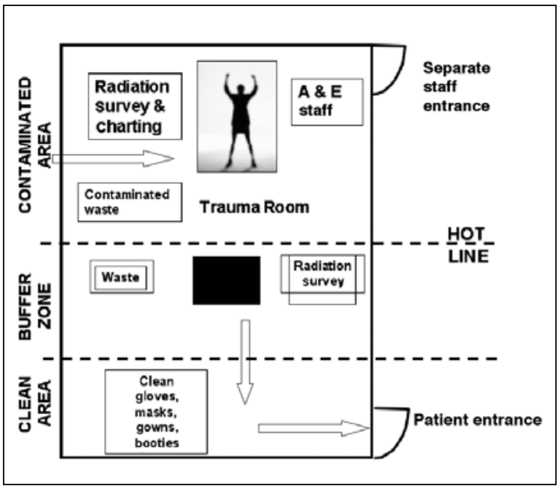

Fig. 2 Scheme of treatment area layout.

contamination. The decontamination process can be constantly monitored by reliable and accurate dosimeters. Radiation protection for the safety of the staff involves the following three cardinal rules: increasing distance, limiting time of exposure, and appropriate shielding.(3)

Increasing distance

There is a fall-off according to the inverse square law, and a doubling of the distance results in a decrease in four times the level of radiation intensity. Beta and alpha particles have a short range of action; however, their biological action at close distances is enormous. Gamma photons and neutrons possess a longer range of action and initiate a more moderate biological action.

Decreasing time of exposure

This has implications on staff scheduling. Sufficient resources should be allocated to rotate staff into shifts when operating in a high dose region. The time allowed is limited by national regulations. Radiation worker and public dose limits are currently capped at 20 mSv and 1 mSv per year, respectively. Pregnant female workers and those nursing infants need particular protection and should avoid exposure, if possible. Depending on the activity of the radioactive source, even a short working period may deliver the annual national dose limits. Informed consent and counselling about acute and chronic radiation side effects are therefore required for radiation health workers.

Shielding

Appropriate shielding depends on the type and energy of radiation, hence the importance of identifying the isotope. Alpha particles are not penetrating and are stopped by even the thickness of a paper;

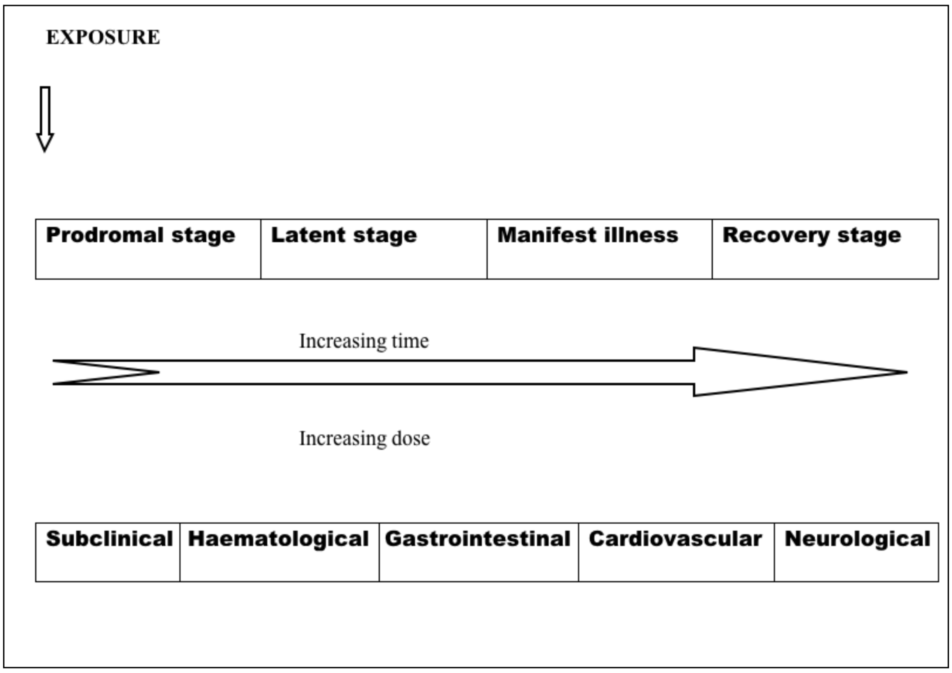

Fig. 3 Spectrum of acute radiation injury with increasing dose and time from exposure.

beta particles (depending on the energy) can be stopped easily by a few centimetres of plastic. Gamma photons (depending on energy) are stopped by a few centimetres to a few metres thickness of concrete, or are stopped by a few centimeters of lead. Neutrons are highly penetrating and can go through even thick concrete, rendering any lead suit shielding impractical.

ACUTE ACCIDENT AND EMERGENCY TRIAGE AND MANAGEMENT

Triage by identifying acute radiation symptoms and inferring dose received can be done with clinical features like acute nausea, fatigue, acute skin erythema (> 4 Sv), confusion (> 10 Sv) and unexplained (non-thermal/chemical) burn injuries. The distance and location of the patient from the epicentre, as well as local microclimate conditions, can increase or decrease the dose received. Initial triage should identify those more severely exposed and contaminated for priority decontamination and treatment. Recognising radiation injury, and rapid treatment with suitable antidote chelators, are essential to increasing survival rates. Admission to the appropriate specialist radiation units for further management is also essential, because certain radiation injuries have a prodomal latent period and manifest with more severe symptoms progressively. There is a spectrum of acute radiation injuries with varying onset periods, depending on the radiation dose received (Fig. 3).

DOSE RECEIVED DICTATES PROGNOSIS AND TREATMENT RESOURCES REQUIRED

Initial treatment of burns and blast injuries should take precedence over radiation injuries. Appropriate triage should include determining radiation dose received, to allocate resources to those with the best chance of survival for intensive management, especially in mass casualty situations. Those receiving less than 1 Sv whole body dose usually display no discernible acute radiation effects and are managed expectantly with long-term follow-up for increased risk of carcinogenesis. Patients receiving whole body dose of 1 to 3 Sv experience acute vomiting, subacute diarrhoea and mild reversible bone marrow depression, and need supportive management in the general ward. Patients exposed to a whole body dose of 4 Sv have a 50% chance of dying without further treatment, because of severe bone marrow suppression. Patients afflicted with a moderate whole body dose of 4–6 Sv will undergo an acute prodrome phase, latent interval phase before suffering full-blown illness manifestations of various organ systems (central nervous system, gastrointestinal, haemopoeitic). This group of patients needs treatment in an intensive care environment with stem cell support and transplantion, if appropriate. Those exposed to more than 10 Sv will experience neurological symptoms like confusion, due to cerebral oedema, and have low survival rates despite best treatment.

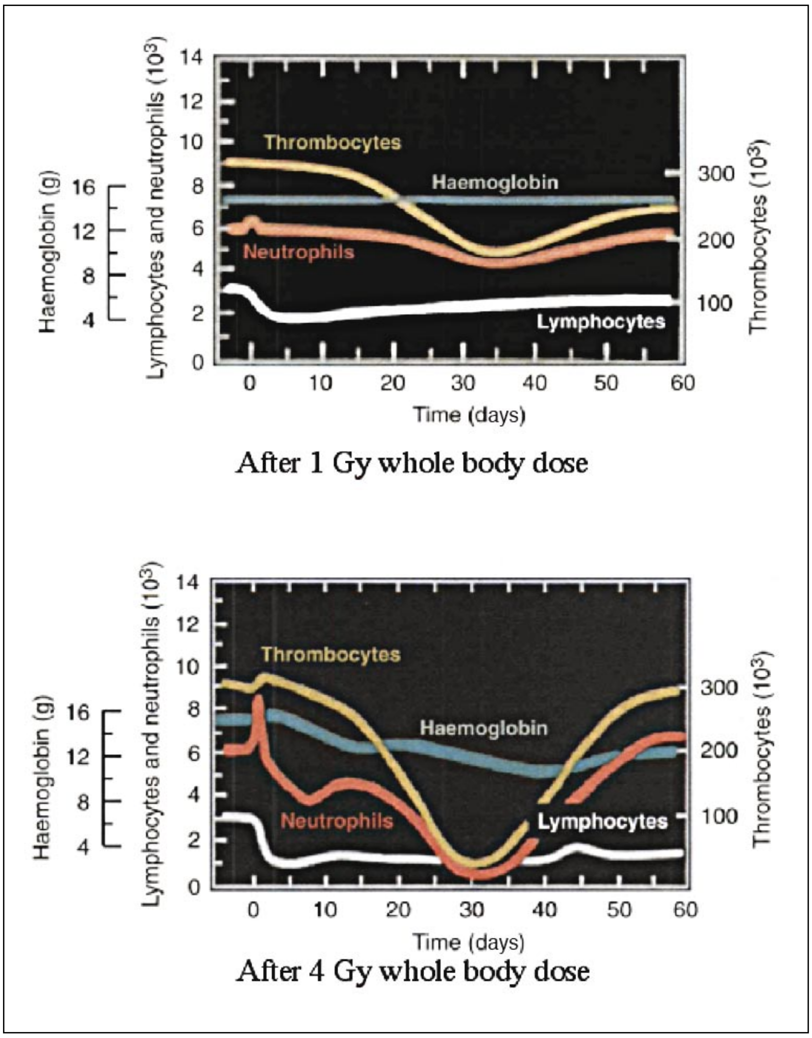

Fig. 4 Blood levels after 1 and 4 Gy whole body doses.

Table II. Specific radioisotope antidote treatments.

Radionuclide	Treatment	Route of administration
Caesium-137	Prussian blue	Oral
Iodine-125/131	Potassium iodide	Oral
Strontium-89/90	Aluminium phosphate	Oral
Americium-241	Ca- and Zn-DTPA	Intravenous

IMPORTANCE OF ACCURATE DOSIMETRY

A variety of more sophisticated biological dosimetry, like leucocyte chromosome aberration quantification, micronuclei assays, comet assays and FISH detecting chromosome translocations, can be used to determine dose received even after long periods have passed, and is believed to have been used forensically in the London incident. These methods require sending blood samples to accredited laboratories in Australia, Europe and the US, and are costly and unsuitable for daily clinical work. A biodosimetry assessment tool relying on serial blood counts is an abbreviated and practical method for daily clinical management and for mass casualty situations.[4] Fig. 4 shows an example of how serial blood differential counts decrease after exposure to whole body doses of 1 Sv and 4 Sv. This delay in haematological manifestations is related to the remaining lifespan and survival of mature blood aggregates, and preferential elimination and destruction of immature blood stem cells by irradiation. Notably, neutrophils (lifespan days to weeks) and platelets (lifespan weeks to months) experience a more acute decrease, and red cells (lifespan three months) are the most resistant, and develop a later onset decrease pattern.[5] The serial blood picture of the patient in the London case follows this classical haematopoeitic manifestation and the patient never recovered sufficiently from multi-organ failure to undergo bone marrow transplant.

TREATMENT BY RAPID ELIMINATION OF RADIONUCLIDES FROM THE BODY

Occasionally, there may be a need for the use of certain heavy metal chelators for the elimination of radionuclides originating from heavy metals. There are certain specific antidote regiments for particular radioisotopes, hence the importance of early identification and treatment[6] (Table II). For ingested radionuclides, gastric lavage or purgatives are sometimes precribed to remove as much of the radioactive material as possible. Superficial decontamination of the wounds requires debridement of the wounds and flushing.

ENVIRONMENTAL DECONTAMINATION AND DISPOSAL OF RADIOACTIVE WASTE

Residual radioactive material may contaminate the area and cause significant economic and social disruption. Clean up strategies will depend on the half life of the isotope. In general, the clean up of radioactive environments is an expensive, difficult and lengthy process. International bodies, like IAEA, deploy their experts to assist with technical advice regarding isolation, handling and safe disposal of radioactive waste.

CONCLUSION

A radiological dispersion device can be used by terrorists to maximise psychological impact, incite fear and economic damage by environmental contamination, as well as inflict physical injuries. Regular simulations involving close multi-agency cooperation are required to prepare for a RDD event. An all-hazard approach is needed to secure the site, protect rescue workers, identify the radiation type, decontaminate and evacuate the injured. Psychological counselling for mildly injured but contaminated victims, general public reassurances by public health officials, backed up by advice from radiation experts, can prevent widespread panic. Lessons can be learnt from the two different radiation incidents. Appropriate A & E management includes triage of injuries, estimation of radiation dose, antidote treatment, early recognition of prodromal symptoms and admission for specialist radiation injury treatment, if necessary. Healthworker safety involves using proper shielding, minimising time of and increasing distance from radiation exposure. The first 24 to 48 hours are the most difficult trials, after which there will be international expert teams on hand to aid environmental decontamination and treatment of victims.

ACKNOWLEDGEMENT

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SINGAPORE MEDICAL COUNCIL CATEGORY 3B CME PROGRAMME
Multiple Choice Questions (Code SMJ 200710A)

	True	False
Question 1. After a radiological dispersion device (RDD)/dirty bomb explosion:		
(a) Isolation and securing the area are important.	☐	☐
(b) Adopting an all-hazard principle from the onset.	☐	☐
(c) Most of severe acute injuries will take the form of blast, burn and wound injuries.	☐	☐
(d) Radiation-related deaths would likely to be few.	☐	☐
Question 2. The following are routes of radioactive particle contamination:		
(a) Ingestion of radioactive particles.	☐	☐
(b) Direct contact with wounds and mucosal membranes.	☐	☐
(c) Inhalation of aerosolised radioactive particles.	☐	☐
(d) Irradiation by gamma rays.	☐	☐
Question 3. The following measures are used to minimise radiation exposure to healthcare workers:		
(a) Decreasing time exposure to radiation.	☐	☐
(b) Increasing distance to radiation sources.	☐	☐
(c) Appropriate barrier and shielding measures.	☐	☐
(d) Administering intravenous antidote prophylaxis.	☐	☐
Question 4. Triage at the accident and emergency department includes:		
(a) Estimation of severity of blast injuries.	☐	☐
(b) Estimation of radiation dose received.	☐	☐
(c) Detailed biological dosimetry using FISH.	☐	☐
(d) Recognising prodromal symptoms of severe radiation injuries.	☐	☐
Question 5. The following statements are true after whole body irradiation:		
(a) Drop in red blood cells precedes drop in neutrophils.	☐	☐
(b) Drop in neutrophils precedes drop in platelets.	☐	☐
(c) Whole body doses of 2 Sv will result in irreversible neutrophilia.	☐	☐
(d) With intensive therapy, whole body doses of 12 Sv can be treated.	☐	☐

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