source energies, mainly by Compton scattering in air. The dose from each of the resulting energy intervals was calculated and plotted as a fraction of the total dose. This was seen to group roughly into three regions, with maxima at 100, 700, and 1500 kev. An exposure to such a source was thus the resultant effect of partial doses from each region, making the exposure energy conditions quite different from those of the clinic or laboratory.

Figure 1.2 illustrates the dose spectrum of 4-day-old fallout from a cloud sample. In the absence of other data to the contrary, this had to be taken as representative of the fallout on all of the islands. At this time the proportion of low energy component was at its maximum. During the several days before and after this time, the general shape of the spectrum apparently did not vary grossly from that illustrated here, since the observed flux decay rates closely followed that of the observed gamma dose rate. For the period between fallout and surveys, therefore, a knowledge of instrument response to each energy region allowed a total correction factor to be calculated. The instruments used were calibrated just prior to the surveys, and their readings have been corrected for the spectrum shape here illustrated.

1.4.2 Rate of Decay of the Fallout Mixture

Decay rates of fallout samples were measured in the field and in the laboratory, where a fairly consistent pattern was observed among various locations and samples. In addition, theoretical considerations based on the radiochemical composition of the fallout mixture permitted decay rates to be calculated for different intervals between the times of initial exposure and later survey readings. These agreed well with the experimental data, and were used both in the dose calculations during the exposure intervals and in extrapolating the later survey readings to earlier times.

1.4.3 Time of Arrival of the Radioactive Cloud, Duration of the Fallout, and Time of Evacuation for Each Case

Only the time of evacuation is known accurately for all the islands. On Rongerik, however, the time of arrival of the radioactive cloud was determined precisely by the continuously recording dose rate monitor at the weather station. The fallout became visible at the time the instrument first indicated the presence of a radiation field above background. The material had the appearance of snow. The times of beginning of fallout on Rongelap and Ailinginae were estimated from similar visual observations, combined with knowledge of the relative distances of these atolls from Bikini and the wind velocities in the area. Fallout was not observed on Utirik, hence the estimate of arrival time there was made on the basis of the Rongerik fallout time, wind, and distance factors.

Two extreme possibilities exist relative to the duration of the fallout: the first, that the fallout occurred entirely within a short time; the second, that it was gradual and extended over a period of many hours. The monitoring instrument on Rongerik went off-scale at 100 mr/hr, ½ hour after the dose rate began to rise above background. If this rate of increase is extrapolated to a point for which subsequent decay would reduce the dose rate to the values found at later times, a long fallout is implied. This was taken as one limiting case, and corresponding doses were calculated. However, the possibility does not seem great that this actually occurred. Existing data are inconclusive, but several indications tending to favor the short time hypothesis are summarized below.

First: a long fallout probably would not be uniformly heavy throughout, the first portion being the most intense and the balance tailing off. The total phenomenon thus tends toward the effect of a shorter fallout. This is supported by monitor data from other nuclear events.

Second: the estimated durations of fallout, of about 18 hours, which result from the above extrapolation for Rongerik and Rongelap, appear too long to have occurred at the distances of these atolls from Bikini, since the wind velocity in the area was high enough for the cloud to pass over the islands in a considerably shorter time.

Third: the accounts of the visibility of the fallout, although conflicting, do not seem to indicate such late cessation.

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Fourth: doses calculated on the long fallout hypothesis are lower than those due to a short fallout, since a short fallout quickly deposits a large amount of activity. On Rongerik, a set of film badge readings covered the range listed below. Several badges worn both outdoors and inside buildings on the island read 50–65 r, and one badge which remained outdoors over the 28.5 hr period read 98 r. Another group kept indoors inside a refrigerator read 38 r. These dose values represent a variety of conditions, but considering the shielding and attenuation factors, are consistent with the assumption that the dose reached the calculated upper limit outside, again favoring the shorter fallout hypothesis. The upper limit of 98 r will result if it is assumed that the fallout lasted one hour during which the intensities rose from zero to the maximum dose rate which then decayed to values observed later. A long fallout will not produce such a high dose of radiation.

Fifth: on Utirik, only a short fallout time is consistent with the later dose rates observed, provided the fallout began as late as was estimated from wind and distance factors. A one hour duration* of fallout appears likely. On the other islands the actual fallout time is known to have exceeded one hour; however, since the approximate dose discussed above was seen to fit the film data on Rongerik, it was used for the other islands as listed in the calculations in Table 1.1. The hour limit is thus "an effective value."

If the long fallout case is also considered, a lower limit for the dose may also be estimated, though the upper limit is taken as most probable. The ranges are then as follows: Rongerik 50 r – 104 r; Rongelap 102 r – 175 r; Ailinginae 53 r – 69 r; and Utirik – 14 r.

The dose value for Rongerik given in Table 1.1 is 75 per cent of the short fallout case value, averaged for 28.5 and 34 hour exposures. This best expresses the average air dose received by personnel who spent roughly half their time inside structures where the dose rate was later found to be roughly half that outdoors. On the other islands no such shielding was present.

Figure 1.3, for the Rongelap atoll, illustrates the cumulative dose as a function of time after the detonation. It can be seen that the rate of delivery of the dose varied continuously, the major portion being received at the higher dose rate prevailing in the early portion of the exposure period. By the time that 90 per cent of the dose had been received, for example, the dose rate had fallen to less than 30 per cent of its initial value. Thus the dose rate of exposure differed markedly from that usually encountered using x-ray units.

1.4.4 Geometry of the Exposures

A third difference between the type of exposure encountered here and other external exposures lay in the geometry of the source. These doses were delivered from a plane source, so that the radiation field did not follow the narrow beam geometry usually employed experimentally. In such a diffuse 360° field, the decrease of dose with depth in tissue is less pronounced than that resulting from a unilateral or bilateral exposure to an X-ray beam, so that for a given energy, the dose at the center of the abdomen is approximately 50 per cent higher than a given air dose would imply for the narrow beam case. Figure 1.4 illustrates an experimental simulation of the field geometry using a spherically oriented group of Co^{60} sources with a phantom placed at their center, compared with a conventional depth dose curve obtained with a single source. It would appear under the circumstances that the midline dose, rather than dose measured in air, would be the better parameter in terms predicting biological effects. On this basis, the air dose values stated in Table 1.1 should be multiplied by approximately 1.5 in order to compare their effects to those of an exposure using a narrow beam geometry. If this is done, assuming a fast fallout of one hour, the following doses in terms of an air dose under laboratory conditions result: Rongelap 260 r; Ailinginae 100 r; Rongerik 120 r; and Utirik 21 r.

* While it is obvious that the fallout lasted longer than one hour, calculations of dose are based on an assumed one hour fallout as explained in the text.

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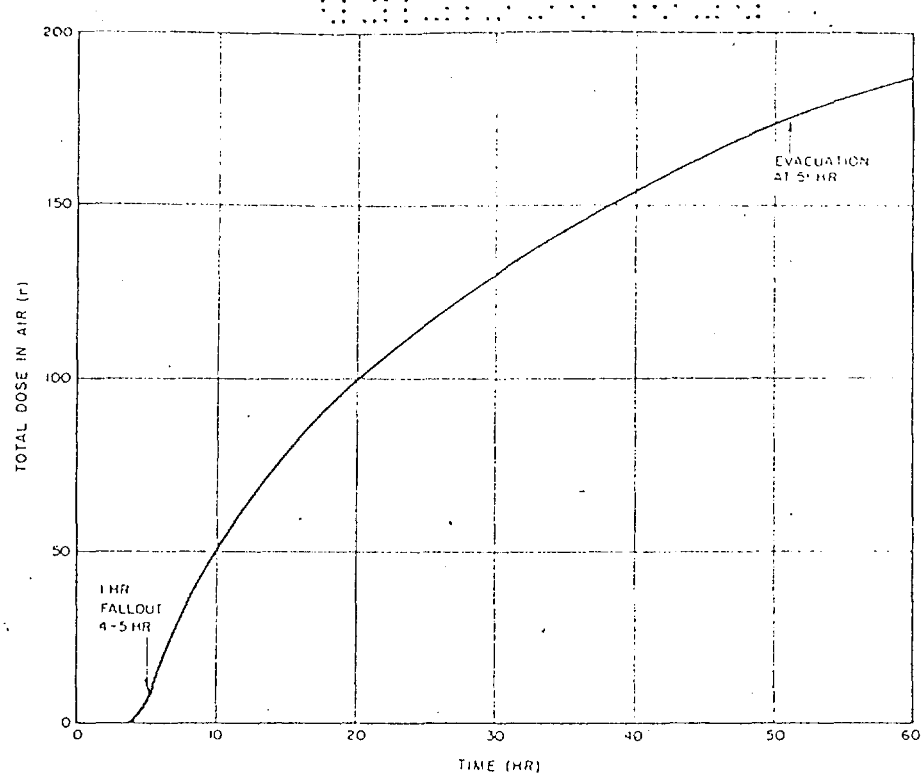
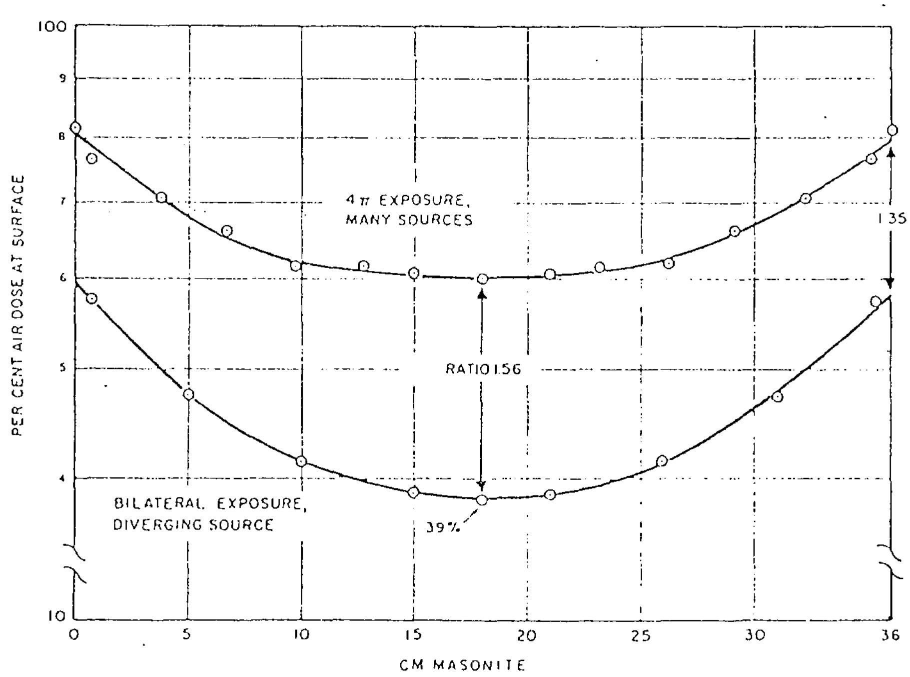


Fig. 1.3 Cumulative Dose as a Function of Time After the Detonation



DEPTH DOSE DISTRIBUTION IN CYLINDRICAL PHANTOM, CO^{60} FACILITY, (NMRI)

Fig. 1.4 Comparative Depth Doses for Bilateral Exposure from a Small Source and Multiple Source 4π Exposure with Cobalt-60

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1.5 ESTIMATE OF MAXIMAL SKIN DOSE FROM THE GROUND

In addition to the total body gamma dose, the very soft gamma and higher energy beta radiation from the plane source contributed to the skin dose. Further skin irradiation resulted from local deposits of fallout material on the body surface itself. The latter is impossible to estimate, but the former may be roughly attempted as follows.

The beta dose rate in air at a height of 3 feet above the surface of an infinite plane contaminated with mixed 24-hour-old fission products is estimated to be about three times the

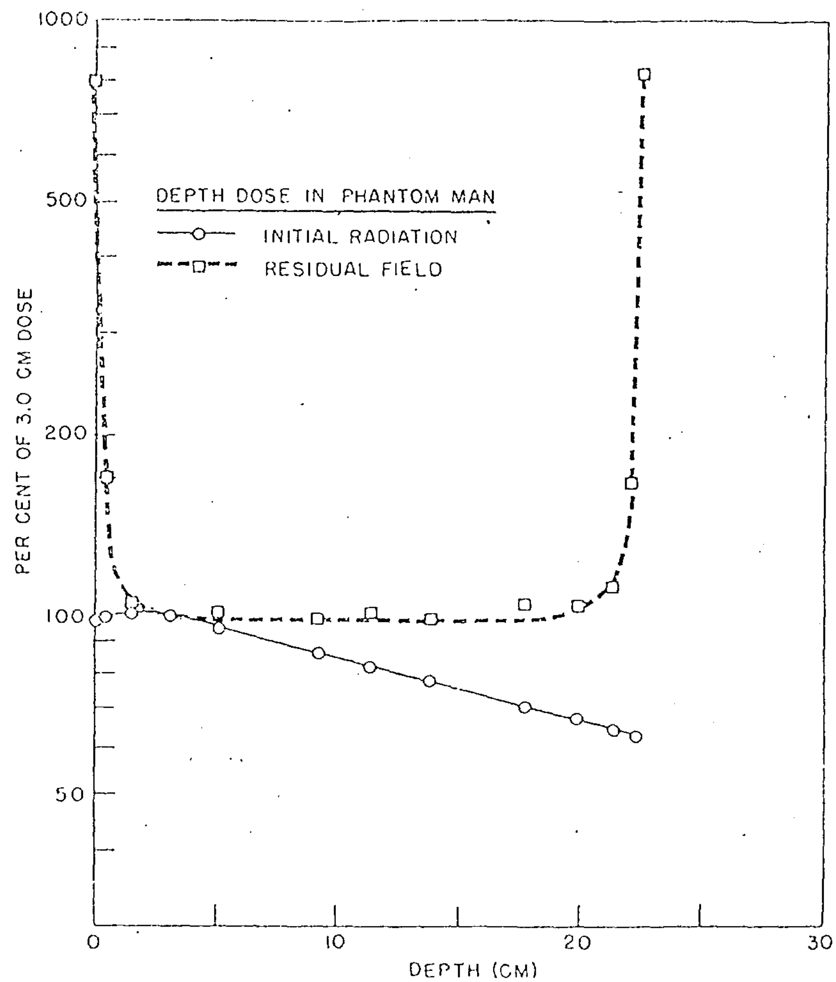

Fig. 1.5 Comparative Depth Doses in a Phantom Man of Initial Atomic Bomb Radiation and Radiation from a Field of Fission Products

gamma dose. The midline gamma dose is approximately 60 per cent of the portion of the air gamma dose due to 80 kv radiation or above. This portion in turn is estimated to be 90 per cent of the gamma dose measured in air by the instrument. Thus the dose at the surface of a phantom exposed to mixed fission product radiation from an external plane source might be expected to be 3/(0.6)(0.9) or about six times the midline dose, if both occur at 3 feet off the ground. Such a depth dose measurement has in fact been made experimentally at a previous

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field test,* using a phantom man exposed to both the initial and residual radiation. The depth doses for each situation are shown in Fig. 1.5, with all data as per cent of the 3 centimeter dose. With the diverging initial radiation from the point of explosion, the exit dose was seen to be 63 per cent of the 3 cm dose, but with the diffuse residual field of fission product radiation, a surface dose some eight times greater than the 3 cm and deeper dose from the harder gamma components was observed. This is seen to be of the same order of magnitude as that estimated above. At heights above and below the 3 foot level this surface dose would become lower and higher respectively, but probably would not exceed 50 times the 3 foot air gamma dose or 80 times the midline dose, even in contact with the ground. An estimate of skin dose due to ground contamination for the Rongelap case would result, for example, in a figure of about 2000 rep to the dorsum of the foot, 600 rep at the hip level, and 300 rep at the head if continuous exposure with no shielding occurred. Some reduction in dose undoubtedly resulted from shielding and movement, and it seems probable that the external beta dose from local skin contamination far outweighed that from the ground in importance. This is emphasized by the fact that clothing probably reduced the beta dose from the ground by 10 to 20 per cent.

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* F. W. Chambers, Project 2.2b, Residual Gamma Depth Dose Measurements in Unit-Density Material, AFSWP, WT-719, Operation UPSHOT-KNOTHOLE.

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CHAPTER 2

CLINICAL OBSERVATIONS AND THERAPY

2.1 INTRODUCTION

It was known immediately that the exposed groups had received a significant amount of penetrating radiation to the entire body, extensive contamination of the skin, and possible internal deposition of radioactive materials. It was therefore decided that clinical observations would be as extensive and frequent as facilities and personnel permitted in order to recognize and care for radiation effects as early as possible. Accordingly complete initial histories and physical examinations with numerous follow-up examinations were carried out. Surveys of the skin were conducted at frequent intervals and the detailed skin findings are reported in chapter 3. Extensive hematological studies were conducted, the detailed results of which are presented in chapter 4. Results of examinations for urinary excretion of radioisotopes are reported in chapter 5.

In addition to periodic examinations, routine sick call was held twice daily. Medical care was available at all times and hospital facilities were available at the Kwajalein Naval Dispensary.

In view of the widespread conflicting opinions in regard to the value of various prophylactic and therapeutic measures in treatment of radiation effects, it was decided in advance that therapy would not be given arbitrarily but would be instituted as indicated clinically for specific conditions on an individual basis. However, if severe granulocytopenia developed (below 1000 cells/cm) the prophylactic use of antibiotics was to be considered. Whole blood transfusions were likewise to be used only in case of development of serious anemia.

2.2 SYMPTOMS AND SIGNS RELATED TO RADIATION INJURY

Several symptoms that developed during the first day or two after exposure probably were attributable to radiation. Itching and burning of the skin and eyes during this period occurred in over one quarter of the Rongelap population, to a lesser extent in the Ailinginae and to a very slight extent in the Americans. The skin symtomatology* might have been due in part to the marked alkalinity of the fallout material (calcium oxide). About two thirds of the Rongelap group reported nausea during this early period and one tenth of the group reported vomiting and diarrhea. Only one Ailinginae individual reported nausea. The people of Utirik and the Americans developed no signs or symptoms that might be related to radiation.

*The symtomatology is based on questionings through an interpreter by several observers. Despite the repeated interrogations and the inevitable suggestion of the interrogators, the stories remained remarkably consistent.

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