Early (Acute) Effects of Radiation

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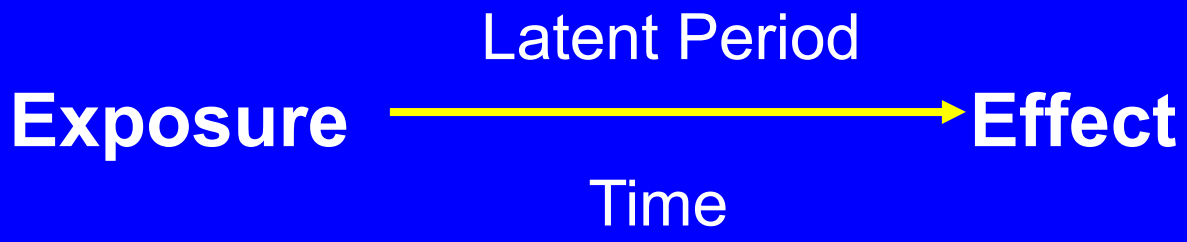
Categorizing Radiation Effects

Radiation effects are categorized in several different ways.

Perhaps the most fundamental way is to divide them into two categories according to the length of time between the exposure to radiation and the manifestation of the effect (the latent period)



General

Categorizing Radiation Effects

Early Effects (Acute Effects)

Occur within two months or so of the exposure

Late Effects (Delayed Effects)

Occur more than two months after the exposure

General

Early Effects (Acute Effects)

Early effects occur within 2 months of the exposure. This definition is somewhat arbitrary in view of the various factors that can affect the length of time between the exposure and the effect. As such, various authors define acute effects in slightly different ways. For example, some define acute effects as those effects occurring within up to 6 months of the exposure.

Normally, acute effects are only observed if the dose is greater than 1 Gy (100 rads) and delivered over a short time (acutely).

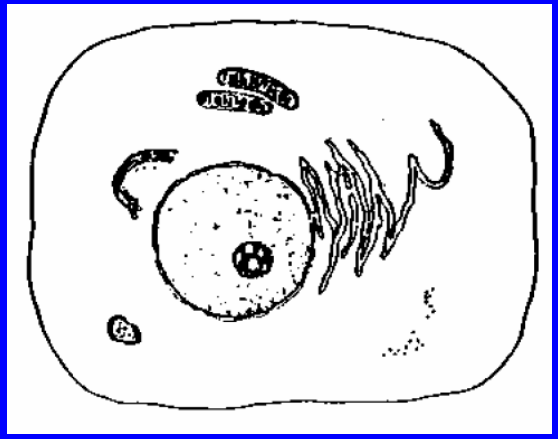
General

Late Effects (Delayed Effects)

Delayed effects are usually considered to be those effects that appear more than 2 months (in many cases, years) after the exposure.

Depending upon the effect, they can be produced by acute or chronic exposures.

One type of delayed effect is considered possible even with the smallest of exposures. The other types only occurs if the dose exceeded a threshold value.



Radiation damage to the cell goes unrepaired. The most important target for such damage is believed to be chromosomal DNA.

Cell Death

Mainly due to DNA double strand breaks and resulting chromosomal aberrations. Cells might survive but are nonfunctional (fibrotic).

Cell Lives

Damage insufficient to kill cell, but cell metabolism impaired. Cell divides and produces many malfunctioning cells.

Early Effect

Death of cells with short cell cycle. The more rapidly the cells divide, the shorter the latent period.

Deterministic Late Effect (Non-Stochastic)

Death of slowly dividing cells. Cells survive longer since a longer time passes before cell divides. This creates a long latent period.

Stochastic Late Effect

General

Absorbed Dose vs. Dose Equivalent

The quantity Dose Equivalent (or equivalent dose) is related to the stochastic late effects that might occur due to the relatively low doses commonly encountered in the field of radiation protection.

The dose equivalent, as measured in rems or sieverts (Sv), does not pertain to the early effects of radiation that result from relatively high doses.

Discussions of the early effects of radiation involve the quantity absorbed dose as measured in units of rads or gray (Gy).

Radiation Syndromes

Radiation Syndromes

General

A syndrome is a combination of symptoms resulting from a single cause (e.g., radiation exposure). These symptoms occur together so as to constitute a single clinical picture.

Collectively, the symptoms that result from an acute exposure to radiation are referred to as an acute radiation syndrome (ARS). Another term, acute radiation sickness (ARS), is sometimes employed instead.

It is common to recognize three or four acute radiation syndromes (ARS) in humans. Which syndrome occurs, depends on the magnitude of the dose.

Radiation Syndromes

General

The designation of these discrete syndromes is highly arbitrary.

In reality, a continuum of effects occur with increasing dose.

Some authors choose to assign overlapping dose ranges to these syndromes.

Radiation Syndromes

Three Radiation Syndromes

We usually identify the following Acute Radiation Syndromes:

1. Hematopoietic/Bone Marrow Syndrome
   ca. 200 – 800 rads (2 – 8 Gy)

2. Gastrointestinal Syndrome
   ca. 800 – 3000 rads (8 – 30 Gy)

3. Cerebrovascular/Central Nervous System Syndrome
   >3000 rads (>30 Gy)

Radiation Syndromes

Three Stages of the Acute Radiation Syndrome

The Hematopoietic Syndrome and the Gastrointestinal Syndrome can be considered to progress through the following stages:

1. prodromal (initial) stage
2. latent stage
3. a period of illness and recovery or death

At higher doses associated with the central nervous system syndrome, the onset of sickness and death are almost immediate, i.e., there is no stepwise progression through the above stages.

Radiation Syndromes

1. Prodromal Stage of the Acute Radiation Syndrome

This is the initial set of symptoms that occurs following a sufficiently large acute dose.

The primary prodromal symptoms include:

nausea
vomiting (emesis)
anorexia (loss of appetite)
fatigue

Radiation Syndromes

1. Prodromal Stage of the Acute Radiation Syndrome

Other symptoms, especially at the higher doses include:

fever (up to 41 degrees C)
headache
diarrhea
dryness of the mouth (xerostomia)
swelling of the parotid gland (parotiditis)

To some degree, the time of onset of these symptoms indicates the magnitude of the dose. This is particularly true regarding the time of onset of vomiting. Nevertheless these symptoms can also be induced psychologically.

Radiation Syndromes

2. Latent Stage of the Acute Radiation Syndrome

This is an asymptomatic period between the prodromal stage and the onset of symptoms of later stages.

The higher the dose the shorter the latent phase. At sufficiently high doses (e.g., > 3000 rads or 30 Gy) the latent phase effectively disappears.

Radiation Syndromes

3. Illness and/or Death Stage of the Acute Radiation Syndrome

Many of the characteristics of the prodromal phase might reoccur, e.g., nausea, vomiting, anorexia, fatigue. Additional symptoms might include fever, hemorrhaging

Radiation Syndromes

3. Illness and/or Death Stage of the Acute Radiation Syndrome

It is generally believed that without medical attention:

death is certain above 600 rads (6 Gy)
50% of exposed would die from 400 rads (4 Gy)
5% of exposed would die from 200 rads (2 Gy)

If the patient survives six weeks, recovery is very likely but not guaranteed.

If the dose exceeds 1000 rads (10 Gy) death is certain, most likely within 60 days.

Hematopoietic Syndrome

Hematopoietic Syndrome

General

The hematopoietic syndrome, sometimes referred to as the bone marrow syndrome, is produced by acute whole body doses of approximately 200 to 800 rads (2 – 8 Gy). Some authors place the range at 100 to 1000 rads and others specify the upper end of the range low as 600 rads.

Death, if it occurs, is primarily a result of damage to the hematopoietic (blood forming) organs: red bone marrow, lymph nodes and spleen.

Damage to other systems, notably the gastrointestinal tract, also plays a role.

Hematopoietic Syndrome

Symptoms as a Function of Dose

Dose	Symptom	Percentage of exposed experiencing symptom	Onset post-exposure
50 – 100 rads (0.5 – 1 Gy)	Anorexia	15 – 50%	3 – 18 hrs
	Nausea	5 – 30%	3 – 16 hrs
	Vomiting	15- 20%	4 – 16 hrs

Hematopoietic Syndrome

Symptoms as a Function of Dose

Dose	Symptom	Percentage of exposed experiencing symptom	Onset post-exposure
100 – 200 rads (1 – 2 Gy)	Anorexia	50 - 90%	3 – 18 hrs
	Nausea	30 - 70%	3 – 16 hrs
	Vomiting	10 - 50%	4 – 16 hrs
	Fatigue and weakness	25 – 60%	3 – 24 hrs
	Bleeding (mild)	10%	1 – 5 weeks
	Fever and infection	10 – 50%	2 days – 5 weeks

Hematopoietic Syndrome

Symptoms as a Function of Dose

Dose	Symptom	Percentage of exposed experiencing symptom	Onset post-exposure
200 – 350 rads (2 – 3.5 Gy)	Anorexia	90 - 100%	1 – 48 hrs
	Nausea	70 - 90%	1 – 48 hrs
	Vomiting	70 - 90%	1 – 24 hrs
	Diarrhea	< 10%	4 – 8 hrs
	Fatigue and weakness	50 – 90%	2 hrs – 6 weeks
	Bleeding	10 - 50%	1 – 5 weeks
	Fever	10 - 80%	1 – 5 weeks
	Infection	10 – 80%	2 – 5 weeks
	Ulceration	30	3 – 5 weeks

Hematopoietic Syndrome

Symptoms as a Function of Dose

Dose	Symptom	Percentage of exposed experiencing symptom	Onset post-exposure
350 - 550 rads (3.5 – 5.5 Gy)	Anorexia	100%	1 – 72 hrs
	Nausea	90 - 100%	1 – 72 hrs
	Vomiting	80 - 100%	1 – 24 hrs
	Diarrhea	< 10%	3 – 8 hrs
	Fatigue and weakness	90 – 100%	1 hr – 6 weeks
	Headache	50%	4 – 24 hrs
	Bleeding	50 - 100%	6 days – 6 weeks
	Fever and Infection	80 - 100%	6 days – 6 weeks

Hematopoietic Syndrome

Symptoms as a Function of Dose

Dose	Symptom	Percentage of exposed experiencing symptom	Onset post-exposure
550 - 750 rads (5.5 – 7.5 Gy)	Anorexia and nausea	100%	1 – 72 hrs
	Vomiting	100%	1 – 48 hrs
	Diarrhea	> 10%	1 – 6 hrs
	Fatigue and weakness	100%	1 hr – 2 weeks
	Headache	80%	4 – 30 hrs
	Bleeding, fever and Infection	100%	10 – 14 days
	Dizziness and disorientation	100%	4 – 48 hrs

Hematopoietic Syndrome

Composition of Blood

Fluid (plasma)

Blood Cells:

a. lymphocytes (white blood cells)

b. neutrophils (white blood cells)

c. platelets (cytoplasmic fragments)

d. erythrocytes (red blood cells)

Hematopoietic Syndrome

Lymphocytes and the Effect of Radiation

Lymphocytes are a type of leukocyte (white blood cell) responsible for antibody production.

They are produced in the lymph nodes, the thymus and parts of the spleen.

Although mature lymphocytes are long lived and not divide, they are very radiosensitive and can be killed directly by radiation.

Hematopoietic Syndrome

Lymphocytes and the Effect of Radiation

Within 15 minutes of a dose as low as 10 rads, the lymphocyte population can be seen to decrease.

The decrease in the white blood cell population is referred to as neutropenia.

The rate of decrease in the number of lymphocytes can be used to estimate the dose.

Recovery of the lymphocyte population is slow.

Hematopoietic Syndrome

Neutrophils and the Effect of Radiation

Neutrophils are the most common type of granulocytes, a type of leukocyte produced in the myelopoietic cell renewal system of the red bone marrow. They fight infection by engulfing foreign particles in the body.

The neutrophils are radioresistant, but their life span is short (less than one day). Damage to their radiosensitive precursors results in a measurable decrease in the number of neutrophils within a few days of the exposure.

Recovery of the neutrophil population is faster than that for lymphocytes.

Hematopoietic Syndrome

Platelets and the Effect of Radiation

Platelets (aka thrombocytes) are cytoplasmic fragments produced by megakaryocytes in the bone marrow (also known as the thrombopoietic cell renewal system). They are not true cells but nevertheless play an important role in promoting the coagulation.

Platelets and mature megakaryocytes are radioresistant, however the megakaryocyte precursor stem cells and the immature megakaryocytes are radiosensitive.

Hematopoietic Syndrome

Platelets and the Effect of Radiation

The lifespan of platelets (8-9 days) is longer than that of the neutrophils which means they disappear more slowly.

The decrease in the platelet population is referred to as thrombocytopenia.

Hematopoietic Syndrome

Erythrocytes and the Effect of Radiation

Erythrocytes (red blood cells) are responsible for carrying oxygen from the lungs to the various tissues of the body.

Comparatively long-lived, they have an average life span of four months (120 days).

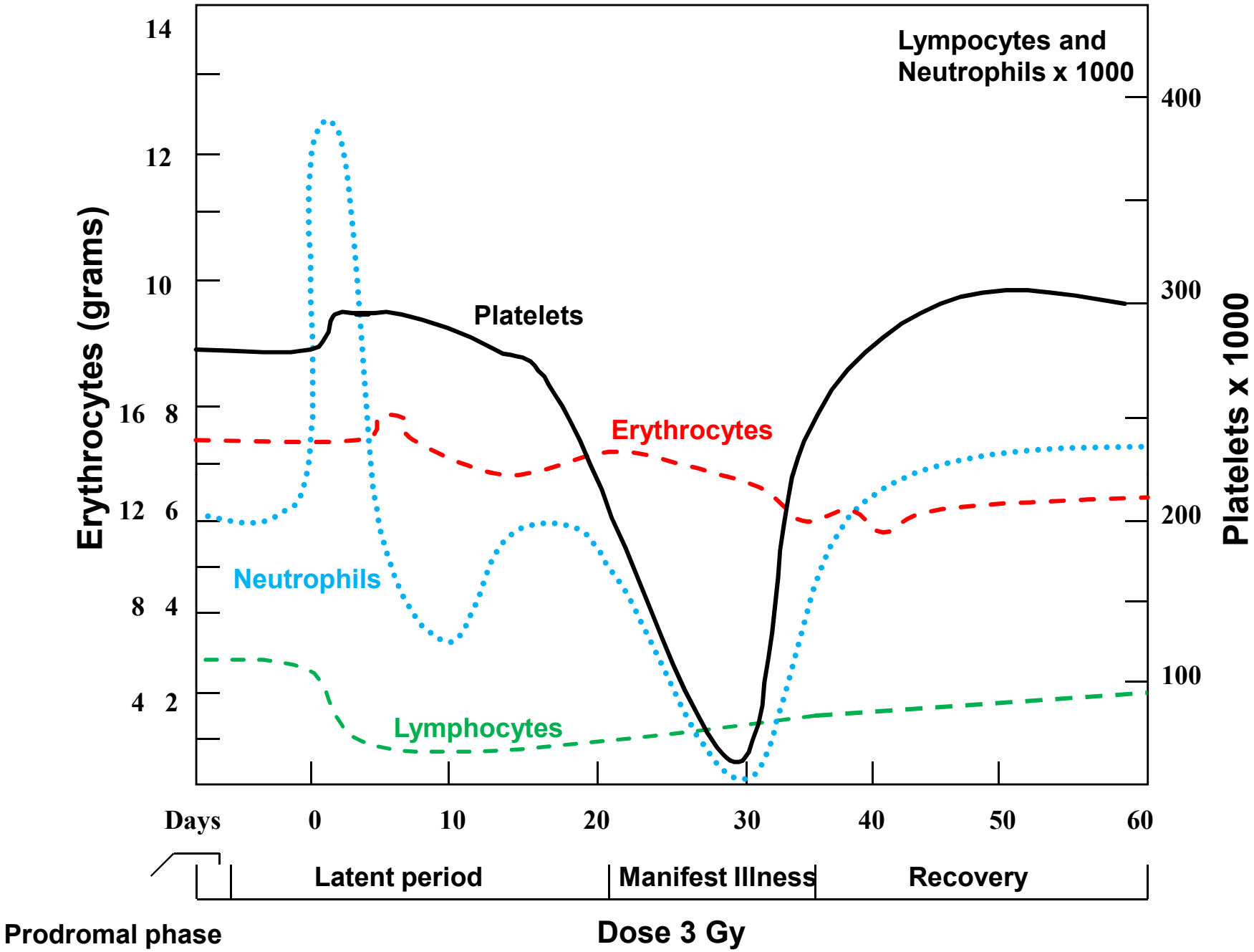
Hematopoietic Syndrome

Erythrocytes and the Effect of Radiation

Approximately one week after the exposure (above 10-20 rads, 0.1-0.2 Gy), a drop in the number of red blood cells will occur.

This decrease in erythrocytes is a result of damage to their radiosensitive precursors, the stem cells of the red bone marrow, the erythropoietic cell renewal system.

For the victim to have any chance of survival, some of these stem cells must survive the exposure.


Lympocytes and
Neutrophils x 1000
Erythrocytes (grams)
Platelets x 1000
14
12
10
16 8
12 6
8 4
4 2
400
300
200
100
Platelets
Erythrocytes
Neutrophils
Lymphocytes
Days
0
10
20
30
40
50
60
Latent period
Manifest Illness
Recovery
Prodromal phase
Dose 3 Gy

Hematopoietic Syndrome

Blood Cells and the Effect of Radiation

Lymphocyte and Granulocyte Populations Approximately One Week After Exposure (x 10^9)		
Dose	Lymphocytes	Granulocytes
100-200 rads (1-2 Gy)	0.8 - 1.5/liter	> 2.0/liter
200-400 rads (2-4 Gy)	0.5 - 0.8/liter	1.5 – 2.0/liter
400-600 rads (4-6 Gy)	0.3 - 0.5/liter	1.0 – 1.5/liter
600-800 rads (6-8 Gy)	0.1 – 0.3/liter	< 0.5/liter
> 800 rads (>8 Gy)	0 – 0.1/liter	< 0.1/liter

Hematopoietic Syndrome

Progress of the Hematopoietic Syndrome

Prodromal Phase

Following doses of 200 - 800 rads, the prodromal phase with its associated symptoms (e.g., anorexia, nausea, vomiting) typically occurs within 1 to 5 days of the exposure.

Latent Phase

This asymptomatic period lasts 1 to 3 weeks after the prodromal phase.

Hematopoietic Syndrome

Progress of the Hematopoietic Syndrome

Illness and Death or Recovery

Following the latent phase a period of extreme illness begins. Symptoms include nausea, fatigue, anemia (brought about by the decrease in the red blood cell population), fever, epilation (hair loss), anorexia (loss of appetite), impaired wound healing and petechial (pinpoint) hemorrhaging on the skin caused by damage to the lining of capillaries.

Hematopoietic Syndrome

Progress of the Hematopoietic Syndrome

Illness and Death or Recovery

Death, if it occurs, is typically within 2 to 6 weeks of the exposure. The most probable causes of death are hemorrhaging and infection.

The hemorrhaging is caused by damage to the radiosensitive cells lining the fine blood vessels and is compounded by the reduced population of platelets.

Infection occurs because the intestinal bacteria penetrate the damaged lining of the gastrointestinal tract. At the same time, the body's ability to fight infection is reduced due to a decrease in white blood cell population..

Gastrointestinal Syndrome

Gastrointestinal Syndrome

General

The gastrointestinal (GI) syndrome is associated with acute whole body exposures from 800 rads (8 Gy) up to 3000 rads (30 Gy).

Estimates for the onset of the gastrointestinal syndrome range from as low as 600 up to 1000 rads (6-10 Gy).

Death results from both the damage to the lining of the gastrointestinal tract and damage to the hematopoietic system.

Gastrointestinal Syndrome

Description of Gastrointestinal Tract Lining

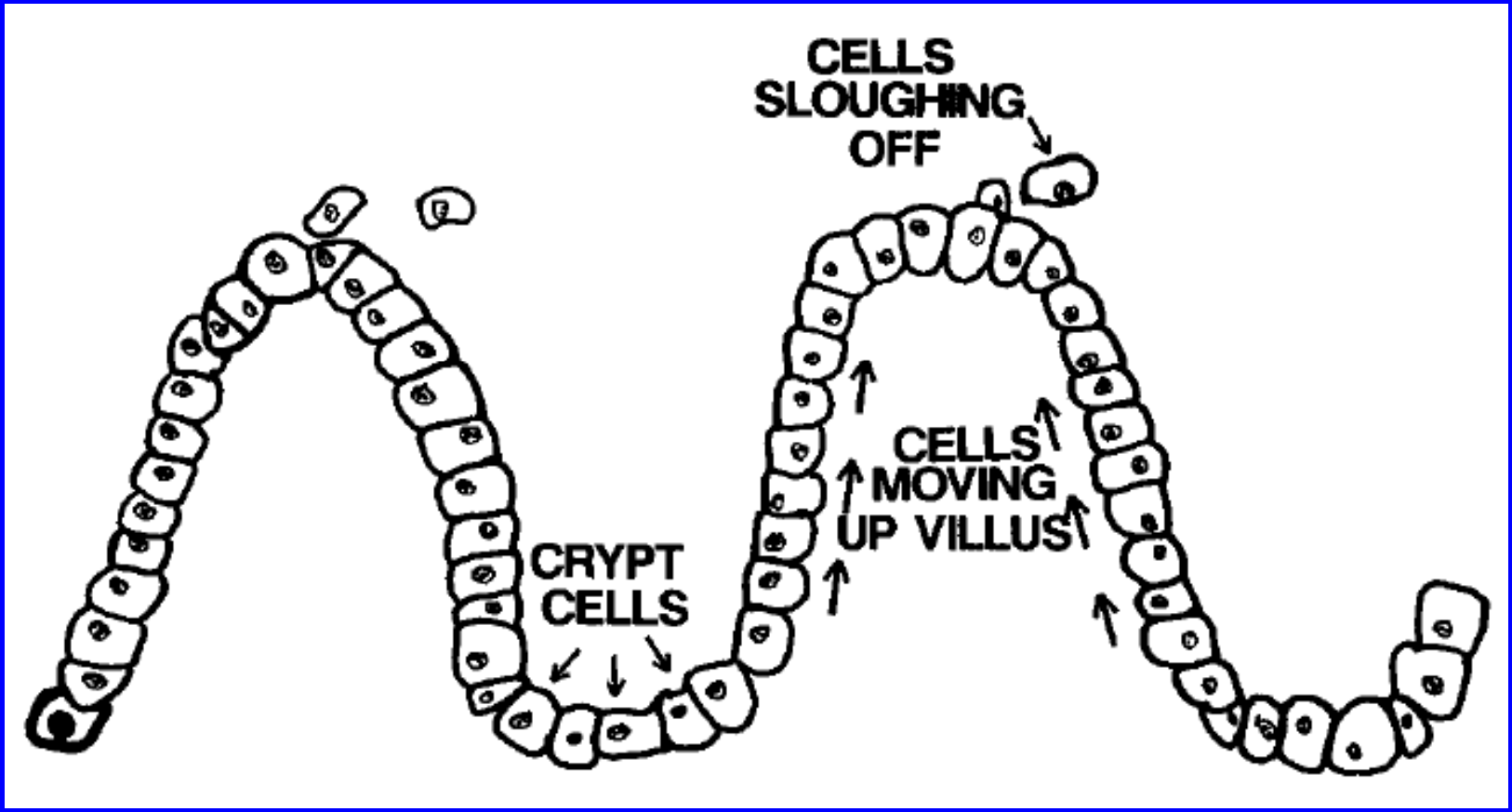
Much of the lining of the gastrointestinal tract is covered with small finger like projections called villi. The villi add to the effective surface area of the lining and thereby increase the capacity of the body to absorb nutrients.

The cells on the surface of the villi are constantly migrating towards the tip of the projections where they are sloughed off. Mitotically active stem cells at the base of the villi (the crypt area) replace those cells that are lost. Each crypt contains 30-40 stem cells.

The turnover rate of the epithelial cells is high - they have an average life span from 7 to 8 days.

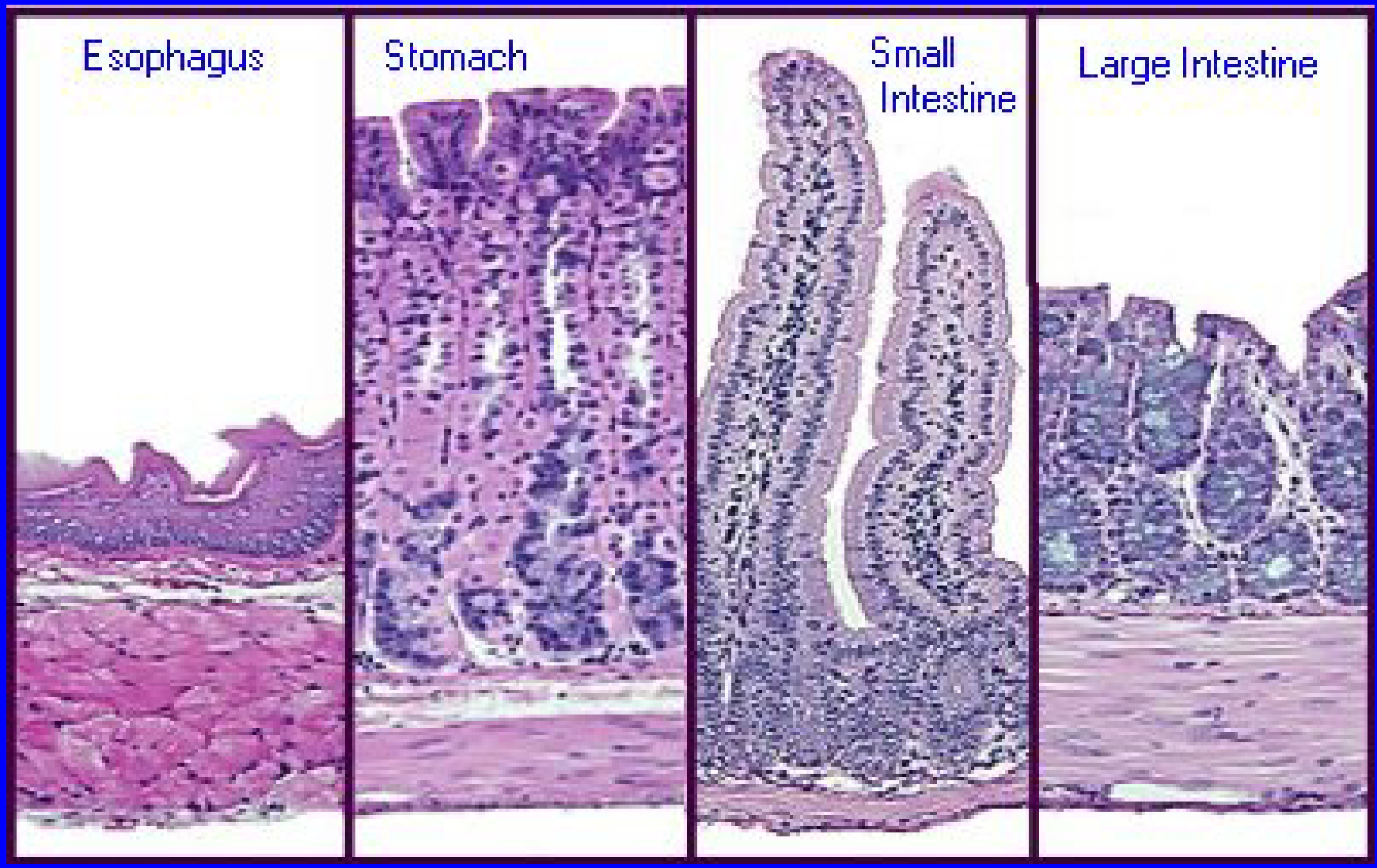
Gastrointestinal Syndrome

Gastrointestinal Syndrome



Gastrointestinal Syndrome

Gastrointestinal Syndrome



Gastrointestinal Syndrome

Effect of Radiation on Gastrointestinal Tract Lining

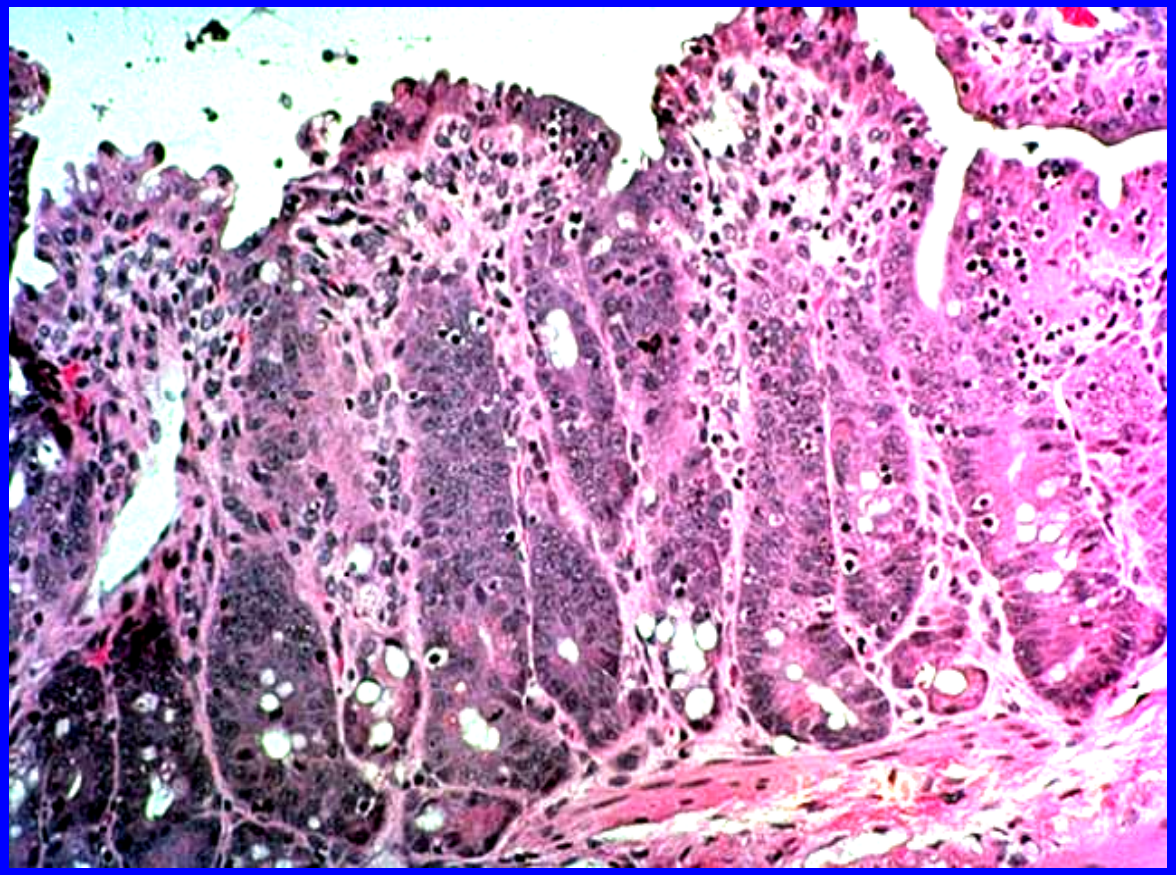
Sufficiently large acute exposures lead to the reproductive death of the rapidly dividing crypt cells. The cells covering the villi continue to be sloughed off but are no longer replaced.

This deterioration of the lining of the gastrointestinal tract then leads to a loss of body fluid, inadequate absorption of nutrients and infection from the intestinal flora (bacteria).

Above 1,000 - 1,200 rads (10-12 Gy) the crypt cells are completely destroyed. At this point, death is certain.

Gastrointestinal Syndrome

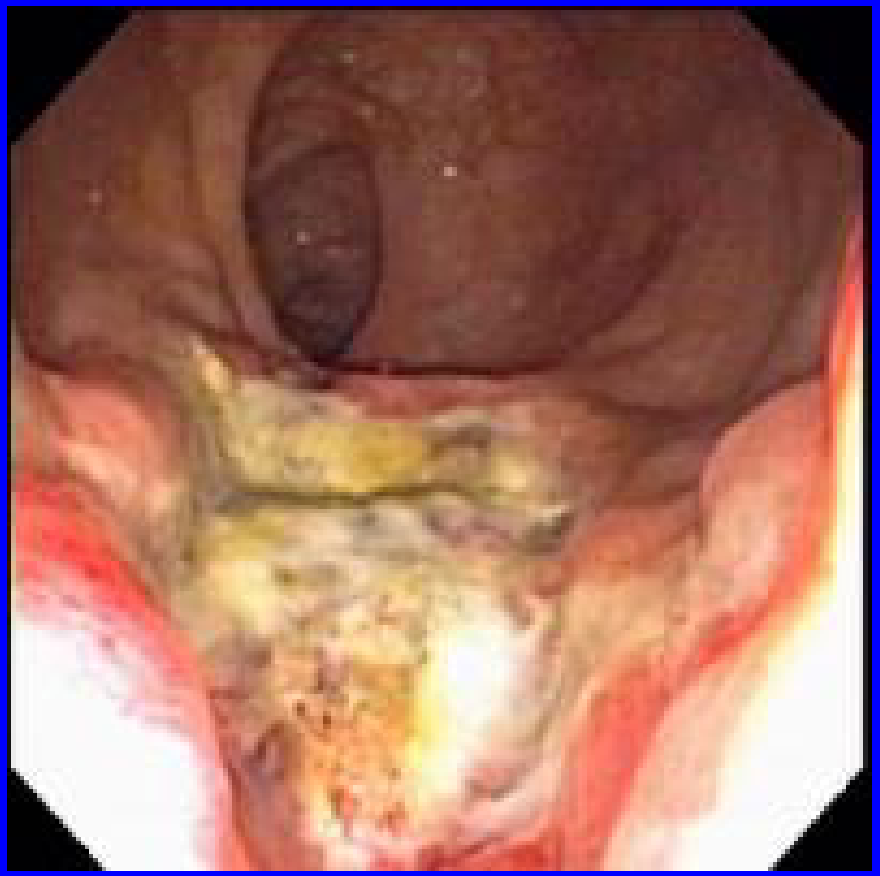
Effect of Radiation on Gastrointestinal Tract Lining



Irradiated GI – loss of epithelial cells

Gastrointestinal Syndrome

Effect of Radiation on Gastrointestinal Tract Lining



Irradiated GI

Gastrointestinal Syndrome

Progress of the Gastrointestinal Syndrome

Prodromal Phase

Within a couple of hours of the exposure the individual will demonstrate a sharp loss of appetite, upset stomach and apathy. Several hours later nausea, severe vomiting and diarrhea (possibly bloody) will occur

Latent Phase

By the third day after the exposure the previous symptoms will have disappeared and the victim will appear healthy. This asymptomatic phase might last for 1-7 days.

Gastrointestinal Syndrome

Progress of the Gastrointestinal Syndrome

Illness

This can include nausea, vomiting, ileus (failure of intestinal tract to move contents), diarrhea, fever, sepsis (whole body inflammation due to infection) hemorrhaging, apathy, anorexia and loss of weight.

Death usually occurs within 3 to 12 days of the exposure. Since the cell renewal mechanism of the gastrointestinal tract has been completely destroyed and cannot be replaced, death is inevitable.

Gastrointestinal Syndrome

Progress of the Gastrointestinal Syndrome

Illness

Causes of death include fluid and electrolyte losses due to the destruction of the lining of the GI tract. These fluid losses also account for the loss of weight, diarrhea and thickening of the blood associated with the GI syndrome. There is an inability to absorb nutrients.

A contributing cause of death is infection which can occur within 24 hours of the exposure as the endogenous bacteria that inhabit the GI tract invade the body across the damaged lining. Damage to the hematopoietic system simultaneously reduces the body's ability to cope with the infection.

Cerebrovascular (Central Nervous System) Syndrome

Cerebrovascular Syndrome

General

Associated with doses over 3000 rads (>30 Gy) to the whole-body.

Always fatal.

Immediate nausea, vomiting, anorexia, disorientation and prostration, and irreversible hypotension; blood pressure will be markedly unstable.

Within hours of exposure, the victim will be listless, drowsy, tremulous, convulsive, and ataxic. Will likely fall into a coma.

Death most likely will occur within 24 to 48 hours.

Cerebrovascular Syndrome

General

Direct damage to the brain might occur due to electrochemical inactivation of the nerve cells that results from damage to the cell membranes.

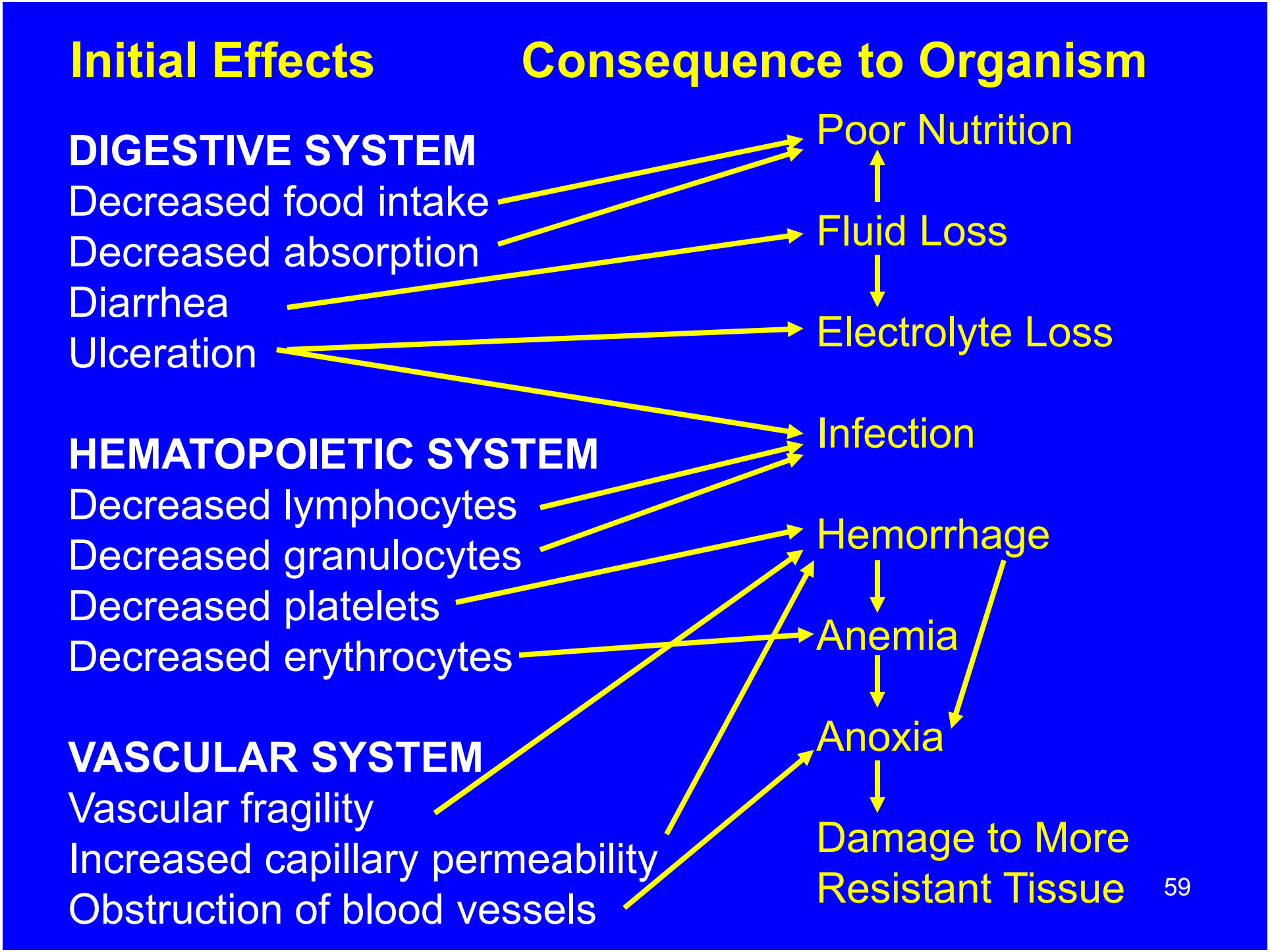
Most likely, death results from several causes, e.g., meningitis (inflammation of the membranes covering the brain), myelitis (inflammation of the spinal cord), encephalitis (inflammation of the brain), and vascular damage.

Cerebrovascular Syndrome

General

The blood vessels of the brain are known to be damaged by large doses of radiation. Because this damage increases the permeability of the vessel walls, fluid from the blood leaks into the skull cavity (edema) and causes a buildup of pressure inside the skull. Perhaps death is partly due to the increased pressure on certain areas of the brain (e.g., the respiratory center).

Death might also involve the change in the blood supply to the brain.


Initial Effects
Consequence to Organism
DIGESTIVE SYSTEM
Decreased food intake
Decreased absorption
Diarrhea
Ulceration
HEMATOPOIETIC SYSTEM
Decreased lymphocytes
Decreased granulocytes
Decreased platelets
Decreased erythrocytes
VASCULAR SYSTEM
Vascular fragility
Increased capillary permeability
Obstruction of blood vessels
Poor Nutrition
Fluid Loss
Electrolyte Loss
Infection
Hemorrhage
Anemia
Anoxia
Damage to More Resistant Tissue

Partial Body Exposures

Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

Exposure limited to skin and adjacent underlying tissue. Exposure might be from low energy x-rays, contamination on skin, external source adjacent to body.

Immediate damage from acute exposures only occurs in the exposed region of skin. This might lead to indirect effects in adjacent tissues at a later time.

The magnitude of the effect is primarily dependent on the dose, but the characteristics of the exposed skin also play a role. Fair skin is more radiosensitive than darker skin. The skin of the hands, feet, scalp, and eyelids is more radiosensitive than that of the face, trunk, arms and legs.

Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

The larger the area exposed (up to 400 cm^2 or so) the greater the effect.

The term “cutaneous radiation syndrome” or “cutaneous radiation injury” replaces the older term “radiation burns” for describing these injuries.

There are two components to the cutaneous syndrome: the early phase during the initial few months following the exposure and the long term chronic phase.

Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

Initial symptoms: itching, tingling, erythema.

Transient erythema (associated with itching) can occur within a few hours of exposure. This is followed by a latent, symptom-free phase lasting from a few days to several weeks.

After the latent phase, intense reddening, blistering, and ulceration of the irradiated site are visible.

It is possible that a third or fourth wave of erythema might occur over the ensuing months or possibly years.

Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

As long as the basal layer of the skin is not destroyed, the skin will heal itself.

Large doses can cause permanent hair loss, damaged sweat glands, atrophy, fibrosis, decreased or increased skin pigmentation, and ulceration or necrosis of the exposed tissue.

Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

Doses of 300-800 rads (3 - 8 Gy)

The minimum threshold for erythema (reddening of the skin). The effects can be compared to a first degree burn, i.e., sunburn. There is a reddening of the skin with some scaling (dry desquamation) possible.

This redness is caused by a dilation of capillaries just beneath the surface of the epidermis - probably due to a release of histamine. No medical treatment is required and the skin will completely recover.

Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

Doses of 300-800 rads (3 - 8 Gy)

In the first wave of erythema (if it occurs) the skin turns red 1 to 3 days after the exposure. The redness begins to fade by the end of the first week.

The second phase begins 2 to 3 weeks after the exposure and may last as long as one month. The second wave seems to be due to damage to the blood vessels. Perhaps the capillaries dilate to compensate for a decrease in oxygen reaching the tissue, a consequence of radiation damage to the small arterioles.

Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

Doses of 1000 - 5000 rads (10 - 50 Gy)

The effects from doses in this range can be considered similar to those from second degree burns.

The first wave of erythema occurs very shortly after exposure while the second phase may begin within the first to second week.

The second phase involves dry desquamation and, at higher doses (> 2000 – 3000 rads), wet desquamation. This loss of epidermis is due to the death of the germinal layer. With wet desquamation the loss of epidermis is associated with ulceration and the exudation of fluid.

Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

Doses of 1000 - 5000 rads (10 - 50 Gy)

In many cases the affected area is sharply demarcated forming a clear contrast with the surrounding healthy tissue.

Treatment is aimed at keeping the tissue clean, preventing infection and reducing any pain or irritation that is present. Healing will take weeks to months. After recovery, the skin might be pigmented and more susceptible to injury.

Treatment might include the oral administration of antihistamines (e.g., Loratadine) which can reduce itching sensation and shorten the duration of the erythema. Topical steroids can also be used to alleviate the erythema.

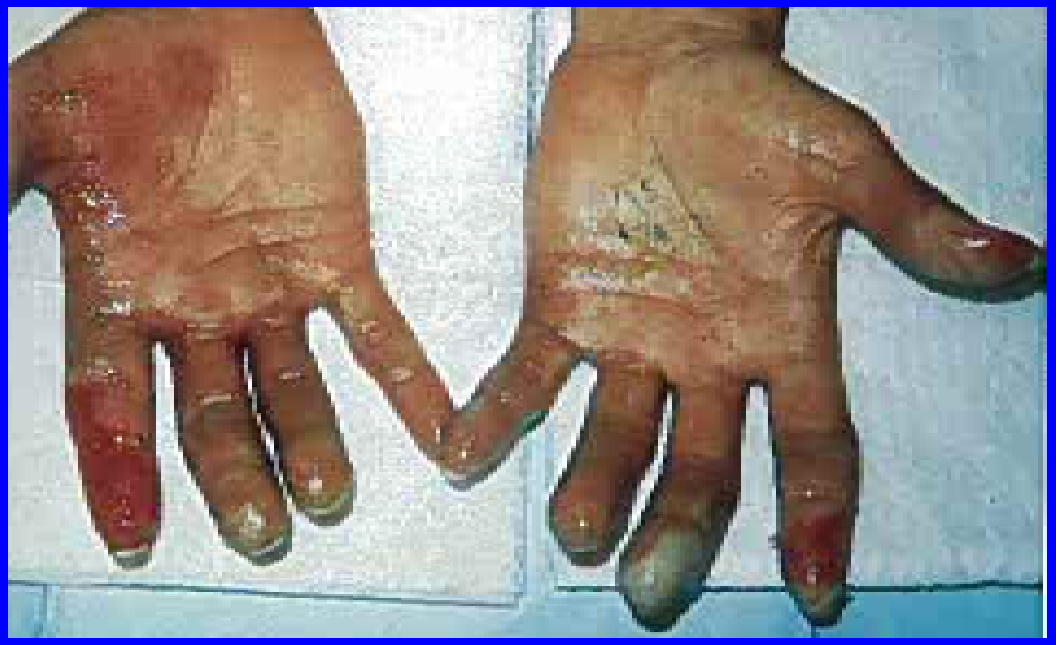
Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

Doses of 1000 - 5000 rads (10 - 50 Gy)

Twenty-four days after the exposure.

Blisters are breaking and dead skin is sloughing off.



Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

Doses above 5000 rads (> 50 Gy)

The results can be compared to a third degree burn.

The associated pain may be intense.

The germinal cells is destroyed and sufficient damage may be done for necrosis of the skin to result.

Infection and gangrene are among the short term concerns. Carcinogenesis is the long term worry.

Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

Doses above 5000 rads (> 50 Gy)

Treatment may require skin grafts and/or amputation.

Delayed tissue death may occur as deep fibrosis and collagen deposition gradually reduce the blood supply to the tissue.

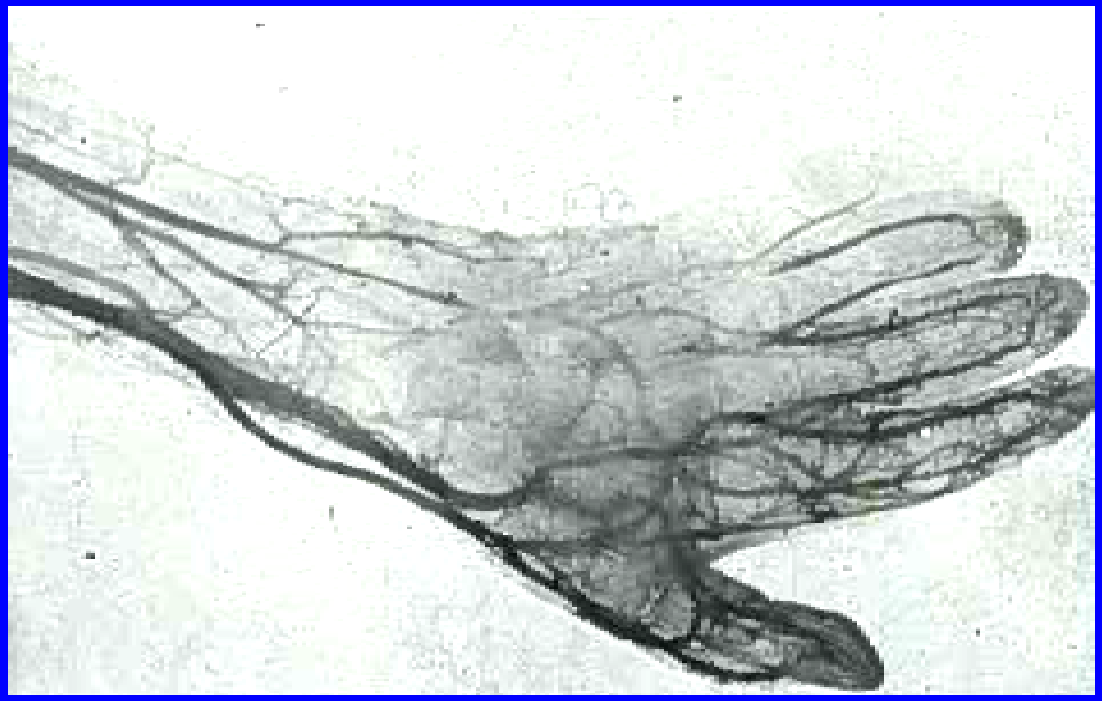
Rather than healing with time, the condition may get progressively worse.

Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

Doses above 5000 rads (> 50 Gy)

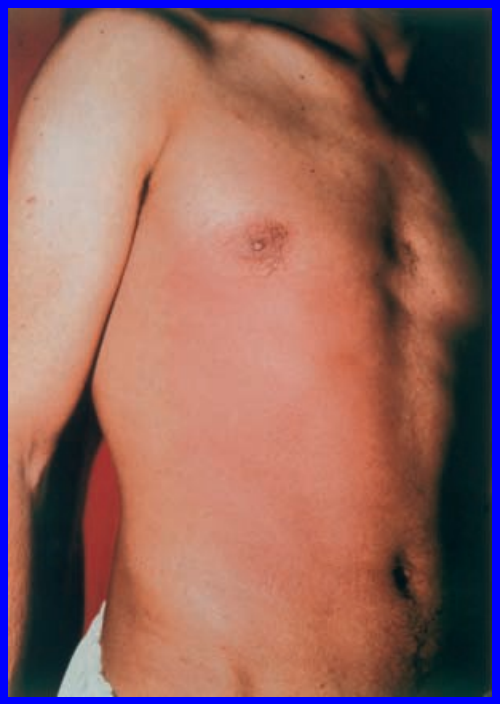
This arteriogram shows the circulatory system in the hand of an individual who picked up an industrial radiography source three weeks earlier. The dose was large enough to destroy many blood vessels.



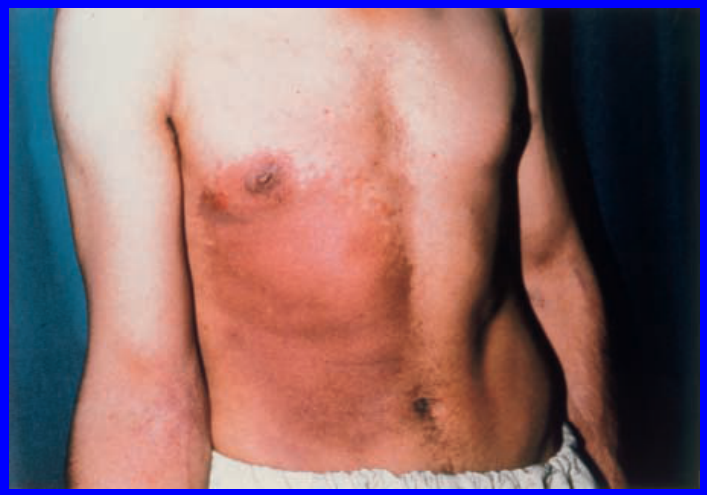
Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

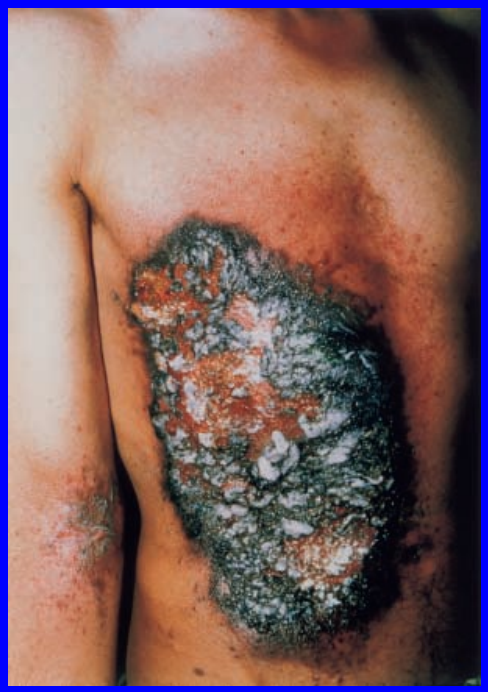
Doses above 5000 rads (> 50 Gy)



Day 6.
Beginning of erythema



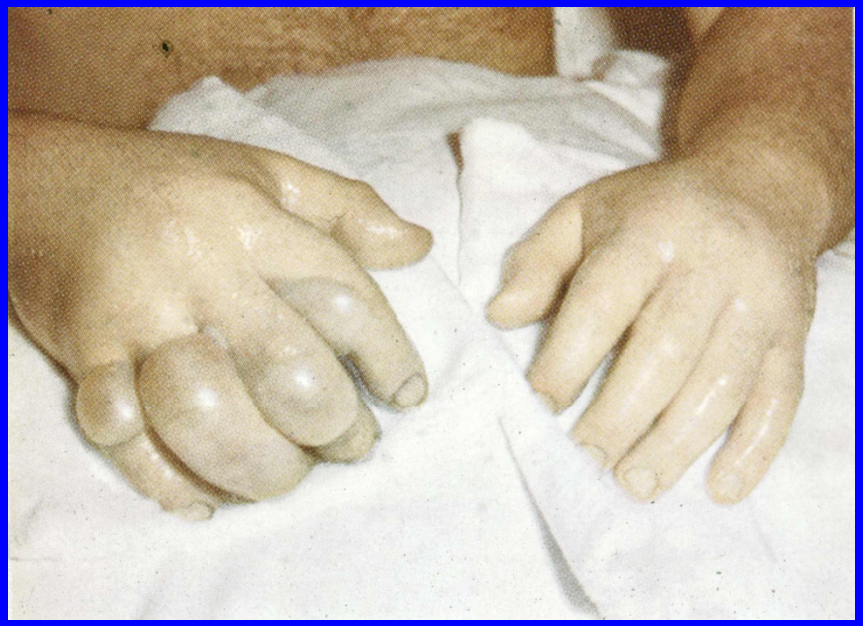
Day 12.
Dark erythema with beginning of dry desquamation



Day 15.
Tissue necrosis

Partial Body Exposures

Skin - Cutaneous Radiation Syndrome/Injury

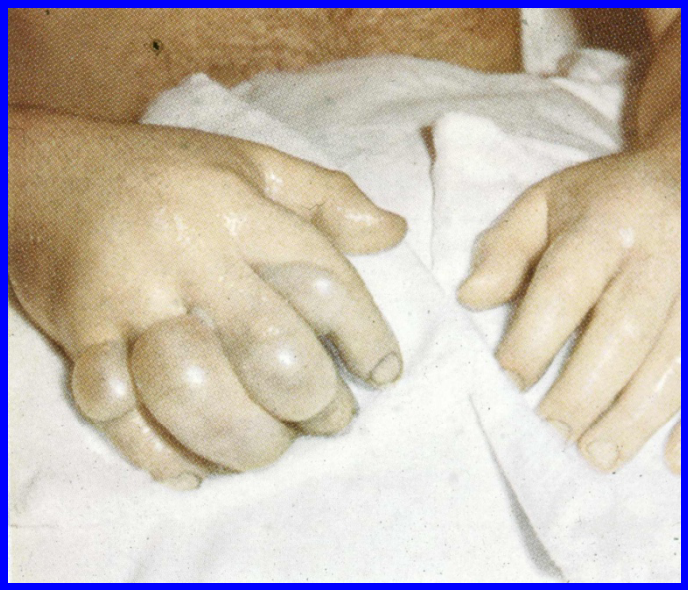


Day 9 following criticality accident.

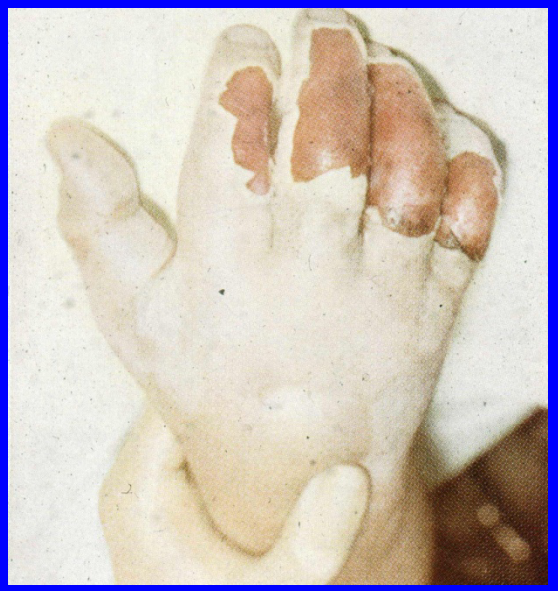
Blood vessels become permeable to fluid so that exposed areas swell (edema). Hempelmann et al., Ann. Int. Med. 36:289-510, 1952

Partial Body Exposures

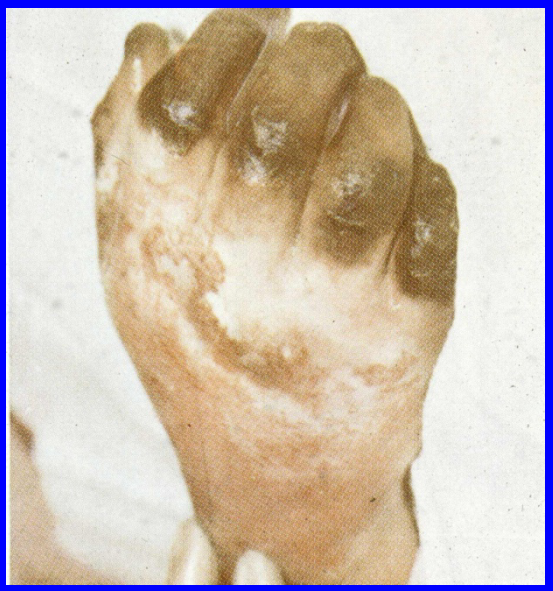
Skin - Cutaneous Radiation Syndrome/Injury



Day 9 following criticality accident.



Day 11



Day 16

Blood vessels become permeable to fluid so that exposed areas swell (edema).

Hempelmann et al., Ann. Int. Med. 36:289-510, 1952

Partial Body Exposures

Chronic Cutaneous Syndrome

The chronic phase of the cutaneous radiation syndrome can involve a gradual fibrosis brought about by the formation of collagenous tissue from the dermal and subcutaneous fibroblasts. There is a disappearance of fatty tissue and possibly blockage of blood vessels. Treatment might involve the administration of interferon, Vitamin E and pentoxifylline. Small localized spider-like veins, possibly associated with an itching and feeling of warmth, might appear on the skin (Telangiectasis). In most cases, these veins can be removed with a laser treatment.

Keratoses might develop in the exposed area - small growths such as a wart. Since these might be precancerous, they might be excised or at least monitored.

Partial Body Exposures

Epilation – loss of hair

Acute doses from 300 to 600 rads (3 – 6 Gy) to the skin may lead to a temporary hair loss approximately three weeks after the exposure. The hair can be expected to regrow within one to two months after the exposure. The new hair may be of a different color (white or gray) and of a different texture.

Acute doses above 700 rads (7 Gy) or so will lead to a permanent hair loss within three weeks.

These results are typical for exposures to the beard and scalp area. Hair on other parts of the body is less easily affected.

Partial Body Exposures

Sterility In Males

10 rads (0.1 Gy) to the gonads can result in a slight decrease in the sperm count.

25 rads (0.25 Gy) can reduce the sperm count by 30% six weeks after exposure.

50 rads (0.5 Gy) can cause brief temporary sterility in many men. Recovery of the spermatogonia and the subsequent increase in the sperm count to normal levels may take 40 weeks.

250 rads (2.5 Gy) will lead to sterility for 1 to 2 years.

500 - 600 rads (5 – 6 Gy) results in permanent sterility.

Partial Body Exposures

Sterility in Females

100 – 200 rads (1 – 2 Gy) temporary sterility for 1 to 3 years

350 - 400 rads (3.5 – 4 Gy) destroys the primary and secondary oocytes and leads to permanent sterility.

Partial Body Exposures

Fibroatrophy

Months or years after exposures of several hundred gray, the exposed tissues can deteriorate and be replaced by fibrotic tissue. The result is a gradual loss of tissue function.

Health Physicist's Role Following Acute Exposures

Health Physicist's Role following Acute Exposures

Immediate Response

First aid treatment for physical injuries should have the top priority.

If external contamination is possible, it should be looked for and dealt with.

Consideration might be given to administering a mild sedative.

Health Physicist's Role following Acute Exposures

Dose Estimates

The health physicist does not prescribe medical treatment. That is the physician's responsibility.

Once the exposed individual is in the care of a physician, the health physicist's role is to help obtain an initial dose estimate and to provide any assistance that is requested. The dose estimate can help determine the appropriate course to follow during the initial handling of the exposed individual.

A more detailed determination of the dose may be required later to help guide the medical treatment.

Health Physicist's Role following Acute Exposures

Assess Possible Intake

If there was a potential for radioactive material to get into the body, the health physicist might be involved in quantifying the potential intake. This assessment might involve some or all of the following:

In vitro bioassay:

- Analysis of nasal swabs
- Analysis of urine
- Analysis of feces
- Analysis of blood (possible but not standard practice)

In vivo bioassay:

- Whole body count

Health Physicist's Role following Acute Exposures

Assess Possible Intake

"Nasal swabs should always be promptly collected and analyzed, because a rule of thumb is that the anterior nares contain approximately 5% of the total inhaled activity, up to an hour or two after inhalation." (Ricks et al 2002).

Potentially contaminated clothing, wound dressing, etc. should be bagged, labelled and analyzed.

Dose Assessment

Dose Assessment

General

Volume 98 (No. 2), February 2010 of the Health Physics Journal contains the papers presented at the 8th International Symposium on EPR Dating and Dosimetry and 3rd Joint International Conference on Biodosimetry.

It is an excellent source of information concerning dose assessment following radiological incidents.

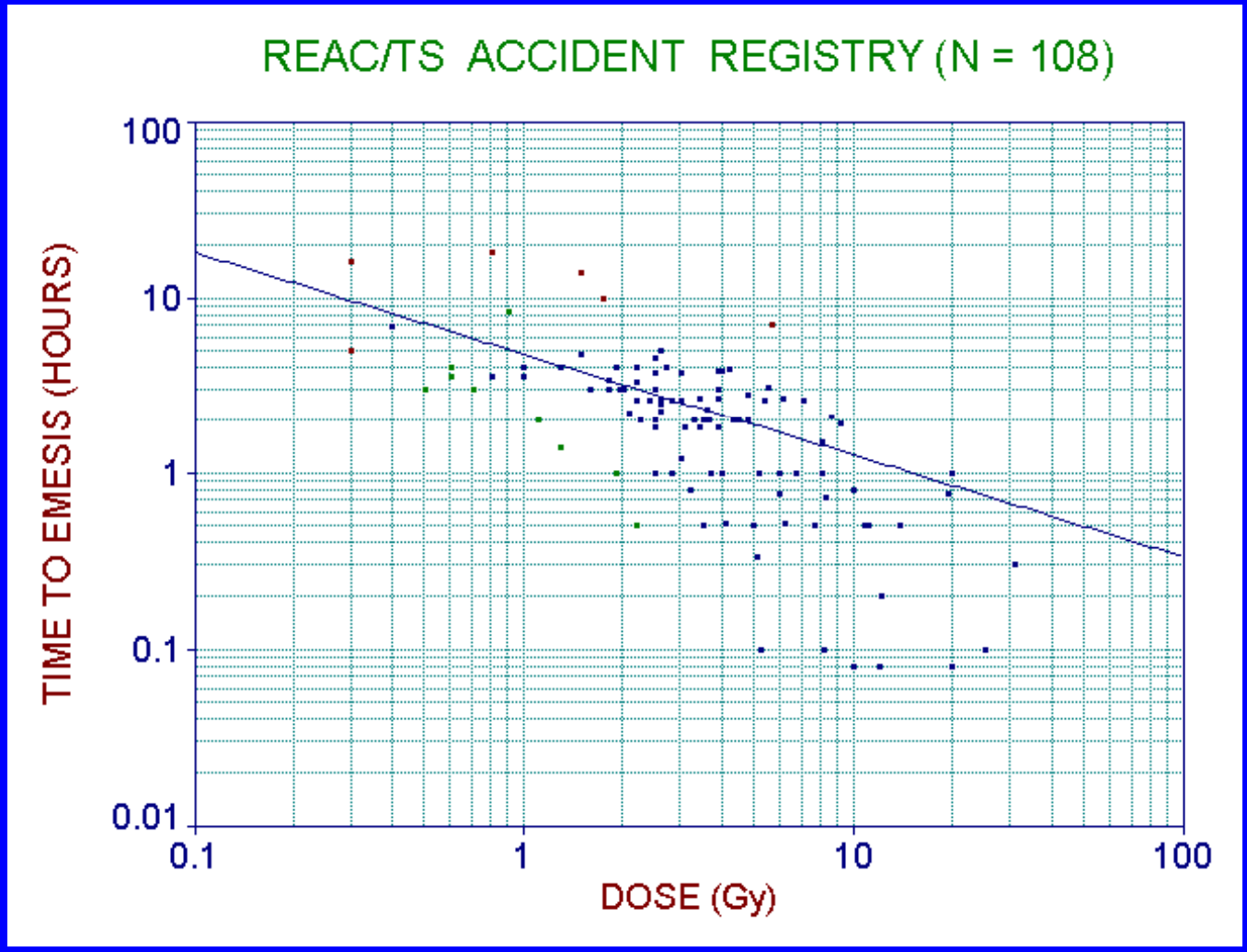
Dose Assessment

Initial Dose Estimate

- Observe and record all clinical responses. Although some of these (e.g., nausea, vomiting, etc.) may have psychological causes independent of the magnitude of the dose, it should first be assumed that they are a consequence of the exposure.
- If erythema occurs, obtain color photographs. These can help determine how localized the exposure was.
- Collect and process all personnel dosimeters but remember that this information may be misleading if the exposure was highly localized and/or the dosimeter was shielded by some part of the body. Obtain available information from area monitors.

Dose Assessment

Initial Dose Estimate



Time to emesis (vomiting) after exposure

Dose Assessment

Initial Dose Estimate

- Obtain available information from area monitors.

- Carefully interview all witnesses as soon as possible. Obtain their names, addresses and phone numbers. Early interviews are important because memories are short and witnesses may become unavailable if a weekend or holiday is near. When conducting the interview obtain information about the duration of the exposure, the position of the individual's body with respect to the source and the location of any objects that might have served as shields.

Dose Assessment

Lymphocyte Counts

Following an initial dose estimate of 20 to 100 rads (0.2-1 Gy), a blood sample might be taken the first day.

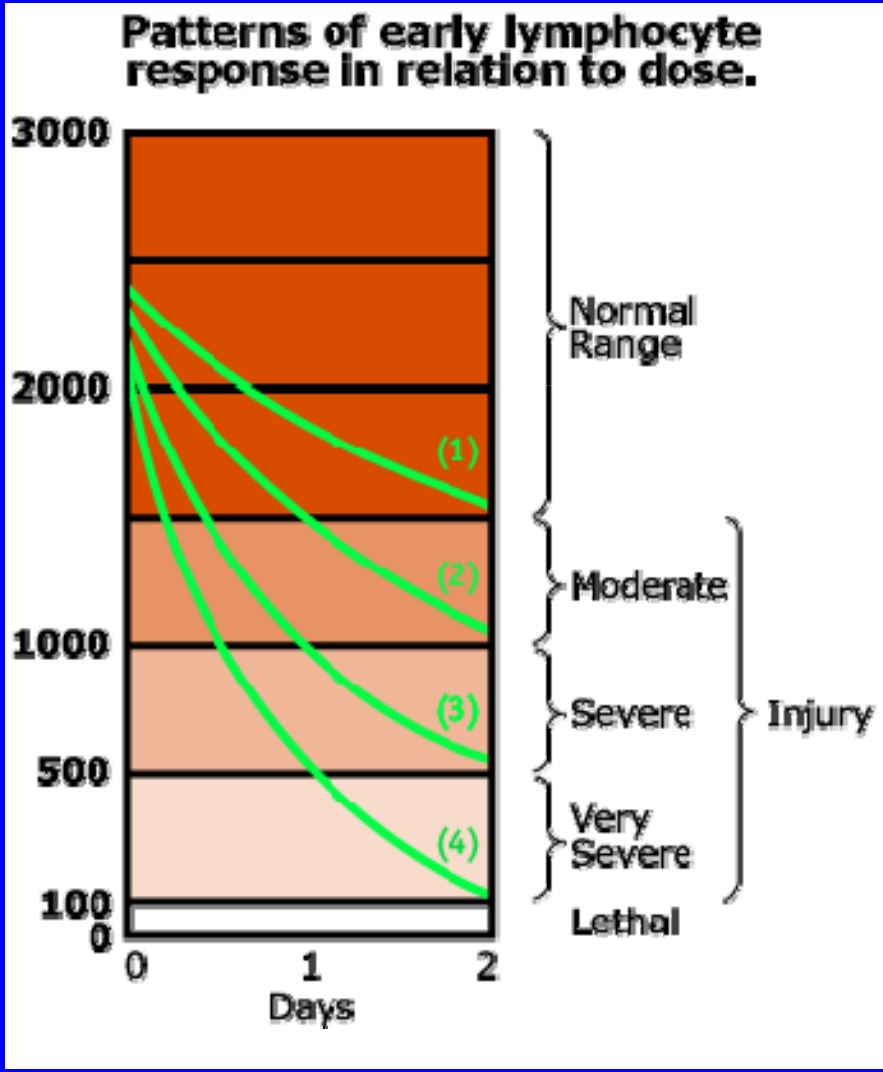
If the dose is estimated to be greater than 100 rads (> 1 Gy), blood samples might be taken every 6 to 12 hours during the first two days after the exposure.

The absolute lymphocyte count is considered the best single indicator of the severity of the exposure. As such, lymphocyte counts will be performed on each blood sample.

The hematocrit, platelet count, and total white blood cell (WBC) count might also be determined.

Dose Assessment

Lymphocyte Counts



Classical Andrews lymphocyte depletion curves and accompanying clinical severity ranges.

Curves 1-4 correspond roughly to the following whole-body doses:

Curve 1 - 3.1 Gy
Curve 2 - 4.4 Gy
Curve 3 - 5.6 Gy
Curve 4 - 7.1 Gy.

Dose Assessment

Lymphocyte Counts

Goans et al (2001) described the following method for estimating the dose – it assumes an exponential decrease in the lymphocyte population during the first 48 hours.

Multiple lymphocyte counts are obtained in the first 48 hours following the exposure and the following equation is solved for K.

$$L_t = L_0 e^{-Kt}$$

L_t is the lymphocyte count at day t
L_0 is the lymphocyte count at the time of the exposure, t = 0
t is the time after the exposure (days)
K is the depletion rate constant ($days^{-1}$)

Dose Assessment

Lymphocyte Counts

The depletion rate constant (K) is determined from the collected data.

This constant is then used to estimate the dose (D) in Gy via the following equation:

$$D = 8.6\ K$$

Dose Assessment

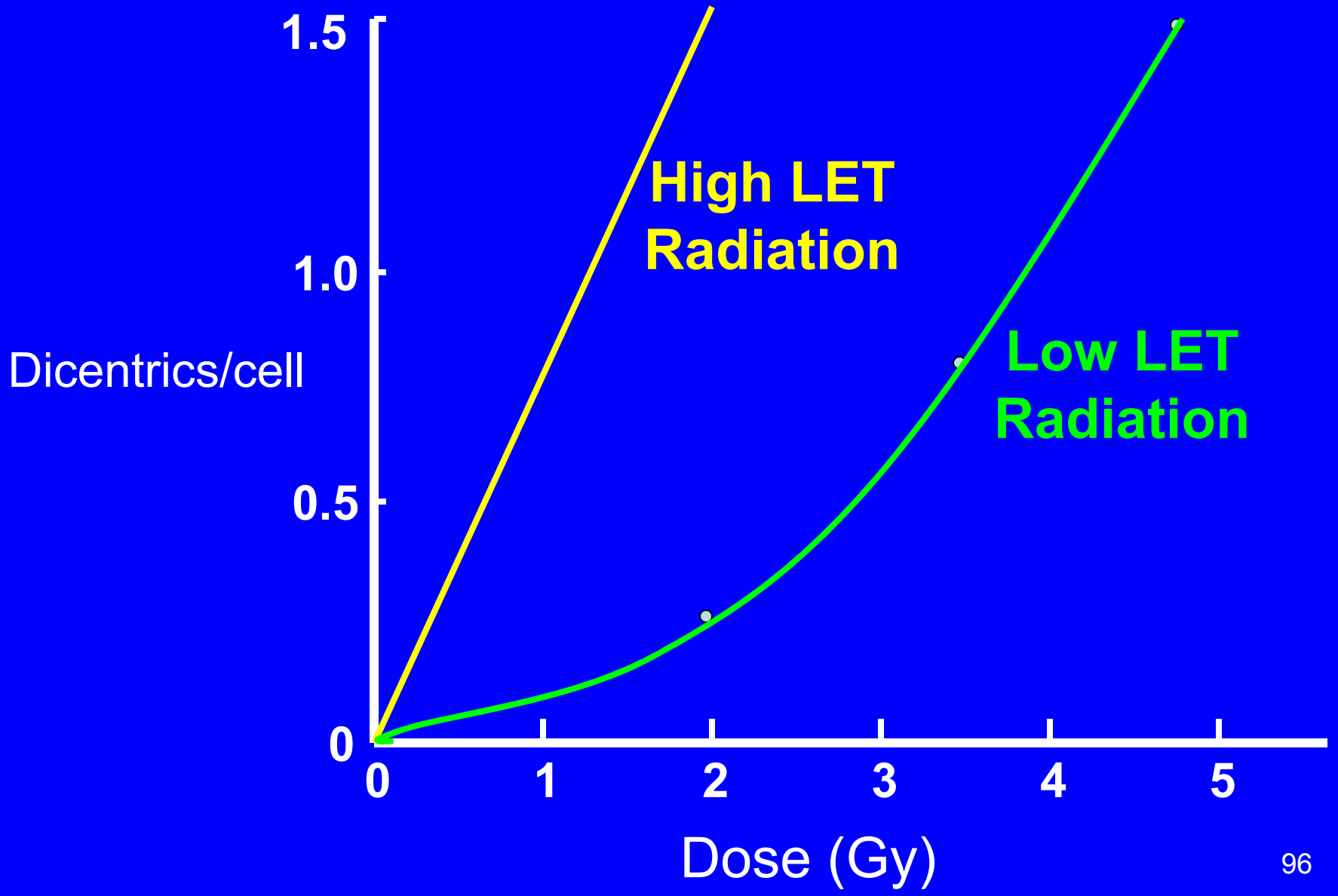
Cytogenetic Dosimetry "the gold standard"

Experts in cytogenetic dosimetry include the REACTS cytogenetics group at the Oak Ridge Institute for Science and Education, and the Department of Defense's AFRRI group. The technique can be useful in situations where the exposure exceeds 10-20 rads (0.1-0.2 Gy).

Peripheral blood lymphocytes are obtained and cultured for a couple of days. The cells are arrested in mitosis and analyzed under a microscope. The average number of dicentric chromosomes per cell is determined.

The number of dicentrics per cell is related to the probable dose with a graph such as the following:

Dose Assessment



Dose Assessment

Electron Paramagnetic (Spin) Resonance

In this technique an electron paramagnetic resonance (EPR) spectrometer is used to estimate the number of free radicals produced in certain materials. The greater the radiation dose, the greater the number of free radicals.

In most materials the free radicals disappear almost immediately after the exposure to radiation. However, in organic materials that contain little to no water (e.g., teeth, bones, hair, fingernails, sugar, etc.), free radicals can persist for weeks to years. As little as 10 mg of material is all that is required in the analysis.

EPR is only applicable if the exposures exceed 10 rads (0.1 Gy) or so, but it can do so long after the exposure.

Dose Assessment

Accident Reconstruction - Mathematical

It might be possible to assess the dose to the victim(s) mathematically.

Given a sufficiently straightforward situation (e.g., a uniform exposure to a gamma source), the calculations might be done by hand.

A more sophisticated approach would be to estimate the dose via computer modeling. A “standard” mathematical human model might be used, or a voxel phantom might be constructed from a CT or MRI scan of the victim. In either case, the dose to the different “tissues” would be determined using a Monte Carlo analysis.

Dose Assessment

Accident Reconstruction - Physical

In some situations (e.g., sealed source exposure), it might be possible to physically duplicate the accident conditions.

A tissue equivalent phantom would be positioned at the same distance(s) from the source and for the same period(s) of time as the victim. This phantom would have numerous dosimeters (e.g., TLDs) distributed throughout its volume. Analysis of the dosimeters would indicate the dose to different body tissues.

One of the most widely used phantoms for this purpose is the Alderson Rando phantom.

Dose Assessment

Neutron Exposure - Screening Method

If the exposure involved neutrons, the following method can be used as a screening technique to separate those who were seriously exposed from those who weren't:

A GM reading out in mR/hr is placed across the stomach of the potentially exposed individual. The latter bends over so that the probe is surrounded by the body. The neutron dose is roughly estimated by using the following relationship:

$$Dose\,(rads) \;=\; 8000\,\frac{Exposure\,rate\,(mR/hr)}{Body\,weight\,(pounds)}$$

$$Dose\,(Gy) \;=\; 3.6\,\frac{Exposure\,rate\,(\mu Sv/hr)}{Body\,weight\,(kg)}$$

Dose Assessment

Neutron Exposure - Screening Method

Ricks et al (2002) provided another quick and dirty way to estimate the neutron dose: "In terms of count rate, 70 counts per minute above background equals one rad of neutron dose."

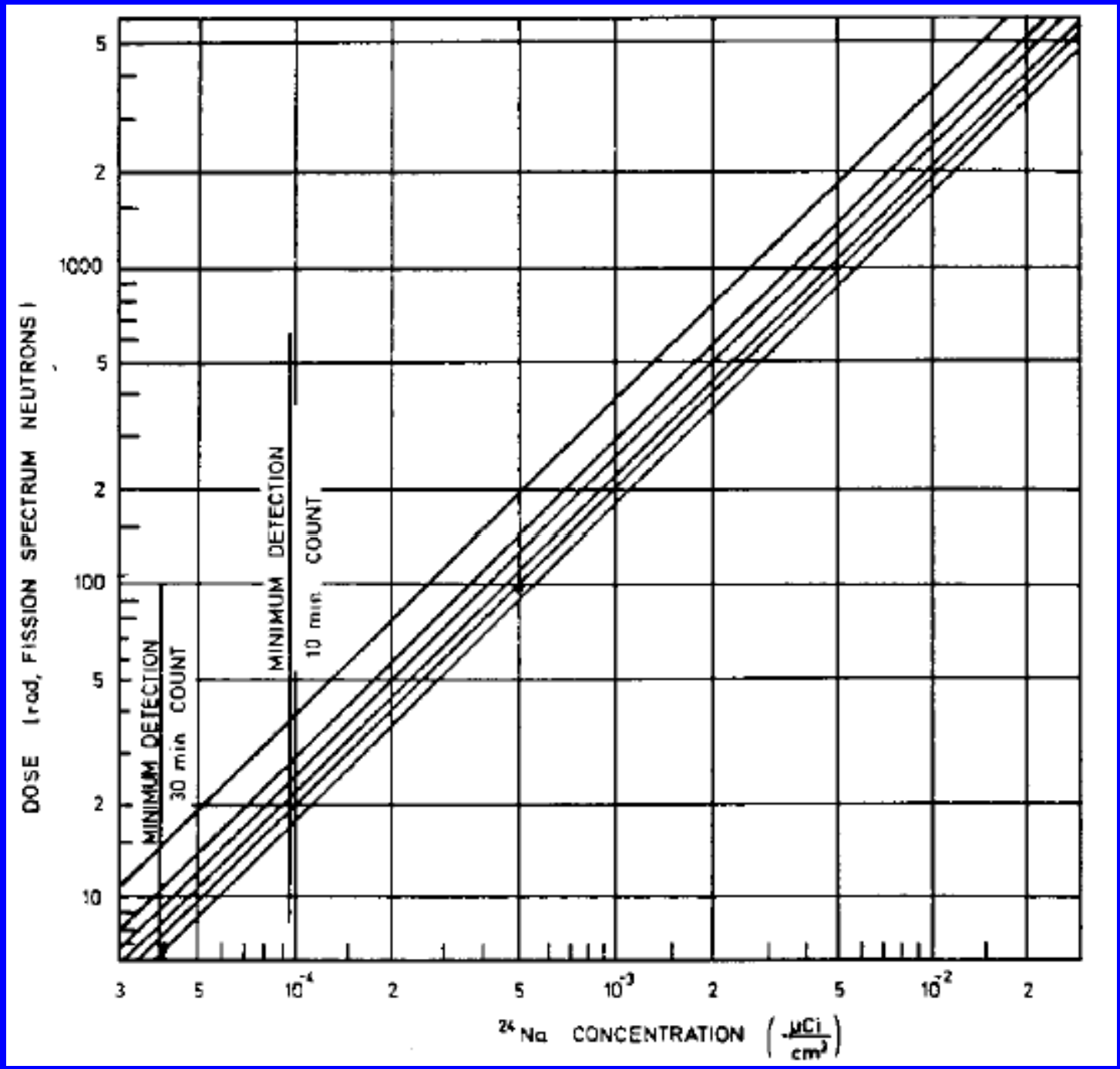
Metal objects such as coins, rings, watches and belt buckles should be collected. Activation products should be quantified by gamma spectroscopy. An estimate of the neutron fluence (n/cm^2) can then be made if the elemental composition of the target material is known. The estimate of the fluence is used to estimate the dose.

Dose Assessment

Neutron Exposure - Na-24 Concentration in Blood

To determine the neutron dose more precisely, the Na-24 concentration in the victim's blood might be measured by gamma spectrometry. This concentration is decay corrected to the time of the exposure.

Given the Na-24 concentration in the blood, a graph such as the following might be used (from IAEA Technical Report Series #152) to estimate the dose due to thermal neutrons.


DOSE (rad, FISSION SPECTRUM NEUTRONS)
5
2
1000
5
2
100
5
2
10
MINIMUM DETECTION
30 min COUNT
MINIMUM DETECTION
10 min COUNT
3
5
10⁻⁴
2
5
10⁻³
2
5
10⁻²
2
²⁴Na CONCENTRATION (μCi/cm³)

Medical Treatment: General

Medical Treatment: General

Hospitalization Guidance (from Ricks et al, 2002):

Dose less than 100 rads (< 1 Gy):
Treat victims as outpatients.

Dose of 100 - 200 rads (1-2 Gy):
While the victim could be treated as an outpatient, in most cases they will be hospitalized.

Dose of 200 – 400 rads (2-4 Gy):
Hospitalization required, preferably in a hospital with an intensive care unit and hematology department.

Dose above 400 rads (>4 Gy):
Victim should be placed in the intensive care unit of a hematology department.

Medical Treatment: General

General

The treatment depends on the symptoms. Nevertheless, the main effort is devoted to avoiding and fighting infection and assisting in the recovery of the blood forming tissues.

This might involve the use of antibiotics, erythrocyte and platelet transfusions, administration of cytokines (colony stimulating factors), and possibly bone marrow transplants.

During the prodromal phase, any nausea and diarrhea might be treated with Ondansetron.

Medical Treatment: General

Issues Regarding Infection

Since infections can appear soon after a large exposure (e.g., within 24 hours), nasal, mouth, throat, vaginal, skin, and urine cultures are made as soon as possible after the exposure.

Identified infections are treated immediately, e.g., oral mystatin to reduce *Candida.* Cultures will continue to be made twice a week.

The patient may be isolated in a laminar flow (bacteria free) room. If such a facility is unavailable, consideration may be given to sending the individual home; the chances of developing an infection at home are less than in a normal hospital setting.

Medical Treatment: General

Blood Cell Monitoring

Close watch is kept on the granulocyte and platelet levels.

If the granulocyte count drops below 1,500/mm^3 the following steps may be taken: administration of oral antibiotics
daily antiseptic baths
trim and scrub finger and toe nails

If the granulocyte count drops below 750/mm^3 and the infection is not responding, a transfusion of white blood cells may be performed.

If the platelet count falls below 40,000/mm^3 and/or bleeding occurs injections of platelets may be warranted

Medical Treatment: General

Palliative Treatment

If the exposure exceeded 1000 rads (10 Gy), the patient is not expected to survive and treatment will be palliative.

Attempts will be made to provide relief from the symptoms rather than provide a “cure.” For example, the patient might be administered pain killers, anti-depressant medication and be fed intravenously.

Medical Treatment: General

REACTS Guidance for Doses Exceeding 2 Gy (200 rads)

- Vomiting - use selective blocking of serotonin 5-T3 receptors or use 5-HT3 receptor antagonists.
- Consider initiating viral prophylaxis.
- Consider tissue, blood typing.
- Treat trauma.
- Consider prompt consultation with hematologist and radiation experts, re: dosimetry and prognosis, use of colony stimulating factors, stem cell transfusion, and other treatment options.
- Draw blood for chromosome analysis; use heparinized tube.
- Note areas of erythema and record on body chart. If possible, take photographs.

Medical Treatment: General

REACTS Guidance for Doses Exceeding 2 Gy (200 rads)

- SUPPORTIVE CARE in a CLEAN environment.
- Prevention and treatment of infections.
- Stimulation of hematopoiesis (use of growth factors, i.e., GCSF, GMCSF, interleukin 11).
- Stem cell transfusions: cord blood, peripheral blood, or bone marrow. Platelet transfusions if bleeding occurs or if platelet count too low.
- Psychological support.
- Observe carefully for erythema (document locations), hair loss, skin injury, mucositis, parotitis, weight loss, FEVER.
- Consultation with experts in radiation accident management is encouraged.

Hematopoietic Cell Transplantations and Colony Stimulating Factors

Hematopoietic Cell Transplantation and Colony Stimulating Factors

Hematopoietic Cell Transplantation

Hematopoietic cell transplantation consists of harvesting blood progenitor or stem cells from one individual for administration to the exposed victim. The donor and recipient should be matched as closely as possible.

The three most important sources of these cells:

bone marrow

peripheral blood progenitor cells

placental/umbilical-cord blood

Hematopoietic Cell Transplantation and Colony Stimulating Factors

Bone Marrow Transplants

With doses between 800 - 1200 rads (8-12 Gy), consideration might be given to a bone marrow transplant if a closely matched donor is available. Much above 1,000 rads (10 Gy), the crypt cells of the gastrointestinal tract are completely destroyed and attempts at salvaging the hematopoietic system are pointless.

The bone marrow is collected from the posterior pelvic bones under anesthesia. Significant pain that lasts a few days is common with this procedure.

Since it takes 2 to 3 weeks for the transplanted marrow to develop sufficiently to do some good, the transplant should be performed within a week of the exposure.

Hematopoietic Cell Transplantation and Colony Stimulating Factors

Bone Marrow Transplants

The body may attempt to reject the transplanted tissue and in the process so weaken itself. However, if the bone marrow transplant is accepted for several weeks, it might provide enough granulocytes for the victim to survive until their own bone marrow recovers and the transplant is finally rejected.

Of the 13 accident victims at Chernobyl who were given bone marrow transplants, two became long-term survivors. It has been speculated that the transplants may, in fact, have been a contributing cause of death in a few cases.

Hematopoietic Cell Transplantation and Colony Stimulating Factors

Peripheral Blood Progenitor (stem) Cell Transplant

These cells are collected directly from the donor's bloodstream following their mobilization from the bone marrow cavity by the use of hematopoietic growth factors.

Their collection is usually four top five days after the mobilization. The donor is likely to experience some pain during the mobilization phase.

Hematopoietic Cell Transplantation and Colony Stimulating Factors

Placental/umbilical-cord Blood Transplant

This is the blood (60 to 180 mls) that remains in the umbilical cord and placenta following birth.

The red blood cells and plasma are often removed while the cord blood is frozen. Advantages include the fact that there are no donor side effects (e.g., pain) and the fact that the cord blood - recipient HLA matching is less crucial.

Hematopoietic Cell Transplantation and Colony Stimulating Factors

Hematopoietic Growth Factors (cytokines)

Cytokines are naturally occurring proteins secreted by human leukocytes that stimulate the production of the progenitor cells in the hematopoietic tissue.

One important group of cytokines are referred to as colony stimulating factors (CSFs). The most important of these that can be produced in useful quantities are the granulocyte colony stimulating factor (G-CSF) and the granulocyte - macrophage stimulating factor (GM-CSF). Both have FDA approval are standard treatments for neutopenia.

Daily administration should begin soon after the exposure.

Hematopoietic Cell Transplantation and Colony Stimulating Factors

Hematopoietic Growth Factors (cytokines)

Another agent, recombinant human IL-11 (interleukin -2), has been approved by the FDA for the treatment of thrombocytopenia as has TPO (thrombopoietin).

Other similar agents currently being evaluated include Peg-MGDF and SD/01 (sustained-duration G-CSF).

These agents are not without side effects. For example, the administration of G-CSF can slow down the recovery of the platelets.

Rescuing Victims of Acute Whole Body Exposures

Rescuing Victims

General

In the course of an accident involving acute whole body overexposures, decisions regarding rescue operations must be made quickly and on the basis of fragmentary information.

NCRP Report 39 Guidance

Where it is necessary to search for and rescue injured persons as part of a life saving operation, the NCRP (in Report #39) at one time offered the following recommendations:

Rescuing Victims

NCRP Report 39 Guidance

1. Rescuers should be volunteers or professional rescue personnel.

2. Rescue personnel should be familiar with the possible consequences of exposure.

3. Women capable of reproduction should not participate.

4. Where possible, volunteers should be over 45 years of age. [This recommendation does not take into account the risks to an elderly individual from the physical strain that exhaustive rescue efforts might entail.]

Rescuing Victims

NCRP Report 39 Guidance

5. The "planned" dose to the whole body should not exceed 100 rems [rads].

6. Hands and forearms may receive a total dose of 300 rems [rads].

7. Such exposures should be limited to once in a lifetime.

8. Persons receiving such exposure should avoid procreation for several months.

9. The best available respiratory protection and protective clothing should be used if appropriate.

Rescuing Victims

NCRP Report 116 Guidance

Only lifesaving activities justify doses much in excess of the annual worker limits.

If the actions do not involve lifesaving the recommended limit is 0.5 Sv (50 rems).

For lifesaving purposes when 0.5 Sv might be exceeded, the volunteers should understand the potential for acute (early) effects and the lifetime increased risk of cancer.

The use of volunteers is desirable.

Older workers should be chosen whenever possible.

Rescuing Victims

Department of Energy Regulations 10 CFR 835

Subpart N—Emergency Exposure Situations

§ 835.1301 General provisions.

(a) A general employee whose occupational dose has exceeded the numerical value of any of the limits specified in § 835.202 as a result of an authorized emergency exposure may be permitted to return to work in radiological areas during the current year providing that all of the following conditions are met:

(1) Approval is first obtained from the contractor management and the Head of the responsible DOE field organization;

(2) The individual receives counseling from radiological protection and medical personnel regarding the consequences of receiving additional occupational exposure during the year; and

(3) The affected employee agrees to return to radiological work.

Rescuing Victims

Department of Energy Regulations 10 CFR 835
Subpart N—Emergency Exposure Situations

§ 835.1302 Emergency exposure situations.

(a) The risk of injury to those individuals involved in rescue and recovery operations shall be minimized.

(b) Operating management shall weigh actual and potential risks against the benefits to be gained.

(c) No individual shall be required to perform a rescue action that might involve substantial personal risk.

(d) Each individual authorized to perform emergency actions likely to result in occupational doses exceeding the values of the limits provided at § 835.202(a) shall be trained in accordance with § 835.901(b) and briefed beforehand on the known or anticipated hazards to which the individual will be subjected.

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