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Civil Defense

The Medical Aspects of Atomic and Thermonuclear Warfare

JUSTIN J. STEIN, M.D., and STAFFORD L. WARREN, M.D., Los Angeles

IT IS IMPERATIVE that all physicians, regardless of their particular interest in medicine, learn as much as possible about atomic energy. Whether we approve of it or not, scientific developments based on atomic energy and nuclear research have changed and will continue to change the whole course of our lives and that of nations.

For many years there was considerable apprehension that, with the growing population and economy of this nation, the natural resources of coal, oil and gas would be depleted. With the advent of the new atomic energy discoveries, almost limitless sources are now available to provide fuel and power. Also deposits of thorium, which are more plentiful than uranium and which can be utilized in the production of atomic energy, are constantly being discovered.

It is unfortunate that, at mention of the term *atomic energy*, immediately most people think in terms of atomic and hydrogen bombs and of their great destructive force. Many of the better things to come will result from atomic energy research. The concentration of effort upon peacetime pursuits has really just begun. Surely, then, this great new scientific discovery—the harnessing of the energy in the atom—will stimulate everyone to wonder, to learn as much as possible about it, and to encourage further atomic energy research.

If we are to achieve these developments, we must have peace for a long time ahead. Peace is based on a nation prepared not only to wage atomic war but to defend itself in case of attack. A well prepared civil defense is the key. The data presented here are what every doctor should know.

The present report is in three parts: Part I—The Phenomenology of the A-bomb; Part II—Preparations for Radiological Defense in California; Part III—The Management of Radiation Injuries.

I. The Phenomenology of the A-Bomb

From Einstein's theory of relativity ($E=mc^2$) it is known that mass and energy are interchangeable. At any time there is a decrease in mass as a result of a reaction, then this decrease in mass is converted into energy. In the Einstein equation, E stands for energy, m for mass, and c^2 is the square of the velocity of light.

In an atomic explosion the energy is released by a nuclear rearrangement of a suitable atomic nucleus and the matter is converted into energy. The sum total of the energy released by an atomic or thermonuclear explosion is as follows: Blast, approximately 55 per cent; thermal radiation, 30 per cent; nuclear radiation, 15 per cent, of which approximately 10 per cent is from delayed or residual radiation.

Uranium is the element of highest atomic number that exists in nature. It consists of a mixture of three isotopic forms with mass numbers 234, 235 and 238. When uranium is fissioned, only about 0.1 per cent of its energy is released.

In uranium ore the uranium-238 isotope constitutes 99.282 per cent; uranium-235, only 0.712 per cent; and the remainder is uranium-234. There is only one part of U-235 for 140 parts of U-238.

When neutrons are added to U-235 nuclei, a violent reaction takes place which results in nuclear fission or the splitting of the atom into two parts with the further release of one to three neutrons or an average of 2.5 neutrons with each fission or splitting of the U-235 nucleus (Chart 1). The two parts of the atom which are split off are called fission products. Neutrons are electrically neutral particles present in all atomic nuclei except simple hydrogen. They are about the same weight as protons and are approximately 1,840 times heavier than an electron. With the emission of neutrons in the fission of the U-235 nuclei, gamma rays and beta rays are also produced. Alpha rays may be emitted in the fissioning process but usually they come from unfissioned material.

Plutonium-239, which is a man-made fissionable material, will undergo fission as a result of bombardment by either fast or slow neutrons, just as U-235 does. It emits alpha particles and has a half life of 24,000 years. The half life of U-235 is 7.07×10^8 years (107,000,000 years).

Plutonium is formed as follows:

Plutonium-238 captures a neutron and becomes 239, which has a half life of 23 minutes and decays by the emission of a negative beta particle with

Chairman, Radiologic Safety Advisory Committee, State of California (Warren); Chairman, Committee on Military Affairs and Civil Defense, C.M.A., and member Radiologic Safety Advisory Committee (Stein).

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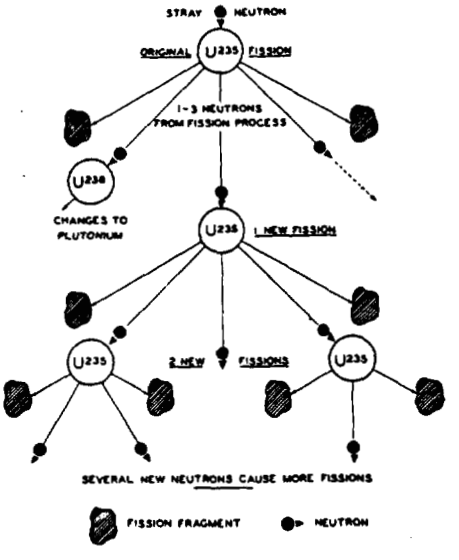
Chart 1.—Splitting or fission of the U-235 nucleus.



neptunium-239 formed, which is a scarce isotope having a half life of 2.3 days. It emits negative beta particles forming plutonium-239 (Pu-239).

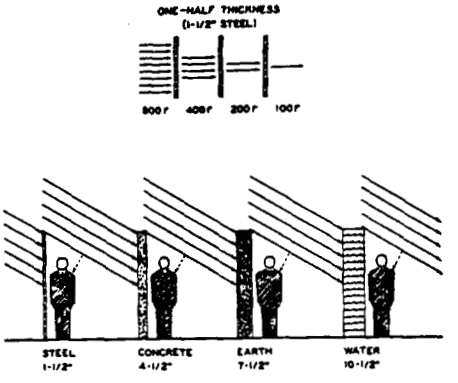
Uranium-235 and plutonium-239 are used in atomic bombs.

It is therefore noted that when the U-235 atom is fissioned or split, neutrons are also produced which help bring about the chain reaction so necessary to cause the explosion. With each fission an average of 2.5 neutrons are added so that if the fissioning or splitting continues a sustained chain reaction may result.

If two unequal parts of U-235 or of Pu-239 can be brought together so that an overcritical mass is formed and held together sufficiently long, the tremendous chain reaction produced in a substantial number of the atoms will result in the production of tremendous heat (more than a million degrees centigrade in a millionth of a second) which will cause the explosion. A critical mass is one in which the number of neutrons being produced is greater than the number necessary to keep the fission reaction going at a fixed rate and when the number is exactly equal to the number of electrons lost.

The efficiency of the bomb will depend upon how long the two fragments of U-235 or Pu-239 can be held together. The more fissioning of the atoms which occurs, the more energy produced. The critical size of a fissionable mass is that amount which is necessary to produce a sustained chain reaction.

Chart 2.—The comparative shielding effects of steel, concrete, earth, and water.



The H-bomb is an open ended weapon because it is not limited in the amount of critical material to be used. Tritium which is used in the hydrogen bomb is produced by irradiating lithium metal in a nuclear reactor.

The "nominal" A-bomb has been the 20 kiloton bomb size. Bombs of this size were exploded over Hiroshima and Nagasaki. Severe damage from this size bomb will cover about 4.6 square miles. The radioactivity produced in this type of bomb at the time of the explosion is equivalent to more than a million tons of radium. Improved A-bombs have been made so that greater efficiency has been obtained.

The hydrogen bombs are spoken of in terms of megatons (one megaton having the explosive equivalent of one million tons of trinitrotoluene). For practical planning purposes in California, the 20 megaton hydrogen bomb is considered as presenting the worst possible disaster. The hydrogen bombs are city-killers. Considerable damage and dangerous levels of radioactivity may be expected out to 20 miles in all directions from the point of explosion, depending upon wind and climatic conditions when the bombs are detonated. There are some observers who believe that, since the improved A-bombs are so effective, there is little need for and few targets worthy of the hydrogen bomb.

Protection from Nuclear Radiation*

Because it has great penetrating properties, nuclear radiation either requires that there be protection by shielding materials or that one be at a considerable distance from the detonation. Time and distance are two very important factors. With greater distances even without protective shielding, one may be completely safe.

*For simplicity, all estimates made here are based on a 20-kiloton bomb, unless otherwise specified.

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TABLE 1.—Comparison of casualties for atomic and conventional bombs

	Hiroshima Atomic Bomb	Nagasaki Atomic Bomb	Tokyo 1,667 Tons TNT and Incendiary	Average of 93 Attacks 1,129 Tons TNT and Incendiary
Population per square mile	35,000	65,000	130,000	.....
Square miles destroyed	4.7	1.8	15.8	1.8
Killed and missing	70,000	36,000	83,000	1,850
Injured	70,000	40,000	102,000	1,830
Mortality per square mile destroyed	15,000	20,000	5,200	1,000
Casualties per square mile destroyed	30,000	42,000	11,800	2,000

The most commonly available materials for shielding against nuclear radiation are steel, concrete, earth and water. The half-thickness† for steel is approximately 1½ inches, concrete 4½ inches, earth 7½ inches and for water 10½ inches (see Chart 2).

It has been estimated that for an air burst of a 20-kiloton bomb at an altitude of 2,000 feet, if an individual was one-half mile from ground zero, it would require 6 inches of steel, or 19 inches of concrete, or 30 inches of dirt to reduce the radiation intensity to 100 r (see Figures 1 and 2). The range of the immediate nuclear reaction does not increase in proportion to the greater energy release of the bomb. In other words, a bomb twice as big does not do twice as much damage.

The bomb may be exploded in the air, on the ground surface, below the ground, and on the surface of or below the surface of water. The manner in which the bomb is exploded will depend upon the type and size of the bomb and, in particular, the military objective. A comparison of casualties for atomic and conventional bombs is shown in Table 1.

Air Burst

An air burst is when a bomb is exploded in the air at such a height that the fire ball does not touch the earth or water surface. A maximum of destructive effect with a minimum of radioactivity remaining in the bomb area can be obtained in this manner. People would be able to enter the bombed area in a matter of minutes following the bomb burst after radiological surveys had been made.

Ball of Fire

A ball of fire with considerably more than 1,000,000°C. of heat in its center is formed in less than a millionth of a second. The intensity of the light is such that the brightness is many times that of the sun at midday. The glare in the sky may be seen for hundreds of miles if the bomb is detonated before sunrise. Within 0.5 of a second the ball of fire measures 900 feet in diameter. At one second it is more than 900 feet in diameter and goes upward at the rate of from 150 to 300 feet per second.

†Half-thickness is that amount of thickness of the material in question which will reduce the radiation intensity by one-half.

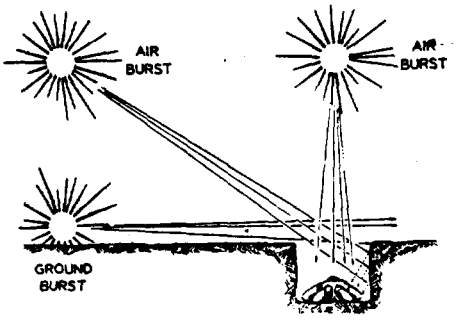

Figure 1.—Foxhole type of shelter of great value except for the overhead bomb explosion.

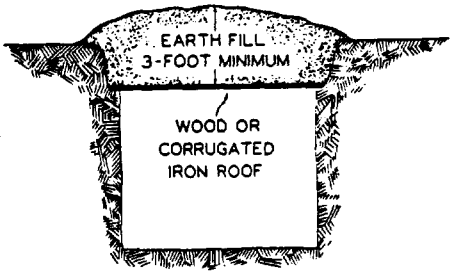

Figure 2.—Three feet of packed earth provides a great deal of protection.

At approximately 10 seconds it is about one-third of a mile from the point of explosion. At about 90 seconds the rising cloud is high enough in the air so that an individual on the ground would be safe from gamma radiation (see Charts 3, 4 and 5).

High winds occur in the immediate vicinity of the explosion, from the updraft; and, depending upon the size of the bomb detonation and the nature of the underlying terrain, various amounts of dirt, rocks and other materials will be sucked up into the rapidly rising column. The top of the rising column consists of radioactive oxides of the fission products, of water vapor and droplets, and of dust and other materials, depending upon the terrain at the site of the detonation. It takes about 8.5 minutes

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Chart 3.—Results of high air burst after 0.5 seconds.

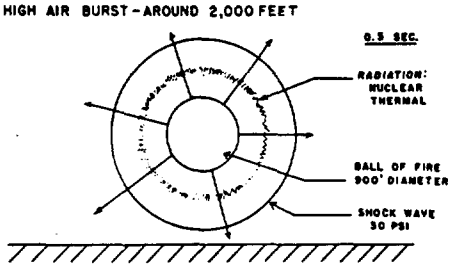
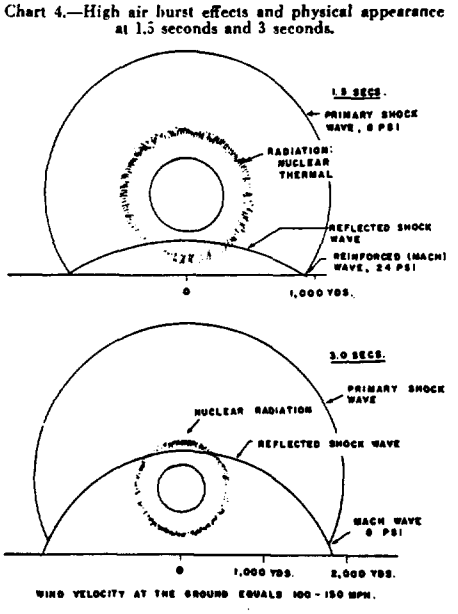


Chart 4.—High air burst effects and physical appearance at 1.5 seconds and 3 seconds.

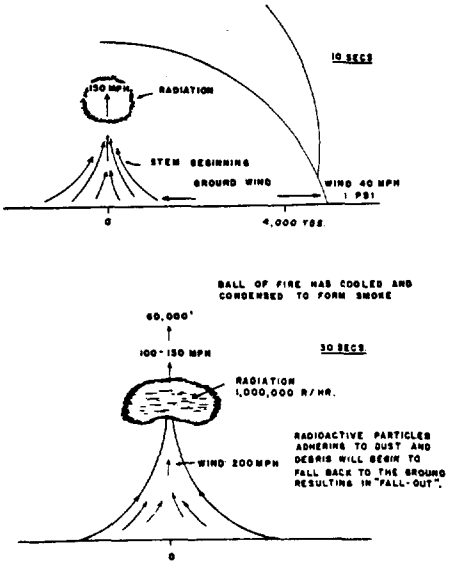


for the atomic cloud to reach 30,000 feet. As the cloud ascends it liberates heat and when it reaches 40,000 to 60,000 feet its temperature is fairly near that of the atmosphere and it will spread out and form the familiar mushroom appearance.

Blast Effect

A shock wave goes out faster from the expanding gases than the expansion of the ball of fire. When the shock wave reaches the ground from a 2,000-foot burst, it may have more than 30 pounds of pressure per square inch (in addition to the normal atmospheric pressure of 14.7 pounds per square inch). This pressure lasts for about one second. It then decreases until it is reinforced by the reflected shock wave at about 1,000 yards in one second. The reflected shock wave is known as the Mach effect, and it increases the pressure to 24 pounds per square inch. At about 10 seconds, or at about 5,000 yards distance, the pressure has dropped to one pound per square inch over that of the normal atmospheric pressure.

Chart 5.—High air burst effects at 10 seconds and 30 seconds.



The instant the shock wave and wind blast have passed with the decreased pressure, a vacuum is formed and the winds are reversed in direction and rush back at lower speeds. This phase lasts for about two seconds.

The effect of the blast will depend upon the size of the bomb and upon prevailing meteorological conditions. Within a radius of one-half mile numerous individuals would die of radiation effects, of trauma from flying objects, and of burns. From one to two miles from the bomb burst there would be radiation injuries, burns, and varying degrees and combinations of different types of trauma. From two to three miles from the bomb burst there would be wounds largely from flying objects.

Thermal Radiation

Flash burns will be produced as far out as two miles and heat can be felt to ten miles. Tremendous amounts of infra-red, visible and ultraviolet light are produced. The intensity of the effects will depend also upon prevailing climatic conditions. The thermal radiation is absorbed in the first three seconds following the explosion. Loose fitting white

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clothing provides more protection than tight fitting dark clothing (Figure 3). The subject of burns is discussed in another paper in this issue.

Nuclear Radiation

The instantaneous radiation consists of gamma rays and neutrons and forms 5 per cent of the 15 per cent of total nuclear radiation. The initial radiation is dangerous to about 2,000 yards. The neutrons travel less than 2,000 yards before they are absorbed in the air. The instantaneous radiations persist for only a millionth of a second and they come from the chain reaction. The alpha particles have a positive charge, low penetrability, and are absorbed in less than 4 inches of air and by thin layers of paper or clothing. The beta rays or particles produced are negatively charged electrons with low penetrability and do not constitute a hazard from the immediate explosion effect. Both the alpha and beta particles may cause serious radiation injuries as a secondary effect from the residual radiation if inhaled or ingested. Skin burns may also be produced.

The delayed radiations comprise about 10 per cent of the 15 per cent total radiations from the bomb. Beta particles and gamma radiation are emitted by the fission products for some time after the bomb is detonated.

Since most of the fission products are either in or around the ball of fire, they ascend with the cloud. Within two minutes after a high air burst the cloud is so far away that there is little danger from radiation unless the wind currents and "fall-out" are unfavorable. As the cloud rises the exposure hazard diminishes by distance and time; since 50 per cent of the gamma radiation is emitted in one second, 80 per cent in the first ten seconds, and practically none after two minutes. Problems associated with the radioactive fall-out will be discussed later.

Surface Burst

A surface burst is one in which the bomb is detonated at or close to the surface. It causes great damage and the blast effect is tremendous, since it is largely outward instead of downward and outward. More thermal radiation is produced and a great cloud of radioactive debris is sucked up into the rapidly ascending cloud. The radioactive metallic oxide particles in the cloud will adhere to the dirt. The contaminated dirt particles in the cloud become contaminated with radioactivity and later fall to the earth, producing what is commonly known as the fall-out.

It would not be safe to enter the bombed area until after studies had been made by radiological monitoring groups. It might be months before one could safely enter the contaminated area to remain for any considerable time.

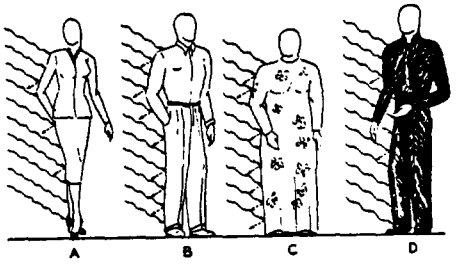

Figure 3.—Loose fitting white clothing provides more protection from thermal radiation than tight fitting clothing.

The ingestion or inhalation of radioactive materials may constitute a great hazard. The beta particles can only penetrate a few millimeters of the intact skin. The deposition of the fission products of plutonium-239 or of uranium-235 in the body is a definite hazard. Thorough washing of the feet, hands, hair and other external surfaces of the body will prevent some of the hazard. It will also help to avoid, if possible, inhalation or ingestion of the radioactive materials.

Packaged food or canned foods can be safely consumed providing the container is intact. Water can usually be safely consumed, especially if there has been a relatively long interval of time between the bomb blast and use of the water. Beef can be consumed if the outer portion has been protected by a cover in some way.

Underwater Burst

In the event of underwater burst, practically all the initial nuclear and thermal radiation is absorbed by the water. There would probably be no direct thermal injuries but there might be many flame injuries from fires aboard ships and in the harbor installations. (See Charts 6, 7 and 8.)

Radioactive Fall-Out

Radioactive fall-out is the term used to describe the great amount of radioactive metallic oxide particles, dirt and debris of all types sucked up into the cloud as it ascends from the earth or from an underwater burst into the sky and which later fall back to the earth or water surface.

What is important in the fall-out is the amount of radioactivity which it contains. The force and direction of the winds, and the atmospheric conditions prevailing will increase or decrease the fall-out hazards. Knowing what the prevailing wind patterns are for any given area and being able to determine them quickly following any bomb burst, is of great importance. The wind patterns are constantly changing and one cannot predict what they will be on any given date.

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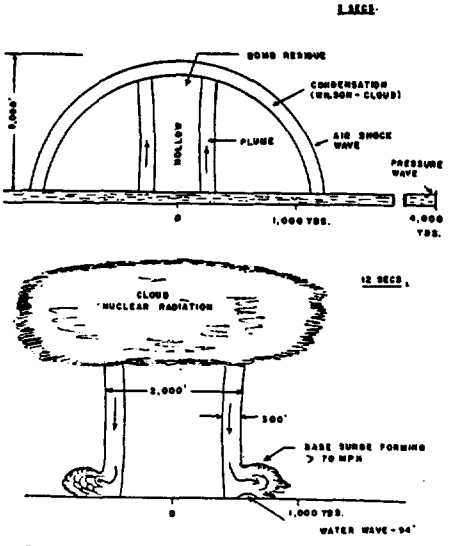
Chart 6.—Results and physical appearance after underwater burst at 2 seconds and 12 seconds.



Recently in discussing the fall-out problem, Libby[3] made the following statement: "The nuclear reactions furnishing the energy in atomic and thermonuclear weapons produce radioactivities as end products. In the ordinary atomic bomb, for each 20,000 tons of TNT equivalent, about two pounds of radioactive materials are produced. In these two pounds are some ninety different radioactive species, varying in natural lifetime from fractions of a second to many years. The mixture as a whole decreases in radioactivity in such a way that for every seven fold increase in age, the radioactivity is decreased ten fold. Thus the radioactivity by seven hours after the explosion has decreased to 1/10 the radioactivity at one hour; at 49 hours to 1/100; at two weeks to 1/1000; and at three months to 1/10,000." (See Chart 9.)

The fall-out pattern can be determined by skilled personnel who have the proper equipment and training. It is very necessary to be able to estimate the pattern, because whole communities may be in the path and with proper warning they could be evacuated, since it may take several hours for the fall-out to reach the ground at a considerable distance. Also, after areas are bombed it can be determined if they are safe to enter and for how long a period of time.

II. Radiological Defense*

It can be safely said that California has one of the finest radiological defense organizations and plans in this country and perhaps the best.

*For brevity: Radef.

Chart 7.—Results and physical appearance after underwater burst at 20 seconds and after 60 seconds.

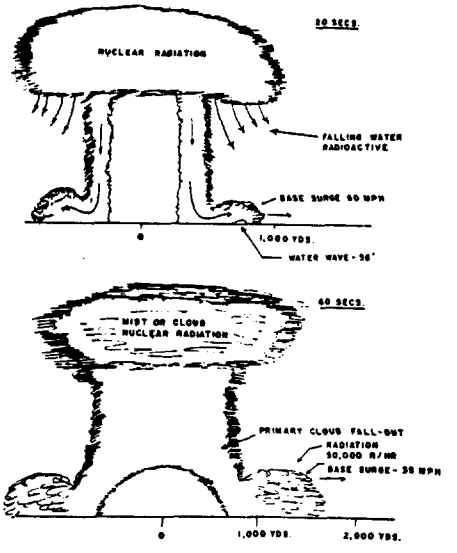
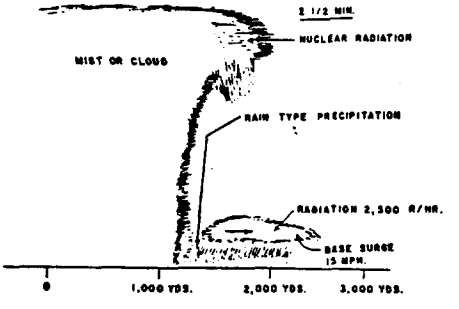


Chart 8.—Results and physical appearance of underwater burst at 2½ minutes.



After the invasion of Korea in June of 1950, and with the formulation of civil defense plans it was decided that radiological defense should be a big factor in the planning. California is highly vulnerable to attack from the air and the sea and has many critical targets.

Basic assumptions are as follows:

1. An enemy exists who is capable of attacking this country.

2. Atomic weapons, guided missiles, high explosives, and sabotage are available to the enemy.

3. The attack could be a surprise one, and if it were an air attack, a certain percentage of the planes could get through to targets here just as our planes could get to critical targets in enemy territory.

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4. All important production, population, military, and harbor centers would be critical targets.

5. Twenty-megaton thermonuclear weapons would be used. (This is a change from earlier assumptions; in the beginning only the 20-kiloton A-bombs were considered in defense planning.)

Effects of the New Weapons

The effects of the 20 kiloton A-bomb have been described in detail. The force of the blast wave of the hydrogen bomb may be 1,000 times as powerful as that of a fission bomb, but the blast and incendiary effects of the hydrogen bomb would be only about ten times as great as those of a fission bomb. The radiation hazards would be increased over the nominal A-bomb but not greatly except for the amount of fall-out produced in surface or subsurface bursts.

Residual Radioactivity

The residual radioactivity with the larger thermonuclear weapons may spread downwind for distances varying from 50 to 300 miles, depending upon the winds. The fall-out path could vary from 10 to 50 miles or more in width.

The hazard of radioactivity could extend out as far as 20 miles in all directions from the bomb center.

Some of the changes in planning following the announcement of the thermonuclear weapons was that about 75 per cent of all first aid equipment should be stored more than 20 miles and preferably 40 miles from the center of critical targets. Also mobile improvised hospital units should be located where feasible, more than 20 miles and preferably 40 miles from the critical target areas.

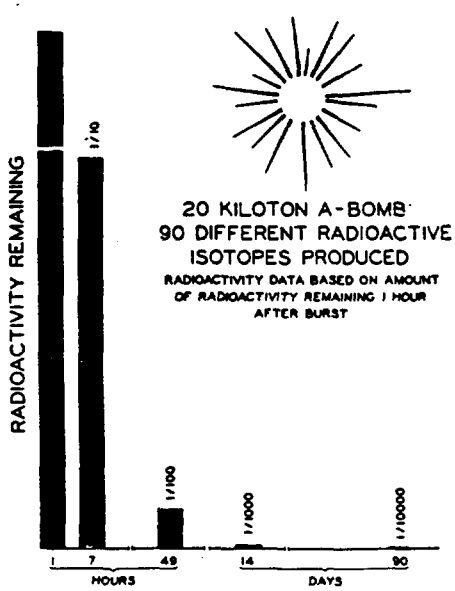
Central Centers

The Radiological Safety Advisory Committee surveyed the state and recommended that, since no single fixed location within the state could be considered safe at all times, there should be at least three control centers established in the northern part of the state and preferably four in the southern part of the state. It was also recommended that mobile communication buses could be used if necessary for this purpose. The purchase of five additional communication buses was recommended to augment the two already in use. Adequate communications are essential to any successful civil defense program and this has been repeatedly demonstrated both in military operations and in natural disasters which have occurred.

Cost of the Program

Since January 1951, approximately $1,100,000 has been spent on radiological defense in California. Almost $400,000 of this sum was spent on radiation detection instruments. Instruments for both training and actual field use have been secured.

Chart 9



Four thousand one hundred and seventy monitoring instruments have been purchased and most of them have been delivered. Five hundred of the instruments have been obtained for use in fixed and improvised hospitals. (Hospital facilities and trained medical personnel will represent our most valuable resource subsequent to an attack. These must not be contaminated with radioactivity from the clothing or by persons coming into the area.)

Sixteen mobile radiological laboratories have been purchased. They are completely self-contained, mobile, radio-chemical laboratories, designed to provide accurate measurements of radioactivity in food, water, air, and soil. They also carry their own communications. (See Figure 4.)

One hundred and five radiological monitor squad trailers were designed by the division staff and constructed at Folsom prison. Each trailer carries all the equipment necessary for a squad of 20 radiological monitors. The equipment includes radiation detection instruments, mobile communication equipment and other materials necessary for efficient squad operation.

How a Problem in Radef Is Handled

Determining the situation with regard to radioactivity can be accomplished as follows:

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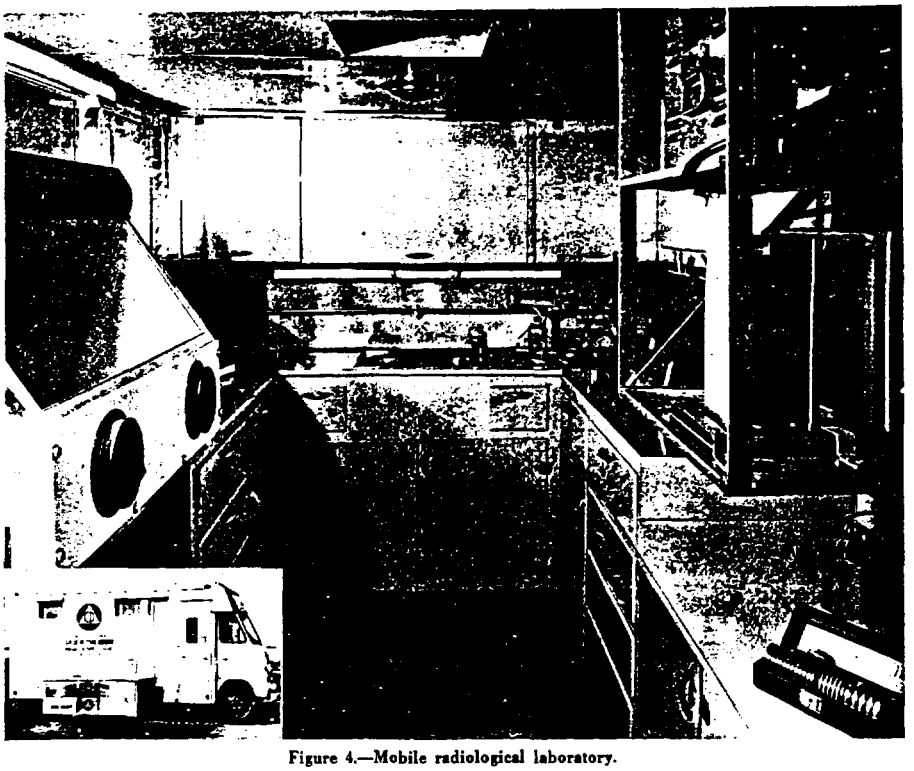

Figure 4.—Mobile radiological laboratory.

1. The protective services of the state, namely, law enforcement, fire control, engineering and utilities, have been given 1500 radiation detection instruments. Selected personnel of those services have been carefully trained in use of the instruments and they have them immediately available in their cars.

In the event of an attack the selected persons would determine the immediate situation in their area and transmit this information to evaluation centers which, in turn, would transmit the information to the designated authorities. This would be the first source of information, since these persons are on duty daily and are usually well dispersed.

2. The volunteer monitors would take over the basic monitoring work as soon as possible. They will be invaluable in the immediate post-attack period and also in the clean-up operations which will be necessary for some time afterward.

The protective services would continue to keep their instruments for use as necessary for their own protection and information while they were busy carrying out their assigned tasks.

3. The personnel of the 63 Division of Highways Maintenance stations have been trained in monitoring and have been issued instruments. Since they are scattered over the state and have fixed installations with instruments immediately available, much valuable information can be obtained from them.

The above plan should be an efficient practical manner in which to obtain enough data to be of value in estimating the fall-out problem and also problems peculiar to any one area.

Training Program

Emphasis has been placed on training in radiological defense. Training courses conducted by the division staff during 1954 alone provided 35 volunteer monitor instructors, 57 protective services monitor instructors, and 23 mobile radiological laboratory specialists. Also, three training courses were conducted for control center and evaluation personnel.

The volunteer monitor instructors who were instructed and assisted by the division staff, in turn trained some 400 volunteer monitors and 5,000 protective service monitors during the year.

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The Radiologist

The radiologist because of his general medical training, his special knowledge of radiation biology and of the clinical effects of radioactivity, will be a most valuable asset to civil defense. He should be encouraged to play an increasingly greater role in civil defense.

Decontamination

The residual radioactivity consists of beta and gamma-emitting fission products and induced radioactive materials. Also alpha particles may be emitted by unfissioned material.

The residual contaminating radioactivity may produce two kinds of hazard. (1) If it remains outside the body and produces localized injuries or it radiates large areas of the body, and (2) If the radioactive material is inhaled, ingested or enters the body through open wounds.

The following are rules and notes applicable in the case of persons and/or areas suspected of being contaminated:

1. Thoroughly cleanse the body and especially the hair, axillae, groins, fingernails and feet and hands (repeated scrubbings if necessary).
2. Monitor suspected areas of contamination.
3. Put on clean clothing.
4. Evacuate affected personnel.
5. Thoroughly cleanse all wounds. Leave wounds open after thorough debridement.
6. All packaged and canned foods may be used if outside containers are cleansed.
7. Even if drinking city water, boil it. The boiling will not remove radioactivity but will make it sanitary. There will be little danger of radioactivity in the water stored in the mains. It should be monitored, however.
8. Neither gamma radiation nor the external radiation from alpha and beta emitters will cause an individual to become radioactive.

1955 Objectives of Radef

With the advent of the thermonuclear weapons, some of the planning and problems to be considered are as follows:

1. Reevaluate previous plans for distribution of instruments and equipment.
2. Revise training goals, particularly with regard to support regions.
3. Increase emphasis on meteorological studies and information.
4. Attempt to obtain additional means of securing immediate post-attack radiological information.
5. Provide assistance and advice for overall Civil Defense planning, as well as for individual civil defense services regarding the atomic and thermonuclear weapons and associated radiation hazards.

III. The Diagnosis and Management of Radiation Injuries

As was stated previously, when either the H-bomb or the fission type of A-bomb in which uranium-235 and plutonium-239 are used is exploded, there is a sudden release of energy in terms of blast, intense heat and light and highly penetrating invisible radiations.

The initial nuclear radiation consists of gamma rays and neutrons. The residual ionizing radiation results in a persistence of radioactive substances, emitting alpha and beta particles and gamma rays.

The initial nuclear radiation, which consists of gamma rays and neutrons, is produced within the first 90 seconds after fission occurs. The two together represent about 5 per cent of the total released nuclear energy.

The residual nuclear radiation which remains after the initial 90 second period consists of the following: Alpha particles from unfissioned material, beta particles and gamma rays from fission products, and materials made artificially radioactive by neutron bombardment.

It must be emphasized that all radiation is damaging to some degree. If the amount of radiation is slight and only a small area of the body is affected, the body cells may recover to such an extent that no obvious damage or cell injury has occurred. For example 5,000 roentgens may be directed all in one treatment to a skin cancer that is one or two centimeters in diameter without doing much injury. However, if 400 roentgens were given to the entire body in one treatment, about 50 per cent of the persons receiving that dose would be dead within 30 days.

It has been estimated that the human body can tolerate a weekly dose of 0.3 roentgens for many years without detrimental injury. Every possible precaution is taken, however, in peaceful pursuits to ensure that no radiation or as little as possible reaches a person in the course of his work with radioactive materials or x-ray generating equipment.

With proper precautions, gamma ray and roentgen rays can be administered to persons who have cancer without producing irreparable tissue injury.

The ionization of tissues or the absorption of the energy from the radiation by the tissues results in the alteration of cell function or in cell death. The effects are largely upon the cell nuclei, then on the cytoplasm; then chromosomal changes, reduction in mitoses, inhibition of enzyme production, changes in cell membrane permeability and other changes. The effects of radiation are greatest during the period of reproduction of the cells. There is still much to be learned about radiation biology, but it is

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TABLE 2.—Summary of clinical symptoms of radiation sickness

Time After Exposure	Lethal Dose (660 r)	Median Lethal Dose (400 r)	Moderate Dose (300-100 r)
	Nausea and vomiting after 1 to 2 hours.	Nausea and vomiting after 1 to 2 hours.	
First week	No definite symptoms.		
	Diarrhea. Vomiting. Inflammation of mouth and throat. Fever.	No definite symptoms.	No definite symptoms.
Second week	Rapid emaciation. Death. (Mortality probably 100 per cent.)		
		Beginning epilation. Loss of appetite and general malaise.	
Third week		Fever. Severe inflammation of mouth and throat.	Epilation. Loss of appetite and general malaise. Sore throat.
Fourth week		Pallor. Petechiae, diarrhea, and nosebleeds. Rapid emaciation. Death. (Mortality probably 50 per cent.)	Pallor. Petechiae. Diarrhea. Moderate emaciation. (Recovery likely unless complicated by poor previous health or superimposed injuries or infections.)

definitely known that the absorption of energy from radiation may produce temporary or permanent injury to one or more biological systems, depending upon the dose given.

The sensitivity of tissues to radiation is usually in the following order: Lymphoid cells, polymorphonuclear and eosinophilic leukocytes, bone marrow, the reproductive organs, salivary glands, skin, mucous membranes, endothelial cells lining the blood vessels and the peritoneum, connective tissue, muscle, bone and nerve cells. The nerve cells are considered to be the most radioresistant.

The radiation changes produced may be early or late. They may be confined to small areas of the body, or, brought about by radiation of the entire body or by the inhalation or ingestion of radioactive materials. Total body radiation in large doses at one time may produce the acute radiation syndrome and cause death in a short time. However, total body radiation may be given in small doses in the treatment of certain types of cancer with little evidence of harm. Similarly radioactive materials may be taken by mouth, with little harm, in the regulated treatment of certain diseases. On the other hand, it may be taken accidentally in harmful doses such as might occur from continuous and repeated exposures to radioactive contamination from the fall-out.

The injudicious use of x-rays and radium by many of the radiologists in the early days resulted in many radiation "burns" or permanent injuries. Also the studies of the radium dial workers who later died of bone sarcoma have been of considerable value in learning about the ultimate effects of the prolonged absorption of the energy of radiations. The probable early effects of acute radiation doses over the whole body are as follows:

Acute Dose	*Probable Effect*
0-25 r	No serious injury
25-50	Possible blood changes but no serious injury
50-100	Blood-cell changes, some injury, no disability
100-200	Injury, possible disability
200-400	Injury and disability certain, death possible.
400	Fatal to 50 per cent of subjects in six weeks.
600 or more	Fatal within a few days to two weeks.

With the acute radiation syndrome (clinical syndrome of radiation sickness) nausea, vomiting, and diarrhea usually occur the first day or two after lethal exposures. Increasingly severe diarrhea, and general malaise and fever follow. The patient may also be relatively free of any severe symptoms for the first few days. Secondary infection is a common terminal symptom. Pharyngitis with symptoms referable to the upper respiratory tract may also occur. In 10 to 14 days epilation may be noted. The exposed person may die from failure of the hemopoietic system within the sixth week, but the length of life and the severity of the symptoms will vary inversely with the amount of exposure to the radiation. A summary of the clinical symptoms of radiation sickness is presented in Table 2.

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Diagnosis

The differentiation of individuals suffering from the acute radiation syndrome or from varying degrees of radiation exposure from those suffering simple shock or combination of trauma and shock, is difficult in the early stages.

If there is leukopenia or a drop in the lymphocytes, the nausea and vomiting, shock and other symptoms are probably not a reaction to merely being in a bombed area but to radiation exposure. If recording monitoring instruments are available, the information they give will be a great help in evaluating the dosage received and the probable prognosis. If all of the individuals in a given area have leukopenia, this will be significant of radiation exposure. Epilation will also be significant of large dosage and of grave prognosis.

Treatment

Although there is a great deal of research under way to find a specific treatment for radiation injury, none has been found. In case of attack, a decision will have to be made whether persons with evidently lethal dosage should receive treatment in the face of overwhelming numbers with little or no exposure to radiation needing all the supplies available. This refers to burns and other trauma.

The following points are of great value in the treatment:

1. Complete rest and food and water are important. The radiated individuals become easily fatigued, and with lowered resistance they are subject to infections.

2. Since infection is common and with a greatly lowered resistance, antibiotics will be of considerable value in patients with sublethal exposure.

3. Transfusions will be of value for persons who have had sublethal exposure, in order to carry them along until the bone marrow recovers the capacity to manufacture enough blood to sustain life.

4. Intravenous feedings for persons who are vomiting and debilitated and unable to take nourishment by mouth.

Individuals react differently to ionizing radiation, and what may be a lethal dose for one may not be for another.

In general, for persons having acute symptoms of diarrhea and bleeding from irradiation within the first two weeks, the prognosis is poor, as it is also for those with purpura and extreme leukopenia in the fourth to sixth week. However, the longer the delay in the onset of evidence of extreme bone marrow damage, the better the prognosis and the more value to be obtained from supportive treatment.

In general, also, treatment for acute radiation injury will not be begun until about the second week, since persons who die sooner probably received dosage for which no treatment would help anyway.

There was very little water, food, shelter or blood, and no antibiotics or general nursing care, for the Japanese who survived the A-bomb blasts. If even good first aid measures had been available, many who died might have been saved.

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