

## Management Of The Irradiated Casualty

SA Bland

### Introduction

Casualties from radiological or nuclear incidents may present in a variety of ways, including contamination, irradiation, trauma and combined injuries. Scenarios that lead to Acute Radiation Syndrome (ARS), through high dose radiation exposure, are fairly limited. These scenarios usually involve:

- The nuclear process (fission), including
  - Nuclear reactor incident, either as an accident or deliberate act.
  - Criticality (brief period of critical mass) incident, such as a laboratory accident.
  - Nuclear detonation.
- Prolonged exposure to highly radioactive sources, including
  - Industrial radiography sources.
  - Radiotherapy sources.
  - Nuclear power sources used in remote locations ('nuclear batteries').

The effects of high dose radiation are primarily due to cell death. Because a certain number of cells have to die before there is organ / system dysfunction, there is a threshold level before the effects are seen (~0.5Sv). The effects of low-level radiation are associated with cell (DNA) damage leading to mutagenesis and carcinogenesis. This article will deal only with high dose radiation exposures.

Irradiation is the mechanism by which ionising radiation exerts its effect on biological material. Where contamination has taken place, either external or internal, irradiation will continue until the contamination is removed. The three mainstays of limiting any radiation exposure are limiting *time* and increasing *distance* and *shielding*. The aims of any medical support for irradiated casualties are the removal of external contamination (decontamination), removal of internal contamination (decontamination/iodine prophylaxis), supportive and definitive management.

Without medical management, the lethal dose to kill 50% of the population at 60 days (LD50/60) is 3.5Sv. This can be increased to at least 5-6Sv with medical support and definitive management. The main cause of death is sepsis and coagulopathy due to haematological and gastrointestinal failure. At very high doses, cerebrovascular failure will contribute to the mechanism of death.

### Types of casualties

During an incident, casualties will need to be sorted so that those requiring specific medical assistance are identified. Casualties, in significant quantities, will require formal medical triage based on the effects of their exposure and/or injuries.

The different types of casualties should be managed as follows:

#### **Externally contaminated only**

They may not require any form of medical assistance. These casualties should be decontaminated as soon as possible with priority given to casualties with injuries or possible irradiation.

#### **Internal contamination possible**

These casualties need further assessment as well as external decontamination; swabs and biological waste (urine and faeces) should be taken for monitoring. Further assessment, including whole body monitoring may be required. Specific treatment is detailed later in this article.

#### **Contaminated wounds**

These should be decontaminated and dressed. Surgical debridement may be required and this should be sufficient to remove any residual radiological material. Large pieces of radioactive shrapnel may emit significant amounts of radiation and removal of these pieces should be expedited as soon as possible with responders taking appropriate personal protective measures.

#### **Irradiated only**

These casualties need to be assessed for the risk of contamination. However, if there is no risk of contamination or complete decontamination has taken place, supportive and definitive care may be continued without risk of secondary contamination of emergency responders.

#### **Combined injuries (contaminated and injured ± irradiated)**

These casualties should be prioritised, both for decontamination and medical support. While decontamination will allow more effective medical interventions, it should not delay lifesaving medical interventions; gross decontamination (removal of clothing) still forms part of a trauma primary survey. Lifesaving interventions include basic airway manoeuvres, C-spine

control, bag-valve-mask ventilation, needle thoracocentesis (for tension pneumothorax) and control of haemorrhage. Where combined injury includes trauma and irradiation, outcome predictions are significantly worse than for trauma or irradiation alone.

### **Trauma associated with nuclear detonation**

Following the detonation of a nuclear device, the following “conventional” traumatic injuries will be seen:

- Flash – causing afterimages, retinal damage and blindness.
- Blast injuries – caused by the initial positive and negative overpressures, and blast winds. In addition, further injuries will occur due to flying debris and crush injuries due to falling masonry.
- Thermal injuries – these are due to the initial intense flash and fireball with further injuries secondary to any fires started. These thermal injuries are different to burns caused by ionising radiation.

The ratio of irradiated casualties to conventional injuries depends upon the type and yield of the detonated device. Devices with a yield greater than 10kT are more likely to cause death by blast and thermal injuries. Below 10kT, the radius for the lethal dose for 50% (LD50) is relatively further away from the epicentre, indicating that injuries or death are more likely to involve significant radiation doses. The implication for incidents caused by smaller devices, including improvised devices used by terrorist organisations, is that there will be proportionally more irradiated casualties than for incidents involving larger (strategic) devices.

Table 1. ARS probability classification.

	Possible category of radiation injury		
	Unlikely	Probable	Severe
Nausea	-	++	+++
Vomiting	-	+	+++
Diarrhoea	-	±	± to +++
Hyperthermia	-	±	+ to +++
Hypothermia	-	-	+ to +++
Erythema	-	-	- to ++
CNS dysfunction	-	-	- to ++
- = absent + = present ++ = excessive +++ = very excessive			

Table 2. ARS and dose characteristics.

Dose	Expected effects	Probability
<1Sv	Below threshold	Unlikely
1-2Sv	Mild	Probable
2-4Sv	Moderate	Severe
4-6Sv	Severe (LD50)*	
6-8Sv	Very severe	
>8Sv	Lethal	
>20Sv	Neurovascular involvement likely to be significant	

\* in absence of medical treatment

## **Classification / grading of irradiated casualties**

There are a number of systems used in the classification of ARS, as well as computer packages used for dose prediction. The greatest difficulty with classifying the extent of irradiation is that, after the initial prodromal stage, there is a latent period before further manifestations of ARS are seen.

### **Probability**

The initial classification is based upon prediction of the likelihood of ARS using prodromal symptoms. The categories are unlikely (no prodromal symptoms), probable (some prodromal symptoms) and severe (significant or severe prodromal symptoms). These symptoms are listed in Table 1. Although these symptoms are sensitive for future ARS, they lack specificity. This system does provide a useful triage tool in the early management of a radiological incident where casualties could be ruled out in the absence of symptoms after 4 hours.

### **Dose**

The simplest system uses dose (sieverts) and can be used to cross-reference with other classification systems (Table 2). The calculation of dose may initially be predicted using personal dosimetry and dose modelling. Prodromal symptoms can also suggest likely absorbed dose, but are less specific. More sensitive and specific dose calculations can be based upon biodosimetry. This can use the predictive fall in lymphocytes as a guide to absorbed dose and is a fairly rapid test. It is recommended that 12 hourly full blood counts (FBC) be taken after an initial baseline sample has been taken as soon as possible. At 24 hours a sample should be taken for cytogenetics looking for chromosomal abnormalities. Unfortunately, the results are unlikely to be available within the first 48 hours.

### **System specific and severity based (British Institute of Radiology)**

This system, used by the British Institute of Radiology, grades the involvement of four specific systems from degree 1 to degree 4. The four systems are neurovascular (N), haematological (H), cutaneous (C) and gastrointestinal (G) Table 3. A grading code is then generated, summarising each system's involvement (Ni, Hi, Ci, Gi), where i is the severity index (1-4).

The grading code is then used to generate a Response Category (RC) and is specific to a time point, such as 3d (3 days). The system code with the greatest number determines the RC (for example, N2H3C1G2 » RC3). If this is at 48 hours post incident, the final RC would be RC3<sub>2d</sub>.

The RC is used to guide further examinations and investigations including the frequency of these tests. The RC is also used to suggest the likelihood of recovery summarised in Table 4.

Table 3. ARS symptoms.

Symptoms	
N	Nausea
	Vomiting
	Anorexia
	Fatigue syndrome
	Fever
	Headache
	Hypotension
H	Neurological deficits
	Cognitive deficits
	Lymphocyte pattern
C	Granulocyte pattern
	Thrombocyte pattern
	Blood loss
	Infection
	Erythema
G	Sensation/itching
	Swelling and oedema
	Blistering
	Desquamation
	Ulcer/Hair loss
	Onycholysis
	Diarrhoea
	Abdominal cramps/pains

#### Computer-assisted classification

Some computer software packages collate all the available information from pre-hospital assessment through to cytogenetic results to predict the absorbed dose and therefore predict or confirm the severity of the ARS. The US Armed Forces Radiobiology Research Institute (AFRRI) has produced such a Biodosimetry Assessment Tool (BAT). (See website for download information at <http://www.afrii.usuhs.mil>.)

#### Initial medical management

Initial medical management includes the removal of any residual radiological hazard (external / internal contamination), diagnosis and therapy.

#### Decontamination

Decontamination should be carried out as soon as possible and consists of gross and definitive decontamination. Gross decontamination is the removal of any obvious contamination (wet / dry) and all clothing. This will remove the majority (up to 90%) of the contaminant. Definitive decontamination involves further washing

and rinsing of the casualty. A number of decontamination procedures have been described but in general the aim is to avoid breaking the skin, avoid internal contamination during decontamination by ingestion or inhalation and taking samples to assess potential internal contamination (nasal and ear swabs). Large quantities of warm water are suggested to prevent hypothermia (with or without detergent).



Fig 1. Example of a radiation monitor used during decontamination.

#### Decorporation

Decorporation is the removal of internal contamination by exploiting the chemical and biological properties of the radioisotope. This process is often with the use of a chelating agent for those radioisotopes that are transition or heavy metals. Alternative methods of removing internal contamination within the lungs and the gastrointestinal tract are bronchial lavage and whole bowel irrigation. A list of common decorporation methods is in Table 5.

#### Radioiodine prophylaxis

During the fission process, fissile material (uranium and plutonium) will produce numerous radioisotopes as fission products. Radioiodine is a small percentage (1-2%) of the total fallout from a detonation or reactor accident. However its concentration within the thyroid, once it is absorbed into the body, means that there is a significant local dose. This effect is used in therapeutic thyroid ablation for hyperthyroidism using iodine-131. In order to protect the thyroid from possible carcinogenic radiation doses, stable iodine in the form of an iodine salt (potassium iodate) can be used as

Table 4. Response Category and implications.

Response Category	Therapeutic interventions	Institutional requirements
RC1 Autologous recovery certain (mild damage)	General support of recovery processes; usually no specific therapy	Outpatient care or general medical ward
RC2 Autologous recovery likely (moderate damage)	+ supportive care; substitution (blood component therapy)	Medical wards with haematological-oncological, neurological and dermatological specialties
RC3 Autologous recovery possible (severe damage)	+ stimulation (growth factor therapy)	Haematological-oncological institutes with reverse isolation; intensive care unit; consultations of all medical specialties
RC4 Autologous recovery most unlikely (serious damage)	+ stem cell transplantation	Specialised hospital with experience in all areas of intensive care medicine, particularly allogenic stem cell transplant

Table 5. Decorporating agents.

Radioisotope	Agent
Americium	DTPA, EDTA
Caesium	Prussian blue
Cobalt	Penicillamine
Iodine	Stable iodine
Plutonium	CaDTPA
Strontium	Aluminium, calcium
Tritium	Hydration, diuresis
Uranium	Bicarbonate

prophylaxis. The stable (non-radioactive) iodine saturates the thyroid gland and prevents the accumulation of radioiodine.

### Diagnosis

Initial diagnosis of ARS is difficult because of the latent period. Identification of potential cases (probable, severe) will initially be based upon dose prediction, personal dosimetry and prodromal symptoms and signs (see Table 1). Investigations will be required to predict the development of the manifest illness phase and many investigations will be required to be repeated.

### Investigations

A summary of all investigations is at Table 6 and Figure 2.

### Therapy

The therapeutic interventions for ARS are a combination of supportive and definitive treatments.

These can then be further sub-divided into:

- Supportive
  - Anti-emetic therapy
  - Analgesia
  - Brain oedema therapy
  - Nutritional support, may require parenteral
  - Antibiotic treatment (including anti-fungal and antiviral treatment)
  - Blood component substitution
  - Trauma supportive treatment
- Definitive
  - Stimulation (growth factor therapy)
  - Stem cell / bone marrow transplantation
  - Surgery

### Anti-emetics

Prodromal symptoms can be treated with anti-emetics and anti-histamines. Anti-emetics likely to be effective are centrally acting and include 5HT-antagonists. This is due to the direct effect of ionising radiation causing a release of neurotransmitters. In addition, glucocorticoids such as dexamethasone may be effective.



Fig 2. Example of biological monitoring sample.

### Brain oedema therapy

Although CNS involvement as part of ARS has a very poor outcome, some brain oedema therapy has been suggested:

- Low dose dexamethasone (20-40mg initially, followed by 2-4mg daily).
- High dose dexamethasone (40-100mg initially, followed by slow dose reduction).
- Mannitol (20%) and diuretics.
- Artificial ventilation (normocapnia).

### Antibiotic treatment

Antibiotic treatment also includes standard infection control measures applicable to the neutropenic patient. Antibiotics should be appropriate to local guidelines and recent microbiological results. Antiviral treatment may be indicated if there is a possibility of herpes simplex or cytomegalovirus. Systemic antifungal therapy may be required in patients with persistent pyrexia despite adequate antibiotic therapy.

### Blood component substitution

This is mainly a requirement for platelet transfusions. Red cell transplants are generally not required. Leukocyte depleted blood products should be used to prevent graft versus host disease.

### Growth factor therapy

A number of growth factors are being investigated, including granulocyte-colony stimulating factor and granulocyte-macrophage colony stimulating factor. This may require early administration and so early diagnosis and prediction of haematopoietic failure is important.

### Bone marrow / stem cell transplant

Where there is complete bone marrow

Table 6. Investigations for ARS.

Time	Tests / Samples	Comments
During decontamination	Nasal swabs, ear swabs, wound swabs	Assess internal contamination risk
As soon as possible	Full blood count	Baseline for serial FBC / haematological profiling
Within 24 hours	HLA typing	Held in case of transplantation
At 24 hours	Cytogenetics	For biodosimetry
Others, as available	Urine, stools	Assess internal contamination risk, stools also for microbiology
As required	Biochemistry (+ amylase)	Fluid and electrolyte assessment
	C-reactive protein, interleukin 8, procalcitonin, blood cultures	Assess possible infection in immunosuppressed patient

failure (RC4(H)), transplantation will be required. This may have significant implications in a mass casualty situation as the process is highly resource dependant and requires suitable donor tissue.

### Summary

The initial management of any irradiated casualty is the early identification of the possibility of a significant exposure through dose prediction and recognition of prodromal symptoms. Subsequent management is aimed at supporting the effected systems until there is recovery. Where there is haematological failure, transplantation (bone

marrow / stem cell) is possible although limited value in a mass casualty scenario.

The provision of gold standard therapy within the field is unlikely to occur and early medical evacuation to an Echelon / Role 4 facility with specialist services will be required. Within the field, early assessment using the above systems of classification could be achieved at Echelon / Role 3 and may be enhanced with the establishment of Radiation Assessment Units. These would select casualties that could benefit from the advanced therapies.

A summary of the levels of care is shown in Figure 3.

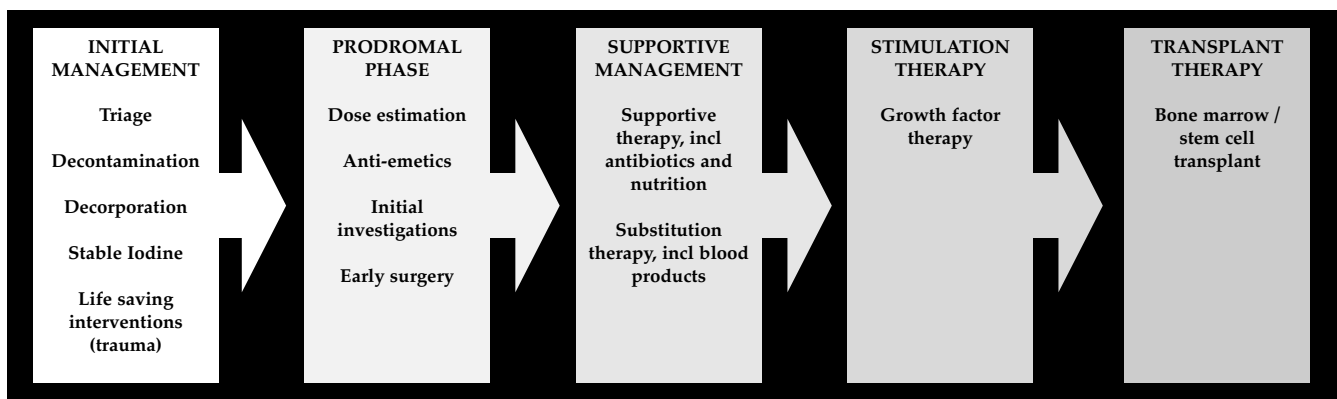


Fig 3. Summary of therapeutic interventions.

### Further Reading

Armed Forces Radiobiology Research Institution. Medical Management of Radiological Casualties. 2nd ed. Bethesda: AFRRRI; 2003.

Fliedner TM, Friesecke I, Beyrer K, editors. Medical management of radiation accidents. 1st ed. Oxford: The British Institute of Radiology; 2001.

International Atomic Energy Agency. Safety reports series, No.2: Diagnosis and treatment of radiation injuries. Vienna: IAEA; 1998.

International Atomic Energy Agency. The radiological accident in Gioânia. Vienna: IAEA; 1988.

NATO NBC Working Group. AMedP-6(B) (Pt 1): NATO handbook on the medical aspects of NBC defensive operation – nuclear.

National Council on Radiation Protection and Measurements. NCRP report No. 138: Management of terrorist events involving radioactive material. Bethesda: NCRP; 2001.