UNITED STATES
ATOMIC ENERGY COMMISSION
Washington 25, D.C.

Tel. ST 3-8000
Ext. 307

FOR RELEASE AT 5:15 P.M. (EDT)
THURSDAY, SEPTEMBER 23, 1954

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United States Atomic Energy Commission
For Delivery at 7th Annual Industrial Health Conference
Houston, Texas - September 23, 1954

THE MEDICAL EFFECTS OF ATOMIC BLASTS

To comprehend the magnitude of the medical problems of atomic attack, it is imperative that we know the fundamentals of the types of weapons and the range of power that may be anticipated in any action brought against this country. While it is obviously impossible to disclose in any detail our own capability, President Eisenhower in his historic speech before the UN General Assembly, December 8, 1953, said:

"Atomic bombs today are more than 25 times as powerful as the weapons with which the atomic age dawned, while hydrogen weapons are in the ranges of millions of tons of TNT equivalent."

Subsequently, there was released the documentary film of the first full-scale thermonuclear test at Eniwetok on November 1, 1952. This tremendous explosion, resulting in a fireball over three miles in diameter, created a large crater in the reef with the lifting of millions of tons of water and coral into the skies. With the earlier announcement, for an experimental device at Nevada, of a yield of 15,000 tons of TNT equivalent, or 15 kilotons, and the original estimation of the Nagasaki bomb at 20 kilotons, it is apparent that we may consider our family of weapons in a great range of possible yields and modes of delivery.

What do these units of energy mean? What is implied by the words "kiloton" and "megaton"? Commission Chairman Strauss in a recent address used an illuminating

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example. During World War I the City of Halifax was devastated by the explosion of a munitions ship in the harbor having aboard over 2000 tons of high explosives. Not only was there enormous property damage but approximately 10,000 people lost their lives or were injured. This blast, in nuclear weapons terminology, had an energy equivalent to slightly more than two kilotons, a very small explosion in these terms. The so-called nominal bomb of 20 kilotons releases approximately 10 times the energy of an Halifax explosion while our largest fission bombs will yield the energy of 250 such ships all consumed in one gigantic detonation.

But when we speak of the thermonuclear weapons, a still larger unit becomes convenient. This is the megaton or 1000 kilotons of TNT equivalent. One megaton would thus be represented by the explosion of a line of such ships bow to stern extending for 20 miles.

With such a great range of possible energy yields, how may we relate the effects of one explosion to those of another of entirely different level of power? The volume "The Effects of Atomic Weapons," published in 1950, was written before these very large weapons had been tested. The yield of 20 kilotons was taken as the basis for the book and extensive data were given for this so-called "nominal" bomb. The existence of yields other than this was not implied but scaling laws which should serve to predict the effects from other yields were included. Without entering into a discussion of the degree to which these laws apply to all situations, we may use them with confidence as being sufficiently descriptive for civil defense needs. Since we are especially interested in blast, thermal effects, and nuclear radiation, the following equations may be used to relate these quantities for any yield (W) in kilotons to the corresponding values given in "The Effects of Atomic Weapons" for the nominal bomb.

$$\frac{r_1}{r_2} = \left(\frac{W_1}{W_2}\right)^{1/3}$$ Where r_1 and r_2 are distances for a given pressure characteristic.

$$\frac{Q_1}{Q_2} = \frac{W_1}{W_2}$$ Where Q is total radiant energy (thermal or nuclear) at a given distance.

$$\frac{t_1}{t_2} = \left(\frac{W_1}{W_2}\right)^{1/3}$$

Where t is the duration of the blast wave.

In certain respects, subsequent tests have shown some of the quantitative statements in the original volume to be in error. These will be corrected in the next revision. The most important of them are noted here.

The description of the atomic explosion by now should be familiar to all. At the moment of energy release a bomb is represented by a small sphere of intensely radioactive material of exceedingly high temperature and under enormous pressure. The mass rapidly expands spherically into the fiercely luminous fireball which then ascends at a high rate of speed. Energy is delivered as blast, heat, and radioactivity.

BLAST EFFECTS

The shock wave characteristically has a very sharply rising front with a prolonged positive pressure phase followed by an even longer negative phase. The time characteristics of this typical shock wave follow from the scaling laws mentioned so that with small explosions, such as those of a few tons of TNT, the wave form is sharp and of short duration while with megaton detonations the blast pressure may be exerted for several seconds.

Experiment has shown that the effects of blast with nuclear detonations do not differ qualitatively from those found with high explosives. Surprisingly high peak pressures may be tolerated without fatal injury provided the attendant accelerations are prevented or minimized. While overpressures of 5 lbs. per square inch may occasionally rupture the ear drum, several times this figure may, in some situations, not cause serious injury. In animals subjected to 15-25 p.s.i. over-pressure, small petechial hemorrhages in the lungs and in the gastrointestinal and urinary tracts are frequently found. Ear-drum rupture is then almost a constant finding and transient central nervous system disturbances and concussion may be observed.

Upon exposures to very high over-pressures, both animals and man may be killed immediately or within a few minutes. The associated pathology is usually as follows:

1. Cardiac contusion. Commotio cordis
2. Entrance of air into the pulmonary venous circulation with cerebral or coronary air embolism.
3. Respiratory tract hemorrhage.
4. Pulmonary edema.
5. Sinus and middle ear hemorrhage.
6. Ruptured ear drums and disruption of the ossicles of the middle ear.
7. Trauma to distended hollow viscera.
8. Central nervous system hemorrhages.

The degree of injury from the direct action of blast appears to be dependent upon both the peak pressure and the duration of the pressure wave.

Over-pressures are accompanied by momentary winds of high velocity reaching 170 miles per hour for 5 p.s.i. Individuals not restrained may be thrown violently for considerable distances and inanimate objects may be accelerated to become missiles capable of causing very serious injury. It appears that the blast peak pressure is in itself of less danger than the mechanical trauma occasioned by the drag forces on detachable objects.

For these reasons it is our present view that the problem of blast injury is closely related to the blast damage of structures and will therefore be more or less co-extensive with the area of light to moderate damage to buildings. Material such as glass, which may be easily fragmented and readily accelerated to high velocities, may be anticipated to be a great source of injury from blast. The wounds and other traumatic manifestations of such missiles are well-known.

THERMAL RADIATION EFFECTS

Since the publication of "The Effects of Atomic Weapons," laboratory and field experiments have given much more adequate information that burning is due to energy in the infra-red and visible portions of the spectrum with no significant contribution from the ultraviolet. About one-half of the thermal injury is caused by the infra-red rays, the remainder being attributable to radiation in the visible range.

Burns produced by a fission bomb differ in no respect from those due to any high intensity heat of short duration. As far as the thermal injury itself is concerned, the treatment presents the same problems as do similar injuries from other heat sources.

With respect to the time interval of the thermal radiation emission during which burns may be produced, for yields which are relatively small multiples of the nominal bomb, it has been found that:

a. There is no burning in the first 0.025 second following detonation.

b. The major severity of thermal burns is attained within the first 0.3 second after detonation.

c. No burns are produced after 0.6 second if the skin is protected prior to that time.

d. There is good relationship between the measured thermal energy and that determined by evaluating the skin burns from laboratory standards during the first 0.3 second.

e. No difference in severity between small and large area burns occurs when other conditions are equal.

f. In animals, moderate burns have been found to heal at normal rates despite the development of irradiation sickness.

For the nominal bomb, the time from detonation to the second maximum of fireball illumination is approximately 200 milliseconds (0.2 second). With larger yields, this duration of the thermal pulse increases and may be as great as several seconds for very large yields.

The following system of grading burns based on laboratory and field experiments has been found to hold:

Grade 1) 2.3 cal/cm^2 in 0.3 second - only erythema present 24 hours after exposure.

Grade 2) 4.5 cal/cm^2 in 0.3 second - patchy or central coagulation necrosis.

Grade 3) 7.5 cal/cm^2 in 0.3 second - complete coagulation of surface without charring.

Grade 4) 10 cal/cm^2 in 0.3 second - coagulation of surface with the formation of an immediate steam bleb persisting as an air-filled blister.

Grade 5) 19 cal/cm^2 in 0.3 second - deep coagulation with carbonization of the surface.

The additional considerations which pertain to very high yield weapons are the absorption of heat by the atmosphere, which is related to visibility, and the relation of the injury produced to the time of delivery of thermal energy. The total amount of heat is directly proportional to the energy release of the bomb. As the time of delivery of the thermal energy is increased, the number of calories per square centimeter required to produce the lesions mentioned increases. With very large yield weapons the figures given for the 0.3 second of delivery must be augmented by 50 to 100%. The scaling laws given and the considerations derived by experiment lead to the following approximate values for thermal flux in calories per square centimeter at various distances and under specified conditions of visibility.

TABLE I

Distances in miles at which certain total thermal energies are delivered related to yield and visibility

Energy release	Visibility 4 miles		Visibility 35-40 miles	
	3 cal/cm^2	10 cal/cm^2	3 cal/cm^2	10 cal/cm^2
20 KT	1.3	0.8	2.2	1.3
100 KT	2.2	1.5	4.3	2.8
1 MT	3.5	2.7	10.0	6.8
10 MT	4.8	4.0	17.0	13.0

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NUCLEAR RADIATION

From an exploding atomic bomb about 6% of the energy is delivered in the form of immediate nuclear radiation while about 11% of the total energy is released as nuclear radiation over a long period of time by fission products and induced radioactivity. Although the intensity and total amount of radioactivity in an area under attack are very much dependent upon the circumstances of the detonation, it is useful to assume that the total radioactivity, both immediate and delayed, will scale as the first power of the total energy yield of the bomb.

Not only does the gamma radiation follow the inverse square law with distance but in addition there are absorption and scattering of gamma photons by the air so that for the smaller weapons the total transmission is effectively limited to the general region of blast damage. The neutron flux transmission is inherently more complicated and there are situations under which neutron exposure may contribute a large fraction of the total radiation injury. The reaction of neutrons in air, however, is such that one would not expect significant neutron fluxes at a distance of greater than 1500 meters from the fireball.

It therefore appears that as the yield of nuclear weapons increases, the blast and thermal effects tend to outrun those of the immediate nuclear radiation.

The delayed nuclear radiation mentioned previously may, however, significantly modify the situation. With an air burst, where the fireball does not come into contact with the earth, the radioactive products of the detonation are carried high into the atmosphere as very small particles and are scattered widely by the winds. The great bulk of this material will undergo radioactive decay before the particles have fallen to the earth. When, however, the detonation is such that the fireball rests upon the ground, great amounts of earth are drawn into the rapidly rising fireball resulting in coarse, highly radioactive particles which tend to fall rapidly while being carried along by the wind. In such cases, there is an area of highly radioactive fallout in which the maximum intensity may be lethal

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following an exposure of only a few hours. Small detonations, such as are fired at the Nevada Proving Ground, produce contamination extending for only a few miles and the dangerously active areas are confined to the controlled bombing range. The dimensions and shape are determined by the whole complex of wind patterns but characteristically there is a narrow fan in which the area of highest contamination has a somewhat elliptical shape. Up-wind and cross-wind contaminations are limited in extent and are far less spectacular in intensity.

For either an air burst or a surface burst, the radioactive material which does not descend quickly is carried by the winds prevailing at the various altitudes so that the fallout of this finely divided particulate material is determined by the wind trajectories and the particle size, the latter greatly influencing the velocity of fall. When such material descends sufficiently to enter the rain cloud bearing level, usually below 20,000 ft., the fallout to the earth may be accelerated by rain or snow, and it is common to find, following a detonation, that rainwater from regions of cloud passage shows readily detectable activity. Other than such incidental concentrations the general fallout tends to be remarkably uniformly distributed over the earth's surface.

Radioactivity resulting from detonations decays with time in accordance with the following equation:

$I = I_o t^{-1.2}$ where I is intensity at time t and I_o is the intensity at unit time. The significance of any measured activity is dependent upon the time since detonation. Within the first few hours and days most of the activity is due to radioisotopes of short half-life so that radioactive elements such as iodine, molybdenum, ruthenium and many others may be demonstrated. The activity of such elements is soon gone and the exposure due to them is of transient character.

It may be of general interest that the average total fallout over the United States from the CASTLE series of tests in the Pacific this past spring has amounted to approximately 100 millicuries per square mile as of this week (September 23, 1954). While this amount of radioactivity is minute, it is possible with techniques available today to detect and measure it accurately. This has been done for all regions of the country. The gamma radiation

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to the body from this material is approximately 0.01 mr/day which is less than 5% of the radiation to the body from cosmic rays and the radium in the soil.

RADIATION EFFECTS IN MAN

In the present discussion, it is obviously impossible to present in any detail the pathology of radiation injury. This extremely complex subject has been voluminously developed in the medical literature and is generally available. The important radiation effects fall into two broad groups, one pertaining to the individual himself and the second related to questions of inheritance of the results of radiation damage to the germ cells. The first category we may call the somatic and the second the genetic effects. Somatic Effects: Here we must distinguish between the effects of external irradiation and those of internally ingested bomb residues. With respect to the immediate region of the explosion and to the areas of close in radioactive fallout in the case of surface or near surface detonations let me say at once that the external radiation hazard is overwhelmingly the important one and the ingestion of radioactive bomb products in this region is relatively trivial in comparison with the external hazard.

The effects of external radiation are not qualitatively greatly different for the various types of nuclear radiation but the regions and tissues of the body affected are very much dependent upon the physical characteristics and energies involved. Thus the highly energetic gamma and neutron radiations penetrate the entire body while the soft gamma rays and beta radiation have only limited penetration through the skin. Alpha radiation is of no external consequence because of its extremely limited penetration.

The immediate effects of whole body gamma radiation are determined by the dosage received and the rate of delivery. The systems most fundamentally affected are the central nervous system, the blood forming organs and tissues and the gastrointestinal tract. The time of onset of symptoms may vary from a few minutes for extremely high doses delivered very rapidly to several weeks for smaller doses delivered more slowly. In general our previously published figures for 50% lethality at approximately 400

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roentgens of immediate gamma radiation from the bomb still seem accurate. Transient depression of white cells and platelets may be detected readily at an exposure of 50 roentgens, and nausea and vomiting will occasionally be found with whole body doses as low as 100 roentgens.

Where the dose is delivered over several days, the amount of radiation to produce death in 50% of those exposed must be increased by a factor which is about two.

In the case of the local radioactive fallout in the vicinity of a bomb exploded on the surface, about one-half of the total possible radiation dose is delivered within the first 24 hours. Measures to prevent or limit such exposure must therefore be undertaken promptly if they are to be effective.

Exposures in the region of 200 roentgens of whole body gamma radiation may cause such a depression of white cells that antibiotics are required to block secondary infections. A decrease in platelets to below 30,000 per cubic millimeter may lead to purpura requiring the use of platelet transfusions, a procedure which is still experimental.

Whole blood transfusions, especially those from many donors, introduce hazards such as those from incompatibility and from infectious hepatitis. Save in a situation of the utmost urgency, repeated small transfusions from different donors may create more hazard than that from the original radiation exposure. During the last spring, when nearly 300 Marshall Islands and Task Force personnel were accidentally exposed in a fallout of the type discussed, no transfusions were used although in some cases white blood cell and platelet counts reached disturbingly low levels. With conservative therapy and good nursing, all have recovered and there have been no instances of jaundice or liver involvement.

Gamma and neutron exposures near lethality may also be expected to cause some delayed manifestations. The joint Japanese-American studies by the Atomic Bomb Casualty Commission at Hiroshima and Nagasaki have shown that within the range of neutron flux there is an appreciable incidence of cataracts among the survivors. Also

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among those who apparently received a heavy gamma radiation exposure, there has been a significant increase in myelogenous leukemia. Because of the rarity of this disease, even the increase in frequency of from 10 to 20 times over the Japanese normal would not have been recognized if these studies had not been made over the entire surviving population of the two cities.

A third possible delayed effect of radiation exposure which has been demonstrated in animals is a statistical shortening of life expectancy. This phenomenon does not result from any specific cause of death but apparently from a general acceleration of the aging process. Whether this factor can be recognized in a human population is as yet unknown. For it to become a significant consequence of sublethal radiation exposure, it would seem necessary that all causes of death operating in earlier years would have to be sharply suppressed.

As stated previously, within the region of the detonation and the associated early fallout in the case of surface bursts, the evidence has been overwhelming that the hazard from inhaled or ingested radioactive material is inconsequential compared to the external gamma dose to the whole body and beta-gamma dose to the skin. More remotely, however, after decay of the isotopes of very short half lives, some of radio-elements such as I^{131} become of significance. Because of the surface contamination of foliage and the high rate of assimilation of iodine from the gastrointestinal tract, it is not difficult to demonstrate the presence of such radioactive material in the thyroids of grazing animals for several weeks after a detonation. The amounts acquired by man are in general much smaller than by sheep and cattle in the same areas. The radioactive iodine decays rapidly and the actual radiation exposure, even to the thyroid where the material is concentrated, is only a minute fraction of that capable of producing recognizable damage. The average exposure from this cause to the people of the United States from the fallout of the entire series of tests this past spring was substantially less than 10% of that accepted as permissible for continuous exposure over an entire year.

Somewhat more complicated is the subject of radioisotopes of long half life that enter into biological processes and food chains. Some of these, such as strontium-90 have an especial affinity for the skeleton and thus present a problem somewhat analogous to that of radium. Fortunately, we have a growing mass of precise information concerning the quantitative relations between ingested radium and thorium and the subsequent development of bone pathology.

The most important result of the presence of excessive amounts of radium in the skeleton is the increase in frequency of osteogenic sarcoma and it is presumed that the most important effect of the ingestion of considerable amounts of Sr^{90} would be tumor production. The amount required to produce such an effect is obviously considerable. I estimate that the amount of such material now present over the United States would have to be increased by the order of one million times before an increased frequency of bone sarcoma from this cause could be recognized.

Genetic Effects: Radiation may not only damage the somatic cells but by acting upon certain stages of the germ cells may give rise to alteration of the genes upon which inheritance depends. It appears to be well established that there is no definite threshold for this effect and that there is a linear relationship between the frequency of the gene changes and the total irradiation. At the present time, it seems that the rate at which the radiation is given is a minor and perhaps negligible factor.

The quantitative studies have necessarily been made with relatively high exposures varying from a minimum of 50 roentgens with mice to a maximum of several thousand roentgens in the case of the more resistant fruit fly. Each species has its own range of sensitivity.

If one assumes that the linear relationship which has been experimentally determined holds for all exposures however small, then the extrapolation of the data leads to the conclusion that a small but finite probability exists for gene mutations at the level of the radioactivity of the natural environment. That mutations do occur in all living things is well established and indeed forms the basis for all evolution. At present, however, we do not know to what extent the normal mutation frequency is caused by the radioactivity of the natural environment and what is due to other factors.

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The second area of uncertainty has to do with the ultimate effect of mutation rates on the welfare and survival of populations. Since many of the important mutations appear to be dominant lethals, their estimation has to be based, not upon the recognition of anomalous characters, but on the estimation of the numbers of individuals who should exist but in fact do not. The technique, which is very useful in laboratory experiments with animals, becomes very difficult of application to a human population for obvious reasons.

Some of the mutations may be recessive and consequently not be detectable until at some future time when an individual carrying such a mutant gene should mate with another individual carrying the identical factor.

The mere occurrence of mutations may be only part of the problem. The fate of the mutations in populations is the important question. These mutations will be subjected to the same forces of natural selection that now act against spontaneous mutations.

The extremely complicated and difficult genetic problem in man constitutes a very important section of the studies being conducted in Japan. No firm conclusions can be given until the statistical work is finished but it seems likely that some evidence of genetic effect will have been obtained among the more highly irradiated survivors at Hiroshima and Nagasaki. At the lower exposure rates, it is quite evident that no changes can be recognized.

This genetic problem which is one of the fundamental aspects of the adjustment of man to the world of the future, is sometimes thrown into confusion by reckless and uncritical pronouncements based upon assumptions which go far beyond our knowledge. We have dire predictions of many monsters and even the obliteration of mankind itself from radiation exposures which are only a small fraction of that from cosmic radiation, from the radium and radon of the soil and air, and from the naturally radioactive potassium and carbon of which we all are partially composed. Such distortions of emphasis are comparable to contending that meteors from outer space are a major threat to safety

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on our highways and threaten the survival of all motorists. It is most essential that we keep our perspective in such matters and base our generalizations on substantial evidence.

To summarize this most complicated subject of the medical effects of atomic blasts is simply to restate some of the outstanding aspects. Any future general war may be fought predominantly with nuclear weapons. These are weapons of mass destruction which follow from the clear demonstration of World War II that the outcome of modern war is to a large extent determined by the industrial productivity of a nation and the ability of a people to withstand great losses and yet hold firm.

The fundamental problem is the prevention of war. It is not to be resolved by negotiation dealing with a particular type of weapon.

We must face the tremendous medical and social problems involved in atomic warfare. Not only must we be prepared for blast and thermal casualties on a scale never before conceived in warfare but we must recognize that these weapons may also be used for their radiological effects to deny the continued use for appreciable lengths of time of large areas outside the zones of immediate damage.

The basic scientific and technical knowledge that is necessary is at hand and rapidly growing. Our greatest task at the present time is the further application of this knowledge in our defense systems, both military and civil.

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