SOME EFFECTS OF Ionizing Radiation ON HUMAN BEINGS

A Report on the Marshallese and Americans Accidentally Exposed to Radiation from Fallout and a Discussion of Radiation Injury in the Human Being

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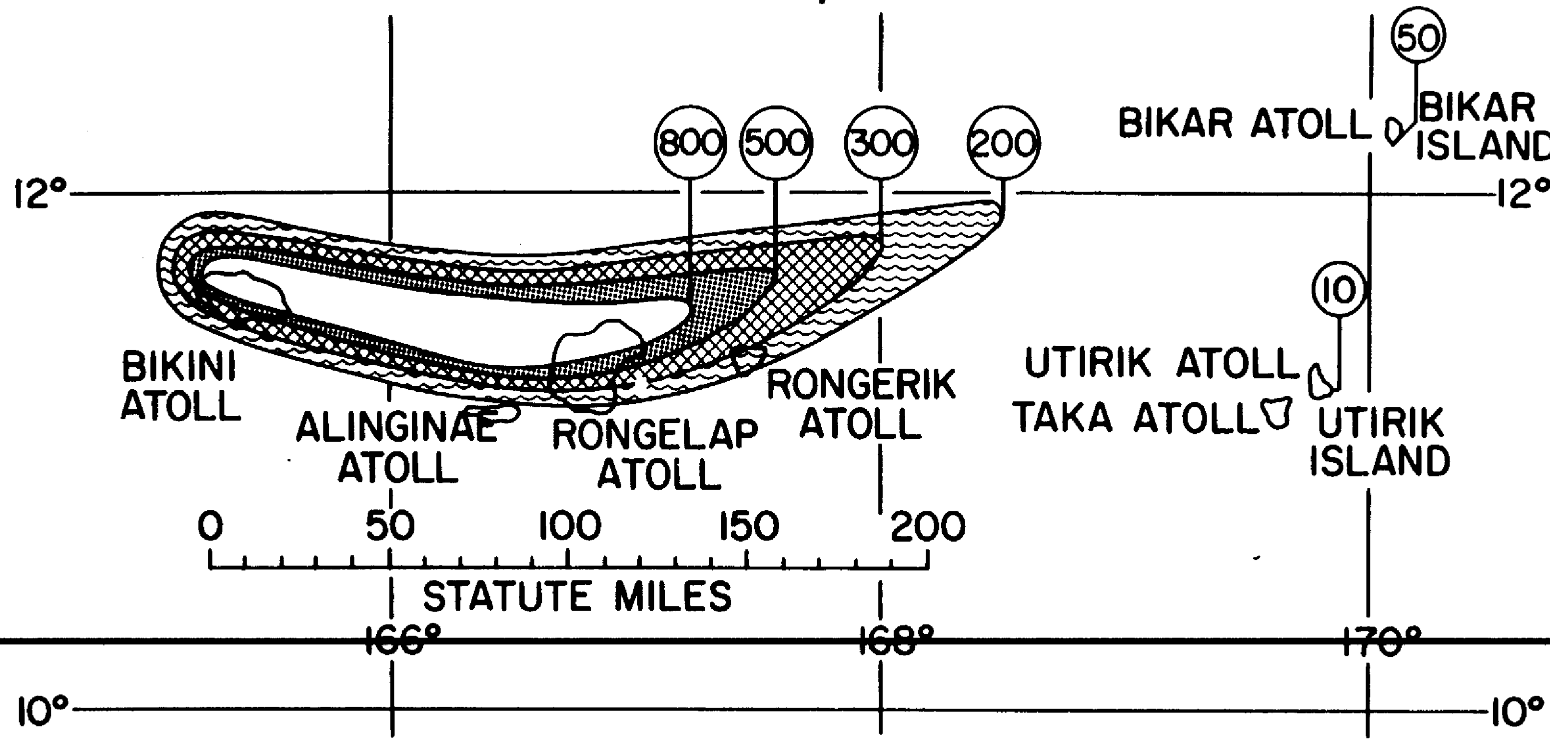
ISODOSE LINES OF
ESTIMATED PATTERN OF RADIOACTIVE FALLOUT

PACIFIC PROVING GROUNDS
MARCH 1, 1954



The numbers on the above map represent the doses that would have been received over approximately 48 hours without shielding. The dose, above which survival is unlikely, is 800 r and below which survival is probable is 200 r.

Introduction

On March 1, 1954, an experimental thermonuclear device was exploded at the U. S. Atomic Energy Commission's Eniwetok Proving Grounds in the Marshall Islands. Following the detonation, unexpected changes in the wind structure deposited radioactive materials on inhabited atolls and on ships of Joint Task Force #7, which was conducting the tests. Radiation surveys of the areas revealed injurious radiation levels; therefore, evacuation was ordered, and was carried out as quickly as possible with the facilities available to the Task Force.

Although the calculated accumulated doses to the exposed human beings were believed to be well below levels that would produce serious injury or any mortality, the Commander of the Task Force requested the Department of Defense and the U. S. Atomic Energy Commission to organize a medical team to provide the best possible care of the exposed persons and to make a medical study of the exposures.

Responsibility for organization of the medical team was shared by the Armed Forces Special Weapons Project, Department of Defense, and the Division of Biology and Medicine, U. S. Atomic Energy Commission. Experienced professional and technical personnel were immediately available from the Naval Medical Research Institute and the U. S. Naval Radiological Defense Laboratory. Since speed was essential in the organization and transport of the medical team to the mid-Pacific area, the assistance of the Medical Department of the Navy was requested, and was promptly received from the Surgeon General.

A team was organized from personnel of the two Navy laboratories and representatives of the AEC Division of Biology and Medicine and the Armed Forces Special Weapons Project. The team was air lifted to the Marshall Islands, arriving on the eighth day after the explosion. Interim care and study had been capably handled by the small medical department of the U. S. Naval Station, Kwajalein, Marshall Islands The commander of the naval station had arranged living facilities for the exposed Marshallese, and installed laboratory and clinical facilities as requested immediately upon arrival of the medical team.

Full cooperation and support from all agencies in the field enabled the medical team to operate at maximum efficiency, so that the degree of radiation injury could be assessed quickly, and appropriate care and study of the injured could be instituted without delay. All of the exposed individuals have recovered from the immediate effects without serious sequelae. Nevertheless it is planned to evaluate the medical and genetic status of the group at appropriate intervals with a view to learning what if any of the known late effects of radiation exposure may be observed. Obviously and indeed fortunately the number of persons receiving 75 roentgens exposure and greater is too small to make it possible to determine with any degree of accuracy the effect on life span.

In addition to providing medical care for these persons, the team accumulated a large body of scientific observations on radiation injury in human beings. The initial data have been supplemented by field resurveys 6, and 24 months after the original investigation.

The results of this work are summarized in the present volume. The data which were obtained substantially increase the fundamental knowledge of radiation injury and the medical capability of caring for persons exposed to large doses of radiation.

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Preface and Acknowledgments

The Undertaking of the care and study of the human beings accidentally exposed to fallout radiation following the March 1, 1954, nuclear test detonation in the Pacific represented the first instance in which study of a large group of irradiated human beings was possible soon after exposure. Although the physical estimates of dose received by the individuals exposed to fallout radiation were thought to be sublethal, precise knowledge of the relative sensitivity of human beings to penetrating ionizing radiation was lacking. Accordingly, in addition to the initial medical team, provisions were made for a second echelon of specialized personnel in case they were needed. A preventative medicine unit of the Commander-in-Chief, Pacific fleet, was alerted for possible bacteriological studies; blood bank personnel, and additional clinicians and nurses were notified in case conditions justified their services in the Kwajalein area. Rear Admiral Bartholomew Hogan, MC, USN, Pacific Fleet Medical Officer,* promised full support of all the medical facilities of the Pacific Fleet were they deemed necessary. With the preceeding planning it was felt that any medical problem, regardless of the severity, could be promptly and adequately handled in the field.

The personnel for the team were obtained within the continental limits of the United States from the Naval Medical Research Institute and the United States Naval Radiological Defense Laboratory. From the former, four medical officers, E. P. Cronkite, R. A. Conard, N. R. Shulman, and R. S. Farr were obtained. Two Medical Service Corps officers, W. H. Chapman and Robert Sharp, were also obtained from the same institution. In addition, six enlisted men, C. R. Sipe, HMC, USN; P. K. Schork, HMC, USN; C. P. A. Strome, HMC, USN; W. C. Clutter, HM, 1/C; R. E. Hansell, HM 1/C; and J. S. Hamby, HM, 2/C were provided. From the United States Naval Radiological Defense Laboratory, one civilian physician, Doctor V. P. Bond; one medical service corps officer, Lt. Com. L. J. Smith; and four enlisted men, W. H. Gibbs, HMC, USN; J. C. Hendrie, HM, 1/C; W. S. Argonza, HM, 2/C; and J. Flannagan, HM, were supplied. The Division of Biology and Medicine, Atomic Energy Commission, sent two civilian physicians, Dr. C. L. Dunham, then Chief of the Medical Branch and Dr. G. V. LeRoy, Consultant and Special Representative of the Director of the Division. The Armed Forces Special Weapons Project supplied one Army medical officer, Lt. Col. L. E. Browning, MC, USA. All personnel were experienced in the study of radiation injury.

The preliminary studies performed by the Medical Department of the Naval Station at Kwajalein were under the direction of Commander W. S. Hall, MC, USN, the station medical officer and his small staff who are to be commended for an excellent job.

Upon arrival of the medical team, it became quite evident that, because of the large numbers of radiation casualties and the huge amount of work involved in collecting data, that primary responsibilities for various phases of the study would have to be delegated in order to obtain the necessary information for biological assay of the degree of injury. In the initial phase, hematological surveys and establishment of clinical records on each individual were emphasized. Dr. V. P. Bond organized and analyzed the results of the daily blood studies. Lt. N. R. Shulman, MC, USN, with the capable assistance of Mr. John Tobin, anthropologist of the Trust Territory, and Kathleen Emil, Marshallese nurse, as interpreters, undertook the establishment of medical histories and initial physical examinations. As the clinical picture

*Now Surgeon General, U. S. Navy.

unfolded, daily sick call and care of the radiation lesions were carried out by Doctor Shulman along lines decided in general conference of the entire group. When epilation and skin lesions appeared, Commander R. A. Conard, MC, USN, was assigned primary responsibility for documentation of the onset, incidence, and detailed description of the skin lesions. During the field phase, Lt. Robert Sharp, MSC, USN, was given the responsibility for decontamination and collection of data from all sources on the radiation intensities of the contaminated atolls and the calculation of probable doses of radiation received. Paul K. Schork, HMC, USN, was in charge of the Hematology Laboratory. The services of Doctor S. H. Cohn were requested, and made available by USNRDL to undertake a field study of the degree of internal contamination, in addition to the studies that were to be performed on urine samples returned to the Los Alamos Scientific Laboratory, New York Operations Office of the Atomic Energy Commission, and the USNRDL.

The authors wish to express their gratitude and indebtedness in particular to Doctor John C. Bugher, then Director of the Division of Biology and Medicine, Atomic Energy Commission, who came to the forward area and was always available for counsel. In addition Captain Van Tipton, MC, USN, Director of Atomic Defense Division of the Bureau of Medicine and Surgery, Department of the Navy; Commander Harry Etter, MC, USN; Captain W. E. Kellum, MC, USN; and Captain T. L. Willmon, Commanding and Executive Officers respectively of the Naval Medical Research Institute: Captain R. A. Hinners, USN, Director USNRDL, and Captain A. R. Behnke, MC, USN, Associate Director NRDL; gave unlimited support and reduced administrative procedures to a bare minimum, thus making it possible for the unit to be assembled and underway in a matter of hours.

Upon arrival at Kwajalein, Rear Admiral R. S. Clarke, USN, Commanding Officer United States Naval Station, Kwajalein, supported the project with all of the facilities at his disposal. As a result, a laboratory and clinic was established and operating within 24 hours after arrival of the medical team.

In addition, we wish to acknowledge the outstanding contributions of Col. C. S. Maupin, MC, USA, Field Command Armed Forces Special Weapons Project: Captain H. H. Haight, MC, USN, Division of Military Application, Atomic Energy Commission; Dr. Gordon Dunning, Division of Biology and Medicine, Atomic Energy Commission; and Dr. H. Scoville of Armed Forces Special Weapons Project who in addition to their primary duties, collected extensive data in the field on the radiation intensities of the atolls and kindly furnished this material to the project personnel. Drs. T. L. Shipman, Thomas White,* and Payne Harris of the Los Alamos Scientific Laboratory kindly furnished very valuable data on urinary excretion of radionuclides. The early studies of the Los Alamos group in particular contributed significantly to the information on the degree and nature of internal deposition of short lived radionuclides. Dr. G. V. LeRoy, Associate Dean, School of Biological Sciences, University of Chicago, participated in the early phase of the study as a consultant to the Medical Group.

The authors of Chapter I are particularly indebted to Dr. C. S. Cook and the Nuclear Radiation Branch at the Navy Radiological Defense Laboratory for information on energy distribution of the gamma radiation. Data on radiochemical and radioactive decay rates were supplied by Dr. C. F. Miller and the Chemical Technology Division of USNRDL and Dr. R. W. Spense of Los Alamos Scientific Laboratory.

In collecting data on the skin lesions, the help of Billiet Edmond, Marshallese school teacher for the Rongelap group in interpretation was invaluable. Miss Patricia Roan of USNRDL prepared the histologic preparations of the skin biopsies and Mr. William Murray and George Needum of USNRDL and C. P. A. Strome, HMC, USN, Naval Medical Research Institute performed the excellent color photography.

In preparation of the material and writing of Chapter V, the authors are indebted to Miss C.

* Deceased.

Jones of USNRDL, who prepared the autoradiographs of the tissues. In addition, Dr. W. P. Norris of Argonne National Laboratory made autographs of specific tissues. Dr. Rachael Reed of USNRDL performed the microscopic pathological studies of the tissues from the animals in whom radioisotopes were deposited internally. Lt. Col. R. J. Veenstra, VC, U. S. Army, was in charge of the care of all the experimental animals collected in the field and returned to the United States Naval Radiological Defense Laboratory. Dr. E. R. Thompkins made the facilities of the chemical technology division of the USNRDL available and provided technical advice on the radiochemical aspects of the project.

The continuous help and cooperation of the Trust Territory representatives in particular, Mr. Maynard Neass, District Administrator of Majuro Atoll and their aid in obtaining the necessary control data on Marshallese inhabitants was indispensable to the success of this study. Particular help was obtained from Mr. John Tobin, the district anthropologist, whose knowledge of the Marshallese language and habits, in addition to services as an interpreter, were invaluable.

The initial measurements on skin and clothing contamination were made by Lt. J. S. Thompson, MC, USN, of V. P. 29 Squadron. We are indebted to him for furnishing his records on the contaminated individuals and the initial decontamination that was performed by his group.

The care and the study of these human beings would not have been successful unless the Marshallese had accepted the importance of their being under careful medical observation and of gathering medical data. At all times these people were most pleasant, cooperative and actively participated in the project. In particular the project officer wishes to express thanks to the Magistrates of the groups, to the Marshallese health aids, school teachers, and nurses.

It is quite impossible to acknowledge the assistance of the numerous individuals in various agencies who assisted in collection of data and editing of the various chapters. The Project Officer wishes to commend all of the professional and technical members of the group for their excellent motivation, initiative, and voluntary long hours of extra work that were essential for the accomplishment of the clinical and research objectives and the rapid collection of the preliminary data in the field. It is quite evident that the entire study of the exposed individuals was a cooperative endeavor involving numerous activities, and that it would have been impossible except for the splendid spirit of unselfish cooperation by all concerned. The fine team work of the group itself made it possible for realistic daily reports on all of the above phases to be forwarded daily to responsible agencies and thus keep authorities informed of the course and severity of events following this untoward and unavoidable accident.

Upon completion of the initial phase of the study, primary responsibility for writing reports on the variouse phases was delegated as follows: C. A. Sondhaus, dosimetry; N. R. Shulman, clinical course and care; R. A. Conard, skin lesions; V. P. Bond, hematology; S. H. Cohn, internal deposition.

The final publication of this monograph on human radiation injury represents the completion of the finest in cooperation and team work of a diverse group who willingly sacrificed personal ambitions and desires for the good of the project at large. It was a distinct privilege to be chosen to direct the medical team, a real pleasure to edit and integrate the separate reports and finally realize their fruition as a homogeneous monograph.

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Chapter I

Radiation Characteristics of the Fallout Material and the Determination of the Dose of Radiation

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Outline

a

1.1 Nature of the Event and Description of the Exposed Groups

FOLLOWING THE DETONATION of a nuclear device at the Pacific Proving ground in the Spring of 1954, significant amounts of radioactive material fell on neighboring populated atolls. The Marshallese inhabitants of Rongelap atoll (designated as Group I) received the highest calculated dose of radiation. Some of the Rongelap people were located temporarily on Ailinginae atoll from the time of the fallout until they were evacuated (Group II). Their calculated dose was smaller than that of the other members of the parent group. The American service men (Group III) were located on Rongerik atoll. The largest group of Marshallese (Group IV) were located on Utirik atoll and received the smallest dose. The Marshallese were living under relatively primitive conditions in lightly constructed palm houses (Fig. 1.1).

The American military personnel had the second highest exposure. They were more aware of the significance of the fallout than were the Marshallese, and promptly put on additional clothing to protect their skin. As far as duties would permit, they remained inside of aluminum buildings. In contrast, most of the Marshallese remained out-of-doors and thus were more heavily contaminated by the material falling on the atolls. Some of the Marshallese, however, went swimming during the fallout and many of the children waded in the water, thus washing a considerable amount of the material from their skin.

The exposed personnel were evacuated to Kwajalein by air and surface transportation. Since a survey of all individuals showed that there was significant contamination of skin, hair and clothes, prompt decontamination was instituted. Clothes were removed and laundered and repeated washings of the skin and hair with fresh water and soap were carried out. In many of the Marshallese, it was difficult to wash the radioactive material from the hair because of the heavy coconut-oil hair dressing.

The exposure groups with individuals involved, the calculated doses of radiation, the probable times of beginning of the fallout and the evacuation times are given in Table 1.1.

Table 1.1—Exposed, and Control Unexposed Groups

Group Designation	Total Number in Group	Approximate Time of Commencement of Fallout	Time of Evacuation	Instrument Readings Used in Dose Calculations	Best Estimate of Total Gamma Dose in Air (r)
Group I.—Rongelap	64	H + 4 to 6 hrs.	H + 50 hrs. (16 people) H + 51 hrs. (48 people)	375 mr/hrs., H + 7 days	175
Group II.—Ailinginae	18	H + 4 to 6 hrs.	H + 58 hrs.	100 mr/hrs., H + 9 days	69
Group III.—Rongerik	28	H + 6.8 hrs.	H + 28.5 hrs. (8 men) H + 34 hrs. (20 men)	280 mr/hrs., H + 9 days	78
Group IV.—Utirik	157	H + 22 hrs.	Started at H + 55 hrs. Completed at H + 78 hrs.	40 mr/hrs., H + 8 days	14
Marshallese, Control Group A	117				
Americans, Control Kwajalein-American	105				

Total Exposed—267; Total Controls—222

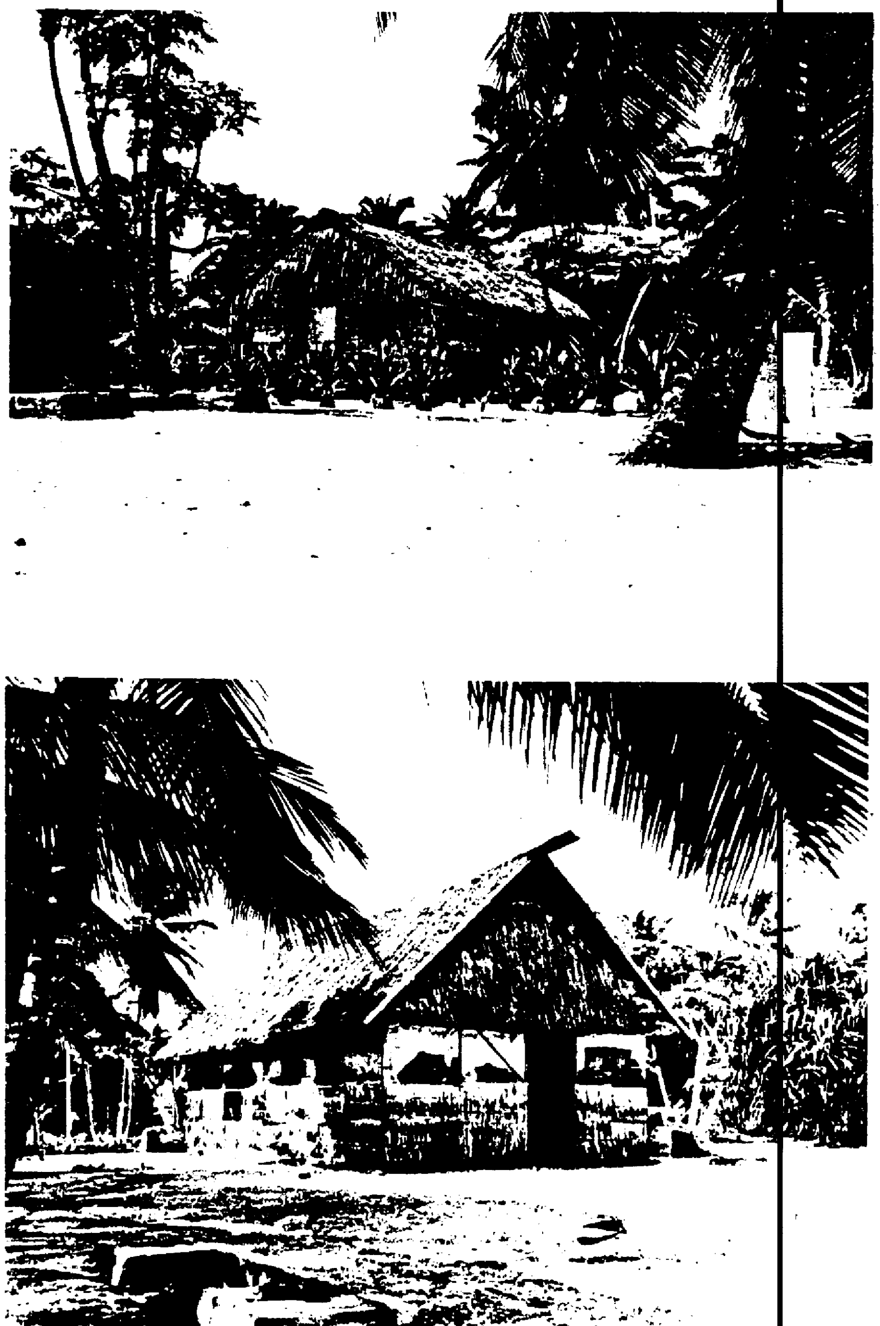


FIGURE 1.1—*Typical construction of the Marshallese homes to illustrate the exposure environment of the Marshallese and the lack of shielding from gamma radiation.*

1.2 Whole Body Gamma Doses

THE ESTIMATED VALUES of external dose given in Table 1.1 were calculated from readings of radiation field survey instruments.* Averages of a number of dose rate measurements on each island at a given time were used. The readings were taken in air, approximately three feet above ground, several days after the inhabitants were evacuated. Before this time, adequate surveys with well calibrated instruments had not been possible, although readings had been taken with a single survey meter at the time of evacuation. However, preliminary calibration of this instrument had not been carried out, nor was its operating condition known to be satisfactory under the emergency condition prevailing at the time of use. For these reasons the later readings, which were higher than the early survey by an average of 50 percent when corrected to the same times, were used in computing the doses listed. The instruments used for the later measurements were calibrated just prior to the surveys.

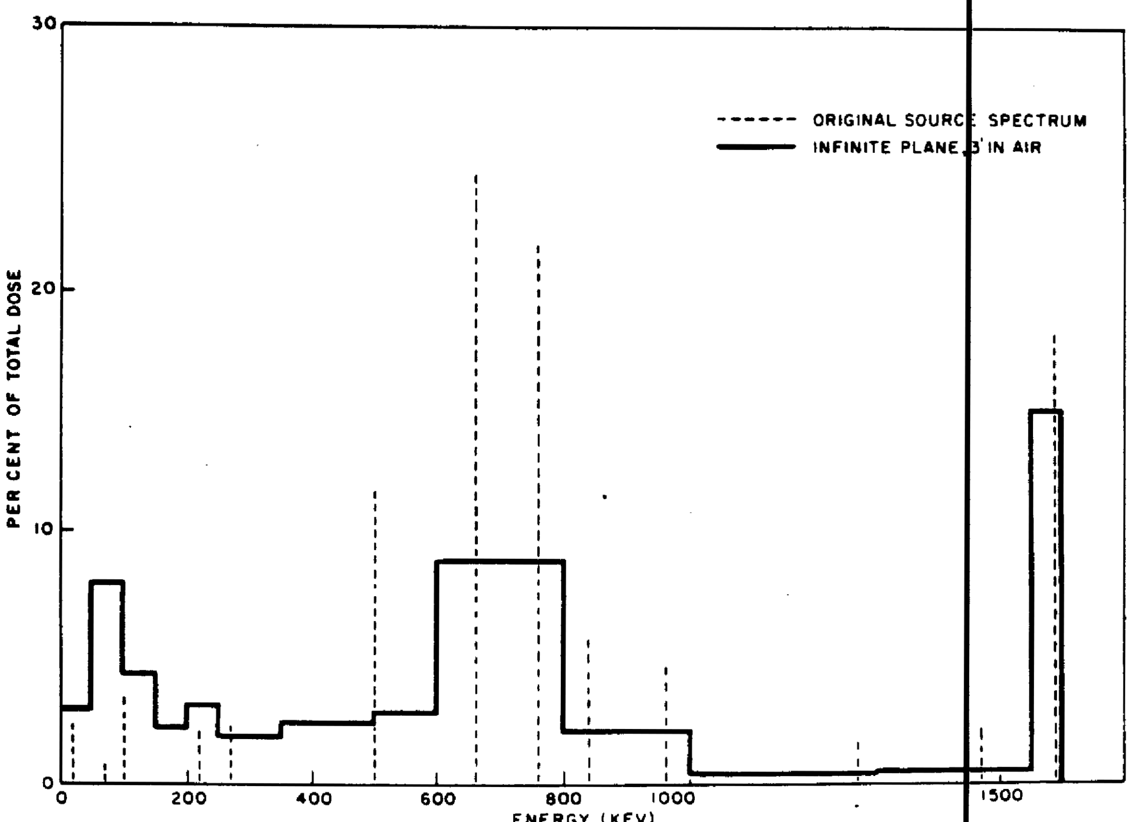


FIGURE 1.2—*Distribution of inherent energies of gamma radiation from mixed fission products, and histogram of degraded energies produced by Compton scattering at level of infinite plane 3 feet in air above uniformly-distributed fission products field.*

1.21 Characteristics of the Gamma Radiation

The fallout material, when deposited on the ground, formed a large planar source of radiation. The energy distribution of the radiation reaching an exposed individual was influenced by its passage through the intervening air. A knowledge of the energy spectrum of the ra-

*Army Navy catalog AN/PDR-39.

diation as it emanated from the material itself made possible an approximate calculation of the proportion of total dose delivered in each of several energy regions. Such a calculation, using spectrometric data on the source material of mixed fission products and taking into account this energy degradation by Compton scattering along the path in air, (1) led to the dose-energy histogram shown in Figure 1.2. Roughly there were three regions, with maxima at 100, 700 and 1500 KEV. The total exposure was thus the resultant effect of partial doses from each energy region, making the exposure energy condition significantly different from those of radiation therapy or experimental radiobiology.

The data in Figure 1.2 are based on the spectrum of 4 day old fission products from a fallout sample. In the absence of other data, this was taken as representative of the fallout on all of the islands to which the individuals were exposed. An energy correction factor for the radiation measuring instrument was calculated by weighting the dose from each energy interval by an average meter response factor for that energy (2). A geometry correction factor was also calculated. The total correction resulting from this procedure was found to be about twenty percent.

Using this correction, the dose rates on the islands at the time of survey were determined. Since radioactive decay of the fission products had occurred between the start of the exposure and this time, it was necessary to obtain a value for this decay rate during the exposure period in order to calculate a total dose in each case. A large number of radioisotopes are present in varying proportions in the fission product mixture, and the total rate of change of radiation intensity resulting from them may differ somewhat with place and time. The best data available in this case came from fallout samples taken soon after the detonation at points some distance from the contaminated atolls. Decay rates of these samples were measured in the field and in the laboratory, and 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 time of initial exposure and later survey readings (3). These agree 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.

1.22 Duration of the Exposures

The time of evacuation is known accurately for all the islands; however, the time of arrival of the radioactive cloud was determined precisely only for Rongerik by means of a continuously recording dose rate monitor located at the weather station on that atoll. As the radiation intensity rose above the background, a material with a misty appearance began to fall. The times of beginning of fallout for Rongelap and Ailinginae atolls were estimated from similar visual observations. These estimates were consistent with the relative distances from the site of detonation and the known wind velocities. Fallout was not observed on Utirik, hence the estimate of arrival time was made on the basis of wind velocity and distance.

Two extreme possibilities exist relative to the duration of the fallouts: the first, that the fallout occurred entirely within a short time; the second, that it was gradual and extended over a longer period. The monitoring instrument on Rongerik went off scale at 100 mr/hr, one-half hour after the dose rate began to rise above background. If this rate of increase is taken as constant, and is extrapolated to a point for which subsequent decay would reduce the dose rate to the values found at later times, the assumption of a long fallout of about 16 hours is found to be necessary. This slow rate of fall and late maximum time of dose rate was one limiting case; however this situation was not considered likely. Existing data are inconclusive, but several indications favor a shorter "effective fallout time hypothesis" and are summarized below.

a. The estimated durations of fallout which result from the above extrapolation of initial fallout rate for Groups I and III appear too long to have occurred at the distances of these people from the shot island, since the wind velocity in the area was high enough to move the cloud over the islands in a considerably shorter time, as little as one-half of the above indicated time.

b. The accounts of the visibility of the fallouts, although conflicting, do not indicate such late cessation.

c. Doses calculated on a long fallout constant rate of increase hypothesis are lower than those due to a short fallout, since a short fallout quickly deposits a large amount of activity. For both a 16 hour and 8 hour fallout assumption, a dose value was estimated. The ranges are then as follows:

Table [illegible]

LOCATION	DOSE IN r FALLOUT TIME	
	8 hr	16 hr
Rongelap (Group I)	[illegible]59 –	209
Ailinginae (Group II)	72 –	[illegible]2
Rongerik (Group III)	70 –	[illegible]06
Utirik (Group IV)	[illegible]2 –	[illegible]

On Rongerik (Group III) a set of film badge readings were obtained which constitute the only direct evidence of total dose. Several badges worn both outdoors and inside lightly constructed buildings on the island read about 50 to 65 r and one badge which remained outdoors over the 28.5 hour period read 98 r. Another group of badges kept indoors inside a steel refrigerator read 78 r. These dose values represent a variety of conditions, but considering the shielding and attenuation factors, are consistent with the assumption that the dose outside during the first 28.5 hours after the beginning of the fallout corresponded to about 12 hours of constant fallout.

For Utirik atoll (Group IV), only a fallout time of about 12 hours or less is consistent with the later dose rates observed, provided the fallout actually began as late as was estimated from wind and distance factors.

A long fallout probably would not be uniformly heavy throughout, the first portion being the most intense and the balance decreasing with time. The total phenomenon would thus tend toward the effect of a shorter fallout. This is supported by monitor data from other nuclear events, where initially heavy fallout is reported to produce a peak of air-borne radioactivity soon after arrival, with the airborne activity level then decreasing. The latter part of the fallout, though still detectable as dust, may then produce only a small fraction of the total dose from material on the ground. Hence the total dose may be estimated fairly accurately by assuming a constant fallout to have been complete in a much shorter "effective" time.

The dose values given in Table 1.1, based on film badge, meter and monitor data, are consistent with a constant fallout hypothesis of about 12 hours effective time.* One exception is made: the dose values for Group III are about 7[illegible] percent of the 12 hour fallout value, averaged [illegible] 28.5 and 34 hour exposures. This was felt to express most accurately 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 such shielding was not available.

Figure 1.3 illustrates the cumulation of radiation dose as a function of time after detonation. The dose rate varied continuously. The major portion of radiation was received at the higher dose rate prevailing in the early portion of the exposure period. By the time that

* [illegible] ing 12 hours actually results in values which are [illegible] than those of Table 1.1 by 3 to 11 r. Table 1.1 [illegible] the values calculated before all spectrum data [illegible] available. [illegible] uncertainty in all the information is [illegible] than this difference, which is neglected.

90 percent of the dose had been received, the dose rate had fallen to less than 10 percent of its initial value. Thus the dose rate also differed from the usual constant rate in the laboratory.

the dose at the center of the body is approximately 50 percent higher than would result from a given air dose with narrow beam geometry. Figure 1.4 illustrates the depth dose curve from an experimental situation using

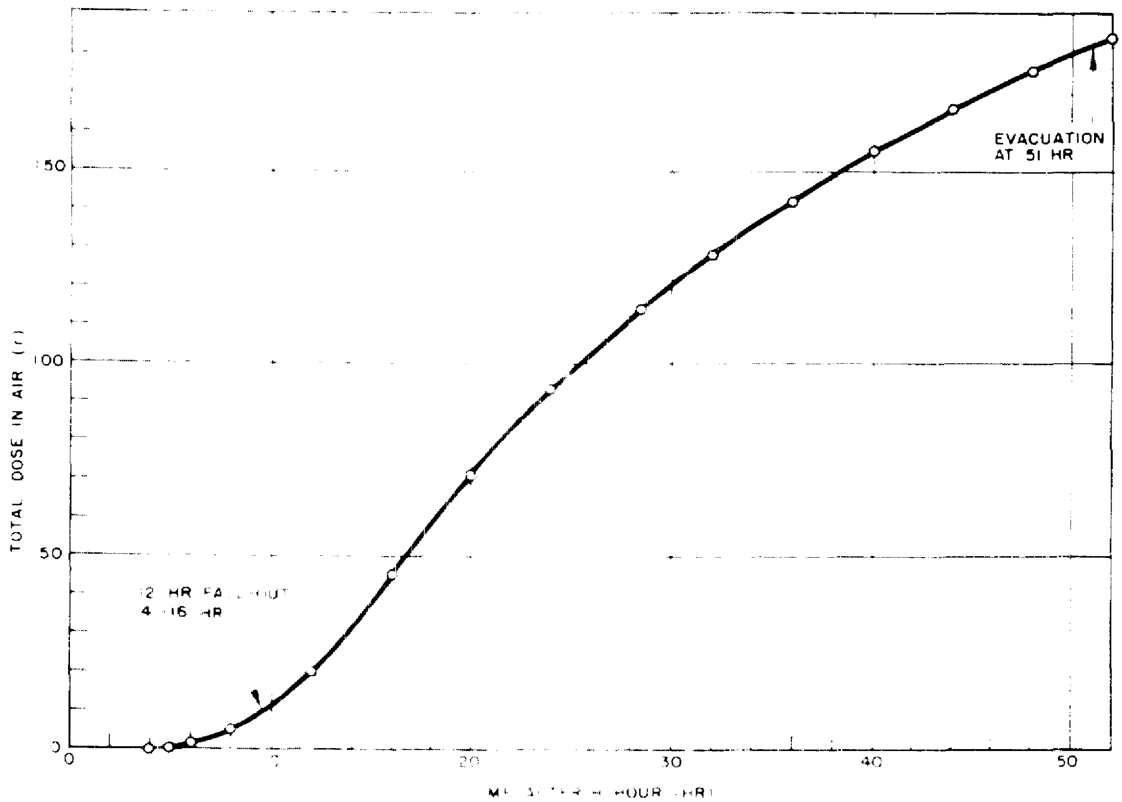


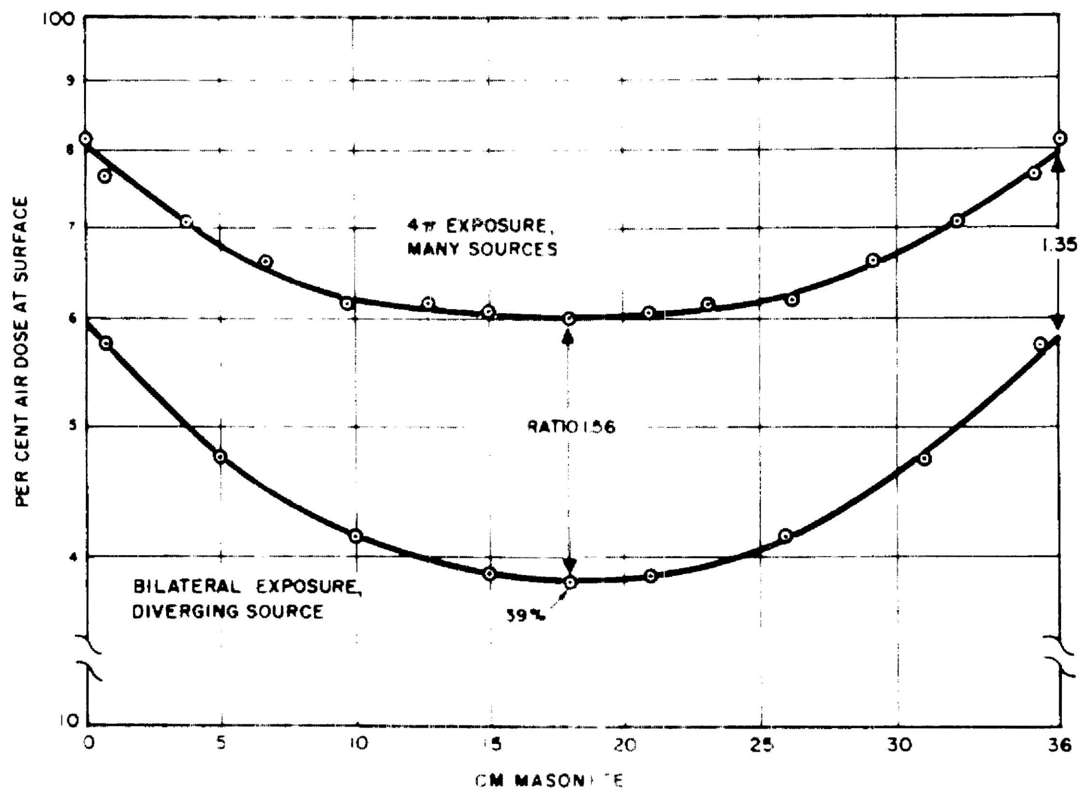
FIGURE 1.3.—*The accumulation of gamma dose as a function of time after commencement of fallout on Rongelap atoll.*

1.23 Geometry of the Exposure

In addition to the dose rate and energy differences the geometry of the exposure to fallout radiation is significantly different from the usual laboratory sources. Since fallout radiation is delivered from a planar source the usual narrow beam geometry is not applicable. In such a diffuse 360° field the decrease of dose with depth in tissue is less pronounced than that resulting from a bilateral exposure to an X-ray beam because falloff from inverse square is in effect neutralized. For the same energy

spherically oriented Co^{60} sources with a phantom placed at their center, compared with a conventional bilateral depth dose curve obtained with a single source (4). In the latter case, the air dose is usually measured at the point subsequently occupied by the center of the proximal surface of the patient or animal with respect to the source. For the field case, all surfaces are "proximal," in the sense that the air dose measured anywhere in the space subsequently occupied by the individual is the same. It is this air dose which is measured by a field instrument; it does not bear the same relationship to the surface dose and depth dose as does the air dose measured in a "point source" beam in the clinic or laboratory. It would appear under these circumstances and in most experimental conditions that the midline dose, rather than dose measured in air, would be the better common parameter in terms of which to predict biological effect. On this assumption 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 a given air dose from a "point source" beam geometry delivered bilaterally. If this is done, assuming a fallout of 12 hours, the following "point source" beam air doses with comparable biologic effect are obtained:

Rongelap, Group I	260 r
Ailingnae, Group II	100 r
Rongerik, Group III	120 r
Utirik, Group IV	20 r



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

FIGURE 1.4—*Comparison of depth dose curves in masonite phantoms from bilateral exposure to a single point source, and simultaneous exposure to multiple sources with a spherical distribution around the phantom.*

The geometry of radiation from a fallout field is not identical either to the geometry of bilateral point sources or spherically distributed sources since the plane source delivers the radiation largely at a grazing angle. However, the total field situation is better approximated by solid than by plane geometry. Exposure geometry of a radioactive cloud would be spherical.

1.3 Superficial Doses of Radiation From Beta and Soft Gamma Radiation

THERE CAN BE no doubt that the doses of radiation to the surface and the first few millimeters of the body were substantially higher than the mid-line dose of gamma radiation as a result of physical considerations of gamma energy and depth dose. In addition, the clinical observations of the skin lesions (see Chap. III) forcefully demonstrated that the dose to the skin varied considerably between individuals and over the surface of any given individual. As will become evident in the following discussions of surface dose, it is obvious that any numbers presented are at best only estimates and represent an approximation of some minimal value. In areas where lesions were severe the doses must have been significantly higher than in non-damaged areas.

To arrive at some physical estimate of the skin dose, an attempt must be made to add up the contributions of the high energy gamma, the very soft gamma, and the higher energy beta radiation from the large planar source in which the individuals were of necessity existing. However, as alluded to above and emphasized in Chapter III, the largest component of skin irradiation resulted from the spotty local deposits of fallout material on exposed surfaces of the body. The dose from deposited material is impossible to estimate; however, that from the large planar source may be roughly estimated as follows.

The beta dose rate in air 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 total air gamma dose. The mid-line gamma dose is approximately 60 percent of the air dose remaining after excluding that portion of the dose below 80 KV. This portion in turn is estimated to be 40 percent 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) (0.6) or about 8 times the mid-line dose, if both are taken at 3 feet off the ground. Such a depth dose measurement has in fact been made experimentally at a previous test, using a phantom man exposed to both the initial and residual radiation (5). The depth doses for each situation are shown in Figure 1.5, with all data as percent of the 3 centimeter dose. With the diverging initial radiation from the point of explosion, the exit dose was seen to be 63 percent of the 3 cm. dose, but with the diffuse residual field of fission products providing a semi-infinite planar source, a surface dose some 8 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 since it is due to soft radiation of short range, it 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 2,000 rep at the level of the dorsum of the foot, 600 rep at the hip level and 300 rep at the head *if continuous exposure with no shielding occurred*. Unknown variation in dose undoubtedly resulted from shielding and movement. It thus seems probable that the external beta dose from local direct skin contamination far outweighed that from the ground in importance, since the latter was not high enough to produce the observed lesions. Clothing probably reduced the beta dose from the ground by 10 to 20 percent.

1.4 Summary

RADIATION DOSES from gamma rays originating externally were calculated for the 267 individuals who were accidentally exposed to fallout following the nuclear detonation at the Pacific Proving Ground in the Spring of 1954. The dose estimations were made using information resulting from radiological safety surveys on

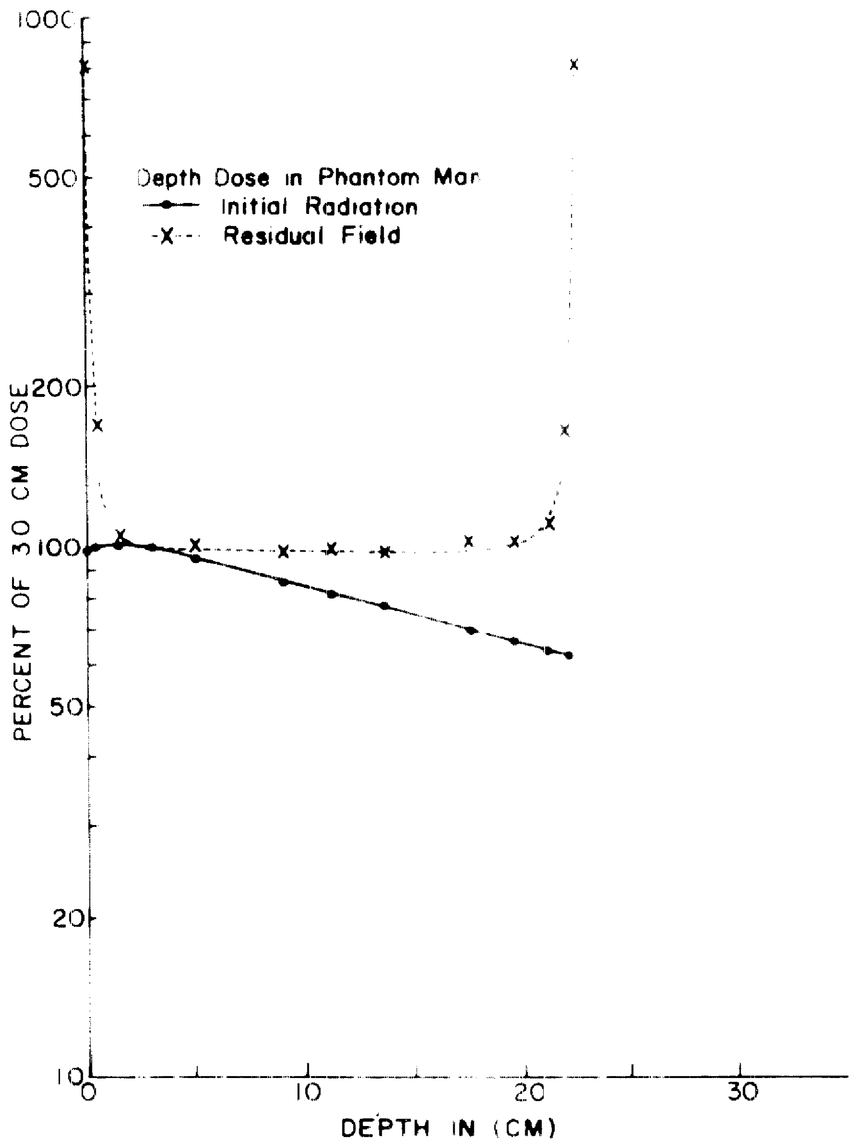


FIGURE 5.—*Comparison of depth dose [illegible] in a masonite phantom man. [illegible] the actual atomic bomb [illegible] and of gamma radiation from [illegible] planar field of fission products [illegible] after an experimental [illegible] detonation.*

the atolls, and spectrometric and radiochemical data. The actual duration of the radioactive fallouts was not known, and the values for length of exposure were subject to uncertainties in the times at which the fallouts began. A range of possible whole body gamma doses was calculated, and the values considered to be most probable are presented. [illegible] diffuse geometry from the semi-infinite planar source was believed to increase the biological effect of the whole body dose expressed as an air dose, compared to the geometry of the usual X-ray exposure. Soft gamma and beta radiation from fallout on the ground and especially on the skin itself resulted in a superficial dose which was great enough to produce lesions. No quantitative data were available on the beta radiation intensity from either the skin contamination or from the ground but a rough estimate of superficial dose from the latter was made.

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Chapter II

Clinical Observations and Treatment

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Outline

2.1 Introduction

When The Exposed groups were first seen at Kwajalein after evacuation from their native atolls, the amount of radiation they had received was not known with certainty. It was known, however, from instrument readings taken at the sites of the fallout and from monitoring all individuals, that a significant amount of penetrating irradiation to the entire body had been received and that extensive contamination of the skin and possible internal deposition of radioactive materials had occurred. The nature of the irradiating material and the circumstances of exposure prevented a precise evaluation of dosage (see Introduction). Even if the precise dose had been known it would not have been possible to predict the biological effects since the quantitative response of man is not known. Accordingly, a complete medical history and physical examination was obtained on each individual and numerous follow up examinations were carried out. In addition, routine sick-call was held twice daily and inspection of the skin of all individuals was made at frequent intervals. Medical care was available at all times. Hospital facilities were available at the Kwajalein Naval Dispensary, and support by the more extensive medical facilities of the U. S. Pacific Fleet had been promised if needed.

From descriptions of the amount of fallout material and from radioactivity measurements, it was apparent that Group I (Rongelap) had received the highest doses of radiation, Group II (Ailinginae) and Group III (Americans) an intermediate amount and Group IV (Utirik) the least. From physical dosimetry it was later estimated that Group I had received approximately 175 r of gamma radiation; Group II, 69 r; Group III, 78 r; and Group IV, 14 r. The most serious clinical and laboratory manifestations of irradiation appeared in Groups I and II. The only abnormalities that could be attributed with certainty to irradiation were skin lesions, epilation, granulocytopenia and thrombocytopenia. The skin lesions were first observed between the 12th and 14th post-exposure days. These lesions were most prevalent in Groups I and II but were present to a slight extent in Group III. Details of the skin symptoms and lesions and their treatment are reported in Chapter 3. Details of hematologic studies are presented in Chapter IV. Granulocytopenia and thrombocytopenia of marked degree developed in many individuals of Groups I and II and was of sufficient severity to warrant serious consideration of prophylactic and therapeutic measures for potential sequelae of these cellular deficiencies.

In view of the conflicting opinions about the value of prophylactic and therapeutic measures such as antibiotics and whole blood transfusions in the treatment of radiation disease (1–5), it was decided that therapy would be instituted only as indicated clinically for specific conditions as they arose. In order to determine the effect of the internal deposition of radioactive material on the course of the externally induced radiation injury, it was necessary to determine the degree of internal radioactive contamination. Details of the measurement of internal deposition of radionuclides are considered in Chapter V. It is sufficient to state here that the contribution from the internally deposited radionuclides to the total acute dose was insignificant.

2.2 Symptoms and Signs Related to Radiation Injury

Several Symptoms That developed during the first two days could be attributed to radiation. These symptoms were associated with the skin and the gastrointestinal tract.

Itching and burning of the skin occurred in 28 percent of Group I (Rongelap), 20 percent of Group II (Ailinginae), 5 percent of Group III (Americans), and none of Group IV (Utirik). Three people in Group I and one in Group II complained of itching and burning of the eyes and lacrimation. These initial skin and eye symptoms were most likely due to irradiation since all individuals who experienced the initial symptoms later developed unquestioned radiation induced skin lesions (epilation and conjunctivitis). (See Chapter III.) Furthermore the initial symptomatology in these people was similar to that reported in instances of accidental laboratory overexposure to radiation, described in Chapter III. It is possible, however, that chemical irritation by the fallout material, which was predominantly highly alkaline calcium oxide, may have accentuated the initial symptoms.

About two-thirds of Group I were nauseated during the first 2 days and one-tenth vomited and had diarrhea. One individual in Group II was nauseated. In Groups III and IV there were no gastrointestinal (GI) symptoms. The information concerning symptoms was obtained by questioning through an interpreter by several individuals. Despite the repeated interrogations and the inevitable suggestions of the interrogators, the stories remained consistent. All GI symptoms subsided by the third day without therapy and there was no recurrence.

The presence, severity, and duration of nausea, vomiting, and diarrhea are known to bear a direct relationship to degree of exposure and probability of the recovery (1, 2, 6), and it is of note that the incidence of these symptoms was correlated with the dose received and that there were no gastrointestinal symptoms in Group IV, the largest group, which received only 14 r. GI symptomatology may have been due to direct injury of the GI tract as observed in animals after whole body irradiation (7, 8) or may have been non specific as is observed following therapeutic radiation.

Various other clinical conditions which were encountered during the course of observations of the exposed groups were not the results of radiation exposure. The incidence and type of disease seen, discussed below, were similar in the exposure groups and in nonexposed individuals.

2.3 Clinical Observation and Therapy With Respect to Hematological Findings

2.31 Clinical Observations and Leukocyte Counts

BETWEEN THE 33rd and 43rd post-exposure days, 10 percent of the individuals in Group I had an absolute granulocyte level of 1000 per cubic millimeter or below. The lowest count observed during this period was 700 granulocytes/mm.³ During this interval the advisability of giving prophylactic antibiotic therapy to granulocytopenic individuals was carefully considered. However, prophylactic antibiotic therapy was not instituted for the following reasons:

(1) All individuals were under continuous medical observation so that infection would be discovered in its earliest stages.

(2) Premature administration of antibiotics might have obscured medical indications for treatment, and might also have lead to the development of drug resistant organisms in individuals with a lowered resistance to infection.

(3) There was no accurate knowledge of the number of granulocytes required by man to prevent infection with this type of granulocytopenia.

The observed situation was not strictly comparable to agranulocytosis with an aplastic marrow as seen following known lethal doses of radiation. In the latter instance, granulocytes fall rapidly with practically none in circulation and no evidence of granulocyte regeneration when infection occurs (6). In the present group of individuals exposed to radiation, most counts reached approximately one-fourth the normal value, but the fall to that level was gradual and the presence of immature granulocytes in the peripheral blood during the period of granulocytopenia was indicative of some granulocyte regeneration.

White counts were repeated at 3 to 4 day intervals on all of the exposed individuals and more frequently on those with the lowest counts. Individuals with symptoms or elevated temperatures were treated only after an attempt to establish a diagnosis was made, even if a period of observation was necessary. During the observation period, the patients were examined at frequent intervals and the temperatures checked every few hours.

Twenty-seven individuals had total leukocyte counts of 4000 or below or absolute neutrophile counts of 2500 or less at some time during the period of observation. Of these 27, [illegible] developed symptoms of disease that required evaluation for possible antibiotic therapy. The 13 instances in which it was necessary to consider the use of antibiotic therapy in neutropenic individuals are summarized below.

Eight neutropenic individuals had symptoms of upper respiratory infection (URI) characterized by malaise, sore throat, nasal discharge, and temperatures between 99 and [illegible] F. The temperatures returned to normal within 24 hours. Since the response of this group to URI appeared identical with that of other individuals with URI without neutropenia, no special therapy was given.

Two individuals developed symptoms of marked malaise, headache, abdominal [illegible], nausea and diarrhea. Both were children, one age 7, the other age [illegible]. In both instances, the symptoms were out of proportion to the physical findings, which were negative except for evidence of head colds and pharyngeal injection. The 7-year-old child had an oral temperature of 102.6° F. when first seen and [illegible] hours later, it was [illegible]° F. The two-year-old child had an initial axillary temperature of [illegible] F. which rose to 103.5° F. in [illegible] hours. Both were given 300,000 units of procaine penicillin intramuscularly when the sharp rise in temperature occurred, and both were afebrile the following day. A second injection of penicillin was given at this time, and therapy was discontinued. In spite of the fact that the neutrophiles remained depressed in both cases long after the fever had passed, both individuals recovered and had no further illness. In Figure 2.1 the leukocyte and platelet counts of the 2-year-old patient and the time of the occurrence of the febrile illness are illustrated.

A one-year-old boy had had symptoms of mild upper respiratory infection for several days and was brought to the clinic when he developed a hacking cough. When he was seen, his axillary temperature was 100.8° F. He had signs of URI, there was pharyngeal injection, and numerous coarse rhonchi were heard throughout the chest. A diagnosis of upper respiratory infection with associated bronchitis was made and the child was given a single intramuscular injection of 200,000 units procaine penicillin. On the following day his temperature was 99° F., no rales or rhonchi were heard, and he recovered without further treatment.

A [illegible]-year-old man came to the clinic complaining of weakness, nervousness, mild abdominal pain and shooting pain in the upper anterior chest bilaterally of several hours duration. He appeared moderately ill, his temperature was 99.6° F., and the only positive physical finding was moderate tenderness in the right upper quadrant of the abdomen. Within a [illegible]-hour period the temperature rose to 101.6° F., following which it fell gradually to normal. The abdominal tenderness continued for [illegible] hours and then gradually disappeared during the subsequent 2 days. A tentative diagnosis of cholecystitis was made. No specific therapy was given. In Figure 2.2 his white blood cell and platelet counts in relation to the appearance of symptoms are shown.

A woman, age [illegible], developed generalized urticaria, fever and headache. No cause for the urticaria was found and the symptoms subsided within [illegible] hours without any therapy.

All individuals in Groups I and II that received antibiotics are listed in Table 2.1. Of the individuals treated with antibiotics, only the first three received it at a time when their neutrophile count was low. These cases are

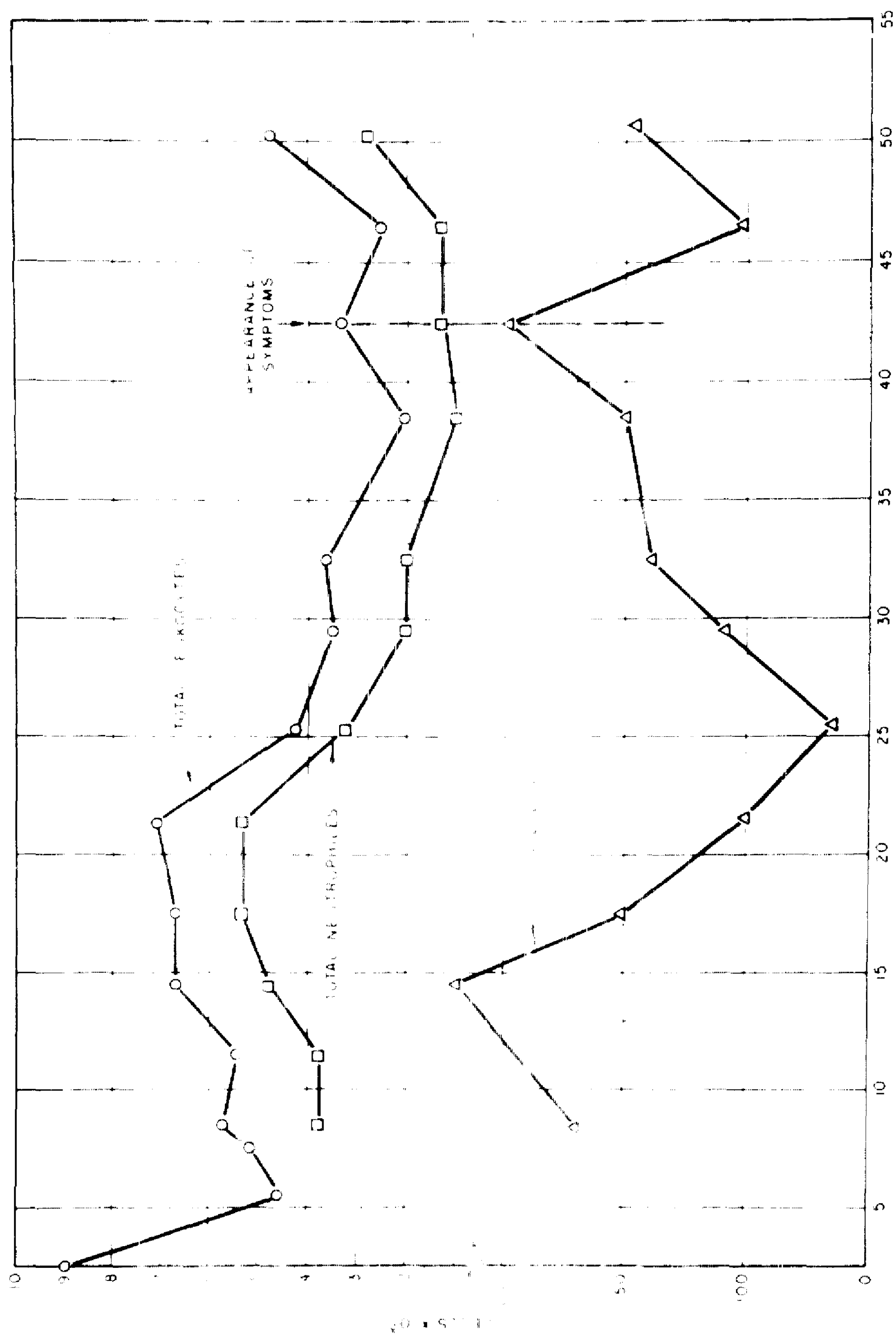

FIGURE 21. *Course of leukocytes and platelets count changes in a two year old boy who developed a severe respiratory infection.*

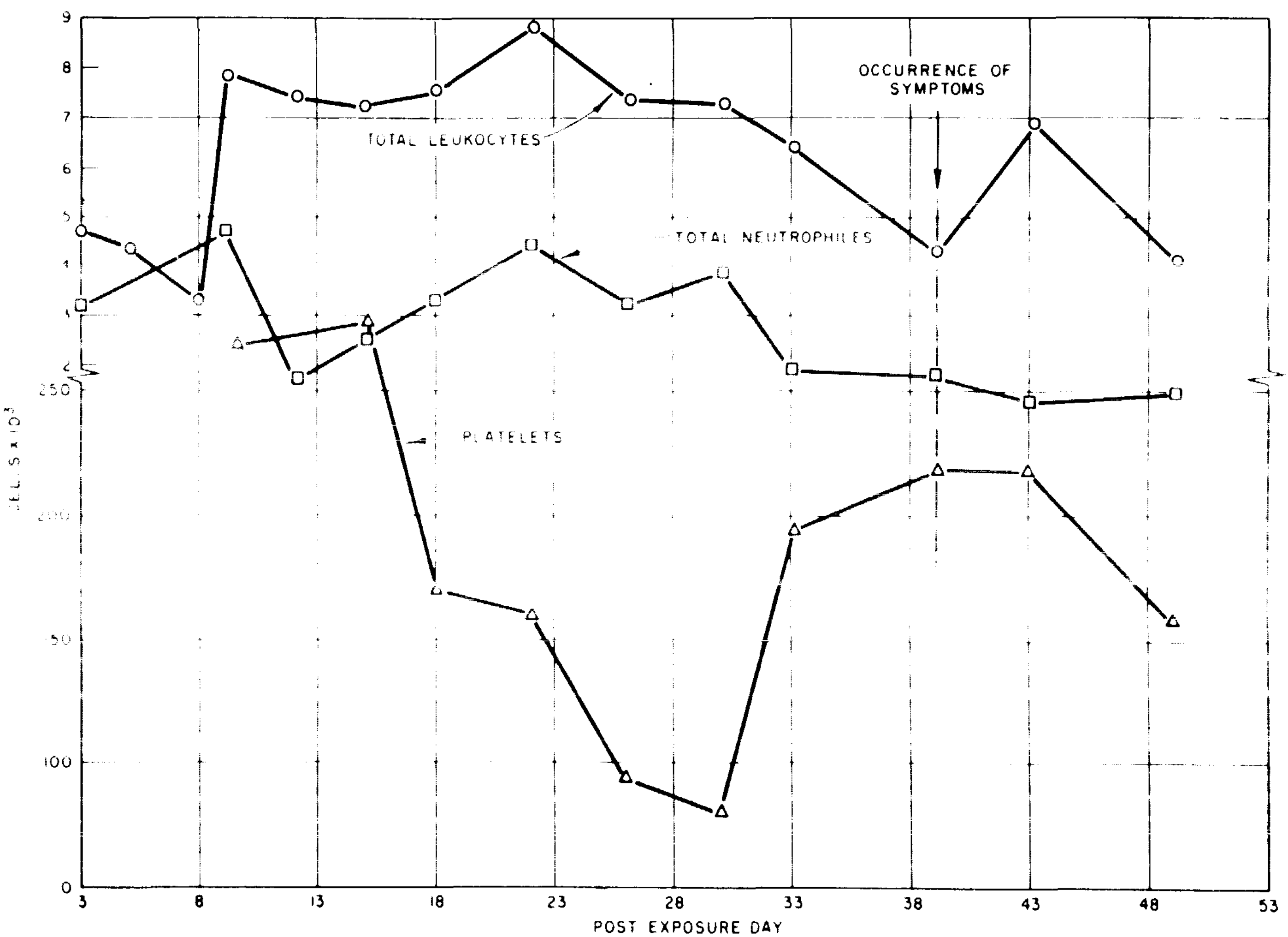

FIGURE 22 *Leukocyte and platelet count trends in a fifty year old man who developed symptoms of cholecystitis.*

Table 2.1—Patients Treated With Antibiotics

Patient No.	Condition	Number of Days Treated	Antibiotic Used
1	URI and bronchitis with high temperature		Penicillin
2, 3	URI, severe, with pharyngitis and high temperature	2	Penicillin
4, 5	Tooth extraction		Penicillin
6	Deep extensive slough of epidermis of foot	2	Penicillin
7	Inflamed tonsils with high temperature and URI	2	Penicillin
8	Rapid progressing undermining impetigo	2	Penicillin
9	Traumatic gangrene of foot	[illegible]	Penicillin
10	Cystitis	5	Gantrisin
11	Furuncle on buttock	2	Penicillin
12	Furuncle on forehead	1	Penicillin

described in detail above. Each appeared to have evidence of a bacterial component associated with URI and antibiotics would have been indicated had they not been irradiated. All other individuals were not neutropenic at the time of treatment and were given antibiotics for specific indications. There was no instance in which it was considered necessary to give prophylactic antibiotics for neutropenia *per se*.

2.32 Clinical Observations and Platelet Counts

All individuals with a platelet count of 100,000 or less were examined daily for evidence of hemorrhage into the skin, mucous membranes and retinae. Urine was examined daily for red cells and albumin, and women were questioned concerning excessive menstruation. There was no evidence of any hemorrhage even though 11 individuals reached platelet levels between 35,000 and 65,000. Two women menstruated when their platelet counts were 150,000 and 130,000 respectively. Both menstruated several extra days and thought that the bleeding was more than usual but not sufficient to cause them concern.

2.33 Hematocrit Changes

In radiation injury an anemia can be produced by three phenomena: a. Partial or complete suppression of erythropoiesis; b. Hemorrhage; c. Hemolysis. (9). The existence of the latter is not universally accepted as a characteristic part of radiation injury. Since hemorrhagic phenomena were not observed a severe anemia would have been expected only if erythropoiesis were suppressed severely for a long time. With complete suppression of erythropoiesis and an unchanged life span of the red cell one would expect a deficit of 0.83 percent per day since the human red blood cell has a life span of approximately 120 days.

Nineteen individuals in Groups I and II had hematocrits between 31 and 35 percent. Nine of the 19 were children, aged 1 to 5 years and would be expected to have a lower hematocrit than normal adults; four were over 70 years of age, in which age group a decreased hematocrit is frequently present without obvious cause. Two of the 19 had had menorrhagia prior to the determination, two were 3 to 4 months pregnant and had not received supplementary iron, and two were young women. These hematocrits could be ascribed to physiological variations rather than to the effects of irradiation on hematopoiesis. Supplementary iron was the only therapy used for the mild anemias observed. Thus no definite evidence of prolonged erythropoietic suppression was observed even in individuals who had received 175 r whole body radiation.

2.4 An Epidemic of Upper Respiratory Infection Occurring During the 4th and 5th Post-Exposure Weeks

Between the 27th and the 42nd post-exposure days an epidemic of upper respiratory disease (URI) occurred. The respiratory infection consisted of moderate malaise, pharyngitis with prominent lymphoid follicles, fever of 99–100° F. during the first day, and a purulent nasal and tracheal discharge for about 10 days. It was of interest to determine whether the appearance of URI could be correlated with the dose of radiation received or with changes in the leukocyte count.

Fifty-eight percent of the individuals in Group I and 56 percent of the individuals in Group II developed URI. Seventy percent of the affected individuals developed symptoms between the 27th and 32nd post-exposure days, and the others developed symptoms in the subsequent 2 weeks. Fifty-seven percent of the affected individuals were observed to have an upward trend in their leukocyte counts, the increase being due primarily to granulocytes. Since an increase in the mean granulocyte count of the entire population occurred about the 29th postexposure day, it seemed pertinent to determine whether in individual instances the increase was related to the presence of respiratory infection.

The relationship between the observed leukocyte increase and the presence or absence of upper respiratory symptoms in Groups I and II is shown in Table 2.2. Seven of the 27 individuals that developed both URI and a leukocyte increase developed the leukocyte increase 3 or more days before symptoms of URI appeared. It is also of interest that the medical personnel involved in the care and study of the radiated individuals had an equal incidence and severity of respiratory infections. The incidence and severity of respiratory infection in Group IV, which had received only slight radiation, was the same as that in Group I and II. The appearance of URI, therefore, did not appear to be related to the dose of radiation or to changes in leukocyte level.

Table 2.2—URI and Changes in Granulocytes in Groups I and II

	Number of Individuals
URI; rise in granulocytes	27
URI; no rise in granulocytes	20
No URI; rise in granulocytes	16
No URI; no rise in granulocytes	19

2.5 Comparison of Diseases Seen in Groups I and II With Those in Group IV

The Diseases That were seen during the period of observation of Group I and II, which were exposed to the highest doses of radiation, are listed in Table 2.3. None of the diseases appeared to be related to the effects of irradiation, either directly or as a result of hematologic disturbances. For comparison, the diseases that were seen during the period of observation of Group IV, which received the lowest dose of

Table 2.3—Diseases That Were Observed in Groups I and II

Disease	Number of Individuals	Disease	Number of Individuals
Furuncle	2	Bronchitis	1
Gum Abscess	1	Aphthous ulcer of tongue	1
Cholecystitis	1	Spondylolisthesis	1
Tinea	1	Impetigo	5
Mittelschmerz	1	Tooth extractions	2
Generalized urticaria	1	Gastroenteritis	10
Erythema multiforme	1	Upper respiratory infections	47
Migraine headache	1	Follicular tonsillitis	1

radiation, are listed in Table 2.4. The high incidence of gastroenteritis in both groups was probably due to the keeping of perishable foods unrefrigerated for long periods by the Marshallese, and was not seen after this practice was stopped. It would appear that a higher percentage of the individuals in Groups I and II developed upper respiratory infections compared to Group IV. However, all of the individuals in Groups I and II were questioned concerning even mild symptoms of URI, whereas only those of Group IV with severe symptoms of URI came to the clinic.

2.6 Changes in Weight as an Indication of Disturbance in the General Metabolism

THE BODY WEIGHT of individuals in Groups I and II was followed routinely. Since they had an unrestricted diet and all ate well, their change in weight might be considered an indication of any disturbance in their over-all metabolism. The weight changes are summarized in Table 2.5. It would be expected that within a period of six weeks, most individuals below 16 years and particularly those below 8 years would gain some weight. The fact that most of them lost weight may indicate that they received a dose of radiation sufficient to interfere with normal metabolism. In spite of their relatively inactive life and hearty appetites many of the adults also lost weight which may indicate some interference with their normal metabolism. There was little difference in observed weight changes between Group I and Group II. It appeared that the difference in doses received by the two groups did not differentially affect their body weight. Whether the observed losses in weight were related to radiation or to changes in environment is not clear. Unfortunately, no satisfactory control existed to aid in interpreting the loss of weight in Groups I and II.

2.7 The Effects on Pregnancy

FOUR WOMEN IN Group I were pregnant when brought to Kwajalein. Two were in the first trimester, one in the second trimester, and one in

Table 2.4—Diseases Observed in Group IV

Disease	Number of Cases	Disease	Number of Cases
Osteoarthritis	[illegible]	Chorioretinitis, unknown etiology	1
Epithelioma of ankle with necrotic degeneration	[illegible]	Thrombophlebitis, antecubital vein	1
Chronic bronchitis	[illegible]	Impetigo	3
Furuncle	[illegible]	Dysmenorrhea	1
Chronic bronchitis and bronchiectasis	[illegible]	Exfoliative dermatophytosis	1
Abscess of sole of foot	[illegible]	Ectropion, right eye	1
Carbuncle	[illegible]	Asthma	1
Tooth extraction	[illegible]	Benign hypertension with headache	1
Fungus infection of gums and palate	[illegible]	Fungus infection, auditory canal	1
Contusion, traumatic	[illegible]	Trichomonas cystitis	1
Gastroenteritis	30	Tinea	1
Upper respiratory infections	[illegible]	Simple headache	5
Arteriosclerotic heart disease, decompensated	[illegible]	Acute bronchitis	1
Pyelonephritis	[illegible]	Possible ruptured intervertebral disc	1
Insect bite, with marked palpebral edema	[illegible]	Fever of unknown origin	1
		Mongolian idiocy	1

Table 2.5—Weight Changes Groups I and II

	AGE CATEGORIES		
	BELOW 7 YEARS	BELOW 16 YEARS	ABOVE 16 YEARS
GROUP I			
Number observed	[illegible]	24	36
Number that gained weight	[illegible]	5	14
Average gain (lb.)	[illegible]	3	3.5
Spread of gain (lb.)	0.5–10.0	0.5–10.0	1–11.5
Number that lost weight	13	19	21
Average loss (lb.)	2	2	4
Spread of loss (lb.)	0.5–5.5	0.5–5.5	0.5–8
Percent of group that lost weight	[illegible]	80	58
GROUP II			
Number observed	[illegible]		9
Number that gained weight	[illegible]		3
Average gain (lb.)			2.7
Spread of gain (lb.)			2–4
Number that lost weight	6		6
Average loss (lb.)	2		2
Spread of loss (lb.)	0.5–3		0.5–4.0
Percent of group that lost weight	88		67

the third trimester. None of these women had abnormal symptoms referable to pregnancy, and as far as could be determined, pregnancy continued in a normal fashion. In Group II, one woman was in the second trimester. No abnormality was detected. Fetal movements were unaffected in the individual in the third trimester. The hematologic changes of the pregnant women are listed in Table 2.6. Two individuals in the first trimester had a marked depression of platelets but at no time was there any vaginal bleeding. So far, the exposure to radiation has not had a deleterious effect on pregnancy. At the 12 month reexamination all of the above women had delivered. One baby was born dead; the others were normal. In the case of the one still born, irradiation occurred to the mother either before conception or early in the first trimester.

2.8 Special Examination of Eyes

At 3 and 6 Months an ophthalmologist examined the eyes of all exposed individuals (10).

Table 2.6.—Blood Counts on Pregnant Individuals in Groups I and II

TRIMESTER OF PREGNANCY	LOWEST PLATELET COUNT	LOWEST WBC	LOWEST NEUTROPHILE COUNT
GROUP I			
First	35,000	4,500	3,000
First	50,000	5,000	2,500
Second	150,000	4,000	3,000
Third	120,000	10,000	7,000
GROUP II			
Second	170,000	7,000	3,200

No lesions ascribable to ionizing radiation were seen. At 12 months slit lamp examinations and photographic recordings of the cornea and lens were made on nonexposed, and on the Rongelap people. The incidence of ocular lesions was not different in the two groups (11).

2.9 Summary and Conclusions

THE CLINICAL FINDINGS in a population accidentally irradiated by fallout material from a nuclear device has been presented. The more seriously irradiated individuals had initial symptoms of anorexia, vomiting and diarrhea which subsided without treatment within 2 days. The same individuals slowly developed granulocytopenia and thrombocytopenia unassociated with secondary complications. The only other manifestations of radiation exposure observed were skin lesions and epilation, described in detail in Chapter III. The incidence of infectious and noninfectious disease in the more severely exposed groups was no greater than that in the least exposed group. If, after irradiation, the platelets and leukocytes fall in a manner and to a degree similar to that observed here, it can be predicted that no hemorrhage or increased susceptibility to diseases similar to those observed in this study will occur and that no special prophylactric measures will be indicated. The use of prophylactic measures, however, should be evaluated in terms of existing conditions. With the degree of hemopoietic suppression observed there is a possibility of increased susceptibility to more virulent pathogens than were present in this incident.

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Chapter III

Skin Lesions and Epilation

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Outline

3.1 Introduction

Fallout of Radioactive material commenced approximately 4–6 hours after detonation of the thermonuclear device. On the most heavily contaminated island, Rongelap, the fallout was described as a powdery material, "snowlike," which fell over a period of several hours and whitened the hair and adhered to the skin. Less striking fallout described as "mist-like" was observed on Ailinginae and Rongerik. Fallout was not visible on Utirik, which was contaminated to only a mild degree. The severity of the skin manifestations was roughly proportional to the amount of fallout observed. The population of the four island groups and incidence of the skin lesions were as follows:

Group	Composition	Fallout observed	Extensiveness of skin lesions and epilation
Rongelap	64 Marshallese	Heavy "snowlike"	Extensive.
Ailinginae	18 Marshallese	Moderate "mistlike"	Less extensive.
Rongerik	23 White Americans 5 Negro Americans.	Moderate "mistlike"	Slight.
Utirik	157 Marshallese	None	No skin lesions or epilation.

Evacuation of exposed personnel to Kwajalein, where medical facilities were available, was accomplished one to two days after the event. Decontamination of the skin was commenced aboard ship and completed after arrival at Kwajalein.

Skin examinations were carried out almost daily during the first 11 weeks and then again at 6 months, 1 and 2 years after the accident. Examinations of unexposed Americans and native personnel were also carried out for comparative purposes. Color photographs and biopsies of lesions in various stages of development were taken.

3.2 Signs and Symptoms

During the First 24–48 hours after exposure, about 25 percent of the Marshallese in the two higher exposure groups experienced itching and a burning sensation of the skin. A few also complained of burning of the eyes with lachrymation. These symptoms were present to a lesser extent in the Americans on Rongerik Atoll who were aware of the danger, took shelter in aluminum buildings, bathed and changed clothes. These precautions greatly reduced the subsequent development of skin lesions in this group. The people on Utirik, the farthest from the detonation, had no early skin symptoms. All skin symptoms subsided within 1 to 2 days. On arrival of the medical team on the ninth post-exposure day, the exposed personnel appeared to be in good health. The skin appeared normal. However, evidence of cutaneous radiation injury appeared about 2 weeks after exposure when epilation and skin lesions commenced. Erythema of the skin was not observed either during the early examinations when a primary erythema might be expected, or later when a secondary erythema might be expected.

After subsidence of the initial skin symptoms, further symptoms referrable to the skin were absent until the visible lesions developed. During the early stages of development of the lesions, itching, burning and slight pain were experienced with the more superficial lesions. With deeper lesions pain was more severe. The deeper foot lesions were the most painful and caused some of the people to walk on their heels for several days during the acute stages. Some of the more severe lesions of the neck and axilla were painful when turning the head or raising the arms. The lesions did not produce any constitutional symptoms.

3.3 Description of Skin Lesions*

3.31 Gross Appearance

The time of appearance and the severity of the lesions varied with the degree of skin contamination in the different groups. The Rongelap group, which showed greatest radioactive contamination of the skin (according to instrument readings) were the first to develop lesions and epilation at about 12 to 14 days after the accident. They also had the most severe lesions. Skin lesions in the lesser exposed Ailinginae and Rongerik groups developed approximately one week after those in the Rongelap group, and were less severe and extensive. The Utirik group did not develop any lesions which could be attributed to irradiation of the skin. The incidence of ulcerating lesions in the different groups reflected the relative severity of the skin injury. Twenty percent of the Rongelap people developed ulcerative lesions while only five percent of the Ailinginae and none of the Rongerik people developed ulcerative lesions. Ninety percent of the Rongelap and Ailinginae groups developed lesions, compared to only forty percent of the Rongerik group. There were more lesions per individual in the Rongelap group than in the Ailinginae or Rongerik groups. A comparison of the incidence and time of appearance of epilation and neck lesions in the two groups is illustrated graphically in Figure 3.

Nearly all of the lesions were spotty and developed on exposed parts of the body not covered by clothing during the fallout. The majority of individuals developed multiple lesions (particularly the Rongelap group), most of which were superficial. There was a difference of several days in the latent period before development of lesions on various skin areas. The order of appearance was roughly as follows: scalp (with epilation), neck, axillary region, antecubital fossae, feet, arms, legs, and trunk. Lesions on the flexor surfaces in general preceded those on the extensor surfaces. Tables 3.1 and 3.2 show incidence according to age and time of appearance of lesions in the various groups.

In the early stages all lesions were characterized by hyperpigmented macules, papules, or raised plaques. (Plate 1.) These frequently were small, 1–2 mm. areas at first, but tended to coalesce in a few days into larger lesions, with a dry, leathery texture.

The pigmented stage of the superficial lesions within several days was followed by dry, scaly desquamation which proceeded from the center part of the lesion outward, leaving a pink to white thinned epithelium. As the desquamation proceeded outward, a characteristic appearance of a central depigmented area fringed with an irregular hyperpigmented zone was seen (Plates 2 and 3). Repigmentation began in the central area and spread outward over the next few weeks leaving skin of relatively normal appearance. Plates 3, 4, 11, and 12 show superficial lesions as they appeared initially and six months later. The mildest manifestation of skin injury was the development of a blotchy increased pigmentation of the skin with barely perceptible desquamation. Such lesions were most often noted on the face and trunk.

Epilation was usually accompanied by scalp lesions (Plates 13, 17 and 19). Some individuals developed new scalp lesions over a period of about a month. Neck lesions usually had a "necklace" distribution, beginning anteriorly and spreading posteriorly. These were more severe in women in whom thick hair

* The description of lesions refers to the Marshallese unless otherwise indicated.

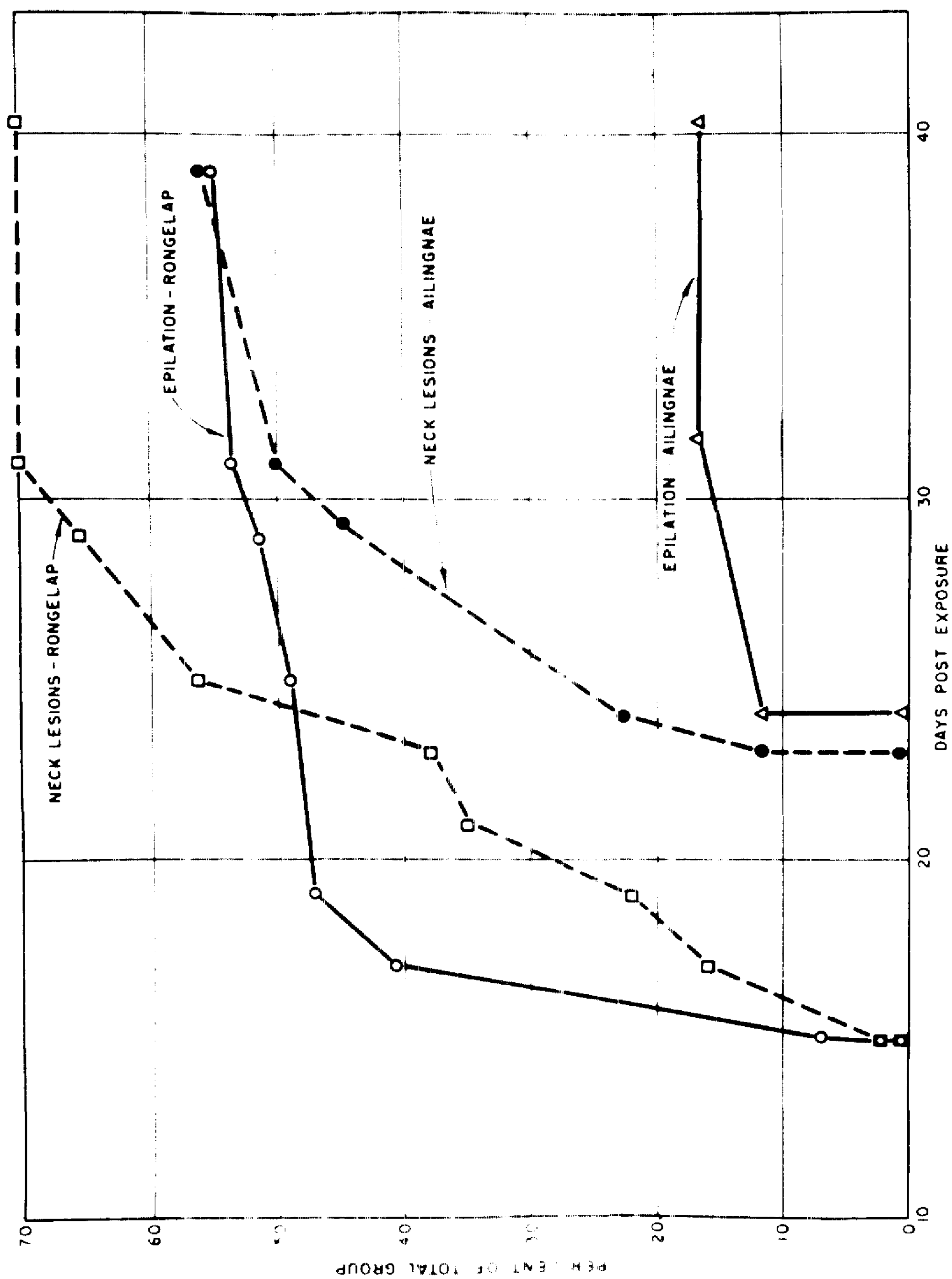


FIGURE 3.1 *Comparison of the Incidence and Time of Appearance of Epilation and Neck Lesions in the Rongelap and Ailinginae Groups.*

Table 3.1 —Lesions in Rongelap Group

Type of Lesion	Percent of Total in Each Group Having Indicated Lesion: Age 0-5 (13 People)	Age 6-15 (13 People)	Age 16 & Over (38 People)	Total Group (64 People)	Median Time of First Observation of Lesions*
Epilation					
[illegible] plus	7. 6	38. 4	13. 8	17. 2	17
[illegible] plus	38. [illegible]	30. 7	5. 5	17. 2	17
[illegible] plus	53. 8	23. [illegible]	8. 3	22. 0	16
Total	100. [illegible]	[illegible]	27. 6	56. 2	16
Skin lesions					
Anus-groin	38. 4	[illegible]	0. 0	7. 8	17
Scalp	100. [illegible]	100. [illegible]	37. 0	62. 5	18
Neck	69. 2	76. [illegible]	68. 0	70. 3	21
Axilla	61. 5	[illegible]	15. 7	23. 4	21
Antecubital Fossae	30. 7	38. 4	34. 2	34. 4	28
Hands-wrists	30. 7	23. [illegible]	18. 4	21. 8	33
Feet	23. 0	53. 8	53. 0	45. 3	28
Arms	15. [illegible]	15. 3	10. 3	12. 5	31
Legs	7. 6	23. 0	4. 3	7. 8	33
Trunk	15. [illegible]	23. 0	4. 3	9. 4	33
Nail pigmentation	61. 5	100. 0	95. 0	89. 0	38

*Post-exposure days

Table 3.2.—Lesions in Ailinginae and Rongerik Groups

Type of Lesion	Ailinginae Group (18 People): % of Total With Lesions	Mean Time of Appearance*	Rongerik Group (Americans) (28 People): % of Total With Lesions	Mean Time of Appearance*
Epilation	[illegible]	27	3. 5**	42
Lesions of				
Scalp and face	38	26	10. 7	32
Neck and shoulders	[illegible]	27	14. 3	30
Back	[illegible]		7. 1	28
Axilla	22	24	3. 5	23
Antecubital fossae	[illegible]	28	25. 0	29
Hand, wrist	[illegible]	38	3. 5	47
Feet	[illegible]	33	3. 5	43
Legs	[illegible]	44	0. 0	.....
Nail discoloration	[illegible]	38	17. 9 (All Negroes)	40

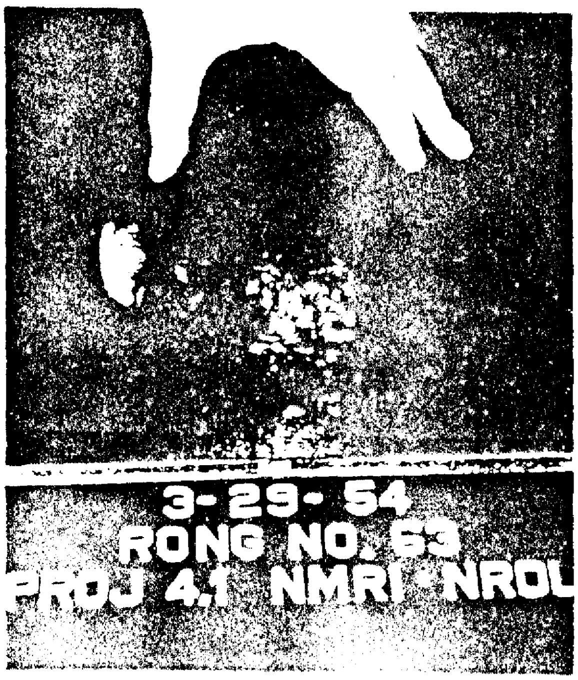
*Days post-exposure

**One case claimed slight epilation

PRIVACY ACT MATERIAL REMOVED

[illegible]

[illegible]



[illegible]

[illegible]

A

[illegible] Hyperpigmented [illegible] plaques and bullae on dorsum of feet and toes at 28 days. The lesion on left foot [illegible] deeper [illegible]. Feet were painful at this time.

[illegible] 19 days later. [illegible] feet no longer painful.

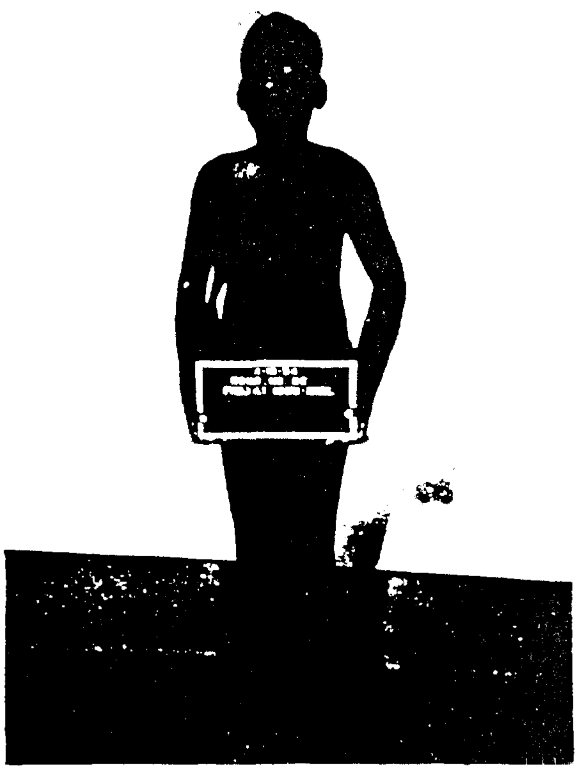
[illegible] left foot [illegible]

[illegible]

PRIVACY ACT MATERIAL REMOVED

[illegible]

[illegible]



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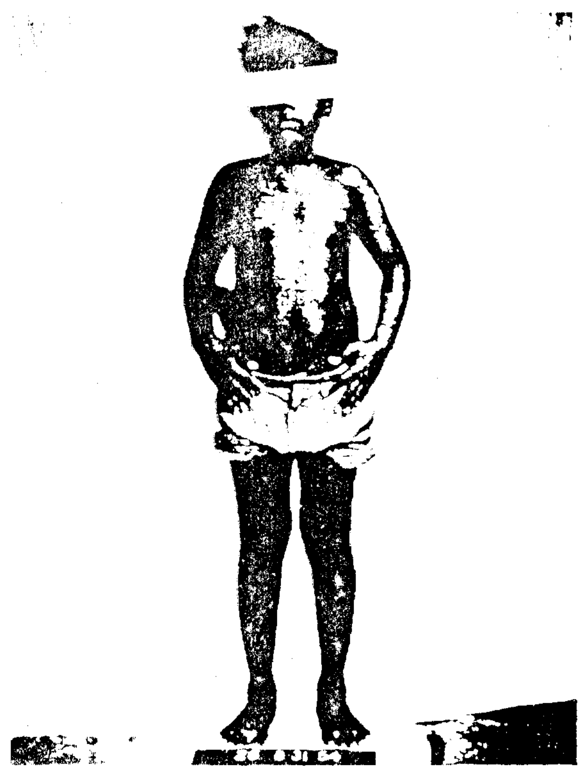
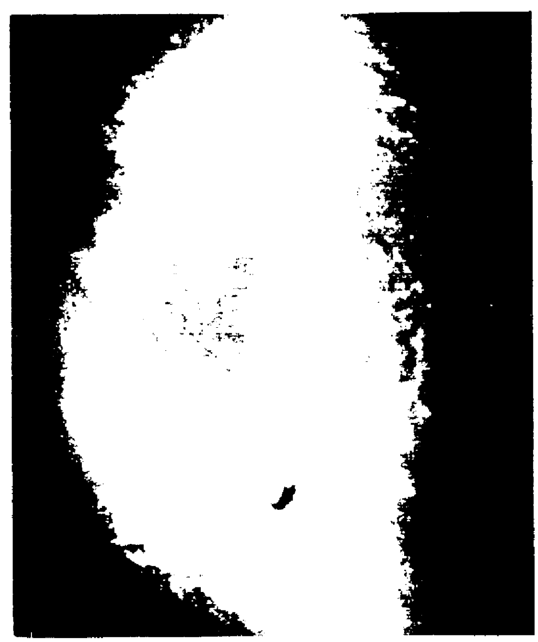


[illegible]

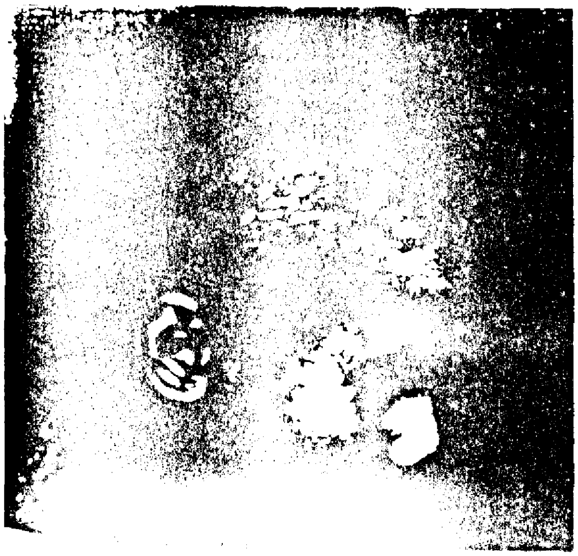
[illegible] of back of scalp at 48 [illegible] contact on designated area. Note [illegible] of left ear.

[illegible] Note [illegible] of left ear [illegible]

[illegible] with considerable scarring. [illegible]



[illegible] of the patient.



[illegible]

[illegible]

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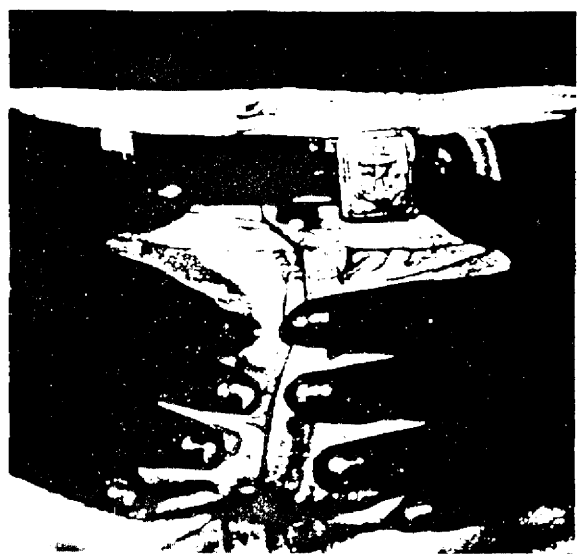
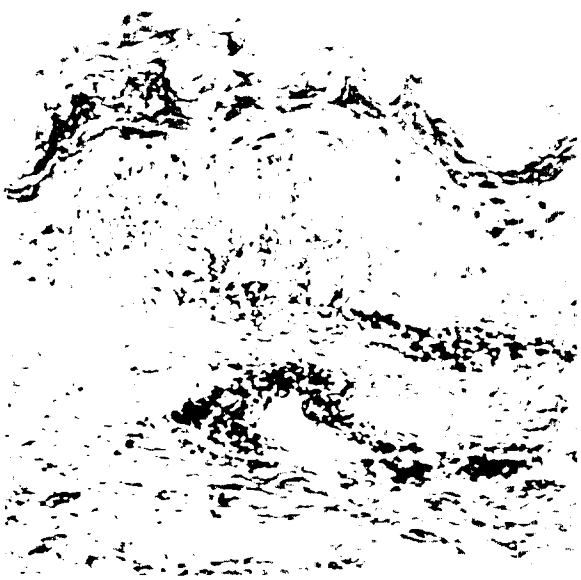


[illegible]



[illegible] ... epidermis ... [illegible] ... absence of ... [illegible]

[illegible] ... of sweat ... and shows ... [illegible] ... shows ... portion of the ... moderate ... The arrow ... at the left ... of the stratum ... The latter ... parakeratotic ... infiltrate ... the super- ... [illegible]

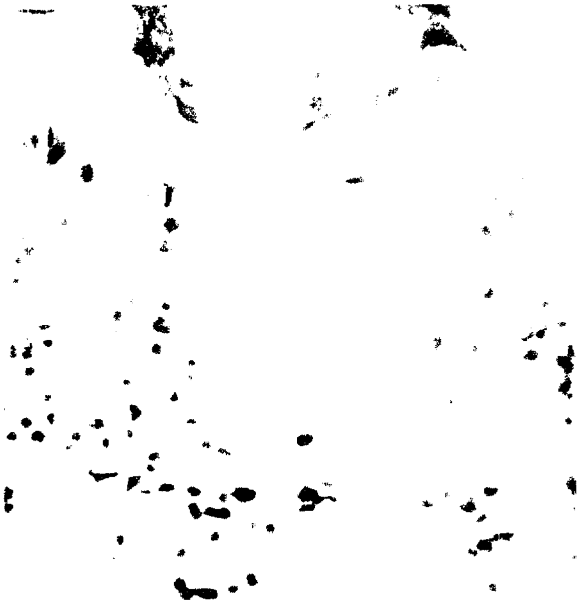


Plate [illegible]

[illegible] H&E [illegible] of the [illegible] layer. Slight [illegible] outward of [illegible] stratum corneum. Pig- [illegible] phores and [illegible] in superficial [illegible] Mixed cellular infiltra- [illegible] Slight [illegible]

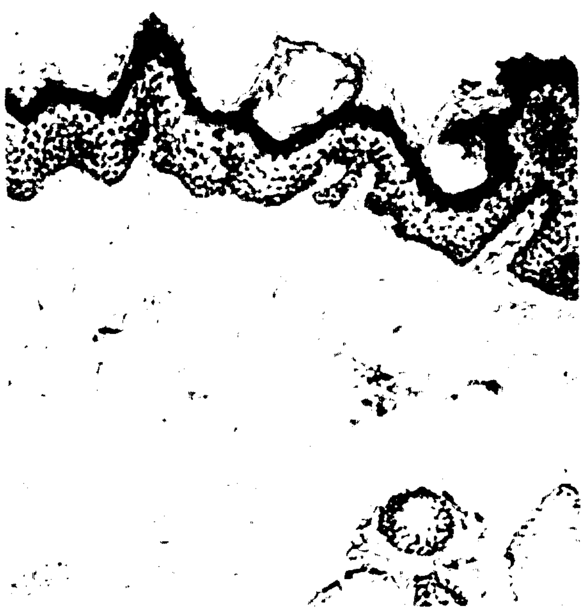
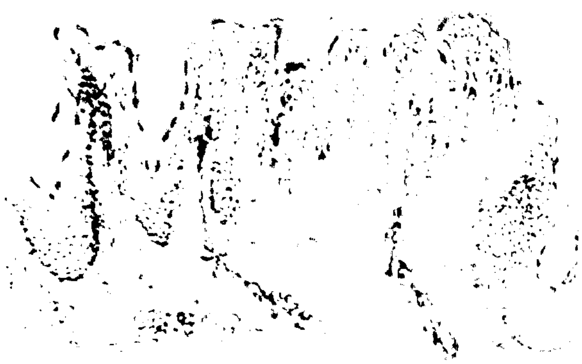


Plate [illegible]

[illegible] H&E (Case # [illegible]) Same as 25. [illegible] halos [illegible] Loosely [illegible] stratum cor- [illegible] superficial [illegible]



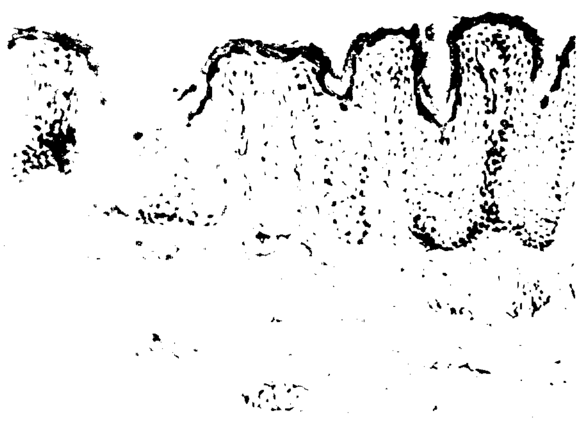


PLATE 28.— [illegible] H&E. Case #[illegible]. Six months post-exposure [illegible] focal atrophy of stratum [illegible] are present and areas of prolongation [illegible] In the dermis a mod- [illegible] telangiectasis is seen. are a [illegible] distribution of [illegible]

H

touched the nape of the neck. Neck lesions are illustrated in Plate 1–4. Axillary lesions (Plate 11) usually consisted of coalescing papules. Antecubital fossa lesions were characterized by formation of thickened plaques. Several babies and one woman developed lesions in the anal region which, though not deep, were painful due to excoriation of the epidermis. These healed rapidly.

Deeper lesions were seen on the scalp, neck, feet, and in one case on the ear. They were characterized by transepidermal necrosis with wet desquamation leaving weeping, crusting ulcerations. Vesiculation was not observed except with foot lesions which developed bullae, frequently several centimeters in diameter, beneath thickened pigmented plaques. These foot lesions occurred on the dorsum of the feet and between the toes. (Only one case showed desquamation on the soles of the feet.) After several days the bullae ruptured and desquamated leaving raw ulcers. Some of these lesions, particularly of the feet, became secondarily infected requiring antibiotics. However, most of the lesions healed rapidly and new epithelium covered the ulcerated areas within a week to 10 days. Foot lesions are illustrated in Plates 5–10. One ear lesion (Plates 13–16) took several months to heal.

The repigmentation of some deeper lesions presented abnormalities. Neck lesions often developed a dusky, grayish brown pigmentation associated with a thickened "orange peel" appearance. Histological appearance of epidermal rugosity was also noted in these lesions (see section on histopathology). In addition, the deeper lesions of the feet failed to repigment, remaining pink or white. At examination 6 months and 1 year after the exposure, the skin appeared normal with no residual changes in the vast majority of cases. However, some of the deeper lesions continued to show evidence of residual damage. Foremost among these was the ear lesion which had healed with considerable scarring, atrophy, scaling of the epidermis and gross telangiectasis. By 6 months the hyperpigmentation and thickening of the skin of the neck lesions had greatly subsided and by 1 year pigmentation changes were mild. Foot lesions had not repigmented at sites of deepest involvement and some atrophy of the skin in these areas was apparent.

Microscopic Appearance

Biopsies were taken of seven neck, and one axillary lesion in the Rongelap group during the third to fourth week after exposure. At the time of biopsy these lesions were in the hyperpigmented stage with little or no desquamation. Most of the biopsies were taken from individuals with lesions of average severity. A second series of biopsies (repeats in three individuals) were taken from this group, 4 at the seventh week and 5 at the eighth week post-exposure. These were taken from the neck and antecubital fossae. All of these lesions had desquamated and the depigmented skin had repigmented to a dusky, gray color with some thickening of the skin ("orange-peel" appearance), plates 25 and 27. Biopsies were not taken from ulcerative lesions or from the feet because of the danger of infection. A third series of 11 biopsies were taken from the Rongelap group at 6 months along with several control biopsies from unexposed natives. Material was obtained in many cases adjacent to sites of previous biopsies.

All biopsy wounds healed rapidly within a week to 10 days with no secondary complications.

The microscopic findings are summarized as follows:

First series—3rd to 4th week. Epidermis. Transepidermal damage was noted with a few intervening arcades showing less damage (Plates 21 and 22). The epidermis in the most extensively involved areas showed considerable atrophy with flattening of the rete pegs and in places the epidermis was reduced to a thickness of 2 to 3 cells (Plates 21, 23, and 24). The cells of the malpighian layer showed pleomorphic nuclei, pyknosis and cytoplasmic halos, giant cells and in a few instances multinucleated cells.

Pyknosis of cells of the basal layer was commonly seen. Focal disorganization of the malpighian and basal layers was usually present in the more extensively damaged arcades (Plate 23). Cells laden with pigment were frequently present throughout the epidermis and intercellular pigment was noted in some sections. The stratum granulosum was usually atrophic or even absent. Imperfect keratinization with parakeratosis was visible in all sections. The stratum corneum was loosely fibrillated and hyperkeratotic.

The arcades of minimal damage were usually found in areas where sweat ducts approached the epidermis (Plate 22). There was an apparent increase in the number of cells and mitotic figures along the neck of the ducts and the adjoining areas where regeneration was underway. In these areas the stratum granulosum appeared almost normal in width. In contrast to the more severely damaged areas where pigment was increased, these areas of minimal damage showed an actual decrease being almost free of pigment.

Dermis. Changes in the dermis were confined largely to the pars papillaris and superficial pars reticularis (Plates 21-24). Mild edema in some cases were noted. Capillary loops were often indistinct and when discernible they frequently were associated with an increased number of pericytes. The endothelial cells showed swelling and were polygonal in shape. Telangiectatic changes were noted in these areas where the overlying epidermis showed greatest damage which were associated with perivascular lymphocytic infiltration. Chromatophores, filled with melanin were prominent in the superficial dermis. The fine elastic fibrils running into the pars papillaris were often altered or absent.

Little if any damage was seen below the superficial pars reticularis. The hair follicles were narrow and in most instances devoid of shafts in this region. There was some telangiectasis of the capillaries and slight mononuclear cell infiltration. Some of the large elastic fibers in this region showed slight swelling in some cases. No damage to fibrocytes or collagen fibers was noted.

Second series—7th and 8th weeks post-exposure. Epidermis. In general, reparative processes of the epidermis had proceeded, except for a few persistent areas of atrophy with narrowing of the epidermis and finger-like downgrowths of the stratum malpighii (Plate 27). These changes occurred in areas of the greatest narrowing of the stratum granulosum. In such areas the basal cells often showed increased pigment. There were many outward epidermal excrescences covered by thickened stratum corneum, still loosely laminated (Plate 25), which probably accounted for the "orange-peel" appearance of the skin noted grossly. In almost all instances the basal layer was intact with little or no disorganization. There were a few scattered areas in which occasional epithelial cells with pyknotic nuclei and perinuclear cytoplasmic halos occurred in the malpighian layers (Plate 26). There were occasional arcades in which the epidermis and particularly the stratum granulosum appeared to be widened. These occurred primarily in relation to contiguous sweat gland ducts where the latter penetrated the epidermis. A narrow zone of parakeratosis and amorphous debris was still present between the stratum granulosum and the loosely laminated stratum corneum. The stratum lucidum was not apparent.

Dermis. The capillary loops in the dermal papillae were not uniformly distinct. Pericytes remained in increased number but fewer lymphocytes were present. Generally, there was a slight telangiectasis of the capillaries in the pars papillaris and the superficial pars reticularis (Plate 27). There was some edema of the pars papillaris (Plate 25). Scattered pigment-laden chromatophores were irregularly distributed in the papillary layer (Plate 26). In some cases hair shafts in the superficial pars reticularis were narrow or absent; in others the hair shafts appeared normal. Small hair follicles (Plate 25) and sweat ducts in some cases showed mild atrophy.

Biopsies of three pigmented lesions were taken from 2 of the white Americans of the Rongerik group. Only 1 of 3 showed evidence of damage, which was slight and confined to the epidermis.

Third series—6th month post exposure. Sections of skin at this time revealed some changes persisting in the epidermis and to a lesser extent in the dermis (Plates 28 and 29).

Epidermis. The following changes were found to varying degrees: focal atrophy of the stratum granulosum; slight focal pigmentary disturbances in cells of the basal layer; slight to moderate hyperkeratinization; and slight disturbances in polarity of epithelial cells in the still persistent basal papillary projections.

Dermis. In the dermis, telangiectasis superficially persisted from a slight to moderate degree in most of the sections, and contributed the only abnormality noted.

3.33 Epilation and Nail Pigmentation

Epilation. The incidence and time of appearance of epilation in the various groups is illustrated in Tables 3.1 and 3.2, and Figure 3.1. Epilation was first observed of the fourteenth post-exposure day in the Rongelap group, and somewhat later in the other groups. It was of a spotty nature and was confined almost entirely to the head region. Epilation was divided arbitrarily into 3 degrees of severity. "1+" indicated loss of hair without obvious thinning; "2+" indicated loss of hair sufficient to cause thin spots; and "3+" indicated an extensive epilation with bald spots. Table 3.1 illustrates that there was a greater degree of epilation in the children (0 to 15 years), with over 90 percent developing epilation to some degree as compared to only 28 percent in the older age group. The preponderance of scalp lesions in the areas of epilation indicated that radiation from the fallout material on the skin was primarily responsible for the epilation. Only three cases of mild epilation developed in the Ailinginae children, and questionable epilation occurred in one of the Americans, characterized by loose hair upon combing but without areas of alopecia.

Regrowth of hair in all individuals commenced some time during the third month after exposure. At the 6 months' examination complete regrowth of hair, normal in color, texture, and abundance had taken place. Plates 13–15, 17, 18, and 19 show epilation and regrowth of hair.

Nail Pigmentation. An unusual observation was the appearance of a bluish-brown pigmentation of the fingernails which was first well documented on the 23rd post-exposure day. The discoloration began in the semilunar area of the fingernails (to a lesser extent in the toenails), and spread outward sometimes in streaks. As the discolored area grew distally the semilunar area usually became clear. Plate 20 shows pigmented bands in the nails at 77 days. At six months, pigmentation had grown out with the nails, and was no longer evident except in three cases which still showed pigment at the distal end of the nail. The pigment was on the under side of the nail plate. Discoloration of the nails was seen in a large proportion of the two higher exposure groups (Tables 3.1 and 3.2). The phenomenon appeared to be a radiation response peculiar to the dark-skinned races since it was seen in all of the exposed American Negroes and none of the white Americans supposedly receiving the same exposure. This lesion was not observed in the Utirik people or in unexposed Marshallese. Since the nail pigmentation occurred in individuals without skin lesions, it appeared to be the result of a more penetrating gamma component of radiation.

3.4 Therapy

The Treatment Of the skin lesions was largely non-specific. Most of the superficial lesions were treated with calamine lotion with one percent phenol, which in most cases relieved the itching and burning. A few of the hyperpigmented lesions not relieved by calamine with phenol were treated with pontocaine ointment, with apparent success. When the epithelium was desquamating, all lesions were treated by daily washing with soap and water followed by the application of a water soluble vanishing type ointment which kept the injured skin soft and pliable. Raw areas, which became secondarily infected, were cleansed with soap and aureomycin ointment was applied. Bullous lesions of the feet were left intact as long as no symptoms were present. If painful, the fluid was aspirated with sterile technique and a pressure dressing applied. A single aspiration was adequate since the bullae did not refill. In one instance, an extensive, raw, weeping ulcer developed for which penicillin was given for two days. During this time the lesion developed healthy granulation tissue. Some of the lesions of the skin of the foot remained thickened and less pliable after desquamation. This was relieved by the use of vaseline or cocoa butter to soften the tissues. The one persistent ear lesion did not heal after desquamation. This was treated daily with warm boric acid compresses and washing with surgical soap to remove the eschar. Slowly, regenerating epithelium grew in from the edges of the ulcer. Upon reexamination, 6 months after exposure, healing was complete with a depigmented scar remaining as evidence of the previous ulceration.

3.5 Factors Influencing Severity of the Lesions

3.51 Character of the Fallout Material

This material was composed mainly of calcium oxide from the incinerated coral, with adherent fission products. Fifty to eighty percent of the beta rays emanating from this material during the exposure period had an average energy of about 100 kev. Since 80 microns of tissue produces 50 percent attenuation of such radiation [illegible], a greater portion of energy was dissipated in the epidermis which is roughly 40 to 70 microns in thickness. The remaining 20 to 50 percent of the beta rays had an average energy of approximately 600 kev. The latter would penetrate well into the dermis since it takes 800 microns of tissue to produce 50 percent attenuation of this energy radiation (1,2). In addition, a wide spectrum of gamma energies irradiated the skin. The gamma contribution to the skin was small compared to the beta dose and is discussed in Chapter I.

3.52 Dose to the Skin

The skin lesions observed resulted primarily from beta radiation from fallout material deposited on the skin. The gamma dose to the skin was small compared to the beta dose, and thus relatively unimportant in producing the lesions. The summation of gamma and beta contributions to the skin is considered in Section 1.3. In general it is evident that skin injury was largely produced by material in contact with the skin. The total surface dose cannot be calculated with accuracy but minimal and maximal values at various depths in the skin can be estimated biologically. Hair follicles in the areas in which epilation occurred must have received a dose in excess of the known minimal epilating dose of about 400 r for 200 kvp X-ray. Since regrowth of hair occurred, the upper limit of dose at the depth of the hair follicle must not have exceeded the permanent epilating dose of around 700 r of 200 kvp X-ray (3). From this a rough idea of surface dose may be made. A dose to the hair follicles comparable to 400–700 r of X-radiation must have been due almost entirely to the more penetrating beta component (average energy, 600 kev). Therefore, the minimal surface dose in rep from this component alone was probably four to five times the dose at the hair follicle, i. e., roughly 1,600–3,500 rep. The soft component (average energy, 100 kev) contributed a considerably larger share to the surface dose but with only slight penetration.

3.53 Protective Factors

The following factors provided some protection:

a. *Shelter.* Those individuals who remained indoors or under the trees during the fallout period developed less severe lesions.

b. *Bathing.* Small children who went wading in the ocean developed fewer foot lesions. Most of the Americans, who were more aware of the danger of the fallout, took shelter in aluminum buildings, bathed and changed clothes and consequently developed only very mild beta lesions.

c. *Clothing.* A single layer of cotton material offered almost complete protection, as was demonstrated by the fact that lesions developed almost entirely on the exposed parts of the body.

3.54 Factors Favoring the Development of Lesions

a. *Areas of more profuse perspiration.* Lesions were more numerous in areas where perspiration is abundant such as the folds of the neck, axillae, and antecubital fossae.

b. *Delay in decontamination.* There was a delay of 1 or 2 days before satisfactory decontamination was possible. The prolonged contact of radioactive materials on the skin during this period increased the dose to the skin. However, the dose rate fell off rapidly and decontamination would have had to be prompt in order to have been most effective.

c. *Difficulties in decontamination.* The thick hair, anointed with a heavy coconut-oil dressing, resulted in heavy contamination. Decontamination of the head was slower than for the other parts of the body and may have enhanced the development of epilation and scalp lesions.

3.6 Lack of Correlation With Hematological Findings

Attempts Were Made to correlate the severity and extensiveness of skin lesions with hematologic findings for individuals in the Rongelap group. No positive correlation was found with depression of any element. Thus, the contamination of the skin apparently did not significantly contribute to the total body dose of radiation.

3.7 Discussion

There Has Been little previous experience with radiation dermatitis resulting from exposure to fallout material from nuclear detonations, and the general consensus, until this event, has been that the hazard from fallout material was negligible. From the present experience it is evident that following detonation of a large scale device close to the ground, serious exposure of personnel with resulting radiation lesions of the skin may occur from fallout material, even at considerable distances from the site of detonation. This incident is the first example of large numbers of radiation burns of human beings produced by exposure to fallout material. With the Hiroshima and Nagasaki detonations fallout was not a problem since the bombs were detonated high in the air. The flash burns of the Japanese were due to thermal radiation only.

Following the Alamogordo atomic detonation, a number of cattle grazing near the point of detonation developed lesions on their backs due to the deposit of fallout material (4). Also, following a detonation at the Nevada Test Site, sixteen horses near the Test Site developed lesions resulting from fallout deposit on their backs (5).

Knowlton *et al.* (6) described burns of the hands of four individuals who were handling fission product material following detonation of a nuclear device. These burns were due largely to beta radiation. The gross lesions of the hands occurred from an exposure of about 1 hour, resulting in doses between 3,000 and 16,000 rep of beta radiation (maximum energy about 1 Mev) with a small gamma component considered to be insignificant. The lesions were described as developing in four phases: (1) An initial phase which began almost immediately after exposure and consisted of an erythema with tingling and burning of the hands, reaching a peak in 48 hours and subsiding rapidly so that by 3 to 5 days there was relative absence of signs and symptoms; (2) a second phase which occurred from about the third to the sixth or eighth day, and was characterized by a more severe erythema; (3) The third phase at 8 to 12 days, was characterized by vesicle and bullae formation. The erythema spread to new areas during the following 2 weeks, and the active process subsided by 24 to 32 days. The bullae dried up, and desquamation and epithelization took place in less severely damaged areas; (4) The fourth phase or chronic stage was characterized by further breakdown of skin with necrosis in areas which were damaged sufficiently to compromise the blood supply. Atrophy of the epidermis and loss of epithelial structures took place, which necessitated skin grafting in some cases.

Robbins *et al.* (7) reported six cases accidentally exposed over much of their bodies to scattered cathode rays from a 1200 kv primary beam with exposure time of about 2 minutes and a rough estimation of dose to the skin of between 1000 and 2000 rep. The lesions described were similar to those reported by Knowlton *et al.* with a primary erythema developing within 36 hours; secondary erythema with vesiculation and bullae formation appearing about 12 to 14 days later; and, in the more severely affected, a tertiary phase characterized by further breakdown of the skin. In comparison with severe roentgen ray reactions these investigators stressed the unique periodicity of cathode ray burns, relative absence of deep damage to the skin, less pain, greater rapidity of healing, and absence of pigmentation. These points would apply to the Marshallese lesions except for the multiphasic reactions and absence of pigmentation. Crawford (8) reports a case of cathode ray burns of the hands which were similar to those described by Robbins *et al.*

Experimental beta radiation burns in human beings have been reported by Low-Beer (9) and Wirth and Raper (10). Both investigators used P^{32} discs applied to the flexor surface of the arms, forearms, or thighs for varying lengths of time. Low-Beer reported "monophasic" skin reactions. He found that a calculated dose of 143 rep to the first millimeter of skin, ignoring self-absorption, produced a threshold erythema. Dry, scaly, desquamation was produced by 7200 rep in the first millimeter and bullous, wet desquamation was produced by 17,000 rep to the first millimeter. Erythema developed in 3 to 4 days, followed later by pigmentation and desquamation with higher doses. Recovery was observed with doses of 17,000 rep. The lesions later showed depigmented centers with hyperpigmented edges (also seen in the present cases).

Wirth and Raper (10) produced primary erythema within 6 hours after exposure to a dose of 635 to 1180 rep of P^{32} radiation. Minute vesicles with dry, spotty desquamation were noted with 1180 rep at about the fifth to sixth weeks post-exposure.

Twenty-three Japaneses fishermen were exposed to the same fallout material which involved the Marshallese and Americans. There were many similarities in appearance of skin lesions that developed. Pigmentation was also common in the Japanese and some degree of erythema was reported (11) which was not seen in the Marshallese. Distribution of lesions was not the same due to different parts of the body being protected by clothing. For example, in the Japanese scalp lesions and epilation were more common on the crown of the head since handkerchiefs were usually worn around the head leaving the crown exposed. Shoes protected the feet of the Japanese, but lesions of the hands between thumb and index finger were common, apparently due to handling contaminated fishing lines. Lesions with belt line distribution occurred in the Japanese fishermen but not the Marshallese. Similar mild lesions were observed on several American sailors who were on ships of the task force exposed to fallout. From available information, the severity and course of the lesions in the Japanese fishermen appeared to be similar to those seen in the Rongelap Marshallese group.

The lesions in this report did not follow precisely the same course as those beta radiation lesions described by Knowlton, Robbins, and others (6–10) and they presented certain unique features which merit further discussion.

The early symptoms of itching and burning of the skin and eyes were probably due mainly to skin irradiation from the fallout material. However, the chemical nature of this material may have contributed to the irritation. It has been noted (12) that irritating chemicals applied during or shortly after irradiation enhance the effects of radiation.

The lack of prominence of an erythema was notable, particularly in view of the severity of some of the lesions that developed. Wilhelmy (13) states that erythema only occurs when the dose reaching the papillary layer exceeds a certain level. Perhaps due to the low energy of the beta radiation the dose to the dermis was insufficient to evoke the response. On the other hand, the darkness of the skin and the development of hyperpigmentation may have masked an erythema. Microscopically, a superficial hyperemia was not prominent.

Wirth and Raper (10) point out that they were impressed in their studies on P^{32} radiation of the human skin with the difficulty of distinguishing between true erythema and tanning, particularly in the skin of brunette individuals. It was unfortunate that color filters were not available to aid in distinguishing an erythema as suggested by Harris *et al.* (14).

In general, the length of the latent period before development of lesions of the skin is considered to be roughly inversely proportional to the dose of radiation (15, 16). In the present series of cases the relatively long latent period is suggestive of a low dose of radiation. Due to the wide spectrum of beta energies and particulate distribution of radioactive material, strict comparisons cannot be made with previous experience. However, the later development of less severe lesions in the Ailinginae and Rongerik groups as contrasted with earlier development of more serious lesions in the Rongelap group is in keeping with a lower skin dose in the former, and a higher skin dose in the latter. It is of interest, however, that the latent period was dependent to some extent on anatomical location. The foot lesions, which were generally the most severe lesions encountered, had a longer latent period than the less severe lesions occurring elsewhere on the body. It is logical to assume that the feet received a higher dose of radiation because of proximity to the ground and this may explain the severity of these lesions. The longer latent period (despite higher dose of radiation) may be related to thickness of the epidermis, differences in length of mitotic cycles or other inherent characteristics of skin in different areas of the body.

The histopathological changes noted, such as destructive and atrophic changes of the epidermis, disturbances in keratinization, and atrophy of hair follicles, when taken together are consistent with radiation injury to the skin (5, 12, 17, 18, 19, and 20). Severe injury to the dermis and blood vessels was not observed. The minimal dermal injury with severe epidermal injury is in keeping with the large component of low energy beta material present, resulting in absorption of the greater portion of the energy in the epidermis.

Hyperpigmentation of injured areas was a consistent finding in the Marshallese and the American Negroes. Pigmented lesions were also observed to a lesser extent in the white Americans. Such pronounced pigmentation is not characteristic of the usual lesions as described following exposure to beta or penetrating radiation, but may be more typical of the response to ultra soft roentgen or "Grenz rays" (21).

There is no satisfactory explanation for the darker dusky-gray color that appeared in some of the skin lesions as healing progressed. Vascular changes or pigment aberrations might have been responsible. The return to near normal in this pigmentation by 6 months showed the transient nature of this change. The continued absence of pigmentation at the site of the deeper foot lesions at 6 months and 1 year later suggests that the pigment-producing elements in these areas were permanently damaged.

The unique features of the lesions such as the marked pigmentation, the absence of obvious multiphasic response, the long latent period, and the severe, spotty epidermal injury with minimal dermal injury are notable. The particulate nature and uneven distribution of the fallout material was responsible for the spotty nature of the lesions and the large component of soft energy beta radiation was responsible for the greater epidermal injury. The prominence of pigmentary changes is probably related to race.* It is generally conceded that blondes with light pigment are more sensitive to radiation than brunettes (17). Lastly it is quite evident that sensitivity and response varied with anatomic location.

In Table 3.3 are listed the approximate surface skin doses required to produce recognizable epidermal injury from beta radiations in animals. It is apparent from the table that beta ray energy is of considerable importance in determining the degree of injury. According to Moritz and Henriques, the difference in dose between that required to produce threshold skin damage and that for permanent damage in pigs is 500 to 1000 rep (26). One is not justified in comparing animal lesions from known doses with lesions in the exposed individuals in this study in order to estimate the skin dose, since species differences in response may exist, and certain radiation factors are not well established, such as accurate knowledge of the beta spectrum of the fallout material and dose rate. Comparison with human data suffers from wide differences in radiation energy and doses reported and methods of determining the rep dose.

The low incidence of infection of the radiation burns is probably due to their superficial nature. Ulceration and partial healing preceded the time of minimal granulocyte counts. It is conceivable, however, that with higher doses of whole-body radiation, the defenses against infection might have been sufficiently impaired to have resulted in serious complications from skin lesions of the severity encountered.

Severe radiation injury is known to predispose to cancer. The probability of the development of malignancies at the site of healed lesions is unknown. Certain factors appear to decrease the probability: (a) The majority of the lesions were superficial. (b) Visible signs of chronic radiation dermatitis are absent in

Table 3.3.—Surface Doses Required to Produce Recognizeable Epidermal Injury

Investigator	Animal	Isotope	Average Energy (Mev)	Surface Dose (rep)
Henshaw et al (22)	Rats	P^{32}	0.5	1,500–4,000
Raper and Barnes (23)	Rats	P^{32}	0.5	4,000
Raper and Barnes (23)	Mice	P^{32}	0.5	2,500
Snider and Raper (24)	Mice	P^{32}	0.5	2,500
Raper and Barnes (23)	Rabbits	P^{32}	0.5	5,000
Lushbaugh (25)	Sheep	Sr^{90}	0.3	2,500–5,000
Moritz and Henriques (26)	Pigs	S^{35}	0.05	20,000–30,000
Moritz and Henriques (26)	Pigs	Co^{60}	0.01	4,000–5,000
Moritz and Henriques (26)	Pigs	Cs^{137}	0.2	2,000–3,000
Moritz and Henriques (26)	Pigs	Sr^{90}	0.3	1,500–2,000
Moritz and Henriques (26)	Pigs	Y^{91}	0.5	1,500–2,000
Moritz and Henriques (26)	Pigs	Y^{90}	0.7	1,500–2,000

* Reported clinical experience with radiation skin lesions is based predominantly on the response of white-skinned people, whereas the lesions described herein were observed primarily in the Marshallese, a highly pigmented people.

the vast majority of cases. Such changes have been generally observed prior to the development of radiation cancer. (c) The lack of any marked histological damage 6 months after exposure implies good repair. (d) Since low energy radiation was chiefly responsible for the skin lesions, the prognosis appears better because none of 1,100 individuals exposed to low voltage X-ray for dermatological conditions developed epidermoid carcinoma 5 to 23 years after treatment (27). (e) Furthermore epitheliomata rarely develop after a single dose of radiation to the skin (2). (f) Lastly the incidence of skin cancer in Negroes is one-sixth to one-ninth the incidence in Caucasians (28) in the United States.

Other factors make the outlook less favorable: (a) Deeper lesions of the feet and neck continued to show pigment aberrations and slight atrophy at 1 year, and one severe ear lesion showed marked atrophy and scarring at this time. (b) It is not known whether or not radiation of the epidermis *per se* can predispose to malignant change. Since the epidermis was heavily irradiated in these cases, compared to the dermis, this becomes an important consideration. (c) Since many children and young adults were involved, the life expectancy of a large number of the individuals will exceed the long induction period for the development of radiation cancer observed in radiologists. (d) Exposure to tropical sunlight, potentially carcinogenic in itself, may increase the probability of neoplastic change. (e) The influence of the sublethal whole-body exposure received by these people on induction of skin cancer is not known.

The occurrence of epilation 2 to 3 weeks after exposure corresponds roughly to the time of appearance of epilation in the Japanese exposed to gamma radiation at Hiroshima and Nagasaki (29, 30). Since the greater amount of epilation occurred over a period of a week to 10 days there was apparently no phasic response dependent on the growth cycle of the follicles (inactive, or telogen and active, or anagen follicles) as has been reported (31, 32).

The regrowth of hair, beginning about 9 weeks after exposure in the Marshallese, was at about the same time as noted in the Japanese fisherman (11), and slightly later than the time of regrowth (6 to 8 weeks) noted in the Japanese bomb casualties. In contrast to the marked pigmentation changes noted in the irradiated skin of the Marshallese, there were no pigment aberrations in the new hair, which was observed to be of normal texture and abundance at 6 months. Increased graying has been reported in animals (33–36) but has not been seen in human beings. Neither was there any appearance of dark hair in aged individuals who already had gray hair as has been reported in human beings (32, 37, and 38). In the Japanese bomb casualties (30) and the Japanese fishermen (11) the new hair was also normal in color, texture, and abundance.

The nature of the bluish-brown transverse bands of pigmentation that developed beneath the nails is not known. Since it occurred in the majority of the more heavily exposed Marshallese groups and in all 5 of the American Negroes, but none of the white Americans, it appeared to be a response peculiar to dark-skinned races. The phenomenon was apparently produced by gamma radiation with a dosage as low as 75 r since this was the estimated dose that the American Negroes received in the absence of significant contamination of the hands. Sutton (39) has reported a case of similar fingernail pigmentation which developed in a Negress, following 150 r of soft X-irradiation to the hands.

3.8 Summary

FOLLOWING THE DETONATION of a thermonuclear device significant amounts of visible radioactive material were deposited on inhabited atolls producing skin lesions, whole-body radiation injury and some internal deposition of radionuclides. The skin lesions in the more heavily contaminated groups were characterized by itching and burning of the skin for 24–48 hours. Epilation and skin lesions were observed, beginning approximately 2 to 3 weeks after exposure, on skin areas contaminated with fall-out. Bluish-brown pigmentation of the finger nails was also a common finding. No primary or secondary erythema was observed and consistently the first evidence of skin damage was increased pigmentation in the form of dark brown to black macules, papules, and raised plaques. The lesions developed largely on the exposed parts of the body not protected by clothing, and occurred usually in the following order: scalp (with epilation), neck, axillae, antecubital fossae, feet, limbs, and trunk. Epilation and lesions of the scalp, neck, and foot (dorsal surface) were the most common. The majority of lesions were superficial without vesicle formation, and after simple dry desquamation healed and repigmented. Approximately 20 percent of the people in the highest exposure group developed deeper lesions, usually occurring on the feet or neck and characterized by wet desquamation with ulceration. Mild burning, itching, and pain accompanied the lesions. The majority healed rapidly with non-specific therapy. Residual pigment aberrations consisting of hyperpigmentation and lack of repigmentation and mild atrophic changes were noted in some deeper healed lesions at six months and one year. Regrowth of hair, normal in color and texture, began about 9 weeks post-exposure and was complete at 6 months. Biopsies of typical lesions at 3 to 6 weeks showed changes consistent with radiation damage with marked epidermal damage and much less severe dermal damage. Biopsies at 6 months showed only a few residual changes. The nail discoloration had "grown out" completely at 6 months in all but a few individuals.

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Chapter V

Hematologic Observations

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Outline

4.0 Introduction

FOLLOWING THE DETONATION of a nuclear device at the Pacific Proving Ground in the Spring of 1954, 28 Americans and 239 Marshallese were exposed to fallout radiations. Sixty-four of the Marshallese on Rongelap atoll (Group I) received an estimated 175 r. of gamma radiation as measured in air; 18 Marshallese on Ailinginae atoll (Group II) received 69 r.; 28 Americans on Rongerik atoll (Group III) received 78 r.; and 157 Marshallese on Utirik atoll (Group IV) received 14 r. Detailed history of the event, as well as clinical and internal contamination findings are reported respectively in Chapters I, II and V. This chapter presents the hematological findings in the exposed individuals during the first 11 weeks, at 6 months, and at 12 months after exposure.

Since it is generally agreed that the degree of change in the formed elements of the blood is the most useful clinical index of the severity of radiation damage, peripheral blood changes were relied upon as a major aid in evaluating the degree of radiation injury in each exposed individual. In addition, changes in the mean blood counts of the exposed groups were followed closely to aid in evaluating the changing status and probable prognosis of the exposed groups. Therefore, emphasis was placed on standardized systematic serial determinations in order that individual and group trends could be evaluated adequately. Since it was necessary to observe the large number of exposed individuals at frequent intervals, the number of different procedures that could be done was necessarily limited. Determinations employed were chosen on the basis of known clinical value, and ease and rapidity with which they could be done reliably under field laboratory conditions. Accordingly, coagulation and biochemical studies were omitted.

An extensive literature exists on the hematologic effects of radiation. These data, and the difficulties attendant on comparing them with the present results are discussed later in this report.

4.1 Methods

HEMATOLOGICAL EXAMINATIONS INCLUDED total leukocyte, neutrophile, lymphocyte and platelet counts, and hematocrit determinations. Whenever possible, an entire exposure group was studied in a single day with 2 days occasionally required to complete the larger groups.

Capillary blood, usually obtained from the finger and rarely from the heel or ear was used. Two pipettes were filled for both the leukocyte and platelet counts. From each pipette a single hemocytometer chamber was filled. All pipettes were rotated for 10 minutes, and the cells were allowed to settle for 10 minutes in the hemocytometer chamber before counting. A 3 percent acetic acid diluting fluid was used for total leukocyte counts. The blood was diluted with 1 percent ammonium oxalate for platelet counts and counted in flat bottom hemocytometers using a dark phase contrast microscope.

Two blood smears were made using a beveled end glass slide for spreading. One blood smear was fixed in methyl alcohol. The other was stained by Wright's method, from which a 100 cell differential count was made. Hematocrits were performed using heparinized capillary tubes. One end of the capillary tube was heat sealed and the tube was centrifuged in a capillary centrifuge at 12,500 rpm for 5 minutes.

Every effort was made to maintain uniform procedures in every phase of the laboratory work. The number of personnel changes for a given procedure was held to a minimum: personnel drawing blood from a single puncture were sufficient in number to allow all samples to be taken in rapid succession, and time intervals were rigidly controlled.

4.2 Methods of Treating Data. Control Groups

PRE-EXPOSURE BLOOD counts were not available on the exposed Marshallese or Americans; hence the individuals could not be used as their own controls. In order to estimate the severity of the hematologic response it was necessary to establish control groups as comparable as possible with respect to age, race, sex, background and habits. A control group of 115 Marshallese from Majuro atoll (Control Group A) comparable with respect to age and sex to exposure Group I was obtained during the initial observation period.* For comparison with the exposed Americans, blood counts were done on approximately 85 American men on duty at Kwajalein. All who had not been on duty in the tropics for more than 2 months were excluded, since the exposed Americans had been in the area for that period of time before exposure. In addition, several who were recently associated with radioactive materials were excluded. The resulting smaller group of 67 was used as the Kwaj American control group.

Data from the control group A were examined to determine the age and sex dependency of the several hematological determinations. To obtain valid comparisons within and among the various exposure groups, the age and sex dependencies noted for the control groups were taken into account. Although each individual in all groups was studied hematologically, those Marshallese with serious long-standing diseases were omitted from the analysis. A total of two from Group A and two from control Group B were omitted on this basis.

In the following descriptions and comparisons of the data, findings in the exposed groups are frequently expressed in terms of percent of the appropriate age and sex control group. It should be noted, however, that in observational studies of this kind, *unknown factors could possibly account for part of the differences noted between the control and exposure groups even though all possible measures were taken to secure comparable control groups.* In addition, it was not possible to obtain more than a single blood sample on each control individual. For these reasons, statistical tests of significance were applied mainly to time changes within an exposure group, and not to differences between control and exposure groups. For the purpose of detecting significant changes in the hematological pattern, nonparametric tests (i. e., statistical tests for which it is not necessary to specify the functional distribution of the variate under study) were used (2–7). The advantages of nonparametric methods have been summarized by Moses (8).

4.3 Hematological Findings, General

IN TABLE 4.1 are shown for control group A, by age and sex, the mean values for the total white, neutrophile, lymphocyte and platelet counts, as well as for the hematocrit. The age and sex breakdown used for comparisons among exposure groups is shown in Table 4.2. In this breakdown the age and sex dependencies noted for the Marshallese control groups were taken into account insofar as was practicable. It should be noted that the Group B control values (Table 4.1) agreed closely with the Group A control data. To allow additional comparison between effects on children and adults, the neutrophile counts were arbitrarily separated into the age groups used for the lymphocyte counts. Monocytes and eosinophiles were broken down also into the same age groups. The age and

*A second control group of 82 Marshallese from Majuro atoll (control Group B) were obtained during the 6 month medical resurvey. While data from these individuals are given in this report, they are not used for comparisons because of a measles epidemic during the resurvey.

Table 4.1.—Hematological Results, Marshallese Control Groups

Age	No. of Individuals Group A M	No. of Individuals Group A F	No. of Individuals Group B M	No. of Individuals Group B F	WBC Group A M	WBC Group A F	WBC Group B M	WBC Group B F	Neutrophile Group A M	Neutrophile Group A F	Neutrophile Group B M	Neutrophile Group B F	Lymphocyte Group A M	Lymphocyte Group A F	Lymphocyte Group B M	Lymphocyte Group B F	Platelet Group A M	Platelet Group A F	Platelet Group B M	Platelet Group B F	Hematocrit Group A M	Hematocrit Group A F	Hematocrit Group B M	Hematocrit Group B F
<5	10	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.3	42.2	35.9	35.0	31.7	38.5	37.4	35.9	37.8
6–10	6	4	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.3	3.9	39.7	38.7	35.0	36.2	41.2	39.2	38.5	37.7
11–15	1	3	2	[illegible]													28.0	38.3	24.5	33.7	42.0	42.3	38.0	39.2
11–20					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.4	3.4								
16–20	5	3	3	[illegible]													27.6	43.3	37.0	32.6	48.4	38.7	42.3	38.2
21–30	17	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.3	3.7	23.6	34.2	25.4	29.3	46.9	38.9	46.2	40.1
31–40	4	9	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.4	25.0	39.2	26.5	30.0	47.2	41.2	46.0	42.5
41–50	3	12	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.7	3.6	[illegible]	35.4	27.4	23.5	42.3	41.8	44.1	42.0
>50	10	4	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.9	[illegible]	32.2	25.3	27.6	43.7	41.7	40.6	41.0

sex dependency of these endpoints are comparable to that in published data (9,10), with the exception of the platelets on which previous comparable data were not available.

Total leukocyte, neutrophile, lymphocyte, monocyte, platelet and eosinophile counts for the several exposure groups are given by day, by sex and age in Tables 4.2 to 4.5. The total white count, neutrophile, lymphocyte and platelet counts at the times of maximum depression (averaged over the time during which counts were consistently the lowest) are shown in Tables 4.6 and 4.7 for each individual in Groups I and II respectively. Hematocrits for all exposure groups are shown in Table 4.8. Hematological findings as a function of time and age are shown also in Figures 4.1 to 4.8. The cumulative distribution curves for the various exposure groups, using the average of counts obtained over the period of maximum depression (days 39 to 51 for leukocytes; days 26 to 30 for platelets) are shown in Figures 4.9 to 4.12.* In the figures emphasis is placed on the separate blood elements rather than on the total leukocyte count, since the component elements have distinct and different time trends after irradiation.

*In Group IV the cumulative distribution curve for platelet counts only is presented since hematological determinations in this group were not made during the 39 to 51 day period. (See Fig. [illegible] for leukocyte comparisons among the other groups.)

[illegible] Hematological Findings, Group I. Rongelap

The absolute neutrophile count of both the younger and older age groups fell during the second week to a value approximately 70 to 80 percent of that of the controls (see Fig. 4.1).

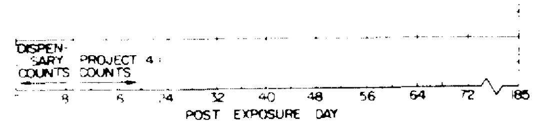

Figure 4.1.—Serial changes in neutrophile counts of Group I, Rongelap, for those less than 5 years and greater than 5 years of age.

Following the depression of the total neutrophile count during the 2nd week, the values were unstable until the 5th week. At this time the beginning of a second drop ($p < 0.01$) was noted for both age groups, and a low value of approximately [illegible]0 percent of controls was reached. The count was maintained at approximately 75 percent of control values from the 7th week to the end of the initial study. No further recovery was evident at 6 months. Although both age groups followed the same general time pattern of response, the lower age group was below that of the older throughout most of the observation period. At 12 months the granulocytes had returned to the control range.

The absolute lymphocyte count of the older age group (Fig. 4.2) had fallen by the 3d day to a value approximately 55 percent of the control group. This value was maintained throughout the study, and there was no definite evidence of an upward trend during the initial or 6 month studies. At 12 months, complete recovery had not occurred. The values for the younger age group likewise fell before the 3d day to a value approximately 25 percent of the control, following which there was a significant upward trend. With the total lymphocyte count, there is a consistent difference between the two age groups. However, during the first 4 weeks the difference is accentuated when expressed as percent decrease because of the relatively high lymphocyte levels in the lower age control group. After this period the differences expressed as percent are less marked since re-

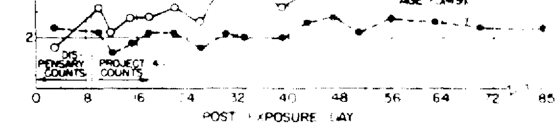

FIGURE 4.2.—*Serial changes in lymphocyte count of Group I (Rongelap) in those less than 5 years and greater than 5 years of age.*

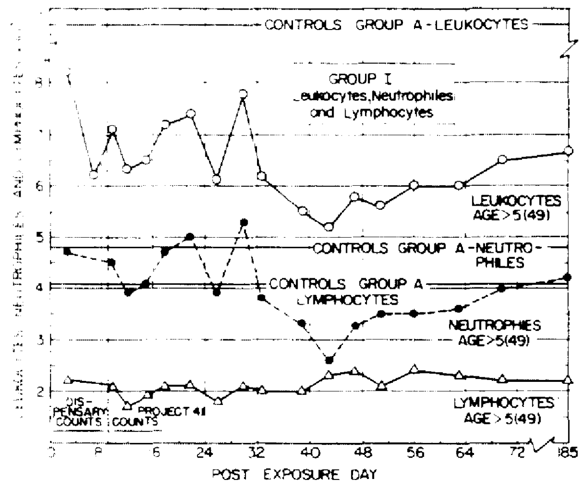

FIGURE 4.3.—*Comparative serial changes in the total leukocyte, neutrophile, and lymphocyte counts in those greater than 5 years old. Group I (Rongelap).*

covery was more rapid in the younger age group.

The cellular elements chiefly responsible for the fluctuations in total white blood cell count can be determined by comparing the total white, neutrophile and lymphocyte counts (Fig. 4.3). It is seen that the lymphocyte count remained essentially constant throughout the period of study, while the total neutrophile count fluctuated with a pattern essentially identical to that of the total white blood count (coefficient of correlation of 0.9). Thus the fluctuations in total count were due to changes in the neutrophile count. This was true of both the older and younger age groups. It can be seen from Table 4.2 that the neutrophile count was consistently greater than the lymphocyte count in the older age group. In the younger groups, differences in the neutrophile and lymphocyte count were less marked and frequently the lymphocyte count was greater than the neutrophile count.

Platelets were first counted 10 days after exposure, at which time platelet values of the females were approximately 60 percent of the appropriate control group (Fig. 4.4). Follow-

Table 4.2.—Group I Rongelap Mean Blood Counts by Day and by Age

P. E. Day	W. B. C. (x 10³)		Neutrophiles (x 10³)		Lymphocytes (x 10³)		Platelets x 10⁴			Monocytes (x 10²)		Eosinophiles (x 10²)	
	<5	>5	<5	>5			<10 M	>10 M	All Ages F	<5	>5	<5	>5
3	9.[illegible]	8.2	6.4	4.7	[illegible]	2.[illegible]				0.8	0.3	0.1	0.7
7	4.9	6.2											
10	6.[illegible]	7.1	3.5	4.5	2.[illegible]	2.[illegible]	28.2	22.7	22.1	2.9	1.7	1.6	1.6
12	5.9	6.3	3.5	3.9	2.[illegible]					4.2	5.4	1.9	1.9
15	7.5	6.5	3.2	4.1	2.4	[illegible]	27.1	21.3	21.7	3.0	2.3	1.1	1.3
18	6.7	7.2	3.4	4.7	2.4	2.[illegible]	21.8	19.1	21.8	2.7	1.7	3.5	1.6
22	7.0	7.4	4.3	5.0	2.6	2.[illegible]	16.8	14.6	15.2	1.9	2.0	2.3	1.8
26	5.7	6.[illegible]	3.0	3.9	2.3	[illegible]	13.2	12.9	10.9	1.9	1.6	1.8	1.3
30	7.6	7.8	4.0	5.3	3.2	2.[illegible]	14.1	12.3	11.8	1.5	0.9	3.4	2.2
33	6.5	6.2	3.1	3.8	3.2	2.[illegible]	17.9	16.6	15.1	1.7	1.6	2.6	2.2
39	5.7	7.5	3.0	3.3	2.6	2.[illegible]	25.5	22.0	22.4	0.9	0.9	0.5	1.0
43	5.2	7.2	2.0	2.6	2.[illegible]	2.[illegible]	26.8	20.9	23.2	1.1	1.1	1.4	0.8
47	5.9	7.8	2.6	3.3	3.[illegible]	2.[illegible]	24.6	20.6	23.9	1.0	1.0	1.1	0.5
51	6.7	7.6	2.6	3.5	3.[illegible]	2.[illegible]	22.1	17.5	21.2	2.5	1.6	0.8	0.7
56	7.6	6.0	3.5	3.5	3.[illegible]	2.[illegible]				1.7	1.2		
63	7.7	6.0	3.9	3.6	3.[illegible]	2.[illegible]	23.1	18.2	20.2	0.5	0.9	0.3	0.6
70	7.6	6.5	3.8	4.0	[illegible]	2.[illegible]						3.4	1.9
74							26.2	21.7	24.7				
185	8.5	6.6	4.6	4.2	3.6	2.[illegible]	24.4	20.3	23.2	1.4	1.1	2.5	1.6
400	10.1	8.[illegible]	4.7	4.8	4.6	2.[illegible]	26.6	19.5	27.6	0.7	1.3	6.7	2.8
Controls Group A	13.2	9.7	4.8	4.8	7.[illegible]	[illegible]	41.2	25.8	36.5	2.0	2.0	9.5	4.7

ing this, the platelet count fell reaching a low of approximately 30 percent of control value during the 4th week. The platelet count rose during the 5th and 6th weeks and reached the value noted for the initial counts on the 10th day. A second decrease in the platelet count ($p<0.01$) developed during the 7th and 8th weeks, and values remained at approximately 70 percent of the control groups during the remainder of the initial observation period. No additional recovery had occurred by the 6th month. At 12 months the counts were higher but still below the control range. The pattern of platelet counts in the male groups was remarkably similar to that noted for the females. Counts of the lower age groups, males, were consistently higher than those of the adult group in absolute counts but consistently lower as percent of control.

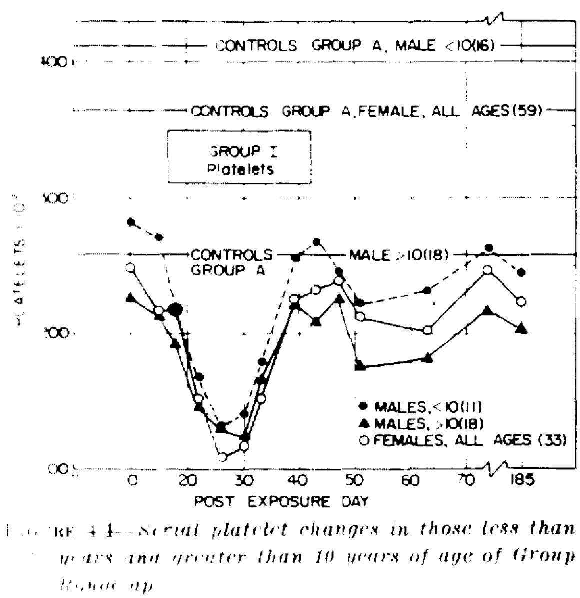

FIGURE 4.4.—Serial platelet changes in those less than 10 years and greater than 10 years of age of Group I Rongelap.

4.32 Hematological Findings, Group II Ailinginae

The pattern of change of all elements in Group II was essentially identical to that of Group I; however, the degree of change was not as marked (Table 4.[illegible]). As with Group I, recovery of all elements was incomplete at 6 months. At 12 months granulocytes were in the control range but platelets and lymphocytes remained depressed but higher than at 6 months.

4.33 Hematological Findings, Group IV. Utirik

Since it was known that Group IV had received a very small dose of radiation compared to the other exposure groups, less frequent de-

Table 4.[illegible].—Group II Ailinginae Mean Blood Count by Day and by Age

P. E. Day	W.B.C. X10³ <5	W.B.C. X10³ >5	Neutrophiles X10³ <5	Neutrophiles X10³ >5	Lymphocytes X10³ <5	Lymphocytes X10³ >5	Platelets X10⁴ <10 (M)	Platelets X10⁴ >10 (M)	Platelets X10⁴ All Ages (F)	Monocytes (X10²) <5	Monocytes (X10²) >5	Eosinophiles (X10²) <5	Eosinophiles (X10²) >5
3	6.[illegible]	7.0	3.0	[illegible].0	[illegible]	2.2				0.8	1.6	0.5	0.4
7	5.5	6.8							---	---	---	---	---
10	6.3	7.3	4.2	4.2	[illegible]	2.2	22.5	22.6	20.9	3.8	2.1	2.6	1.6
12	6.3	7.6	1.8	4.7	[illegible]	2.2				3.4	5.8	4.4	2.6
15	7.1	7.0	2.3	4.5	4.2	2.2	29.0	20.2	24.6	3.7	2.6	2.3	1.4
18	6.8	7.8	2.9	5.0	3.5	2.4	27.5	21.7	24.9	2.3	1.5	3.2	2.3
22	8.9	8.7	5.3	[illegible].4	2.7	2.9	23.5	17.0	22.9	1.5	2.4	5.8	2.4
26	8.4	7.0	4.8	4.4	3.2	2.2	20.0	13.8	17.4	2.3	2.4	0.6	1.6
30	9.6	8.6	5.3	6.2	3.7	2.0	19.5	12.8	18.2	1.9	1.9	4.1	2.0
33	7.7	[illegible].8	3.3	5.2	3.5	2.2	24.0	15.8	22.7	2.8	2.2	6.0	1.9
39	7.5	[illegible].2	2.9	4.2	4.7	[illegible].9	26.5	20.8	27.0	1.1	1.7	2.7	1.6
43	6.9	[illegible].5	2.7	3.6	3.9	2.7	28.0	19.6	25.3	0.6	1.4	2.8	0.6
47	7.3	[illegible].7	3.5	3.8	3.4	2.7	27.0	20.0	26.1	2.2	1.9	1.5	0.7
51	8.4	[illegible].3	3.8	3.6	[illegible]	2.2	32.0	18.2	25.0	2.7	2.8	2.2	1.0
54	[illegible].6	[illegible].3	2.8	3.5	5.2	2.5	37.0	19.8	23.8	1.5	1.9	1.8	0.8
185	[illegible]	[illegible].5	4.8	[illegible].9	[illegible]	2.2	25.2	19.2	23.9	1.1	1.4	1.5	2.2
400	[illegible]	[illegible].8	4.2	[illegible].7	[illegible]	[illegible].6	38.7	21.4	28.3	1.0	1.1	1.7	2.2
Controls Group A	3.2	[illegible]	4.8	4.8	[illegible]	[illegible]	41.2	25.8	36.5	2.0	2.0	9.5	4.7

Table 4.[illegible].—Group IV Utirik Mean Blood Count by Day and by Age

P. E. Day	W.B.C. X10³ <5	W.B.C. X10³ >5	Neutrophiles X10³ <5	Neutrophiles X10³ >5	Lymphocytes X10³ <5	Lymphocytes X10³ >5	Platelets X10⁴ <10 (M)	Platelets X10⁴ >10 (M)	Platelets X10⁴ All Ages (F)	Monocytes (X10²) <5	Monocytes (X10²) >5	Eosinophiles (X10²) <5	Eosinophiles (X10²) >5
4	[illegible].4	8.2	4.7	[illegible].2	[illegible]	[illegible].2				0.6	0.2	2.0	1.2
14	[illegible]	8.6	4.1	[illegible]	[illegible]	[illegible]				4.9	4.2	3.6	2.7
19							38.9	28.1	35.6	---	---	---	---
29	[illegible]	[illegible].7	4.9	[illegible]	[illegible]	[illegible].2	3[illegible].5	25.6	31.7	2.2	1.7	3.1	2.0
Controls Group A	3.2	[illegible].7	4.8	[illegible]	[illegible]	[illegible]	4[illegible].2	25.8	36.5	2.0	2.0	9.5	4.7

terminations were carried out on these people. In the greater than 5 age group the total white blood cell and neutrophile counts were depressed slightly below control values during the 1st and 2d weeks (Table 4.[illegible]). The lymphocyte counts were below control levels consistently, and the total white count equal to the control value obtained on day 29 was due to a neutrophilic leukocytosis.

Platelet counts on the 29th day were significantly lower than on the 19th day and, except for the older age males, were lower than control values. The 29th day coincides with the time of maximum depression for the more heavily exposed groups.

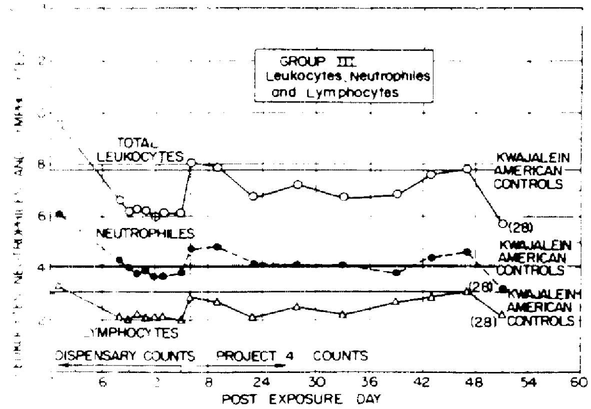

FIGURE 4.5—*Serial total leukocyte, neutrophile and lymphocyte count in exposed Americans (Group III).*

4.34 Hematological Findings, Group III (Americans)

The neutrophile count in general reflected the time course of the total leukocyte count (Fig. 4.5). Neutrophiles accounted almost entirely for the marked rise in total count on post exposure day one, and the values for absolute neutrophile count fluctuated near the control values thereafter in the course of the study. The lymphocyte counts fell to below control levels in the first few days, and remained at a level approximately 75 percent of the control value throughout most of the remainder of the observation period.

In Groups I and II the fluctuations in the total leukocyte count were accounted for almost

Table 4.5—Group III Americans Mean Blood Count by Day

P[illegible] Day	W.B.C. x 10³	Neutrophiles x 10³	Lymphocytes x 10³	Platelets x 10⁴	Monocytes x 10²	Eosinophiles (x 10²)
1	9.6	[illegible]	[illegible]		0.1	1.6
8	6.6	[illegible]	2.1		1.[illegible]	0.5
9	6.2	[illegible]	2.0		2.0	0.4
10	6.3	[illegible]	2.2		2.2	0.3
11	6.2	[illegible]	2.1		1.8	0.5
12	6.0	[illegible]	2.1		1.5	0.7
13	6.[illegible]	[illegible]	2.1		1.7	1.2
15	6.[illegible]	[illegible]	2.0		1.7	1.3
16	8.[illegible]	[illegible]	2.9	22.0	2.8	2.5
19	7.9	[illegible]	2.7	22.2	2.4	2.1
23	6.7	[illegible]	2.1	17.9	1.6	1.4
28	7.2	[illegible]	2.5	14.4	2.0	2.1
33	6.7	[illegible]	2.2	16.1	1.8	2.2
39	6.8	[illegible]	2.7	20.1	1.4	1.5
43	7.6	[illegible]	2.9	21.8	1.4	2.0
47	7.8	[illegible]	[illegible]	20.2	2.7	1.5
51	5.7	[illegible]	2.2	18.8	2.4	1.7
Kwaj-American Controls	7.8	[illegible]	[illegible]	23.8	2.6	2.7

Table 4.6.—Group I Rongelap Mean Blood Counts at Time of Maximum Depression

Case No.	W. B. C. (Average from Day 39 to 51)	Platelets (×10⁴) (Average from Day 26 to 30)	Neutrophiles (Average from Day 39 to 51)	Lymphocytes (Average from Day 39 to 51)
Age Less Than 5				
2	7220	110	2870	[illegible]050
3	7320	155	2770	[illegible]200
5	5620	115	2570	2650
17	6230	105	3350	2650
19	5650	115	3070	2400
21	4750	85	2670	[illegible]950
23	7150	195	4100	2800
32	5450	95	2600	2650
33	5600	85	1670	[illegible]570
42	5500	80	2520	2920
54	4750	145	2620	[illegible]950
65	6050	105	2520	2400
69	4770	115	1420	[illegible]170
Age 5 to 15				
15	3920	200	1470	2320
20	5020	120	3020	[illegible]950
24	5620	105	3450	[illegible]970
26	6020	145	3470	2320
35	5100	140	2700	2150
36	4720	130	2520	2470
39	4720	165	2900	[illegible]550
47	7220	120	4720	2250
61	5600	105	2500	2970
67	5120	115	2970	[illegible]920
72	4100	185	[illegible]800	[illegible]970
75	4200	110	2320	[illegible]720
76	5750	[illegible]50	2800	2870
Age greater than 15				
4	6420	130	2650	[illegible]550
7	5220	105	2520	2520
9	5470	125	2700	2420
10	4550	105	2770	[illegible]570
11	3120	85	[illegible]570	[illegible]350
12	4670	150	3270	[illegible]270
13	4050	55	2370	[illegible]520
14	4570	55	2770	[illegible]700
18	6100	45	4320	[illegible]650
22	4470	130	2500	[illegible]900
25	6250	110	4050	2120
27	6620	110	3600	2850
30	5700	85	3920	[illegible]600
34	5900	125	3650	[illegible]350
37	5970	150	3120	[illegible]570
40	5600	140	2450	2870
46	4620	135	2350	2100
49	6620	180	4050	2220

Table 4.6.—Group I Rongelap Mean Blood Counts at Time of Peak Depression—Continued

Case No.	W. B. C. (Average from Day 39 to 51)	Platelets (×10⁴) (Average from Day 26 to 30)	Neutrophiles (Average from Day 39 to 51)	Lymphocytes (Average from Day 39 to 51)
Age Greater Than 15				
52	5620	160	2970	2450
55	4400	135	1450	2720
56	6170	125	3520	2550
57	5020	55	2020	2700
58	4750	80	2600	1850
60	6970	160	4050	2470
62	8300	110	5170	2820
63	4270	65	2550	1520
64	5600	70	3220	2050
66	6100	145	2820	3120
68	4600	120	2400	2020
71	7950	105	4950	2700
73	3970	60	2630	1260
74	9900	155	7250	2550
78	5400	95	3350	1950
79	7800	70	5120	2500
80	5670	100	2920	2520
82	5250	130	2620	2470

entirely by changes in the total neutrophile count. Group III differed since the changes in total leukocyte count were reflected almost equally in the lymphocyte and neutrophile count. The significance of this difference in response in the two groups is not apparent.

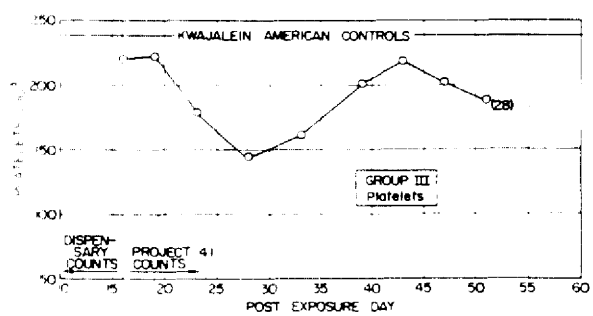

Figure 4.6.—Serial platelet counts in exposed Americans (Group III).

The platelet count (Fig. 4.6) were not markedly depressed when the initial counts were taken during the 3d week. At the end of the [illegible] week, however, the platelet count began to fall to reach a low of approximately 60 percent of control levels at the end of the 4th week. The value then returned to approximately the control level at the start of the 7th week, following which a second depression was noted. The platelet counts were at a level of 80 percent of the control value at the time of the last observation during the 8th post exposure week.

4.35 Monocytes and Eosinophiles All Groups

From Table 4.2 it is seen that the mean monocyte count for Group I rose abruptly from an early value below control levels to a well-defined peak on day 12, following which it fluctuated at values below the control level for the duration of the observation period. A similar time trend was noted in Groups II and III.

Table 4.7.—Group II Ailinginae Mean Blood Counts at Time of Maximum Depression

Case No.	W. B. C (Average from Day 39 to 51)	Platelets x 10³ Average from Day 26 to 30	Neutrophiles Average from Day 39 to 51	Lymphocytes Average from Day 39 to 51
		Age Less Than [illegible]		
6	9, 750	21[illegible]	[illegible], 470	5, 600
8	8, 350	18[illegible]	[illegible], 520	4, 350
44	4, 570	80	2, [illegible]50	2, [illegible]70
		[illegible]		
48	6, 220	[illegible]	2, [illegible]70	3, 150
53	6, 170	24[illegible]	[illegible], [illegible]00	2, 500
81	4, 700	24[illegible]	2, [illegible]20	2, 150
		Age Greater Than [illegible]		
1	6, 170	[illegible]	[illegible], [illegible]70	2, 370
16	4, 670	[illegible]	2, 200	2, 270
28	6, 270	[illegible]	[illegible], [illegible]20	2, 270
29	6, 750	[illegible]	4, [illegible]00	2, 220
31	5, 650	1[illegible]	2, [illegible]50	2, 450
41	5, 120	[illegible]	[illegible], [illegible]50	2, 270
43	6, 150	[illegible]	[illegible], [illegible]00	2, 000
45	5, 650	[illegible]80	4, [illegible]70	1, 470
50	7, 050	[illegible]	[illegible], [illegible]70	2, [illegible]00
51	7, 750	[illegible]7[illegible]	4, [illegible]20	2, [illegible]50
59	12, 400	[illegible]	8, [illegible]20	3, [illegible]70
70	5, 070	8[illegible]	[illegible]00	[illegible], [illegible]50

The eosinophile count in the older age individuals, Group I, rose from very low levels observed on day 3 to values approximating 35 percent of control during the second week, where it remained from the 3d to the 5th week (Fig. 4.7). The counts then decreased

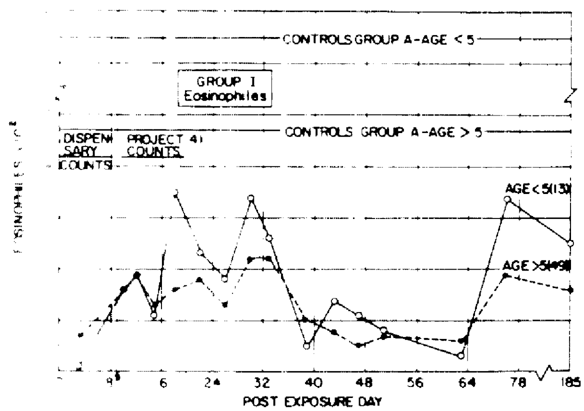

FIGURE 4.7.—*Serial eosinophile counts on those less than and greater than 5 years of age of Group I Rongelap.*

(p[illegible]) and remained at a value approximately [illegible] percent of control throughout the remainder of the study. The time trend of response was similar in the younger age individuals, however changes in the younger age group were relatively greater if considered in terms of the control values. Similar trends in eosinophile count were not evident in other exposure groups.

It is possible that the rise in eosinophiles represents that reported by Minot and Spurling [illegible] as occurring "—— two to three weeks after [illegible] wavelength irradiation".

4.36 Hematocrit. All Groups

The hematocrit values for all exposed groups are shown in Table 4.8. When hematocrits were first done on the 22d day, mean values for Groups I and II were below those of the control population. A significant trend in values after [illegible] could not be detected statistically.

Table 4.8.—Hematocrit: All Exposure Groups

Age*	[illegible] M	[illegible] M	All Ages (F)	[illegible] M	[illegible] M	All Ages (F)	15 (M)	>15 (M)	All Ages (F)	Adults (M)
	[illegible]			[illegible]			Group IV			Group III
22	37.5	43.[illegible]	39.0	37	[illegible]3	39.2				....
23									....	45.7
26	36.3	[illegible]	37.5	36.[illegible]	43.2	36.8			....	....
28									....	44.5
29							39.9	45.1	39.4	....
30	37.9	42.2	37.1	36.0	[illegible]	36.7			....	....
33	37.4	42.2	36.8	35.[illegible]	43.8	37.3			....	45.4
39	37.8	42.4	37.4	36.0	4[illegible].2	36.8			....	46.7
43	37.3	4[illegible].8	37.6		[illegible]	40.2			....	44.0
47	39.0	43.4	38.3						....	....
185	38.0	[illegible]	38.2	37	[illegible]	37.3			....	
Controls	[illegible]	[illegible]	39.9	39.[illegible]	[illegible]	39.9	39.6	46.0	39.9	44.9

*Age in years.
(M) = Male.
(F) = Female

4.37 Morphology of Peripheral Blood

Significant morphological cellular changes, with the exception of abnormal mononuclear cells* seen in several individuals during the period of most severe neutropenia, were not observed. Apparently similar cells have been observed previously by Minot and Spurling [illegible]. Complete evaluation of these changes would necessitate an exhaustive serial study of the hematology slides. Similar differences of opinion are reported in the literature.

4.38 Comparison of Hematological Findings in Children and Adults, Group I

It is seen from Tables 4.2 to 4.4 and Figures 4.1, 4.2 and 4.4 that differences in the degree of depression of cellular elements were present between children and adults. In Table 4.9, the mean values of the neutrophile, lymphocyte and platelet counts at time of peak depression for each element are given in terms of absolute count and percent of appropriate control value (mean platelet counts were calculated for the less than 5 and greater than 5 age groups for this comparison).

Table 4.9.—Comparison by Age of Mean Neutrophile, Lymphocyte and Platelet Counts in Group I (Rongelap) at the time of Peak Depression

Type of Cell	Absolute count × 10³: Age<5	Absolute count × 10³: Age>5	Percent of control: Age<5	Percent of control: Age>5
Neutrophile	2.7	3.1	56	64
Lymphocyte	2.9	2.2	40	54
Platelet (females only)	96	120	23	34

*There was considerable difference in opinion with respect to classification of these cells. They were classified as atypical monocytes, degenerating lymphocytes, atypical myelocytes, monocytoid [illegible]cytes and lymphocytes and [illegible] to myelocytes. At the time of this report there was no unanimity of opinion with respect to classification and significance of these cells.

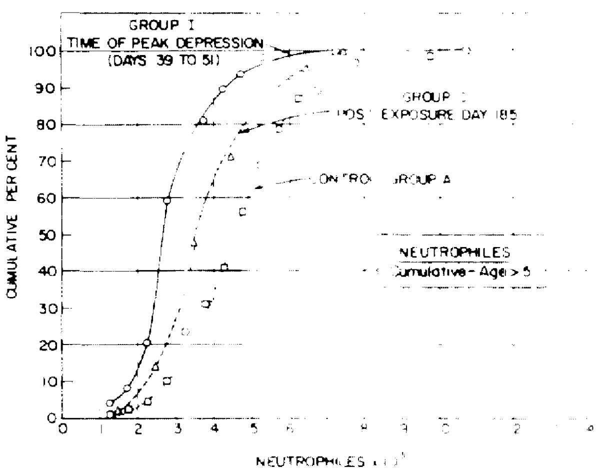

FIGURE 4.8.—*Cumulative neutrophile counts for Group I (Rongelap) at the time of maximum depression and at 6 months after exposure.*

It is seen that in terms of absolute counts, the children showed a greater depression of the lymphocyte count. Expressed as percent of control, all elements were affected more markedly in the younger age group. These results would indicate that children are more sensitive to radiation, or that other biological or physical factors resulted in a relatively greater effect. One physical consideration that may have accounted in part for the apparently greater dose received by the children involves a consideration of dose distribution in the body. Because of their relatively small diameter, the dose received at the center of the body of a child would be greater than for an adult exposed to the same dose as measured free in air.

4.4 Discussion

4.41 General

An estimation of the severity of radiation damage incurred can be attempted by comparing the present results with previous hematological data on total body exposure. The present data represent the only large series in which systematic serial counts on the same individuals have been possible, and thus they comprise the most complete data available on human beings exposed in the high sublethal range. It is also of importance, therefore, to examine the present results in conjunction with past experience in an effort to gain a better understanding of the hematological response of human beings exposed to penetrating radiation in the sublethal range.

In the following discussion it will be generally assumed that the hematological effects noted were due primarily to the penetrating gamma radiation received. The beta radiation injury of the skin may have contributed to fluctuations in the white count during the period of active lesions during the third, fourth and fifth week, but is considered not to have contributed significantly to depression of any of the formed elements (Chapter 3). The degree of internal contamination with fission products (Chapter 5) was probably too small to contribute significantly to the early hematological effects observed. Although it is not possible to say with certainty that these added factors did not materially affect the hematological pattern seen, it will become evident in the discussion that the changes observed are not inconsistent with those to be expected from exposure to penetrating radiation alone. Thus, the hematological changes noted are considered to be the result of a single exposure to penetrating gamma radiation, delivered at a rapidly decreasing dose rate over a period of approximately 2 days. Unless otherwise stated all discussion will be limited to the older-age subdivision of Group I.

The principal sources of previous data available for comparison, and the characteristics and limitations of each are summarized in Table 4.10. Perusal of the table will make apparent the difficulties involved in attempting strict comparisons; however, some statements can be made despite the obvious limitations. For easy reference, "normal" values for peripheral blood counts, from the present data and from the literature are presented in Table 4.11.

Table 4.10.—Characteristics of Available Data on the Hematological Effects of Penetrating Radiation

Characteristics	Japanese Bombings	Clinical Radiotherapy	Laboratory Accidents	Exposed Marshallese	Large Animals
Numbers in groups	large	small	small	large	large
Adequacy of Controls	fair	poor	poor	good	very good
Serial counts	no	yes	yes	yes	yes
Counting techniques*	fair	fair	good	good	good
Chance of bias due to sampling techniques	large	large	large	small	small
"Normal" individuals	yes	no	yes	yes	yes
Internal contamination	none	none	none	minimal	none
Additional trauma (burns, etc.)	yes	no	yes	yes	no
Species extrapolation necessary	no	no	no	no	yes
Type of radiation	gamma, some neutrons	hard X-rays, gamma	gamma, neutrons, X-rays, betas	gamma, beta to skin	hard X-rays, gamma
Dosage estimation	poor	good	poor	fair	good
Single exposure	yes	usually no	yes	yes	yes
Dose rate	Instantaneous	~5r/min	Instantaneous	Varying ~5r/hr.	~10r/min.
Body region	Total body	Usually partial body	Total and partial body	Total body; beta to skin	Total body
Dosage range	Sublethal and lethal	Sublethal	Sublethal and lethal	Sublethal	Sublethal and lethal
Geometry	Narrow beam	Narrow beam	Narrow beam	360° field	Narrow beam
Depth dose curve	Moderate fall off	Variable	Rapid fall off	Essentially flat	Variable; rapid fall off to flat

*Same technicians for all counts, rigidly standardized techniques throughout, etc.

4.42 Comparison With the Japanese Hiroshima and Nagasaki Data

The limitations stated in Table 4.10 apply to the Japanese low dose groups* E to H in particular, in which values given by Oughterson et al. (12) and Le Roy (1[illegible]) are pooled and include individuals located at the time of the bombing so that they may not have received significant exposure. Hence, while the pattern of change with respect to time is of value, absolute counts probably are high. The time course of hematological change in the people of Group I correspond most closely with these low exposure Japanese groups in which definite signs of severe radiation exposure were present in some individuals but in which essentially no mortality occurred (initial hematological studies on the Japanese terminated at 15 weeks). The early period up to approximately 6 weeks was characterized by considerable variation in total white counts in both the Group I and Japanese

*The Japanese casualties were divided into groups A to H on the basis of degree of exposure as determined roughly by distance from the hypocenter and approximate degree of shielding. In groups E to H essentially no mortality ascribable to radiation exposure occurred after the first 4 months.

Table 4.11.—Mean Peripheral Blood Count Values for Several Control Populations (x10[3])

	Source of Data Determination					
	Japanese (Kobe)		Americans*	Americans	Kwaj-American Controls	Control Group A
	[illegible]947–1948 ([illegible]8)	[illegible]948–[illegible] ([illegible])	[illegible]	([illegible]2[illegible])		
Total White count	[illegible] 9	[illegible]	[illegible] 4	7. [illegible]	7. 8	9. 7
Neutrophiles	[illegible] 5	[illegible]	[illegible] 4	4. [illegible]	4. 1	4. 8
Lymphocytes	[illegible] 9	2. [illegible]	2. [illegible]	2. [illegible]	3. 1	4. 1
Monocytes	[illegible] 6	[illegible]	[illegible]	0. 4	0. 3	0. 2
Eosinophiles	[illegible] 9	[illegible]	[illegible] 2	0. 2	0. 3	0. 5
Basophiles		[illegible]	[illegible]	0. 0	0. 0	0. 1
Platelets				**250	238	308

*Age 21 years

**The mean value for 50 normal young American [illegible] using the technique employed in the present study was 25[illegible],000.

casualties. This fluctuation may be associated with the presence of thermal or other injuries in the Japanese or the active skin lesions in the Marshallese, or may correspond to the "abortive rise" noted for animals following exposure (14, 15). From the 6th week until the termination of the acute studies on the Marshallese during the 10th week, the Japanese and Marshallese counts remained at similar levels.

The neutrophile count in both the Japanese and Marshallese in general paralleled the total white count. The lymphocyte count in both groups was depressed early and remained depressed at values of approximately 2000 until week 10. The high value of 2692 reported for the Japanese for weeks [illegible] to [illegible] must be suspected of being high for the reasons given earlier.

Various characteristics of the Japanese hematological trends should be pointed out: a) while high dose exposure groups with significant mortality showed an early depression with a definite low point at [illegible] weeks, the lower dose groups showed no definite minimum at 4 weeks but rather a continued depression until the 8th or 9th weeks. b) While mean leukocyte counts of the heavily exposed groups had recovered in part and were approaching normal ranges,

these means, 15 weeks after exposure were still below means for control populations listed in Table 4.11. In fact, data of Kikuchi and Wakisaka (22, 23) indicate that hematologic recovery was not complete 2 years after exposure. The studies of these authors, performed independently of the Joint Commission and Atomic Bomb Casualty Commission, suggest the early blood response and prolonged recovery of the Japanese was similar to that reported here for the Marshallese.

The present findings in the Marshallese are in accord with these characteristics, namely [illegible] total white cell and neutrophile counts showed no definite minimum at 4 weeks as evidenced in Japanese groups A to D, but rather fluctuated during the first weeks with minimum neutrophile counts occurring in the 6th week or later, [illegible] neutrophile counts were unstable over the first [illegible] weeks, and recovery to control levels was not complete by the 6th month, c) lymphocyte counts remained depressed throughout the period of observation.

Platelet data in the Japanese are not sufficient to allow more than rough qualitative comparisons. This is unfortunate since changes [illegible] platelet counts in the present studies appeared to show a more consistent pattern than did the leukocyte counts. Platelet counts of one individual, considered as a typical response in a non fatal Japanese (15) indicated an apparent low approximately on day 30. This time trend agrees with that seen in the Marshallese and Americans exposed to fallout radiation.

It is worthy of note that the period of peak incidence of purpura in the Japanese victims occurred between the 27th and 30th day, which corresponds to the time of maximum platelet depression in the exposed Marshallese.

4.43 Comparison With Data From Laboratory Accidents

Although in the Los Alamos (18) and Argonne accidents (19) the type of radiation and the conditions of exposure were markedly different from either the Japanese or the Group I situations, a large component of penetrating gamma and neutron radiation was received and thus attempts at comparison may be of value. Some findings in the hematological responses are pointed out. A uniform early rise in white and neutrophile counts over the first few days, similar to that seen early in the American group was observed uniformly.* In of three high-exposure four or lethal cases, the total white and leukocyte counts continued to show some degree of depression into the 7th week or beyond. In the lymphocyte counts in individuals exposed to as little as 50 rem showed an initial marked depression. In most cases the lymphocyte counts remained at low levels throughout the period of observation. The platelet counts were done by a different method, and absolute counts are therefore not comparable. However, of the three high dose survivors, times of maximum depression were not inconsistent with the value of 30 days obtained in the present studies. In higher dose non-survivors, however, the platelet counts had reached minimum values as early as the 8th day.

The Argonne Laboratory accident (19) involved four individuals who were estimated to have received 136, 127, 60 and 9 rep, respectively. The findings in the two highest exposed individuals in general were consistent with those in the present study. An initial neutrophilic leukocytosis was followed by fluctuations in total count, with low values continuing into the 7th week. Recovery was not complete by the 20th week. The lymphocyte depression was rapid and marked, recovery was not evident by the 20th week. Minimum values for the platelet counts were obtained between the 25th and 31st day.

Comparison with Animal Data. The time trends and severity of peripheral blood count change following total body radiation in animals has been examined critically recently (15), and the following general conclusions are presented.

a) An initial rise in total white count (reflected in the neutrophile count) may occur. Thereafter the magnitude of depression of the total white and neutrophile counts, and within limits their duration are a function of radiation dose. A secondary or abortive rise in the total white count (reflected in the neutrophile or lymphocyte count) may occur, followed by a second decrease. There is little species difference in the rate of depression of the total white or neutrophile count at comparable doses; however, the rate of recovery and time for complete recovery is quite different in various species. Small animals (mouse, rat, hamster) show relatively complete recovery to control levels, even at doses in the lethal range, by the end of the 4th week or earlier. Data on dogs are inadequate to indicate when recovery is complete; however, return to control levels at high dose levels has not occurred by the 5th week. Swine require 9 to 15 or more weeks for complete recovery.

b) The response of lymphocytes is essentially identical in all animal species. Depression can be detected within a few hours, and recovery from the minimum values (achieved in 36 to 48 hours) requires longer than does neutrophile recovery. Lymphocytes fall to very low levels

*No counts were taken in Groups I and II during the first 72 hours.

at doses well below the lethal range, and increasing dose results in no or minimal further decrease in count. Lymphocyte depression appears to have no causal relationship with acute radiation deaths.

c) Platelet counts have been studied most extensively in dogs (20). As with neutrophiles, the rapidity and magnitude of depression is a function of dose below the lethal range. Maximum depression occurs by the 9th or 10th day with doses in the high lethal range, by the 10th to 15th day at sublethal levels. Recovery begins during the 3d week, but is not complete by the 30th day when most studies have been terminated. Insufficient data are available to indicate the time required for complete recovery.

Considerable evidence including studies on the mouse using splenic homogenates, induced bacterial infections and spontaneous infections have indicated that critical neutrophile levels exist, below which survival is correlated with the absolute neutrophile count following whole-body irradiation (15). From data on dogs, it appears that survival is likely unless neutrophile counts remain below 1,200 cells for a period of time.

Platelet data on dogs indicate that animals with external purpura have platelet counts of 50,000 or below.

Sufficient data on large animals are not as yet available to quantify the extent of maximum depression of either the neutrophile or platelet counts as a function of dose in the sublethal range. The response of the platelet count in the present study was much less subject to fluctuation than were the neutrophile or lymphocyte counts. For the preceding reasons, systematic investigation of the platelet and leukocyte counts in large animals as a function of dose in the sublethal range are indicated.

It is not possible to say at present whether severity of exposure, or of radiation damage correlates better with absolute levels of peripheral blood count, or with degree of change from control or pre-exposure levels. Some evidence on this point can be gained by comparing the degree of depression of the neutrophile counts in Groups I and III, both of which had essentially the same calculated exposure but for which control hematological values were considerably different (the lymphocyte count is not suitable for comparison since degree of depression was essentially the same in these groups and the higher-dose Rongelap group). At the time of peak depression for each element, the neutrophile counts were essentially identical in terms of absolute counts, but considerably different in terms of the respective control values. Thus, some evidence is afforded that absolute counts, rather than counts relative to control values, may be the more reliable index of exposure in this dose range.

4.45 Approximation of Minimal Lethal Dose for Man

Some indication of severity of exposure can be gleaned from a comparison of minimum individual counts in Japanese groups in which fatalities occurred. In general, a significant number of deaths was encountered only in individuals whose neutrophile count fell below 2000. In Group I, 42 or approximately 50 percent had neutrophile counts below 2000 at some time during the observation period, and 10 percent had counts below 1000. By this criterion, then, the effective dose received by the Rongelap people approached the lethal range.

In the dog (Cronkite and Bond, unpublished data) approximately an additional 50 to 100 r are required to lower the neutrophile count by 1000 cells/mm^3 in the high sublethal dose range. If these data can be applied to man, an additional 50 to 100 r would have placed the dose well in the lethal range. On the other hand, however, it is clear from the present data and from clinical experience with therapeutic radiation that neutrophile counts between 1000 and 2000 in human beings are in general well tolerated. Human beings with these levels of neutrophiles show no clinical evidence of illness, are physically active, and generally do not need prophylactic antibiotic therapy.

The people of Group I are estimated to have received 175 r as calculated from dose rate readings measured in air from the planar fission product field. From the preceding paragraphs it is seen that an additional 50 to 100 r of laboratory radiation or an average of 75 r, probably would have resulted in some mortality. Correcting this average value for geometry,* it follows that the minimal lethal dose for man exposed in a fission product field is approximately 225 r measured in air.

It is possible also to estimate the added increment of dose that would have resulted in some mortality among the Group I people from consideration of the minimum platelet counts observed, the platelet levels in dogs exposed in the high sublethal range (20), and the estimated rate of decrease of platelet level with increasing dose in this dosage range. Such an analysis leads to the same conclusions as those derived from neutrophile data.

4.46 Peripheral Counts as an Index of Severity of Exposure

The relative value of the several hematological determinations in estimating the degree of exposure, as well as the approximate dose ranges over which maximum sensitivity for each determination exists, can be estimated by comparing the degree of hematological change among the several exposure groups. The relative degree of change in neutrophiles, lymphocytes and platelets can be seen in Tables 4.2 to 4.5 and Figures 4.9 to 4.12. Lymphocyte counts were depressed appreciably even in the low exposure Group IV. In the higher dose groups however, with widely different physical estimates of exposure, the lymphocyte counts showed essentially identical degrees of depression. The lymphocyte counts of Groups I and II were constantly depressed at a level of approximately 2000 cells. Thus, while sensitive at very low doses, this endpoint may be a poor index of the degree of exposure at higher doses.

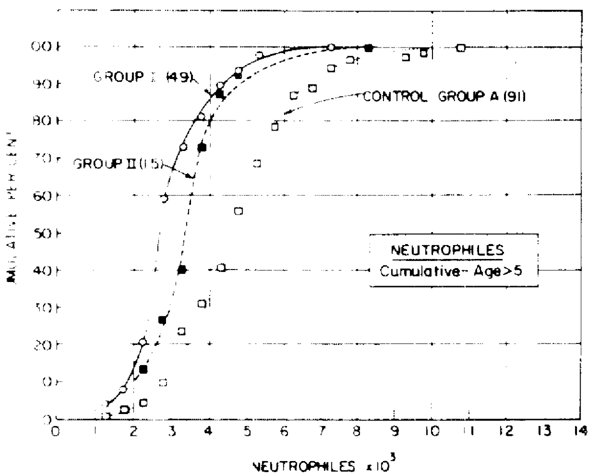

FIGURE 4.9.—*Cumulative neutrophile counts for Groups I (Rongelap) and II (Ailinginae) and control Group A at the time of maximum depression.*

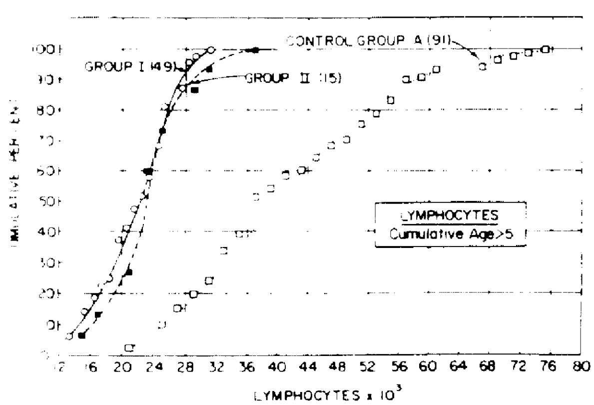

FIGURE 4.10.—*Cumulative lymphocyte counts for Groups I (Rongelap) and II (Ailinginae) and control Group A at the time of maximum depression.*

The total neutrophile count of Group I was consistently more depressed than was that of Group II and the difference was of the order of 500 to 1000 cells. However, day to day wide fluctuations in the neutrophile counts occurred. Accordingly, this endpoint appeared to be of limited usefulness as an index of relative expo-

* From geometric and depth dose considerations set forth in Section [illegible], 1 roentgen measured in air in a fission product field would be expected to be equivalent in its effect on man to approximately [illegible] roentgens of penetrating X- or gamma radiation under geometric conditions usually used for large animals in the laboratory. Thus, the minimal lethal dose for man exposed to penetrating radiation under the usual laboratory conditions would be [illegible] (approximately 325 r). The degree to which energy differences between the radiations may alter the [illegible] of effects cannot be evaluated at present.

sure severity except when counts on groups to be compared are performed at the same time.

The platelet count showed a more systematic trend than did the neutrophile count. Differences between the low-dose Group IV and controls at the time of maximum depression for all groups with the exception of adult males

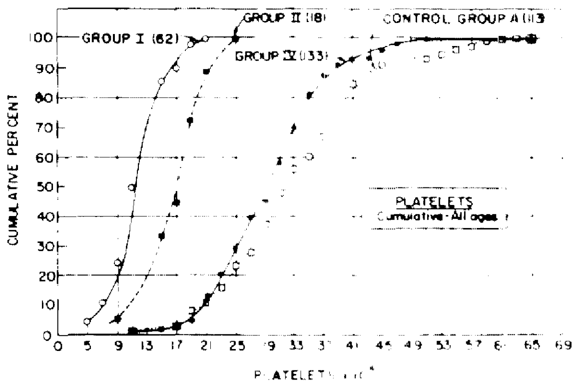

FIGURE 4.11.—*Cumulative platelet counts for Groups I (Rongelap), II (Ailingnae) and IV (Utirik) and control Group A at the time of maximum depression.*

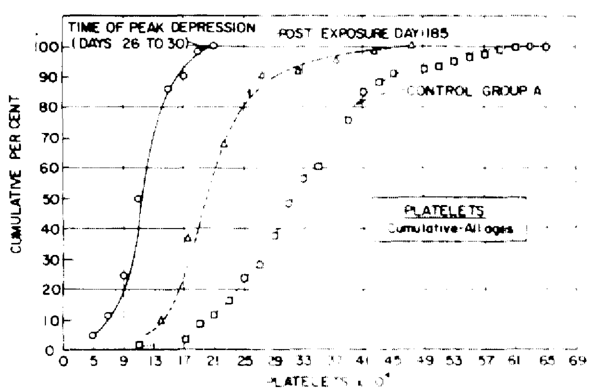

FIGURE 4.12.—*Cumulative platelet counts for Group I (Rongelap) at the time of maximum depression and 6 months after exposure.*

could be noted, and detectable differences existed between the means for the Marshallese higher exposure groups. Platelet counting is as easy as, and more reproducible than leukocyte counts (1, 21). Thus, the platelet count may prove to be a useful index of degree of exposure throughout a large part of the sublethal range.

The above considerations are in accord with previous findings on ... and at times

Conclusions

CONSIDERATION OF THE degree of depression of peripheral cellular elements indicates that exposure of Group I was moderately severe, probably within 50 to 100 r of the level where some fatalities would have resulted.

The degree of effect evidenced in Group I people is not inconsistent with the physical estimates of gamma dose received, when the geometry of exposure and other factors are considered. Beta lesions of the skin, and the low levels of internal radioactive contamination observed are considered not to have contributed significantly to the hematological changes seen.

The extensive serial hematological data obtained, considered in connection with previous data, allow reasonably accurate characterization of the hematological response of human beings exposed to single doses of penetrating radiation in the high sublethal range. The pattern of change of some elements may be different for higher dose levels; (see earlier discussion).

The time course of events is different from that observed in large animals and may be described as follows:

The total white count increases during the first 2 or more days and then decreases below normal levels. The total count then fluctuates over the next 5 or 6 weeks, with no definite minimum and with some values above normal (the presence of thermal or beta lesions, or other acute processes during this time may account in part for these fluctuations). The count becomes stabilized during the 7th or 8th weeks at low levels, and minimum counts probably occur at this time. A definite trend upward is apparent in the 9th or 10th weeks; however complete recovery may require several months or more.

The neutrophile count parallels the total white blood cell count. Complete return to normal ranges does not occur for several months or more. The initial rise in total white count is due to a neutrophilic leukocytosis.

c) The drop in lymphocytes is early and profound. Little or no evidence of recovery may be apparent several months after exposure, and return to normal levels may not occur for months or years.

d) The platelet count, unlike the fluctuating total leukocyte count, falls in a regular fashion and reaches a low on the 30th day. Some recovery is evident early; however, as with the other elements, recovery may not be complete several months after exposure.

4. As an index of severity of exposure, particularly in the sublethal range, the total white or neutrophile counts are of limited usefulness because of wide fluctuations and because several weeks may be required for maximum depression to become evident. The lymphocyte count is of more value in this regard, particularly in the low dose range, since depression occurs within hours of exposure. However, since a marked depression of lymphocyte count occurs with low doses and, since further increase in dose produces little more depression, this index is of little value at the higher doses.

5. Platelet counts showed a regular pattern of change in the present studies, with the same time of maximum depression in all exposure groups and with the degree of depression roughly proportional to the calculated doses. It appears, therefore, that the platelet count has considerable promise in the sublethal range as a convenient and relatively easy direct method of determining the degree of exposure.

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Chapter V

Internal Deposition of Radionuclides In Human Beings and Animals

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Outline

5.1 Introduction

FOLLOWING A NUCLEAR detonation in the spring of 1954, a large group of people were contaminated with fission products. In addition to a sublethal external gamma radiation exposure and beta irradiation of the skin, detectable amounts of radionuclides were deposited internally. It has been assumed that in all situations resulting from a contaminating event, the ratio of external to internal dose would be exceedingly high. However, a detailed study of the internal contamination in the exposed human population and in animals was made to determine the kind and degree of internal deposition. Three general problems were investigated: (1) The determination of the contribution of the internal contamination to the acute radiation syndrome observed; (2) The possibility of long term effects, and (3) The qualitative and quantitative nature of the internal contamination produced by exposure of individuals to mixed fission products. There was no previous situation in which human beings were exposed to an environment contaminated with mixed fission products. Concurrent studies were undertaken by the Japanese, however, on radioactive material to which a small group of Japanese fishermen near Rongelap at the time of the detonation were exposed. The report of the extensive investigations undertaken on the ashes by the Japanese have been published (4).

Evaluation of the internal contamination of the human beings was made by a study of the radioelements excreted. As very little information is presently available concerning the ratio of excreted radioelements to the amount deposited in the body, it was necessary to base the evaluation on data obtained from animals which had been contaminated in the same event. Detailed studies of animal tissues and animal excreta then provided data on which estimates of the human body burden were based.

5.2 General Nature of Internal Radiation Toxicity

THE NATURE OF the radiation hazard from internally deposited fission products can best be understood in terms of the biophysical behavior of the radionuclides.

Fission products entering the body through inhalation or ingestion concentrate in various tissues and act as sources of internal radiation. The ability of a radionuclide to enter the blood stream is determined by its solubility, chemical properties and physical state. The radioelements formed in fission are predominantly oxides which have a limited solubility in body fluids. On this basis, only a few of the radioelements can become available to the body. However, the amount which can produce injurious effects when deposited within the body is minute because of the close proximity of the isotope to the tissues it irradiates, and because the isotope continues to irradiate these tissues until it is removed by biological turnover or is rendered harmless by radioactive decay. The effects of radiation from internally deposited emitters are the same as those from external radiation. The distinguishing feature of internal radiation, however, is its long continuing nature.

Radioactive isotopes follow the same metabolic processes in the body as the naturally occurring inactive isotopes of the same element or of chemically similar elements. Thus strontium and barium, which are analogous chemically to calcium, are deposited in the calcifying tissue of the bone. Although nearly two hundred radioisotopes are produced in the fission process, only a few are potential chronic internal radiation hazards. These fission products, which are listed in Table 5.1, constitute a large percentage of the fission yield, and localize in the bone. The "bone seekers" have, in

Table [illegible] —Biologically Hazardous Internally Deposited Fission Products

[illegible] Element [illegible]	Type of Radiation	Fission [illegible] (Percent)	[illegible] Life		Fraction Reaching Critical Organ [3]	
			[illegible]	Biol. [illegible] Days	By Ingestion	By Inhalation
Sr^{89}	β	[illegible]	[illegible]	3.9×10^3	.25	0.22
[illegible]	β	[illegible]	[illegible]	~500	2.8×10^{-4}	0.14
Zr^{95}	[illegible]	[illegible]	[illegible]	~100	.35	
Ru^{103}	[illegible]	[illegible]	[illegible]	20	.04	
Ru[illegible]	β	[illegible]	[illegible]	20	.04	
I[illegible]	[illegible]	[illegible]	[illegible]	180	0.2	0.15
Ba[illegible]	[illegible]	[illegible]	[illegible]	~200	.07	.20
La[illegible]	[illegible]	[illegible]	[illegible]	35	1.2×10^{-3}	0.1
[illegible]	[illegible]	[illegible]	[illegible]	~100	.25	
Pr[illegible]	β	[illegible]	[illegible]	50	1.3×10^{-3}	.063
[illegible]	[illegible]	[illegible]	[illegible]	500	2×10^{-4}	0.10

From [1] Seaborg and Perlman, Rev. Mod. Physics, *20*, 585, 1948.
[2] Hamilton, J. G., Rev. Mod. Physics, 20, 718, 1948.
[3] Handbook 52, U. S. Dept. of Commerce, National Bureau of Standards.

general, long radiological and biological half lives and produce high energy beta particles. Thus, they cause greater damage to bone and to the radiosensitive bone marrow than to other tissues. The damage to the blood forming tissue results in a reduction of blood cells, and thus affects the entire body.

Information on the biological effects of internally deposited isotopes is derived from the limited studies of accidental radioisotopic poisoning in humans, or from animal experimentation. The best documented data on the effects of small amounts of internally deposited emitters in human beings are obtained from studies of radium poisoning. As a result of radium deposition, terminal anemia, bone necrosis and osteogenic sarcoma appeared after a number of years. The residual activity in the body associated with these effects is [illegible] to 2 micrograms of radium. Radium is a particularly hazardous element when deposited internally because of its long biological and radiological half life.

Very few data are available on the long term biological effects in human beings of the shorter lived isotopes such as Sr^{89}, I^{131}, P^{32} and [illegible]. The metabolism, excretion and biological effects of a number of fission products have been studied in animals by Hamilton (1), Abrams (2), Bloom (3). However, most of these studies do not cover the problem of the long term effects in animals produced by small amounts of internally deposited isotopes.

Few data are available concerning the effects of internal contamination with mixed fission products from nuclear detonations. Contamination is not produced by every detonation of a nuclear device. For example, no internal contamination was detected in individuals exposed to the air burst at Nagasaki and Hiroshima.

In field tests of the contaminating type of atomic detonation, animals that inhaled fission products during short periods of exposure were found to have insignificant amounts of internal contamination.

The long term effects (primarily malignant changes) resulting from radium deposition have been used to set the limits for maximum permissible body concentrations of a few bone seeking radioisotopes in the body (5). Maximum permissible body content of other radioisotopes are estimated on quantities resulting in a dose of [illegible] rem per week to the tissue of highest concentration.

5.3 Internal Contamination in Human Beings

THE INTERNAL CONTAMINATION study was begun 15 days post-detonation with the collection of pooled 24 hour urine samples from the Marshallese and American groups. Maximum activity in the urine occurs during the first few days after internal contamination. By 1 week an approximate equilibrium state is reached in which the contaminants remaining in the body are firmly fixed, chiefly in the skeletal tissue. The activity in the urine then derives from radioelements which have been replaced in the natural process of biological turnover. Thus, the study made is essentially that of an equilibrium condition.

The urine samples were sent to laboratories in the United States for analysis, since the high background encountered in the field masked the relatively low levels of activity in the aliquot samples used. A field laboratory is most desirable for a rapid survey, and was shown to be feasible, if adequate facilities are provided for the counting of the samples.

The first urine samples, mentioned above, were collected for the Los Alamos Scientific Laboratory (LASL). Similar samples collected 44 days post detonation were also sent there. On the 23rd, 24th and 47th days post detonation, 24-hour urine collections from each individual from Rongelap and Ailinginae were sent to the New York Operations Office, Atomic Energy Commission (NYOO AEC) for analysis. In addition, samples from representative individuals in these groups were collected 2½, 3 and 6 months post detonation and sent to NYOO–AEC.

The USNRDL collected samples from each member of the exposed groups at 45 and 46 days post detonation. Samples from representatives of these groups were also collected at 2½, 3 and 6 months by the USNRDL. In addition, samples from a representative group of 6 Americans and 29 Marshallese were collected for 6 consecutive days beginning [illegible] days post detonation.

5.31 Methods

As a complete radiochemical analysis of all the urine samples was not feasible, samples were analyzed for only Sr^{89}, Ba^{140}, the rare earth group and fissile material. These analyses are the most useful for evaluating the concentration and identity of all the potentially hazardous internally deposited radioactive isotopes. Measurement was also made of the gross beta activity of all the samples.

To facilitate the processing of the large number of urine samples sent from the field, a scanning method for beta measurement consisting of a basic oxalate precipitation with a lanthanum carrier was employed on an aliquot of the 24 hour urine samples. This method rapidly concentrates the radioactive elements into a small volume and eliminates the normal K^{40} background. A carbonate precipitation of the entire 24 hour sample increased the sensitivity of measurement sufficiently for analysis of samples collected later than 2½ months post detonation.

The beta activity was counted with a thin end window Geiger-Muller counter. The counter was calibrated with a U_3O_8 standard, and an appropriate correction for self-absorption was made using a Sr^{89} standard.

5.32 Findings and Interpretations

Beta Activity of the Urine. Internal deposition of radioactive elements was evidenced by the presence of significant amounts of beta activity in the urine. This activity decreased rapidly as a function of time, as it was derived mainly from short-lived radioisotopes. For example, at 3 months post detonation, the mean activity of the urine of adults from Rongelap was 28 percent of the value measured 45 days post detonation, and at 6 months, the activity in the urine was barely detectable in most of the individuals.

Comparison of the means of the urine samples for the adults from Rongelap and Ailinginae and from Americans from Rongerik showed that at 45 days post detonation the

Table 5.2—Summary of Human Urine Analysis, Gross Beta Activity

Time Post Detonation	[illegible] Months			[illegible]			[illegible] Months			6 Months		
	No.	Volume (24 hrs) ml	D/M 24 hrs	No.	Volume (24 hrs) ml	D/M 24 hrs	No.	Volume (24 hrs) ml	D/M 24 hrs	No.	Volume (24 hrs) ml	D/M 24 hrs
Rongelap												
Age in years												
A (<5)		[illegible]65	404							8	360	12
B (5–16)	[illegible]	439	758							12	510	5
C (>16)	[illegible]	[illegible]81	1208	[illegible]	[illegible]	[illegible]	10	379	339	33	625	0
Ailinginae												
Age in years												
A (<5)		[illegible]	21[illegible]									
B (5–16)		275	126							3	400	0
C (>16)	[illegible]	722	553							12	655	0
American	[illegible]	[illegible]58	309									

All values corrected for decay.

highest activity was in the Rongelap group (Table 5.2). The Ailinginae group had less than half that of the Rongelap group, and the Americans had about one-quarter the activity of the Rongelap group.

The mean gross beta activity of the urine of the three groups above was roughly proportional to the external dose each group received. However, a comparison of the mean beta activity of the urine of Ailinginae and American groups indicated that the latter had a somewhat lower amount of internal contamination, even though both groups received about the same external dose. This may be accounted for by the fact that the Ailinginae group drank contaminated water from open containers and ate contaminated food up to the time of evacuation, whereas the Americans ingested much less contaminated food and water since both were largely stored in closed containers. Indoctrination of the Americans concerning radiation hazards probably was also a factor in reducing the amount of contamination which they received.

The variation of gross activity among the individuals in any of the three groups was quite large (Tables 5.3 and 5.4). This is chiefly the result of variations in the quantity of water and both the kind and quantity of food ingested. The degree of exposure of the individual to air-borne activity is also a factor in determining the individual degree of contamination. While there were large variations among individuals, the day-to-day levels of activity for each individual were fairly consistent.

Further information on the source of individual variations was obtained by grouping the individuals from the Rongelap and Ailinginae groups according to age (Tables 5.3 and 5.4). While the activity excreted per unit volume of urine is about the same for both children and adults, the mean activity of the urine excreted in 24 hours by children under 15 years was significantly lower than that excreted by adults. The data available do not indicate definitely whether the lower total excretion indicates a smaller total body burden in the children resulting from lower inhalation and ingestion, or whether it represents a higher degree of fixation of the radio-elements by growing bone.

Table 5.3.—Gross Beta Activity in Urine of Rongelap People on 46th Day Post Detonation

Case No.	Total Volume 24 hrs (ml)	Beta Activity (d/m/24 hrs)	Case No.	Total Volume 24 hrs (ml)	Beta Activity (d/m/24 hrs)
Age < 5 yr			Age > 16 yrs		
2	120	712	4	455	634
3	150	894	7	810	1,700
5	155	313	9	355	201
23	40	223	10	980	549
33	260	[illegible]	[illegible]	450	1,583
54	80	385	13	340	1,677
69	455	30	14	780	2,460
			18	455	1,670
Mean	167	40?	22	47	77
			30	960	438
			34	750	570
			37	480	792
			40	550	1,450
			46	330	495
			49	425	0
			52	780	0
			55	320	1,080
			56	700	3,220
Age 6–15 yr			57	550	1,095
			58	750	2,170
20	265	1,900?	60	810	580
24	560	[illegible]	62	980	1,985
26	650	1,032	63	635	2,260
35	255	[illegible]	66	855	1,715
36	190	236	68	300	2,010
39	280	1,100	[illegible]	290	1,450
47	650	1,705	75	230	0
67	450	974?	78	965	52
72	[illegible]	507	[illegible]	465	2,038
75	540?	[illegible]	80	540	1,353
76	980	1,180	82	670	2,140
Mean	439	758	Mean	581	1,208

Values corrected for decay.

No correlation was found between body weight of the people from Rongelap and the total activity per 24 hours excreted in their urine.

Gross beta activity measurements were also made on the samples sent to NYOO, AEC.* Their results essentially corroborate the findings by the USNRDL, particularly the ratio of the activities among the three groups studied. The absolute values of the activity determined by NYOO-AEC, however, were lower than USNRDL values by a constant factor.

Radiochemical Analysis of the Urine: Estimate of Body Burden. Radiochemical analyses of the Rongelap urine samples indicated that the alkaline earth and rare earth groups together contributed 75 percent of the

*Personal communication [illegible] Harris [illegible] NYOO, AEC.

Table 5.4.—Gross Beta Activity in Urine of People From Ailinginae and the Americans

AILINGINAE [illegible] POST DETONATION		
Case No.	Total Volume 24 hrs (ml)	Beta Activity d/m/24 hrs
Age 0–5 yr		
6		
8		
44	[illegible]50	217
Mean	[illegible]50	217
Age 6–15 yr		
48	180	[illegible]
53		
81	370	88
Mean	275	[illegible]20
Age 16+ yr		
[illegible]	900	765
16	880	827
28	680	202
29	780	
31	260	846
41	920	62
43	610	774
45	850	680
51	410	400
70	440	
Mean	722	553

AMERICANS DAY 44 POST DETONATION		
Case No.	Total Volume 24 hrs (ml)	Beta Activity d/m/24 hrs
401	1,970	0
2	650	0
3	1,224	820
4	440	78
5	735	0
6	900	248
7	1,340	0
8	1,410	1,260
9	....	....
10	....	....
1	1,580	385
2	1,460	0
3	1,810	965
4	720	438
5	1,380	830
6	1,030	0
7	945	....
8	1,520	0
9	1,300	466
20	1,070	0
21	550	353
22		....
23	1,180	0
24	1,160	750
25	1,380	187
26	510	323
27	565	....
28	1,220	0
Mean	1,158	309

Values corrected for decay.

beta activity at 65 days post detonation (Table 5.5). The predominant radionuclide is Sr89, which contributes [illegible] percent of the total beta activity at this time.

Assays of fissile material made on pooled samples of urine were all negative within experimental limits.

The early urine samples analyzed by the LASL (collected [illegible] days post detonation) contained fair amounts of [illegible] to the alkaline [illegible].

On the basis of the radiochemical analyses of the urine, the body burden (the radioisotopic deposition in the tissues) was estimated. The ratio between the activity of the urine and the amount of isotope fixed in the body is required for this calculation. However, few ratios are available for the deposition of the various radioelements in humans, so that it was necessary to utilize ratios obtained from animal studies. Of the animals collected on Rongelap, the pig was selected as the closest to the human in size and metabolism. A detailed study was therefore made of the excretion of these animals and

Table 5.5.—Radiochemical Analysis of Urine From the Rongelap People (45 days post detonation)

Sample	Beta Activity (c/m/24 hour)			
	Gross beta activity	Sr^{89}	Ba^{140}	Rare earth activity
1	[illegible]	490	120	197
2	[illegible]	510	130	244
3	[illegible]	480	120	324
4	[illegible]	620	150	284
5	[illegible]	328	110	474
6	[illegible]	[illegible]	170	353
Average	[illegible]	[illegible]	134	312
Percent of total Beta activity	[illegible]	[illegible]	10.7	25.5

on the radioactive content of various tissues. Details of the animal study are presented in a subsequent section.

The estimate of the mean body burden of the Rongelap group at 82 days post detonation is presented in Table 5.6. The body burden at one day was calculated in the following manner. A formula was obtained from urinary excretion data reported by Cowan, [illegible] and Love ([illegible]) in a case of accidental inhalation of Sr^{89}. The excretion curve was best represented by four exponential terms. Very similar results were obtained by approximating the biological decay of strontium with a power function, based on human excretion of the metabolically similar element, radium ([illegible], 7, 8).

Estimates were made of other radioelements present in significant amounts at one day, as shown in Table 5.6. These estimates were made on the basis of the level of Sr^{89} at one day, together with the data on the activity of the various fission products at this same time (9) and [illegible] isotope absorption and retention data ([illegible]).

The LASL has also estimated the body burden at one day, on the basis of radiochemical analysis of pooled urine samples from a representative number of the Rongelap and American groups (10). These calculations were based on the analysis of I^{131} in the early samples of urine ([illegible] days post detonation) as well as the [illegible] physical and biological data [illegible] fission products (1, 5, 9). Their findings are presented in Table 5.6.

Table 5.6.—Mean Body Burden of the Rongelap Group

Isotope	[illegible]	Activity at 1 day μc, [illegible]	Activity at 1 day μc, LASL
Sr^{89}		[illegible]	2.2
Ba^{140}	[illegible]	[illegible]	0.34
Rare earth group	[illegible]	[illegible]	—
I^{131} [illegible]		[illegible]	[illegible]
Ru^{103}			0.013
Ca^{45}		[illegible]	0.019
Fissile material		[illegible]	0.016 (μgm)

On the basis of an assumed uptake of 20 per cent per 24 hours, the integrated dose to the thyroid from I^{131} and other shorter lived iodine isotopes was calculated by the USNRDL to be about 100 rep. The LASL has estimated that this dose was about 150 rep for Rongelap group and 50 rep for the Americans.

The differing approaches used by the USNRDL and the LASL for estimating the body burden gave results which, except for Ba^{140}, are very close.

The mean body burdens of the individual nuclides presented in Table 5.5 were calculated for the Rongelap group. Values for the Ailinginae group were approximately half those of the Rongelap group, and values for Americans, about one fourth those of the Rongelap group.

The total amount of radioactive material present in the G. I. tract at one day post detonation in the members of Group I was estimated as approximately 3 mc. This activity was contributed chiefly by isotopes of short radiological and biological half life and limited solubility. Thus the levels of activity in the tissues of the body were relatively low. The concentration of radioisotopes at 6 months post detonation was barely detectable in the urine of most exposed individuals.

Iodine, which is quite soluble, is probably the most hazardous internal radioemitter in the early period following exposure (30). The dose to the thyroid was appreciable, but low compared to the partially or totally ablating doses of I^{131} used in therapy of hyperthyroidism or carcinoma. At one day post detonation Sr^{89} was calculated to be near the maximum permissible level (5) for this nuclide. At later times following exposure, this longer-lived fission product presents the greatest potential internal hazard.

The present study confirms the observations made in animal experiments that most of the radioactive elements formed in fission, as well as the fissile material itself, are not readily absorbed from the lungs and the G. I. tract. Only I, Sr, Ba and a few of the rare earth elements were absorbed to any significant degree.

An attempt to measure bone-fixed radioactive emitters by means of sensitive film badges taped below the knee, over the epiphysis of the tibia on a number of persons, yielded no positive results.

No correlation could be obtained between the degree of internal contamination and the clinical and hematological findings. In view of the short half-life of the most abundant fission products deposited internally in this situation, the possibility that chronic irradiation effects will occur is quite small. Thus, an evaluation of the data on the internal contamination, including that of Sr^{89}, leads to the conclusion that the internal hazard to the contaminated inhabitants of the Marshall Islands is minimal both from the acute and the long range point of view.

5.33 Source of Internal Contamination

The fallout material consisted largely of calcium oxide and calcium carbonate. The fission products were adsorbed mainly on fairly large particles. The material was 10 percent soluble in water, and completely soluble in acid.

Internal deposition of fission products resulted from inhalation and ingestion of the fall-out material. Ingestion appears to be the more important of the two routes of entry into the body. The activity in the air settles out fairly rapidly, but contaminated food, water and utensils retain their activity for long periods of time.

The amount of fission products reaching the bloodstream through the respiratory tract is a function of particle size and solubility of the airborne contaminants. The particles with which the activity was associated were considerably larger than the optimum size for deposition in the alveolar tissue of the lung. Thus, the probability of the retention of inhaled airborne contamination was not appreciable during the exposure period.

The hypothesis that ingestion was the chief source of internal contamination is supported by the finding that the gastro-intestinal tract, its contents, and the liver of autopsied chickens and pigs sacrificed at early intervals following detonation were more active than the alveolar tissue.

The importance of ingestion as a continuing source of contamination is evidenced by the level of internal contamination of the pigs from Rongelap. These animals had about ten times the body burden of the human population of the same locality. As the air-borne activity had already dropped to a low value at the time of evacuation of the humans, the contamination of the pigs during their prolonged stay on the island necessarily derived from ingestion of radioactive food and water.

Radioanalysis of water and soil samples from Rongelap indicated high levels of contamination from the fallout at early times following detonation.

It appears that during the first month a limited amount of fission products was available to plants growing on the contaminated soil. Significant amounts of beta activity as well as small amounts of alpha activity were present on the external surface of plants at 42 days post detonation. Only very small amounts of beta activity and no alpha activity were detected in the edible portions of fruits such as pandanus, papayas and coconuts. However, high levels of activity were found in the coconut tree sap, and the isotopic concentration was very similar to that of water.

High levels of activity were found in fish taken from Rongelap lagoon. It appears that the ingestion of contaminated water and fish were the principal sources of internal contamination of human beings. Of the individual radionuclides, Sr^{89}, because of its high solubility and relatively long radioactive half-life was probably the isotope of greatest potential hazard in the environment.

Internal Radioactive Decontamination Therapy. Since there is no method of counteracting the effects of radiation from internally deposited emitters, treatment consists of removing the nuclides from the body as rapidly as possible. The ability of ethylene-diamine tetra-acetic acid (EDTA) to mobilize certain of the fission products from the skeleton and increase the rate of their excretion has previously been demonstrated (11–13). It is most effective with the rare earth group, but has no effect on strontium (13). These studies have shown that most of the biologically hazardous material remaining in the body is firmly fixed in bone within a short time, so that effective systemic decontamination by chemical agents can occur only in a short period following exposure. Nevertheless, an attempt to effect internal decontamination was made 7 weeks post detonation, since it would mobilize and make detection of isotopes easier, even though it was realized that the procedure would have limited value at this time.

A representative group of seven individuals from Rongelap were selected for this study. During a control period of 5 days, 24-hour urine samples were collected daily for radioanalysis in order to establish a basal excretion rate. During the next 3 days, calcium EDTA was administered orally, 1 gm per 25 lbs of body weight daily instead of the preferable intravenous drip because parenteral therapy was not practical under the circumstances.

Twenty-four hour urine samples were collected daily during the treatment period and for 5 days following treatment to determine the effectiveness of EDTA in accelerating the excretion rate of the radioelements.

No side effects from the use of EDTA were observed. Blood counts and blood pressure remained unchanged throughout the treatment.

The mean activity of the urine during the EDTA treatment period was 2.5 times the pretreatment activity. The probability that the differences observed are due to chance is less than 0.01. Thus the oral administration of EDTA for a period of 3 days beginning 52 days post detonation increased the excretion rate of internally deposited fission products, but the over-all effect on decreasing the body burden was slight, as the excretion rates were very low at this time.

Summary. The first instance of internal deposition of mixed fission products in humans occurred as a result of fallout following a thermonuclear explosion. This internal contamination resulted from both inhalation and ingestion of fallout material.

High levels of activity were found in water and on the external surfaces of plants. The contamination of the internal portions of fruits and vegetables was small. Of the individual radionuclides, Sr^{89}, because of its high solubility and relatively long radioactive half-life was probably the isotope of greatest potential hazard in the environment.

Few of the fission products present in the environment were readily absorbed from the lungs and the G. I. tract. Radiochemical analysis of the urine samples from the Rongelap people indicates that Sr, Ba and the rare earth group together constituted 75 percent of the total beta activity of the urine at 45 days post detonation. Sr^{89} was the predominant radionuclide at this time, contributing 42 percent of the total beta activity. Assays for fissile material in the pooled urine samples were negative.

The human body burden of individual radionuclides was estimated from radiochemical analysis of the human urine and of the tissues and urine of animals from Rongelap. The mean body burdens of the radionuclides in the Ailinginae group were approximately one-half those of Rongelap, and the mean body burdens of the Americans about one-fourth of the Rongelap group. While the activity excreted per unit volume of urine was the same for adults and children from Rongelap, the total activity excreted in the urine in 24 hours by children under 15 years of age was significantly lower than that excreted by the adults.

The total amount of radioactive material in the G. I. tract at one day post detonation was estimated to be 1 mc in people from Rongelap. This activity was contributed chiefly by isotopes of short radiological and biological half-life and limited solubility, and thus the levels of activity in the tissues of the body were relatively low. The concentration of radioisotopes [illegible] months post detonation was barely detectable in the urine of most of the exposed individuals.

The estimated dose to the thyroid from I^{131} and other short-lived iodine isotopes [illegible] to 150 rep for Rongelap. Iodine is probably the most hazardous internal radioemitter at early times after exposure. The dose to the thyroid, although greater than tolerance, was low compared to the partially or totally ablating doses of I^{131} used in the treatment of hyperthyroidism or carcinoma.

At one day post detonation, the concentration of Sr^{89} was calculated to be near the maximum permissible level for this nuclide. At later times following exposure, this longer-lived fission product presents the greatest potential internal hazard.

Oral administration of calcium EDTA beginning 7 weeks post detonation to a representative group of individuals from Rongelap increased the rate of excretion of activity 2.5 times. However, the decrease of the body burden was slight, as the excretion rate was very low at this time.

Analysis of the internal contamination indicates that the dose to the tissue of the body was near, but, with exception of the dose to the thyroid, did not exceed the maximum permissible dose levels. The activity fixed in the body decreased rapidly as a function of time. The contribution of the effects of internal contamination to the total radiation response observed appears to be small on the basis of the estimated body burden of the radioelements. In view of the short half-life of the most abundant fission products in the situation, the possibility that chronic irradiation effects will occur is small.

5.4 Internal Contamination of Animals

THE INTERNAL CONTAMINATION of a number of animals collected on Rongelap was studied. The activity in their urine was studied, and radiochemical analyses were made of various tissues. These data provided the basis for estimating the body burden of the radioisotopes in human beings. In addition, hematological and pathological studies were made, and autoradiographs of selected tissues were prepared. A number of the animals are also being studied for the appearance of possible [illegible] effect [illegible] radiation.

A special study was carried out to determine the effect of the radiation on the fertility of chickens and the [illegible] of their eggs.

The animals collected from Rongelap and Utirik included 41 chickens, 9 baby chicks, [illegible] swine, 4 ducks and 1 cat. These were shipped alive to the USNRDL. Three fish and one large clam were taken from the Rongelap lagoon. Collection dates and mortality data for these animals are presented in Table 5.7. In addition, a boar, a cat and two chickens were autopsied in the field and representative tissues were collected.

5.41 Methods

Tissue samples were taken from all animals which died spontaneously or were sacrificed. [illegible] specimens were obtained from the lung, liver, [illegible] tract and the skeleton. The samples were ashed at 550° C in a muffle oven, and the ash [illegible] up to volume with 2 N HCl. An aliquot [illegible] for beta measurement. The beta activity was determined by means of a thin [illegible] window Geiger-Muller counter. Sr^{89} was [illegible] as the basis for the mass absorption correction for the samples, as it was the major [illegible] element deposited. The correction [illegible] an approximation, as mass absorption is a function of the average energy of the [illegible]. Beta activity was measured in total [illegible] and this value was converted to μc. "Sr^{89} [illegible]".

The gamma activity of the tissue samples was measured in a well-type sodium iodide scintillation counter which has an efficiency of about [illegible] percent for a Co^{60} standard. The gamma

Table 5.7—Mortality and External Radiation Dose of Animals From the Living Areas of Rongelap and Utirik

External Dose (**Day of Collection) Animals	Series [illegible] 280 r Day [illegible]			Series B [illegible] r Day 2[illegible]			Series [illegible] [illegible] r Day [illegible]			Series D [illegible] r Day 51–5[illegible]			Total		
	Total Rec'd	Dead	Sac'd	Total Rec'd	Dead	Sac'd	Total Rec'd	Dead	Sac'd	Total Rec'd	Dead	Sac'd	Total Rec'd	Dead	Sac'd
Hens	[illegible]	[illegible] Day 23	[illegible]					[illegible]	2 Day [illegible]4	11	5 Day 67 #36, 74 #39, 92 #35, 99 #7, 130 #24		37	8	3
Roosters								[illegible]		[illegible]			4	1	[illegible]
Chicks													9	[illegible]	
Ducks									[illegible] Day [illegible]				4		1
Pigs			[illegible]			Day 38 [illegible], [illegible] #6, 82 #24, 82 #25				[illegible]*			11		5
Cat	1												1		
													66	18	9

*Animals from Utirik [illegible]

**Day Post Detonation

activity was obtained [illegible] and was converted to μc [illegible] equivalent.

Samples were analyzed radiochemically for Sr^{89}, Ba^{140}, the rare earth group, [illegible] and tissue material.

For excretion studies the animals were caged individually, and their excreta collected at 24-hour intervals. The feces and urine of chicks [illegible] were collected and ashed combined, but were collected and ashed separately for the pigs. Beginning 5 weeks post detonation, the excreta of a representative group of chickens was collected at weekly intervals for a period of 2½ months. Collection of pig excreta was begun at 6 weeks post detonation, and the collection was made at weekly intervals for a 6-week pe-

Table 5.8.—Radiochemical Analysis of Tissues and Urine of Pigs From Rongelap on 82nd Day Post Detonation

	Beta Activity [illegible] Total Sample			
Sample	Gross Activity [illegible]	[illegible]	Ba^{140} × 10^{-3}	Total Rare Earth × 10^{-3}
Pig #24 (25.8 kg)				
Skeleton (total)	[illegible]800	5660	660	1010
Liver		[illegible]40	0.33	6.4
Colon & Contents	[illegible]	[illegible]0	2.4	3.2
Lung (Alveolar)		[illegible]22	0.20	0.8
Stomach	[illegible]	[illegible]22	1.1	1.3
Intestine (Small)	[illegible]	[illegible]62	0.50	0.51
Kidney	[illegible]	[illegible]2	0.42	0.74
Remaining Tissues	[illegible]			
Total	[illegible]630	[illegible]667	[illegible]665	1020
Urine Sample (24 hr)	[illegible]	[illegible]7	[illegible]2	1.6
Pig #25 (22.7 kg)				
Skeleton (total)	8600	[illegible]100	530	690
Liver	[illegible]	[illegible]	0.20	5.5
Colon & Contents	[illegible]	[illegible]0	3.2	4.9
Lung (Alveolar)		[illegible]26	0.23	0.33
Stomach	[illegible]	[illegible]2[illegible]	0.13	0.30
Intestine (Small)	[illegible]	[illegible]8[illegible]	0.88	0.88
Kidney		[illegible]4	0.19	0.52
Remaining Tissues	22[illegible]			
Total	88[illegible]	[illegible]107	534	702
Urine Sample (24 hrs)	[illegible]2	[illegible]4	0.40	0.54

[illegible] Gross Beta Activity	Skeleton	Total Body	Urine (24 Hrs)
Sr^{89}	62.[illegible]	[illegible]8.0	69.0
Ba^{140}	6.[illegible]	6.5	7.9
Rare Earth	[illegible]	[illegible]0	10.5
	[illegible]8	[illegible]3.5	87.4

All values corrected for decay.

riod. Radioanalysis of the excreta was performed in the same manner as that of the tissue samples, described above.

5.42 Findings and Interpretation

Gross Observations. The animals had been free on the islands. Although malnourished, they showed no other evidence of disease. Autopsy of two chickens which died during shipment revealed no pathological findings that could be associated with radiation.

On the basis of an assumed [illegible]-hour effective fallout time, the animals from Rongelap received an integrated external dose of 28[illegible] to 360 r, depending on the date of their collection (see Table 5.7). The pigs from Utirik received a calculated dose of [illegible] at the time of their evacuation. The animals had showed extensive external contamination, ranging from 0.[illegible] to 5 mr per hour at 30 days post detonation. This activity was reduced about [illegible] percent by washing with water alone.

Radioactivity of Tissues and Excreta. The gross beta activity of the pigs at 82 days post detonation was about 4 μc. The distribution of activity in the individual tissues is shown in Table 5.[illegible]. Over 90 percent of the beta activity was localized in the skeleton. The highest activity in a soft tissue was found in the liver, which had, however, less than 0.5 percent of the total body burden. The colon contents had the second highest activity for the soft tissues, about [illegible] percent of the total. The alveolar tissue of the lung had an activity less than 0.02 percent of the total activity in the body.

Gross beta and gamma activity of the chickens [illegible] days post detonation was approximately [illegible] μc. The gross activity per body weight of the chicken is approximately the same as that of the pig. The distribution of activity in the tissues of the chicken (Table 5.9) was very similar to that in the pig. Most respiratory tract activity was localized in the turbinates, as a result of entrapment of the large particles, which could not penetrate to the alveolar tissue.

The beta activity in the skeleton of chickens [illegible] days dropped to 4 percent of the value at [illegible] days post detonation, while in the same period the gamma activity dropped to 0.2 percent

Table 5.9—Beta and Gamma Activity of Chickens From Rongelap (μc x 10[illegible])

	Hen #[illegible]		Hen #2		Hen #[illegible]		Hen #39		Hen #35		Hen #7		Hen #24	
Day of Death**	Day 2[illegible]		Day 2[illegible]		Day [illegible]		Day [illegible]		Day 121		Day 138		Day 159	
Day analyzed**	Day 2[illegible]		Day 2[illegible]		Day [illegible]		Day [illegible]		Day 122		Day 140		Day 159	
Tissue	Beta	Gamma	Beta	Gamma	Beta	Gamma	Beta	Gamma	Beta	Gamma	Beta	Gamma	Beta	Gamma
Tibia	600	38[illegible]	[illegible]180	4[illegible]	[illegible]	[illegible]		[illegible]53	215	[illegible]9	41.3	31.3	33.2	8.1
Skeleton	[illegible]	15800	[illegible]900	[illegible]6900	[illegible]	[illegible]		[illegible]70*	[illegible]120	850*	600	454*	437	117.5*
Liver	[illegible]		[illegible]2	[illegible]				[illegible]	[illegible]2	33	17.[illegible]	13.5	10.7	1.8
Gizzard								[illegible]	[illegible]	[illegible]	10.3	7.9	3.6	0.6
Gizzard (contents)					[illegible]3						7.[illegible]	1.2	0	0.3
Crop					[illegible]3			[illegible]	[illegible]		12.2	[illegible].3	4.5	0
Intestine (L) and contents					[illegible]3			[illegible]	[illegible]		14.0	10.7	8.9	0.29
Intestine (S) and contents					[illegible]			[illegible]			[illegible].4	6.4		
Pancreas					[illegible]							[illegible]	0.75	0
Spleen													0.26	[illegible]
Kidney	[illegible]8	[illegible]			[illegible]			[illegible]	4.2	20.0	14.9	12.4	0.79	0.23
Lungs (Alveoli)		[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	4.5	7.6	4.3	16.8	0.83
Trachea					24	[illegible]		[illegible]	[illegible]	3.7	[illegible].9	0.2	[illegible]	[illegible]
Turbinates					[illegible]7	[illegible]		[illegible]	[illegible]	7.6			[illegible]	

*Calculated using ratio of [illegible] skeleton [illegible] tibia.
**Day post detonation

of the 24 day value. These data indicate that most of the activity is associated with short-lived isotopes. The initial drop in activity is very rapid, and after 45 days the decay curve is essentially that of Sr[illegible], the most abundant of the longer-lived elements deposited.

The residual total beta activity found in the two larger fish at 4 months post detonation averaged 2.5 μc (Table 5.10). There was, at the same time, about twice as much gamma activity. The fish were collected 56 days post detonation, and the drop in activity between that time

Table 5.10.—Beta and Gamma Activity of Fish From Rongelap Three Months Post Detonation

Fish #1 (402 gm)

	Gross Activity, μc: Beta	Gross Activity, μc: Gamma	Ba, Sr and Rare Earth Total Activity Percent	Radiochemical Analysis (Percent in Ba, Sr and Re Fraction): Sr^{89}	Ba^{140}	Rare Earth
Head	0.568	[illegible]	9.9	38.3	[illegible]6	52.1
Scales + Fins + Tail	0.500	[illegible]58	9.5	17.4	[illegible]9	72.7
Viscera	0.900	[illegible]36	48.0	1.4	0.6	98.0
Gills	0.160	[illegible]43	7.8	13.9	6.7	79.4
Remainder of Body	0.596	[illegible]	8.3	45.2	11.2	43.6
Total	2.72[illegible]	[illegible]				

	Fish #2 ([illegible] gm) Gross Activity, μc: Beta	Fish #2 Gross Activity, μc: Gamma	Fish #3 (168 gm) Gross Activity, μc: Beta	Fish #3 Gross Activity, μc: Gamma
Head	0.10[illegible]	0.23	0.045	0.017
Scales + Fins + Tail	0.067	0.23	0.058	0.084
Viscera	[illegible]620	2.14	0.115	0.205
Gills	0.043	0.09	0.023	0.011
Skeleton	[illegible]	[illegible]35	0.030	0.070
Muscle	[illegible]	[illegible]53	0.038	0.074
Total	[illegible]	[illegible]58	0.301	0.461

Clam #[illegible]

Total Beta Activity [illegible]

Radiochemical Analysis

Radioelement	Percent of Total Activity
Zr^{95}	21.4
$Ru^{103, 106}$	32.4
Other	1.4
Sr^{89}	[illegible]7
Ba^{140}	[illegible]7
Rare Earths	33.4

Samples collected two months post detonation.

and the analysis at 4 months represents only radiological decay. Thus, the results are not directly comparable to those obtained from animals which were returned alive, and in which biological turnover as well as radiological decay were operating.

The largest fraction of the gross beta activity in the fish was contributed by the concentration of radioactive material in the viscera. In two of the fish in which bones and muscle were separated and analysed, equal amounts of activity were found in each fraction. However, the storage of these fish in formaldehyde for 3 months may have permitted the diffusion of the radioelements from bone to muscle to take place. Further studies on fresh fish will clarify this point.

The contamination of the fish in the lagoon was considerably greater than that of the land animals studied. As fish form a large staple item in the diet of the Marshallese, the high level of contamination is important.

At the end of a 2½-month experimental period, the excretion by the chickens of both beta and gamma activity per 24 hours was 5 percent of the value measured at the start at 37 days post detonation (Fig. 5.1).

Analysis of pig excreta indicated a similar decrease of activity with time. In a 6-week period, the gamma activity excreted per 24 hours decreased to about 5 percent of the activity excreted at 45 days post detonation.

The excreta of the pigs from Utirik contained less than 10 percent of the gross beta activity found in the excreta of the pigs from Rongelap at the same time. This ratio of 10 was approximately the same ratio found between the activity of the food, water and soil samples of the two locations.

Radiochemical Analysis of Tissues and Excreta. Radiochemical analysis of pig tissues indicated that 62 percent of the skeletal beta activity was derived from Sr[illegible], 7 percent from Ba^{140}, and 10 percent from the rare earth group at 82 days post detonation (Table 5.8). The radioisotopic composition of the urine at this time was similar to that of the skeleton. The distribution of activity in the body of the pig may represent the distribution in human beings. The absolute amount of internal contamination of the Rongelap people was, however, only a tenth of that found in the animals.

At 4 months post detonation, the alkaline earths comprised less than 2 percent of the total activity in the clam (Table 5.10). The rare earth group constituted 33 percent of the total beta activity. The balance of the activity was contributed chiefly by Zr^{95} (21 percent) and Ru[illegible] (32 percent). About 50 percent of the material found in the viscera of the fish was of the rare earth group. Very small amounts of strontium and barium were found. In the tissues of the fish, strontium, barium and the rare earths contributed only about 10 percent of the total activity.

5.4.3 Autoradiographs

A number of autoradiographs of the tibiae and femurs of 1 chick, 4 pigs, 1 rooster and 2 chickens were prepared both at the USNRDL and at the Argonne National Laboratory (ANL) to determine the pattern of deposition of fission products. Contact printing on X-ray no-screen film was found to be the most satisfactory method of preparing the autoradiographs. The discussion and conclusions presented below summarize the findings reported by Norris (15).

The autoradiograph of a tibia from a chicken sacrificed at 45 days post detonation (Fig. 5.2) indicated a relatively uniform distribution of the activity throughout most of the bone, with the highest concentration of activity in the area adjacent to the epiphysis. This area of high activity corresponds to an area of dense trabecular bone.

The tibia and femur of a baby chick, which died spontaneously 47 days post detonation, showed the heaviest concentration of radioactive material in the diaphysis (Fig. 5.3). The end regions of the bone, which were laid down after the animals were removed from the contaminated environment, were relatively lacking in activity. The region of greatest activity was [illegible] epiphyses, which appeared to be ab-

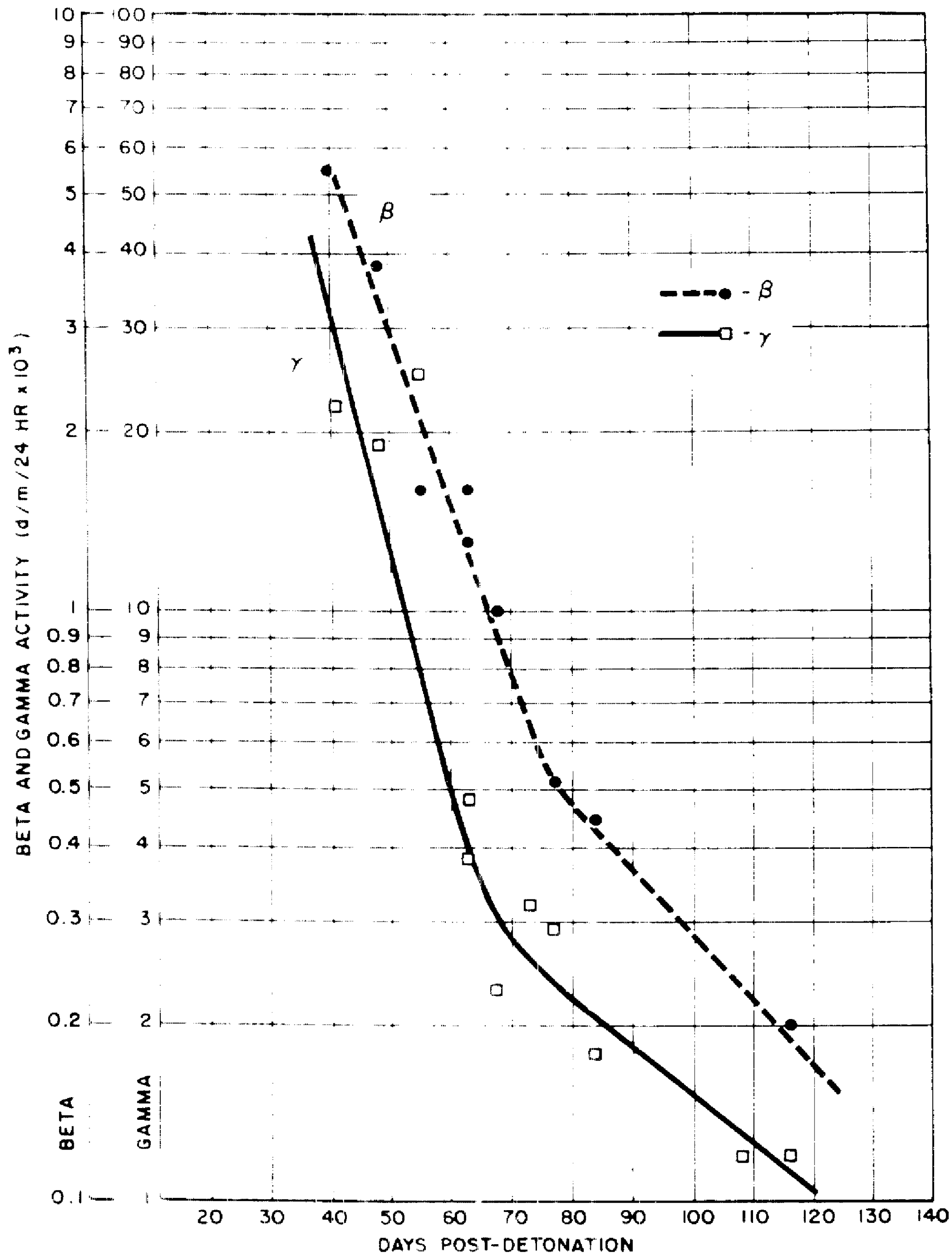

FIGURE 5.[illegible] — *Beta and gamma activity in chicken excreta.*

normally constricted, possibly because of a decreased rate of endosteal resorption.

A tibia from a pig sacrificed 45 days post detonation had an area under the growing [illegible] free of activity (Fig. 5.4). As in the chick described above, this area corresponds to the growth which took place after the animal was removed from the area of contamination. The

FIGURE 5.[illegible] *Autoradiograph of tibia of chicken sacrificed 45 days post-detonation* [illegible]

marrow cavity in this tibia contained dense trabecular bone along its entire length, a formation not normally found in mammalian bones. There are also two distinct areas of increased density in the trabecular region, which appear as two lines of radioactivity in the autoradiograph. The center of the diaphysis was abnormally thick, possibly because of a failure of the normal resorptive process.

No other evidence of a double line of radioactive deposit appeared in the animals studied, except possibly in a sow sacrificed 38 days post exposure (Fig. 5.5). Here a faint deposit of activity in the trabecular bone is noted, separate from the higher level in the epiphysis.

Looney ([illegible]) has shown that a typical osseous [illegible] in trabecular space is a characteristic [illegible] pathological finding following radioactive

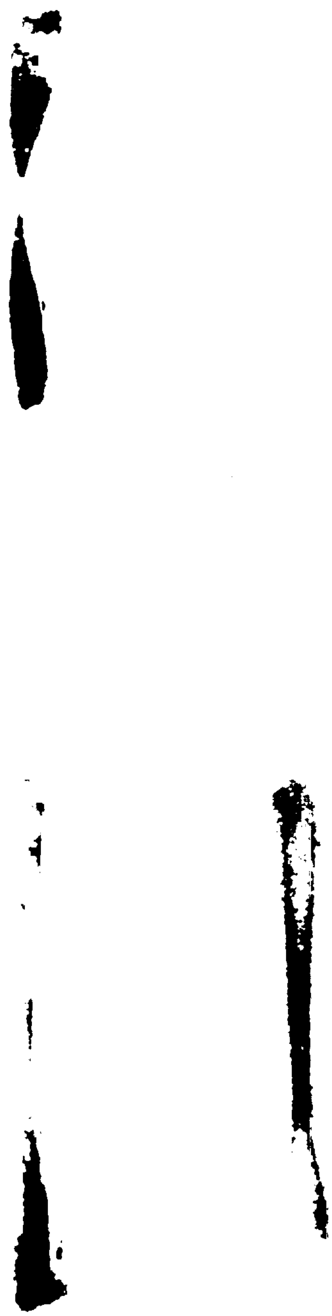

FIGURE 53.—*Autoradiograph of tibia and femur of baby chick sacrificed [illegible] days post detonation (ANL).*

deposition. For example, clinical studies have shown that following radium deposition in bone, atypical osseous tissue is formed in cancellous bone. These formations appear as areas of increased density in roentgenograms (8).

It is difficult to interpret the anomaly in the pig, described above, and the dense trabecular bone in both the pig and chicken. No normal controls are available for comparison with these animals, and the history of the animals from the time of exposure to the time of collection is not known. Severe dietary changes and disease also produce changes in the pattern of deposition of osseous tissue, and such changes are often indistinguishable from changes produced by exposure to radiation.

5.44 Pathology

Sections of lung, liver and tibia, as well as thyroid and other endocrine organs of most of the fowl and pigs dying spontaneously or sacrificed, were prepared. A few pathological changes were found including an aplastic marrow in one duck. However, none of the changes could definitely be ascribed to radiation. Sections of bone examined by Lisco at the ANL also indicated no detectable pathological changes.

5.45 Egg Production in Chickens

In birds, extraordinary demands are made on the calcium metabolism in the production of egg shell. It was, therefore, of particular interest to observe, during the process of egg production, the metabolism of those internally deposited radioelements which are metabolically similar to calcium.

Forty-four days after detonation, a group of hens from Rongelap began laying eggs for the first time since their collection. During the next month and a half, 319 eggs were laid by 6 hens. All of the eggs were normal, except for two eggs from one hen which were laid without shells. The shells were complete, smooth and of normal shape. The weights of the eggs ranged from 30 grams to 64 grams,

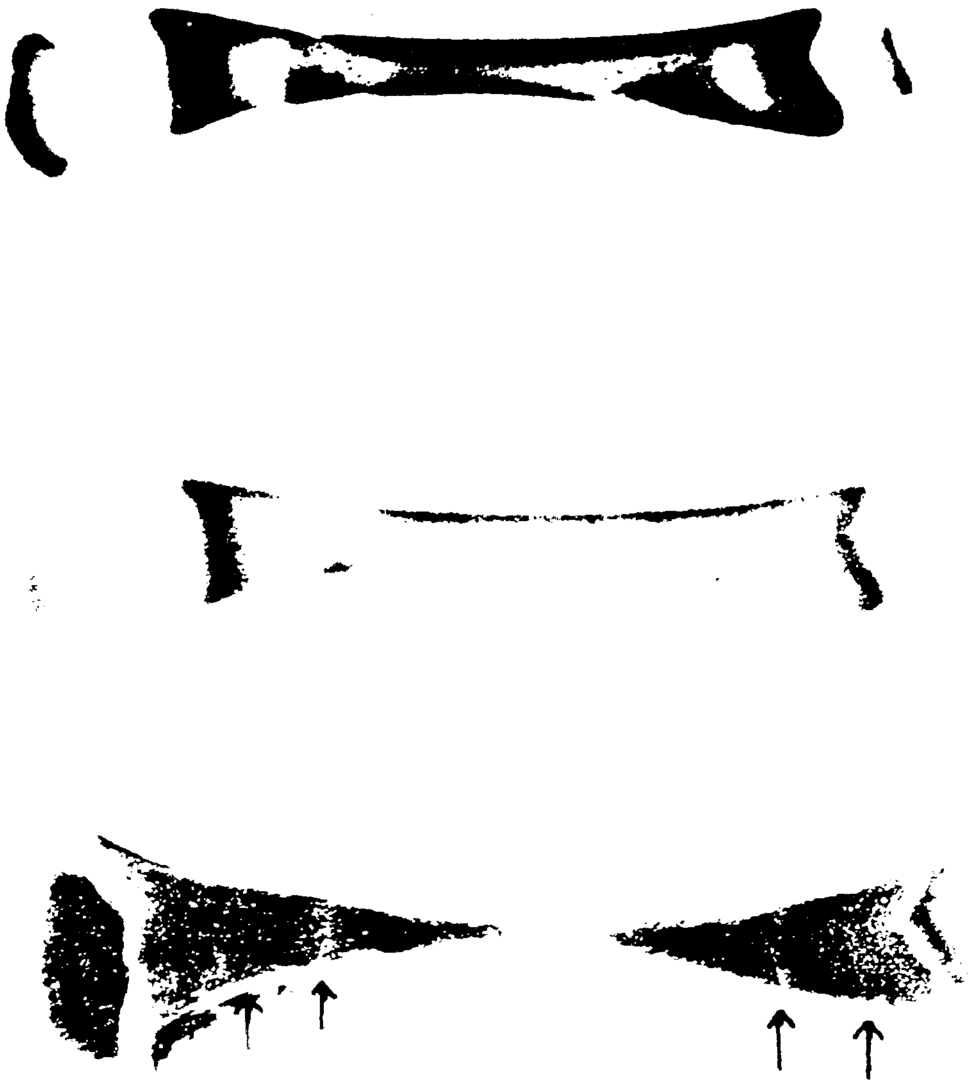

FIGURE [illegible] sacrificed [illegible] days post [illegible]

Fig. [illegible] …toradiograph… [illegible] sacrificed 58 days post- [illegible]

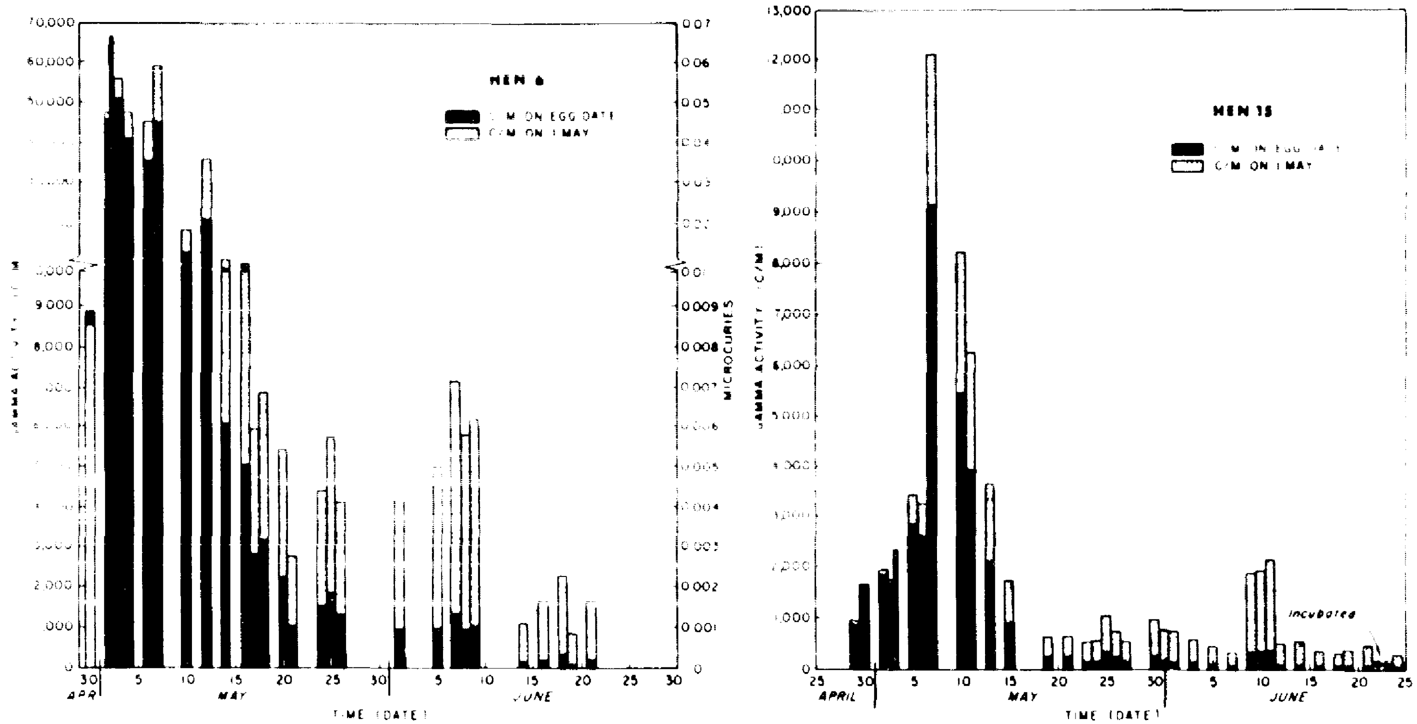

FIGURE 5.6. *Gamma activity in egg shell as a function of time (maximum gamma activity was noted in 8th egg laid as typically illustrated in hen 15. The gamma activity in hen 6 represents the highest concentration of activity seen in any of the shells)*

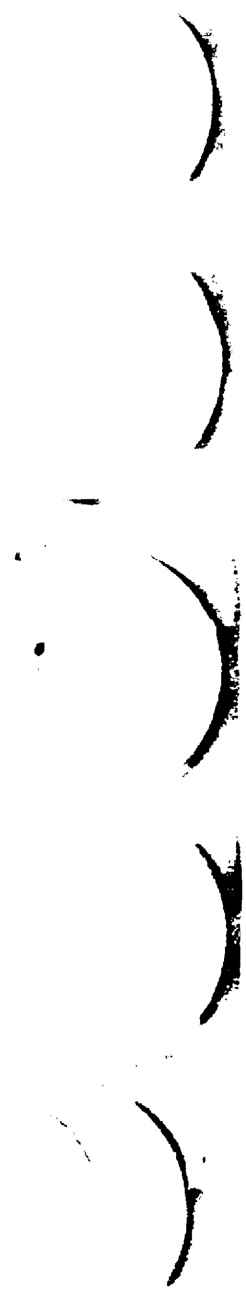

FIGURE 54.—*Autoradiograph of chicken eggs showing pattern of deposition of fission products in yolk.*

but those from a given hen were of uniform weight. In 14 eggs studied, the shell and membranes weighed an average of [illegible] percent of the whole egg weight, and the washed shell weighed 6.8 percent of the whole egg weight. These values are within the normal range for eggs of domestic hens.

The gross beta and gamma activities of the shell, albumen and yolk were measured in the first 50 eggs obtained, and the gamma activity of the shell was measured in the remainder of the eggs. An increasing amount of gamma activity appeared in the shells of the first few eggs laid by each hen. The maximum gamma activity was usually noted in about the eighth egg laid. After the activity reached a maximum value, the subsequent eggs in the series showed a general decline in activity. Two examples of this phenomenon are illustrated in Figure 5.6.

The highest gamma activity found in a single egg shell was 66,[illegible] counts per minute measured at 60 days post detonation. For gamma energy of approximately [illegible] mev, this figure corresponds to 0.07 μc. The yolks and albumens had much less activity than the shells as was anticipated. The average distribution of gamma activity in the eggs is given in Table 5.11. The results of the radiochemical analysis of two eggs are presented in Table 5.12.

The alkaline earths are the principal fission products deposited in the shell. In the albumen and yolk, the beta activity contributed by the alkaline earths was only a little greater than that associated with the rare earths.

The pattern of deposition of the radioactivity within the egg was also studied by means of autoradiographs. A series of [illegible] eggs were hard boiled, sectioned, and autoradiographs were prepared of the cut surfaces. Only four of the yolks of these [illegible] eggs were sufficiently radioactive to produce autoradiographs (see Fig. 5.7). These 4 eggs were laid on successive days by the same hen. There is a correlation between the rings of radioactivity in the yolk and those of pigment.

The amount of activity removed from the body of the chicken through egg laying is very much greater than the amount excreted in the urine and feces during the period of this study. Egg production in the chicken represents a [illegible] form of natural decontamination.

Table 5.11.—Distribution of Gamma Activity in Chicken Eggs

	Percent of Total Gamma Activity	Percent of Total Beta Activity
Shells	81	68
Yolks	15	23
Albumen	4	8

Table 5.12.—Radiochemical Analysis of Chicken Eggs

Sample	Beta Activity, c/m Total Tissue, at 4 Months Post Detonation			
	Sr	Ba	Rare Earths	Gross Beta Activity
Egg No. 2				
Yolk	[illegible]55	546	663	1,560
Albumen	[illegible]2	92	90	260
Shell	18,[illegible]80	[illegible],520	6,060	30,000
Egg No. 2[illegible]				
Yolk	[illegible]15	825	997	2,178
Albumen	45	132	132	316
Shell	22,[illegible]00	1,900	7,830	38,000

5.46 Fertility and Hatchability Studies in Chickens

Preliminary studies on the contaminated chickens were begun 2½ months post detonation, with the mating of hens and roosters and the incubation of the eggs obtained. In the first [illegible] eggs, [illegible] were hatched. One of the chicks had the crippling slipped-tendon condition, "congenital perosis," which is not uncommon. Radioanalysis of the chick tissues indicated that only a barely detectable amount of radioactive material was transferred to the chick, although the mother hen had at this time considerable contamination.

In another hatch six months post detonation, [illegible] eggs were incubated. Of these, 28 were in-fertile, 3 fertile ones were opened prematurely, 11 developed complete embryos but failed to hatch, and 27 live chicks were hatched, one of which had congenital perosis. The latter chick and six normal ones were sacrificed and their tissues radioanalyzed. Again, only barely detectable amounts of internally deposited activity were found. The remaining baby chicks are being raised and observed for possible long term effects. At the present time all the chicks are growing normally and are in good health. Comparison of the fertility and hatchability data of Rongelap hens with those from domestic hens does not demonstrate any effect of radiation on these phenomena.

5.47 Internal Radioactive Decontamination Studies in Chickens

A study was undertaken to determine the ability of both sodium EDTA and zirconium citrate (15) to increase the excretion rate of internally deposited fission products in the contaminated chickens. On the basis of previous experience, it was not expected that any appreciable decontamination could be effected at the time of this experiment 4 months following internal radioactive deposition.

The excretion rates of 8 chickens with large body burdens of internal contaminants were determined for a period of 4 days as the base line for the study. Following this, two chickens were injected daily I.P. with 75 mg. sodium EDTA for four days, two received injections of 70 mg. of zirconium citrate (15), and two were injected with both zirconium citrate and sodium EDTA. Two chickens were kept as controls. The mean beta and gamma activity excreted by these chickens was determined individually for each of the treatment days and for 1 day following cessation of treatment. Neither the zirconium citrate nor the sodium EDTA alone was effective in increasing the excretion rate as reflected by the beta activity measurements made. The combined administration of zirconium citrate and sodium EDTA, however, doubled the excretion rate of the beta activity. No detectable change in the rate of excretion of gamma activity was noted. The excretion rate of fission products at this long period post contamination was less than 0.1 percent per 24 hours. Thus, the enhancement of the excretion rate by the combination of zirconium citrate and sodium EDTA did not significantly decrease the total body burden.

5.48 Summary

Studies of animals provided data on the nature and distribution of the radioisotopes in the tissues and the excreta. Over 90 percent of the activity in the body of animals was localized in the skeleton. The pattern of deposition of the fission products in the skeleton seen in autoradiographs resembles that of the alkaline earths. Morphological changes which were observed in some of the bones may be the result of the exposure of the animal to external radiation, although the effects of severe dietary changes and other disease cannot be ruled out.

The alkaline earths Sr^{89} and Ba^{140} and the rare earth group together constituted 75 percent of the gross beta activity in the pig at 82 days post detonation. The fish and clam had a much lower concentration of the alkaline and rare earths, and a body burden considerably higher than that of the land animals.

The internal distribution of fission products in the pig is probably representative of the distribution in human beings. An estimate of the human body burden was derived from the data on pigs.

Studies made on egg production of contaminated hens gave no evidence of any effect of radiation. The rate of production and the eggs produced were both normal. The extraordinary ability of fowl to mobilize calcium in shell formation resulted in the presence of very high activity in the shells of the first few eggs. The activity was associated with the fission products of the alkaline earth group. A significant amount of activity was found in the yolk, and lesser amounts in the albumen. The removal of activity from the body of chickens by egg production provides an effective natural decontamination process.

Fertility of the hens and the hatchability of the eggs produced by the mating of contaminated roosters and hens showed no effect of radiation. The baby chicks hatched from these eggs are growing normally, and the amount of radioactivity in their tissues is barely detectable.

While the administration of the combination of zirconium citrate and sodium EDTA to chickens doubled the excretion rate of fission products, the rate at this long time after exposure was so low that the body burden was little affected.

In the 6 month period post detonation neither significant gross changes nor pathological changes which could be definitely ascribed to radiation were detected in any of the animals. Gross beta activity of urine and tissue samples indicated that all the animals had significant internal contamination. The level of internally deposited radioisotopes in the pigs from Rongelap was ten times the amount in human beings from this area. The difference in the amount of internal contamination of the animals and the human beings was the result of the prolonged stay of the animals in the contaminated area. The chickens were found to have the same concentration of radioisotopic material per unit of body weight as the pigs.

All of the animals remaining will be observed throughout their lifetime for the possible appearance of any long term biological effects resulting from their exposure to external and internal radiation.

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Chapter VI

Human Radiation Injury Resulting From the Use of Nuclear Devices

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Outline

6.1 Introduction

6.11 Significance of the 1 March Shot

The events following the first shot detonated at the Pacific proving grounds in 1954, described in this report, served to emphasize new problems resulting from the use of atomic weapons. These different effects, the importance of which was only vaguely appreciated before, were brought into sharp focus by the present episode. In this chapter the medical problems associated with the use of atomic weapons or nuclear reactor accidents will be discussed. In particular the problems associated with large scale fallout, as they were brought out in the present experience and as they may pertain to the thinking and planning of civil defense, the military and industries employing nuclear power will be discussed. Human radiation injury resulting from exposure to fallout and other nuclear radiations will be described, as well as current thought on the diagnosis and treatment of the disease states resulting from exposure to these radiations.

6.12 Extrapolation of the Present Findings to More General Situations

It must be emphasized that the large experimental nuclear device, the detonation of which led to the exposure of human beings to fallout radiations, was exploded close to the ground on a tropical coral atoll under geologic and geographic conditions that are significantly different from most populated areas of the world. Each of these conditions, i.e., size of weapon, height of burst, type of terrain, weather conditions, presence or absence of water under or near the burst will obviously influence markedly the rate and extent of contamination by fallout, and the particle size and chemical nature of the fallout material. These factors have been discussed in official releases (1-4). It follows therefore, that the events observed and the extent reported here are not necessarily typical of potential fallout situations in the future. It is clear, however, that the cardinal effects to be expected from fallout radiations, as exemplified by the events described in this report, are clear-cut and can be predicted with a reasonable degree of assurance.

In particular, this accident has emphasized the particulate nature of the fallout material that rendered it visible in many areas. It should not be inferred that serious fallout will necessarily be visible under other conditions of detonation. Also, the chemical nature of the material (calcium oxide) will be encountered in only limited areas of the world. Although, as stated in Chapter III, the chemical action of the fallout material was considered to have contributed little or none to the effects seen, the degree of adhesiveness of the material to skin or hair might be quite different with different fallout material, and in a colder climate where sweating would be minimal.

6.2 The Effects of Kiloton Weapons

6.21 Blast and Thermal Effects

Before the problems of fallout associated with megaton weapons are discussed in detail, the medical effects of kiloton weapons will be reviewed briefly for contrast. The effects of such weapons have been considered chiefly in the context of the nominal or 20 KT weapon detonated high in the air (5). The blast and heat effects have been treated thoroughly by Oughterson et al. (6) and little additional comment is required here. Blast and heat accounted for the vast majority of serious casualties in the Hiroshima and Nagasaki incidents. It should be pointed out, however, that in cities with more substantial dwellings than were present in

Japan, or if partial shelters are employed, the percentage of casualties from these sources would decrease and the percentage with radiation damage would increase.

6.22 Immediate Gamma and Neutron Radiations

The radiation hazard is due essentially entirely to the immediate neutron and gamma radiation from the weapon and exposure to these radiations is only a matter of seconds in duration. Fallout is relatively of no significance.* Thus, there is no significant contamination of the skin and, therefore, no beta lesions of the skin. Likewise, there is no significant danger of ingestion or inhalation of radioactive material, and hence no internal emitter problem.

Both the immediate gamma and neutron radiations are highly penetrating and will produce acute total body radiation injury in man. The ratio of neutron to gamma ray contribution to the total effective dose at distances of biological significance varies with weapon type. With most common shielding materials (earth, concrete), the relative neutron contribution to the total dose decreases with passage through the materials.

6.23 Dependence of Effects on Circumstances of Weapon Detonation

The effects previously described were for a high air burst only. With surface, underground and underwater bursts of kiloton weapons, in addition to blast, heat, and immediate ionizing radiations, serious contamination from fallout can occur. Its extent would of course be less than with the "megaton" weapon; however, its potential seriousness cannot be ignored.

*Significant levels of neutron induced radioactivity may be present for a short time near ground zero.

6.3 Added Effects of Megaton Weapons

6.31 Immediate Blast, Heat and Radiation Effects

WITH THE MEGATON BOMB, the same problems encountered with earlier atomic weapons are also encountered, only magnified many times. The area of total destruction, instead of one or two miles in diameter, may extend several times that far, depending upon the size of the weapon. There are blast, heat and radiation casualties as before, and the same problems of handling mass casualties on an unprecedented scale with minimal or no facilities pertain. In addition, the problem of extensive fallout is likely to enter.

6.32 Phenomenology of Fallout

SIGNIFICANT FALLOUT RESULTS only when the fire ball of the bomb comes in contact with the surface of the earth. With the high air burst, radioactivity condenses only on solid particles from the bomb components itself, and on dust in the air. The particles are small, are drawn high into the atmosphere and do not settle to the earth for periods of days or even months. By the time they reach the earth's surface, the major part of their radioactivity has been dissipated harmlessly in the atmosphere and no significant hazard results. If, however, the weapon is detonated on the surface or close enough so that the fire ball touches the surface, then large amounts of material are drawn up into the bomb cloud. Many of the particles thus formed are heavy enough to descend rapidly while still intensely radioactive. The result is a comparatively localized area of extreme radioactive contamination and a much larger area of some hazard.

The fallout area consists, in effect, of a large contaminated plane (except as modified by buildings or other structures), emitting alpha, beta and penetrating gamma rays. It is apparent that most of this fallout area is beyond the range of destruction by blast or heat, and thus one is dealing with essentially a "pure" radiological situation.

The extent and potential seriousness of fallout was clearly indicated in official releases of the Atomic Energy Commission (1-4). From these statements, the bomb's cloud could drop radioactive ashes in a cigar-shaped zone about 220 miles long and 20 to 40 miles wide. There could be sufficient radioactivity in a downwind belt about 140 miles in length and of varying width up to 20 miles to seriously threaten the lives of nearly all persons remaining in the area for 36 hours and who did not take protective measures. The zones thus outlined for potential morbidity and lethality depend obviously on weapon size, wind and other weather conditions, etc. Strauss(1) emphasized that possible casualty figures given are for the *worst possible* situation. Casualties might be reduced greatly in number because many in the area would take shelter or evacuate the area. Also, the pattern of fallout might be spotty in nature, and thus, many would escape exposure. Nevertheless, the area where potentially serious casualties may result may exceed by orders of magnitude the relatively small areas for conventional weapons.

6.33 The Effects of Gamma Radiation From Fallout

The gamma radiations are penetrating and, as seen in the Marshallese, produce the same type of injury produced by the initial radiation from the conventional weapon. In the one case radiation is delivered from a distant source, in the other from essentially a plane field. In both situations, penetrating radiation of the entire body results. Qualitatively, the results are identical. Quantitatively (e. g., dose-effect relationships), there may be differences due to incompletely known and understood differences in the energy of radiation and in dose rate, and in the geometry of exposure (see sec. 6.42). For these reasons, and for additional reasons to be advanced later, instrument readings of roentgen dose measured in air and published dose-effect tables for man should be used only as a rough guide in casualty estimation.

For order of magnitude of doses that may be encountered in the fall out area, the following figures for total dose for the first 36 hour period, are quoted from chairman Strauss' release (1). Ten miles downwind from the large device fired at the Bikini Atoll on March 1, 1954, within the test site, a total dose of 5,000 roentgens was delivered over a period of 36 hours. The largest total dose delivered outside the test site was 2,300 r for the same period at the north-west end of Rongelap Atoll about 100 miles from Bikini. Two other areas in Rongelap 110 and 1[illegible] miles from Bikini received 2,000 and 150 r respectively. Another area, 125 miles from Bikini received 1,000 r over the 36 hour period.

Effects that may be expected for given doses of penetrating radiation given over a few minutes or hours are indicated in Table 6.1 (7). It is emphasized that such tables are derived mostly from animal data and thus, should be taken as approximations only. These values vary considerably from the British estimates (8).

Table 6.1.—Effects of Acute Total Body Irradiation on Human Beings

50 r	No casualties. No reduction in effectiveness.
100 r	Two percent may be casualties (nausea and/or vomiting) for short period of time. No evacuation contemplated. No significant reduction in effectiveness.
150 r	Twenty-five percent casualties in a few hours. First definite reduction in effectiveness. Fifty percent of the casualties in this group will have to be evacuated.
200 r	All must be evacuated as soon as possible. Fifty percent will be noneffective.
300 r	Approximately 20 percent deaths. All need evacuation immediately. All are noneffectives.
450 r	Fifty percent deaths.
[illegible] or 650 r	Lethal dose, but not necessarily for all so exposed.

With regard to the problem of dose rate, there is essentially no difference in effect of a given dose delivered over a few seconds, a few minutes or a few hours. However, a dose delivered over several days or weeks will be much less effective for some effects, than will the same dose delivered over a few minutes. Some data indicate that the effect of a given total dose decreases roughly as the fourth root of the number of days over which the dose is given; thus, a dose delivered over 16 days would be one-half as effective as the same dose delivered over one day. These relationships were worked out on animals, using the so-called "rectangular" dose schedules, e. g., doses delivered at a constant rate. There are no data available to aid in evaluating adequately the effect of a constantly changing dose rate as encountered in a fission product field. Also, the relationships were worked out using acute effects, such as 30-day mortality and it is not at all certain how closely they apply to longer-range effects such as cancer production, shortening of life span, etc. Genetic effects apparently are dependent on total dose and show little or no dependence on dose rate.

6.34 The Effects of Beta Radiation From Fallout

Extensive beta lesions from fallout in human beings had not been encountered previously. As described in Chapter III, the lesions, both clinically and histologically, were consistent with previous data on experimental human and animal beta ray burns.

Several points should be made regarding the beta lesions from fallout radiations. Beta lesions of the skin and depilation can occur in the absence of lethal doses of gamma rays and can be serious. Thus steps should be taken to prevent them. And it would appear that, with reasonable precautions they can be prevented, or at least markedly reduced in severity. Contact of the fallout with the skin can be prevented by remaining within suitable shelter or by wearing ordinary clothing. If exposure cannot be prevented, early and complete decontamination of the skin and hair would prevent or lessen the severity of the lesions. Particular attention should be given to the hair because of the likelihood of activity being trapped there. If the hair is contaminated, and it cannot be cleansed promptly by washing, clipping or shaving should not be delayed.

6.35 The Effects of Internal Emitters From Fallout

The fallout material can be inhaled or ingested and it will, of course, contaminate exposed food or water supplies. Thus, as with beta burns the possibility of a hazard from this source is possible. As with the beta burns, however, the problem may not be too serious and relatively simple measures will aid in minimizing exposure. The particle sizes of the fallout material probably will exceed the optimal size for a major inhalation hazard. From data on the Marshallese exposed to fallout, it is seen that the degree of internal hazard in the exposed persons was small. This is encouraging, since these people lived in a relatively primitive state where maximum probability of contamination of food and water supplies existed. If the hazard was minimum under those conditions, it should be even less under conditions of modern American living. With all of the testing of nuclear devices in Nevada and elsewhere, the level of strontium, the most important fission product as far as internal hazard is concerned, is still only about 1/1000 of the permissible body burden as recommended by the National Committee on Radiation Protection in National Bureau of Standards Handbook 52, for industrial workers (9).

The problem should not be neglected, however. The effects of internally deposited radioactive materials may not become apparent for many years and, thus, the problem in the Marshallese will not be fully evaluated for years. Every possible precaution against inhaling radioactive material, or of ingesting contaminated food and water should be taken. Gas masks that efficiently remove fission product particles from the air are available and even a wet cloth over the face is of considerable value for this purpose. Sprinkling of an area is effective in reducing the amount of dust in the air. Plain water, or soap and water will remove a large proportion of contaminant from most surfaces. That remaining is firmly fixed and is not likely to become airborne easily. If a personnel decontamination center is established, it should be relatively mobile and isolated from more permanent buildings where definitive care is given. This stems from the fact that contamination can only be transferred, not destroyed, and the decontamination area is likely to become quite "hot" in a relatively short time. Tinned goods can be eaten with complete safety and it is highly unlikely that city water systems outside the area of blast damage will be contaminated soon after a burst. One thing appears to be certain—any effects from internal radiation will be long range and will be of no concern in the acute period. Total body radiation from gamma rays, and skin irradiation from beta emitters will be the chief radiological concern at early times following an explosion.

6.36 Evasive Action; Protection From Fallout

Some warning of possible fallout will be available and the falling radio-active material may actually be visible. As stated, the pattern of fallout will depend on wind velocities and other weather conditions, and the pattern is thus difficult to predict under the best of circumstances. However, it will be apparent that in closer-in areas, fallout may not occur for several minutes after the blast and this period may extend to several hours at greater distances and with slower wind velocities. Thus, there is some time for evasive action. Consideration might be given to evacuating the area if possible fallout patterns have been investigated and are believed to be predictable. Or it may be possible to take shelter. Sufficient time probably would be available to allow relatively complete preparation for an extended stay in adequate shelters with storing of sufficient food and water to allow some advantage to be taken of the decay of fission product radiation with safer evacuation of an area a few days after the fallout. Facilities may, for the most part, be essentially intact, such as water, power, fire fighting equipment, etc. In this sense, at least, one is immeasurably better off than within the area of blast and thermal damage.

With regard to effectiveness of shelters in the fallout area, the following estimates have been released. A frame house would reduce the total dose received by one-half, and a brick or concrete structure would be more effective. A basement would reduce the total exposure to one-tenth of its value. In a shelter of thickness equivalent to three feet of earth, the dose would be reduced to one five-thousandth of its value, affording complete protection in the most heavily contaminated areas.

It should also be noted, on the other hand, that while the decay of fission product radiations is extremely rapid over the first few minutes after detonation, the rate of decay becomes considerably less rapid in the succeeding hours [2]. Thus, with fallout occurring some hours after the blast, if adequate shelter is not available, earlier evacuation may be better than relying on partial shelter and on rapid decay of the radiation field. Starting at 1 hour after the blast, a given dose rate will fall to about 44 percent of its value by 1 hour later. However, at 10 hours after the blast, a given dose rate will fall by only 11 percent of its value in a period of 1 hour, e. g., the dose rate at 11 hours will be 89 percent of what it was at 10 hours. Such statements as "more than 80 percent of the radiation dose from atomic debris will be delivered within 10 hours of the explosion time" are true only if fallout occurs immediately after the detonation. If the maximum fallout and thus maximum exposure rates in a fallout area have not occurred for several hours, the rate of fallout in the area obviously will not be as rapid as it would be for earlier fallout material.

6.4 Estimation of the Severity of Exposure to Gamma Radiation

6.41 Predictions From Physical Estimates of Dose

If the absolute sensitivity of man to radiation were known, and if it were feasible to determine the dose to groups under catastrophe conditions a realistic statistical prognosis could be made. However, the problems involved with estimation of dose received by the individual present real practical difficulties. It is probable that dose estimates will be available from dosimetry devices or from dose contour lines and the position of the individual during exposure. Some of the difficulties of relying heavily on dose estimates are obvious. The exact position of the individual and the degree of shielding will not be known precisely. The dosimetry device records the dose or a dose rate which may not reflect accurately because of shielding, energy dependence of the device, etc., the deposition of energy within the individuals at the site of interest, namely bone marrow and gastrointestinal tract. More important, because of individual differences in sensitivity, individuals exposed to the same measured dose may differ widely in their responses. Thus, estimates of dose calculated from dose rates or derived from an integrating dosimeter or from position of an individual during exposure cannot be accepted as the best index of the probable fate of an individual, or as the final index to therapy, triage or prognosis. Since the syndromes of radiation injury have varying symptoms and are dose dependent, the symptomology is in sense, a personal indicator of one's fate. Experience with human radiation injury at Hiroshima, Nagasaki, with reactor and critical assembly accidents and the fallout accident described herein strongly suggest that the best method for estimating the seriousness of exposure at the individual level is the symptomatic approach. As with any disease, an accurate appraisal of the patient's condition results only from a thorough evaluation of the history, physical and laboratory examination (see Section 6.53 below).

6.42 Influence of Geometry of Exposure on the Effective Dose; LD_{50} for Man

The influence of the geometry of exposure on the effective dose is discussed in Chapter I, and the minimal lethal dose for man in Chapter IV. Dose rates from which the total dose received by the Marshallese was calculated were measured free in air in a plane 3 feet above the ground surface. Because of the planar geometry of exposure and the energy of the beam, for this measured dose rate, the dose rate at the center of the body would be greater than for the same dose rate from a high energy X-ray source, measured in air at the proximal skin surface. The effects of fallout gamma radiation would thus be expected to be greater, for the same dose measured in air, than would laboratory radiations.

The high initial incidence of nausea, vomiting and diarrhea in the high-exposure Marshallese group, and the profound neutrophile and platelet count depression indicated a greater effect than might have been expected from 175 r in the laboratory, in keeping with the above. As indicated in Chapter IV, from this value for the dose received, and from the degree of leukocyte depression it is possible to estimate the dose at which a small incidence of mortality would have resulted without treatment. These considerations would place the threshold for mortality at approximately 225 r, and the LD_{50} at approximately 350 r for fallout gamma radiation. It is also clear from the above considerations, that a figure for an LD_{50} for man, independent of the condition of exposure is essentially meaningless.

The LD_{50} figure of 350 r is below the value of 400 or 450 r commonly quoted (7). A recent re-evaluation of the Japanese Nagasaki and Hiroshima bombing data has resulted in a figure well above the 400 or 450 r value for the immediate radiation from the bomb. The error in this figure, as well as that obtained from the Marshallese data, is very great. However, the profound hematological effects seen in the Marshallese would argue strongly for lowering, or at least not raising, the current LD_{50} estimates for civil defense and other planning, this particularly under circumstances where fallout radiations may be expected to be the chief radiological hazard.

6.5 Radiation Syndromes as a Function of Type of Exposure, Dose and Time After Exposure

6.51 Effects of Superficial, Penetrating and Internal Radiations

Radiation injuries can be divided into three general classes:

a. The syndromes of whole body radiation injury which are produced by penetrating ionizing radiation, and which are dose dependent.

b. Superficial radiation burns produced by soft radiations (beta and low energy X or gamma radiations).

c. Radiation injury produced by the deposition of radionuclides within the body. The clinical picture varies with the site and amount of deposition.

Each of the above is associated with an early phase in which acute symptoms and signs may be observed, and a late phase in which chronic changes or manifestations such as cancer may be observed. Also, the degree of injury is proportioned to dose. Particularly in Class a, total-body irradiation, the disease entity seen is highly dependent on dose.

6.52 The Syndromes From Total Body Penetrating Radiations

The dose-dependent syndromes resulting from total-body exposure of the mammal have been described in detail (1-3) and need only be summarized here. After large doses (approximately 6,000 r or more* the *central nervous system syndrome* (CNS) is produced (10). Death may occur under the beam after some hours, and is preceded by hyperexcitability, ataxia, respiratory distress, and intermittent stupor. Doses capable of producing this syndrome are always uniformly fatal. If an occasional animal survives this CNS he has yet to experience the *gastrointestinal syndrome* (GIS), (10, 12) which when produced by doses in excess of 500 r is always fatal within 3-9 days.** The GIS is so named because of the marked nausea, vomiting, diarrhea, and denudation of the small bowel mucosa. The GIS is a uniformly fatal syndrome in most laboratory animals. If the short duration GIS of a few hours does not produce the 3-4 day death, the survivors of this syndrome have yet to experience the sequelae of bone marrow depression which has been termed the *hemopoietic syndrome* (HS). The HS is not necessarily fatal. It is the clinical picture that is seen in the lethal range for all mammals and in general the LD_{50} values reported represent the LD_{50} for the sequela of hemopoietic depression—granulocytopenia and depressed defenses against infection, thrombopenia, and anemia with the possible resulting infections, diffuse purpura, and hypoxia due to anemia, any of which may be fatal. More detailed descriptions of the pathogenesis of these phenomena have been published (10-16).

The above picture of radiation syndromes is based on animal experimentation; however, human experience (6, 17-22) has indicated that man probably corresponds quite closely to the general mammalian response outlined above with the exception of some differences in time of occurrence. The CNS apparently was not observed by the Japanese at Hiroshima and Nagasaki (21, 22) nor would one expect it to be observed since doses to produce this syndrome were well within the area of total destruction. The GIS with deaths in the 1st week are well documented clinically and pathologically as are deaths from the HS (6, 18, 21, 22). However, in the case of man, deaths from infection were most prevalent in the 2d to 4th weeks (maximum incidence during 3d week) and from hemorrhagic phenomena in the 3d to 6th weeks (maximum incidence in 4th week). In the Japanese, after the bombing of Hiroshima and Nagasaki, deaths from radiation injury were occurring as late as the 7th

*Species variation.

**There are species and strain variations. The 3-4 day deaths are most prevalent in dogs, rats and mice. In others deaths on 5-6th days are seen. Guinea pigs and hamsters survive 6-8 days.

week. This is in contrast to other mammals where deaths from the acute phase are uncommon after the 30th day.

6.53 Probability of Survival as Related to Symptoms

Hence, individuals exposed in the lethal range (where some, but not all, will die in the first several weeks following exposure) can be divided according to symptoms and signs, into groups having a different prognosis. Thus they may be divided into three groups in which survival is, respectively, *improbable*, *possible* and *probable*. It will be apparent that there is no sharp line of demarcation among the groups.

Group 1.—*Survival improbable.*

If vomiting occurs promptly or within a few hours and continues and is followed in rapid succession by prostration, diarrhea, anorexia, fever, the prognosis is grave; death will almost definitely occur in 100 percent of the individuals within the 1st week. There is no known therapy for these people; accordingly, in a catastrophe, attention should be devoted principally to others for whom there is some hope.

Group 2.—*Survival possible.*

Vomiting may occur early but will be of relatively short duration followed by a period of well-being. In this period of well-being marked changes are taking place in the hemopoietic tissues. Lymphocytes are profoundly depressed within hours and remain so for months. The neutrophile count is depressed to low levels, the degree and time of maximum depression depending upon the dose. Signs of infection may be seen when the total neutrophile count has reached virtually zero (7–9 days). The platelet count may reach very low levels after 2 weeks. External evidence of bleeding may occur at 3 or 4 weeks. This group represents the lethal dose range in the classical pharmacologic sense. In the higher exposure groups of this category, the latent period lasts from [illegible] to 3 weeks with little clinical evidence of injuries other than slight fatigue. At the termination of the latent period, the patient may develop purpura, epilation, oral and cutaneous lesions, infections of wounds or burns, diarrhea, and melena. The mortality will be significant. With therapy the survival time can be expected to be prolonged and if sufficient time is provided for bone marrow regeneration the survival rate will be increased.

In groups 1 and 2 the blood picture is not as well documented as in group 3. There are good clinical reasons to believe that in the lethal range the granulocyte depressions will be marked and below 1,000 per mm^3 during the 1st week. Good observations in Japan (21, 22) confirm this contention. However, in the sublethal range it takes much longer for the granulocyte count and platelet count of man to reach minimal values, as compared to other mammals (see Chapter IV and reference 10). Despite the chaotic conditions that existed in Hiroshima, the data of Kikuchi and Wakisaka (22) shows that there was a more rapid and marked decrease in Groups 1 and 2 than in Group 3.

Group 3.—*Survival probable:*

This group consists of individuals who may or may not have had fleeting nausea and vomiting on the day of exposure. In this group there is no further evidence of effects of the exposure except the hematologic changes that can be detected by serial studies of the blood with particular reference to lymphocytes and platelets. The lymphocytes reach low levels early, within 48 hours, and may show little evidence of recovery for many months after exposure. The granulocytes may show some depression during the second and third week. However, considerable variation is encountered. A late fall in the granulocytes during the 6th or 7th week may occur and should be watched for. Platelet counts reach the lowest on approximately the 30th day at the time when maximum bleeding was observed in Japanese who were exposed at Hiroshima and Nagasaki. This time trend in the platelet count and the development of hemorrhage is in marked contrast to that seen in laboratory animals when platelets reach their lowest level around the 10th to 15th days and hemorrhage occurs shortly thereafter.

In this group, individuals with neutrophile counts below 1,000/mm³ may be completely asymptomatic. Likewise, patients with platelet counts of 75,000/mm³ or less may show no external signs of bleeding. It is well known that all defenses against infection are lowered even by sublethal doses of radiation and thus, patients with severe hematological depression should be kept under close observation and administered appropriate therapy as indicated.

6.6 Relative Hazards of Beta and Gamma Radiation From Fallout

COMBINED BETA BURNS to the skin and whole body gamma radiation injury can be sustained, as in the present experience. However, situations may occur following fallout in which prompt evacuation from the area would limit the whole body dose to minimal levels, but in which delay in decontamination of the skin would permit severe radiation burns. The reverse situation is not only conceivable but occurred to a limited extent in the Marshallese and Americans. Those, who were inside, and or completely clothed, received practically no skin burns but received apparently the same degree of whole body radiation. One might also be exposed in the open, decontaminated promptly and then enter a shelter because of delay in evacuation. Under these circumstances, one would receive predominantly whole body radiation injury.

In the course of the present accident the presence of some open skin lesions did not seem to exert a deleterious influence on the spontaneous course of the hematologic depression. However, with more severe degrees of hematologic depression open wounds of any type would present additional potential portals of entry for bacteria. Certainly in the case of thermal burns (23, 24), the chances of recovery are diminished as a result of the combined injury.

6.7 Therapy of Radiation Injury

THE TREATMENT OF acute radiation injury has been discussed (25). It is essentially that which sound clinical judgment would dictate. Supplies and medications are those indicated for the mass casualty situation, and emphasis should be chiefly on the magnitude of the supply problem. Antibiotics will be required in large amounts to combat the infection that plays a large role in morbidity and mortality among irradiated individuals, and blood, plasma and other intravenous fluids will be required to correct the shock, anemia and fluid imbalance. These agents should be used, as in all clinical conditions, when clinical and laboratory findings (if laboratory work is possible) indicate their need. Any marked prophylactic use of these agents has not been demonstrated, and considerations of probable short supply in the face of overwhelming demand would militate against their use in the absence of clear cut indications. There are no drugs specific for radiation injury in man. Considerable progress has been made in developing agents effective in animals if given prior to irradiation. Of great experimental interest in post exposure therapy has been the development of effective therapy by injection of splenic and bone marrow preparations. However, the experimental ability and genetic specificity of these preparations indicates that these agents may not be of practical value. In addition substitution therapy by transfusion of separated platelets and neutrophiles to combat hemorrhage and infection is of experimental interest [illegible] present techniques are not sufficiently [illegible] to warrant consideration of stock-

[illegible] specific drugs for the treatment [illegible] of the skin. Careful cleanlito nuclear devices detonated under different conditions, it is possible to predict from the findings, with reasonable assurance, the chief problems that will result from fallout. These are as follows:

1) The medical problems in the immediate vicinity of a kiloton atomic weapon or a megaton bomb will be essentially similar. With the larger weapon, of course, the areas of damage are much larger and, thus, the numbers of casualties with mechanical, thermal, or radiation injury are greatly increased.

2) In addition, with large weapons, an area of fallout can extend for thousands of square miles beyond the range of thermal and blast injury, resulting in gamma irradiation, beta irradiation of the skin and a potential internal hazard in the absence of blast or thermal injury. Serious fallout can occur several hours after detonation and at considerable distances. At this late time, the early, very steep fall in dose rate has already occurred and the dose rate falls off at a much slower rate. There may be adequate time for countermeasures and early evacuation or other effective evasive action will reduce by a large amount the total dose received.

3) The gamma radiation is by far the most serious hazard in the fallout area. It is penetrating, and exposure can result in the same acute radiation injury observed in the Japanese at Hiroshima and Nagasaki. The quantitative dose-effect relationships may be altered because of dose rate and other differences between the two types of exposure.

4) Beta radiation of the skin from fallout definitely can be a problem in the absence of lethal doses of associated gamma radiation. Although late in appearing, the skin lesions may be sufficiently serious to result in a "casualty". Of equal importance, however, is the consideration of the effectiveness of rather simple countermeasures in preventing the lesions. The lesions apparently result mainly from material deposited directly on the skin, although beta radiation from the ground, building, or even clothes may contribute to a small degree. Thus, shelter within a building, covering exposed skin areas with clothing and early skin and hair decontamination would go far toward preventing this hazard.

5) Some degree of internal contamination will occur in persons exposed to fallout. The amounts deposited in the body, however, will be relatively small. It appears certain that no contribution to the acute medical picture seen will result from this cause. It appears also, although data are incomplete, that little or no long-term hazard is likely to result from this cause, particularly if reasonable precautions are taken to avoid excessive inhalation or ingestion of the material. The acute medical problems in the fallout area will be concerned principally with total-body gamma exposure; some with beta irradiation of the skin.

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