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October 30, 1978

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Dr. Victor Stello
Deputy Director
Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

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Dear Dr. Stello:

This is to comment on NRC regulations for self protecting SNM in research reactor fuel element, i.e. the requirement of a total external radiation dose rate in excess of 100 rem per hour at a distance of 3 feet from any accessible surface. One major weakness in this specification is that the dose rate is not connected with a specific quantity of SNM. If the intent of the regulation is to assure that a person handling the SNM would receive an incapacitating dose before he could complete the construction of a weapon, then it seems that the specified dose should be tied to quantity of material to be handled.

I suggest that the NRC consider the following specifications:

SNM quantity	5 kg
Incapacitating dose	1000 rem
Total exposure time	0.5 hr
Dose rate limit	$\frac{2000 \text{ rem/hr}}{5 \text{ kg}}$
	$= \frac{100 \text{ rem/hr}}{.250 \text{ kg}}$
	$= \frac{0.4 \text{ rem/hr}}{\text{gm}}$

This specification will allow research reactor fuel elements which have less than .25 kg to be self protecting if the dose rate at one foot is less than 100 rem; specificaally the dose rate limit would be calculated as 0.4 rem/hr for each gram of SNM material.

Relating the self-protection criteria to the weight of SNM will reduce radiological concerns since the total radiation level of irradiated fuel could be lowered. The increased radioactivity of the present requirements results in at least two concerns. First is the additional exposure to the reactor staff both during normal operation and special activities, such as shipment of

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expended fuel. Second, the possible consequences of industrial sabotage, as defined in 10 CFR Part 73, would be substantially increased by the increased activity level. Clearly the probability and consequences of sabotage and theft must be evaluated when defining the radioactivity level necessary to for SNM to be self protecting.

The basis for these recommended numbers is as follows:

SNM quantity, 5 kg: Formula quantity as defined by the NRC
Incapacitating dose, 1000 rem:

References:

Saenger, E. L., Medical Aspects of Radiation Accidents, U. S. Atomic Energy Commission (undated, but preface dated 1963).

Travis, E. L., Primer of Medical Radiobiology, Year Book Medical Publishers, 1975.

Saenger describes five clinical radiation injury groups with Group IV being in the dose range 600-1400 rad. This group is described in an accelerated version of the Acute Radiation Syndrome. Complications of gastrointestinal injury dominate the picture with early incidence of vomiting. Early onset of diarrhea, ataxia, disorientation, coma and cardiovascular collapse are all of importance.

Travis describes the gastrointestinal (GI) syndrome and states that doses between 1000 R and 10,000 R will result in the GI syndrome in all animals studied. In humans some symptom of the GI syndrome appear at a dose of 600R (the threshold dose). The full syndrome is apparent at 1000R. The LD_{100} for humans (between 600 and 1000R) is in the dose range of the GI syndrome. Survival time does not vary with dose in the syndrome; death occurs at the same time regardless of dose. In humans death occurs within 3 to 10 days if medical support is not administered and within approximately 2 weeks even with medical support. The prodomal stage of the GI syndrome occurs within a few hours post exposure and is characterized by severe nausea and vomiting, which may be accompanied by severe cramps and diarrhea.

This early sickness is justification for a total dose in the neighborhood of 1000R.

Exposure time, 0.5 hour: For elements loaded with .25 kg a person would have to handle 20 elements to obtain a formula quantity of SNM. The handling time would have to be less than 1.5 minutes per element to keep the total

exposure below 1000 rems. It is likely that the handling time per element in an unshielded configuration would be greater than 1.5 minutes and the absorbed dose correspondingly larger.

Impact on Research Reactors: The attached table lists research reactors with approximate fuel loading per element and operating power. Those in category I and III have less than .250 kg so the requirement for self protection would be less than 100 rems by an amount which is the ratio of the individual element loading to .25 kg. The reactors in category II are all more heavily loaded than .25 kg so their fuel would have to give a dose rate greater than 100 rem/hr. These four reactors all operate at higher powers and the loading per element per megawatt is comparable to those facilities in category I.

It appears from this table that the requirement of dose rate for a specified quantity of SNM as suggested here would not have an adverse effect on the operation of these reactors.

It is significant to note that an average fuel element in category I has about .16 kg so that one attempting to divert this fuel would have to transfer more than 30 elements.

In summary, I consider that relating the definition of self protecting SNM to the mass of SNM as recommended above results in an effective deterrent to theft while reducing the radiological concerns. I, therefore, recommend that 10 CFR Part 73 be revised to exempt from the requirements of Part 73 SNM which is not readily separable from other radioactive material and which has a total external radiation dose rate in excess of 0.4 rem per hour per gram at a distance of three feet.

Sincerely,

T. G. Williamson, Director
Reactor Facility

TGW:ec

cc: Mr. A. A. Sinisgalli
U.S. Nuclear Regulatory Commission
Mail Stop 228
Washington, D.C. 20555

APPROXIMATE SNM LOADING PER ELEMENT

I. Plate Elements with less than .25 kg:

	Fuel Loading	Reactor Power
Babcock & Wilcox	.190 kg	1 MW
Georgia Tech.	.188	5
University of Lowell	.124	1
University of Michigan	.140	2
Rhode Island	.124	2
Union Carbide	.196	5
University of Virginia	.192 and .162	2

II. Plate Elements with more than .25 kg

General Electric (GETR)	.511	50
M.I.T.	.445	5
University of Missouri (Columbia)	.775	10
NBS	.300	10

III. TRIGA Elements greater than 20% enriched

Ore. State, Texas A&M, Wisc. Washington State, G.A.	.123	1

IV. Other research reactors either operate at less than 1 MW or have fuel enriched to 20% or less.

Primer of MEDICAL RADIOBIOLOGY

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1975

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After this time the animal becomes obviously ill and exhibits the specific signs and symptoms of the particular syndrome reflecting the organ system damaged. This third phase is termed, appropriately, the *manifest illness stage* and also will last from minutes to weeks depending on the dose. Finally, the animal either recovers or dies as a result of radiation injury. Table 6-2 summarizes these stages.

The three radiation syndromes will be discussed in relation to findings in humans. Although the time of appearance of the signs and symptoms varies among different mammals, generally speaking, all mammals will exhibit similar signs and symptoms. Survival time following different doses varies greatly among species, with humans appearing to be a relatively radioresponsive species (see Table 6-1).

Radiation Syndrome in Humans

Data concerning the exposure of humans to acute total body radiation has been accumulated from the following sources:

1. Accidents in industry and laboratories (approximately 50 reported cases).
2. Pacific Testing Grounds accidents involving exposure to fallout.
3. The exposure of individuals at Hiroshima and Nagasaki.
4. Medical exposures involving total body or near total body radiation for cancer therapy or other reasons.

Although all of these situations provide an opportunity to study the response of humans to total body radiation, difficulties arise over the estimation of dose and the extent of exposure received by individuals in all cases except possibly one—medical exposure. In spite of these problems, the study of these individuals has resulted in a general pattern of the radiation syndromes in humans. One important point to keep in mind is that in most of these individuals medical sup-

TABLE 6-2.—STAGES OF THE TOTAL BODY SYNDROME

STAGE	TIME	MAJOR SYMPTOMS
Prodromal	Days–minutes	N-V-D syndrome Nausea Vomiting Diarrhea
Latent	Weeks–hours	None
Manifest illness	Weeks–hours	Symptoms reflect the systems damaged *Bone Marrow*—fever, malaise *Gastrointestinal*—malaise, anorexia, severe diarrhea, fever, dehydration, electrolyte imbalance *CNS*—lethargy, tremors, convulsions, nervousness, watery diarrhea, coma

port resulted in an increased survival time. Without this life-sustaining support, survival time would be decreased.

BONE MARROW SYNDROME.—The bone marrow syndrome in humans occurs between 100 and 1000 R with death occurring in a few individuals at a dose of 200 R. The $LD_{50/60}$* for humans is approximately 450 R or 250–300 R absorbed dose (rads) and is in the dose range of the bone marrow syndrome. Death of the individual in this syndrome is due to destruction of the bone marrow to an extent that will not support life.

The prodromal stage of the bone marrow syndrome occurs a few hours postexposure and consists mainly of nausea and vomiting. The latent stage lasts from a few days to 3 weeks postexposure, during which time the number of cells in the circulating blood are not severely depressed. The individual appears and feels well during this time; however, stem cells in the bone marrow are dying during both the prodromal and the latent stages resulting in a decreased production of mature cells and, therefore, a decrease in the number of cells in the circulating blood. This drop in blood cell count appears during the manifest illness stage, occurring at 3 weeks and possibly continuing through the fifth week postexposure (i.e., at low doses). During this time the individual exhibits the specific signs and symptoms of the bone marrow syndrome. The depression of all blood cell counts (pancytopenia) results in anemia (due to depression of RBCs and hemorrhage) and serious infections (due to the depression of white cells—leukopenia).

Survival in the dose range of the bone marrow syndrome decreases with increasing dose. At the lower limits of the dose range, 100–300 R, the bone marrow will become repopulated to an extent great enough to support life in the majority of individuals (Fig. 6-2). Full recovery of a large percentage of these individuals will occur from 3 weeks to 6 months postexposure. A few sensitive individuals may die 6 to 8 weeks after an exposure of 200 R; doses from 400 to 600 R (dose range of the $LD_{50/60}$) result in a decreased number of survivors. In these individuals partial repopulation of the bone marrow may occur, but not to a sufficient extent to support life. No human has been reported as surviving a dose of 1000 R.

As dose increases, survival time decreases—death occurring in

*Because humans appear to both develop and recover from the bone marrow syndrome later than other species, deaths may occur as late as 60 days postexposure. In addition, the majority of deaths occur by 30 days in humans whereas in animals they occur by 15 days. For these reasons the expression $LD_{50/60}$ may be more meaningful in humans than the $LD_{50/30}$ used in animals.

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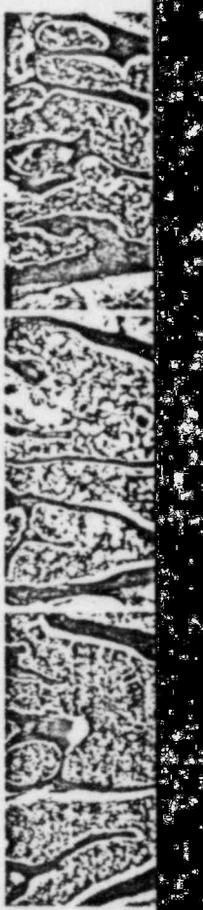

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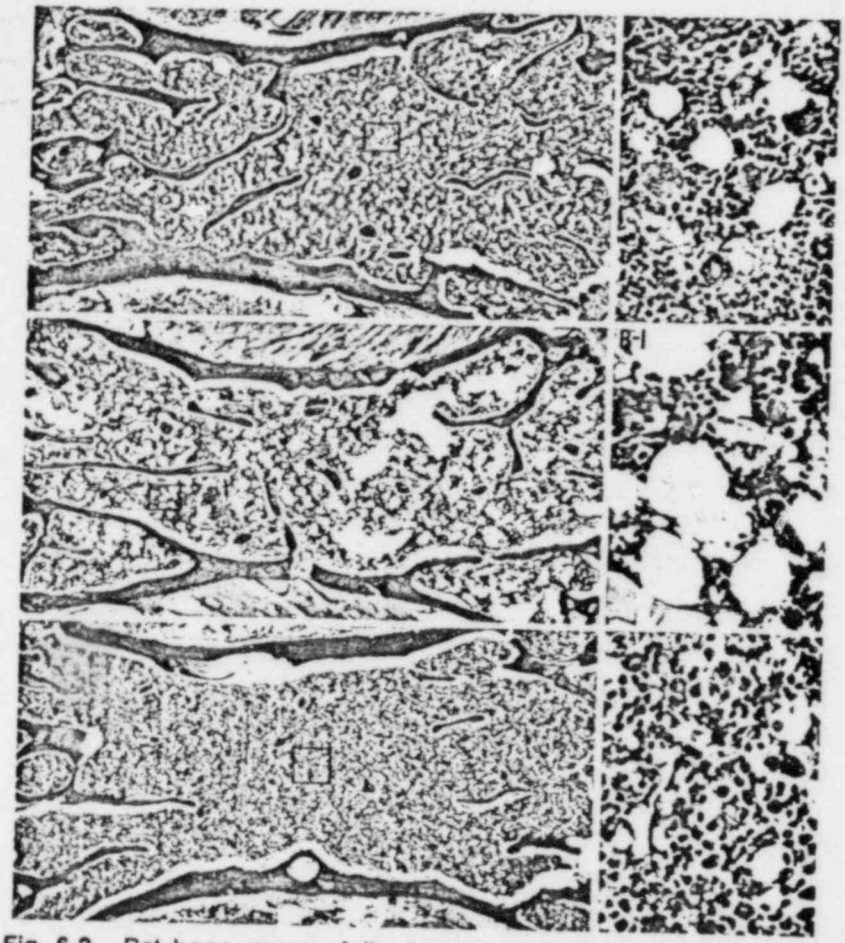


Fig. 6-2.—Rat bone marrow following a total body dose of 500 rads. **A**, normal. **B**, one week postexposure exhibiting hypocellularity and relative increase in fat. **C**, three weeks postexposure, contents now appear relatively normal indicating regeneration (absence of bony trabeculae in C is not a result of irradiation but is due to the area of the tissue sectioned). (H & E stain; A to C, magnification × 40; A-1 to C-1, magnification × 300.)

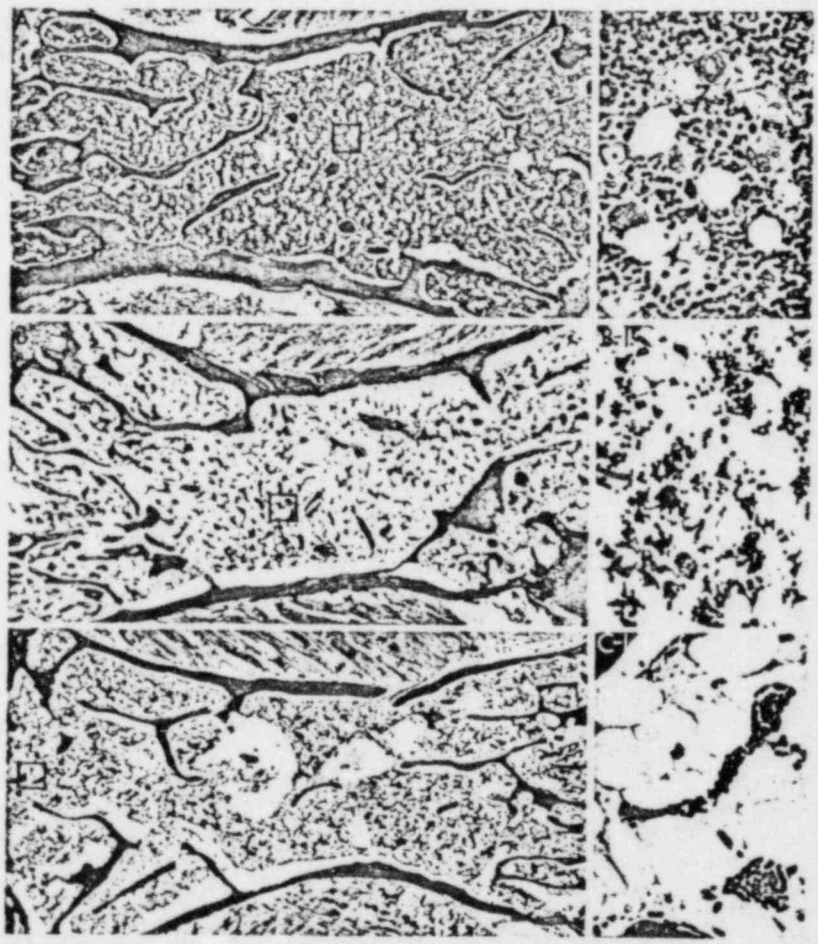
approximately 4 to 6 weeks at doses of 300 to 500 R but in 2 weeks at doses of 500 to 1000 R.

The primary cause of death from the bone marrow syndrome is destruction of the bone marrow resulting in infection and hemorrhage. The bone marrow is normally filled with cells that supply mature cells to the circulating blood. After exposures in this dose range, the number of cells in the bone marrow steadily decreases until the

bone marrow is not capable of producing those cells which are necessary in the circulating blood to sustain life (Fig. 6-3).

GASTROINTESTINAL (GI) SYNDROME.—The second defined acute radiation syndrome is the gastrointestinal (GI) syndrome. Doses between 1000 and 10,000 R will result in the GI syndrome in all animals studied; however, in humans some symptoms of the GI syndrome appear at a dose of 600 R (the threshold dose). The full syndrome is apparent at 1000 R. The LD_{100} for humans (between 600 and 1000 R) is

Fig. 6-3.—Rat bone marrow following a total body dose of 1000 rads (**B** and **B-1**) and 2000 rads (**C** and **C-1**), both illustrating a dramatic hypocellularity and increased fat content compared to normal (**A** and **A-1**). Those cells present are red blood cells due to hemorrhage. (H & E stain; A to C, magnification × 40; A-1 to C-1, magnification × 300.)



in the dose range of the GI syndrome. Survival time does not vary with dose in this syndrome; death occurs at the same time regardless of dose. In humans death occurs within 3 to 10 days if medical support is not administered and within approximately 2 weeks even with medical support.

The prodromal stage of the GI syndrome occurs within a few hours postexposure and is characterized by severe nausea and vomiting, which may be accompanied by severe cramps and diarrhea. From the second through the fifth day, the individual enters the latent stage and feels well. At the end of this time, there is a recurrence of severe diarrhea, nausea and vomiting accompanied by fever, signaling the onset of the manifest illness stage, which may persist from the fifth through the tenth day. Death occurs from the GI syndrome during the second week postexposure if life-sustaining support has been administered (fluids given, transfusions, etc.).

The GI syndrome is due to damage in two organ systems: the gastrointestinal tract and the bone marrow. The full GI syndrome does not occur if only the GI tract has been irradiated because the bone marrow plays an integral role in this syndrome.

The lining of the GI tract, particularly the small intestine, is severely damaged by doses in this range. The mitotic activity of the cells in the Crypts of Leiberkuhn, the radiosensitive precursor cells to the population of cells on the villi, will be decreased drastically following exposure. As a result the villi, which slough dead cells into the intestinal lumen every 24 hours and are dependent on the Crypts of Leiberkuhn for replacements, lose cells and become shortened, flattened and partially or completely denuded (Figs. 6-4 and 6-5).

The consequences to the individual of these changes in the GI tract are profound. The flattened villi result in decreased absorption of materials across the intestinal wall. Fluids leak into the lumen of the GI tract resulting in dehydration. Overwhelming infection occurs as bacteria that normally live within the GI tract gain access to the bloodstream through the intestinal wall causing systemic infection.

The effects of these drastic changes in the GI tract are compounded by equally drastic changes in the bone marrow. In fact, the effects of damage in the bone marrow occur at a time when damage in the GI tract is reaching its maximum. Of primary importance is the severe decrease in the number of circulating white cells. This depression occurs as bacteria are invading the bloodstream from the GI tract, therefore compounding an already severe problem. The remaining blood cells may not exhibit a severe decrease in numbers due to the fact that death occurs before radiation damage is reflected in these cell lines.

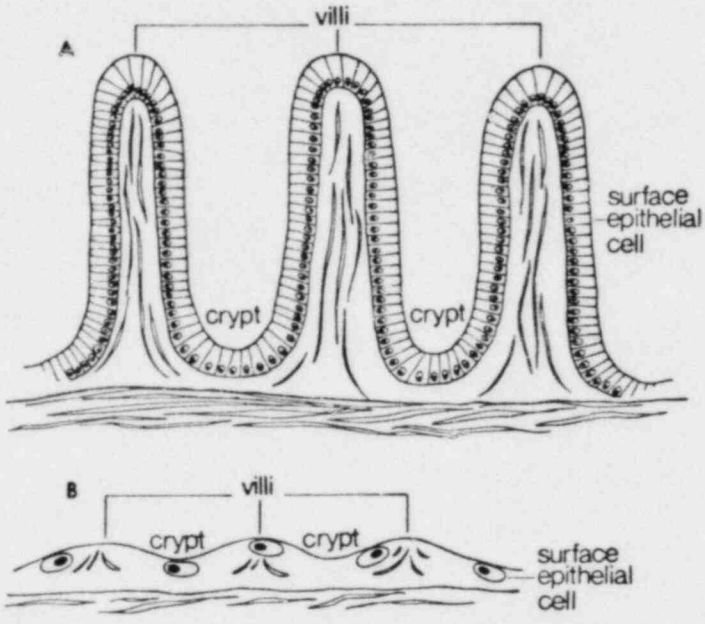


Fig. 6-4.—Diagrammatic representation of changes in the small intestine following total body exposure in the dose range of the GI syndrome. **A**, pre-irradiation; **B**, postirradiation.

Although attempts at regeneration occur in the GI tract after irradiation, particularly at the lower dose levels of the GI syndrome, the damage incurred by the bone marrow will probably still result in death (Fig. 6-6). Death from the GI syndrome is due primarily to infection, dehydration and electrolyte imbalance resulting from the destructive and irreparable changes in the GI tract and bone marrow.

CENTRAL NERVOUS SYSTEM (CNS) SYNDROME.—The full CNS syndrome occurs at a dose of greater than 5000 R in humans. Although CNS damage is evident at lower doses (2000 R), death from the full CNS syndrome occurs within 2 to 3 days following an exposure of 5000 R to all individuals.

The prodromal stage varies from a few minutes to a few hours dependent on dose. The signs and symptoms of this phase are extreme nervousness, confusion, severe nausea and vomiting, a loss of consciousness and complaints of burning sensations of the skin. A latent period next appears and may last for several hours, although often it is of shorter duration. The manifest illness stage begins 5 to 6 hours post-exposure, at which time there is a return of watery diarrhea, convulsions, coma and finally death.

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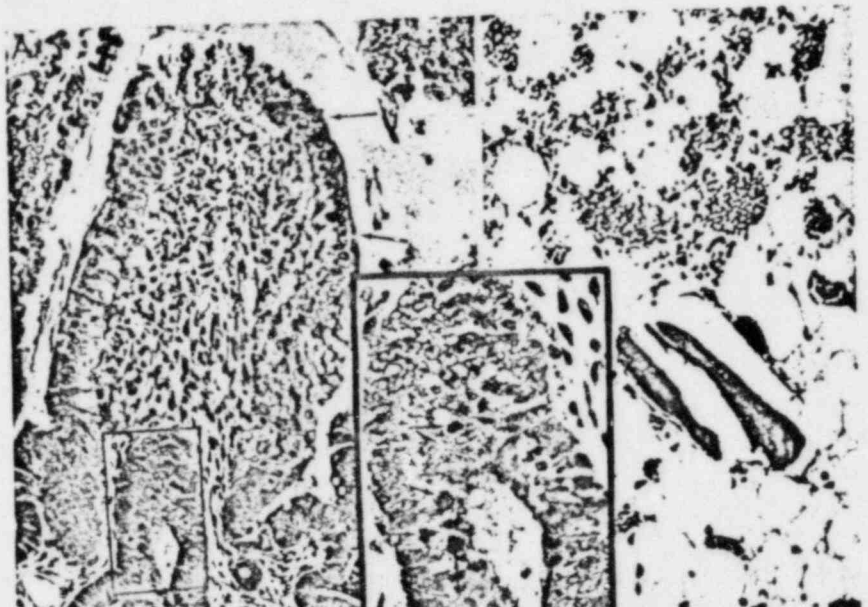

Fig. 6-6.—GI tract and bone marrow of rat exposed to 1000 rads total body irradiation. **A,** high-power view of edematous villi exhibiting atypical epithelial cells *(arrows)* and crypt with numerous mitotic figures. Insert indicates regenerative attempts *(arrows)*. **B,** bone marrow from same animal. Note the absence of all stem cells, only red blood cells are present. Although regenerative efforts occur in the crypts, the damage in the bone marrow is sufficient to cause death of the animal. (H & E stain; A and B, magnification × 175; insert, × 350.)

The cause of death in the CNS syndrome is not fully known or understood. Examination of the CNS after an individual has been exposed to a dose within this range reveals few changes in the parenchymal cells of the brain. This is not surprising keeping in mind the fact that these cells are nondividing and do not manifest damage as do the cells in the bone marrow or GI tract in which division of stem cells is necessary to provide the end cell to carry on the function of those systems. Damage in the CNS may be a result of damage to the blood vessels that supply the system resulting in edema in the cranial vault, vasculitis (inflammatory changes in the vessels) and meningitis (inflammation of the meninges). Death is suggested to be due to increased pressure in the confining cranial vault as a result of increased fluid content caused by these changes.

The bone marrow and the GI tract do not exhibit dramatic changes in the CNS syndrome because the individual does not live

TABLE 6-3.—SUMMARY OF ACUTE RADIATION SYNDROMES IN HUMANS AFTER WHOLE-BODY IRRADIATION*

SYNDROME	DOSE RANGE	TIME OF DEATH	ORGAN AND SYSTEM DAMAGED	SIGNS AND SYMPTOMS FINDINGS	RECOVERY TIME
Hemopoietic	100–1000 R†	3 weeks to 2 months	Bone marrow	Decreased number of stem cells in bone marrow, increased amount of fat in bone marrow, pancytopenia, anemia, hemorrhage, infection	Dose dependent—3 weeks to 6 months; some individuals do not survive
GI	1000–5000 R‡	3 to 10 days	Small intestine	Denudation of villi in small intestine, neutropenia, infection, bone marrow depression, electrolyte imbalance, watery diarrhea	None
CNS	> 5000 R	< 3 days	Brain	Vasculitis, edema, meningitis	None

*From Rubin, P., and Casarett, G. W.: *Clinical Radiation Pathology*, Vol. II (Philadelphia: W. B. Saunders, 1968).
†$LD_{50/60}$ for humans in this dose range (450 R).
‡LD_{100} for humans in this dose range (1000 R).

Medical Aspects of Radiation Accidents

A HANDBOOK FOR
PHYSICIANS, HEALTH PHYSICISTS
AND
INDUSTRIAL HYGIENISTS

Eugene L. Saenger, M.D., *Editor*

College of Medicine
University of Cincinnati

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The Group III and IV patients will require skilled care in order to achieve survival.

TABLE 3.1—CLINICAL RADIATION INJURY GROUPS

Group No.	Clinical manifestations	Dose classification by—	
		Thoma and Wald*	Gerstner**
I	Mostly asymptomatic. Occasional minimal prodromal symptoms.	10–160 rad.....	51–100 r 101–150 r
II	Mild form of Acute Radiation Syndrome. Transient prodromal nausea and vomiting. Mild laboratory and clinical evidence of hematopoietic derangement.	200–400 rad....	150–400 r Hematopoietic.
III	A serious course. Hematopoietic complications servere, and some evidence of gastroenteric damage present in upper portion of group.	400–600 rad (297+).	401–600 r Hematopoietic.
IV	An accelerated version of Acute Radiation Syndrome. Gastroenteric complications dominate clinical picture. Severity of hematopoietic complications is related to survival time after exposure.	600–1400 rad...	Gastrointestinal.
V	A fulminating course with marked central nervous system impairment.	10,000 rad ±50 percent.	Cerebral.

*Doses in rad according to approximate ranges of table III of Thoma and Wald [1].
**Approximate doses in r from table III and section on Dependency of Acute Radiation Syndrome on Air Dose of Gerstner's [2]. These doses are expressed as air dose, i.e., exposure dose, and are thus in terms of roentgens.

3.2 CLINICAL PROCEDURES

There is no substitute for careful daily history and physical examination of these patients. Only physicians, nurses and technicians with pertinent duties should be permitted access to such patients.

The Acute Radiation Syndrome is conveniently divided into four stages as follows:

1. Initial or prodromal — 1–4 days duration
2. Latent period — 2–3 weeks
3. Manifest illness — 2–6 weeks
4. Recovery stage

The most important findings to be sought for during the prodromal stage are listed in table 3.2A. For each item, the time of onset, severity, change and duration should be charted. This list should be reviewed and observations recorded at least daily, or oftener as needed.

called cerebral, gastrointestinal and hematopoietic forms (col. 4, table 3.1). This classification originally based on extensive animal studies, although of some value, may not be of much help in the assessment of the individual patient, and it is suggested that the concept of injury groups will be found more useful and will facilitate the proper investigation and care of the patient.

Briefly, the injury groups are as follows [4, 5]:

Group I: Most of the patients are asymptomatic; a few of them may have minimal prodromal symptoms.

Group II: These patients developed the Acute Radiation Syndrome in mild form. After transient prodromal nausea and vomiting, laboratory and mild clinical evidence of hematopoietic derangement dominates the picture.

Group III: A serious course occurs in these patients. Complications of hematopoietic malfunction are severe and some evidence of gastrointestinal damage may also be present.

Group IV: An accelerated version of the Acute Radiation Syndrome occurs. Complications of gastrointestinal injury dominate the picture. The severity of the hematopoietic disturbances is related to the length of survival following the exposure.

Group V: A fulminating course with marked central nervous system impairment occurs in this group.

TABLE 4.2—CLINICAL STAGES OF THE ACUTE RADIATION SYNDROME

	Approximate duration
1. Initial or prodromal stage	0 to 48 hours.
2. Latent stage	2 to 3 weeks.
3. Manifest illness stage	2d or 3d to 6th week.
4. Recovery stage	8 to 15 weeks.

4.3 Dose Response Relationships

Before discussing the clinical pictures and management in relation to the five groups, a few brief comments on the dose response relationships will aid in the understanding of the problem.

Doses are expressed in rad of total body irradiation and relative uniformity of distribution of the radiation throughout the body is thus implied. It should be realized that in most accidents there may be marked nonhomogeneous absorption of radiation in the body due to the proximity of the source of irradiation, partial shielding by surrounding objects, and the attenuating effect of the inverse square law. Furthermore, energy deposition in the body may be attenuated by absorption within the body. Thus even at considerable distances from the radiation source (where inverse square law effects are negligible), inhomogeniety will result from absorption of some of the

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radiation within the body. This situation may be particularly so for neutron irradiation.

If the dose can be confidently estimated, individuals who have received 50 rad of total body irradiation or partial body irradiation can be excluded from extensive investigation or study and will not require treatment. Where only a few such individuals are involved, particularly in civilian accidents, careful study will be important from the point of view of both the patient and the responsible organization. A review of well documented cases of total body exposure in the dose range of 50 rad or less has failed to yield evidence of symptoms, significant laboratory findings or short-term effects requiring any therapy.

When the dose is 100 rad most individuals will show no symptoms. About 15 percent of cases may show some of the features of the syndrome in mild form. At doses of 200 rad most of those exposed will show clinical symptoms and signs and will have significant laboratory test abnormalities. Fatalities may begin to occur at 200 rad and probably approach 50 percent at 450–500 rad. Statements such as these involving percentages serve to emphasize the factor of individual sensitivity which may be of the greatest importance. One man, for instance, may show prostration resulting from a dose of total body irradiation of, say, 100 rad, whereas another man may show no appreciable disability. The figures for 50 percent lethality in human beings (450–500 rad) are hypothetical since they are based on the supposition that there will be no therapeutic intervention. It is likely that with optimum treatment, according to present day knowledge, fatalities should rarely occur below a dose of 500 rad. A fatal outcome is probably inevitable at about the 800–1000 rad dose level, in spite of all currently available treatment.

4.4 Clinical Stage I (Initial or Prodromal Stage)

There may be difficulty in assessing this phase since it can be influenced by psychological factors of the individuals involved. The principal manifestations include anorexia, nausea, vomiting, extreme sweating, prostration, and malaise. The time of onset and the severity of these symptoms will depend on the dose. With large groups of patients a panic reaction may obscure the true significance of the symptoms in the prodromal period. Mass vomiting, weakness, diarrhea, etc., may be anticipated if groups of exposed people are kept together. For this reason, whenever possible, patients should be separated and put to bed immediately. Additional injuries, such as trauma or burns, may further complicate the picture and may tax the diagnostic acumen of the observer.

The prodromal stage will be considered from the point of view of development of symptoms in relation to time, and thus it will be seen that observations made in the first few hours might enable the clinician to make a useful preliminary assessment of the situation.

First Post-Exposure Hour: Symptoms during this period indicate either an overwhelming dose or a severe psychological reaction.

One to Five Hours Post-Exposure: The onset of prodromal symptoms occurs in this time interval in 90 percent of those exposed to a significant dose of radiation. In general, the earlier the onset, the higher the dose is likely to have been.

In Group I cases, the incidence of vomiting is negligible at 2 hours. If no vomiting has occurred by 4 hours, the patient is most probably in Group I.

In Groups II and III, the onset begins at one hour or soon thereafter.

In Groups IV and V, the timetable of events is accelerated. Early onset of diarrhea, ataxia, disorientation, coma or cardiovascular collapse is of serious prognostic importance and will indicate Group V cases. The amount of intensive care devoted to these very seriously injured patients will be determined by the total number of cases at risk and the availability of facilities.

Six to Eight Hours Post-Exposure: During this time the prodromal symptoms reach their maximum intensity.

Groups III, IV, and V cases show weakness and fatigue, conjunctivitis, sweating and paresthesia.

Twenty-Four to Forty-Eight Hours Post-Exposure:

In Group I and II cases, the prodromal symptoms have subsided.

In Group III, IV, and V cases there may be a persistence of symptoms with perhaps some gradual tailing off in Group III.

In Groups IV and V the clinical picture will be merging into that of the manifest illness without any intervening latent period.

Thus it can be seen that, provided there are no complicating features such as physical trauma, burns, etc., and no undue psychological overlay such as panic, hysteria, etc., it might be possible during the first post-incident 24 hours to diagnose provisionally from clinical observation alone the injury group into which the patient falls.

4.5 Clinical Stage II (Latent Period)

In Group I cases there will be no manifest illness and perhaps only minimal prodromal symptoms; therefore there will be no recognizable latent period. These patients will not need to be hospitalized if such facilities are limited, although they should avoid excessive physical activity and should be observed carefully and followed if adequate facilities are available.

In Group II cases the latent period is normally 2–3 weeks, during which time the patient is essentially asymptomatic apart from some weakness and fatigue.

In Groups III and IV the latent period is shorter, perhaps 5–14 days.

Group V cases may not have a discernible latent period. Fever, profuse sweating, insomnia, headache and skin changes may continue and intensify after the initial prodromal phase. In addition, other symptoms to be described later will appear.

4.6 Clinical Stages III and IV (Manifest Illness and Recovery)

Group I Cases:

These cases, as previously stated, show no symptoms attributable to radiation. They should be diligently followed, however, so that significant changes in the laboratory findings will not escape detection in individuals in whom overt prodromal symptoms might not have appeared. Certain of these patients might develop anxiety symptoms difficult to differentiate from those due to the radiation syndrome. Here, reassurance from the attending physician will be of great importance.

Group II Cases:

These patients show a mild to moderate "hematopoietic form" of the Acute Radiation Syndrome.

Seventeen to twenty days post-exposure there may be epilation, perhaps preceded by scalp tenderness for 1–2 days. The distribution of the epilation will depend on the orientation of the body in respect to the direction of the radiation. However, hair loss may be most marked in areas of the head in contact with the pillow. Clinical experience in radiation therapy has shown that epilation rarely occurs with single doses of less than 350 rad and that complete epilation occurs readily with single doses of 450–600 rad. However, the skin doses may vary with the type and energy level of the radiation and thus the occurrence of epilation could give only an extremely rough idea of the minimum dose that the patient may have received. Epilation may involve areas of the trunk and extremities and observation of the pattern of epilation may serve to indicate the geometry of the original accident situation. It can also be caused by beta radiation, the effect of which is confined to the skin. (See sec. 4.8.)

At about the same time (18–21 days) various other clinical manifestations begin. Chills, fatigue, fever, headache, exertional dyspnea and sore throat may occur. The patient's general condition deteriorates, requiring confinement to bed. Mucosal reddening and

tonsillar swelling may be seen in the oropharynx and some days later bleeding from the gums may occur after brushing the teeth. Hematuria and melena may occur or may be detected by laboratory tests and mild purpura may be seen. There is usually a gradual weight loss, and secondary infections, most often involving upper respiratory tract, are apt to occur.

Forty to fifty days after the exposure the clinical manifestations begin to remit and convalescence usually begins between 60 and 90 days.

Clinical recovery should be apparently complete within about 6 months, although some weakness may persist longer.

Group III Cases:

This group shows an accelerated version of the hematopoietic manifestations of the Acute Radiation Syndrome, and definite evidence of gastrointestinal changes. Vigorous therapeutic measures are indicated, although the prognosis is poor.

Twelve to fourteen days after the exposure the onset of symptoms is heralded by fever and sore throat. Marked pharyngitis with ulceration may be seen. Within a few days there is hyperemia and bleeding from the gums and loosening of the teeth.

At 16–18 days post-exposure, epilation begins and progresses rapidly. At about this time purpura of the skin and mouth are seen and occult blood can be found in the stools. These manifestations persist and during the subsequent week large ecchymoses develop. Marked pancytopenia is evident by this time and the bone marrow may show almost complete acellularity.

During the fourth post-exposure week the patient becomes prostrate, lethargic and intermittently disoriented. Oliguria may be noted and diarrhea begins, sometimes accompanied by massive hemorrhage from the bowel. There is often severe and progressive abdominal pain or cramps and sometimes ileus. Hematemasis and hematuria and, in females, vaginal bleeding, occur.

Between 25 and 40 days, in spite of vigorous therapy including parental fluids, nutrients, blood transfusions and other supportive measures, death may occur, preceded by profound shock and coma.

Group IV Cases:

These patients have received an overwhelming dose of radiation and their total clinical course is abbreviated to about 15–30 days. The gastrointestinal manifestations of the disease predominate and sometimes the total survival may be too brief for many of the characteristic hematological findings to be observed. Sometimes, however, there

may be a rapid development of pancytopenia within 7–10 days, together with a hemorrhagic gastroenteritis.

After a shortened latent period, of perhaps 5–8 days, during which fatigue and low grade fever occur, the manifest illness begins with nausea, vomiting, diarrhea, high fever and pancytopenia. There is gradual progression of these symptoms over the next several days and later there may be blood in the stool or vomitus. Extreme prostration and episodes of shock and cyanosis indicate a downhill course uninfluenced by resuscitative measures which leads to the demise of the patient, usually 15–30 days after the exposure.

Group V Cases:

These patients received such massive irradiation that survival is for a period of hours or perhaps a few days. There has been one well studied and well documented case of a man who, as a result of a criticality accident, received an acute dose of about 10,400 rad to the head and 12,000 rad to the upper abdomen (fast neutrons plus gamma rays). The description which follows is based on observations recorded on this patient [1].

A person who has received this order of exposure will show immediate disorientation, ataxia and mental incapacitation progressing rapidly to semi-consciousness and severe prostration. He may complain of severe burning sensations in the first few post-exposure minutes. After 20–30 minutes, severe cardiovascular shock appears and the patient may seem to be almost moribund. He may be incoherent, retching, vomiting and hyperventilating. The skin may appear dusky, reddish-violet, but may be cold. The mucous membranes appear cyanotic and the conjunctivae hyperemic. This paradoxical picture of shock in association with skin hyperemia is due to the early appearance of the erythema which was caused by the massive dose of irradiation.

The shock is manifested by a rapid, hardly perceptible pulse and by a precipitously falling blood pressure.

Watery diarrhea and vomiting occur in the first hour or two and anuria persists throughout the clinical course.

Some coherence may return to the patient, during which time he may complain of cramps. Physical examination is likely to reveal nothing abnormal apart from the features already described. The high temperature may be maintained for several hours and then fall. Lymphopenia and marrow destruction may be observed within hours of the accident.

The illness terminates fatally following increasingly severe restlessness, incoherence, abdominal pain and sweating; the patient finally subsiding into collapse and coma.