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Mass Casualty Management For Radiological And Nuclear Incidents

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Introduction

Since the end of the Cold War, the risk of a strategic nuclear strike seems much less likely. However, the proliferation of 'weapons of mass destruction (WMD)' presents a new threat to both military and civilian populations. This change in threat was reflected in the New Chapter of the Strategic Defence Review. Examples of chemical and biological asymmetric actions have been seen in Tokyo and the US East Coast with the use of sarin and anthrax respectively. Concern about the proliferation of radiological material has been expressed both nationally and internationally. The use of nuclear and radiological devices on the battlefield and against troops conducting peace support operations remains a credible threat.

Chest radiograph	< 20μSv
Polar flight from UK to Japan	50-70μSv
Annual background dose	1-2mSv
IRR99 annual occupational limit	20mSv
Threshold for ARS	0.5-1Sv
LD50/60 (without supportive therapy)	3.5Sv
LD50/60 (with supportive therapy)	5-6Sv

Table 1. Example of radiation doses (sieverts).

The recent use of the term radiological (CBRN), in additional to the more traditional nuclear, biological and chemical (NBC) threats, may be a cause for confusion. It is important to have a clear understanding of how the terms radiological and nuclear are applied. A radiological incident in the most general terms refers to any incident where a hazard from ionising radiation (alpha, beta, gamma, X-ray and neutron) exists. For the purpose of this paper, a nuclear incident refers to a subgroup of radiological incidents that involves the fission process. This is important because the fission process (nuclear detonation or nuclear reactors) yields extremely high levels of radiation, which includes neutron radiation. Non-nuclear radiological incidents are likely to involve a single radioisotope, while nuclear incidents will produce over 300 fission products – a mixture of intermediate weight radioisotopes including strontium, caesium and iodine. Neutron radiation may exert its effects directly and indirectly. Neutrons will interact directly with human tissue causing damage to DNA or activate low molecular weight atoms (such as sodium) making them radioactive. The term nuclear material may be used to refer to fissile material (uranium and plutonium), fission products or spent reactor fuel rods.

In order the quantify the amount of potential damage sustained by ionising radiation, the SI units of grays (joules/kg) and sieverts are used to measure absorbed dose and radioactive dose equivalent respectively. The sievert for most types of radiation (beta, gamma, X-ray) is the same as the gray, but for more damaging radiations (alpha, neutron), the sievert is used to standardise the potential damage caused by ionising radiation based on type of radiation and dose. For example, an alpha particle is ten times more damaging than a beta particle for the same energy (1Gy = 10 Sv). Dose itself can be calculated as a product of dose rate (Sv/hour) and time (hour).

A range of radiations exposures is given in Table 1 to help illustrate the dose required to cause cell death and acute radiation syndrome (ARS). Low dose exposures, which lead to DNA damage and potential carcinogenesis, are important but will not effect immediate medical management after a radiological / nuclear incident.

Threats

The perceived threat from radiological and nuclear devices ranges from true weapons of mass destruction to weapons of mass disruption. Any device that results in a detectable increase in the levels of background radiation or causes contamination will cause a significant burden on health services, whether combined with trauma or not. The presence of a radiological hazard will require additional precautions for emergency responders that may reduce their effectiveness to provide medical assistance. Where high levels of radiation exist, acute radiation syndrome (ARS) should be suspected. Casualties exposed to both radiological and traumatic insult will have a greater mortality than those exposed

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to individual insults.

Current threats on the battlefield, during peace support operations and for civil defence include nuclear detonation, a direct attack on a nuclear installation, radiological dispersal devices (RDD), including 'dirty bombs', and sealed source irradiation (Figure 1).

Nuclear detonation

Nuclear weapons use weapons grade fissile material such as uranium and plutonium. On acquiring critical mass, a chain reaction occurs leading to a release of thermal energy, gamma and neutron radiation and fission products. The effect of a nuclear explosion is due to three mechanisms: blast, thermal and irradiation. The yield of the device depends on the amount and type of fissile material, effective detonation and enhancements. The yield may range from 0.01kt through to an order of megatons. A nuclear detonation will also cause a phenomenon known as an electromagnetic pulse. This release of energy has a specific effect on unshielded electronic devices rendering them useless. This has implications both for command and communications as well as for specific medical devices.

While a strategic strike may use high (megaton) yield devices, improvised devices are likely to be no more than 10kt. Incomplete fission may cause low yields (0.01kt) leading to significant levels of residual fissile material as well as fission products including iodine. The yield of the detonation is important for casualty predictions. Casualty modelling can be based upon the radius from point zero to the distance of 50% mortality (LD50). Below 10kt, significant levels of irradiation can be expected in survivors outside the conventional (blast/thermal) injuries limit. This is summarised in Table 2. At yields above 10kt, the lethal range of the fireball extends beyond the radii of blast or initial radiation. Low yield weapons, therefore, generate a greater range of casualties – contaminated, irradiated, blast, thermal and combined.

Attack on a nuclear installation

The devastation seen during the 911 attacks highlights the possibility of an attack on a nuclear installation. As well as power production, some nuclear reactors are used

Fig 1. Radiation and nuclear threats.

in research establishments. In general, reactors are well protected and shielded with inherent safeguards. However, a Chernobyl type event would produce a combination of contaminated, irradiated and traumatic casualties. Because such installations are generally isolated, immediate casualties are likely to be local employees and perhaps responders. Radiological hazards would include fission products and spent fuel rods. There may be a risk of prompt criticality leading to a high flux of neutrons. This is unlikely and very localised, but would cause significant dose rates and ARS.

Radiological dispersal device (RDD)

RDDs are devices used to disseminate radioactive material into a population. This release may be overt or covert. Overt releases are likely to involve the use of explosives, the so-called 'dirty bomb'. Radioactive materials may include radioisotopes (cobalt, caesium, iridium) used in medical diagnostics and therapeutics, industrial radiography and nuclear batteries. Nuclear material may also be used. The use of explosive dispersion will generate conventional casualties, including thermal and blast injuries. The radiological effects from an RDD depend on the amount of material, radioactivity and area of dispersal. The greater the blast and dispersal pattern, the less radioactive material will be present per surface area. High levels of irradiation (>2Sv) are unlikely but could be due to pieces of radioactive shrapnel. External, internal and wound contaminations are likely and could pose a threat to emergency responders. However, life saving interventions, such as needle thoracocentesis and haemorrhage

Table 2. LD50 Radii for Shock, Thermal and Irradiation.

YIELD	SHOCK WAVE	THERMAL RADIATION	IONISING RADIATION	
			INITIAL	RESIDUAL
0.01kt	60	60	250	1270
0.1kt	130	200	460	2750
1kt	275	610	790	5500
10kt	590	1800	1200	9600

control, should not be delayed by potential contamination. Overt releases are likely to have a concentric emergency response around the incident site with an inner and outer cordon.

Covert releases have been seen accidentally, an example being the release of Caesium-137 in the Brazilian town of Gioânia in 1985. This led to 249 people being internally or externally contaminated and irradiated, 20 requiring hospital admission and 4 deaths. The initial presentation of exposed casualties, with erythema and localised lesions, was mistaken for an allergic condition. A deliberate release may target a densely populated area, a point in the food chain or a drinking water source. Typical radioisotopes are likely to be in soluble salt or possibly gaseous form. A large number of acute radiation syndrome cases is unlikely, but low level contamination may have the potential to lead to long-term effects as well as associated anxiety after the discovery of the release. The health response for this type of release is likely to be modelled on the response to an epidemic with significant public health and primary care resource requirements.

Sealed source irradiation

Some radiological material may be in a form that presents no risk of contamination. These sources may be those used for medical therapy and industrial radiography. The dose rate from the source is a function of its radioactivity and mass. The greater the dose rate the higher the risk of detection en route and in situ. Cases of significant irradiation may be possible if the source is placed in an area where people may be near the source for a period of time; the absorbed dose being a product of dose rate and time.

A summary of the threat types is given in Table 3 below.

Incident Management

Whether conventional or CBRN, the emergency response should be generic. A major incident is an event that requires additional resources that are not routinely available. This applies to the healthcare response as well as to other emergency responders, including the military chain of command. The incident may be simple or compound depending on whether emergency responders are compromised by the incident. Responder compromise may occur in catastrophic events such as a nuclear detonation or where an asymmetric attack is directed against emergency responders or facilities (HQs and hospitals).

An incident may also be compensated and uncompensated depending on the scale of the incident and adequacy of the response. Where the incident is uncompensated, a review of the most efficient allocation of resources is required and for healthcare response the use of the expectant triage category may be used.

Any incident will require a structured approach, which should be similar to the Major Incident Medical Management and Support framework. This consists of:

- Command / Control / Communication
- Safety
- Assessment
- Triage / Treatment / Transport

Command / Control / Communication

A radiological / nuclear incident should not significantly alter the C3 elements of the emergency response. An uncompensated response may require difficult decisions with regard to resource allocation. The tasking and level of medical support will also depend on the overall operational picture. One specific aspect of a nuclear detonation, the EPM, may interfere with standard forms of communication and contingency plans should be in place for this eventuality. Any CBRN event will require a disciplined response. Immediate actions will include the control of the incident site with stringent access control, control of casualties and the directing of personnel and resources with the establishing of chains of command and communications.

Safety

The basics of radiological protection rely on three factors: time, distance and shielding. The safety of personnel both on and off scene must remain paramount. This is an important force protection issue and in the war-fighting scenario, the main effort will remain the priority. Where a CBRN attack was part of the threat assessment, a certain level of collective protection (ColPro) and individual protective equipment (IPE) will be available as a force protection measure as well as for use in medical support. In the absence of IPE, universal precautions including facemask and

Table 3. Summary of Radiological / Nuclear Threats.

THREAT	EMP	Casualties	Trauma (acute)	Contam	Radiation injury (>0.5Sv)	Iodine	Types of radiation	Example (a)ccidental/ (d)eliberate
Nuclear detonation (10kt)	Yes	$10_4 – 10_5$	Yes	Yes	Yes	Yes	α, β, γ, n	Hiroshima (d)
Attack on nuclear reactor	No	$0 – 10_2$	Yes	Yes	Yes	Yes	α, β, γ, (n)	Chernobyl (a)
Overt RDD (explosive)	No	$0 – 10_3$	Yes	Yes	Possible	If used	α, β, γ	-
Covert RDD	No	$0 – 10_2$	No	Yes	Unlikely	If used	α, β, γ	Gioânia (a)
Sealed source irradiation	No	Unknown	No	No	Possible	No	γ	Medical and industrial

surgical gown will provide protection from secondary contamination. **An irradiated casualty is not a hazard to emergency responders.** For example, a patient given radioiodine for thyroid ablation (internal contamination) remains a risk to the population while patients receiving radiotherapy (irradiation) are not.

A casualty from a RDD incident is unlikely to be a significant hazard to emergency responders in appropriate IPE/PPE, after the removal of any large fragments of radiological material. Where there is a high gamma dose rate any large fragments of radiological material should be removed using forceps and kept at a distance in a shielded container.

Significant hazards will exist immediately after a nuclear detonation. As well as fires and falling masonry, there will be very high residual radiation levels and contamination. This is due to fallout of fission products, residual fissile material and neutron-activated debris. Specific advice on expected dose rates and stay times and distances will be provided after an initial radiological survey and analysis.

The decision to exceed safe exposure limits either to provide medical support or to continue the mission will be a command decision based on the operational situation and health physics advice on dose rates.

Assessment

Initial medical assessment will concentrate on:

- Type of incident and hazard
- Numbers of casualties
- Risk of contamination and PPE requirements
- Casualty types
  - Conventional (penetrating / blast / burns)
  - Irradiation
  - Psychological
- Emergency response required on scene

Pre-hospital Triage (Role 1 / 2) and the generic approach to trauma and CBRN

Triage

Whether the incident has a conventional, CBRN or combined aetiology, the priority for the health response remains the appropriate use of limited resources for as many casualties as possible. Some form of triage will be required not only for the prioritisation of casualties for medical treatment and transportation, but also for decontamination. In the war fighting scenario, survivors and casualties may still have an operational role within the incident scene or area of responsibility. Triage should therefore be carried out as close to the point of 'wounding' as possible without compromising the safety of the responder. Since many scenarios are likely to involve trauma or cause a physiological disturbance, any triage system is likely to be modelled on either the "Triage Sieve" or "START" system. The triage categories used by NATO are:

- T1 (Red) – Immediate
- T2 (Yellow) – Urgent
- T3 (Green) – Delayed
- Dead
- (T4 – Expectant)

The traditional triage sieve prioritises casualties based on:

- Ambulatory
- Airway problem
- Breathing problem
- Circulatory problem

The generic CBRN system suggested in this paper adds an extra level to the triage assessment, based on:

- Signs of toxicity, in the case of radiation / nuclear
  - Dose of irradiation, using
  - Dose prediction or modelling (distance and shielding)
  - Personal dosimetry
  - Symptoms (prodromal – vomiting, diarrhoea, headache)
  - Signs (prodromal – erythema, CNS depression, pyrexia)
- For uncompensated responses, another assessment may be made for expectant cases.

Although prodromal signs and symptoms are quite sensitive, especially above 2Sv, they are not necessarily specific. This template can be used for all CBRN incidents but the triage tool in Figure 2, is specifically for radiological and nuclear events.

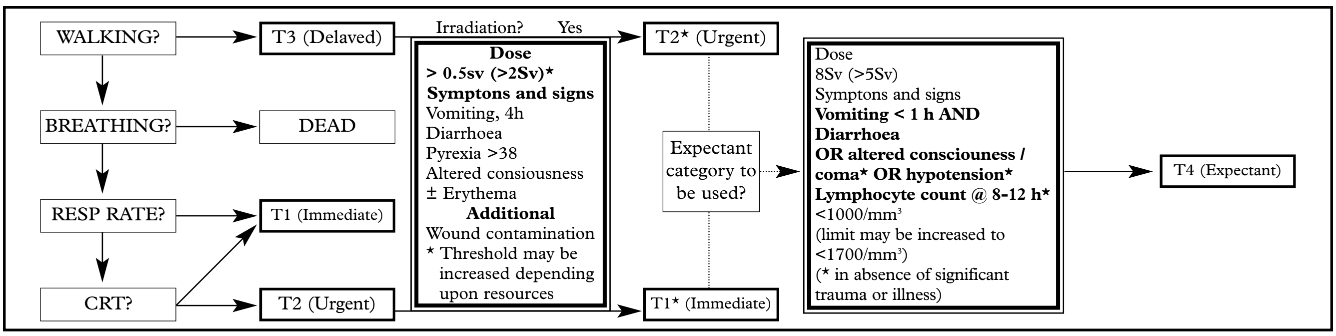

Figure 2. Modified triage sieve.

Contamination

The protection of emergency responders from secondary contamination and the prevention of further casualty irradiation and internal contamination will depend on timely and effective decontamination (Figure 3). The next assessment of a casualty should, therefore, be contamination. Casualties prioritised by triage should be prioritised for decontamination and later, where indicated, decorporation. Decorporation is the removal of internal radiological contamination by exploiting the radioisotope's chemical and biological properties. Examples include the use of stable iodine (potassium iodate) to block the uptake of radioiodine into the thyroid, Prussian Blue (a chelating agent) and urine alkalisation to increase the elimination of metals such as caesium and uranium respectively.

During decontamination, samples such as ear and nose swabs, should be taken to help quantify the risk of internal contamination. Further samples will include 24-hour urine collections and regular stool samples. The ability to provide this service to all casualties will depend on the resources available, although this screening can be provided retrospectively.

For severe cases, such as those triaged T1 (Immediate) and still contaminated, decontamination and primary survey can be simultaneous with the provision of life saving interventions.

Irradiation / Injuries (Primary Survey)

The next assessment of the casualty is for the effects of the specific insult. For radiological / nuclear incidents, this will either be irradiation or specific injuries (i.e. penetrating, burns, flash, and blast). This principle can be applied to all CBRN incidents (the four Is):

- Injuries (conventional)
- Irradiation (nuclear / radiological)
- Intoxication (chemical, including biotoxins)
- Infection (biological)

The primary survey used for trauma will provide an opportunity to look for any signs of ARS. In the first 24 hours these will only be prodromal symptoms and signs. For covert or delayed presentations, burns may be noticed and further questioning and examination may reveal symptoms and signs specific to the manifest syndromes associated with ARS (haematological, gastrointestinal, neurovascular). A number of classification systems for ARS have been suggested but during the early phase of the response (< 12 hours) a simple classification would be:

- ARS unlikely – no prodromal symptoms and < 0.5Sv
- ARS probable – mild prodromal symptoms and 0.5 – 2Sv
- ARS severe – consistent or severe prodromal symptoms >2Sv

Prophylaxis / Treatment

The final step in the generic CBRN approach is the assessment and administration of specific prophylactic agents and definitive treatment. Where there is a risk of exposure to radioiodine, stable iodine should be provided. Additional treatment during the initial response is the use of antiemetics. Current thinking suggests that 5-HT antagonists, such as ondansetron, may be the most effective. The release of histamine during the prodromal phase of ARS perhaps causing the erythema may indicate the need for an antihistamine with antiemetic properties as well. These interventions may be vital in the maintenance of operational effective during war fighting.

The generic approach to CBRN incidents (TCIP) can be memorised by the mnemonic – "To Come In Please" and is summarised in Figure 4.

Fig 3. US Navy wet / dry decontamination areas.

Figure 4. Generic approach to CBRN casualties.

	C	B	RN	Trauma
T *O*	**TRIAGE**			
C *OME*	**CONTAMINATION** / Contagious			
I *N*	Intoxication (Chemical)	Infection (Biological)	**Irradiation (Radiological / Nuclear)**	Injuries (Conventional)
P *LEASE*	**PROPHYLAXIS (AND TREATMENT)**			

Hospital triage (Role 2+/3)

Triage (secondary)

The principles of triage used in the pre-hospital environment can be used in the emergency department or receiving area of a Role 2+ / 3 unit. This secondary triage may be extended to include the triage sort using Glasgow coma score (GCS), respiratory rate and systolic blood pressure. Using the Triage Sort Score, casualties are prioritised (T1, T2 and T3).

Triage for radiological casualties can use additional facilities to help predict whole body dose and therefore modify the casualties' likely outcome and triage category. The primary triage uses symptoms seen within 4 hours. The next level of radiological triage is at 8-12 hours using a lymphocyte count; this is a relative fall if a previous sample has been taken or absolute count if not. At the same time, a sample should be taken for HLA tissue typing. The use of near patient testing (Coulter (FBC) counters) means that this facility may be located in the reception area and could be mobilised and taken forward to casualty clearing stations and holding areas. Triage within the hospital is therefore based upon:

- Triage sieve / sort
- Signs of irradiation
  - Dose of irradiation, using
  - Dose prediction or modelling (distance and shielding)
  - Personal dosimetry
  - Symptoms (prodromal) @ 4 hours
  - Fall in lymphocyte count @ 8-12 hours

A summary of triage criteria (expected prodromal symptoms and lymphocyte counts) is given in Table 4. At the 24-hour point more specific and sensitive bioassays can be taken. These cytogenetic assays take some time to process and although very sensitive have little to contribute during the first 24 hours. These tests may be useful for a tertiary level of triage for more advanced therapies, such as colony stimulating factors and bone marrow transplantation. Serial full blood counts should also be taken looking at the fall in lymphocytes, neutrophils and platelets.

The US Armed Forces Radiobiology Research Institute (AFRRI) has developed a Biodosimetry Assessment Tool (BAT). This is a PC based application that uses physical dosimetry, symptoms and signs, and cytogenics to provide an estimated dose and guide subsequent management.

Treatment

Treatment at role 2+/3 within the first 24 hours will reflect that at role 1 / 2. This is essentially supportive and symptomatic. Decorporation is likely to be started at this stage if there is a significant internal contamination hazard. Specialist advice and quantification of the hazard is likely to be required.

Definitive management of traumatic injuries will be required and there is no immediate alteration to standard practice during the immediate management. Radiation burns, including local irradiation and necrosis may require specific management, but a delay period to allow demarcation maybe required.

Triage for Surgery

The requirement for surgery in the presence of ARS does alter the management. ARS (> 2Sv) will over a period of time cause the casualty to experience bone marrow suppression leading to immunosuppression, coagulopathy and anaemia. Bacteraemia is also likely, due to the gastrointestinal manifestation of ARS. There is a window of opportunity within the first few days when surgery should be planned. The limitation of the window is that damage control surgery requiring further definitive surgery may not be an option. The use of internal fixation may also be contraindicated because of possible infection of metalwork by gut flora. Alternatives may include limited external fixation, traction and splintage. Casualties with injuries requiring surgery and potential ARS may take precedence over injuries in the absence of irradiation. This prioritisation may depend on available resources and likely prognosis.

An alternative to early surgery for injuries that are amenable would be to delay surgery until adequate treatment and recovery from ARS. This, however, will not be for weeks or months and so this option has only limited application.

The mortality of combined injuries is significantly worse than individual insults, such as trauma or irradiation alone. Outcome based on normal trauma data would also underestimate poor outcome. The use of an expectant category for these casualties may be appropriate especially where there are limited resources or a poor prognosis is expected.

The possible uses of the early and delayed surgery, and expectant categories is summarised in Table 4. The different levels of response are a reflection of the health requirements and resources, but remain arbitrary and for guidance only.

Burns

Burns, in the context of radiation injury, are associated with a poor prognosis. Once a burn exceeds a surface area of 50%, even in the absence of combined injury, a poor outcome is much more likely. When combined with radiation, prognosis will be significantly reduced. One suggested system of resource allocation uses the percentage burn and the radiation dose to determine which casualties would benefit most from the limited resources. This is shown in Figure 5.

Expectant (T4) casualties

The use of the expectant (T4) triage category reflects the optimisation of limited resources. This utilitarian approach aims to

Table 4 Summary of prodomal symptoms and triage.

	ARS degree and the approximate dose of acute whole body irradiation (Gy)					
	< Threshold (< 1 Gy)	Mild (1-2Gy)	Moderate (2-4Gy)	Severe (4-6Gy)	Very severe (6-8Gy)	Lethal (>8Gy)
RISK OF ARS	UNLIKELY	PROBABLE	SEVERE			
Vomiting – Onset		2 h after exposure or later	1-2 h after exposure	Earlier than 1 h after exposure	Earlier than 30 min after exposure	Earlier than 10 min after exposure
% of incidence		10-50	70-90	100	100	100
Diarrhoea		None	None	Mild	Heavy	Heavy
Onset		-	-	3-8 h	1-3 h	Within minutes or 1 h
% of incidence		-	-	< 10	> 10	Almost 100
Headache		Slight	Mild	Moderate	Severe	Severe
Onset		-	-	4-24 h	3-4 h	1-2 h
% of incidence		-	-	50	80	80-90
Consciousness		Unaffected	Unaffected	Unaffected	May be altered	Unconsciousness
Onset		-	-	-	-	Seconds/minutes
% of incidence		-	-	-	-	100 (at > 50Gy)
Body temperature		Normal	Increased	Fever	High fever	High fever
Onset		-	1-3 h	1-2 h	< 1 h	< 1 h
% of incidence		-	10-80	80-100	100	100

	< Threshold (< 1 Gy)	Mild to moderate (1 – 5 Gy)	Severe to very severe (5 – 9 Gy)	Lethal (> 10Gy)
Lymphocyte count @ 8-12 hours	Normal – 2500/mm³	1700 – 2500/mm³	1200 – 1700/mm³	<1000/mm³
		Relative fall of 50%		

	Surgical Triage Levels			
Compensated	SURGERY	EARLY SURGERY		EXPECTANT
Uncompensated	SURGERY	EARLY SURGERY	DELAYED	EXPECTANT
Catastrophic	SURGERY	DELAYED		EXPECTANT

Surgery – definitive surgical management for trauma only casualties
Early surgery – surgical management (within hours / days) taking precedence over trauma only casualties prior to ARS
Delayed surgery – surgical management delayed until after recovery from ARS (after weeks / months)

	Potential Expectant Triage Levels			
Compensated				EXPECTANT
Uncompensated			EXPECTANT	
Catastrophic		SUPPORTIVE	EXPECTANT	

CLASSIFICATION OF COMBINED INJURIES

Radiation (dose (Gy))		Burn (%BSA) I < 10%	II 10-30%	III >30%
I	< 2	Minor	Moderate	Major
II	2-4	Moderate	Moderate	Major
III	> 4	Major	Major	Major

Major also includes: any B(II), any R(II) with injuries requiring thoracotomy, laparotomy, craniotomy or major amputation

POTENTIAL TRIAGE

Where there are limited resources, these could be diverted to the treatment of moderate cases.
Minor cases should be treated as conventional burns, with appropriate radiation monitoring and follow-up for < 2Gy.

Reference: Kumar P, Jagetia GC. A review of triage and management of burns victims following a nuclear disaster. Burns. 1994; 20:397-402.

Fig 5. Classification of combined injuries (burns).

do the greatest good for the greatest number, saving resources where treatment is futile. This is a difficult decision to make and should be made at the most senior level of command available. The decision and its reasoning needs to be documented as this may be required for medico-legal purposes.

Expectant criteria associated with poor prognosis and a high level of whole body irradiation includes:

- **Dose**
  - 8Sv (limit may be reduced to 5Sv (LD50))
- **Symptoms**
  - Vomiting < 1 h AND
  - Diarrhoea
  - OR altered consciousness / coma*
  - OR hypotension*
- **Lymphocyte count @ 8-12 h**
  - <1000/mm3 (limit may be increased to <1700/mm3)*

  (* in absence of significant trauma or illness)

The lower section of Table 4 shows the association of the expectant category with prodromal symptoms and lymphocyte count.

Summary

The decisions required for the provision of an appropriate medical response to a radiological or nuclear incident range from the traditional major incident response through to a compromised response due to a catastrophic event. A summary of the most likely clinical findings in the first 12-24 hours is given in Table 4. From these findings, appropriate management based upon the needs and available resources can be planned. This includes triage for surgery and the use of the expectant (T4) triage category.

FURTHER READING

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