TRANSLATION

THERMONUCLEAR WEAPONS

By M. B. Neyman and K. M. Sadilenko

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THERMONUCLEAR WEAPONS

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Atomic Weapons

The chain reaction of fission of uranium was discovered in 1939. The belligerent countries immediately centered the main scientific research on the mastery of atomic energy. During the period of fascistization of Germany and Italy, and during World War II, many great West European scientists, including atomic scientists, emigrated to America. The United States government used them for work on the development of an atomic bomb in collaboration with American scientists. It was through the collective work of these scientists that the first atomic bomb was, in fact, created. The Italian physicist E.Fermi, who died in the United States at the end of 1954, and the German scientist J.R.Oppenheimer, took a prominent part in this work.

Before considering thermonuclear weapons, let us familiarize ourselves with the first and best known form of the nuclear weapon, the atomic bomb. Since the chain fission of uranium that takes place in the atomic bomb is utilized as a "primer", i.e., as the means of initiating a thermonuclear explosion, let us dwell in somewhat more detail on the operating principles of the atomic bomb.

The property of nuclear "explosives" of exploding spontaneously as soon as the critical mass is reached, is utilized to build the atomic bomb. Several lumps of uranium or plutonium, each of which is below the critical mass and cannot explode, are used. At the intended instant for detonation, these chunks in the atomic bomb are rapidly brought together, and the explosion takes place immediately.

Figure 8 is a schematic diagram of the layout of an atomic bomb.

Inside the atomic bomb is a plutonium sphere surrounded by a substance that reflects neutrons. The mass of the sphere is less than critical. Another chunk of plutonium is in the form of a cylinder of such dimensions that it can be placed inside a channel in the plutonium sphere, to yield a solid sphere of critical mass. A device charged with a conventional explosive, on its explosion, is able to impart a jolt to this cylindrical piece of plutonium.

In order to cause the atomic bomb to explode under certain conditions, for instance at a predetermined altitude, a detonator, which may operate on the barometric principle, the time-delay principle, or on any other principle, is placed in the atomic bomb. Everyone knows that a barometer indicates the altitude of a given locality above sea level. On descent of the bomb, the pointer of the barometric detonator is deflected and, at a predetermined altitude, closes an electric circuit inside the bomb, thus producing an electric spark which ignites a cap setting off a conventional high explosive in the atomic bomb. When the high explosive is detonated, it forces the cylindrical chunk of plutonium into the channel; the critical mass is formed, the fission chain reaction commences, and explosion occurs.

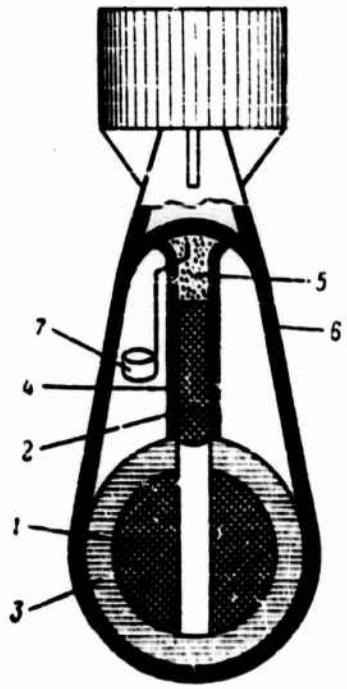

Fig.8 - Schematic Diagram of Atomic Bomb (Charge Divided into Two Parts):

1 - Plutonium sphere;
2 - Plutonium cylinder;
3 - Neutron reflector;
4 - Guide channel; 5 - Conventional high explosive;
6 - Bomb casing; 7 - Detonator

To shorten the time required for development of the chain reaction and to increase the number of nuclei fissioned, the plutonium sphere is surrounded with a substance that reflects the neutrons emitted. With such an arrangement of the bomb, the explosion is generated inside of a few millionths of a second, that is, practically instantaneously.

To increase the effectiveness of the atomic bomb, besides a strong casing which slows the scattering of the nuclear fuel, and a neutron reflector, a neutron source may also be placed at the center of the bomb. Such a source naturally accelerates the development of the chain reaction in plutonium when the mass of the latter exceeds the critical mass, and ensures certain explosion, at the predetermined instant.

The neutron source used in laboratories, for example, is an intimate mixture of beryllium and polonium. Polonium is radioactive and emits alpha-particles on disintegration. The alpha-particles penetrate the beryllium nuclei, and the following reaction takes place, forming a carbon nucleus, with emission of a neutron:

$$_4Be^9 + {}_2He^4 = {}_6C^{12} + {}_0n^1$$

In all types of atomic weapons, the principal parts of the design are as follows: 1) nuclear fuel (atomic charge); 2) a neutron reflector surrounding the atomic charge; 3) conventional high explosive whose explosion rapidly brings the parts of the atomic charge together; 4) a detonator; 5) the bomb casing. An additional neutron source is ordinarily placed in an atomic bomb.

When uranium or plutonium atoms are split, the "fragments" formed fly out at an immense speed, about 30,000 times as fast as a rifle bullet. The path of these "fragments" is short. Its length in air is 2 cm, since the "fragments" collide with the molecules in air and readily lose speed. In denser substances, the path of the "fragments" is only fractions of a millimeter. As a result of collisions with the atoms of the bomb substance, the "fragments" rapidly slow down. The energy transferred by the "fragments" to the atoms and molecules of the nuclear substance are liberated in the form of heat - the temperature rapidly rises to several million degrees. With the rising temperature, the pressure sharply increases. Consequently, forces arise which tend to expand the nuclear charge, burst the surrounding casing, and dissipate the bomb material. If the velocity of the reaction is substantially higher than the rate of this dissipation, then most of the explosive will have time to explode. If velocity of the reaction is low, then only a small part of the explosive will have time to "burn", while the rest will be hurled out in various directions and will not have time to react. Thus, to increase the explosive utilization factor, the speed of development of the explosive process must be increased and the rate of divergence decreased.

How can the rate of development of the explosive chain reaction in a plutonium charge be increased? For this purpose, the charge is surrounded with a neutron reflector designed to return the outward-traveling neutrons to the sphere of reaction.

To decrease the rate of dispersion of the plutonium, the atomic bomb is provided with a strong casing.

It is believed that only 2% of the nuclei in the atomic bombs dropped on Japan had time to fission, while the remaining nuclei were scattered without fission. In modern atomic bombs, a considerably larger proportion of the plutonium atoms (tens of percent) have time to enter the fission reaction.

The first atomic bomb was exploded in July 1945 at a test field in the United States. A massive steel tower 33 m high (about as high as an eight-story house) was built for the test. The first atomic bomb was attached to the top of this tower. The bomb was exploded by ignition of a blasting cap by an electric current, which flowed when the circuit was closed at the control station several kilometers from the tower.

Atomic bombs were then dropped on Japanese cities.

One of the atomic bombs was dropped on the Japanese city of Hiroshima. This bomb was exploded at an altitude of 300 m above the city. The bomb was made of uranium-235. Another bomb, made of plutonium, was dropped on Nagasaki (exploded at an altitude of 600 m).

At present, atomic bombs are apparently no longer made of uranium-235, but of plutonium-239 which is produced in considerable amounts and is more readily available.

Each atomic bomb dropped on Japan killed tens of thousands of people within a few seconds, due to the action of the shock wave. Many people also died from the fatal burns received from the direct action of the thermal radiation of the explosion, or from the fires started by it. Many Japanese were killed by radiation sickness induced by the effect of penetrating radiation. Many survivors were maimed or

blinded (some of them only temporarily) from the unusually bright flash.

The bomb destroyed more than half the houses at Hiroshima and Nagasaki. Many of the houses still left standing were damaged.

The blast energy of atomic bombs is usually compared with the explosion energy of the widely used explosive trinitrotoluene (trotyl or tola). The explosion of the first atomic bomb is considered equivalent to the explosion of 20,000 tons of TNT. The weight of the TNT charge of an explosion energy equal to that of a given atomic bomb is called its TNT equivalent. The TNT equivalent of the first atomic bomb, consequently, was 20,000 tons.

The Americans call an atomic bomb with this TNT equivalent a nominal bomb, and use it as a comparison standard for the explosions of atomic and thermonuclear bombs of various power.

The atomic bombs in existence today differ considerably in power. What methods are used to increase or decrease the power of a bomb?

If there are only two chunks of nuclear fuel in an atomic bomb, and the atomic explosion takes place on their contact, then the total weight of the nuclear fuel in the bomb must be less than twice the critical mass. This follows from the fact that the mass of each chunk of nuclear fuel must be less than critical? Is it not possible, by some method, to explode a mass considerably greater than critical The active mass of nuclear fuel in a bomb can be increased only if the explosion takes place as a result of the combination, not of two or three but of a large number of chunks of nuclear fuel. Such an increase in the charge of an atomic bomb can be accomplished, for example, by using the layout schematically shown in Fig.9.

The inner spherical surface of the thick casing of the atomic bomb carries a number of explosive charges in the form of spherical concave lens. On simultaneous detonation of these charges, the resultant jets of gas, directed perpendicularly to the surface, will be concentrated in a single point, namely the center of the bomb.

If portions of nuclear fuel, in the shape of spherical biconvex or concavo-

convex lenses are placed on the surface of these charges, and the same number of corresponding portions of nuclear fuel are placed opposite them in the central part of the bomb, and if all the explosive charges are then simultaneously exploded, the explosion will result in pairwise collisions of the portions of nuclear fuel (on the diagram, the directions of the flying masses of plutonium are shown by arrows). The operating principle of the atomic bomb, in which an inward-directed controlled explosion takes place, is called implosion. Here the total amount of nuclear fuel may considerably exceed the critical mass, so that the power of the atomic explosion can be several times as great as the explosive power of the first atomic bombs. To increase this power still more, the bomb casing may be made of natural uranium. At the high temperature of the explosion, fast neutrons are able to split the uranium nuclei in the bomb casing, thus liberating a large additional amount of energy.

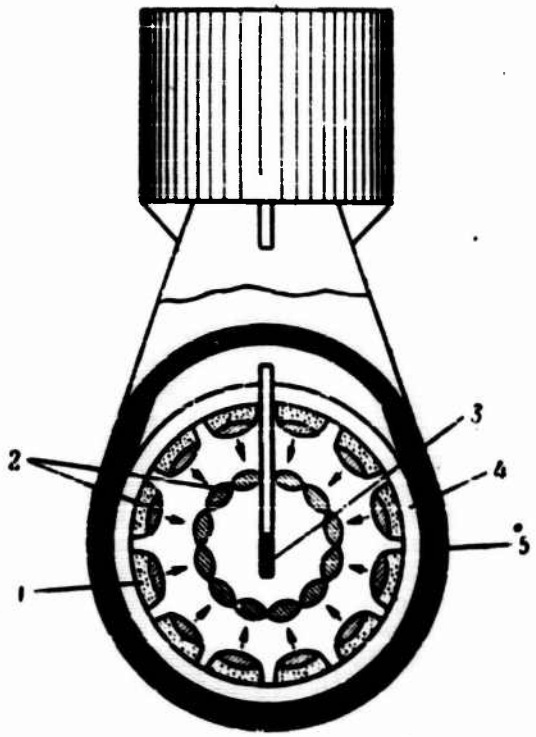

Fig.9 - Schematic Diagram of Atomic Bomb (Charged Divided into Several Parts):

1 - Explosive material; 2 - Plutonium; 3 - Neutron source; 4 - Neutron reflector; 5 - Casing

Atomic weapons have been continuously improved since they were first created. The first atomic bomb had a TNT equivalent of 20,000 tons, but today atomic bombs with a TNT equivalent from several thousand tons, up to 500,000 tons, are known. The improvement also centered on finding new schemes and materials to increase the

utilization factor of the atomic charge and to decrease its critical volume and mass.

The creation of effective neutron reflectors and the use of artificial neutron sources now make it possible to accomplish an explosive fission chain reaction in very small volumes and masses of the charge.

Modern nuclear weapons may be divided into two types: atomic and thermonuclear. Atomic weapons may in turn be divided into two forms: 1) explosive atomic weapons and 2) radiological warfare agents (ERV).

The only thermonuclear weapons known are of the explosive type.

Radiological warfare agents may be various radioactive substances emitting rays capable of injuring the human organism. These substances may be delivered by aerial bombs, artillery shells, rockets, and reaction mines. Radiological warfare agents may be scattered from aircraft in the form of smoke, mist, or dust. A retreating enemy, or his diversionists in the rear, may use radiological warfare agents to contaminate reservoirs, wells, and food products.

Many "wastes" of nuclear (atomic) reactors may be used as radiological warfare agents. These reactors are devices in which atomic energy is gradually liberated.

In nuclear reactors, natural or enriched uranium is used as atomic fuel. The "fragments" of uranium and plutonium atoms formed during a chain reaction in a nuclear reactor consist of nuclei of various radioactive atoms. Of the more than 300 different radioactive isotopes formed in a reactor, only a few, characterised by a long half-life and emitting beta-particles or gamma-rays on disintegration, can be used as radiological warfare agents. A list of such isotopes, together with their radiation energy, is given in Table 1. The energy of beta- and gamma-rays is given in megaelectron volts*.

Besides the fission "fragments" of uranium or plutonium, radioactive isotopes

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*An electron-volt (ev) is the energy acquired by an electron moving between electrodes to which a potential difference (voltage) of 1 v is applied. A million electron-volts is known as a megaelectron-volt, abbreviated as Mev.

which can be produced in nuclear reactors by neutron bombardment of a number of stable elements, can also be used as radiological warfare agents.

Table 1

Characteristics of Several Isotopes Formed in Nuclear Reactors

Name of Isotope	Half-Life	Abundance in the Mixture of "Fragments", in %	Radiation Energy, in Mev	
			Beta	Gamma
Strontium-89	54,5 days	4,6	1,46	—
Strontium-90	25 years	5	0,61	—
Yttrium-91	57 days	5,9	1,53	—
Zirconium-95	65 days	6,4	0,36—0,91	0,23—0,92
Columbium-95	37 days		0,15	0,02—0,77
Ruthenium-103 . . .	40 days	3,7	0,14—0,70	0,04—0,61
Iodine-131	8 days	2,8	0,25—0,81	0,08—0,72
Cesium-137	33 years	6,2	0,50—1,18	0,66
Barium-140	13 days	6,1	0,48—1,02	0,01—0,54
Cerium-141	28 days	5,7	0,1 —0,58	0,15—0,32
Cerium-144	282 days	5,3	0,31—0,45	0,03—0,23
Praseodymium-143 . .	14 days	4,3	0,92	—
Neodymium-147. . . .	11 days	2,6	0,38—0,82	0,09—0,53

Thus, when ordinary sodium is placed in a reactor, its nuclei absorb neutrons, forming a radioactive isotope of sodium over the reaction:

$$_{11}Na^{23} + _{0}n^{1} = _{11}Na^{24}$$

Radiosodium Na^{24} disintegrates, ejecting a beta-particle of energy 1.4 Mev (fast electron), and is transformed into the stable magnesium isotope Mg^{24} which, at the instant of its formation, emits high-energy gamma-rays (1.4 - 2.8 Mev). The half-life of Na^{24} is 15 hours.

On introduction of calcium, zinc, cobalt, and certain other elements into a nuclear reactor, radioactive isotopes are formed over the reactions:

$$_{20}Ca^{44} + {}_0n^1 = {}_{20}Ca^{45}$$

(half-life T = 163 days; energy of beta-rays 0.24 Mev);

$$_{27}Co^{59} + {}_0n^1 = {}_{27}Co^{60}$$

(T = 5 years, energy of gamma-rays 1.3 Mev);

$$_{30}Zn^{64} + {}_0n^1 = {}_{30}Zn^{65}$$

(T = 250 days, energy of gamma-rays 1.1 Mev).

Some of the isotopes so formed (for instance the isotope Co^{60} and Zn^{65}) disintegrate relatively slowly, emitting high-energy gamma-rays, and for this reason may be suitable for use as radiological warfare agents.

Combination weapons, chemical and atomic, may also be used. Examples are aerial bombs loaded with a mixture of radioactive poisons and ordinary poisons.

The use of radioactive incendiary devices to produce physiological damage by radioactive smoke is not impossible, for instance, aerial bombs or missiles in which part of the total charge consists of radioactive substances. The use of radioactive incendiaries will complicate the extinction of fires and the treatment of burns.

In recent years, a new form of atomic weapon has acquired great significance, namely thermonuclear bombs, which have a TNT equivalent considerably higher than that of plutonium bombs, and therefore have a greater radius of action. The TNT equivalent of thermonuclear bombs reaches several million tons, and even tens of millions of tons.

The transport and combat vehicles using atomic energy for motive power include the first atomic submarines. The world's first atomic icebreaker "Lenin" has been launched in the USSR.

The foreign press states that by 1960 seagoing ships of all types, powered by atomic energy, will have been built. The first light atomic cruiser is scheduled for completion by 1959, and the first atomic aircraft carrier by 1961. A 22,000-hp

atomic engine has been designed and is being built for a tanker of 38,000 tons displacement. It is planned to put the tanker into operation in mid-1959.

Atomic locomotives and aircraft are also possible. An aircraft with a low-power experimental nuclear reactor, installed in the nose section, has already flown. For the safety of the population, the reactor was operated only while the aircraft was flying over a specially designated area. The takeoff and landing were accomplished with the reactor inoperative. Precautionary measures to exclude the possibility of a reactor explosion during an aircraft accident were also taken.

Chapter 3

THERMONUCLEAR WEAPONS

In order to induce thermonuclear reactions on the earth, extremely high temperatures must be produced by the aid of some source, which latter must be surrounded with light nuclei capable of entering nuclear interactions. The explosion of an atomic bomb can, in particular, serve as such a source. It is on this principle that the so-called hydrogen bomb has been constructed. Let us familiarize ourselves with its layout.

The Hydrogen Bomb

Figure 13 is a schematic diagram of the layout of a hydrogen bomb. At the center is the atomic bomb (1). Its explosion creates a focus of high temperature (over 10 million degrees). The atomic bomb is surrounded by the substance (2), consisting of atoms with light nuclei, which enter into a thermonuclear reaction under the influence of the high temperature developed by the explosion of atomic bomb.

In contrast to uranium and plutonium, the thermonuclear fuel (deuterium, tritium, lithium, etc.) has no critical mass. For this reason, the size of the surrounding atomic "trigger" of light nuclear explosive is unlimited in principle.

The fission of all the nuclei contained in 1 kg of uranium-235 or plutonium is accompanied by the liberation of over 20,000 billion calories. The same energy can be liberated on the complete transformation of about 150 gm of hydrogen into helium. Obviously the energy liberated on explosion of a hydrogen bomb, whose weight is not

limited by a critical mass, may be hundreds and thousands of times as great as the explosive energy of an atomic bomb. This of course does not mean that the radius of destruction from the explosion of a hydrogen bomb will likewise be several hundreds or thousands of times greater than that of the destruction caused by the explosion of an atomic bomb. In reality, the radius of destruction from the explosion of a hydrogen bomb does not increase as rapidly. For example, the radius of destruction on the explosion of a hydrogen bomb with a TNT equivalent of 10 megatons would not be 1000 times as great as the radius of destruction of the shock wave from the explosion of an atomic bomb with a TNT equivalent of 10,000 tons, but only about 10 times as great.

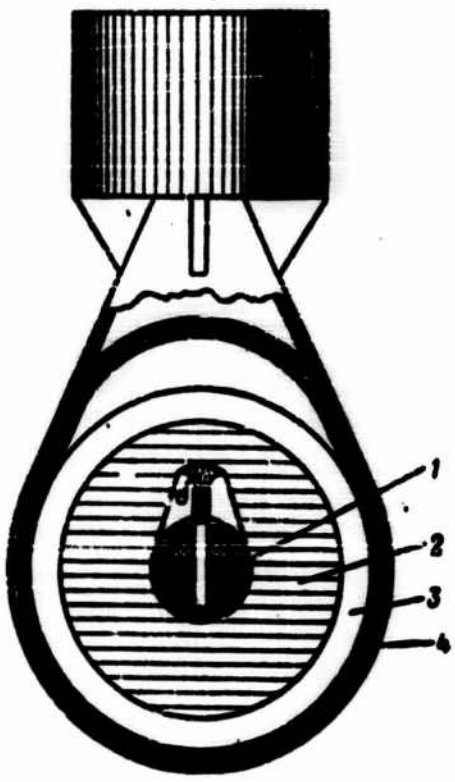

Fig.13 - Schematic Diagram of Hydrogen Bomb

1 - Atomic bomb; 2 - Mixture of deuterium, tritium, and lithium; 3 - Reflector; 4 - Bomb casing

In the design of a hydrogen bomb, the propagation of the explosion is accelerated more than the dissipation of the charge, in order to increase the utilization factor of the plutonium and thermonuclear fuel.

As stated in the foreign literature, the advantages of the hydrogen bomb over an atomic bomb include:

1) Relatively low cost of damage per unit area;

2) Existence of considerably greater natural resources of hydrogen and lithium than of uranium and thorium;

3) Practically no upper limit on the size of the explosive charge, thus permitting construction of hydrogen bombs with large TNT equivalents.

The disadvantages of the hydrogen bomb include:

1) Difficult tactical application;

2) Impossibility of extended storage of hydrogen bombs containing tritium because of the spontaneous radioactive disintegration of this hydrogen isotope;

3) Necessity of secure protection for the expensive aircraft used as carriers of nuclear weapons, for the arsenals of such weapons, etc.

Possible Thermonuclear Reactions

Since the time from the initial explosion to the dissipation of the bomb material is of the order of millionths of a second, the mean duration of the reactions, at the temperatures and pressures produced by an atomic explosion, must likewise be no longer than millionths of a second, in order to realize the hydrogen bomb.

The literature contains very detailed discussions on the thermonuclear reactions of hydrogen, its heavy isotopes deuterium and tritium, and two lithium isotopes: lithium-6 and lithium-7. Table 4 contains a list of these reactions, giving their thermal effect in thousand million calories per gram-atom*, the TNT equivalent in thousand tons per kilogram of charge, and the reaction time at temperatures of 20 million degrees.

In considering the possibility of the extensive use of a given nuclear reaction in a hydrogen bomb, a number of circumstances must be taken into account. The most important are: availability and low cost of the "explosive", possibility of inducing thermonuclear reactions at the temperature of the atomic "trigger", and amount of energy liberated by such a reaction. The greater this energy, the greater will be

*A gram-atom is the number of grams of a given substance numerically equal to its atomic weight. Thus, 1 gram-atom of hydrogen weighs 1 gm, 1 gram-atom of helium weighs 4 gm, and 1 gram-atom of uranium-235 weighs 235 gm.

the temperature rise, the more easily will it be maintained, and the more powerful will be the action of the explosion.

For comparison, the Table also gives data on the fission of uranium and plutonium. The hydrogen isotopes H^1, H^2, and H^3 are denoted by H, D, and T.

Table 4

Characteristics of Certain Thermonuclear Reactions

No.	Nuclear Reaction	Thermal Effect in Thousand Million Calories per Gram-Atom	TNT Equivalent in Thousand Tons per 1 kg*	Energy Liberated by 1 kg of Substances Participating in the Reaction, in kcal	Duration of the Reaction at a Temperature of 20 Million Degrees
1	$H + H = D + {}_1\beta^0$	34	1,8	$1,65 \cdot 10^{10}$	10^{11} years
2	$H + D = {}_2He^3$	120	6,2	$3,9 \cdot 10^{10}$	0,5 sec
3	$H + T = {}_2He^4$	480	23,5	$11,7 \cdot 10^{10}$	0,05 sec
4	$D + D = {}_2He^3 + {}_0n^1$	79	3,9	$1,93 \cdot 10^{10}$	0,00003 sec
5	$D + D = H + T$	96	4,7	$2,35 \cdot 10^{10}$	0,00003 sec
6	$D + T = {}_2He^4 + {}_0n^1$	420	17,6	$8,2 \cdot 10^{10}$	0,000003 sec
7	$T + T = {}_2He^4 + 2{}_0n^1$	270	12,2	$4,4 \cdot 10^{10}$	—
8	${}_3Li^6 + D = 2{}_2He^4$	540	67	$1,2 \cdot 10^{10}$	—
9	${}_3Li^6 + T = 2{}_2He^4 + {}_0n^1$	380	42	$6,6 \cdot 10^{10}$	—
10	${}_3Li^7 + H = 2{}_2He^4$	410	51	$4,65 \cdot 10^{10}$	1 min
11	${}_5B^{11} + H = 3{}_2He^4$	190	9,2	$5,0 \cdot 10^{10}$	3 days
12	Fission of uranium or plutonium	4800	20	$2,0 \cdot 10^{10}$	—

*In the third column, the energy of reactions 1 - 7 is given in terms of the TNT equivalent per kilogram of explosive, based on the weights of heavy and superheavy water, instead of that of the free isotopes of hydrogen.

As will be seen from the Table, thermonuclear reactions differ greatly in their

duration, from millionths of a second to tens of thousand millions of years. The thermal effect ranges from 34 to 540 thousand million calories per gram-atom, with a maximum difference of about 16 times.

With rising temperature, the speed of thermonuclear reactions increases. Figure 14, as an example, shows how the velocity of thermonuclear reactions between

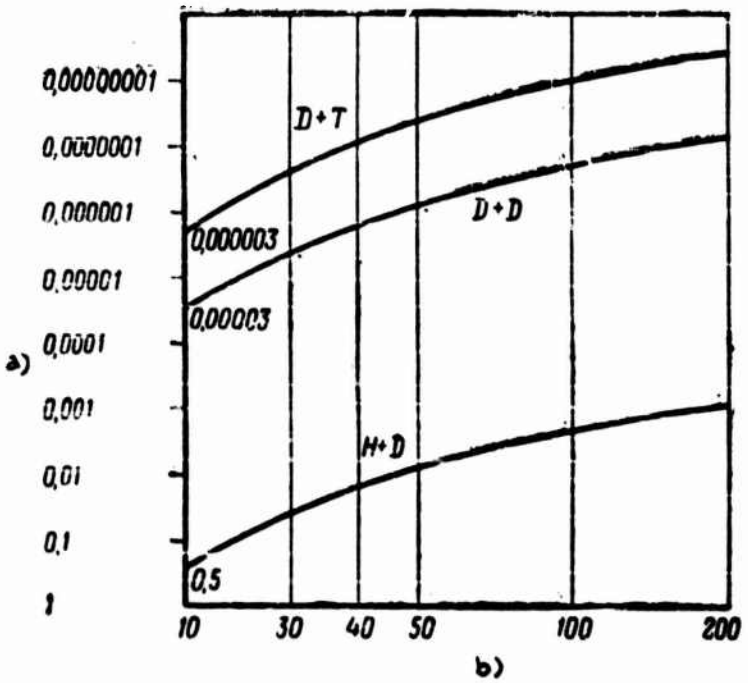

Fig.14 - Relation between Duration of Several Nuclear Reactions and Temperature

a) Reaction time (seconds); b) Temperature (millions of degrees)

hydrogen isotopes increases and their time accordingly decreases, when the temperature rises from 10 million to 200 million degrees. It will be seen from the curves of the diagram that, even at temperatures considerably higher than 10 million degrees, the reactions H + D and D + D do not proceed fast enough to be utilised for building a hydrogen bomb. The reaction between deuterium and tritium nuclei, to give helium and a neutron, is the thermonuclear reaction most easily induced.

Of the substances listed in Table 4, the natural elements - hydrogen and lithium - are of course the most readily available. A natural mixture of hydrogen isotopes usually contains only about 0.016% of deuterium and hardly any tritium. Natural lithium consists of 92.6% of lithium-7 and 7.4% of lithium-6.

Composition of the Nuclear Fuel of the Hydrogen Bomb

The most effective thermonuclear reaction at temperatures of the order of 10 million degrees, produced by the explosion of an atomic detonator or "trigger" is the reaction No.6 in Table 4, between deuterium and tritium. The high density of a mixture of deuterium and tritium can be obtained either by using highly compressed gases, or by using liquid isotopes, which demands very low temperatures. Finally, one may utilize chemical compounds of hydrogen isotopes. It should be remembered here, however, that all additions of heavier nuclei lead to a sharp increase in heat capacity, make it difficult to maintain high temperatures, and in this case make it necessary to increase the temperature produced by the "trigger".

Among the hydrogen compounds in which deuterium and tritium may be introduced into the bomb, heavy water and superheavy water (with the respective formulas D_2O and T_2O) are simple and available. Hydrogen does not participate in these thermonuclear reactions. It lowers the temperature attainable in the explosion, and increases the total ballast weight of the explosive. It was therefore desirable to use as thermonuclear fuel, not heavy water and superheavy water, but deuterium and tritium in liquid form.

However, to hold these gases in the liquid form, a low temperature must be maintained. Special double-walled vessels have to be built for this purpose.

The air is evacuated from the space between the walls, thus decreasing the inflow of heat. Such a vessel is placed inside the second vessel of similar design, filled with liquid nitrogen, which has a temperature of about -190°C. The liquid hydrogen, deuterium or tritium, kept at a temperature of about -250°C, is placed in

the inner vessel. Hydrogen evaporates relatively fast, even from such vessels. Such devices are to be found only in a few well-equipped laboratories. The use of devices of this type in a hydrogen bomb would obviously be quite inadvisable.

The lightest element capable of giving a solid compound with hydrogen is lithium, and the resultant compound - lithium hydride (LiH) - is a light solid crystalline substance, resembling ordinary salt in appearance, but chemically very active. Since there are two lithium isotopes and three hydrogen isotopes, six lithium hydrides of different isotopic composition are obviously possible. Table 5 gives their formulas.

Table 5

Lithium Hydrides

Isotopic Composition		Formula of Lithium Hydride
Lithium Isotope	Hydrogen Isotope	
Lithium-6	protium (ordinary hydrogen)	Li^6H^1
Lithium-7	protium	Li^7H^1
Lithium-6	deuterium	Li^6H^2
Lithium-7	deuterium	Li^7H^2
Lithium-6	tritium	Li^6H^3
Lithium-7	tritium	Li^7H^3

In designing a hydrogen bomb, the volume occupied by the thermonuclear fuel, and the weight of the casing in which it is placed, are of great importance. Figure 15 gives an idea of the relation between the volumes occupied by 1 kg of deuterium in liquid form, in the form of a gas compressed to 200 atm, in the form of heavy water, and in the form of a compound with lithium, lithium deuteride. The advantage of heavy water and lithium hydride, in volume occupied, will be obvious from the sketch.

One must also point out the unsuitability of compressed hydrogen, which must be

stored in steel cylinders weighing many tens of times more than the hydrogen they contain.

The above considerations show that it is expedient to use hydrogen isotopes in thermonuclear weapons in the form of chemical compounds rather than in the free form.

Of the thermonuclear reactions discussed in the literature, those shown in Table 4 are basic for possible use in a hydrogen bomb.

Of all the substances enumerated, as already stated, a deuterium-tritium mixture can most easily be exploded. But the manufacture of large hydrogen bombs based

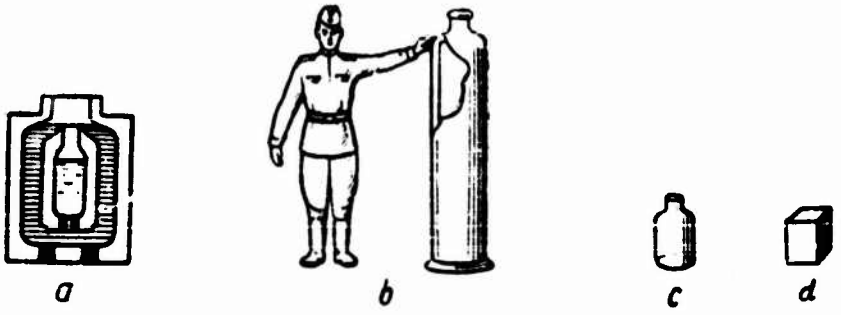

Fig.15 - Volumes Occupied by 1 kg Deuterium in the Form of Liquid Deuterium (a), Compressed Gas (b), Heavy Water (c), and Lithium Deuteride (d)

on tritium is improbable, owing to the high cost of tritium and the difficulty of preparing it in large amounts. On the other hand, even reactions Nos.4 and 5 with deuterium, to say nothing of reactions Nos.8 - 10 with lithium, demand an initial temperature of the order of tens of millions of degrees, which could hardly be provided by an atomic "detonator". It must therefore be considered that tritium is used in modern hydrogen bombs only as an exciter, assuring a further rise in the temperature and the possibility of reactions with the participation of hydrogen, deuterium, and the two isotopes of lithium.

In the light of all the above, the action of hydrogen bombs may be presented as follows: At first there is a chain explosion inside the bomb, due to the fission re-

action of uranium or plutonium. If the fission were to affect all the uranium or plutonium, and all the energy were converted into thermal energy, then the temperature would reach hundreds of millions of degrees. In reality, however, the temperature is many times lower, because only a small part of the "detonator" is fissioned, and only part of the fission energy is liberated in the form of heat.

For this reason, according to present literature information, the temperature generated by the explosion of an atomic "detonator" can only ensure the rapid progress of the thermonuclear reaction of deuterium with tritium. In a mixture of these hydrogen isotopes, the reaction proceeds to a marked degree inside of a few millionths of a second, and the temperature rises sharply reaching tens of millions of degrees, which could ensure the occurrence of reactions Nos.4, 5, 8, 9, and 10. Among the latter reactions, reaction No.10 is of greatest interest, because of the fact that it is accompanied by great heat liberation and takes place in ordinary lithium hydride, a substance that is cheap and available in large amounts.

When the thermonuclear reaction takes place in lithium hydride, the temperature can rise still further. Of course, in the case of a further rise of the temperature to hundreds of millions of degrees or more, thermonuclear reactions with the participation of heavier elements, for example, boron, beryllium, carbon, nitrogen, and oxygen, can also be realized. One must, however, note that the thermal effects of these reactions are smaller than those of the reactions leading to the formation of helium nuclei from hydrogen.

Modern Thermonuclear Weapons

In conventional atom bombs, the liberation of nuclear energy takes place as a result of a fission chain reaction of the nuclei of plutonium-239, uranium-235, or uranium-233. In such a bomb, one and the same nuclear fission reaction takes place repeatedly.

The picture of the development of the process during the explosion of a

deuterium-tritium bomb is far more complex. At first the fission reaction develops in the atomic charge. Then, owing to the sharp temperature rise, the thermonuclear reaction tritium-deuterium begins.

This reaction yields helium nuclei and free neutrons. An immense quantity of energy is liberated, leading to a further temperature rise. Thus the deuterium-tritium bomb differs fundamentally from the conventional atomic bomb in the fact that the process (reaction) in the atomic bomb takes place in a single phase, while in the deuterium-tritium bomb it takes place in two phases. On this basis, the conventional atom bomb may be called a single-phase bomb, and the deuterium-tritium bomb a two-phase bomb.

A bomb with liquid hydrogen isotopes consists of a reservoir with a heat-impermeable casing, which keeps the deuterium and tritium in a highly cooled liquid state for a long time. This casing may be made, for example, in the form of three layers, consisting of a solid alloy, solid carbon dioxide, and liquid nitrogen.

The hydrogen bomb with liquid hydrogen isotopes proved to be impractical, since its size and weight were too great. For instance, the American hydrogen bomb of this type weighed 62 tons and was the size of a truck. This first thermonuclear weapon, naturally, could not be carried on an aircraft.

From the instant of its conception, the thermonuclear weapon was ceaselessly improved. One of the steps in this direction was replacement of the liquid hydrogen isotopes by solid chemical compounds of heavy hydrogen with lithium, especially with lithium-6. This permitted a reduction in the size and weight of the hydrogen bomb, since this compound (lithium deuteride) is a light solid. Thus a new type of two-phase bomb appeared, in which, in a mixture of lithium and deuterium heated to a temperature of millions of degrees, the following nuclear reactions take place:

The neutrons formed on the fission of the plutonium detonator (first phase) enter into the already familiar reaction with lithium:

The tritium formed by this reaction enters into thermonuclear reaction with deuterium (second phase). Simultaneously, fusion of the atomic nuclei of lithium and deuterium takes place.

This type of two-phase bomb has great advantages over the douterium-tritium bomb. Lithium hydride, in contrast to tritium, is stable and may be stored for any length of time. It costs considerably less to produce than tritium.

A certain part of the thermonuclear charge may likewise consist of a lithium compound of superheavy hydrogen, i.e., of tritium. Thus, lithium hydrides began to be used as thermonuclear fuel.

While the temperature rises to 10 million degrees on the explosion of a single-phase bomb, it rises still more on the explosion of a two-phase bomb, to several tens of millions of degrees. Such a temperature will ensure the occurrence of nuclear reactions that are more difficult to excite.

Moreover, on the formation of helium nuclei from deuterium and tritium nuclei, many fast neutrons escape. For comparison, we note that if 1 kg of a deuterium-tritium mixture participates in a fusion reaction, then 30 times as many neutrons are liberated as on fission of the atomic nuclei of 1 kg of uranium or plutonium. The energy of the neutrons liberated on the formation of helium is several times as great as that of the fission-liberated neutrons.

It has proved possible to utilize the fast neutrons formed in the zone of the thermonuclear reaction to increase the power of the explosion, if the thermonuclear (hydrogen) charge is placed in a casing made of the relatively cheap natural uranium-238. Thus, it appeared possible to build still more complex bombs, in which the process takes place in three phases. An example of the three-phase bomb is the so-called uranium thermonuclear bomb, sometimes termed a hydrogen-uranium bomb. This three-phase bomb has a detonator in the form of plutonium charges, whose explosion (first phase) causes a thermonuclear reaction in lithium hydride (second phase).

The fast neutrons formed on the fission of plutonium, and on the reaction of deuterium with tritium, induce the fission of the uranium-238 (third phase) of which the casing of the three-phase bomb is made.

The foreign literature contains reports on a design of a three-phase nuclear bomb, in which the nuclei are first split, followed by fusion, and again by fission. Figure 16 shows such a scheme.

The central part of the bomb contains lithium hydride, around which several plutonium charges are placed. The casing of the bomb is made of uranium-238 or of natural uranium. The detonation of the three-phase bomb begins with the explosion of the plutonium detonators (a), under the action of the neutrons emitted by uranium sources. A thermonuclear reaction then takes place in the lithium hydride (b). Finally, the fast neutrons cause the fission of the uranium (c).

The question arises: Why does the fission reaction of uranium-238 take place in the three-phase bomb?

This is explained by the fact that the powerful neutron flux, formed by the reaction of deuterium with tritium, strikes the uranium casing. These neutrons have considerably higher energies and velocities than the neutrons formed by the fission of uranium. Such fast neutrons, on colliding with nuclei of uranium-238, are able to induce their fission.

Several plutonium "detonators" are used in this bomb to raise the temperature of the lithium hydride at a sufficiently rapid rate to ensure a thermonuclear reaction. The simultaneous explosion of detonators present is accomplished by a special electric system. The electric current is switched on automatically by a barometric or other device. The bomb casing has openings in which neutron sources (beryllium) are inserted shortly before the explosion. One of these is shown in the sketch.

If we assume that the diameter of such a three-phase bomb is 1 m, and the thickness of its uranium casing is about 5 cm, then the weight of the uranium will be

about 3 tons. If only 15% reacts on explosion of the bomb, i.e., about 500 kg of uranium, then the TNT equivalent of this bomb would be about 10 million tons. This

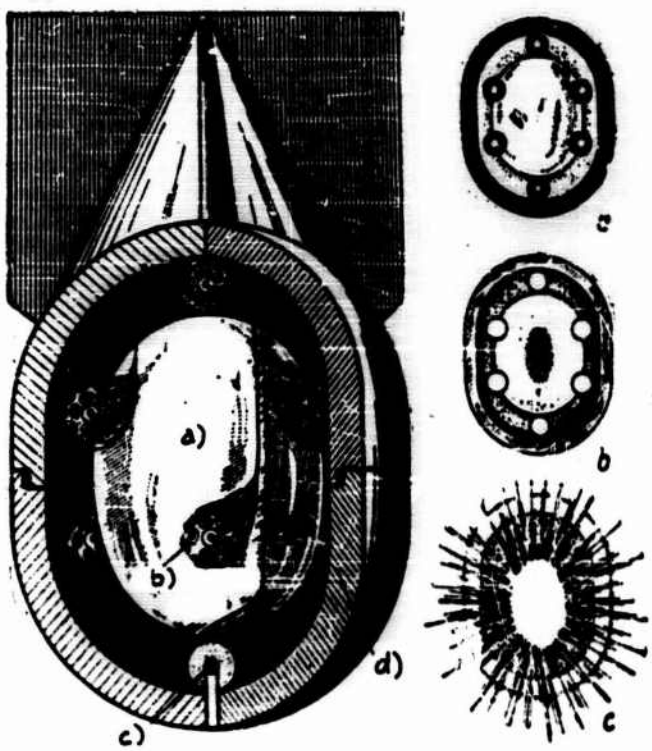

Fig.16 - Schematic Diagram of Thermonuclear Three-Phase Bomb (Hydrogen-Uranium Bomb) and the Processes Taking Place on Explosion

a - First phase: the plutonium charges explode; b - Second phase: thermonuclear reaction of lithium with hydrogen takes place; c - Third phase: fast neutrons induce fission of the uranium-238 nuclei

a) Lithium hydride; b) Plutonium charge; c) Neutron source; d) Uranium-238

means that the explosion of a three-phase bomb would be about 500 times as powerful as that of a conventional bomb (TNT equivalent = 20,000 tons).

The above scheme of the three-phase bomb differs advantageously from all earlier schemes by the fact that its power can be increased many times over that of a bomb

without a uranium casing. It is stated that in a hydrogen-uranium bomb, 80% of the explosion energy can be obtained as a result of the fission of uranium. The advantage of this system is also that the increase in explosive power goes to the account of natural uranium, which is relatively inexpensive (especially by comparison with tritium) and consists mainly of uranium-238.

By using uranium-238 as the bomb casing, the power of the weapon can be increased from tens or hundreds of thousands of tons to millions or tens of millions of tons.

Thus there may be single-phase, two-phase, and three-phase bombs. The nuclear processes taking place in the three-phase bomb are shown schematically in Fig.17. Conventional atomic bombs are single-phase. Thermonuclear bombs may be two-phase or three-phase.

According to the foreign literature, three-phase uranium bombs have preference in military economics over the other types of bombs. One of the reasons for this opinion is as follows: To produce nuclear fuel, pure uranium-235 is separated from natural uranium at special plants. The uranium-238 produced during this process is a waste product. This waste product can then be utilized to build the casings for three-phase uranium bombs.

The development of thermonuclear weapons proceeds at the same time in two directions: that of increasing the TNT equivalents and of designing bombs of very great yield, on the one hand; and that of decreasing the caliber and weight of the bombs, on the other. The foreign literature states that bombs with a TNT equivalent of 10 million and 14 million tons have already been tested. According to the published data, military specialists are now working on the production of thermonuclear bombs with a TNT equivalent of the order of tens of millions of tons.

It is a rather complicated matter to decrease the size and weight of thermonuclear charges. In this connection, the literature has mentioned the development of new principles permitting radical modifications in the design and production of

thermonuclear bombs. They have, for example, reported the possibility of finding a new method of detonating thermonuclear bombs based on the utilization of shock waves. This would make it possible to build small bombs which could be exploded without an atomic detonator.

The operating principle of the new thermonuclear bombs is not known. The foreign literature reports that the possibility of building small thermonuclear bombs

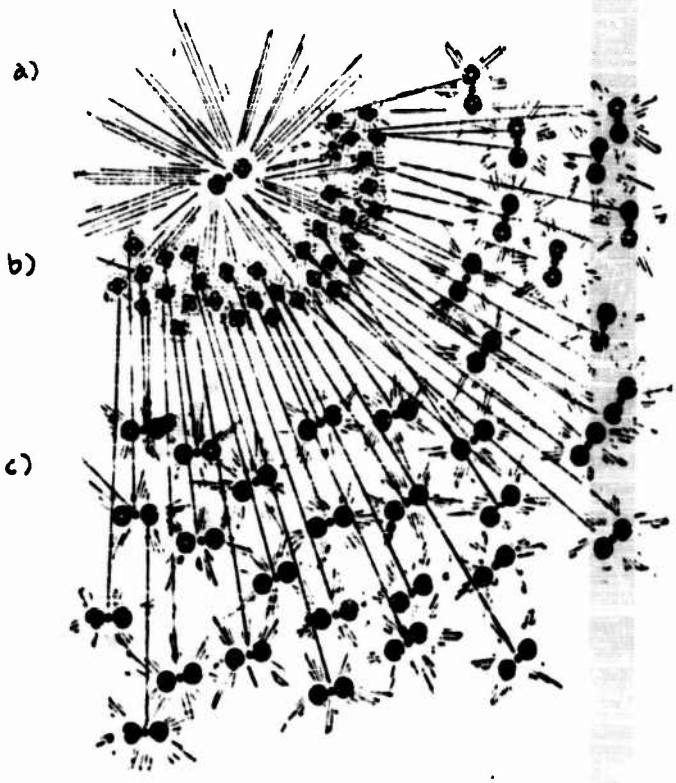

Fig.17 - Nuclear Processes Taking Place in a Hydrogen Bomb with a Casing of Uranium-238

a) Fission reaction of plutonium nuclei; b) Fusion reaction; c) Fission reaction of uranium-238 nuclei

has been proved by the American tests of thermonuclear weapons in May - June 1956, which are said to have included a small bomb useful as warheads for antiaircraft guided missiles.

The foreign literature also states that the decrease in size and weight of thermonuclear charges will permit their delivery on target by aircraft, pilotless aircraft, and rockets of short, intermediate, long, and superlong range, and also their use as warheads in aircraft rockets.

Work is also going on today on improving the ballistic properties of thermonuclear bombs with the object of delivering them by supersonic aircraft, and also on increasing the accuracy of fire of rockets with thermonuclear warheads.

Tritium

Superheavy hydrogen, or tritium, exists only in negligible amounts in nature. It is formed in the upper layers of the atmosphere under the action of cosmic rays.

The fundamental reaction of tritium formation is the reaction of fast cosmic neutrons with nitrogen:

$$_7N^{14} + _0n^1 = _6C^{12} + _1H^3$$

Tritium, however, cannot accumulate in appreciable quantities, since it is a radioactive isotope with a half-life of 12.4 years. On disintegration, it emits a beta-particle and is transformed into helium:

$$_1H^3 = _2He^3 + _{-1}\beta^0$$

The artificial preparation of tritium is based on the reaction of slow neutrons with the nuclei of the light isotope of lithium $_3Li^6$:

$$_3Li^6 + _0n^1 = _2He^4 + _1H^3$$

To prepare tritium in large amounts, natural lithium, which is a mixture of two isotopes, lithium-6 and lithium-7, is placed in a nuclear reactor instead of part of the shim rods. Under the action of slow neutrons, lithium-6 is transformed gradually into tritium and helium.

The tritium formed in the reactor is partially dissolved in the lithium, and forms a chemical compound - lithium hybride - in which an atom of tritium combines with an atom of lithium (LiT). It is very difficult to separate the tritium from lithium hydride, since this stable compound is decomposed with difficulty, even on strong heating. It is therefore disadvantageous to irradiate metallic lithium in the reactor. A lithium salt - lithium fluoride (LiF) - was formerly irradiated. Recently, alloys of lithium with magnesium, from which it is easier to separate the

tritium, are being used.

Tritium is a gas. For storage and use, it is usually converted into tritium water (T_2O) which is obtained by the combustion of tritium in oxygen or air.

The production of tritium in nuclear reactors involves a decrease in plutonium production, since the introduction of lithium with the object of producing tritium causes an additional consumption of nuclear fuel without a corresponding formation of plutonium. The production of 1 kg of tritium in a nuclear reactor involves a decrease of about 80 kg in its plutonium production. The production of tritium also results in an immense consumption of power and of the uranium raw material.

During the initial period of work on the creation of thermonuclear weapons in the United States, 1 kg of tritium cost 500 million dollars. To prepare 1 kg of tritium took 11 - 12 tons of metallic uranium. The daily production of 2 gm of tritium required 10 kg of uranium-235 and a 1-million-kw reactor. The immense plant producing tritium had to operate 2.5 years to produce the amount of tritium necessary for a single hydrogen bomb (obviously of the deuterium-tritium type). The production of tritium today is considerably less expensive. But even today in the United States tritium is still thousands of times as expensive as gaseous deuterium, and still costs hundreds of thousands of dollars per kilogram.

Deuterium

Natural water, in which the hydrogen usually contains 0.014% of deuterium, is the most convenient raw material for deuterium production. Water is readily available, and its supply is practically inexhaustible.

The production of deuterium in the pure form involves the necessity of separating the hydrogen isotopes.

It is incomparably simpler to separate the hydrogen isotopes than to separate the isotopes of other elements. Indeed, deuterium is twice as heavy as ordinary hydrogen, while, for example, the difference in the weight of the uranium isotopes

U^{238} and U^{235} is less than 1.3%. For this reason, a number of physical properties (density, thermal conductivity, etc.) of compounds of heavy and light hydrogen differ appreciably, while there are practically no such differences between the compounds of the two uranium isotopes. For example, the density of heavy water, D_2O, is 1.1079 gm/cc, and it boils at 101.42°C and freezes at 3.802°C.

Such differences in properties make it relatively simple to separate heavy water from ordinary water by distillation (on account of the difference in the boiling points) and also by electrolysis. Thus, deuterium can be separated from water in the concentrated form by various methods.

The method developed first was based on the decomposition of water by an electric current. Everyone knows that water in this case is dissociated into hydrogen and oxygen. Experiments showed that ordinary water, H_2O, was decomposed far more readily by the electric current than heavy water, D_2O. For this reason, the deuterium content of the hydrogen liberated by electrolysis is about 5 times less than its relative abundance in the water being decomposed.

It is clear that the undecomposed water, after electrolysis, will be more and more enriched in deuterium. This method permits ultimately to obtain a water in which the hydrogen contains over 99% of deuterium and only about 1% of ordinary hydrogen. This method of producing heavy water can be used only in countries and regions producing large amounts of electric power at low cost.

The second method is based on the fact that the boiling point of ordinary water is somewhat lower than that of heavy water. Light water can therefore be separated from heavy water by repeated distillation. In this way, at experimental plants, the deuterium content in the hydrogen of water could be increased from 0.014% to 88 - 92%. Electrolysis is more expedient for further concentrating the deuterium.

An advantage of the distillation method is the possibility of producing larger quantities of deuterium, as well as the simplicity of the equipment. A shortcoming, however, of the method is its cost, since the repeated evaporation of large quan-

tities of water requires vast amounts of heat.

The methods of very low-temperature distillation of hydrogen obtained from water, and containing 0.014% of deuterium, have also proved economically disadvantageous.

The most expedient method of preparing deuterium was found the chemical method. This method is based on the fact that deuterium in gaseous hydrogen, where its atoms are paired with protium atoms, tends to combine with oxygen and pass into water (HDO) over the reaction

$$HD + H_2O = H_2 + HDO$$

This reaction proceeds most rapidly at 500°C and, in the presence of catalysts*, even at 100°C.

The catalyst used for this purpose may be metallic palladium or platinum applied to charcoal, or nickel with chromium oxide.

Figure 22 is a schematic diagram of the industrial plant for preparing deuterium-enriched water. Steam is mixed with hydrogen and enters the first column, which contains layers of catalyst. Passing through the column, the water becomes gradually enriched in deuterium. The hydrogen in the steam entering the column contains 0.014% of deuterium, while in the discharged steam it contains 0.02% (in the sketch, the percentage of deuterium in the water in all cases relates to the hydrogen of the water).

The deuterium abundance of the hydrogen is correspondingly decreased: the intake hydrogen contains 0.01%, while the discharge hydrogen contains 0.005% of deuterium. The steam leaving the column is separated from the hydrogen by the cooler (3), liquid water being formed in the condenser while the hydrogen escapes. The water then enters the boiler (4), where it is evaporated, and then is fed to the second

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*Substances which, without themselves undergoing change, will change the speed of a chemical process are called catalysts.

column. Here it is mixed with hydrogen containing 0.03% of deuterium. As a result of the reaction, the hydrogen of the water is now enriched with deuterium to 0.0[illegible]%,

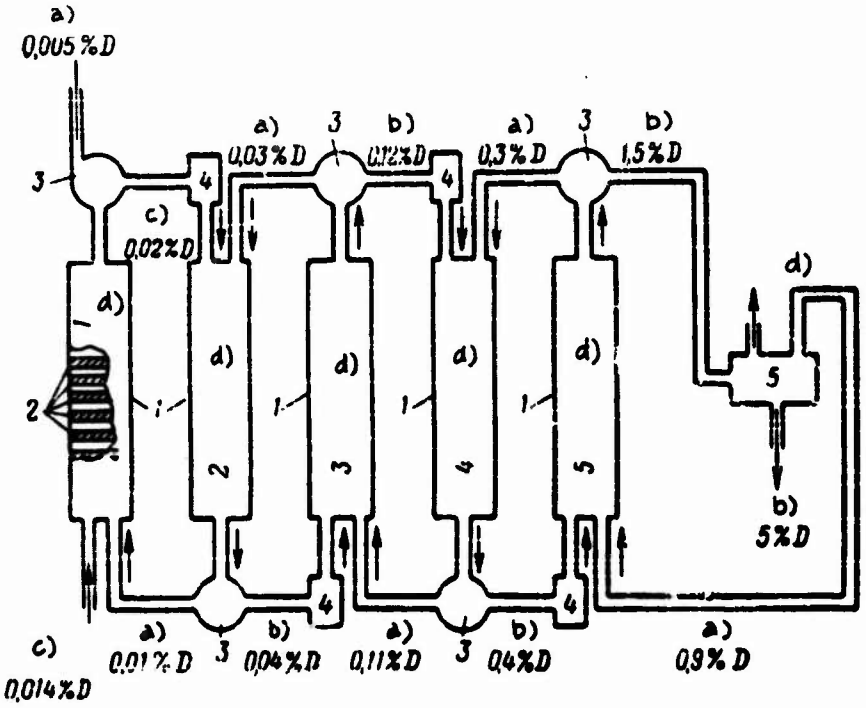

Fig.22 - Installation for the Preparation of Deuterium-Enriched Water

1 - Exchange column; 2 - Catalyst layers; 3 - Coolers; 4 - Boilers; 5 - Electrolyzer

a) Hydrogen; b) Water; c) Water vapor; d) Oxygen

while the deuterium content in the free hydrogen decreases. The process of enriching the water with deuterium is repeated in the third, fourth, and fifth columns as shown in the sketch. The water leaving the fifth column contains 1.5% of deuterium. This water is then routed to the electrolyzer (5), in which the deuterium content in the hydrogen of the water is brought to 5%. Further concentration of the deuterium is accomplished at the electrolysis plant by the above method.

This chemical method of producing heavy water and deuterium is today the most

advantageous. Thanks to the large number of scientific studies on the separation of deuterium in the USSR, the United States, and other countries, the cost of deuterium production has considerably declined during recent years. According to the American literature, 1 kg of heavy water cost about $5000 at the beginning of the first tests of thermonuclear weapons. Today it costs considerably less. According to the literature, 1 kg of heavy water today costs about $200, and 1 kg of gaseous deuterium about $1000.

Lithium

Lithium is a silvery white metal, usually with a yellowish tinge if impurities are present. It is characterized by low specific gravity (0.53), low hardness, low melting point (186°C), low boiling point, and high electric conductivity. Lithium is an active element. It combines with oxygen and nitrogen at room temperature, and with hydrogen on heating. It dissolves readily in acids and violently decomposes water under evolution of hydrogen.

In recent years, lithium has become highly important in atomic technology. A few years ago, the world production of lithium compounds was very small. These were used in the manufacture of certain ceramic wares, to improve the properties of lubricating oils, in preparing the flux used in aluminum welding, in the manufacture of alkaline storage batteries and dry batteries, and, in small amounts, in metallurgy, to remove gases dissolved in metals. About 3000 tons of lithium carbonate were used annually in the United States for all these purposes.

In 1955 - 1956 the production of lithium carbonate in the United States increased to 20,000 tons a year, of which 17,000 tons were purchased by the United States government for secret purposes, obviously for the production of tritium and lithium thermonuclear weapons. Over 100 tons of metallic lithium-6 can be separated from 17,000 tons of lithium carbonate.

The most widely distributed natural minerals containing lithium are spodumene

($Li_2O \cdot Al_2O_3 \cdot 4SiO_2$) and lepidolite ($LiF \cdot KF \cdot Al_2O_3 \cdot 3SiO_2$). The richest deposits of those minerals are located in Rhodesia, Canada, and the United States.

Two processes are used today for separating lithium from its ores.

The first process consists in fusing the lithium minerals with lime, thus forming caustic lithia (LiOH). Large amounts of materials must be processed in rotary kilns, but on the other hand the raw material used (lime) is relatively cheap.

The second process is based on roasting lithium minerals at 1100°C, followed by treatment of the product with concentrated sulfuric acid. The lithium sulfate obtained is dissolved in water. Treatment with soda yields the water-insoluble lithium carbonate. This method is less cumbersome than the former but is more complicated, and a more valuable raw material must be used.

The lithium compounds prepared by the above methods can easily be converted into the salt LiCl, which melts on heating and is decomposed by an electric current into metallic lithium and chlorine.

Metallic lithium contains 92.6% of the isotope $_3Li^7$ and 7.4% of the isotope $_3Li^6$. The same methods used to separate hydrogen isotopes may be used to separate lithium isotopes: the electrolytic method, the distillation method, and the chemical exchange method.

Lithium isotopes may also be separated by the electromagnetic method. This is based on separating a beam of fast lithium ions, under the action of a magnetic field, into two beams, one containing $_3Li^6$ ions and the other the heavier $_3Li^7$ ions. The literature describes no practically useful methods of separating lithium isotopes.

Detection of Atomic and Thermonuclear Explosions

There are well-developed methods today which permit the easy detection of an explosion, determination of the place and time of the explosion, and the type of bomb exploded, at any point of the globe.

Up to now there has not been a single case in which explosions of atomic or hydrogen bombs were not detected by the aid of suitable scientific and technical means. The development of nuclear physics and of the atomic industry is inseparably linked to the improvement of technique and instrumentation, permitting a reliable detection of explosions of nuclear weapons at a distance.

According to the literature data, the occurrence of an atomic or thermonuclear explosion can be established by the generally adopted method of tracing all types of significant tremors of the earth's crust (earthquakes, seaquakes, powerful explosions). This method is adopted in seismology (the science of oscillations in the earth's crust) and is effected by means of seismographs, which are instruments detecting tremors of the earth's crust. A seismograph indicates the force and direction of propagation of tremors. Owing to the nonuniform rate of propagation of the transverse and longitudinal oscillations of the earth's crust arising during an explosion, the readings of a single seismograph are sufficient to determine the epicenter of the explosion.

Detailed information about an atomic explosion may also be obtained by a study of the atmospheric radioactivity.

The literature states that aircraft, specially equipped with air-sampling instruments, are used to study the atmospheric radioactivity in atomic explosions. Such an instrument (a sampler), which is schematically shown in Fig.40, may be placed, for example, in the aircraft wing. In his cockpit, the pilot opens the stopper of the wing sampler at the required time by means of a lever or other device. The air enters the sampler and passes through filters which retain the dust.

Here the dust particles of plutonium, uranium-235, and the fissioned "debris" formed during the chain reaction of the explosion are retained. In the next part of the instrument, filled with a solution of alkali, the carbon dioxide gas, which may con-

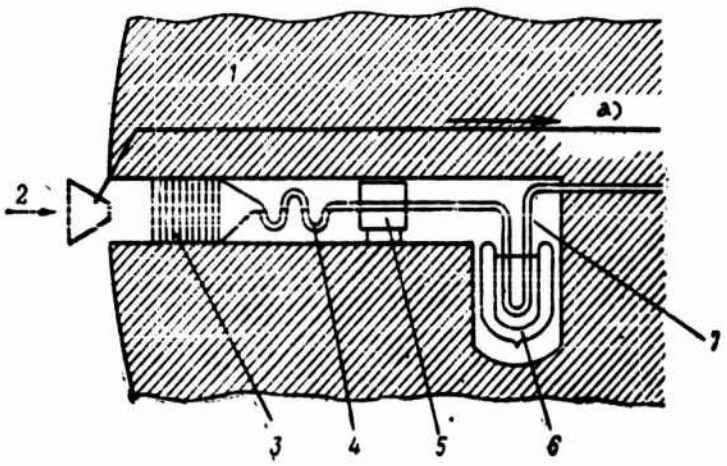

Fig.40 - Possible Schematic Diagram of Aircraft Air Analyzer

1 - Aircraft wing; 2 - Stopper of sampler; 3 - Filter absorbing the plutonium, uranium-235, and fission "debris"; 4 - Carbon dioxide absorbers; 5 - Miniature stove; 6 - Dewar vessel with liquid air; 7 - Tube for freezing water

a) To aircraft cockpit

tain radioactive carbon formed during the explosion, is absorbed. In the next unit of the analyzer, which is a miniature stove, the tritium contained in the sample is burned, forming tritium water which is condensed in the cooler. The more detailed separation of the substances trapped by the gas analyzer, and their analysis, is accomplished later at special laboratories.

The filters are first examined at the laboratory. From the composition of the substances caught by the filter, one may judge the character of the explosion.

The contents of the alkali absorbers and of the water frozen in the analyzer are then investigated. If radioactive carbon dioxide is detected in the alkali absorbers, and the water contains tritium, there is every reason to suppose that a

thermonuclear bomb has been exploded somewhere.

In examining the filters of the analyzer, besides plutonium and uranium, one may also detect fission "fragments" which differ in their half-lives and in their chemical properties.

In 1954, after several tests of thermonuclear weapons, scientists in Japan and other countries took many air samples at great altitudes. In these samples they detected, by this method, the radioactive isotopes: strontium-90, zirconium-95, barium-140, lanthanum-140, yttrium-91, cerium-141, and other fission "debris" of uranium and plutonium. The number of these isotopes proves to be so great that their origin could not be explained by the explosion of atomic detonators. The conclusion was therefore drawn that these "fragments" had been formed as a result of the fission of a heavy uranium casing of powerful thermonuclear bombs of a new type. A number of scientists assumed that in this case explosions of thermonuclear bombs took place, and the term three-phase bombs was proposed for them.

A problem no less important than the determination of the type of the exploded bomb is the determination of the time of explosion. This problem can be solved by the collection of radioactive explosion products on a paper filter by means of the above-described instrument, and observing the decay of their radioactivity with time.

Table 10 shows the decay of the radioactivity with time, taking the radioactivity 1 hr after the explosion as unity.

Table 10

Variation in Radioactivity of Fission "Fragments" with Time

Time in Hours	1	25	50	75	100	125	150	175	200
Radioactivity in arbitrary units	1	0,021	0,0091	0,0059	0,004	0,003	0,0024	0,0020	0,0017

It will be seen from this Table that the radioactivity had fallen, within 25 hrs after the explosion, to almost one fiftieth of its value 1 hr after the explosion. During the following 25 hrs, the radioactivity decreased still further by a factor of 0.021:0.0091 = 2.3. In the same way we may find how many times the radioactivity decreases during each succeeding 25-hr period.

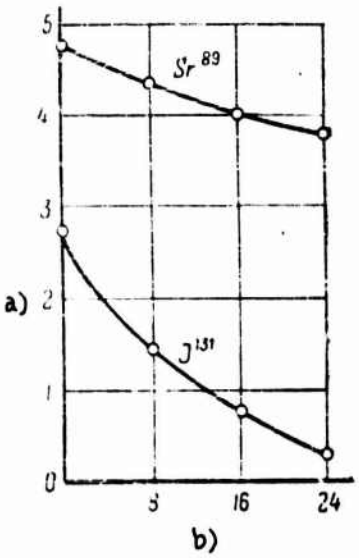

Fig.41 - Radiation of Strontium-89 and Iodine-131 Content of the "Fragments", Against Time Elapsed after Explosion of a Nuclear Bomb

a) % in fission "debris"; b) Time in days

Knowing how the radioactivity of the dust varies with time, the instant of explosion can be determined.

A somewhat different method of determining the time of explosion of a thermonuclear bomb is based on the fact that the different fission "fragments" of uranium and plutonium decay at different rates. Thus, for instance, one of the "fragments", strontium-89, has a half-life of 54.5 days, while another, iodine-131, has a half-life of 8 days. Figure 41 shows the curves of the decline in the content of these isotopes in the "fragments" with the passage of time. At the instant of the explosion, strontium-89 composes 4.6% of the fission "fragments", and iodine-131, 2.8%. About 24 days after the explosion, the content of these isotopes had fallen respectively to 3.7 and 0.4%.

If the strontium-89 and iodine-131 are separated by chemical methods from the "fragments", and the activity of each of these isotopes is separately measured, it will be easy to calculate the ratio of their activities at various periods after the explosion. Table 11 gives the results of such calculations.

It will be clear from the Table that this ratio, which is 0.23 at the instant

of explosion, gradually increases and becomes 4.3 forty days after the explosion. By experimental determination of the ratio of activity of strontium and iodine, isolated from the dust collected after the explosion, it is easy to establish the time

Table 11

Ratio of Activities of Sr^{89} and I^{131} in Air, as a Function of Elapsed Time since Explosion

Time since Explosion, in Days	0	8	16	24	40
Ratio of activities of Sr^{89} and I^{131}	0,23	0,44	0,8	1,5	4,3

of explosion. The same calculation may be performed, using a determination of the activities of any other pair of "fragments" with different half-lives.

The radioactive cloud formed as a result of an atomic explosion remains in the troposphere and is carried off by the wind. By taking air samples at great altitudes and finding the products of the atomic explosion, one may approximately determine the site of the explosion, if meteorological data on speed and direction of the wind are available. Of course, to solve this problem, one must first determine the instant of explosion.

Figure 42 schematically shows the direction of motion of the air masses at altitudes of 10 - 12 km. If an air sample was taken at point (1) and if analyses have shown that the explosion (for instance) occurred 8 days previously, then the region of explosion (2) can be determined, provided, of course, that we know not only the direction but also the speed of the wind.

A rapid determination of the site of explosion of a nuclear bomb dropped by the enemy is also very important, especially for a rapid determination of the localities of possible damage and for better organization of the rescue operations. For this reason, one must be able to determine the site of an explosion at a considerable

distance. From information in the foreign literature, simple instruments resembling sundials may be used for this purpose. One such instrument is shown in Fig.43.

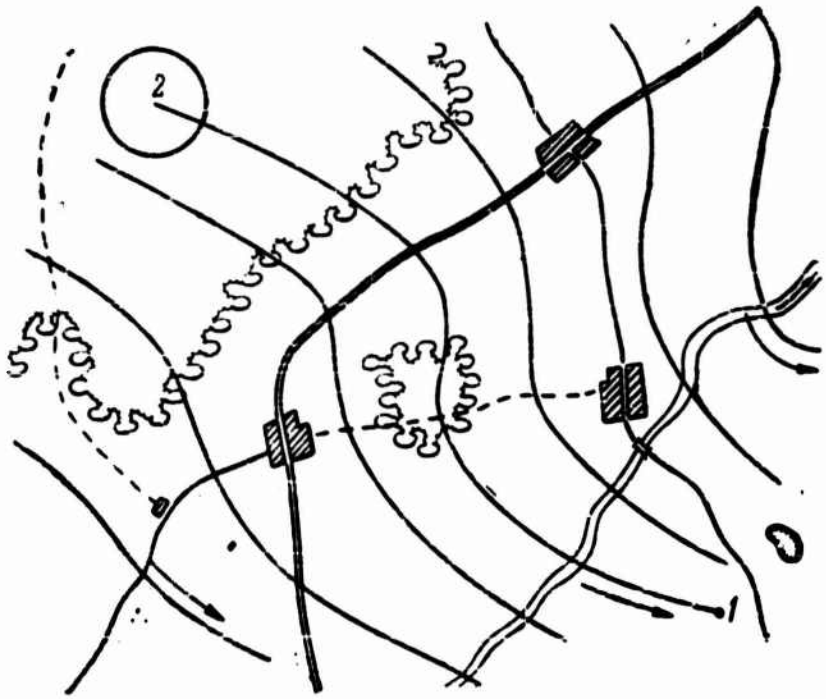

Fig.42 - Schematic Diagram of Motion of Air Masses:
1 - Place of air sampling; 2 - Region of explosion

This device is a square metal plate with a vertical rod at the center. A circular scale is placed around the rod. The surface of the instrument is coated with a paint which changes color on heating. Such instruments are placed in areas where there is danger that a nuclear bomb will be dropped.

After a nuclear explosion, the heat rays, striking the surface of the instrument, change the color of the heat-sensitive paint everywhere except in the places covered by the shadow of the rod. A print of the shadow of the rod is obtained, from which the direction of the explosion site is easily determined. If one has readings of at least two such instruments, the site of the explosion is determined

by the intersection of the lines giving the respective direction of the site of explosion from each instrument.

Thermonuclear Weapons Testing

At the end of World War II, Oppenheimer proposed the utilization of thermonuclear reactions for powerful bombs. But the experiments then conducted in the United States ended in failure. This work was resumed in 1950.

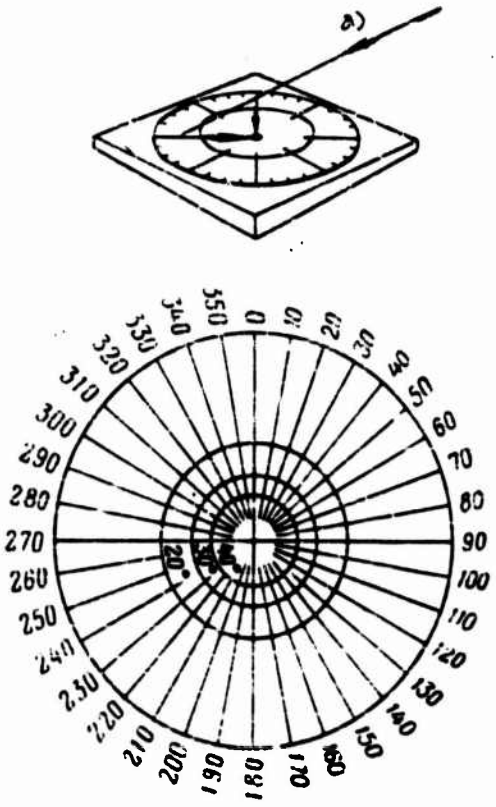

Fig.43 - "Sundial" Type Instrument

a) Direction of rays

For the laborious calculations of the probability of various thermonuclear reactions, modern electronic computers were then used for the first time. It is well known that computers operate at such speed that a single machine can replace hundreds of qualified mathematicians. The calculations performed by the aid of these computers showed that, at the temperature of explosion of a plutonium bomb, a thermonuclear reaction in a mixture of deuterium and tritium could commence. To verify these conclusions, a small amount of tritium and deuterium was prepared, and a mixture of them was introduced into a plutonium bomb. The bomb was exploded at the end of 1951 in one of the test fields of the United States. Careful measurements showed that the number of neutrons formed on explosion of the bomb was somewhat in excess of the number of neutrons formed on

explosion of an atomic bomb. This fact could be explained only if the tritium and deuterium had actually entered partially into a thermonuclear reaction during the explosion, forming helium and neutrons. After experiments, the work on tritium production was speeded up in the United States, and in November 1952, in the Pacific Ocean on Eniwetok, one of the small islands of the Marshall group, the first large-scale experimental thermonuclear explosions were carried out.

According to the foreign literature, it was only in this first thermonuclear explosion in November 1952 that the reaction between tritium and deuterium was utilized. It was really not a bomb at all that was set off, but a specially constructed installation on the ground, weighing 62 tons. The deuterium and tritium were employed in this installation either in the form of compressed gases or in the form of water. As for the thermonuclear explosions staged somewhat later by the Americans in the spring of 1954, according to the literature, these were already explosions of bombs that did not contain tritium introduced from outside, but were filled instead with lithium deuteride. It is therefore possible that a hydrogen bomb need contain only an atomic detonator and lithium deuteride. During the first stage of the explosion, the presence of neutrons assures the formation of tritium and its interaction with the deuterium. This causes a sharp temperature rise (according to the literature data, to tens of millions of degrees), so that a direct interaction between lithium and deuterium now proves possible.

According to data in the foreign literature, a great funnel was formed during the thermonuclear explosion on Eniwetok Island in 1952. The diameter of the fire ball was about 3 - 5 km, and the intense glow lasted 4 sec. The radioactive cloud reached an altitude of 30 km in 10 min.

In autumn 1953, as stated by a Tass report, a powerful thermonuclear weapon, consisting of a thermonuclear bomb, was tested in the USSR.

At the beginning of 1954, when the whole world was waiting for the Geneva conference, the United States staged a series of thermonuclear explosions on Bikini

Island in the Pacific Ocean (Fig.44). These included explosions of bombs with a TNT equivalent of several million tons. A hydrogen-uranium (three-phase) bomb is believed to have been exploded on 1 March 1954.

The United States press advertised these explosions in every possible way. They wrote much about the destruction caused by these explosions and asserted that

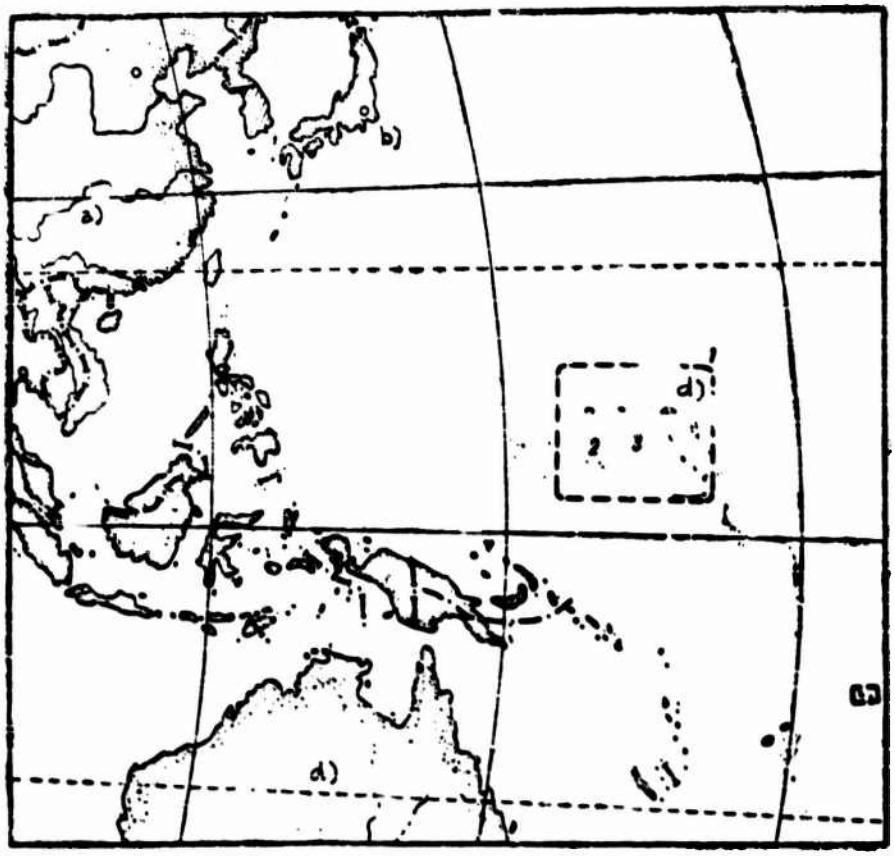

Fig.44 - Map of Region of Pacific Ocean

1 - Test zone for United States nuclear weapons;
2 - Eniwetok atoll; 3 - Bikini atoll

a) China; b) Japan; c) Australia; d) Marshall Islands

the ocean water had been involved in thermonuclear reactions under the influence of the high temperatures developed in these explosions. The newspapers claimed that the

explosive force, alleged to have been measured in these experiments, was about five times as great as the calculations.

Such reports, of course, do not correspond to reality. Obviously, at the temperature reached during the tests and, consequently, also reached by that part of the bomb material that has time to enter into reaction before being dissipated, the force was greater than expected, i.e., the coefficient of utilization factor of the charge was higher than expected, but, of course, it could not have exceeded it by 100%.

In the explosion of hydrogen bombs charged with lithium hydride, and a fortiori, with deuterium and tritium, as stated, temperatures are developed at which thermonuclear reactions with the participation of hydrogen and oxygen cannot proceed at explosive speed, i.e., such heavy nuclei will not enter into reaction. To "ignite" such mixtures during the millionths of a second that the high temperature of the hydrogen bomb explosion lasts, would demand superhigh temperatures that could not be provided by any thermonuclear reaction whatever. There is, therefore, no reason to fear that water or soil can enter into a chain or thermonuclear transformation. The destructive force of any bomb is limited to its own specially prepared contents. Obviously, the exaggerated data published in the United States on the power of thermonuclear explosions were based on incorrect calculations.

The literature contains statements to the effect that Soviet workers have attained such success in the production of hydrogen weapons that it was not the Soviet Union that was in the position of backward countries, but the United States.

In recent years, in accordance with the research plan in atomic energy, new types of thermonuclear weapons have been tested in the USSR. The explosions of thermonuclear bombs were the most powerful of all explosions ever staged. A powerful thermonuclear bomb was dropped from an aircraft in November 1955 and exploded at a great altitude. The explosion was staged at a great altitude with the object of avoiding radioactive effects.

These tests completely justified the corresponding research calculations. They also showed important new achievements of Soviet scientists and engineers. Our scientists and engineers succeeded, with the relatively small amount of nuclear materials used, in obtaining an explosion of a force equal to that of several megatons of conventional explosive.

These tests, in which a thermonuclear bomb was first dropped from an aircraft, showed that the Soviet Union continues to move ahead of the United States in this field of military technology. It was May 1956 before the first tests in the United States on dropping of a thermonuclear bomb from an aircraft and its explosion in the air.

In order to develop and improve thermonuclear weapons and means of protection against them, test explosions have been periodically staged. In the USSR, atomic and nuclear weapons have been tested in accordance with the plan for research and experimental work in atomic energy. These tests have the object of improving atomic and thermonuclear weapons and developing powerful atomic and hydrogen charges of new design for the armament of various sectors of the military forces. Extensive research has been staged, in this connection, on problems of the protection of humans. In order to ensure the safety of the population and of the test personnel, tests have as a rule been staged at great altitudes, a fact which has sharply decreased the radioactive fallout.

How and where have tests of atomic and thermonuclear bombs been staged?

According to the foreign literature, atomic and thermonuclear bombs have been tested at special fields remote from populated points. Such proving grounds are usually located in valleys surrounded by hills, in deserts, or on small islands far from the continents.

If the action of the explosion is to be tested in the air, the bomb is dropped from an aircraft; for a ground explosion, a steel tower up to 100 m in height is erected on the test site. On the top of this tower, the atomic or hydrogen bomb is

placed, with lines running from it to the command point, at a distance of 10 - 30 km from the tower. This command point is placed in a special concrete bunker. Objects, on which the action of the explosion is to be studied, are placed around the tower at various distances from it. Figure 45 is a schematic diagram of one such test of an atomic bomb.

For this test, standard stuccoed frame houses were built at a distance of 1 - 2 km from the tower. Automobiles filled with gasoline and oil were placed at

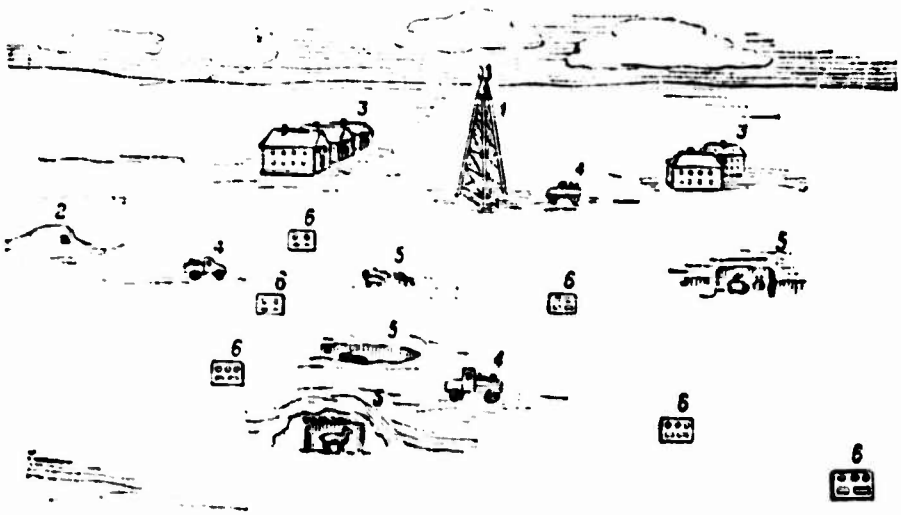

Fig.45 - Possible Version of Proving Ground for Atomic and Thermonuclear Weapons

1 - Site of explosion; 2 - Command point; 3 - Standard houses; 4 - Automobiles with manikins and instruments; 5 - Experimental animals; 6 - Instruments for measuring flash, flux of fast and slow neutrons, shock waves, gamma-radiations, etc.

various distances from the tower. Manikins dressed in clothing of various materials were placed in the houses and in several automobiles (Fig.45). Experimental animals, dogs, goats, rabbits, rats, etc. were placed on the ground and in earthwork bunkers. Various instruments for measuring the temperature, the flux of radiant energy, the number of neutrons, the pressure of the shock wave and other factors were placed at

many points on the surface of the ground, on the walls of the houses, in the rooms, on the automobiles and on the manikins.

When all preparations for the tests are completed, the explosion of the atomic or thermonuclear bomb takes place at a predetermined time. Since the temperature of the explosion reaches several million degrees, the flash is considerably brighter than the sun; for this reason the eyes of all observers must be protected by special black goggles.

Atomic explosions are photographed, and motion pictures taken, at safe distances, from the ground (or water) and from the air. Radio-controlled aircraft with

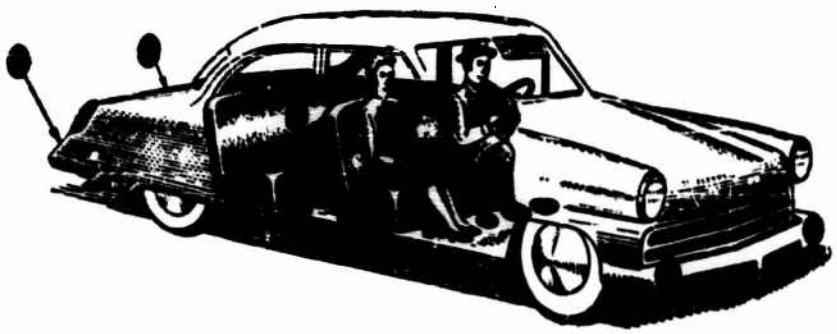

Fig.46 - Automobiles with Manikins. The black circles indicate the location of instruments for measuring power of the shock wave, temperature, neutron flux, luminous and gamma-radiation

automatic motion-picture and still cameras are used for short-range aerial photography.

Figure 47 shows a series of consecutive photographs of a two-story house at a distance of 1 km from the site of explosion of an atomic bomb with a TNT equivalent of the order of 20,000 tons.

The first picture (a) was taken 0.01 sec before the explosion. The second picture (b) was taken 0.03 sec after the atomic blast. It will be clearly seen that the paint that had covered the plaster on the wall facing the tower began to smoke and burst into flame. In another 0.03 sec, the tar that had covered the roof also

began to ignite, as will be seen in the photo (c). Soon the shock wave reached the house, which burst into flame and began structurally to disintegrate: photo (d). The last photograph (e), taken 10 sec after the explosion, shows the house collapsed by the shock wave. The wooden beams and boards which, at the instant of explosion,

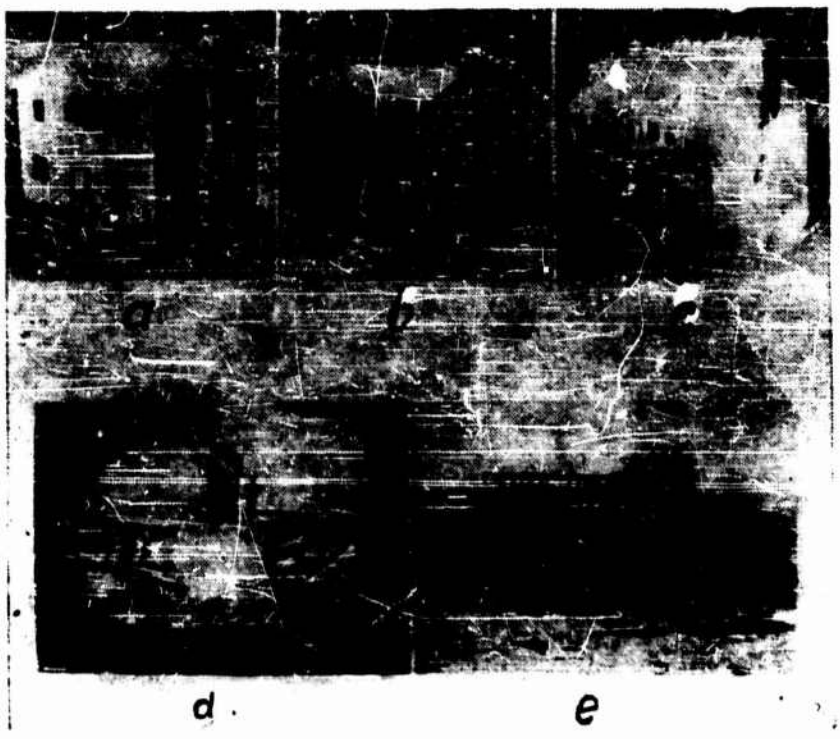

Fig.47 - Stages of Destruction of a Two-Story House by Nuclear Blast

had been protected by a thin layer of plaster, remained entirely uncharred. The manikins inside the house were likewise entirely unaffected by the thermal radiation, they had been reliably protected by the relatively thin plastered wooden wall.

Automobiles at distances of 500 - 1800 m from the site of explosion were affected to a varying degree. The paint was scorched, and many suffered mechanical damage. Automobiles farther than 800 m away were less affected. Some automobiles could be driven away soon after the explosion.

The animals on the ground at distances up to 800 m suffered greatly, and many

of them died. The surviving animals were affected by radiation sickness in severe form and died 1 - 4 weeks after the explosion, while those in shelters at a depth of 1 - 2 m underground at a distance of 500 - 800 m from the explosion site showed almost no damage. Animals in shelters at distances of 800 - 1000 m did not suffer at all.

How is the utilization factor of nuclear fuel in atomic and hydrogen bombs determined? According to the literature, this problem can be solved during an atomic bomb test, for example, by sampling the air from the cloud formed after the explosion. This sample is then analyzed for plutonium, barium, and iodine. Barium and iodine are necessary fission products of plutonium. It is simpler to determine these than the other fission products. Knowing that the total barium and iodine amount to 3 - 4% of the weight of the fissioned plutonium, the amount of plutonium that has time to undergo fission is calculated. Since the amount of unfissioned plutonium is also determined by the analysis, one can approximately calculate the percentage of the plutonium that has fissioned and, consequently, the utilization factor for the nuclear fuel.

In the case of a thermonuclear bomb, the same method may be used, but, depending on the type of bomb, the substances characteristic of the thermonuclear explosion must be determined in the sample, for example, lithium and helium.

An interesting experiment was performed in one of the hydrogen bomb tests. It is desirable to use neutron beams of maximum power for the artificial production of new transuranium elements by neutron irradiation of uranium. The scientists decided to use the powerful neutron flux formed on explosion of a hydrogen bomb to irradiate heavy atoms. For this purpose, several kilograms of uranium were buried in the ground in the blast area of the hydrogen bomb, in such a way that the material was irradiated by the neutrons without being scattered by the shock wave. The experiments were successful, and the calculations were substantiated. It was precisely in this way that the transuranium elements 99 and 100, einsteinium and fermium, were first obtained.