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FEASIBILITY AND POTENTIAL EFFECTIVENESS OF PARTIAL-BODY SHIELDING FOR PERSONNEL PROTECTION AGAINST IONIZING RADIATION

by

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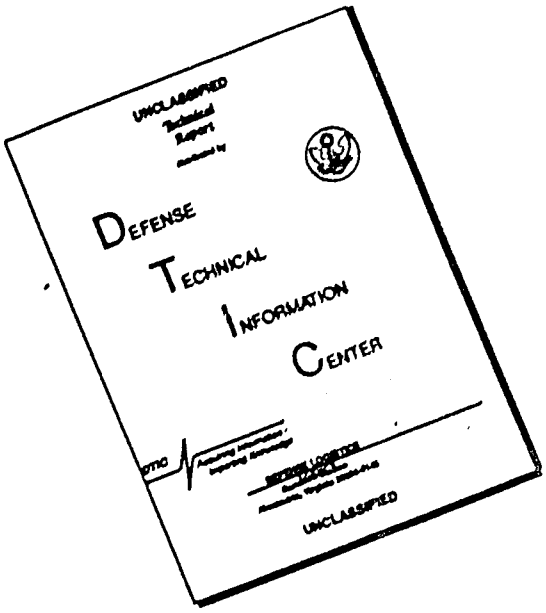

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USNRDL-TR-67-39, dated 11 April 1967 by E. S. Shapiro.

SPECIAL SUMMARY

The Problem

Following a surface or underground nuclear explosion, certain personnel may be called on to perform essential postattack missions that will subject them to the radiation hazards of radioactive fallout. Decisions to send such personnel into the fallout field and scheduling their activities there will depend to a large extent on their anticipated biological response to doses of fallout ionizing radiation. As a means of reducing the potential dose to a person during his exposure period, and hence controlling to some degree his response to radiation, the use of a body shield has been suggested. In this connection, certain questions concerning the feasibility of such a shield naturally arise. What areas of the body should be shielded? What minimum shield weight is required to produce operationally significant shielding factors? Will the location and weight of such a shield permit an individual to efficiently perform his tasks?

The Findings

Based on biological and physical information available at the present time, the following statements concerning partial body shielding can be made:

1. The weight of the shield should not exceed 50 lb for personnel whose postattack functions require strenuous, prolonged effort; other personnel may efficiently carry up to about 70 lb.

2. If it is assumed that adequate protection against the neural and hemapoietic syndromes is available in the form of drugs and small, lightweight shields, respectively, and if it is further assumed that the severity of the gastrointestinal syndrome may be controlled by regulating the dose to the abdomen, then the only extensive body shield required is one covering the abdomen. It has been shown in this study that a shield of this type, whose weight can be effectively carried, may be of significant value to both Group A and Group B (Sec. 1.2) in many operational situations.

3. If it is assumed that localized control of the neural, hemapoietic and gastrointestinal syndromes is not possible, then a hip-to-neck shield is required. Such a shield would be of little value to Group A personnel because of the excessive weight required to produce significantly lower

doses. Such a shield would, however, be of value to Group B personnel, since markedly lower entry times and longer stay times can be obtained by wearing a solid-trunk shield of tolerable weight.

4. Both the solid-trunk and solid-abdominal shields are feasible methods of extending the length of the latent period.

5. A grid shield may prove to be more effective on a weight-by-weight basis than a solid shield because of enhancing biological and geometrical factors.

6. Drug protection in conjunction with partial-body shielding could result in significantly better protection than that obtainable from shielding alone, and could markedly reduce the weight requirements of an effective shield for the same protection.

Recommendations

From types of data and the number of assumptions used in this analysis it is apparent that further experimental work is mandatory before real reliance can be assigned to the above findings. Such work should be directed towards solving the problem of interest: the effects on human beings subject to radiation from fallout in terms of operational significance. All aspects of the problem: biological response, solid- and grid-shield phenomenology, weight-efficiency relationships, and combined drug-shield effectiveness in reducing radiation effects are sorely in need of further research.

ABSTRACT

The feasibility of partial-body shielding is discussed from two points of view. The first assumes that limited clinical and experimental data are extrapolable to the operational situations of interest and that it is possible to selectively protect against the neural, hemapoietic, and gastrointestinal components of the acute radiation syndrome. Under this assumption, it would appear that (a) neural syndrome symptomatology may be adequately controlled by means of drugs, (b) the hemapoietic syndrome may be controlled by a light-weight (under 10 lbs) lead epicondylar cuff, and (c) in many operational situations the gastrointestinal syndrome may be controlled by an abdominal shield sufficiently light in weight to permit postattack personnel to efficiently perform their tasks.

The second point of view discussed assumes that, at present, there is not an adequate basis for selective syndrome shielding, and that a metal shield covering all of the body from the hips to the neck is the only adequate form of protection. Under this assumption it would appear that weight limitations preclude the use of this type of shield in most situations in which personnel must enter the fallout field at specified times and remain until the completion of their mission. However, in the case of personnel who are not required to enter the field at any specified time and who may be recalled after receiving a predetermined dose, trunk shields of acceptable weights will significantly lower entry times and extend stay times. The use of a grid (sieve) trunk shield is discussed and it appears that a shield of this type, of acceptable weight, may be of benefit in many operational situations in which the solid shield was not. Drug protection in conjunction with both solid and grid shields is evaluated, and it is concluded that a marked reduction in the weight requirements of effective shields of both types could result from such a combination.

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5. A grid shield may prove to be more effective on a weight-by-weight basis than a solid shield because of enhancing biological and geometrical factors.

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SECTION 1

INTRODUCTION

1.1 PROBLEM AND OBJECTIVE

Following a surface or underground nuclear explosion, certain personnel may be called on to perform essential postattack missions that will subject them to the radiation hazards of radioactive fallout. Decisions to send such personnel into the fallout field and scheduling their activities there will depend to a large extent on their anticipated biological responses to doses of fallout ionizing radiation. As a means of reducing the potential dose to a person during his exposure period, and hence controlling to some degree his response to radiation, the use of a body shield has been suggested. In this connection, certain questions concerning the feasibility of such a shield naturally arise. What areas of the body should be shielded? What minimum shield weight is required to produce operationally significant shielding factors? Will the location and weight of such a shield permit an individual to efficiently perform his tasks? The purpose of this report is to provide answers to these and other related questions.

1.2 SCOPE AND GENERAL APPROACH

For purposes of this report, postattack personnel may be divided into two groups. Group A consists of personnel who must enter the fallout field at specified times and remain until their mission is completed, whereas Group B consists of personnel who are not required to enter the field at any specified time and who may be recalled after receiving a predetermined dose.

Group A includes rescue workers, first-aid teams, and possibly firefighters; Group B includes such personnel as recovery and reclamation teams.

Partial-body shielding applied to these two groups, if feasible, will serve the following purposes:

(1) Permit Group A personnel to operate in otherwise inaccessible areas; that is, areas where, without shielding, they would receive unacceptably high doses.

(2) Permit Group B personnel to enter the field at earlier times and to remain for longer periods.

The bulk of the present study was devoted to investigating the feasibility of shielding Group A personnel and included, in order, the following areas.

1. Biological responses to radiation.

2. The quantitative relationships between dose and these responses.

3. Relative radiosensitivity of different parts of the body.

4. Determination of parts of body to be shielded.

5. Determination of shielding required to significantly alter biological responses.

6. Determination of most efficient shield design and material.

7. Human tolerability to recommended shields.

8. Conclusions on the feasibility of Group A partial-body shielding.

The remaining sections of this report are devoted to the effects of partial-body shielding on entry times and stay times of Group B personnel. Since this group will be operating under predetermined dose criteria, it is apparent that any shielding of the radiosensitive areas of the body will permit earlier entry and/or longer stay times. With the results of 6, 7, and 8, above, entry times and stay times corresponding to different types of shields were computed (Section 6.4.1) for several operational situations.

The effectiveness of drug protection in conjunction with partial-body shielding is also discussed, with particular emphasis on its potential to Group A personnel.

1.3 LIMITATIONS OF STUDY

None of the data on which the conclusions of this study rely can be directly related to the operational situation of interest; namely, the protection of human beings in a radioactive fallout field. Rather, the data comprise the results of laboratory animal experiments, limited clinical case histories, nuclear-accident information, human-engineering studies, simplified gamma-ray penetration experiments, etc. These data have been evaluated, and, when germane to the problem at hand, have been extrapolated to the fallout situation. Consequently, the results and recommendations of this study should be considered flexible and subject to modification as new information becomes available.

SECTION 2

BIOLOGICAL RESPONSES TO IONIZING RADIATION

2.1 GENERAL

Ionizing radiation may elicit two responses in man: (1) the acute radiation syndrome, and (2) delayed effects. The latter response includes carcinogenesis and genetic effects, and is not considered within the scope of this report. Both responses may result from acute doses of radiation (namely, doses received in 24 hrs or less) or protracted doses (doses received over periods greater than 1 day).

2.2 THE ACUTE RADIATION SYNDROME

2.2.1 Description of the Syndrome

The acute radiation syndrome is an acute illness resulting from radiation injury to the whole body or to a substantial part of the body that runs a roughly predictable course over a period of time varying from a few hours to a few weeks. The appearance and severity of symptoms and the times and time periods described below will depend on the magnitude of the dose, the time over which the dose is accrued, the parts of the body irradiated, and the radiosensitivity of the individual.

The most conspicious features of a "typical"* syndrome are described by reference 1 as follows: Within 2 hr after exposure, anorexia, nausea, malaise, listlessness, drowsiness, and fatigue develop rather abruptly. Deterioration of the exposed person's general condition progresses rapidly and may lead to profuse vomiting, extreme weakness, and/or even prostration. This early reaction culminates about 8 hr after exposure and then subsides rather quickly. On the second postexposure day, nausea and occasional vomiting may continue, but the general condition is markedly improved. On the third postexposure day, all complaints have disappeared. The above symptoms define what is known as the "initial reaction," "prodromal phase," or "prodrome" of the acute radiation syndrome. After subsidence of prodromal effects, the individual is asymptomatic and capable of performing normal work, or even of exerting strenuous physical effort. This state, the "latent period," may extend to about three weeks post-irradiation day, when a new phase is entered rather abruptly. The

* Variation in specific conditions of irradiation, as noted, would cause variations in the basic syndrome.

individual experiences chills, malaise, a feverish feeling, fatigue, and shortness of breath on exertion. The general condition may deteriorate and manifestations of severe bone-marrow depression (characterized hematologically by leukopenia and thrombocytopenia) may appear. This phase culminates about the 30th day. Thereafter, either death ensues, or recovery starts and becomes obvious between the 40th and 50th days.

More specifically, the acute syndrome that will most likely be encountered in an operational situation may be divided into three subcategories, each contributing in a characteristic way to the overall syndrome described above. These are: (a) the neural syndrome, (b) the hemapoietic syndrome, and (c) the gastrointestinal syndrome.*

The neural syndrome is characterized by the fatigue, nausea, etc., of the prodrome described above. Doses below 100 rads may be capable of initiating this syndrome.

The hemapoietic syndrome is characterized by the hematological changes mentioned above. Doses of 200 rads or more may be expected to initiate this syndrome.[1]

The gastrointestinal syndrome is characterized by the loss of the epithelial lining of the intestine.[2] According to Cronkite,[3] doses of 500 rads will certainly produce a severe form of the syndrome.

The above dose-response relationships are based on nuclear-accident reports, long-time radiotherapy records, and the results of studies of casualties from the nuclear explosions over Hiroshima and Nagasaki. However, the single acute exposures received in these cases do not parallel the exposure conditions that would generally be encountered in a fallout situation. For example, postattack personnel may have received significant doses of initial radiation (from the explosion) and/or residual radiation (while in shelter) before their entry into the fallout field (that is, a fractionated dose). Also, the time over which doses are received by postattack personnel will probably be longer than those of the case studies. An indication of the importance of the latter parameter may be inferred from the work of Thomson and Tourtellotte,[4] who found that, although the LD_{50} for mice is relatively independent of dose rates between 240 and 2530 R/hr, it is appreciably higher for dose rates less than 240 R/hr. Although a considerable amount of experimental effort is currently being applied to rate effects, particularly in large animals, the work is not sufficiently clarified to permit its use in the present analysis. In any case, for the treatment presented herein, rate effects would not significantly affect the general conclusions drawn.

* A fourth category, namely, the central nervous syndrome, is not considered in this report because of the exceptionally high doses associated with it ($\geq$ 2000 rads).

2.3 THE ACUTE RADIATION SYNDROME AND PARTIAL-BODY SHIELDING

2.3.1 Two Points of View

In view of the preceding discussion of the acute radiation syndrome - in particular, the dose ranges associated with the gastrointestinal, hemapoietic, and neural syndromes - it appears that the feasibility of partial-body shielding may depend to a great extent on the unshielded doses personnel will be expected to receive, and hence may vary from one operational situation to another. For example, when doses in excess of 500 rads are anticipated, protection against the gastrointestinal, hemapoietic and neural syndromes may be required, whereas in the case of doses in the 200-500 rads range hemapoietic and neural protection alone may suffice.

In order to determine if, in fact, the feasibility of partial-body shielding depends significantly on the expected exposure level itself, it is necessary to determine whether it is possible to selectively protect the body from the three syndromes; i.e., whether it is possible to control the syndromes individually by protecting specific areas of the body. If such selective protection is possible, then less extensive shielding requirements (above and beyond less shielding thickness) would be required as the unshielded dose decreases.

On the other hand, if selective protection is not possible, then a body shield must cover all of the highly radiosensitive parts of the body, and must be of sufficient thickness to reduce the dose to all such areas to a predetermined level based on an acceptable symptomatology. For example, if it were desired to protect against the serious form of the hemapoietic syndrome, then the dose to all radiosensitive areas of the body must be reduced to less than 200 rads.

As will be seen, the acceptance or rejection of the concept of selective protection is not clear cut at present, and depends to a great extent on the viewpoint adopted concerning the extrapolability of limited clinical experiences and animal experiments to operational situations. Consequently, partial-body shielding will be evaluated in this report from two points of view; the first assumes selective protection is feasible, while the second does not.

2.4 THE PREPRODROME, LATENT PERIOD, AND PARTIAL-BODY SHIELDING

In extreme situations, civilian personnel may be permitted to accrue doses capable of producing severe acute radiation symptoms while performing their mission before the prodrome or during the latent period. The time of the onset of the prodrome and the length of the latent period depend on the total acute dose and the exposure period. This dependency

is shown in Figure 1,* where it can be seen that the latent (or remission) period, particularly, can be extended by significant amounts when acute doses are less by relatively small factors. This aspect of partial-body shielding is discussed further in Section 6.

* Synthesized by J. D. Teresi from published information and reproduced here from USNRDL-TR-905, 22 November 1965, "Time History of Biological Response to Ionizing Radiation," by E. Laumets. Note: Figure 1, or indeed any summarization at this time in quantitative terms of biological effects of radiation, particularly involving onset times in human beings, must be considered tentative. Figure 1 is presented herein to provide perspective; the conclusions of the report and the selection of exposure levels for the injury groups used (Sec. 4.2) do not depend on the precise values given in Figure 1.

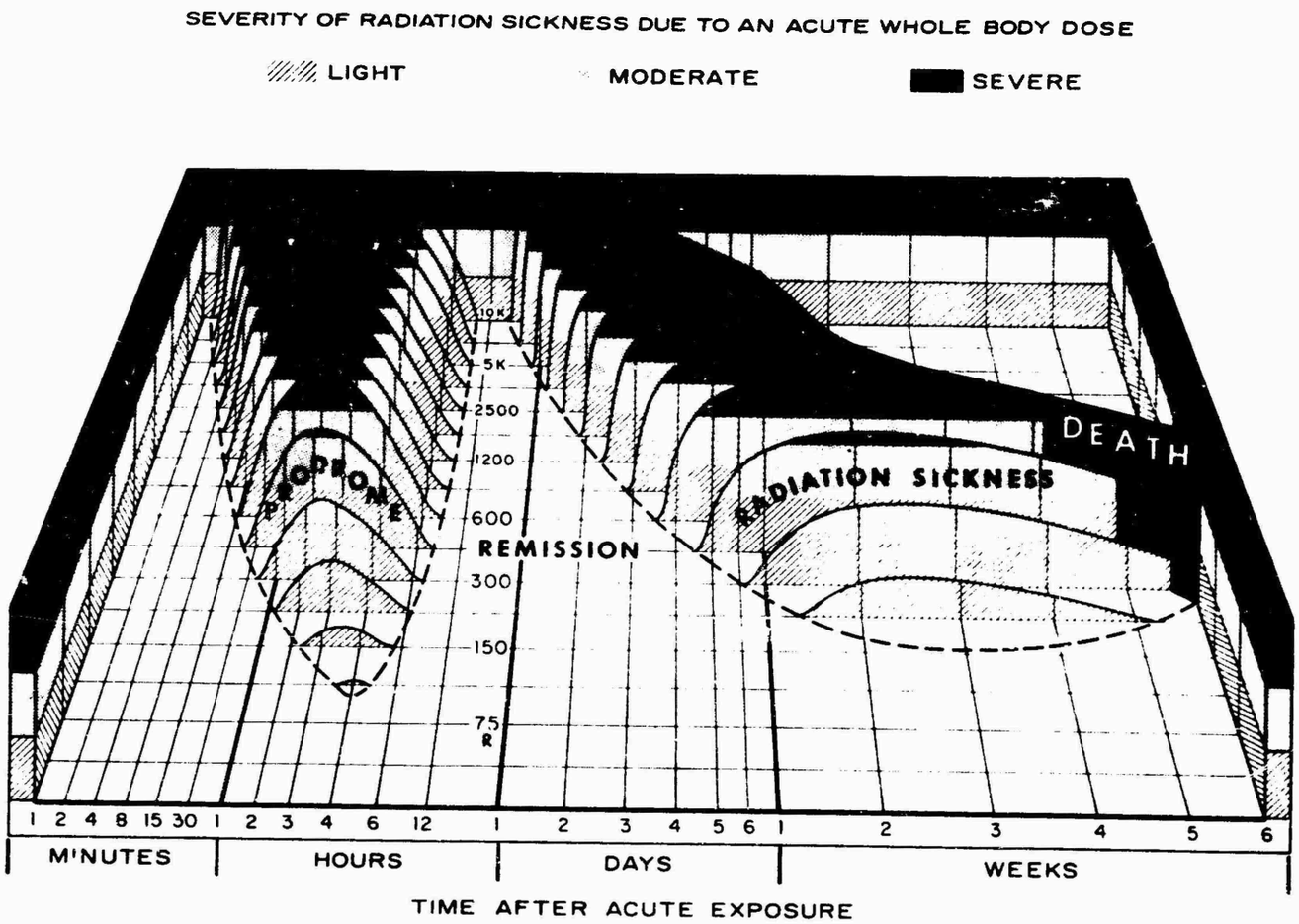

Fig. 1 The Acute Radiation Syndrome

SECTION 3

SITES OF THE NEURAL, HEMAPOIETIC, AND GASTROINTESTINAL SYNDROMES

3.1 GENERAL

In an attempt to design a shield of minimum weight, a study was made to determine whether there exist in the human body specific sites where the neural, hemapoietic, and gastrointestinal syndromes are initiated. As mentioned earlier, this study was motivated by the following considerations: (a) If such sites exist and are sufficiently localized, then protection of large areas of the body is unnecessary, and (b) if such sites exist, then in situations in which only the hemapoietic and neural syndromes are anticipated (i.e. unshielded doses less than 500 rads), not only thinner but less extensive shielding may suffice.

3.2 SITE OF INITIATION OF THE NEURAL SYNDROME

A review of case histories of patients receiving doses in the neural syndrome range,[5,6] indicates that although irradiation of any portion of the body above the hips can elicit the neural syndrome to some degree, the syndrome occurred most frequently and most severely in those patients undergoing abdomen and thorax irradiation. The general trend found can be seen from the work of Court-Brown[5] as summarized in Table 1. The exposures used in irradiations summarized in Table 1 were all comparable. It must be noted that the criterion of interest in this literature review was relative radiosensitivity. Head and neck irradiation, for example, can produce symptoms,[6,7,8] but it produces them less frequently than does abdomen and thorax irradiation.

It must also be noted that, in some patients, the knowledge that they have been or will be exposed to radiation is enough to produce some of the "shock" symptoms of the syndrome; for instance, nausea and vomiting. In the reirradiation of patients who on first irradiation exhibited symptoms, Kereiakes* found that, regardless of the site of the reirradiation, many again showed symptoms, although the doses were extremely low. The value of shielding in these cases is dubious.

---

* Kereiakes, J., University of Cincinnati School of Medicine, personal communication, May, 1965.

TABLE 1

Relative Radiosensitivity of Body Areas[5]

Area Irradiated	% Developing Symptoms of Any Kind	% Developing Vomiting
Whole spine and sacroiliac joints	97	57
Whole abdomen	90	60
Upper half of trunk	84.5	31
Whole body	50	25
Lower Abdomen and thigh	0	0
Both thighs	0	0

3.3 SITE OF INITIATION OF THE HEMAPOIETIC SYNDROME

The sites of this syndrome are the blood-forming organs of the body. In the adult human, the major hemapoietic organs include the sternum, clavicle, epicondyles of the humerus, ulna and radius, the pelvis, the cranium, the ribs, and the vertebrae.

3.4 SITE OF INITIATION OF THE GASTROINTESTINAL SYNDROME

Early experimental work on animals[9,10] indicated that protection of the abdomen was a successful means of lowering the severity of the gastrointestinal syndrome.

Swift et al[11] found that shielding a small portion of the small intestine in rats significantly lowered deaths due to this syndrome. Similarly, Abrams and Kaplan[12] found that only 22% of abdominal-shielded rats died following exposure to an LD_{95} of 550 R.

According to Quastler,[2] "the small intestine is the target organ for primary effect and later critical changes." He further states, "In producing acute intestinal radiation death, irradiation of any major portion of the exteriorized small intestine alone is almost equivalent to whole-body irradiation... The intestine is responsible for the initiation of the process." These conclusions were based on the findings of Osborne,[13] Quastler et al.,[14] and Bond.[15] More recently, Carsten and Innes[16] demonstrated that the maximum LD_{50} for 30 days for rats was approximately 650 rads for lower-body exposures and 1300 rads for upper-body exposures.

Hansen et al[17] observed that shielding the lower portion of dogs increased the LD_{50} from 250 to 1775 R. According to Hansen: "In view of the similarity of the dog's response to that of the human, it is interesting to speculate whether or not similar modifications will be seen in humans exposed to upper-body irradiation. There is no evidence which indicates otherwise."

3.5 CONCLUSIONS

The preceding discussion may be summarized as follows:

(i) The site of initiation of the neural syndrome cannot be localized; irradiation of any portion of the body above the hips can produce it. However, by far the most sensitive areas are the abdomen and the thorax.

(ii) The sites of initiation of the hemapoietic syndrome are the blood-forming organs of the body.

(iii) In laboratory animals, the site of initiation of the gastro-intestinal syndrome is the small intestine.

SECTION 4

KINDS OF PROTECTION TO BE CONSIDERED

4.1 GENERAL

In the broadest sense, partial-body shielding may be defined as any form of protection against the acute radiation syndrome. With this definition in mind, the subsequent discussion will include, where applicable, remarks on the feasibility of drugs as protective agents as well as the more conventional metal shields.

4.2 PROTECTION AGAINST THE NEURAL SYNDROME

In view of the results of Section 3.2 it appears that, in the majority of exposed persons, the severity of the neural syndrome can almost entirely be controlled by regulating, by means of a body shield, the dose to the area between the hips and the neck. However, as will be shown in Section 6, this type of protection will not be practical in many operational situations because of the large weight of such a shield.

An alternate method of controlling the nausea, vomiting, diarrhea, etc., of the neural syndrome may possibly be the use of drugs. Pyridoxine, long known to be of value, has been described by Shorvon[18] as a "reliable but not infallible" form of treatment. Leichsenring[19] found that oral doses of psyquil, a phenothiazine derivative, had very high antiemetic effects in cancer patients undergoing radiation treatment. Conte and Casara,[20] using thiethylperazine on patients in whom sickness and vomiting occurred, reported positive results in 90% of 60 cases studied. Chassard[21] found that metoclopramide was very effective in controlling the digestive disorders accompanying radiation sickness in 86% of the patients given the drug. Stoll[22] found that both trifluoperazine and haloperidol (tranquilizers) relieved vomiting, nausea, and listlessness in 90% of 252 cases studied.

Of unusual interest in the study of drug therapy are the results of Parsons et al.[23] and Kurohara et al.[24] who found that placebos could be effective in the treatment of radiation sickness. Parsons found that 61 to 72% of his patients responded favorably when given placebos, while Kurohara noted that responses in patients receiving bona fide drugs and placebos were identical. Both of these results indicate the importance

of the "psychological factors" that influence an individual's response to radiation. The environment of the post-attack situation will differ considerably from that of the clinic; the response to radiation of personnel in stress situations may differ from those predicted. A thorough indoctrination on radiation and its effects may itself be an effective form of protection. Unfortunately, the role of these factors cannot adequately be evaluated at this time.

4.3 PROTECTION AGAINST THE HEMAPOIETIC SYNDROME

In view of Section 3.3, it appears that the severity of the hemapoietic syndrome can be entirely controlled by adequately protecting the blood-forming organs. Fortunately, protection of the entire hemapoietic system of the body is not necessary; appropriate shielding of either the sternum, pelvis, skull or epicondyles of the arm bones, for example, should provide more than an adequate reservoir of healthy blood precursors needed to restore the bone marrow to normal or protective levels.*

Cole et al.[25] have demonstrated that a 0.6-cm lead cuff shielding the epicondyle of the dog resulted in survival in the presence of normally fatal (hemapoietic death) exposures in excess of 600 R from 1 Mvp X-rays. The cuff transmitted 2-3% of the exposure and weighed less than 6 lb. If these results are extrapolable to man, then protection against the hemapoietic syndrome would appear entirely feasible.

4.4 PROTECTION AGAINST THE GASTROINTESTINAL SYNDROME

The results of Section 3.4 indicate that a suitable form of protection against the gastrointestinal syndrome may possibly be found in the form of an abdominal shield, of sufficient thickness to reduce the unshielded dose to less than 500 rads and of sufficient height to eliminate the effects of scattered radiation. Here, as in Section 3.4, such a conclusion is based on animal data whose extrapolability to man, although reasonable, must nevertheless be demonstrated.

4.5 CONCLUSIONS

The results of this section may be summarized as follows:

(i) It is possible that the incapacitating effects associated with the neural syndrome may be adequately controlled by the use of drugs. If this is not true, then the only form of protection available is a body shield covering the area from the hips to the neck.

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* Alpen, E., USNRDL, personal communication, October, 1966.

(ii) It is likely that the serious form of the hemapoietic syndrome may be adequately controlled by an epicondylar lead cuff of minimal weight. If this is not true, then wider coverage of the blood-forming organs is required, and this could be accomplished by a hip-to-neck shield.

(iii) It is highly likely that the serious form of the gastro-intestinal syndrome may be adequately controlled by a shield encompassing the body and completely covering the abdomen. If this is not true then hip-to-neck shielding is required.

In view of these conclusions it appears that the feasibility of partial-body shielding must be approached from two points of view. The first, and more optimistic, requires an evaluation of a shield that protects only the abdominal cavity. In such a view, primary control of the neural syndrome by drugs (with possible amelioration by the abdominal shield) is implied. The second, and less likely point of view is that, in the absence of human data to the contrary, complete coverage of the trunk is required. The feasibility of both of these types of shields will be studied in the next section.

SECTION 5

MAXIMUM WEIGHT OF AN EFFECTIVE BODY SHIELD

5.1 STUDIES IN THE PERFORMANCE OF HEAVILY-LADEN PERSONNEL

The ability of heavily laden personnel to efficiently perform tasks comparable to those that may be required of postattack personnel has been the subject of only a few studies.

Leopold and Derrick[26] carried out tests to determine the effect of wearing light body armor and a field pack--a total weight of 58 lb--on the performance of Marines. Two of their tests were comparable to tasks that may be required of postattack personnel.

The first test was a "forced march" of 4964 ft. The first 3700 ft was along a trail through a thickly wooded, undeveloped area of relatively rough terrain consisting of moderately steep mounds, wide shallow holes, protruding tree roots, etc., which impeded movement. The remainder of the march was along a gravel road.

In the second test, troops ran 30 ft, hit the deck, crawled 20 ft, got up, ran, jumped over a trench, jumped over a 2½-ft-high barricade, stooped under a 4-ft-high by 8-ft-long wire-top cage, ran 100 ft, and finally dropped to the ground.

The mean performance times for these two tests were approximately 11 min and 51 sec, respectively. Unfortunately, unladen troops were not similarly tested, although it seems unlikely that they could do much better.

From these data, it can be concluded that, carrying optimally placed loads of 58 lb, personnel can efficiently perform strenuous tasks for <u>short</u> periods of time.

The above tests in no way indicate the maximum load that personnel might reasonably be expected to carry. However, Cathcart, Richardson, and Campbell[27] performed tests consisting of long marches at various rates--continuous and with periodic rest periods--and concluded that the effective maximum load was 45% of the body weight. This corresponds to 69 lb for the "average" man.

Gardner,[28] cites an analysis of work done by the Hygiene Advisory Committee of the British Army and of tests conducted by the William Frederick Institute in Germany during the latter part of the nineteenth century, from which it was concluded that about one-third of the body weight of a combat soldier represents the maximum load to be carried. This value agrees with available physiological data[28] based on energy-output studies.

5.2 CONCLUSIONS

The maximum weight that can effectively be carried by an individual depends on the nature of his task. From the foregoing data, it appears that postattack personnel whose tasks are equivalent in energy requirements to long marches may carry up to about 70 lb, whereas personnel whose tasks are equivalent to those of combat soldiers may carry about 50 lb. These two values bracket the weight of body shields considered in this report. Although much heavier shields are possible, whatever added protection the heavier shield would provide would be offset by the longer time that would be required to complete the task in the fallout field.

SECTION 6

THE SOLID SHIELD

6.1 DESIGN

In this section two types of body shields have been considered: (a) a solid shield of uniform thickness encompassing the body from the hips to the neck, and (b) a solid shield of uniform thickness encompassing the abdomen. In Section 7, grid or sieve shields covering the same areas as (a) and (b) are discussed.

6.2 MATERIAL

A well-designed shield should be constructed of readily available materials that will provide good protection against gamma radiation and have good structural properties. Lead and steel satisfy most of these requirements, although lead, while offering better radiation protection than steel on a weight basis, has poorer structural properties. Morris[29] investigated the use of leaded rubber and concluded that such material is of little value for gamma energies greater than 0.4 Mev. Roughly, it may be stated that the protection provided by a uniformly distributed shield is a function of the density of the shield material, so that lighter (more flexible) materials would require proportionately greater thicknesses that would make them impractical.

The calculations below of the shielding factors of solid shields are based on lead. Conclusions concerning the feasibility of lead shields will apply to shields of other materials of similar electron density.

6.3 CALCULATION OF THE SHIELDING FACTOR

6.3.1 General Attenuation Considerations

In the presence of a body shield, gamma photons penetrating the body will have traversed air, lead, and tissue media. Because of the complicated scattering process in this type of source-shield-body geometry, the shielding factor of the shield is not easily calculated. An estimation of photon transmission can be found from the work of Laumets and Ksanda,[30] who, on interpreting test data on the penetration through steel pipes of gamma rays that were first attenuated in air, concluded that attenuation is of the form $e^{-\bar{\mu}_s t}$, where t is the thickness of the pipe wall (inches) and $\bar{\mu}_s$ is an effective attenuation coefficient

(inches^{-1}) that takes into account both absorption and multiple scattering (buildup). The gamma rays in the above experiment entered the pipes at nearly right angles. At 2 hr, $\bar{\mu}_s$ = .91 inches^{-1}, and increased to 1.22 inches^{-1} at later times.

During early times of interest, the average energy of the mixed fission products is approximately 1.25 Mev. The linear absorption coefficient of steel, μ_s, corresponding to this energy is 1.09 inches^{-1}. At later times the average energy is approximately 0.7 Mev, and μ_s is 1.34 inches^{-1}. If it is assumed that an effective attenuation coefficient $\bar{\mu}_\ell$ also exists for air-lead scattering with the relationship:

$$\frac{\bar{\mu}_\ell}{\mu_\ell} = \frac{\bar{\mu}_s}{\mu_s}$$

where μ_ℓ is the linear absorption coefficient of lead, then $\bar{\mu}_\ell$ at early times has a value of 1.59 inches^{-1} and later times a value of 1.53 inches^{-1}.

6.3.2 The Solid-Trunk-Shield Shielding Factor

The shield may be approximated by a cylindrical shell of thickness t inches, inner radius 6 inches, and height 24 inches. Small changes in radius and height will not significantly alter the shielding factor of the shield.

Since the data given in Table 1 are based on exposures measured at the skin, the shielded exposures should be calculated for the interior wall of the shield for comparison purposes. However, in the presence of isotropic irradiation of this energy, the unshielded midline (of body) dose (rads) and the exposures at the surface (roentgens) are approximately numerically equal; hence, for ease of calculation, the shielding factors have been computed for a point at 4 ft above the ground (i.e. above the fallout field) on the midline of the body. (See Figure 2.) Since radiation passing through the open bottom of the cylinder will constitute less than 5% of the free-field dose[31] and will be attenuated by the legs and pelvis, it may be neglected in the shielding calculations.

A further simplification was to assume that the penetration of gamma rays through body tissue to the midline point of interest is only a function of tissue density (1 g/cc). Then, the attenuation by this tissue was accounted for by increasing the thickness of lead (density = 11.4 g/cc) by 6 inches x $\frac{1}{11.4}$ = 0.53 inches.

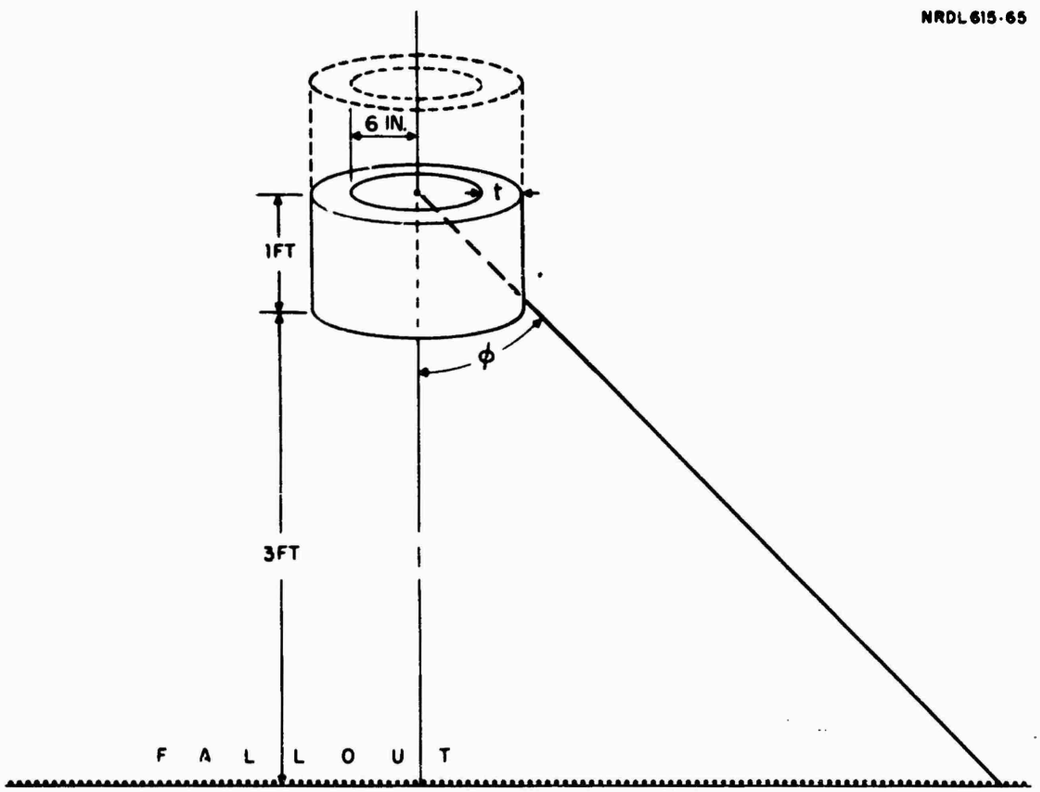

Figure 2 Geometry for Calculating Solid-Shield Shielding Factors

If the value of $\bar{\mu}_\ell$ of Ref. 30 is assumed to be independent of the angle of incidence of the gamma rays with the pipe, the shielding factor F is given by:

$$F = \frac{I\,(t + 0.53)}{I\,(0.53)} \qquad (1)$$

where $I(x) = \int_{\tan^{-1} 1/2}^{\pi/2} \tan\varphi\, e^{-[48\,\mu \sec\varphi + \bar{\mu}_\ell x \csc\varphi]}\, d\varphi$

(this derivation contains the simplification that $\bar{\mu}_\ell \gg \mu$)

and μ is the linear absorption coefficient of air. For a gamma energy of 1.25 Mev, $\mu = 1.91 \times 10^{-4}$ inches^{-1}, and for a 0.7 Mev energy, $\mu = 2.54 \times 10^{-4}$ inches^{-1}. F vs thickness and weight for the first day and for later times is plotted in Figure 3.

6.3.3 The Solid-Abdominal-Shield Shielding Factor

This shield differs from the solid-trunk shield only in its height which has been taken to be 12 inches. Consequently, the shield thickness required to provide a given shielding factor may be found directly from the upper graph of Figure 3, while the weight would be $\frac{1}{2}$ that of the solid-trunk shield giving the same shielding factor (lower graph in Figure 3).

6.4 MAXIMUM PROTECTION PROVIDED BY THE SOLID SHIELD

6.4.1 The Solid-Trunk-Shield

(a) Group A Personnel

In Section 5.2 it was concluded that the weight of the shield should not exceed 50 lb for personnel whose postattack functions require strenuous, prolonged effort, whereas other personnel may efficiently carry up to about 70 lb. Consequently, from Figure 3 it is seen that trunk-shielding factors of 0.67 to 0.75 are realizable for personnel who must enter the radiation field during the first day, while factors of 0.60 to 0.69 are feasible for personnel entering the field at later times. Thus it appears that if in fact a trunk shield is necessary, it is of value to Group A personnel only in situations in which unshielded doses on the order of 300 rads are expected, since only in these cases will shielded personnel receive less than 200 rads. As mentioned earlier, complete hip-to-neck coverage is predicated on the assumption that selective-syndrome protection is not possible and that the entire trunk must be protected to the same degree. The degree of protection required will depend on a predetermined acceptable symptomology. Normally, those symptoms associated with the serious forms of the neural and hemapoietic syndromes will be considered unacceptable, so that doses on the order of 200 rads will be the highest that personnel will be permitted to receive. It is noted that shielding factors of 0.65-0.75 will reduce trunk exposures to $\frac{2}{3}$ to $\frac{3}{4}$ of their unshielded values no matter what the total levels encountered. At levels higher than 300 rads (unshielded), amelioration of the overall severity of the effect would thus occur also; e. g. (1) by eliminating the gastrointestinal syndrome, or by (2) delaying the prodrome. The first of these effects would not bear directly on operational performance, and data are unavailable for quantitative discussion of the second.

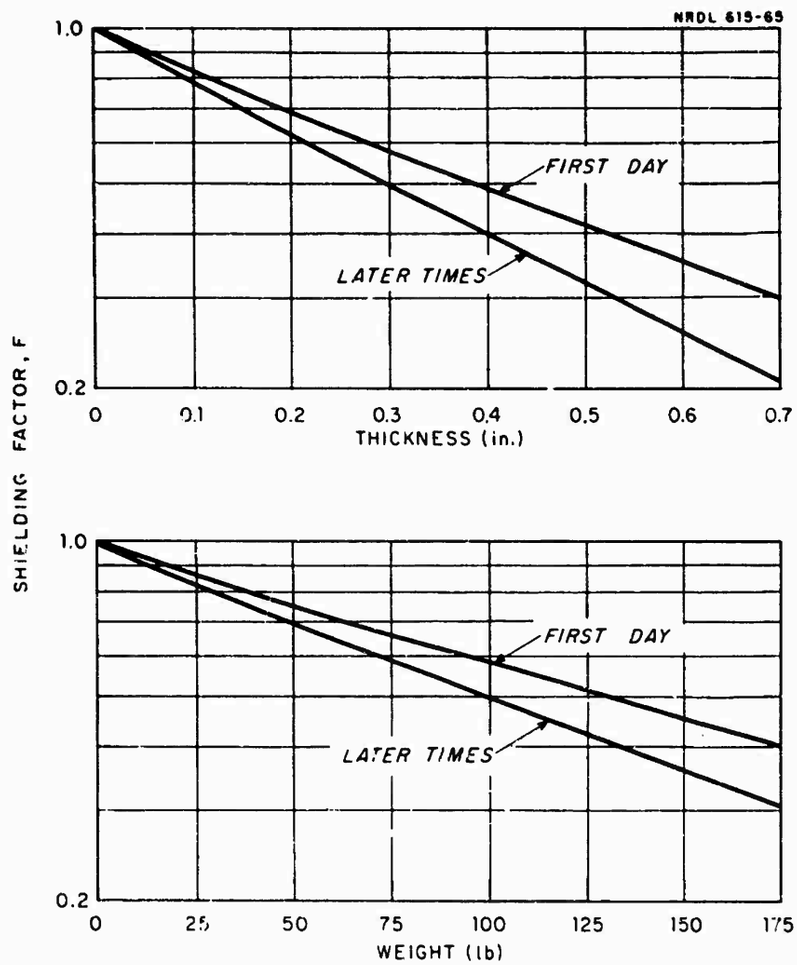

Figure 3 **Shielding Factor Vs Thickness and Weight For First Day and Later Times**

Thus, in view of the limited utility of this shield, and the uncertainties associated with radiation field measurements and human response to radiation, and the real (vs calculated) efficiency of the shield, it is considered that a solid-trunk-shield is not a feasible form of protection for Group A personnel.

(b) Group B Personnel

Since Group B personnel will have flexible entry times and predetermined doses, the effectiveness of partial-body shielding applied to these personnel is measured in terms of the earlier entry times and longer stay times that such shielding provides.

As mentioned above, on the basis of the weight criteria of Section 5.2, namely, 50 to 70 lb, shielding factors of 0.75 to 0.67 during the first day and 0.69 to 0.60 during later times are the best that can be hoped for. If it can be shown that the 0.75 and 0.69 shielding factors (corresponding to weight limitations imposed by the necessity of performing strenuous activity) significantly alter entry and stay times, the practicality of partial-body shielding for Group B personnel will have been established. To simplify calculations, the 0.75 factor is assumed for all postattack times, since the feasibility of this factor implies that of the 0.69 factor.

The relationship between entry time t_E(hr) and stay time s (hr) may be found from the equation for the dose D received by a person wearing a shield with a shielding factor F:

$$D = F\, d_o \int_{t_E}^{t_E + s} t^{-1.2}\, dt = 5\, F\, d_o \left[t_E^{-0.2} - (t_E + s)^{-0.2} \right] \quad (2)$$

where d_o is the dose rate (rad/hr) at 1 hr measured at 4 ft above the ground.

From Eq. (2), it is seen that

$$s = \left[t_E^{-.2} - \left(\frac{D}{5\, F\, d_o} \right) \right]^{-5} - t_E \quad (3)$$

Equation (3) has been evaluated for several values of D/d_o, taking F = 1 (no shielding) and F = 0.75. The results are shown in Figures 4 to 7. Note that operationally meaningful changes in entry and stay times can be achieved by a shielding factor as poor as 0.75. For example, if the dose rate of 1 hr after detonation is 3000 rad/hr and a dose of 300 rad will be acceptable, personnel who enter the fallout field at 1 day wearing a shield with a 0.75 shielding factor may stay 3.4 days, whereas unshielded personnel may stay only 2.2 days.

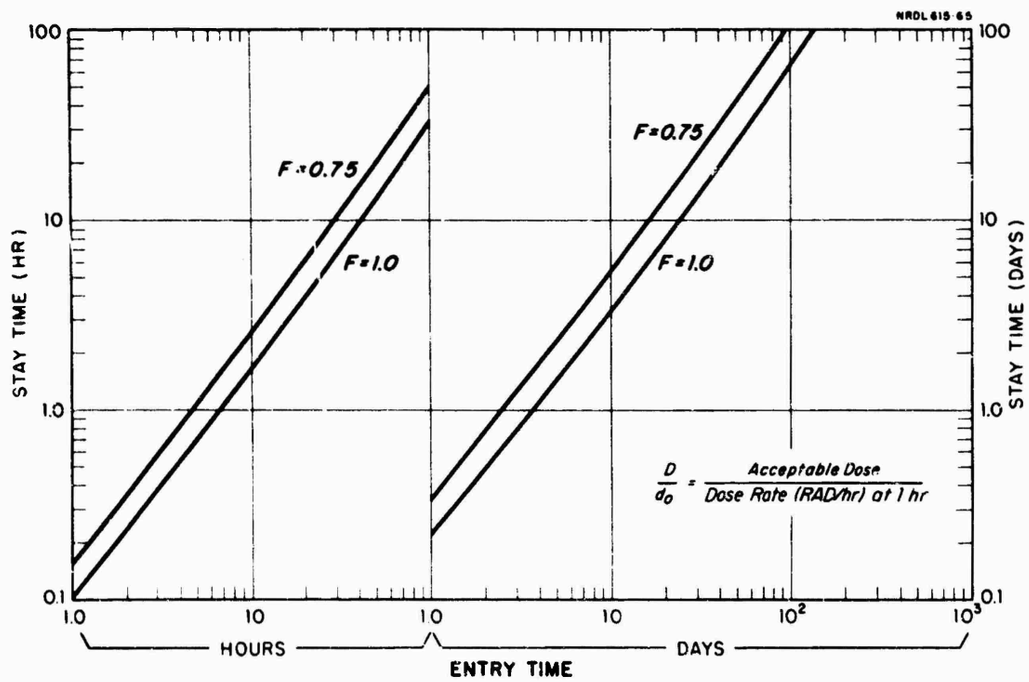

Figure 4

Stay Time Vs Entry Time for F = 1.0 and 0.75 and for D/d_o = 1/10

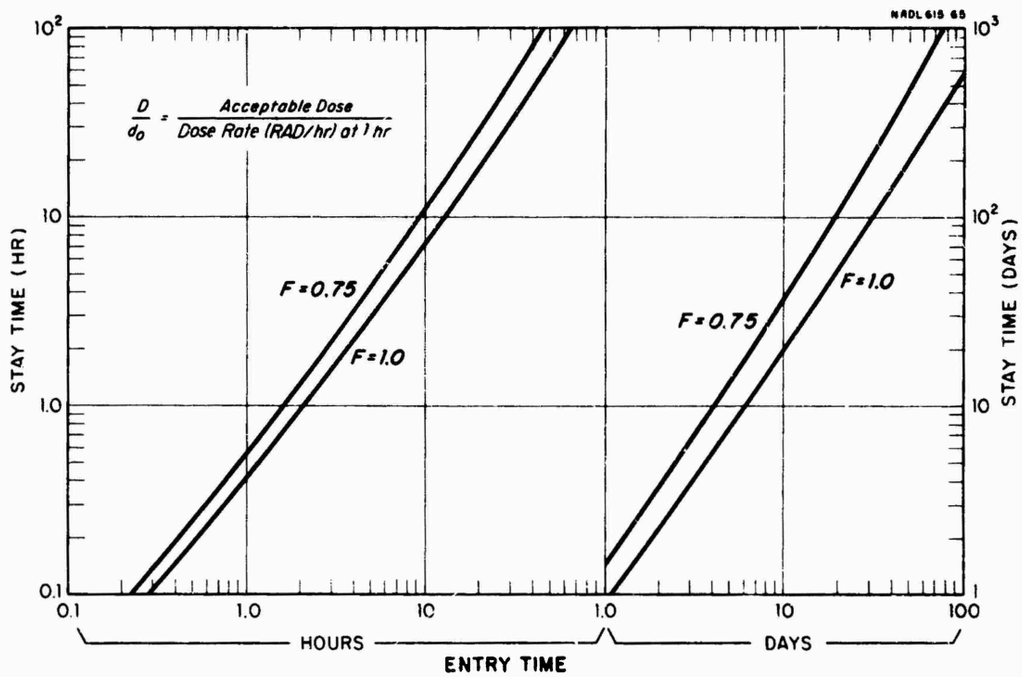

Figure 5 Stay Time Vs Entry Time for F = 1.0 and 0.75 and for $D/d_o = 1/3$

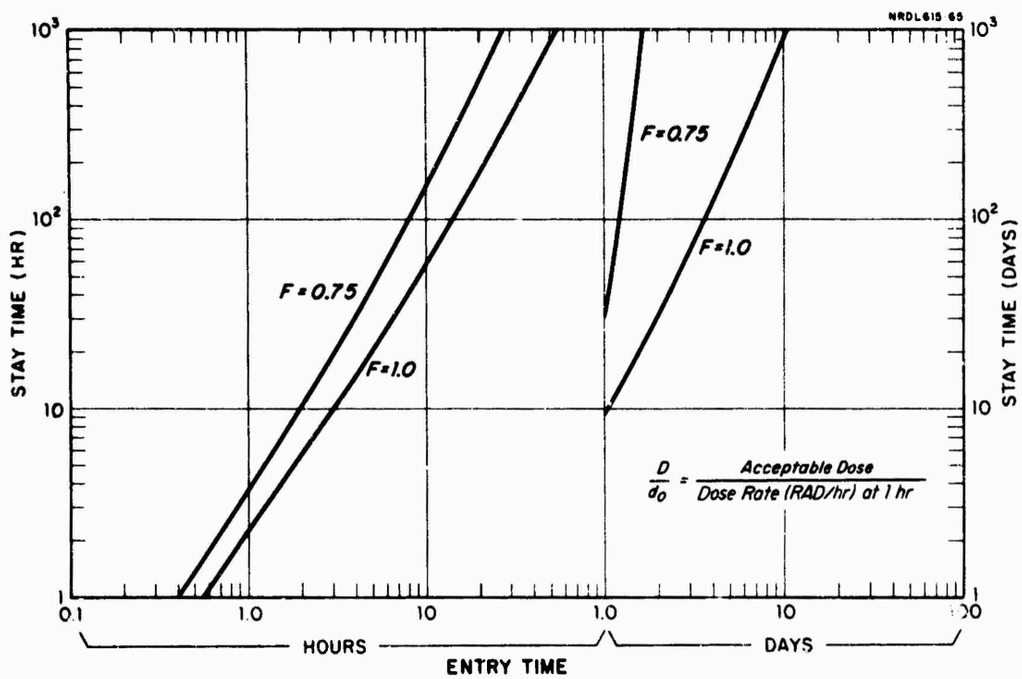

Figure 6 Stay Time Vs Entry Time for F = 1.0 and 0.75 and for $D/d_o = 1$

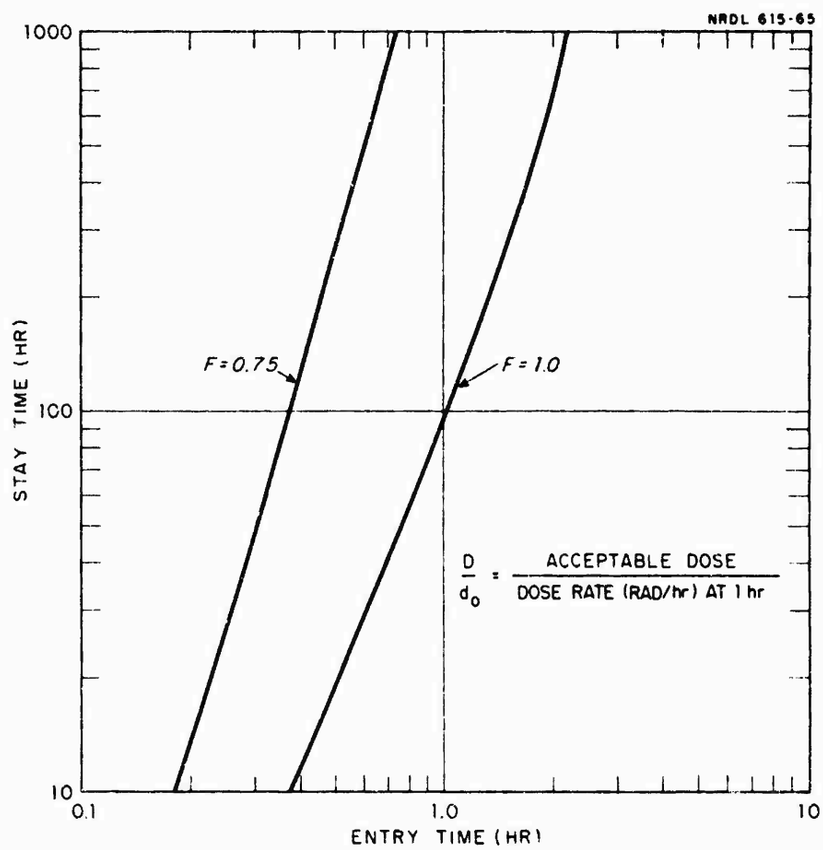

Figure 7 Stay Time Vs Entry Time for F = 1.0 and 0.75 and for $D/d_o = 3$

6.4.2 The Solid-Abdominal Shield

(a) Group A Personnel

Solid abdominal shields weighing between 50 and 70 lbs. will provide first-day shielding factors of .48 to .57 and later shielding factors of .37 to .50. Since the use of this type of shield is predicated on the ability to selectively shield against the gastrointestinal syndrome, the above shielding factors are meaningful only in situations in which unshielded doses larger than 500 rad are anticipated. It thus appears that the abominal shield may be of value in situations in which unshielded doses in excess of 1000 rads are anticipated. Further, in these situations the differences between unshielded and shielded doses are considerably larger than those provided by the trunk shield and hence variations due to improper field measurements, differences in biological response, etc. will tend to be less serious. For example, if a shield whose predicted shielding factor is 0.50 only reduces the dose from 1000 rads to 550 rads (instead of to 500 rads), the biological response will nevertheless be significantly altered. Therefore, it appears that an abdominal shield is a feasible form of protecting Group A personnel against the gastrointestinal syndrome.

(b) Group B Personnel

In Section 6.4.1 it was seen that the use of solid-trunk shields by Group B personnel could result in significantly earlier entry times and longer stay times. In the case of the more effective abdominal-shield, even more striking changes would be noted in these parameters. These changes in entry time and stay time may quantitatively be predicted by using Eq. (3), Section 6.4.1.

6.4.3 The Effect of Partial-Body Shielding on the Latent Period

As mentioned earlier, the length of the latent period is sensitive to relatively small changes in the acute dose. For this reason even the poorest trunk-shield shielding factor of 0.75 can markedly increase the length of the latent period, as can be seen from Figure 8, which is replotted from Figure 1 values.

6.5 CONCLUSIONS

The preceding discussion indicates that

(a) If the acute radiation syndrome can be controlled only be regulating the dose to the entire trunk, a solid-trunk shield is not a feasible form of protection for Group A personnel, but can be of value to Group B personnel.

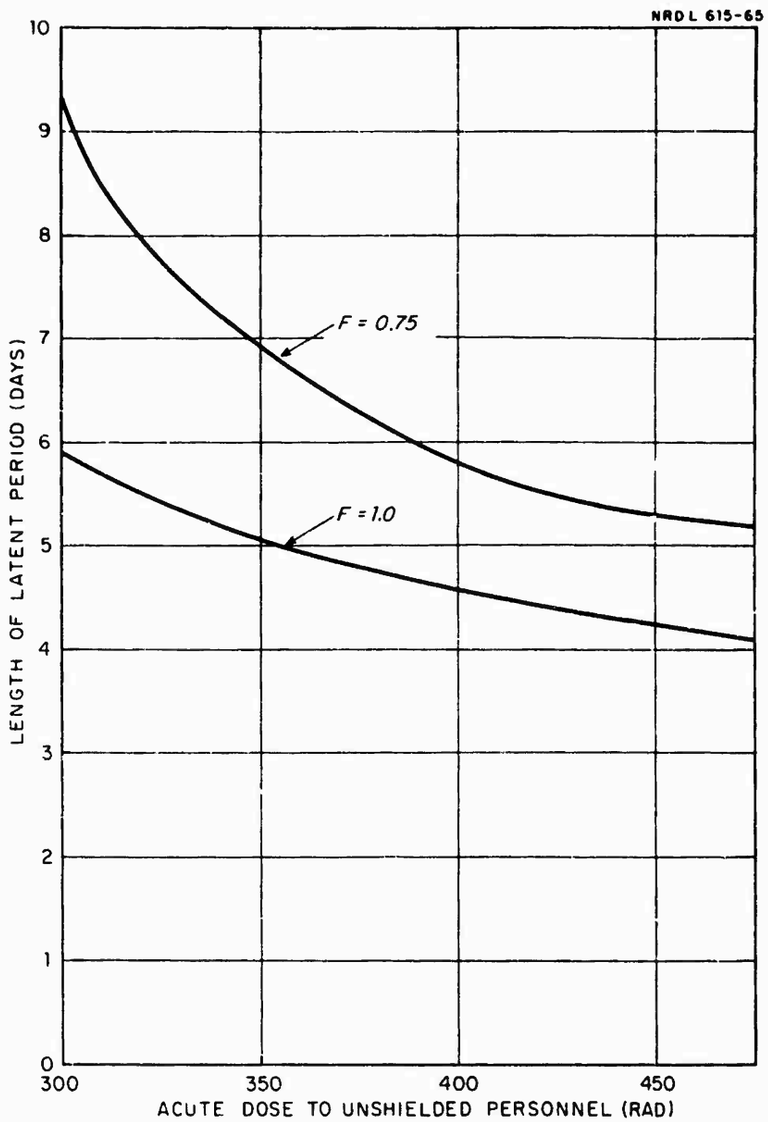

Figure 8 Length of Latent Period Vs Unshielded Acute Dose for F = 1.0 and F = 0.75

(b) If it is po ible to selectively protect against each of the three syndromes, then a solid abdominal shield is a feasible means of protecting both Group A and Group B personnel against the gastrointestinal syndrome.

(c) Both the trunk and abdominal shields will be of value in increasing the length of the latent period.

SECTION 7

THE GRID SHIELD

7.1 GENERAL CHARACTERISTICS

The grid (sieve) shield is of the same shape as the solid shield described in Sec. 6, the only difference being the presence of regularly spaced holes throughout the shield. The effect of these holes is two-fold: (1) the biological response to grid-transmitted radiation may be less severe than that to the same amount of homogeneous radiation--a biological effect, and (2) amount of fallout radiation transmitted through the grid shield is usually less than that transmitted through a solid shield of equivalent weight--a geometrical effect.

Because of a paucity of biological and physical data, precise quantitative statements cannot be made concerning these two effects. Thus, the following discussion on the potential value of the grid shield is essentially a qualitative one.

7.2 BIOLOGICAL BASIS OF GRID SHIELDING

7.2.1 Case Histories

Grid shielding of irradiated areas in patients undergoing therapeutic radiation treatment has long been practiced by radiologists, primarily in Europe, as far back as the 1920's. As applied in therapy, the thicknesses of the shields are such that only tissue beneath the openings receives significant radiation. Using skin damage as a criterion, which is a notoriously poor one for quantitation,* it has been found[32,33,34,35,36,37] that grid-shielded patients can tolerate higher transmitted doses than solid-shielded patients receiving homogeneous radiation. On the basis of experiments using circular, polygonal, star-shaped, etc., holes,[38] it appears that, for a fixed hole area, the efficiency of the grid increases as the wall area of the hole increases. Because of this effect, it has been suggested[39] that the ability of damaged skin tissue to recover depends on the surface area of the damaged tissue-undamaged tissue interface (the interface being considered as a cylinder or prism whose depth is the thickness of the tissue of interest). It was observed by Glocker[40] earlier that, for a fixed open-area/closed-area ratio, the efficiency of the grid increases as the hole size decreases because of the reduction in back scatter.

* L. J. Cole, USNRDL, personal communication.

Unfortunately, skin damage is not an endpoint of interest in this study. In presenting their case histories in grid shielding, only a few radiologists have discussed the presence or absence of radiation-sickness symptoms in their patients. Harris[41] found an improved hematological tolerance using grids. Eichhorn and Matschke[42] noted that "the sparing of the papillary plexus of the skin is important in attenuating the radiation syndrome." Marks,[37] in reviewing his experiences in grid shielding, states: "In the 200 cases treated, no radiation-sickness or blood changes were encountered, nor have any deleterious effects on bone been observed, since the small apertures of the grid, by reducing the volume of tissue irradiated, greatly limit the quantity of secondary radiation. Bone absorption, for this reason, is much less than in conventional roentgen therapy." Similar observations were made by Devois,[43] who found no changes in the blood picture and little radiation-sickness. Since, obviously, no controls were used in Marks' or Devois' work, it can only be inferred from the tenor of their remarks that the amount of grid-transmitted radiation used in their studies would normally be expected to produce some radiation-sickness symptoms if it were homogeneously distributed.

7.2.2 Animal Experiments

Grid-shielding information of a somewhat more quantitative nature is available in the work of Kereiakes *et al.*[44,45,46] and Lane, Mauderli, and Gould.[47]

From their studies on mice, using 200 KVP X-rays and grid shields with circular holes, Kereiakes *et al.* concluded that, with death as an endpoint, (1) for a given midline dose, the grid shield increased the percentage of survivors; (2) for a fixed open-area/closed-area ratio, the efficiency of the shield increases as the hole diameter decreases if the midline dose is less than 1600 rad; for doses higher than 1600 rad, the opposite is true; and (3) for a 900 rad midline-tissue dose, the beneficial influence of grid shielding is exerted only if the dose transmission to the tissue surrounding the damaged tissue does not exceed 10%. Typical examples of their results are shown in Fig. 9. Although in fallout shielding, the biological endpoints, species, and radiation field differ from those of the above experiments, it is considered* that similar conclusions can be made. In particular, it is believed that dose transmission to the tissue through the closed area may be as high as 25% without altering the beneficial effect of the grid shield.

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* Kereiakes, J., personal communication, May, 1965.

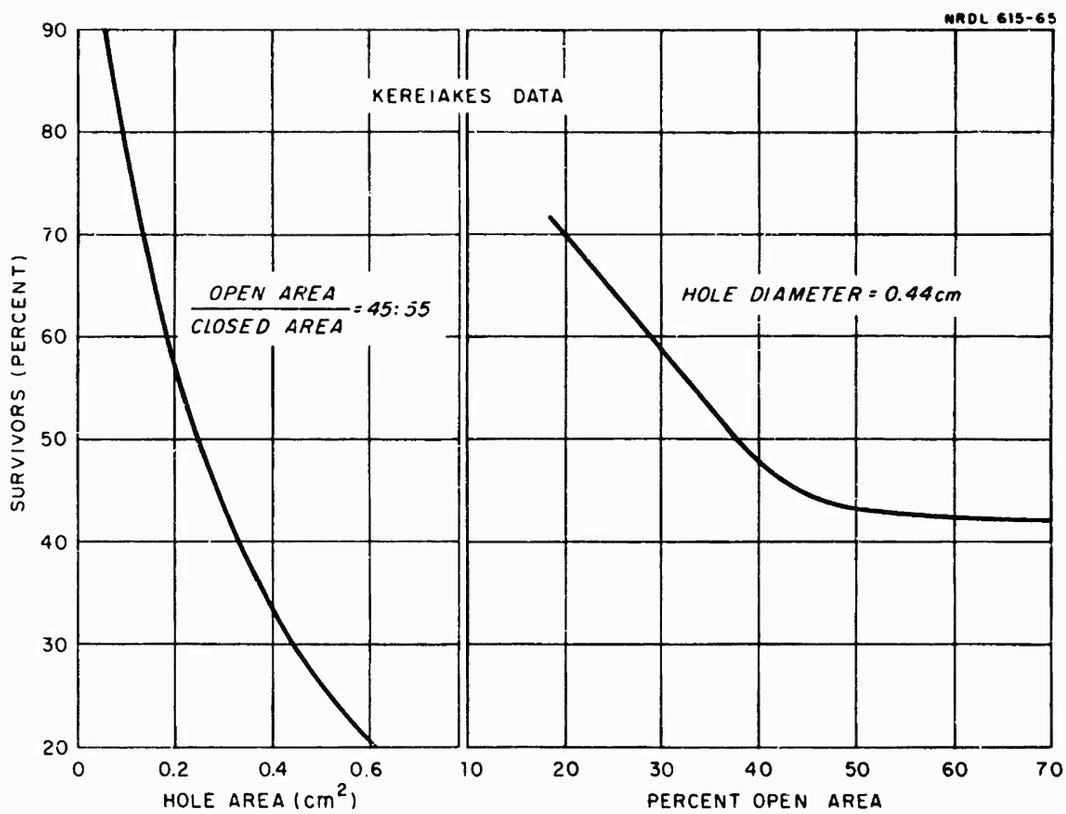

Figure 9 Percent Survivors Vs Hole Area for Open-Area/Closed-Area Ratio of 45:55, and Vs Percent Open-Area and Hole Diameter = 0.44 cm; 800 rads Midline Dose in all Cases

Using Co^{60}, whose gamma energy is close to that of early-time fission products, Lane et al.[47] irradiated rats through shields with holes in the form of conical frustrums (the inner and outer open-area/closed-area ratios being 2:3 and 2:5, respectively). Taking 30 day death as their endpoint, they concluded that, depending on the exposure rate, the LD_{50} for unshielded rats was between 725 and 825 R, whereas it was between 1780 and 1980 R for grid-shielded rats. Calculations made using Lane's data are presented graphically in Fig. 10.

On the basis of the aforementioned studies, there appears to be a "biological shielding factor" associated with the grid shield that provides protection over and above that provided by a solid shield of the same mass.

7.3 GEOMETRICAL BASIS OF GRID SHIELDING

The clinical and experimental data discussed in 7.2 were based on radiation entering the shield at nearly right angles, so that the increased protection provided by the grid shield over the solid shield could be explained on the basis of biological phenomena. In the case of radioactive fallout, the protection provided by the grid shield would be further enhanced by geometrical considerations. A precise calculation of the dose transmitted through a grid under fallout conditions is extremely difficult; however, an analysis of a shield consisting of parallel horizontal bands of lead should reflect the shielding properties of the grid. A vertical cross-section of such a shield is shown in Figure 11.

Most of the radiation transmitted to P through the band-shield will come from that portion of the source beyond (to the left of) A. The solid shield shown in Figure 11 is of the same total weight as the band shield, and most of the dose will come from the source beyond B. Noting that $\bar{\mu} \gg \mu$, the ratio of band-shield dose to solid-shield dose (homogeneous dose) to P is given by:

$$R = \frac{I_1 + I_2 + I_3}{I_4}$$

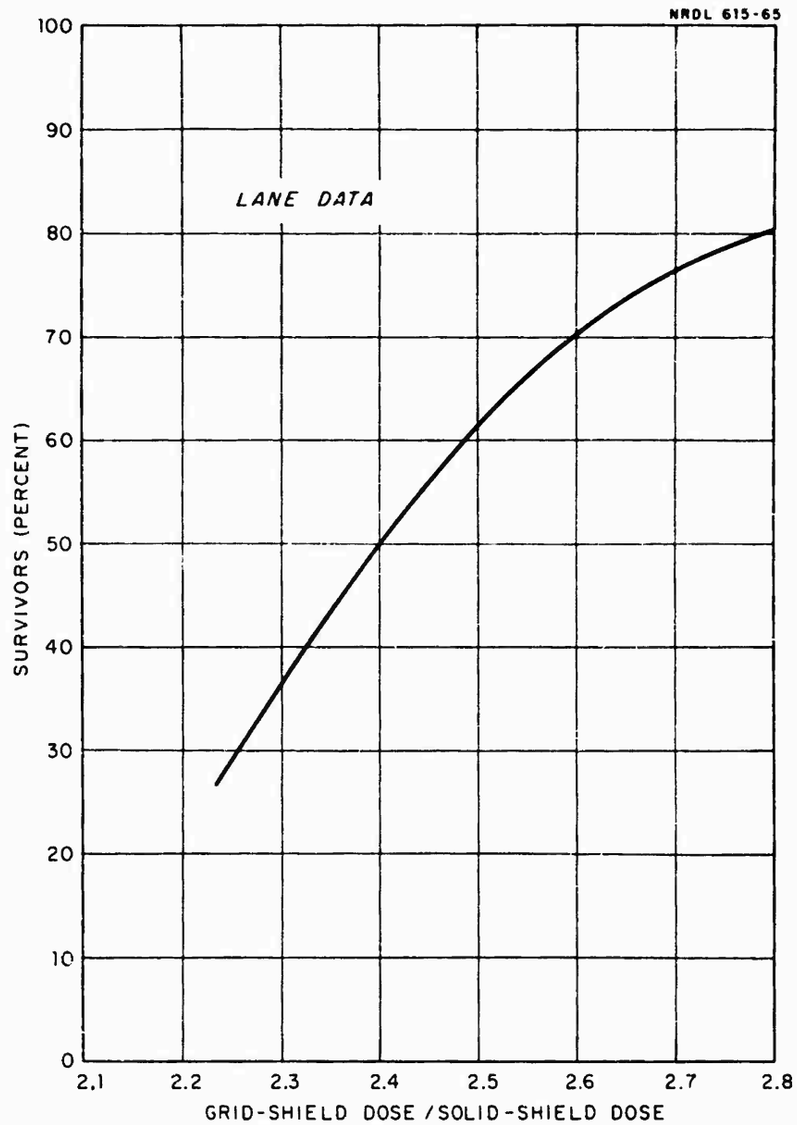

Figure 10

Percent Survivors Vs $\frac{\text{Grid-Shield Dose}}{\text{Solid-Shield (Homogeneous) Dose}}$

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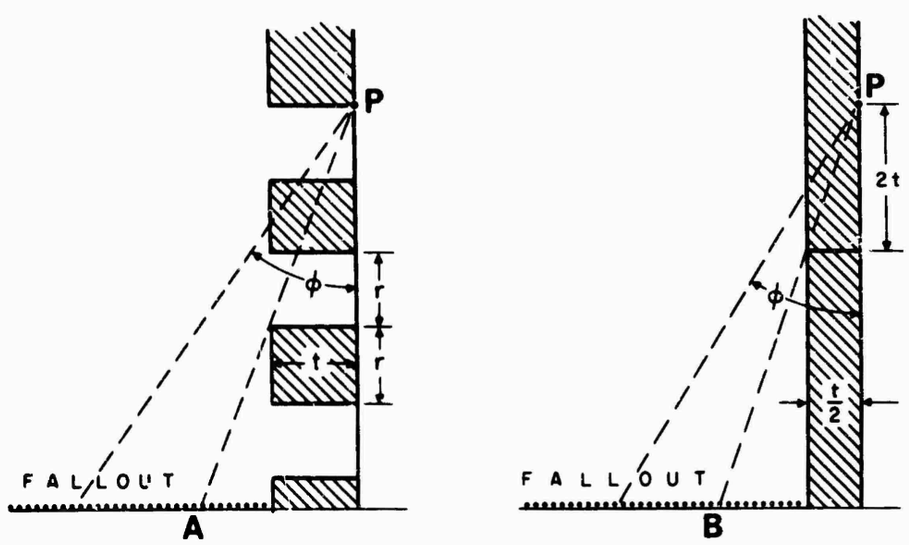

Figure 11
Source-Shield-Point Geometry for Grid Shield and Solid Shield

where $$I_1 = \int_{\tan^{-1}\frac{t}{3r}}^{\tan^{-1}\frac{t}{2r}} \tan\phi \, e^{-(\mu h + \bar{\mu}_\ell r)\sec\phi} \, d\phi$$

$$I_2 = \int_{\tan^{-1}\frac{t}{2r}}^{\tan^{-1}\frac{t}{r}} \tan\phi \, e^{-\left[(\mu h - \bar{\mu}_\ell r)\sec\phi + \bar{\mu}_\ell t \csc\phi\right]} \, d\phi$$

$$I_3 = \int_{\tan^{-1}\frac{t}{r}}^{\frac{\pi}{2}} \tan\phi \, e^{-\mu h \sec\phi} \, d\phi$$

$$I_4 = \int_{\tan^{-1}\frac{t}{4}}^{\frac{\pi}{2}} \tan\phi \, e^{-(\mu h \sec\phi + \bar{\mu}_\ell \frac{t}{2}\sec\phi)} \, d\phi$$

and t is shield thickness, r is hole diameter, h = 4 ft, and μ and $\bar{\mu}_\ell$ are defined in 6.3.2. Figure 11 below is a two-dimensional slice of a grid shield consisting of a series of cylindrical strips arranged vertically, with a strip height and strip spacing both equal to r.

Sample calculations show that, for realistic values of t and r, the value of R is less than 1, usually on the order of 0.7 to 0.8. For the grid shield, scattering of radiation from various lead-air interfaces near P may increase this ratio.

7.4 EXTRAPOLATION OF CLINICAL AND EXPERIMENTAL DATA TO A FALLOUT SITUATION

The success of grid shielding in the above-cited studies appears to depend primarily on the fact that, by means of the grid, the boundaries between damaged and undamaged tissue were well defined. This fine demarcation suggests that a crucial design feature of an operational grid shield must be that it is accurately and tightly fitted so that certain tissues are shielded at all times. In view of the complex geometry of the radiation field and the many body movements (turning, bending, stooping, etc.,) that personnel would be required to perform, such a shield poses a difficult engineering problem.

Even if such a design feature is possible, extrapolation from the clinical and experimental data is still not clear cut. All of these data were based on radiation entering the shield at nearly right angles, and erythemal patterns exactly matching the grid patterns were observed in all cases. In the case of fallout radiation entering the shield obliquely, it is not possible to state whether such well-defined patterns will occur. If they do, then an attempt at extrapolation can be made. If they do not (meaning all tissue is damaged to varying degrees), then the clinical and experimental data are not directly applicable to the fallout situation.

If we assume for the moment that the aforementioned animal data, especially those of Kereiakes and Lane, are extrapolated to human beings in a fallout situation, the potential benefit of the geometrical and biological effects of grid shielding can be seen from the following example:

Unshielded personnel are expected to receive an acute dose of 850 rads. It is required to provide a trunk shield that will reduce the dose to personnel to less than 200 rads. A grid shield with an open-area/closed-area ratio of 1:2 whose thickness permits 25% transmission through the closed-area will provide a "geometrical shielding factor" of $0.33 + 0.67 \times 0.25 = 0.50$. Since an obvious characteristic of doses less than 200 rads is the nearly total absence of fatalities--certainly less than 20%--the grid shield can be said to provide a "biological shielding factor" no worse than 0.35 (the reciprocal of the dose ratio corresponding to 80% survivors shown in Figure 10). Consequently, in the presence of a grid shield, the dose of 850 rads will elicit the response normally associated with $850 \times 0.50 \times 0.35 = 150$ rads. The weight of the shield would be approximately 135 - 175 lb, depending on the time of interest, as opposed to 265 - 345 lb for a solid shield with the same shielding factor (cf. Figure 3).

Unfortunately, the weight of the grid shield in the above example is excessive in view of the results of Sec. 5. The values of the open-area/closed-area ratio and the transmission factor (on which the weight depends) used above are compatible with those used by Kereiakes and Lane, so that it appears that if a direct extrapolation of experimental results to a fallout situation is at all possible, it can be done only in situations where a high degree of protection and very heavy shields are required. Nevertheless, it is interesting to speculate on the possible advantages of a grid shield in situations where poorer shielding factors (and hence lighter shields) are acceptable; e.g., a shielding factor of 0.50. An increase in the grid-shielding factor can be accomplished by increasing the open-area/closed-area ratio and/or increasing the closed-area transmission factor. Thus, if a grid shield with an open-area/closed-area ratio of 2:1 and a transmission factor of 0.30 provided, in addition to its "geometrical shielding factor" of 0.77, a "biological shielding factor" of 0.65 or less, then the "effective shielding factor" of the grid would be 0.77 x 0.65 = 0.50 or less. This shield would only weigh from 55 to 72 lb, whereas a solid shield providing the same protection would weigh from 140 to 185 lb.

As the above analysis shows, any discussion of the operational utility of grid shielding is, by necessity, fraught with uncertainties and assumptions, due to lack of experimental information.

However, there is sufficient evidence to justify further experimental work in the biological and physical aspects of grid shielding, with emphasis on fallout protection.

SECTION 8

DRUG PROTECTION AND PARTIAL-BODY SHIELDING

8.1 DRUG PROTECTION ALONE

The use of drugs to provide biological protection (prophylaxis) against radiation and to improve therapy of radiation sickness has been the subject of many investigations. Among the drugs that are of some benefit are desoxycorticosterone (used in the therapy of radiation sickness), the flavonoids and dramamine (increased survival in irradiated animals), glutathione, cysteine, cysteinamine, and other sulfhydryl-containing amino acids, and diethyl-dioxystilbene dipropionate (protection against damage to leucopoiesis).[48] Mixtures of serotonin and 2-mercaptoethylamine (MEA) or 2-aminoethylisothiuronium (AET) have been found to significantly increase survival in irradiated animals.[49,50] Of these drugs, cysteine and related compounds and the serotonin mixtures appear to be the most effective prophylactic agents.

8.2 DRUG PROTECTION AND PARTIAL BODY SHIELDING

The use of drugs in conjunction with partial-body shielding has been the subject of only a few investigations. Sullivan and Thompson,[51] using mice, shielded the areas adjacent to the abdomen and exposed 90% of the intestine to radiation, with and without cysteine prophylaxis. They noted marked protection with the drug; for example, 8% mortality for those animals receiving a 1200-R acute exposure as opposed to 100% mortality for those animals not receiving cysteine. Maisin et al.[52] noted a beneficial effect of preirradiation administration of MEA to rats and use of solid lead shielding of selected areas of the body, with greatest protection to those animals receiving shielding of the bone marrow.

The most definitive results are those of Wang and Kereiakes,[53] who irradiated mice protected by lead grid shields and a serontonin-MEA-AET mixture. On the basis of percent survivors, it was found that the combined actions provided protection corresponding to an "effective" shielding (dose-reduction) factor of 0.28. (In this case the dose-sensitivity is reduced by the drug in addition to the generation of adjacent injured-uninjured regions. These two effects are lumped for simplification into the concept of "biological shielding factor" as before.) Irradiation of mice protected by the shield alone or by the

drug alone gave effective shielding factors of only 0.81 to 0.57 and 0.48 to 0.34, respectively, which indicates that simultaneous use of both protective measures can be beneficial. It is seen that the drug-shield combination is at least twice as effective as the shield alone.

Assuming that a human wearing the solid shield described in Sec. 6 would respond to the serotonin mixture in a similar fashion, the desired "effective" shielding factor of 0.37 could then be realized by a weight of approximately 40 to 50 lb, depending on the time of interest.

Note that more detailed consideration involving combinations of drugs and vehicles would in fact require taking into account side effects (e.g., toxicity), which have been noted in most, if not all, of the radiation-protection drugs.

SECTION 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 GENERAL

As has been stressed throughout this report, the type of partial-body shielding required to adequately protect against the acute radiation syndrome depends to a great extent on the viewpoint adopted concerning the applicability of existing experimental data to human beings in general and to postattack recovery personnel in particular. Consequently, any conclusions concerning the feasibility of partial-body shielding must be made within the framework of the viewpoint adopted.

9.2 CONCLUSIONS

1. The weight of the shield should not exceed 50 lb for personnel whose postattack functions require strenuous, prolonged effort; other personnel may efficiently carry up to about 70 lb.

2. If it is assumed that adequate protection against the neural and hemapoietic syndromes is available in the form of drugs and small, light-weight shields, respectively, and if it is further assumed that the severity of the gastrointestinal syndrome may be controlled by regulating the dose to the abdomen, then the only extensive body shield required is one covering the abdomen. It has been shown in this study that a shield of this type, whose weight can be effectively carried, may be of significant value to both Group A and Group B personnel in many operational situations.

3. If it is assumed that localized control of the neural, hemapoietic and gastrointestinal syndromes is not possible, then a hip-to-neck shield is required. Such a shield would be of little value to Group A personnel, because of the excessive weight required to produce significantly lower doses. Such a shield would, however, be of value to Group B personnel, since markedly lower entry times and longer stay times can be obtained by wearing a solid-trunk shield of tolerable weight.

4. Both the solid-trunk and solid-abdominal shields are feasible methods of extending the length of the latent period.

5. A grid shield may prove to be more effective than a solid shield because of enhancing biological and geometrical factors.

6. Drug protection in conjunction with partial-body shielding could result in significantly better protestion than that obtainable from shielding alone, and could markedly reduce the weight requirements of an effective shield for the same protection.

9.3 RECOMMENDATIONS

From types of data and the number of assumptions used in this analysis it is apparent that further experimental work is mandatory before real reliance can be assigned to the above conclusions. Such work should be directed towards solving the problem of interest: definition in operationally significant terms of the effects on human beings subject to radiation from fallout. All aspects of the problem: biological response, solid- and grid-shield phenomenology, weight-efficiency relationships, and drug-shield effectiveness, are sorely in need of further research.

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13. ABSTRACT The feasibility of partial-body shielding is discussed from two points of view. The first assumes that limited clinical and experimental data are extrapolable to the operational situations of interest and that it is possible to selectively protect against the neural, hemapoietic, and gastrointestinal components of the acute radiation syndrome. Under this assumption, it would appear that (a) neural syndrome symptomatology may be adequately controlled by means of drugs, (b) the hemapoietic syndrome may be controlled by a light-weight (under 10 lbs) lead epicondylar cuff, and (c) in many operational situations the gastrointestinal syndrome may be controlled by an abdominal shield sufficiently light in weight to permit postattack personnel to efficiently perform their tasks.

The second point of view discussed assumes that, at present, there is not an adequate basis for selective syndrome shielding, and that a metal shield covering all of the body from the hips to the neck is the only adequate form of protection. Under this assumption it would appear that weight limitations preclude the use of this type of shield in most situations in which personnel must enter the fallout field at specified times and remain until the completion of their mission. However, in the case of personnel who are not required to enter the field at any specified time and who may be recalled after receiving a predetermined dose, trunk shields of acceptable weights will significantly lower entry times and extend stay times. The use of a grid (sieve) trunk shield is discussed and it appears that a shield of this type, of acceptable weight, may be of benefit in many operational situations in which the solid shield was not. Drug protection in conjunction with both solid and grid shields is evaluated, and it is concluded that a marked reduction in the weight requirements of effective shields of both types could result from such a combination.

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