IAEA Post Graduate Educational Course in Radiation Protection and Safety of Radiation Sources

Intervention for Chronic and Emergency Exposure Situations

The Medical Management of Radiation Injuries



Psychological Effects

Lecture

Introduction I

- Importance of psychological impact of radiation accidents has been in the past underestimated
- Many people of different professions are involved in emergency preparedness and response to radiation emergencies. Being joined in the overall response organization they need to understand on one hand the basic philosophy and objectives of radiological protection of the general public and emergency workers, and on the other hand, the aim of the response activities implemented in an radiation emergency.
- Therefore, specialists of different professions should understand basic facts about ionising radiation and human behaviour in an emergency situation.

Introduction II

- Importance of psychological impact of radiation accidents has been in the past underestimated
- This lecture will
  - explain the nature and causes of psychological effects in radiation emergency
  - describe the symptoms of psychological stress caused by the accident
  - present elements for management of psychological consequences of the accident

Content I

- We will start the lecture with a short summary of possible medical consequences of radiation accidents.
- Then we will present psychological consequences and explain what are the symptoms of a stress caused by the accident.
- In the last part of the lecture we will cover the way to manage and minimize psychological effects of radiation accidents.
- We will conclude the lecture with a short summary of discussed subjects.

Content II

- Medical consequences of the radiation accidents
- Psychological consequences of radiation accidents
- What is psychological stress caused by the accident
- What can we do about stress
- Management of psychological effects
- Summary

Psycho-social Effects and Radiation Accidents I

- Psycho-social effects of an radiation accident can far outnumber any direct effects
- The wide spread public anxiety and pessimism in Chernobyl accident appeared to be out of all proportions to the eradiation induced health effects
- In accident management it is therefore necessary to take these effects into account

Psycho-social Effects and Radiation Accidents II

- Recent experience (Goiânia, Chernobyl, Tokai Mura) has shown that psycho-social effects of an accident can far outnumber any direct health effects.
- In accident management it is therefore necessary to take these effects into account.
- Public distress is a reality with direct relevance to policy makers.
- That was clearly seen in the case of the Chernobyl accident when the widespread public anxiety and pessimism appeared to be out of all proportion to the radiation induced health effects.

Psycho-social Effects and Radiation Accidents III

- In general, psychological reactions to radiological and nuclear accidents will be more or less similar, and sometimes independent on the scope and intensity of the accident.
- We may reasonably expect that the radiological accidents would in average be more confined, though out of usual locations than nuclear, and threat therefore not so massive, though more unexpected.
- Regarding their nature, radiological accidents may be recognized with delay, and people could either exaggerate the danger or underestimate or deny it.

Psycho-social Effects and Radiation Accidents IV

- Population is a community of individuals. Anxious and insecure individuals reject nuclear activities because they don't want to accept an additional risk in a society where there are already too many risks.
- On the contrary, other individuals, especially those with a scientific knowledge about nuclear matters, express more balanced judgment.
- Very often general public ask representatives of scientific community, and physicians in particular, about their attitude to the practices or events.
- Therefore, physicians should try to influence public perception of risk for nuclear activities using current knowledge on the subject.

Medical Consequences of Radiation Accidents

- Health effects directly related to radiation exposure
  - Deterministic
  - Stochastic
- Health effects indirectly related to radiation exposure
  - Caused by the accident per se
  - Caused by the intervention

Medical Consequences of Radiation Accidents

- Radiation accident may induce health effects in affected population. These are very often due not only to the radiation exposure but also to the societal disruption, economic disorganisation and environment impact, which are usually accompanying any radiation accident.
- Therefore, medical consequences of the radiation accidents could be classified into two categories: those directly related to the accidental exposure and those, which are indirectly caused by the accident.
- Deterministic and stochastic effects fall into the first category. Medical consequences, which could be caused indirectly by exposure, or by the intervention aimed to reduce/minimize exposure fall into the second category.

Health Effects Directly Related to Radiation Exposure I

- Not related to awareness of exposure or to subjective perception of risk
- Can be prevented or reduced by protective actions which minimise public exposure

Health Effects Directly Related to Radiation Exposure II

- Health effects directly related to radiation exposure may be limited in number (deterministic effects)
- and/or may be very numerous but spread out in time and will possibly never show up as a recognisable increase against the background (stochastic effects).
- Direct effects of exposure are not dependent on awareness or subjective perception of risk. They can be prevented or reduced only by effectively implemented protective actions.

Health Effects Indirectly Related to Radiation Exposure I

- Can far outnumber any direct effects
- Can affect hundreds of thousands
- Can last for many years
- Do not correlate well with actual exposure but with subjective perception of risk
- Protective actions to reduce exposure may be counterproductive with respect to such effects

Health Effects Indirectly Related to Radiation Exposure II

- On the other hand, health effects related indirectly to the exposure may be widespread both geographically and temporally and may affect a very large number of people, thus far outnumbering the direct radiation effects.
- Psychological effects in affected population are among the most important health consequences indirectly caused by the accident or intervention. Protective actions aimed to reduce exposure may even be counterproductive with respect to psychological effects.
- Experience has shown that this type of accident consequences must have serious negative effects on the mental health of affected population.

Why Do People Fear Ionising Radiation? I

- Unknown threat
- Can not be seen or felt
- Conflicting information in mass media
- Contradictory data from different "scientists"
- Use of "radiation theme" in economical and political discussions
- Long term consequences of radiation exposure
- Lack of education among general public, physicians and other professionals
- Social understanding of any situation involving the term "radiation" is negative

Why Do People Fear Ionising Radiation? II

- Discussion about psychological effects and their relative importance within the consequences of the accident should start from an answer to the question "Why do people fear ionising radiation?"
- First of all, in spite ionising radiation is well investigated, one may find contradictory information in the specific literature, literature for general public or mass media. Public consider physicians to be credible sources of information about health hazards.
- Unfortunately, there is no common approach to the understanding of radiation from general physicians. This fact influences public perception of radiation in every day life as well as in an accident.
- In accident situation, people are completely dependent on authorities to get information on their own exposure as radiation cannot be seen or felt in any way. On the other hand, it is regrettably likely that authorities will be mistrusted in the aftermath of an accident

Psychological Effects I

- Psychological effects include
  - Psychic suffering
  - Changes in risk perception
  - Modification in individual and social behavior

Psychological Effects II

- It is now generally agreed that radiation accidents have serious negative consequences to the mental health of affected population.
- Psychological effects include psychic suffering, changes in risk perception and modifications in individual and social behaviours.
- Psychic suffering can be simply the perception that one's psychic welfare has deteriorated, or it also can be more intensive change with medical symptoms and pathological conditions. All these different aspects damage health as defined by WHO: a state of well-being – mental, physical and social.

Psychological Effects (Cont'd) I

- Major accidents showed that affected people
  - Believe in the threat to their health
  - Doubt what has been reported about accident and resulted doses
  - Got modification in the life style
  - Have somatic complains
  - Got substance abuse (alcohol, tranquilizers, sleeping pills)

Psychological Effects (Cont'd) II

✓ From the studies performed after three major radiological accidents, i.e. TMI, Goiânia and Chernobyl accident, common reactions and psychological consequences can be summarised as follows:

a. individuals relate all their present health problems to radiation, although they either don't know the doses they were exposed or don't believe in the reported doses;
b. they live under the threat of possible delayed effects;
c. life style has been modified by changes in food consumption, substance abuse, the elimination of some activities and new habits induced;
d. somatic complains are reported;
e. individual coping mechanism include apathy, avoidance, depression, denial, information seeking, search for the culprit, etc.

✓ All these individual reactions were gradually pronounced and intense, depending on factors related to the accident as well as to affected individual.

The Severity of Psychological Reactions II

- The severity depends on:
  - Factors related to the accident:
    - suddenness, intensity, duration, available social support etc.
  - Factors related to individual:
    - past experience, personal loss, perception of threat, personal coping abilities etc.

The Severity of Psychological Reactions II

- Stress reactions to radiation accidents will be similar to people's reactions in other accidents. In general, they will depend on factors related to the accident itself and affected individual.
- First group of factors includes:
  - intensity and duration of the accident, which influences the length or prolongation of suffering,
  - the proportion of affected community, and
  - the nature of disaster.
- Second group of factors is individual related. Most of these factors are demographic (sex, age). Others are perceptual: perception of the accident, of it's health consequences, of the authorities' competence. Influencing factors may also include beliefs about everyday life and coping abilities. There are also sociological factors like the management of the situation by individual, by the community, affective support from family and relatives, the financial compensation for victims, etc.

The Severity of Psychological Reactions III

Second group of factors is individual related.

- Most of these factors are demographic (sex, age).
- Others are perceptual:
  - perception of the accident,
  - of it's health consequences,
  - of the authorities' competence.
- Influencing factors may also include beliefs about everyday life and coping abilities.
- There are also sociological factors
  - like the management of the situation by individual,
  - by the community,
  - affective support from family and relatives,
  - the financial compensation for victims, etc.

What Is Psychological Stress Caused by the Accident? I

- A normal reaction to abnormal event
- Unusually strong psychical and emotional reactions experienced in the face of an accident could interfere with one's ability to function during or after the event
- In some cases these reactions can turn into post traumatic stress disorder
- New diagnostic entity "chronic environmental stress disorder" has been proposed

What Is Psychological Stress Caused by the Accident? II

- In the aftermath of the Chernobyl accident, attempts have been made to allocate the prototypical public reaction to a diagnostic category.
- A general feature of affected people has been to see radiation as the causative agent of all ills. This reaction was, in the first years, generally labelled as 'radiofobia'.
- Radiofobia, however, is not a suitable term, because it implies that the fear of radiation is by itself a pathological reaction of the individual, while in reality it is a normal feeling resulting from conflicting information and lack of knowledge.
- Chronic fear leads to stress with secondary pathologies as a consequence.

What Is Psychological Stress Caused by the Accident? IV

- Parallels have been drawn to an established psychiatric entity named 'post-traumatic stress disorder'.
- This is a syndrome seen after catastrophic events like fire storms, earthquakes and severe road accidents, implying sudden, traumatic personal experience that provokes extreme emotional response.
- It is characterised by traumatic recalling, such as nightmares; avoidance of thoughts; and, at a later stage, arousal with irritability and difficulties of concentration.

What Is Psychological Stress Caused by the Accident? VI

- While in the Chernobyl accident, persons present at the accident site may have had this type of traumatic experience, this is not true for the general public.
- Instead, there was a slowly growing knowledge of a threat from an invisible agent that could neither be seen, felt or smelled, nor effectively avoided.
- Information in the beginning was scant and conflicting.
- Severe, chronic stress was provoked by the growing conviction that things were going seriously wrong with peoples' lives and the lives of their children.
- The true nature of the threat was poorly understood.
- The health effects were disputed, increasing uncertainty.

What Is Psychological Stress Caused by the Accident? VI

- From a psychological point of view, the situation can be compared with other accidents, involving chemical pollution of the environment, and even to other, less dramatic, real or perceived chronic environmental threats to health with diffuse origins.
- Symptoms and features reported from toxic waste disposal sites include headache, nausea, demoralisation, declining quality of life and distrust of authorities.
- On the basis of these experiences, a new diagnostic entity has been proposed, named "chronic environmental stress disorder".
- The principal characteristic of this reaction is, as it was seen after the Chernobyl accident,
  - apathy, asthenia, diminished interest and 'learned helplessness'.

Stress Reactions – Physical I

Physical

Early	Late
✓ Nausea	✓ Fatigue
✓ Muscle tremors	✓ Increased use of alcohol and drugs
✓ Sweating	✓ Exaggerated startle response
✓ Dizziness	✓ Sleep - related difficulties
✓ Chills	
✓ Increased heart rate	
✓ Increased blood pressure	
✓ Hyperventilation	

Stress Reactions – Physical II

- A psychological impact has many features, generally related to the notion of the stress. Stress corresponds to a permanent situation of biological, psychic and social maladjustment, which requires alertness, tension and energy on the part of the subject.
- This physiological reaction depends on how the person experiences the situation.
- If a person's well-being is harmed over a long period, then pathologies, including
  - generalized anxiety,
  - panic attacks
  - and depression may appear.

Stress Reactions – Physical III

- Any psychological stress has general health effects or reactions, which could be divided into three categories: physical, cognitive and emotional. They can appear in early stage of an accident or later.
- Symptoms of stress may mimic somatic disease.
  - Diffuse pain anywhere without any underlying organic disease may be due to stress.
- Stress can not only induce functional gastrointestinal disturbances but also overt organic disease like gastritis and peptic ulcer.
- Also, stress is believed to be a relevant factor in the aetiology of diseases like ulcerative colitis, hypertonia and ischemic heart disease.

Stress Reactions – Cognitive

Cognitive

- Early
  - Confusion
  - Difficulty making decisions
  - Impaired thinking
  - Difficulty problem solving
  - Memory loss
  - Calculation difficulties
  - Difficulty to remember names
- Late
  - Decreased attention span
  - Poor concentration
  - Memory problems
  - Flashbacks

Stress Reactions – Emotional

Emotional

- Early
  - Anxiety
  - Anger
  - Fear
  - Irritability
  - Guilt
  - Overwhelmed
  - Grief
  - Hopelessness
- Late
  - Feeling abandoned
  - Resentment
  - Feeling alienation
  - Withdrawal
  - Numbness
  - Depression

Psychological Problems Late

- Continuation of some early problems
- Concerns about the consequences of the exposure
- Discrimination from the other people
- Establishment of illness behavior

Changes in Health Behavior of Affected People

- Extensive medical examinations have further enhanced worries about current and future effects
- Change in illness behaviour and diagnostic behaviour together with vast screening programmes have lead to increase in number of diagnosed diseases in most organ systems

Psychological Stress of Injured Individuals

- Patient needs
  - Comfort, relief of symptoms
  - Stability and authoritative support
  - Information
  - Concern
  - Hope
  - Control
  - Stimulation
- Patient problems
  - Overly scientific approach
  - Repeated tests, examinations
  - Photographs
  - Reactions of others
  - Too many 'experts'
  - Too much media attention

Medical / Nursing Staff Problems

- Fear / anxiety
- Isolation by others
- Lack of knowledge (medical treatment, long term effects, etc.)
- New experiences:
  - Interactions with "experts," public officials, reporters, etc.
  - Loss of autonomy (activities may be monitored / managed by authorities)

What Can We Do About Stress?

- Accidents can not be predicted

  BUT
- Psychological reaction to the radiological accident could be

  prevented / decreased / relaxed

  using different methods applied

  before / during / after the accident

Management of Psychological Consequences

- To reduce the psychological consequences several measures are available
  - Medical response
  - Public health follow-up
  - Social assistance
  - Government actions guidelines
  - Community accountability

How to Reduce Psychological Effects

- Have an ongoing information programme
- Give clear, simple and timely advice
- Give consistent advice (one official point)
- Use international guidance
- Ensure protective actions are justified
- Correct false information
- Consider education and counselling

Warning of the Population

- Timely warning is one of the most important psychological aspects of dealing with the accidents
- Provide to the person a sense of control over the situation
- Call for the active attitude to the situation:
  - Searching process
  - Preparation for protective actions

Requirements for Warning Message

- Consistency
- Accurate, timely and complete
- Clear
- Simple
- Sufficient
- Concrete
- Provided through multiply channels
- Frequently repeated

Implications for Health Care Management

- Education is needed before, during and after an incident
- Debriefing sessions aid in relieving stress and anxiety of staff

Education about radiation health effects is urgently needed for health professionals to limit the public health problem of socio-psychological effects

Mitigation of Public Non-radiological Consequences

- One of the functional elements in IAEA-TECDOC-953
- Applicable for all planning categories
- Should be performed by facility, local or national level
  - Depending on the particular planning category

Non-radiological Impacts Long Term Protective Actions

- Effects on
  - Mental health
  - Economic conditions
  - Employment
  - Long term needs for social welfare

  and other non-radiological impacts caused by taking longer term protective actions should be considered

Non-radiological Impacts Capabilities

- Establish capability for addressing the public's concerns and reactions during an actual or perceived nuclear or radiological emergency
- Assure that affected people will perceive, understand, believe, personalize, and respond to the warning

Non-radiological Impacts Long Term Monitoring

- Before long-term monitoring or other activities are conducted in areas designed for unrestricted use after an accident, ensure the public understands the reasons for these continuing activities (e.g., scientific investigations of behavior of radioisotopes in the environment)

Non-radiological Impacts Compensations

- The process used to develop the system of compensation for emergency workers and the public following an emergency (radiation, chemical or other) should be established following careful consideration of the benefits and long-term social, psychological and economic effects

Summary

- The nature and causes of psychological effects in radiation emergencies were explained
- The symptoms of psychological stress caused by the accident were described
- Elements for management of psychological consequences were presented

Where to Get More Information

See references
on cover page of this lecture

Preparing for radiological incidence

- Preparing for radiological terrorism means planning in advance so as to act appropriately.
- In the event of a terrorist disaster, you and your facility will be required to carry out these "10 basics of response."

10 basics of response.I

1. Assure medical staff that when an incident combines radiation exposure with physical injury, initial actions must focus on treating the injuries and stabilizing the patient.
2. You or your hospital must be prepared to manage large numbers of frightened, concerned people who may overwhelm your treatment facility.
3. You or your hospital must have a plan for distinguishing between patients needing hospital care and those who can go to an off-site facility.
4. You or your hospital must know how to set up an area for treating radiation incident victims in an emergency room.
5. You or your hospital should be aware that a good way to approach decontaminating a radioactively contaminated individual is to act as if he or she had been contaminated with raw sewage.

10 basics of response. II

6. You or your hospital must know how to avoid spreading radioactive contamination by using a double sheet and stretcher method for transporting contaminated patients from the ambulance to the emergency treatment area.
7. You must know how to recognize and treat a patient who has been exposed to significant levels of radiation.
8. You should recognize the radiological findings of illness/injury caused by biological or chemical terrorist agents.
9. You should know what agencies or organizations to contact in the event of a radiation emergency and how to reach them.
10. You or your hospital must have a plan to evaluate and counsel noninjured patients exposed to radiation at a location outside of the hospital.

Treatment Modalities for Acute Radiation Exposure. I

Modality	dose, Gy	Effects	Treatments
Minimal	0.5-1	Vomiting	Antemetics e.g.,metoclopramide
Supportive	2.5	Hematopoietic syndrome Thrombocytopenia Leukocytopenia (Pancytopenia) Infection Severe internal bleeding (from thrombocytopenia)	Hospitalization Routine isolation No laminar flow Blood products (esp. platelets) Broad spectrum antobiotics Antifungals Antivirals Parenteral feedings
Intensive			

Treatment Modalities for Acute Radiation Exposure. II

Modality	dose, Gy	Effects	Treatments
Intensive	3-8	Gut endotoxins leak into gut Infection Bone marrow destruction	Hospitalization Broad spectrum antibiotics Septicemia
	7-8		Bone marrow transplantation Stem cell growth stimulators Hematopoietic growth factors (e.g., GM-CSF. GCSF)
		Pancytopenia Immuno-incompetence Severe internal bleeding (from thrombocytopenia)	Blood products (esp. platelets) Routine isolation Antifungals Antivirals Parenteral feedings
		Skin Burns	Burn treatments

Treatment Options for Victims of Acute Radiation Exposure I

Diagnoses	Suggested treatment
Nausea, vomiting	Diphenhydramine, 25-50 mg iv q4-6h Ondansetron 10 mg iv q4-6h Lorazepam 1-2 mg iv q4-6h
Apprehension	Nembutal 100 mg iv q8h Lorazepam 1-2 mg iv q4-6h
Fever	Acetominophen 650 mg po q4-6
GI Bleeding	Aluminum hydroxide/simethicon 30 ml q4h Famotidine 20 mg iv or po q12h Ranitidine 100 mg iv q12 or 150 mg po q12
Pain, cramps mucositis, GI inflammation	Morphine 5-10 mg iv or po q1h

Treatment Options for Victims of Acute Radiation Exposure II

Diagnoses	Suggested treatment
Pancytopenia	Blood component therapy Platelet, RBC transfusion Hematopoietic growth factors
GI sterilization	Gentamycin/vancomycin/nystatin bowel prep
Mucosal infection	Nystatin suspension Chlorhexidine washes Diluted H2O2 (peroxide) washes
Opportunistic infections	Reverse isolation Acyclovir 5-10 mg/kg/q8h iv Trimethoprim-sulfamethoxazole twice a week for PCP prophylaxis Fluconazole 200 mg po or iv q12 Amphophotericin
Bone marrow aplasia	Referral to transplant center

Pattern of Testing for Management of Acute Radiation Injury I

Initial examinations:
(Frequency: days 1, 2, and 3 post-exposure,
then 2 or 3 times a week depending on the clinical situation)

a. General physical examination
b. Past medical history
c. Complaints
d. Signs and symptoms
e. Presence of skin burns
f. Presence of GI disorders

Tests to perform daily:

a. CBC, blood count
b. Weight test
c. Guiaic (blood in excreta)
d. Attention to iv and po input and
e. urinary and GI output

Pattern of Testing for Management of A R Injury II

Tests to perform on days 1, 2, and 3 post-exposure, and 2 or 3 times a week depending on the clinical situation.

Laboratory Tests:

Hematology

Blood cell profile: WBC, RBC, HGB, HCT, MCV, MCH, MCHC, RDW-SD, PLT.

Blood Smear: Neutrophil, Lymphocyte, Monocyte, Eosinophil, Basophil.

Electrolyte profile: Na, K, Cl, CO2.

Chemistry profile :
BUN, Creatinine, Glucose, Uricacid, Cholesterol, Triglycerides, Calcium, Phosphorus, Total Albumin, Globulins, Total bilirubin, Alk phos, ALT / SGPT, AST / SGOT, LD

Thyroid function studies : T4-RIA

Biochemistry : PT - Prothrombine time (if clinically applicable), PTT - Partial thromboplastin time (if clinically applicable) Clotting time (if clinically applicable), Bone marrow aspiration (if clinically applicable), Chromosome (FISH)

Opthalmology: Slit lamp (6 months post exposure)

Local Skin Absorbed Doses [1]

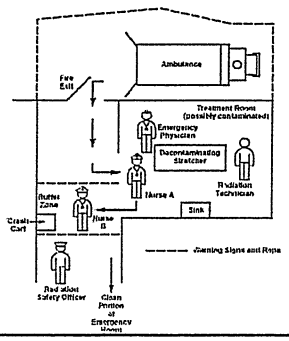
(adapted from Linnemann, 2001)

Condition	mrem	mSv	rem	Sv
Erythema	600,000	6,000	600	6
Dry Desquamation	1 million	10,000	1,000	10
Ulceration	2 million	20,000	2,000	20
Radiodermatitis	2.5 million	25,000	2,500	25
Epilation	300,000	3,000	300	3

[1] These dose-effect relationships are good approximations but can vary from individual to individual. They are energy dependent.

Epilation occurs 10 to 20 days post exposure.

Stylized Map of Radiation Emergency Room



Radiation Accident Hospital Response	
1. NOTIFICATION	• Number of patients • Type of injury/illness • Is the patient contaminated? • Staff/HEAP preparation
2. PATIENT ARRIVAL	• Medical report • Rad dosimetry report • Clean team transfer
3. TRIAGE / EVALUATION / TREATMENT	• Cut away clothing • Isolate contaminated area
4. DRY DECONTAMINATION	• Remove contaminated soil/ash from skin/cloth
5. RADIOLOGICAL ASSESSMENT	• Survey/document • Sample nares and contamination areas/blood
6. WET DECONTAMINATION	Priorities • Wounds • Hair • Skin Methods • Dilute • Wash • Rinse • Dry • Survey Repeat as necessary to reduce contamination level Dilute and wash contaminated
7. PATIENT EXIT	• Clean patient • Clean team transfer • Final survey at control line
8. STAFF EXIT	• Remove and contain non clothing • Survey at exit control
9. REA CLEAN UP	

Treatment of Radiation Exposed Patients at General Hospitals

Type of Exposure	Possible Consequences	Initial Laboratory Treatment at a General Hospital
External Exposure		
Localized exposure, most often to hands	Localized erythema with possible development of blisters, ulceration, and necrosis	Clinical observation and treatment Securing of medical advice if necessary
Total or partial body exposure, with minimal and delayed clinical signs	No clinical manifestation for 3 hours or more to lowest exposure Not life-threatening Minimal hematological changes	Clinical observation and symptomatic treatment Sequential hematological investigation
Total or partial body exposure, with early prodromal signs	Acute radiation syndrome of mild or severe degree depending on dose	Treatment as above plus securing of specialized treatment Full blood count and HLA typing before transfer to a specialized center
Total or partial body exposure, with thermal, chemical irradiation burns and/or trauma	Severe combined injuries, life-threatening	Treatment of life-threatening conditions Treatment as above and early transfer to a specialized center

External Contamination

Low-level contamination, intact skin that can be cleaned promptly	Unlikely, mild radiation burns	Decontamination of skin and monitoring
Low-level contamination, intact skin where cleaning is delayed	Radiation burns Percutaneous intake of radionuclides	Securing of specialist advice
Low-level contamination, with thermal, chemical, or radiation burns and/or trauma	Internal contamination	Securing of specialist advice
Extensive contamination, with associated wounds	Likely internal contamination	Securing of specialist advice
Extensive contamination, with thermal, chemical, or radiation burns and/or trauma	Severe combined injuries and internal contamination	First aid, plus treatment of life-threatening injuries; early transfer to a specialized center

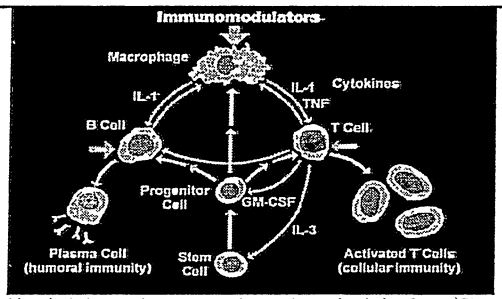
Internal Contamination

Inhalation and ingestion of radionuclides–insignificant quantity (activity)	No immediate consequences	Securing of specialist advice
Inhalation and ingestion of radionuclides–significant quantity(activity) of radionuclide	No immediate consequences	Nasopharyngeal lavage Early transfer to a specialized center to enhance excretion
Absorption through damaged skin (see under external contamination)	No immediate consequences	Securing of specialist advice
Major incorporation, with or without external total, or partial body, or localized irradiation, serious wounds and/or burns	Severe combined radiation injury	Treatment of life-threatening conditions and transfer to a specialized center

Acute Radiation Syndrome
casualty management

Management of life-threatening but potentially survivable radiation injury.

- The measures may be unnecessary either in a minimally injured patient or in one judged to be expectant.
- Simultaneously managing severe immune system compromise and resulting infectious complications,
- managing concurrent traumatic injuries and/or medical conditions, and preventing hemorrhage and severe anemia due to thrombocytopenia.
- potentially survivable radiation insult will not suffer life-threatening sequelae for at least 2 weeks after the exposure.
- Aggressive symptomatic control to include the liberal use of narcotics is reasonable.
- If the radiation accident/incident involved risk of internal contamination in addition to the external irradiation injury, health care providers should initiate appropriate evaluation and therapy for the specific contamination.



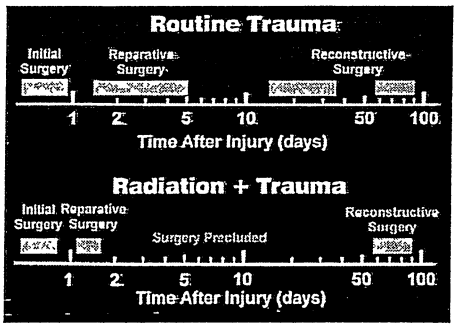
Cytokines include granulocyte-macrophage colony-stimulating factor (GM-CSF), macrophage colony-stimulating factor (M-CSF), granulocyte colony-stimulating factor (G-CSF), stem cell factor (SCF), and interleukin series (IL-1 - IL-16).

Shielding and recovery

As a general rule, cytokine therapy is sufficiently powerful to revive bone marrow function and to move the patient toward recovery.

- If a patient's bone marrow is completely depleted of stem cells, additional cytokine therapy would not be expected to have any effect.
- In this situation, the patient usually is assumed to have sustained a dose that will prove fatal due to gastrointestinal (GI) damage.

Timing of surgical management of combined injuries.



Timing of surgical management of combined injuries.

- Prevention and management of infections and sepsis is usually the pivotal issue in determining survival in someone injured with a potentially fatal dose of radiation.
- Infection prevention is enhanced by maximum avoidance of invasive procedures or central lines and catheters after the first 48 hours following exposure.
- Any break in skin, mucosal barrier, or indwelling line is a potential source of pathogens.
- Surgical procedures, particularly, are relatively contraindicated from 48 hours after exposure to the period of recovery from neutrophil nadir.
- Thus, any attempt at wound debridement or reconstruction should be initiated during the first 48 hours after exposure. This may alter the usual management plan during "classic" trauma cases when the plan frequently emphasizes delayed primary closure and multiple visits to the operating theater



- Initial surgical management . Compared with practices in "classic" trauma cases, radiation injury management may necessitate, more aggressive initial debridement and the use of amputation, cultured skin for grafting, and tissue flaps.
- The goal of this initial surgical management is to minimize open wounds that may serve as a subsequent source of infection.



Burns and open wounds .

Burns and any open wounds must be carefully dressed with topical antibiotics to minimize colonization.
Nosocomial infection risk . Nosocomial infections can be a disaster in radiation casualty cases. To minimize the risk, casulaties should be managed as outpatients as much as feasible during the latent period of the acute radiation syndrome.

Nosocomial infection risk

- If granulocyte nadir is imminent, the scene should switch to full reverse isolation, if available.
- Nursing and infection control personnel should be forewarned of the need for rigorous environmental control to include the following measures:
  a. Laminar flow isolation
  b. Strict hand washing before and after patient care
  c. Surgical scrubs for the staff
  d. Gowns, caps, gloves, masks for the staff
  e. Double-bagging of all disposables

Neutropenic fever therapy

- While the irradiated patient is at severe risk of sepsis, antimicrobial measures can significantly and favorably alter the clinical course.
- Any neutropenic fever should be meticulously evaluated and, unless a specific pathogen is identified, empiric triple antibiotic therapy should be initiated.
- Empiric and/or specific therapy should be maintained until granulocytes exceed 800/mm3. If antibiotics fail to control the fever, or if specific fungal or viral pathogens are suspected on clinical grounds, aggressive use of antifungal and antiviral agents should be considered.

Neutropenic fever therapy

Neutropenic fever therapy consists of the following steps:

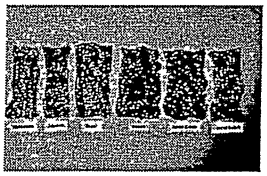
- Survey for possible source, pancultures
- Administer antibiotics for absolute neutrophil count (ANC) <500/mm3
- Use broad spectrum antibiotic coverage
- Add amphotericin for prolonged fever lasting 5 to 7 days after starting standard antibiotics
  Continue antibiotics for duration of ANC <1000
- Broad spectrum antibiotic coverage includes double beta-lactam antibiotics such as a third-generation cephalosporin and ureidopenicillin, monotherapy with imipenem or a third-generation cephalosporin, and vancomycin plus a third-generation cephalosporin.

Gut decontamination

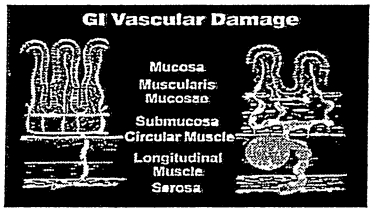
- In a situation of severe immunocompromise, as with acute radiation syndrome, a significant source of infection may be pathogenic bacteria that normally inhabit the human colon.
- The pathophysiologic changes that occur during radiation injury, combined with use of antibiotic therapy, significantly alter the normal gut flora and cause many gastrointestinal (GI) pathogens to gain access to the patient's circulation.
- Early selective decontamination of the gut using poorly absorbable oral antibiotics.
- , Ciprofloxacin, Polymixin B, and Trimethoprim-Sulfamethoxizole preparations or other sulfa-based oral medications

- Prophylaxis against fungal, viral, and *Pneumocystis c.*.
- Diflucan has been shown to be of symptomatic benefit in radiotherapy patients, and the use of acyclovir is known to be of use as a prophylactic agent with other immunocompromised patients.
- Efficacy has been shown for Fluconazole at 400 mg/day intravenously or peritoneally. Older agents -- amphotericin, ketoconazole, and nystatin -- have a long history of failure to prevent infection.
- Immunoglobulins . Immunoglobulins have been used in the past with no obvious benefit. But because of no apparent risk, their use is neither recommended nor discouraged.
- Use of glucocorticoid steroids is discouraged as they have obvious immune-suppressing side effects that further worsen the effects of the radiation injury.

Nutrition



The gastrointestinal tract is especially vulnerable to radiation injury. The radiation-injured patient requires careful attention to nutritional needs as his system is placed under extreme stress during periods of manifest illness. Nutritional compromise only exacerbates immune insult

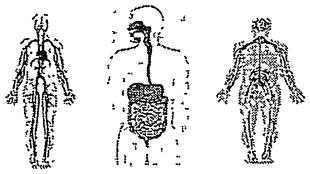


- Gastrointestinal damage. The physician managing a radiation-injured patient must respect the increased nutritional and metabolic stress of the patient while, to minimize the mechanical injury to the bowel mucosa and to hasten mucosal repair.
- To this end, a normal full diet may not be in the patient's best interest.
- Rather, an elemental diet, which is available in a variety of commercial preparations, seems to be preferable.

Acute Radiation Syndrome : casualty management summary

- Review points
- Cytokine therapy is a powerful tool in treating patients who have life-threatening but survivable radiation injury.
- Peripheral stem cell transfusion and bone marrow transplant should be reserved for patients who have a potentially survivable insult but whose bone marrow does not respond to cytokines.
- Because aggressive control of infectious agents is necessary, employ selective gut decontamination, prompt therapy of neutropenic fever, prophylactic antiviral and antifungal agents, and stringent nursing environmental control.
- Surgical procedures are precluded from 48 hours after radiation exposure to when the recovery phase is initiated.
- Aggressive fluid, blood product, and symptomatic therapies are indicated.

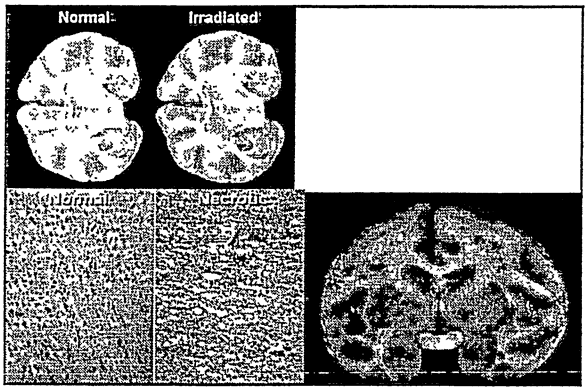
Radiation syndromes



- Clinically and pathologically, radiation injury has traditionally been divided into the broad categories of the hematopoietic, gastrointestinal, and central nervous system (CNS) syndromes.
- can be misleading oversimplifications since no one syndrome occurs in isolation. Rather, the syndromes interact and affect one another in a complex manner.

Central nervous system

- Evidence of the central nervous system (CNS) syndrome generally appear after exposure to radiation in the tens of gray.
- Once the CNS symptoms develop, death occurs before the appearance of lesions from either the hematopoietic syndrome or the gastrointestinal syndrome.
- Clinically, signs of the hematopoietic syndrome develop after doses of 2.5 to 5 Gy and signs of the gastrointestinal syndrome after doses of 8 to 12 Gy.

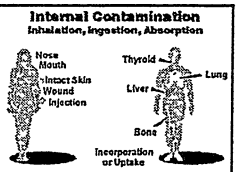


Radionuclide Contamination : Risk

- The probability of external and internal radioactive contamination has increased with the use of radionuclides in research projects, medical applications, nuclear power generation, and industrial processes.
- Among the hundreds of recorded accidents with significant radioactive contamination were those in Chernobyl in 1986 and Goiania in 1987. Each of the accidents resulted in many victims who required internal and external decontamination.
- More recent examples of internal radioactive contamination occurred with phosphorus-32 at the National Institutes of Health and at the Massachusetts Institute of Technology with the accidental ingestion of phosphorus-32.

Radionuclide Contamination

- Review points
- Contaminant internalization consists of intake, distribution, and metabolism.
- Intake routes are inhalation, ingestion, wound contamination, and skin absorption.
- Inhalation is the primary intake route.
- Absorption depends on the contaminant's chemical characteristics and solubility.
- Ingested insoluble radionuclides expose the gastrointestinal tract to radiation as they transit.
- Contaminant absorption through abrasions, lacerations, and punctures depends on the substance's solubility, pH, tissue reactivity, and particle size.
- After absorption, distribution, and uptake, a radionuclide is excreted in its original state or as a metabolite.
- Primary excretion routes are urinary tract, liver, and lungs



Distribution

Once a radionuclide is absorbed, it crosses capillary membranes, through passive and active diffusion mechanisms, and then is distributed throughout the body.

The rate of distribution to each organ is relative to the blood flow through the organ, the ease of chemical transport across cell barriers, and the affinity of the radionuclide for naturally occurring chemicals within the organ.

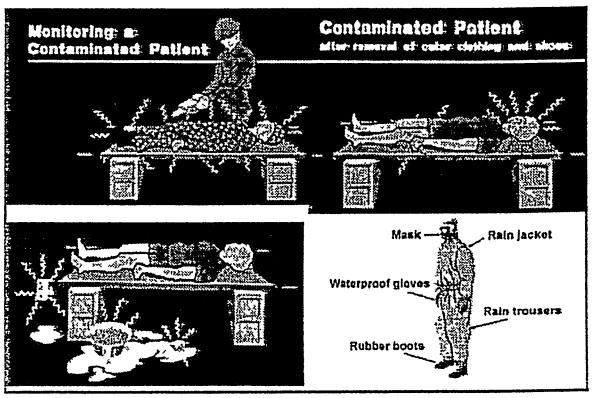
The liver, kidney, adipose tissue, and bone have relatively high capacities for binding chemicals because they are high in proteins and lipids

Radionuclide Contamination : Patient management I

- Attend to life-threatening injuries and conditions first.
- Then, evaluate skin and clothing contamination.
- If external contamination is detected, internal contamination is highly likely.
- The initial evaluation for victim/patient contamination includes a history of the accident, initial area and patient surveys, and nasal swipes of the victim.
- Early recognition of internal contamination provides the greatest opportunity for contaminant removal and reduces the potential for injury.

Radionuclide Contamination : Patient management II

- Minimize the risk of caretaker exposure by following decontamination principles similar to those for biological and chemical agents.
- If circumstances allow, caretakers should have protective clothing before coming into contact with contamination.
- Protective clothing consists of gloves, overshoes, and a plastic apron. Surgical gowns are acceptable.
- Contain irrigation fluid in holding tanks
- Bag contaminated clothing and medical supplies and give them to radiation safety personnel.

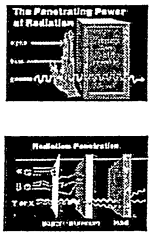


Radionuclide Contamination : Patient management III

- Estimated doses of up to 0.05 cGy have been assigned to U.S. medical personnel who have cared for radiation victims.
- The highest actual dose recorded for a U.S. health care worker was 0.014 cGy, which occurred during the care of a radiation accident victim of a commercial nuclear power plant accident.
- That dose approximates the dose received during a single chest radiograph.

External contamination treatment I

- Use beta-gamma and alpha monitoring instruments for the initial radiation survey of the skin and clothing.
- If contamination is present on the clothing, remove it and repeat the monitoring over the patient's skin.
- Contaminants may be held to the surface of the skin by electrostatic forces, surface tension, or binding with skin proteins.

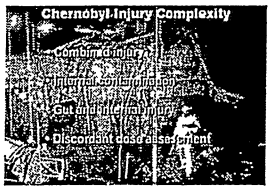


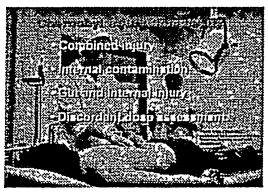
External contamination treatment

Depth of the skin is important relative to type of radiation.

- Alpha rays on the skin surface do not reach the basal cell layer of the epidermis.
- Beta rays are reduced by a factor of 2 by 1 millimeter of skin. Skin on most areas of the body has a depth of 2 millimeters. The epidermis is approximately 0.1 millimeter in depth except over areas of external friction. Those areas include the palms, digits, and soles of the feet where the thickness of the stratum corneum can reach 1.4 millimeters.
- Health physicists estimate the skin radiation dose at the basal epithelium, which lies adjacent to the small blood vessels of the dermis, which can be affected by beta and gamma rays.

Injury Complexity





Skin decontamination

- Skin decontamination should be undertaken to decrease the risk of skin beta burns, to lower the risk of internal contamination of the patient, and to reduce the potential of contaminating caretakers and the environment.
- Remove patient's clothes.,
- Washing the patient with detergent and water is 95 percent effective.
- Soap and detergents emulsify and dissolve contamination.
- Gentle brushing or the use of an abrasive soap or abrasive granules dislodge some contamination physically held by skin protein or removes a portion of the horny layer of the skin.
- Addition of a chelating agent helps by binding the contaminant in a complex as it is freed from the skin.
- Keep in mind that the stratum corneum of the epithelium is replaced every 12-15 days. Thus, contamination that is not removed and is not absorbed by the body will be sloughed within a few days.

Decontamination techniques . For skin and wound decontamination, use a cleaning solution. I

- Soap and water or normal saline
- Betadine and water
- Phisoderm and water
- Hydrogen peroxide
- Dakin solution (0.25 percent sodium hypochlorite)
- Avoid further damage to the skin; cease washing before abrasion occurs.
- A detector count of less than 1 millirem per hour beta and less than 1,000 disintegration's per minute alpha are safe decontamination end points.
- For wound decontamination, use copious irrigation with the same detergents as for intact skin and surgical debridement

Decontamination techniques . For skin and wound decontamination, use a cleaning solution. II

- For stubborn hand and distal extremity skin contamination that is not removed by washing, wrap the contaminated area and, over time, sweating will decrease contamination.
- To decontaminate hair, use any commercial shampoo without conditioner.
- Conditioners bind material to hair protein, making contamination removal more difficult.
- Consider clipping or shaving hair to remove alpha contaminants. Do not remove eyebrows without significant cause since they grow back slowly if at all.

Internal contamination treatment

Once a contaminant is absorbed, inhaled, or ingested, it is important

- to decrease the uptake into the circulatory system,
- to decrease the deposition in critical organs,
- to increase the excretory rate of the contaminant.

- A number of procedures are available for respiratory contamination and gastrointestinal contamination

Treatment agents

- Prussian blue . Prussian or Berlin blue is ferric ferrocyanide. This chemical is not absorbed by the gastrointestinal (GI) tract and works through two modes of action. It decreases the absorption of many radionuclides from the GI tract and removes some radionuclides from the capillary bed surrounding the intestine and prevents their reabsorption.
- In Brazil, following the release of cesium-137 from a medical radiation source, Prussian blue was used to treat contaminated human victims. Cesium-137 is easily absorbed by the body through ingestion, inhalation, and skin penetration. Its physical half-life is 30 years, and its biologic half-life is 100 days. It emits beta and penetrating gamma radiation, and it is distributed uniformly throughout the body. Prussian blue decreases the biological half-life of cesium-137 to 30 percent of the original 100 days

Treatment agents: Blocking/diluting agents

- Blocking and diluting agents work by preventing the uptake of a radionuclide in a critical organ or by overwhelming the critical organ with stable compounds that reduce the uptake and incorporation of the radionuclide.
- Potassium iodide is an excellent example of a blocking agent. If given within 30 minutes of exposure to iodine-131, potassium iodide prevents the uptake of iodine-131 by the thyroid gland. If given within the first 6 hours, the blocking effectiveness is 50 percent. At 24 hours, its blocking effect is zero.
- Stable strontium in the form of strontium lactate, given by mouth in doses of 500 to 1,500 milligrams daily for several weeks decreases strontium-85 and strontium-90 uptake in bone and testes.
- Water (3 to 4 liters peritoneally) increases tritium urine concentration

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Treatment agents: Chelation agents

- Chelators are mobilizing agents; they enhance the elimination of metals from critical organs.
- Chelators are organic compounds (ligands) that exchange less firmly bonded ions for metal ions. The stable complex, chelator and metal, is then excreted by the kidney.
- New chelators, including DMSA (meso-2,3,-dimercaptosurrinic acid) for lead toxicity and DMPS (2,3 dimercapto-1-propanesulfonic acid) for mercury toxicity, have not been used for metals, including plutonium and americium.
- Sodium bicarbonate has been used to treat uranium contamination.

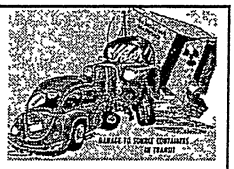
Radionuclide Contamination : Patient management summary

- Attend to life-threatening injuries first, then perform external decontamination, following standard decontamination principles.
- Skin decontamination decreases the risk of skin beta burns, lowers the risk of internal contamination of the patient, and reduces the chance of further contamination.
- Skin and wounds are decontaminated by washing with cleaning solutions but not to the extent that the skin is further damaged or abraded.
- The goal of internal contamination treatment is to decrease the uptake into the circulatory system, decrease the deposition in critical organs, and increase the excretory rate of the contaminant.
- Gastrointestinal contamination, which is more easily treated than respiratory contamination, may require stomach lavage, emetics, laxatives, or adsorbents.

Radionuclide Contamination : Patient management summary

- Health physicists and medical specialists can advise on the risks and benefits of removing contaminants.
- Prussian blue, an effective means of reducing the body's uptake of cesium, thallium, and rubidium from the gastrointestinal tract, is an investigational new drug.
- Blocking and diluting agents prevent the uptake of a radionuclide in a critical organ or overwhelm the critical organ with stable compounds that reduce the uptake and incorporation of the radionuclide.
- Mobilizing agents increase the metabolic rate of internal contaminants and thereby increase elimination.
- Chelating agents enhance the elimination of metals from critical organs.

Accidents/terrorism

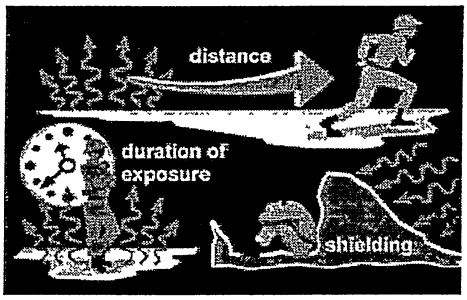


Accidents and terrorist use of radiation dispersal weapons also cause combined injury although it occurs in a less predictable distribution.

Persons injured by radiation may receive physical trauma before or after the exposure.

In a vehicle accident, the casualties receive deceleration injuries and lacerations; then they may be irradiated and/or contaminated.

Their level of irradiation injury depends on the activity of the nuclides involved and the standard protectors: time, distance, and shielding.



First Actions FIRST!

- **Standard emergency medical procedures**
  - **Ventilation**
  - **Perfusion**
  - **Stop hemorrhage**
- **Decontamination after stabilization**
- ***Survivable radiation injury is NOT acutely life threatening***

Emergency resuscitation takes precedence over any radiation injury.
A radiation injury so severe as to cause acute neurological symptoms is not survivable.
Other causes of morbidity and mortality are much more devastating then most radiation injuries.
Control of hemorrhage is highly important in the radiological casualty, as hematopoietic injury will be commonplace and the patient will have difficulty replenishing the lost blood

Combined Injury and Infectious Disease : Emergency procedures

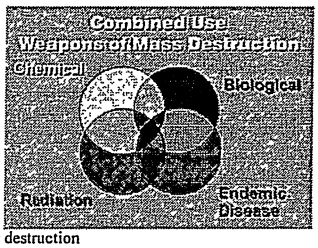
Decontamination

- After being stablilized, the patient can be decontaminated of external and internal radionuclides.
- It is very difficult for a patient to be so contaminated as to present a direct irradiation hazard to health care providers.
- Any such patient would have already received a severe irradiation injury due to conditions of time, distance, and shielding.

Combined Injury and Infectious Disease : Emergency procedures

Assessment

- Once decontamination is complete, the patient is "clean" and subsequent medical care should be rendered concomitantly with appropriate evaluation of the radiological injury.
- Obviously, if decontamination must take place in a primary treatment area, every reasonable effort must be made to control effluents and subsequent long-term contamination of the facility.



Weapons of mass destruction
All potential adversaries who have the capability of creating a nuclear device also have the capability of using chemical and biological agents.
Endemic disease also plays a role in any region where these devices are used.
Very little knowledge is available on the combined effects of these agents, particularly in regard to radiation

MEMR

Medical Effects of Ionizing Radiation

Lesson objectives

Understand the nuclear threat.

Anticipate likely injuries.

Understand how to treat radiation exposure and contamination.



The threat in 1987

In 1987, there were two basic scenarios for a nuclear blast.

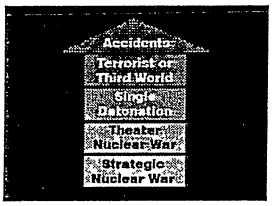
- Limited use of tactical nuclear weapons on a European battlefield
- General exchange of large-yield thermonuclear weapons

Medical response then

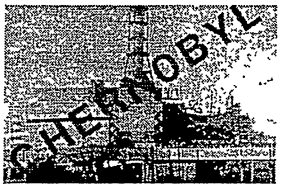
The victims of classical trauma in the limited tactical nuclear weapons scenario would probably have consumed all available medical resources. Nuclear radiation casualties would have lived or died, depending on the dose received.

Radiation victims of a general exchange of large-yield thermonuclear weapons would have been regulated to the end of the line. Casualties would have been treated with whatever was available after the massive destruction of cities and the medical infrastructure.

The threat today: Accidents



Nuclear accidents involving medical or industrial nuclear material are the most likely threat today, followed by terrorism, a single nuclear detonation, and then nuclear war scenarios.

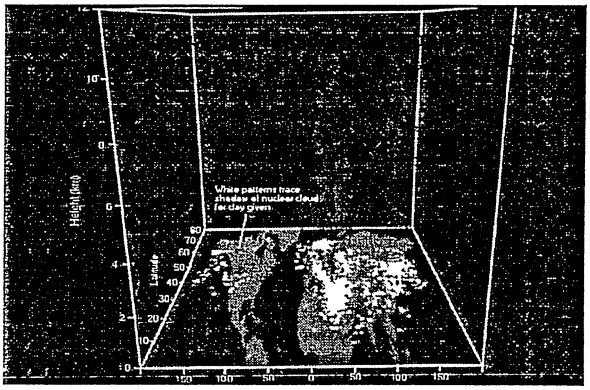


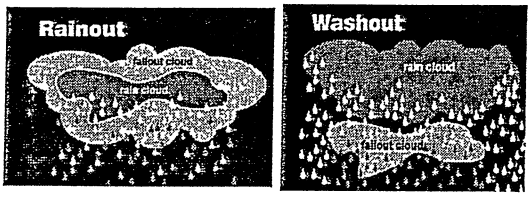
In Russia, the nuclear reactor explosion in Chernobyl in 1986 was, a disaster as is the contamination of the Technya River basin.

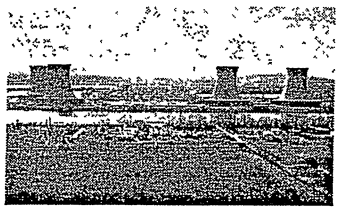
In addition, the Russian navy has a host of deteriorating submarine reactors.





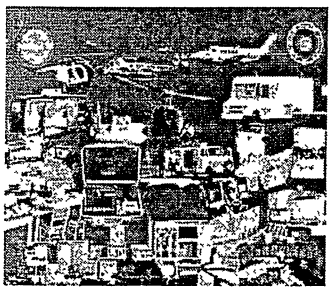






Three Mile Island nuclear reactor

In the United States, we are more at risk from the vast amount of medical and commercial nuclear material than from events like the Three Mile Island incident on March 28, 1979. Although the event was covered extensively by the media, the amount of radionuclides released was actually very small and the safety measures in place to halt the meltdown worked.



Modern technology makes all kinds of materials available,

for instance,

to a terrorist for a fuel oil/fertilizer truck bomb.



The bogeyman factor

Radiation is as feared as leprosy in biblical times, the plague in the Middle Ages, and HIV positive hemophiliac children in the 1980s.

Fear -- on the part of patients and health care providers -- is one of the biggest problems in radiation casualty situations.

Accurate information about radiation exposure, injury, and treatment will enable medical care providers to respond appropriately to radiation casualties.

Review points

- Fear and avoidance was the typical medical response to radiation casualties in the late 1980s.
- The most likely nuclear threats today are from accidents and terrorists.
- Information and training will enable medical professionals to deal with the fear of radiation.

Other incidents

The greater risk is from incidents like that in March 1996 when 21 Texans were exposed to up to 0.3 Gy of radiation from an abandoned and then stolen cobalt-60 industrial unit.

In Brazil, a medical radiocesium unit was dismantled, exposing 21 people, 3 of whom died.

In other incidents, radiation detectors went off when a truck loaded with steel happened to enter a monitored nuclear facility.

A junk dealer had sold an old cobalt-60 radiotherapy machine as scrap metal, which was made into good, but radioactive, cobalt steel.

Potential Nuclear Incidents

Detonation
- Improvised nuclear device
- Commercial military weapon

Radiation dispersal weapon

Point source contamination

- A nuclear detonation requires weapons grade materials and the right equipment to assemble a bomb.
- But a nuclear hazard does not require a nuclear explosion.
- Radioactive materials common in a factory or hospital would be scattered as the result of a conventional explosion.
- Or an unsuspected source of radiation could expose a large number of people.



The materials to make a bomb are available. Fortunately, 90% of people arrested for selling nuclear material are con artists selling low-quality goods. The other 10%, however, have access to the real thing.

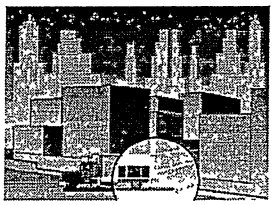
Keeping equipment out of the hands of would-be bomb manufacturers is part of. government's antiproliferation strategy. The export of dual-use technology is closely monitored.



The first nuclear weapons built with 1945 technology, such as the Nagasaki "fat man," were large and unwieldy. Such a weapon weighed as much as 10,000 pounds.

Today, unlike early nuclear weapons, an efficient, commercially built 1-kiloton bomb could fit in a backpack and lends itself to use by a terrorist or terrorist group that seeks to carry out a single detonation in an area likely to have plenty of television coverage.

In this scenario, the surrounding medical communities will remain intact and medical professionals will be expected to provide First World tertiary care. The battlefield paradigm of triage and treat only the ones capable of survival on their own will not apply.



Explosives may be planted near a factory or hospital that uses significant amounts of radioactive material. Or radioactive material that is removed from such a site can be packed in the back of a truck with fertilizer and diesel fuel.

Wide scatter dissemination

Many communities have factories and hospitals with significant amounts of radioactive material. Anyone trapped inside a target structure and their rescuers will be internally and externally contaminated although there will be no initial high-energy radiation and no fallout of fission products.

An explosion near a nuclear medicine facility's cobalt-60 source. :

- ✓ Will spread the radioactive material throughout the rubble of the target structure.
- ✓ There will be conventional blast and burn injuries as well as exposure to radiation from the contaminants.
- ✓ Therefore, every fire fighter, rescuer, and immediate victim will be exposed to a continuous radiation field.



Immediate victims and their rescuers are subject to internal and external contamination from ionizing radiation.

Internal contamination

If the radioactive material is an alpha emitter, such as plutonium, then the prime danger will be
inhalation and
ingestion of dust.

The immediate victims and bystander rescuers will almost certainly inhale a significant quantity of the nuclide long before they know they are exposed.

Internal contamination means continuous exposure to the organs until the radionuclide is eliminated from the body or undergoes complete decay.

External contamination

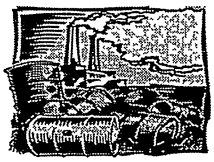
External contamination will occur when radioactive particles accumulate on the surface of skin and clothes.

Although such particles are usually alpha - beta emitters, they can cause substantial local injury if not washed off.

Decontamination procedures,
which are 95% effective, are simple.

a. Remove patient's clothing.

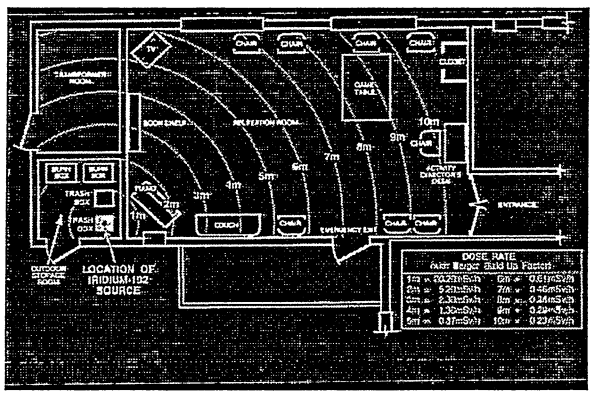
b. Wash patient with soap and water.



Ground water contamination may occur from illegal dumping of radioactive materials.

Low scatter dissemination

Irradiation occurs in the presence of a source active enough to emit a sufficient quantity of neutrons or gamma rays from, for instance, a cobalt therapy device or an extremely high level of ground contamination.



Protracted exposure

Individuals exposed to significant radiation doses over a protracted period of time would not be radioactive but would suffer from acute radiation syndrome. Hospitals and clinics would note a substantial number of patients with acute gastroenteritis and no lymphocytes.

Individuals exposed to only 0.5 to 1 Gy (Gray) might be relatively asymptomatic; but over a period of a few weeks, a large percentage would develop endemic diseases. We know that, at this exposure level, the bacterial pathogen minimum infective dose decreases by at least one order of magnitude in rodents.

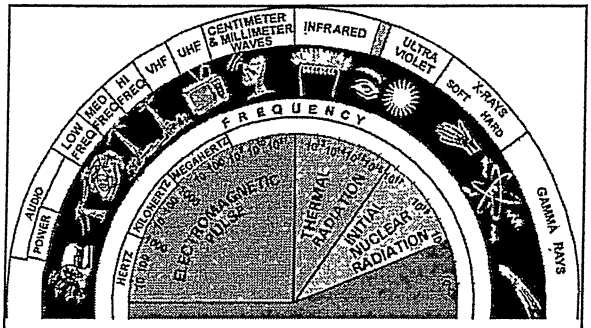
Hazards summary

a. A radiation hazard does not require a nuclear detonation; radiation exposure may occur as a result of a conventional explosion involving industrial and medical radiation sources.

b. Modern nuclear weapons are small enough to be easily concealed.

c. The immediate victims of a radiation accident will suffer internal and external contamination.

d. Acute radiation syndrome results from exposure over an extended period of time.



Electromagnetic spectrum.

Physical principles of ionizing radiation I

Nuclear energy is generated from a change in binding energy within the nucleus.

A thermonuclear fission-fusion device releases more energy than a pure fission device.

Only 15% of energy released in a nuclear explosion is in the form of radiation; 85% is as heat and blast.

While heat and blast are the same forms of energy regardless of the source, there is exponentially more of each in a nuclear explosion.

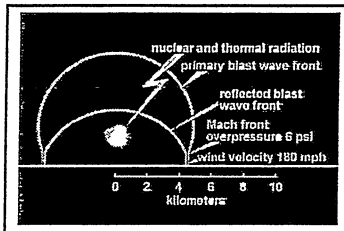
Physical principles of ionizing radiation II

Radiation is in several forms:

charged particles, neutrons and gamma rays.

Of the three, charged particles are the only form stopped by as little as normal clothing unless the source is internalized. In that case, the radiation threat depends on the type of source.

The amount of absorbed radiation is measured in gray.
The unit of biological effectivity is the Sievert.
Previously used equivalents were the rad and the rem
(1 gray = 100 rad; 1 Sievert = 100 rem).



Injury patterns

Immediate causes of death

The results within 11 seconds of a 1-megaton air burst.

Most persons close enough to a nuclear explosion to develop radiation injury symptoms within 1 to 2 hours of the detonation,
will have been killed by the pressure wave, the thermal pulse, or the resulting fires.
Most who are picked up by the blast winds will suffer significant impact injuries.

Injury patterns
Blast injuries

Missile injuries
Lacerations
Penetrating wounds
Blunt injuries



Blast injuries are caused by the overpressure wave that travels outward from ground zero at several hundred kilometers per hour. A 1-megaton weapon creates a static overpressure of 6 pounds per square inch and dynamic overpressures, or winds, of 300 kilometers per hour at 4 kilometers from ground zero. Biologic systems are more resistant than physical structures to overpressure, but they are subject to injuries from flying objects and to being impaled upon stationary objects.

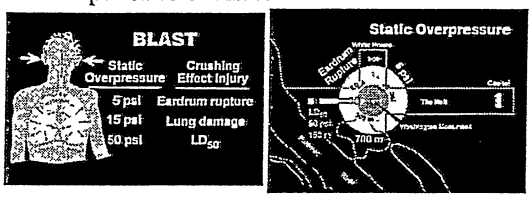
Medical Effects of Thermal Energy





Flash burns
Flame burns

Example of blast effect



We can extrapolate from the example the effects of blast energy.

The scenario could be the Washington Monument or other target selected by terrorists for shock value.

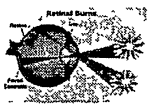
Medical Effects of Thermal Energy



- Nuclear weapons emit electromagnetic waves across the spectrum.
- The infrared waves, traveling at 300,000 miles per second, set fire to everything.
- The retina of a person who looks directly at the flash will be burned. Such burns can occur 10 miles from the detonation.
- Someone who looks in another direction will be flash blinded, a temporary condition

Medical Effects of Thermal Energy

- Flash burns
- Flame burns
- Eye injury
  - Retinal burns
  - Flash blindness dazzle
  - Loss of night vision





Hiroshima and Nagasaki patients.



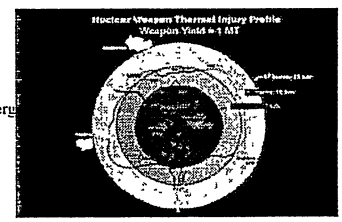


Thermal injuries are burns regardless of their etiology.

Because dark colors absorb heat and ignite and light colors reflect heat, the burns exhibit the patterns of the dark colors of the clothing worn.

Injury patterns

Range of infrared thermal energy



Hydrogen weapon effects
If a 1-megaton hydrogen weapon was detonated atop the Washington Monument, only those people outside a 5-kilometer perimeter of the detonation would require treatment.
Those closer would not survive.

Radiation injuries

- Radiation injuries are determined by the type and amount of radiation exposure and shielding if any.
- Most radiation medicine data are based on controlled dosages to specific parts of the body, or data are based on carefully modulated whole-body dosages.
- Exposure after the detonation of a nuclear device is neither controlled nor modulated.

Acute radiation syndromes

- The four syndromes, which are progressive and dose dependent, are hematopoietic, gastrointestinal, cardiovascular(CV), and central nervous system (CNS).
- The radiation dose received determines the onset of nausea and vomiting.
- The sooner the onset of symptoms and the longer they last, the higher the dose received.
- The initial treatment for a radiation casualty is
  - washing and
  - observing the patient.
- Washing addresses fallout and contamination.

Stages of ARS

- Acute radiation syndrome (ARS) patients go through four stages:
  - Prodrome,
  - latent,
  - manifest illness,
  - and recovery or death.
- While many factors determine how each patient fares, the better the patient's health to begin with, the better the chance of recovery.

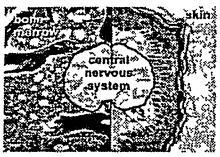
Acute radiation syndromes for total-body irradiated, untreated victims.

a. Treatment should increase survival up to about 10 Gy.
b. Partial shielding and aggressive therapy may result in survivors estimated to have received 20 Gy.
c. Those exposed to 30+ Gy, even with supportive care, will probably not survive.

The prime patients in intensive care beds will be those with lower exposures.

Syndrome/Dose	Prognosis
Hematopoietic	
0-2 Gy	Excellent
2-6 Gy	20%-30% death
Gastrointestinal	
6-10 Gy	80%-100% death
10+ Gy	100% death
CV/CNS	
30+ Gy	Certain death

Acute radiation syndromes ARS Hematopoietic Symptoms



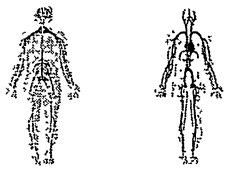
An initial lymphocyte drop is followed by agranulocytosis.
The higher the dose, the steeper the drop.
Absolute lymphocyte counts, during the first 3 days after exposure, are the best predictor of patient dose.



Acute radiation syndromes ARS **Gastrointestinal** Symptoms

When injured, the gut mucosa sloughs and shuts down.
This exposes the patient to translocation of bacteria.
Since this happens at the same time that the granulocyte count falls, sepsis and opportunistic infections complicate the effects of fluid and electrolyte losses.

Acute radiation syndromes ARS central nervous system Symptoms



Central nervous system changes are probably due to microvascular leaks.
These patients will almost certainly die.

Criteria for Triage Decisions

- ✓ Conventional injuries
  - Trauma
  - Burns
- ✓ Radiation injury
  - Prodromal symptoms
  - Hematologic picture

Initial criteria in triage decisions should always be conventional physical injuries.

Secondary criteria are radiation injuries.

Exposure Potential

Symptoms	Unlikely	Probable	Severe
Nausea	–	++	+++
Vomiting	–	+	+++
Diarrhea	–	+/–	+/– to +++
Hyperthermia	–	+/–	+ to +++
Erythema	–	–	– to ++
Hypotension	–	–	+ to ++
CNS dysfunction	–	–	– to ++

Symptoms indicative of exposure levels. Absence (-) or degree of severity (+ to +++) of symptoms indicate ascending levels of possible radiation exposure.

Estimation of exposure I

Radiation exposure levels can be estimated, based on the onset and duration of certain symptoms.

In the past, when a patient was exposed to an estimated dose of 6 Gy, treatment was expectant.

But we can no longer allow triage to regulate these patients to the end of the line.

With aggressive therapy, we should anticipate survival at 10 Gy and a few survivors after 20 to 30 Gy of partial-body exposure.

Estimation of exposure II

A triage estimation of radiation injury in these casualties can be made based upon history and symptoms (i.e., the severity of nausea and vomiting).

The presence of neurological signs indicates a nonsurvivable injury.

Serial lymphocyte counts in the first 48 hours helps confirm irradiation insult.

A drop of more than 50% in the absolute lymphocyte count indicates a significant radiological injury.

Lymphocyte Count As Indicator of Radiation Exposure

Little exposure
1.5 x 10^9/liter in 24 hours

Severe exposure
1.0 x 10^9/liter in 24 hours 0.5 x 10^9 /liter in 48 hours

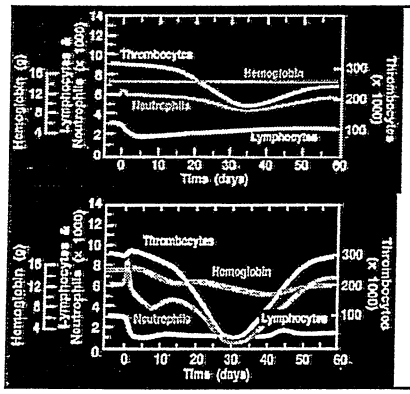
Lymphocyte Count As Indicator of Radiation Exposure

The most available quick test for radiation exposure is the absolute lymphocyte count.

The initial response to exposure is a drop in the count.

The steeper and more profound the drop, the higher the radiation dose received.

While immunocompromise indicated by the drop is the initial killer in exposure incidents, it is also the effect most amenable to aggressive treatment.



1 Gy

Hematological responses

after whole-body exposure to

3 Gy

Hematological response I

Bone marrow stem cell derivative cells are rapidly affected by radiation exposure. The charts available here are for whole-body exposure. In partial-body exposure cases, a portion of the marrow is spared.
The higher the dose, the more severe the effects on the marrow.

Hematological response II

Risk of infection
At 3 weeks, untreated opportunistic infections become paramount.
Infection may occur for the following reasons:

1. Oropharyngeal respiratory tree colonization
2. Wound contamination
3. Intestine colonization
4. Artificial invasive devices
5. Profound immunosuppression
6. Pathogens in environment

Review points

- Describe the immediate threats posed by a nuclear explosion.
- Relate the various radiation syndromes to radiation dose.
- Identify the symptoms of each radiation syndrome.
- Explain how to assess radiation dose in a triage situation.

MITIR

Medical Effects of Ionizing Radiation

Lesson objectives

Understand the nuclear threat.

Anticipate likely injuries.

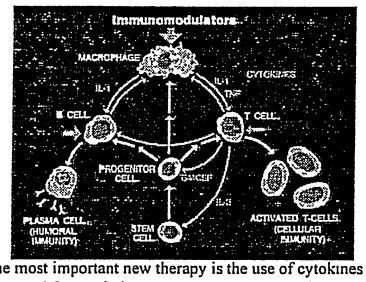
Understand how to treat radiation exposure and contamination.

Treatment of the radiation casualty Neutropenic Fever Therapy

- Survey for possible source: pan-cultures
- Antibiotics for ANC < 500/mm3
- Broad spectrum antibiotic coverage
  - Double beta-lactam antibiotics such as a third-generation cephalosporin and ureidopenicillin (piperacillin)
  - Monotherapy with imipenem or a third-generation cephalosporin
  - Vancomycin plus a third-generation cephalosporin
- Add amphotericin for prolonged fever lasting 5-7 days after starting standard antibiotics
- Continue antibiotics for duration of ANC <1000

Treatment of the radiation casualty

- Initial therapy is directed toward fluid and electrolyte balance, maintenance of nutrition, and alleviation of the granulocytopenia.
- If blood component therapy is required, all blood products must be irradiated with 20 Gy prior to infusion to prevent graft versus host disease.
- Infection should be managed with reverse isolation precautions and specific broad-spectrum antimicrobial therapy as per immune compromised patient protocol.
- All invasive monitoring is precluded.
- A long-term central line is a death sentence.
- Therapy must be directed toward infection prevention and shortening the period of relative immunoincompetence.
- Every deep vein catheter is a probable disaster.

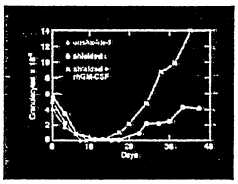


Cytokines at work.

The most important new therapy is the use of cytokines such as two approved for use in bone marrow transplant patients.
granulocyte-macrophage colony-stimulating factor (GM-CSF)
granulocyte colony-stimulating factor (G-CSF)

Cytokine therapy

- The most important new therapy is the use of cytokines such as two approved for use in bone marrow transplant patients.
  - granulocyte-macrophage colony-stimulating factor (GM-CSF) granulocyte colony-stimulating factor (G-CSF)
- Others under evaluation include megakaryocyte growth and development factor/ thrombopoietin (MGDF/Tpo) and the interleukin 3 (IL-3) agonist, synthokine.
- Cytokine dosages
- The current recommendation is to initiate cytokine therapy as soon as possible so as to decrease the period of absolute neutropenia, thereby reducing the risk of infection during recovery from marrow aplasia.
- The recommended once-a-day dosages are as follows.
  - G-CSF - 2.5-5.0 (µg/kg/day (100-200 (µg/m2/day)
  - GM-CSF - 5.0-10.0 (µg/kg/day (200-400 (µg/m2/day)



Effect of shielding and rhGM-CSF on recovery following exposure to 8 Gy of radiation.

Cytokines and shielding

When combined with the probability of partial shielding, cytokine therapy should change accidental irradiations at dosages once considered 100% deadly to a nonlethal injury.

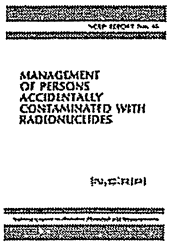
Treatment strategies for moderate- and high-dose partial-body radiation exposure.

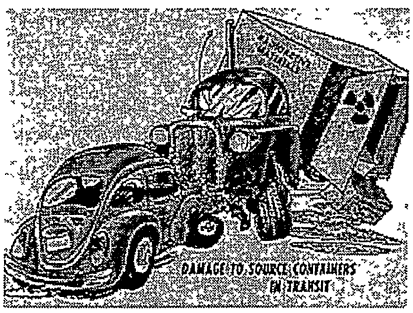
- Acute Radiation Syndrome Treatment
  - Moderate – dose partial-body exposure
  - High-dose partial-body exposure
- Treatment strategies summarized in the linked tables relate to moderate- and high-dose partial-body exposure.
- They relate only to instances of radiation injury with no other trauma, including the effects of biological or chemical weapons.

Internal contamination

The best source of information on medical care of individuals with internal contamination is the NCRP

(National Council on Radiation Protection and Measurements) Report No. 65, available from NCRP.





Internal contamination I

All of the transuranic elements are heavy metals.

- Oxides or base metals are insoluble and must undergo hydrolysis to be absorbed and circulated.
- Salts, such as uranyl fluoride, are immediately systemic, excretable, and toxic.

Sources of internal contamination

The two primary sources of internal contamination are

- accidents (industrial, institutional, transportation, military) and
- medical misadministrations.
- A third source is military wounding.

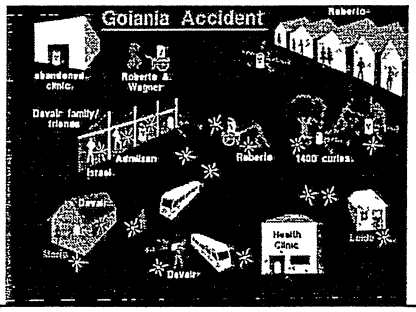
Internal contamination II

- A patient whose body contains a radionuclide is considered internally contaminated. That patient will continue to receive additional exposure until the radionuclide either completely decays or is removed.

Fear versus information

- Fear on the part of medical care providers is one of the biggest problems contaminated patients face. In Brazil, an entire village was contaminated with significant amounts of cesium from an abandoned clinic. The patients were initially refused treatment at nearly all available hospitals.
- However, if care is taken in the external decontamination process and if normal biohazard precautions are observed, such patients are not hazardous to anyone.
- Basic decontamination procedures will protect the medical care staff.
- But if the room becomes contaminated, the staff should be rotated in shifts to minimize exposure.

Internal contamination
Chain of events in the Goiania accident.



Goiania accident data

124,000+ screened, 244 contaminated
54 treated, 34 treated and released
20 hospitalized
10 Naval Hospital Rio
10 Goiania General Hospita
4 deaths

Area of contamination: about 800 acres (2,000 x 2,000 meters)
Dose emitting from various sites; one site emitting 1.2 Gy/hour
Aerial overflights used to identify hot spots: 200,000 mR/hour
Air and water samples not contaminated

Internal contamination III

The hazard

- The extent of internal radiation contamination is determined by the following factors:
  - Amount of radionuclide(s)
  - Energy and type of radiation
  - Length of time in the body
  - Critical organ
- When a radionuclide enters the human body, the body reacts exactly as it would to a nonradioactive isotope.
- As far as the body is concerned, tritium and hydrogen are identical as are iodine-127 and iodine-131.
- The target organ of the specific nuclide depends primarily on the organ's metabolism.
- Therapy is directed toward moving the nuclide out of the body and preventing deposition of a hazardous quantity.

Guidelines for bioassay sampling.

Optimum Sampling Time After Exposure			
Suspected Radioactive Material	Optimum Sample Time		Sample Quantity
	Feces	Urine	
Plutonium	24 hours	14-21 days	24-hour total
Uranium	24 hours	24 hours	24-hour total
Tritium	N/A	12 hours	1 voiding

Internal contamination

Assessment methods

- Medical care providers need to know the patient's level of contamination and the location of contamination. A hospital nuclear medicine technician will have the resources or know where to obtain the resources to adequately scan the patient. To determine exactly how much contamination has been internalized takes time.

Elements of the hazard

- The biologic half-life is determined by normal chemical and metabolic processes such as urination, respiration, desquamation, gastrointestinal motility, and phagocytosis.
- The physical half-life is determined by the isotope and its intrinsic rate of decay.
- Speeding up the metabolic processes -- through cathartics, dilution, and chelation -- decreases the patient's exposure.

The three stages of internal contamination

- The three stages of internal contamination are intake, metabolization, and elimination.
- The route of entry and the state of the element alters toxicity. For example, the decay rate of inhaled/exhaled tritium gas is insignificant. Yet tritium ingested as tritiated water is absorbed through the lungs, the gastrointestinal tract, and the skin and immediately equilibrates with total body water.

Internal contamination IV

Assessment methods



- Medical care providers need to know the patient's level of contamination and the location of contamination
- A hospital nuclear medicine technician will have the resources or know where to obtain the resources to adequately scan the patient.
- To determine exactly how much contamination has been internalized takes time.

Internal contamination V

Elements of the hazard

a. The biologic half-life is determined by normal chemical and metabolic processes such as urination, respiration, desquamation, gastrointestinal motility, and phagocytosis.

b. The physical half-life is determined by the isotope and its intrinsic rate of decay.

c. Speeding up the metabolic processes -- through cathartics, dilution, and chelation -- decreases the patient's exposure.

Internal contamination VI

The three stages of internal contamination

- The three stages of internal contamination are
  - intake,
  - metabolization,
  - elimination.
- The route of entry and the state of the element alters toxicity.

  e.g. the decay rate of inhaled/exhaled tritium gas is insignificant. Yet tritium ingested as tritiated water is absorbed through the lungs, the gastrointestinal tract, and the skin and immediately equilibrates with total body water.

Principal Routes of Intake

- Inhalation
- Ingestion
- Contaminated wounds
- Absorption

Principal Routes of Intake

Intake paths

- In the case of inhalation, a nasal swab obtained before decontamination should provide enough particulate material for a health physicist to analyze.
- Because most insoluble compounds, when ingested, will pass straight through the gut, the toxicity is based on dosage delivered during transit time. Shorten the transit time, lower the dose.
- Wound contamination by radioactive material looks like all other contamination: dirt, metal, road rash. Unless the contaminant is a pure alpha emitter, a local hospital's nuclear medicine technician can help provide wound screening.
- Some materials, such as tritiated water, are absorbed directly through intact skin. Others move through only damaged (e.g., burned) skin.

Internal contamination I

Metabolization

- Each radionuclide is metabolized like its closest chemical counterpart.

Elimination

- Once a radionuclide enters the body, all therapy should be directed toward increasing elimination and concomitently decreasing the effective radiation dose and chemical toxicity.

Deter absorption

- One effective treatment is to block or inhibit absorption to encourage rapid gastrointestinal transit.

Internal contamination II

Ion exchange resin

- ✓ Prussian blue (ferric ferrocyanide) has been used to successfully treat radiocesium poisoning.
- ✓ Prussian blue is indicated for cesium, thallium, and rubidium contamination.
- ✓ The recommended dosage is 1-3 grams by mouth, 3 times daily for up to 3 weeks.
- ✓ The drug reduces the biologic half-life of cesium-137 to one-third the normal value.

Internal contamination Chelation Therapy Using DTPA

- Chelation therapy:Calcium diethylenetriaminepentaacetic acid (CaDTPA) and zinc diethylenetriaminepentaacetic acid (ZnDTPA) are investigational drugs controlled by REAC/TS. (Radiation Emergency Assistance Center and Training Site) at Oak Ridge, Ten
- The drugs are the only known effective treatment for contamination by transuranic elements. Findings indicate that chelation agents cause up to 90% of soluble transuranic elements to exit the body in urine.
- A decision to initiate chelation therapy is based solely on empiric data. The therapy must begin as soon as possible after contamination.

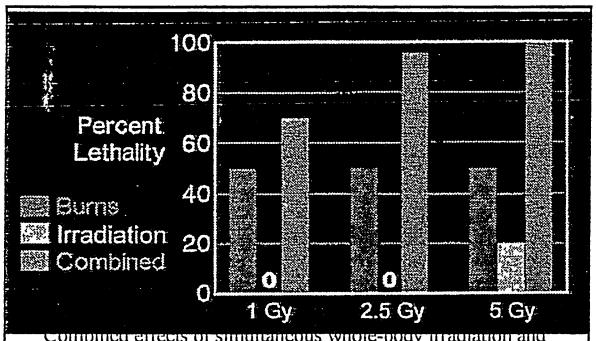
Chelation Therapy Using DTPA

- Chelation therapy initiated solely on empiric data and history
- Continue therapy based on accurate dose assessment and urinary excretion levels
- Dose: 1 g/day in one dose intravenously or by aerosol inhalation; Europe trying insufflation
- Initial dose = CaDTPA, subsequent doses = ZnDTPA
  - **Caution:** Higher or more frequent doses may cause severe trace metal deficiency, especially Mn and Zn

Combined injury

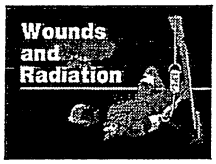


- Radiation exposure and physical trauma combined are worse than either alone.
- Burns and irradiation
- The change in lethality is dramatic when even nonlethal doses of radiation combine with LD50 burns. A geometric progression will be typical in victims of terrorist attacks, for instance, in which many casualties will suffer combined injuries.

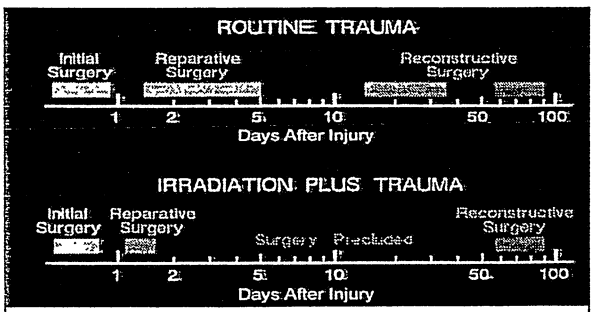


Combined effects of simultaneous whole-body irradiation and burns on rats, based on Messerscmidt's data.

Wounds and irradiation



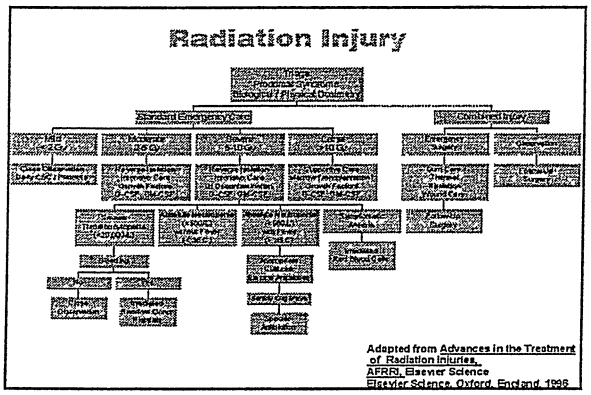
- The progressive effect of combined wounds and irradiation can be reversed if all wounds are closed early.
- In experiments, the procedure resulted in no increase in lethality and even improved recovery when compared with recovery from radiation injury alone.
- This effect is probably due to the metabolic response to trauma and the elimination of the nidus of infection prior to leukopenia.

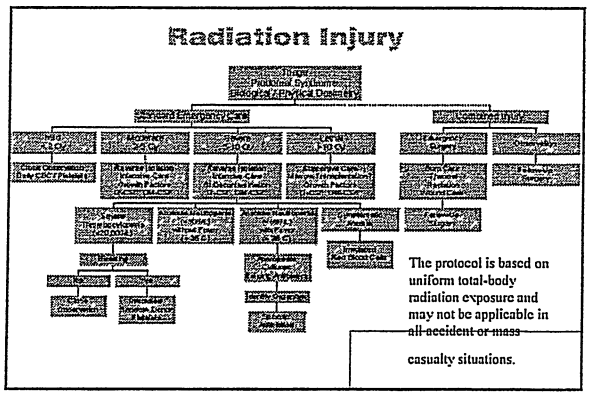


Comparison of the timing of surgery involving routine trauma and combined irradiation and trauma.

Combined injury
Surgical intervention

- Primary closure involving radiation combined injury must be completed in the first 48 hours after irradiation. This is a marked change compared with the timing of surgery for routine trauma.
- Reconstructive surgery must be postponed for two months until complete resolution of the radiation injury.
- Surgery during the exclusion period will result in excessive mortality.





Treatment protocol

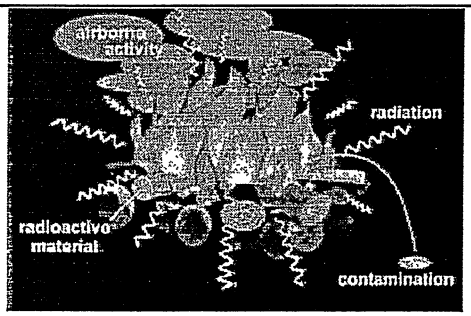
- Because radiation injury is not immediately life threatening, initial care of a combined injury casualty should address conventional injuries like burns and wounds.
- After emergency procedures for ventilation, perfusion, and hemorrhage, the casualty should be stabilized.
- Radioisotope decontamination should precede emergency surgery, which should be followed by definitive care and treatment of radiation injuries.

Misconceptions

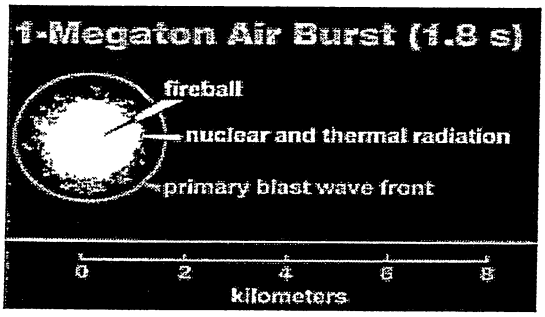
To understand radiation, one must differentiate between radioactive materials, radiation, and contamination.

The analogy of a fire helps to explain.

- Radioactive material emits radiation in the same sense that burning wood emits heat. Just as you can be exposed to heat from burning wood without being set afire, you can be exposed to radiation without being contaminated or becoming radioactive.
- A spark from the fire could land on and contaminate you as could a radioactive substance that lands on or enters your body. While you would still not be radioactive, the contaminant on you would be and could expose those around you to radiation.



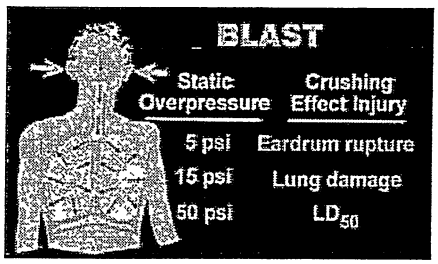
A fire is somewhat analogous to a radiation source in terms exposure and contamination.



Blast and Thermal Effects of Nuclear Weapons

Blast wave

- A nuclear explosion is a sudden, large-scale release of energy.
- The release converts all materials in the vicinity of the explosion into hot, compressed gases that, with the considerable increase in temperature and pressure, expand rapidly and initiate a "shock wave" in the surrounding medium whether it is air, water, or land.
- A shock wave in air is generally referred to as a "blast wave" because it is accompanied by a strong wind. In water or in land, the shock is much like that of a sudden impact.
- The blast or shock wave behaves much like a moving wall of compressed air and is responsible for most of the material damage caused by a nuclear explosion.

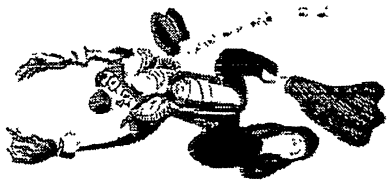


If physical structures can be demolished by the blast and thermal effects of a nuclear explosion, one can imagine the damage such energy inflicts on biological systems.

Biological effects

Blast wave effects

- Biological injury is caused primarily by pressure generated by the blast wave that accounts for 50 percent of the energy released in a nuclear detonation.
- A peak overpressure of 5 pounds per square inch ruptures the eardrum;
- 15 causes lung damage, primarily by rupturing the alveoli;
- 50 is the lethal dose, or LD50.
- That is, an overpressure of 50 pounds per square inch is lethal to 50 percent of the exposed population if no medical intervention occurs.



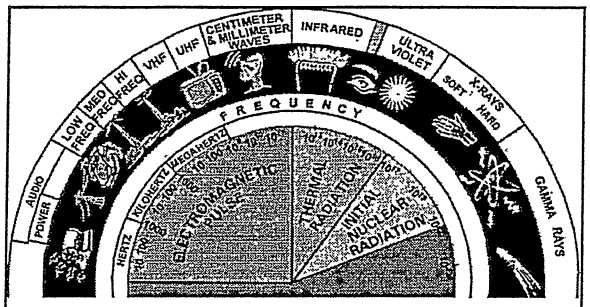
Scuba divers, who subject themselves to pressures of 45 pounds per square inch or more, prevent damage by adjusting gradually to the pressure change. Pressure change in an explosion is instantaneous.

Blast and Thermal Effects of Nuclear Weapons : Biological effects I

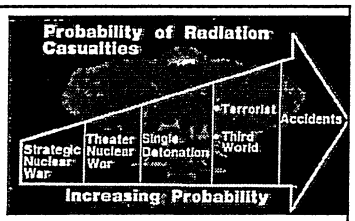
- Overpressure injury . The rate of pressure change in the area of an explosion is instantaneous, allowing those in the path of the blast wave and the resulting overpressure no time to adjust. Hence, blast injuries are a result of not only the pressure level but also the rate of change.
- Dynamic pressure injury . Strong winds that give rise to the dynamic pressure phase, or compression phase, cause sharp objects to become airborne missiles that may cause lacerations, puncture wounds, and blunt injuries. Glass shards, for example, will be a serious hazard. A 10-gram glass shard moving at 15 meters per second can cause lacerations; the same shard moving at 55 meters per second can cause serious wounds.

Blast and Thermal Effects of Nuclear Weapons : Biological effects II

- Protection against blast wave injury.
- Advance warning is the best protection against personal injury from blast wave effects. In open terrain the most effective protection is to reduce the exposure area and wear protective headgear.
- Reduce the exposure area (i.e., become a smaller target) by lying facedown with your head pointed away from ground zero. Place yourself behind a protective barrier if one is available. A narrow trench or foxhole will also provide adequate protection from blast winds carrying debris likely to cause displacement injuries.



Thermal effects
Thermal energy accounts for about 35 percent of the total energy yield in a fission weapon detonation. As illustrated in the electromagnetic spectrum chart, thermal radiation comprises all frequencies in the infrared, visible light, and ultraviolet regions.

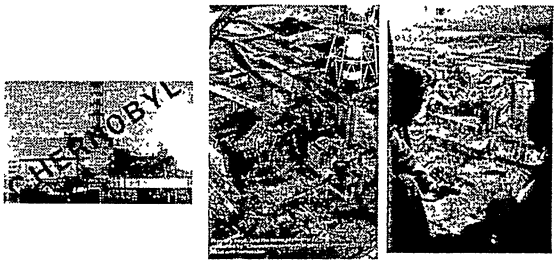


The threat

The probability of a strategic nuclear war decreased with the end of the Cold War. Third World act of aggression or of a terrorist attack, has increased, and the possibility of a nuclear accident or incident is always present.
Nuclear accidents or incidents include worker overexposures, medical misadministrations of radiopharmaceuticals, and loss of radioactive sources.

Acute Radiation Syndrome (ARS) Introduction

- Acute radiation syndrome was gleaned from a review of human experience in accidental and clinical exposures to ionizing radiation.
- Accidents included those at Chernobyl, Ukraine, and Goiania, Brazil.
- Clinical experience comes from patients undergoing total-body irradiation for neoplastic diseases.



Aerial view of the Chernobyl nuclear reactor disaster.

Acute Radiation Syndrome : Introduction I

Variables
Individual response to and ability to recover from radiation injury is related to the following conditions:

- Total dose and quality of radiation
- Dose rate
- Portion of the body exposed
- Comparative intrinsic genetic cellular radiosensitivity
- Uniformity of exposure
- Age and health of the victim
- Presence of coexisting injuries or illnesses

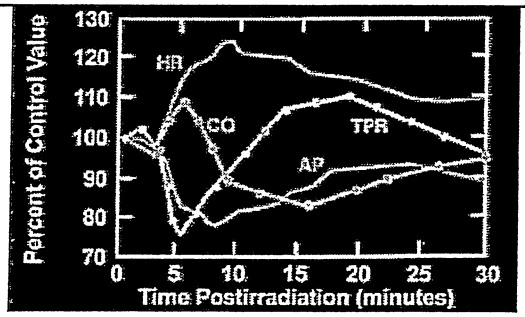
Acute Radiation Syndrome : Introduction II

Phases

- Regardless of the dose range received, a person manifesting acute radiation syndrome will experience four phases:

1. Initial or prodromal phase
2. Latent phase
3. Manifest illness phase
4. Recovery phase

- The latent phase may be asymptomatic or even a period of apparent clinical improvement.
- During the manifest illness phase, the affliction may be severe enough to be life threatening



Hematodynamic effects of acute radiation. HR = heart rate; CO = cardiac output; TPR = total peripheral resistance; AP = arterial pressure.

Acute Radiation Syndrome

- Hematological,
- gastrointestinal, and
- cardiovascular/central nervous system (CNS) syndromes.

- These syndromes are, as a rule, produced only with total-body or nearly total-body irradiation by photon or mixed photon/neutron radiation.
- High-dose injuries to smaller percentages of the body produce local injury effects but may not cause manifestation of ARS.

Cardiovascular/CNS syndrome I

- Acute radiation doses of 30 Gy and above uniformly bring death within 72 hours and usually between 24 to 48 hours, well before the insult to the gastrointestinal or bone marrow systems becomes clinically apparent.
- Doses in this range cause significant direct effects as well as free radical overload of the cells and basement membranes of the microcirculation system. This leads to, among other damage, massive loss of serum and electrolytes through leakage into the extravascular space, circulatory collapse, edema, increased intracranial pressure, and cerebral anoxia.
- In less than an hour and possibly within minutes of exposure, patients receiving these doses begin experiencing prodromal symptoms: a burning sensation within minutes and severe nausea and usually projectile vomiting within an hour. The symptoms, which are severe and may last more than 24 hours, also include diarrhea that is occasionally bloody, cutaneous edema and erythema, hypotension, hyperpyrexia, disorientation, prostration, loss of coordination, and possibly seizures.

Cardiovascular/CNS syndrome II

- Following the prodromal phase, there may be a brief latent phase of apparent clinical improvement; but this will last only for hours to days.
- The victim will succumb to a complex of gross CNS dysfunction and total cardiovascular collapse, leading to a relatively prompt and inevitable death.
- Radiation doses in this range are uniformly fatal regardless of therapies attempted; therefore, aggressive medical support with pressors, fluids, steroids, and the like will bring only temporary improvement and may only serve to prolong suffering.
- Thus, therapy should be palliative in nature, and the clinician caring for such a patient is encouraged to be generous with any palliative measure such as opiates or tranquillizers.

Gastrointestinal syndrome



Normal mucosal crypt stem cell

- If an irradiated patient survives the insults to the cardiovascular/central nervous system, the next system to be threatened will be the gastrointestinal (GI) system.
- Generally, exposure to a dose range of 8 to 30 Gy will be fatal since that dose range causes reprodactive death of the mucosal crypt stem cell.

Gastrointestinal syndrome



Irradiated mucosal stem cell.

- Loss of these cells eliminates the bowel's ability to replenish the short-lived mucosal cells that normally slough off during routine GI function.
- Since the rate of cell turnover is highest in the small intestine, radiation injury is usually most severe in that part of the tract.

Gastrointestinal syndrome
Pathophysiologic sequelae I

Denuding of sections of bowel, in turn, causes a host of pathophysiologic sequelae.

- Invasion of lumenal bacteria into the circulation,
- loss of fluid and electrolytes,
- loss of absorptive capability,
- significant gastrointestinal hemorrhage
- loss of blood,
- dysfunctional bowel motility,
- resulting in severe bloody diarrhea, anemia, ileus, severe electrolyte disturbances, and malnutrition.

Gastrointestinal syndrome
Pathophysiologic sequelae II

Systemic effects .

- The invasion of potentially pathologic bacteria into the bloodstream of a patient experiencing a host of simultaneous insults, quickly overwhelms the victim's ability to fight such infections.
- Malabsorption leads to malnutrition;
- Paralytic ileus causes vomiting and abdominal distension; fluid and electrolyte shifts result in dehydration, acute renal failure, and cardiovascular collapse,
- Gastrointestinal bleeding leads to anemia.
- Sepsis, septic shock, and eventually death ensue.

Gastrointestinal syndrome
Pathophysiologic sequelae III



Syndrome phases .

- Within 30 minutes to 2 hours after exposure, patients receiving radiation doses of 8 to 30 Gy may experience severe prodromal symptoms of anorexia, nausea, vomiting, and occasionally watery diarrhea with abdominal cramps, which increase in intensity for 4 to 8 hours, difficult to control with antiemetic medications.

Gastrointestinal syndrome
Pathophysiologic sequelae III

Syndrome phases .

Listlessness, drowsiness, and fatigue. Occasionally, prodromal symptoms include parotid gland pain, metallic taste sensation, mild hypotension, and tachycardia. The prodromal symptoms continue but diminish over the first 48 hours after exposure.

- Then, during a 5- to 7-day latent period, the patient demonstrates apparent clinical improvement.
- Then ensues the course of manifest illness: return of severe diarrhea and then vomiting and diarrhea with fever, progressing to bloody diarrhea, shock, and death.

Gastrointestinal syndrome
Treatment

- In spite of considerable advances in the medical armamentarium for treatment of radiation injury, no patient with full-scale gastrointestinal syndrome has survived.
- This system and possibly the lungs are the organs that can limit survival probability, assuming the patient survives the bone marrow insult as well.
- The clinician caring for such an individual is faced with the difficult dilemma of deciding whether heroic measures might provide even a small chance of survival or whether such measures will only prolong an unpleasant death.
- Aggressive palliative symptomatic control with liberal narcotics, antiemetics, and antidepressants is encouraged

Pulmonary effects I





- Radiation doses in the 8- to 30-Gy range will usually cause death from the gastrointestinal (GI) syndrome. However, such doses will also produce potentially life-threatening pulmonary effects of respiratory insufficiency and pneumonitis, which will be seen from 14 to 30 days after exposure.

Pulmonary effects II

Pneumonitis is likely caused by a complex of factors

- breakdown of vascular permeability,
- fluid imbalance,
- free radical tissue interactions,
- infectious agent,
- biological and chemical toxin insult,
- inhalation injury from heat, smoke, and fumes.

- The patient injured by fatal whole-body radiation may die of the GI syndrome before the pulmonary effects become manifest.
- However, a patient spared the GI effects by partial-body shielding or dose inhomogeneities may succumb to the pulmonary effects.

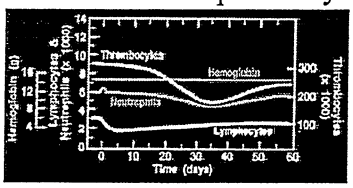
Hematopoietic syndrome

- **The stem cell lines of the bone marrow are among the most radiosensitive tissues of the body. This is because of their high mitotic rate and their high nuclear-to-cytoplasmic ratio**



Normal bone marrow cells.

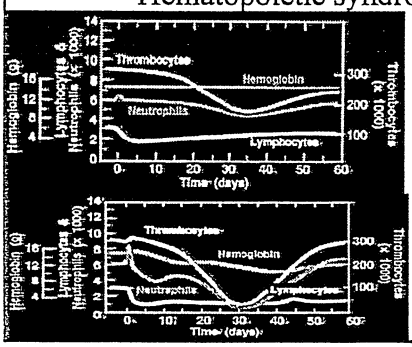
Hematopoietic syndrome



Hematological response to 1-Gy, whole-body exposure

- Cytotoxic injury . Cytotoxic injury to bone marrow cells and nucleated blood cells can occur at ionizing radiation doses as low as 0.25 Gy,
- Clinical depression of cell counts is usually not noted until a dose of 1 Gy.
- At doses of 2.5-3 Gy, life-threatening suppression of blood counts occur; and at higher doses, many of the counts drop to zero.

Hematopoietic syndrome



Hematological response to 1-Gy, whole-body exposure

Hematological response to 3-Gy, whole-body exposure

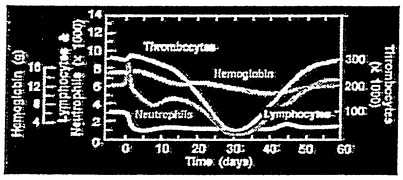
Hematopoietic syndrome



Bone marrow damaged by radiation injury.

- Survival potential . Even at ionizing radiation doses of 2.5 Gy and higher, a small percentage of the surviving stem cell population is capable of reproducing a continuously expanding progeny.
- While this replenishment occurs, the counts of the shorter lived cell populations drop to a nadir and then recover, assuming the patient is surviving.
- The severity and duration of the nadir will depend upon the severity of the dose received, upon the patient's inherent ability to repair bone marrow damage, and upon whether therapies received enhance or further injure the reparative process.

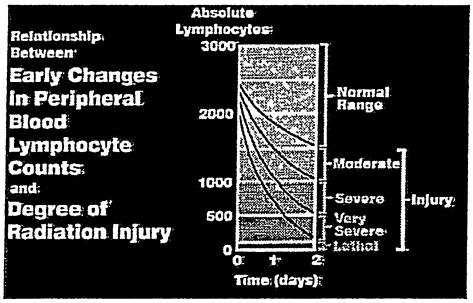
Hematopoietic syndrome: Red blood cells.



Hematological response to 3-Gy, whole-body exposure

Red blood cells.

- After exposure to ionizing radiation, there is usually no depression or only a very mild depression of red blood cells unless there is concomitant hemorrhage.



Mean granulocyte count following irradiation.

Lymphocytes I .

- Lymphocyte counts are usually the first blood counts to drop after exposure to ionizing radiation.
- A drop in lymphocytes occurs 24 to 48 hours after the injury. The speed and extent of the lymphocyte drop is linearly proportional to the severity of the dose to the bone marrow.
- A minor drop is noted after doses of 0.25 to 1 Gy.
- At about 1.5 Gy, the drop is around 50 percent.
- At 3 Gy, the count drops to 1000/mm3;
- at 4 to 5 Gy, it drops to less than 500/mm3.
- A drop to zero implies a dose of greater than 6 Gy.
- Thus, the drop in lymphocyte count is a crude but simple and sensitive, and therefore important, estimation of severity of injury within 48 hours after exposure. For example, a patient whose lymphocyte count stays above 1500/mm3 after 48 hours may have received a clinically significant dose, but the overall prognosis is quite good. On the other hand, a patient whose count drops to less than 500/mm3 in 24 hours demonstrates a profound life-threatening injury.

Lymphocytes II.

- Lymphocyte counts are usually the first blood counts to drop after exposure to ionizing radiation.
- Thus, the drop in lymphocyte count is a crude but simple and sensitive, and therefore important, estimation of severity of injury within 48 hours after exposure.
- e.g lymphocyte count stays above 1500/mm3 after 48 hours may have received a clinically significant dose, but the overall prognosis is quite good.
- count drops to less than 500/mm3 in 24 hours demonstrates a profound life-threatening injury.

Hematopoietic syndrome: Syndrome phases

- Patients injured with doses in the hematopoietic range will experience Prodromal Phase symptoms of nausea and vomiting which, compared with those for the other syndromes, are less severe and easier to control. They last only a few hours, with time of onset from later than an hour to about 24 hours after exposure.
- There is usually a lack of central nervous system syndrome signs, very little change in blood pressure, and only mild watery diarrhea. Fatigue, malaise, anorexia, and drowsiness may be observed but are not consistently correlated to dose received as are the onset and severity of nausea and vomiting.
- The prodromal phase is followed by the latent phase that lasts up to a month and is relatively asymptomatic except for some fatiguability and weakness.
- The latent phase is followed by the manifest illness phase, characterized by neutropenic fevers, systemic and localized infections, sepsis, and hemorrhage.

Hematopoietic syndrome: Granulocytes

- An ionizing radiation dose of 2 Gy or less usually causes a very gradual depression of counts to 50 percent or less with a nadir of more than 40 days.
- Doses greater than 2 Gy cause an initial paradoxical rise in counts, a rise that lasts only hours or days and is followed by a precipitous drop. This is caused by prompt demargination of white cells into the circulation. Any CBC taken during this paradoxical rise may be misinterpreted as evidence of infection.
- Doses greater than 5 Gy usually cause the precipitous drop to continue relentlessly to a nadir of zero or near zero in 3 to 4 weeks.

Acute Radiation Syndrome : manifestations summary I

- Acute radiation syndrome is a complex of acute injury manifestations that occur after a sufficiently large portion of a person's body is exposed to a high dose of ionizing radiation.
- The four phases of acute radiation syndrome are
  1. prodromal,
  2. latent,
  3. manifest illness,
  4. recovery.
- Different ranges of whole-body doses produce different manifestations of injury.

Acute Radiation Syndrome : manifestations summary II

The three dose ranges that produce the most characteristic manifestations are referred to as the hematological, gastrointestinal, and cardiovascular/central nervous system syndromes.

- Radiation doses in the cardiovascular/central nervous system syndrome range are uniformly fatal regardless of therapies.
- Doses in the gastrointestinal syndrome range, which also produce life-threatening pulmonary effects, are usually fatal.
- Doses in the hematopoietic syndrome range are survivable.
- **The therapeutic goal** is to lessen the severity of thrombocytopenia and neutropenia while minimizing and treating infectious insults

Acute Radiation Syndrome : manifestations summary III

The therapeutic goal is

- to lessen the severity of thrombocytopenia and neutropenia
- while minimizing and treating infectious insults

Radiation safety officer



radiation safety officer
advisor to the on-scene commander, addresses the following issues:

1. Contamination control procedures
2. Exposure limits and safe-stay times
3. Radiological safety guidance
4. Decontamination procedures
5. Radioactive materials handling guidance
6. Site restoration and cleanup

Treat conventional injuries



Treat any life-threatening traumatic injuries or medical conditions before addressing radiation-related issues.
Therefore, follow standard medical emergency procedures -- ventilate, perfuse, stop hemorrhage -- and decontaminate after stabilization.

Treat conventional injuries

Call appropriate emergency assistance providers for help.

Treat any life-threatening traumatic injuries or medical conditions before addressing radiation-related issues.

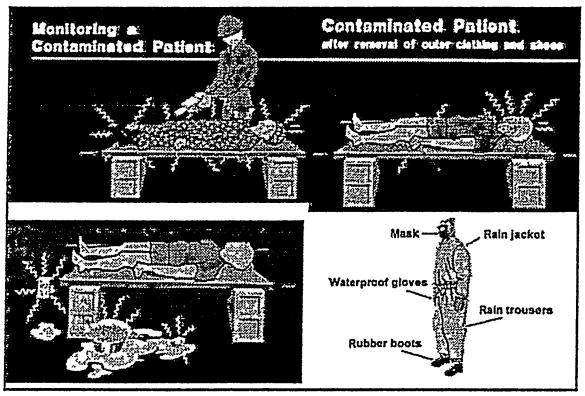
A patient with a potentially survivable radiation injury will survive 3 to 4 weeks until the period of manifest illness.

This is more than enough time for any traumatic causes of mortality to take their toll.

It is essential that the traumatic injuries be managed without delay. Therefore, follow standard medical emergency procedures -- ventilate, perfuse, stop hemorrhage -- and decontaminate after stabilization.

Decontaminate I

- The patient with a chemical or biological injury, must be decontaminated prior to any medical intervention,
- The radiation casualty poses no significant immediate health threat to medical personnel.
- Remember, a patient injured with external irradiation only is not contaminated.
- Secondary contamination of medical personnel by a contaminated patient is a treatable and manageable situation.
- While it is preferable to promptly decontaminate a patient prior to medical intervention if the medical situation and logistics allow, decontamination should never take precedence over the treatment of life-threatening conditions.
- Common sense and a deliberate step-wise approach are the best response in such a situation.



Decontaminate II

Patient decontamination is accomplished in steps:

- Establish checkpoint
- Survey upon entering
- Remove clothing
- Wash body areas exposed to radiation
- Periodically change clothing of personnel performing decontamination

Estimate injury I

- Patient is stabilized and decontaminated.
- Detailed history and physical examination.
- Estimation of extent of injury - important process in the management of the radiation casualty -
- The radiation casualty will fall into one of three broad categories:
  a. Radiation injury unlikely
  b. Radiation injury probable
  c. Radiation injury severe

Estimate injury II

- The radiation casualty will fall into one of three broad categories:
  - Radiation injury unlikely
  - Radiation injury probable
  - Radiation injury severe
- Those for whom radiation injury is unlikely will need minimal intervention.
- Those for whom radiation injury is probable will most benefit from some form of radiation specific therapeutic intervention.
- Those for whom radiation injury is severe are not likely to survive regardless of the amount of intervention.
- This estimation of injury is especially important in a mass casualty or field situation where medical resources are limited and it is imperative that they be allocated to those most likely to benefit.

Prodomal symptoms

Dose (Gy)	Onset (hours)	Duration (hours)	Latency
0.5-2	Absent to 6	< 24	Absent or 3 weeks
2-3.5	2 - 6	12 - 24	2 - 3 weeks
3.5-5.5	1 - 2	24	1.0 - 2.5 weeks
> 5.5	Minutes to 1	48	2 - 4 days

Time of prodromal stage as a function of radiation dose received.

- The primary and simplest means of estimating severity of injury are to note the timing and severity of prodromal symptoms, as shown in the table, and to examine serial blood lymphocyte counts.

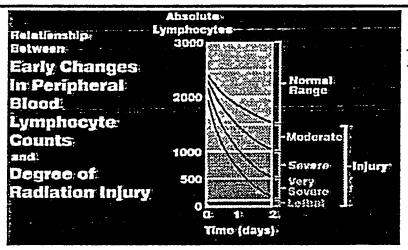
Radiation injury probability.

- Unlikely radiation injury demonstrates no more than episodes of nausea and vomiting and usually retains lymphocyte counts above 1500/mm3 in 48 hours.
- Probable radiation injury has prodromal symptoms of more severe and sustained nausea and vomiting that commence within 1 hour to 1 day of exposure and last for hours. This patient has a lymphocyte drop to around 100 to 1500 lymphocytes/mm3 but no central nervous system (CNS) symptoms.
- Severe, potentially fatal radiation injury and who may have to be categorized as expectant in a triage situation, presents with uncontrollable nausea and vomiting within 1 hour after exposure. Those symptoms are frequently associated with prompt, explosive, bloody diarrhea, hypotension, a burning skin sensation, and gross CNS signs.

Radiation injury probability.

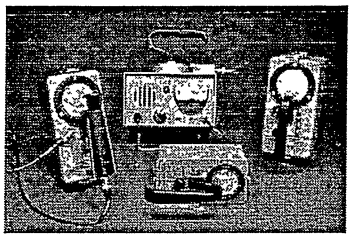
	Unlikely	Probable	Severe
Nausea	—	++	+++
Vomiting	—	+	+++
Diarrhea	—	—/+	—/+ to +++
Hyperthermia	—	—	—/+ to +++
Hypotension	—	—	+ to ++
Erythema	—	—	—/+ to ++
CNS Dysfunction	—	—	—/+ to ++

Use of symptoms to assess probability of radiation injury.



Lymphocyte count

- Lymphocytes in a fatal exposure may promptly fall to zero or near zero.
- Rarely, patients with extreme suppression of lymphocytes but with less severe prodromal symptoms survive the injury.
- Prodomal symptoms and hematologic evaluations should be considered together in the rapid assessment of radiation injury.

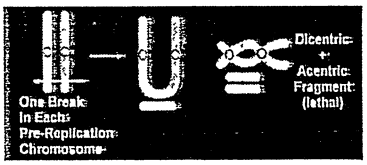


Physical dosimetry

- prodromal effects (time of onset, degree and duration of symptoms)
- hematologic changes (lymphocyte counts),
- physical dosimetry is another important source of information in evaluating a patient's injury.
- A film badge worn by a radiologist is an example of a physical dosimeter.

Use of Peripheral Blood Lymphocytes as a Biodosimeter

- Introduced by M. Bender in 1964.
- Isolated lymphocytes stimulated by phytohaemagglutin (PHA) into mitosis
- Arrest of metaphase mitotics using colchicine
- Scoring of dicentric chromosome aberrations in metaphase spreads



Biodosimetry .

- Prodromal symptoms.
- Hematologic changes.
- Physical dosimetry.
- Biodosimetry is a highly technical, state-of-the-art evaluation of radiation dose received and is performed by a laboratory on patient's blood and/or tissue, usually taking from 4 to 20 days to complete.
- Therefore, clinical care must proceed, using other sources of information while waiting for the biodosimetry information. Biodosimetric information can be used to either confirm or modify dose estimates.

Acute Radiation Syndrome : triage summary

Review points

- Be aware of emergency numbers for the appropriate radiological emergency response experts available to you.
- Treat life-threatening conventional injuries or medical conditions before addressing radiation injuries, including decontamination procedures.
- Prodromal symptoms are used to identify the radiation injury category of unlikely, probable, or severe, a determination that affects allocation of limited medical assets to patients most likely to benefit.
- Prodromal effects, hematologic changes determined by lymphocyte count, physical dosimetry, and biodosimetry, in that order, are the most useful sources of information in radiation injury evaluation.