

Modeling of hydrogen and atomic bombs in chemistry courses of secondary stage

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Abstract:

This work presents a study on nuclear chemistry. The work concentrate on nuclear weapons specially hydrogen bomb and atomic bomb. The differences between hydrogen bomb and atomic bomb are studied. Also, comparison between nuclear fission and nuclear fusion is studied. The factors affecting on explosion are discussed in the present work.

Key words:

Nuclear chemistry; nuclear weapons; hydrogen bomb; atomic bomb.

1. Introduction:

1.1. Nuclear chemistry:

Nuclear chemistry is the branch from chemistry handling radioactivity, nuclear reaction, and conversions in the nuclei about atoms, like nuclear transformation and nuclear characteristic [1].

It is radiochemical science for example the radium, actinides also radon combined with the chemistry coupled with equipment (for instance nuclear reactors) which are designed for performance nuclear operations. This involves the corrosion of outer layer and the behavior under natural and unnatural process (as in amid the incident). The response of materials and objects after placement in a storage or nuclear waste disposal facility is crucial [2].

It involves the investigation of the chemical effects of radiation absorption in animals, plants, and other substances. The radiation chemistry rules a large portion of radiation biology since

radiation has an influence on living organisms at the molecular level. To explain it differently, the radiation changes the biochemicals inside an organism, the change of the bio-molecules next alterations the chemistry that happens inside the organism; this alteration in chemistry later can result in a biological outcome. consequently , nuclear chemistry profoundly benefits the understanding of medical therapies (like cancer radiotherapy) and has empowered these treatments to enhance [3,4].

It contains the study of generating and employing of radioactive sources for a set of processes. These encompass radiation therapy in healthcare applications; the use of radioactive materials inside in industry, science and the ecosystem, also the utilization of radiation to adjustment materials like polymers [5].

It also involves the examination and application of nuclear processes within

non-radioactive fields of human activity. For example, nuclear magnetic resonance (NMR) spectral technique is frequently employed in artificial organic chemistry, physical chemistry and for chemical structure analysis within large-molecular chemistry [6].

1.2. History of nuclear chemistry:

Following Wilhelm Rontgen detected X-rays within 1895, several scientists initiated on studying ionizing radiation. Among of these appeared Henri Becquerel, who examined the relationship among phosphorescence along with the blackening of photographic plates. Once Becquerel (engaged in France) found that, in the absence of external energy source, the uranium produced rays that could blacken (either fog) the photographic plate, radioactivity was detected. Marie Skłodowska-Curie (engaged in Paris) and her spouse Pierre Curie separated two fresh radioactive elements from uranium raw. They applied radiometric techniques to determine which path the radioactivity was in following each chemical isolation; they divided the uranium ore to each of the varied chemical elements which were recognized during that time, and measured the radioactivity for each part [7]. They afterward attempted to separate these ones radioactive fractions more, to isolate a tinier fraction highly active (radioactivity divided by mass). In this manner, they separated polonium and radium. It was observed in about 1901 that elevated radiation doses might result in damage to humans. Henri Becquerel had kept a sample of radium inside his pocket and as a consequence he endured a highly localized dose that led to a radiation burn. This harm caused the study of the biological characteristics of radiation, which over time gave rise to the advancement of medical treatment [8].

Canada and England, demonstrated that radioactive decay can be illustrated by a simple formula (a first-order linear derivative equation, currently called first degree kinetics), this means that a certain radioactive matter has a distinct "half-life" (the time it takes for the quantity of radioactivity existing in a source to decrease by half) [9]. He also formulated the terminology alpha, beta and gamma beams, he transformed nitrogen to oxygen, and above all he monitored the students who carried out the Geiger–Marsden experiment (gold flake experiment) that demonstrated that the 'plum pudding design' of the atom was incorrect. Inside the plum pudding model, suggested by J. J. Thomson in 1904, the atom is formed of electrons encircled by a 'cloud' of positive charge to equilibrium the electrons' negative charge. As for Rutherford, the gold flake experiment indicated that the positive charge was limited to a tiny nucleus first direction to the Rutherford model, and in the end to the Bohr model of the atom, wherein the positive nucleus is enclosed by the negatively charged electrons [10].

Marie Curie's daughter (Irene Joliot-Curie) and son-in-law (Frederic Joliot-Curie) in 1934 were the first to discover synthetic radioactivity: where boron was bombarded with alpha particles to produce the nitrogen-13 isotope, which is deficient in neutrons; this isotope released positrons. moreover, they bombarded magnesium and aluminum using neutrons to generate new radioisotopes [11].

Otto Hahn pioneered a new line of research in the early 1920s. By means of "emanation method", which he had lately created, plus the "emanation ability", he established what came to be known as "applied radiochemistry" to

Ernest Rutherford, employed in

investigate of general chemical and physio-chemical questions. In 1936 Cornell University Press released a book in English (and subsequently in Russian) labeled Applied Radiochemistry, that held the lectures provided by Hahn when he served as guest professor at Cornell University in New York, Ithaca in 1933. This influential publication greatly affected all nuclear chemists and physicists in the United Kingdom, United States, the Soviet Union, and France across the 1930s and 1940s, which laid the fundamentals for advanced nuclear chemistry [12].

Hahn and Lise Meitner found radioactive isotopes of thorium, radium, uranium and protactinium. In addition, he discovered the radiation recoil phenomenon and nuclear symmetry, and was a pioneer in rubidium-strontium chronology. In 1938, Fritz Strassmann and Hahn, Lise Meitner found nuclear fission, for which Hahn obtained the 1944 Nobel award for Chemistry. Nuclear fission was the foundation for nuclear reactors and weapons. Hahn is indicated to that the father of nuclear chemistry as well as godfather of nuclear fission [13].

1.3. Applications of nuclear chemistry:

Nuclear chemistry has multiple significant applications across different fields [14].

1.3.1. Medicine (Nuclear Medicine):

a- Medical Imaging: Radioisotopes such as Technetium-99m are utilized in imaging techniques like positron emission tomography (PET) and single-photon emission computed tomography (SPECT) [15]. These methods are essential for diagnosing various

medical conditions, particularly cancer, bone disorders, and heart diseases.

b- Cancer Treatment: Radiation therapy employs isotopes like Cobalt-60 and Iodine-131 to effectively target and eliminate cancer cells while minimizing harm to surrounding healthy tissues [16].

c- Sterilization of Medical Equipment: Gamma radiation is used to sterilize medical instruments, ensuring they remain free of bacteria and viruses [17].

1.3.2. Energy Production:

Nuclear Power Generation: The fission of Uranium-235 and Plutonium-239 releases heat, which is transformed into electricity [18]. This process is super efficient, producing huge quantity of energy with low carbon emissions.

1.3.3. Agriculture:

a- Food Irradiation: Exposing food to gamma radiation destroys bacteria, insects, and parasites, extending shelf life while preserving nutritional value [19].

b- Pest Control: The sterile insect technique (SIT) involves sterilizing insects with radiation before releasing them into the wild, reducing pest populations without the need for chemical pesticides [20].

1.3.4. Environmental Applications:

a- Pollution Monitoring: Radioisotopes serve as tracers to track the movement and dispersion of pollutants in the environment [21].

b- Ground water Dating: Scientists use radioisotopes to determine the age and source of groundwater, which is crucial for managing water resources [22].

1.3.5. Space Exploration:

Radioisotope Thermoelectric Generators (RTGs): Spaceship and satellites use RTGs, which produce energy using the decay of Plutonium-238 [23]. These generators provide a reliable energy source in deep-space missions where solar power is impractical.

1.3.6. Archaeology and Geology:

Radiometric Dating: Carbon-14 dating is widely used to establish the age of ancient relics, fossils, and geological formations [24]. Additionally, isotopes such as Potassium-40 and Uranium-238 help date rocks and analyze Earth's geological history.

1.3.7. Industrial Applications:

a- Industrial Radiography: Gamma rays from isotopes such as Iridium-192 are utilized to inspect metal welds and uncover structural faults in materials[25].

b- Thickness Measurement: Radiation-based techniques are employed in industries such as metal and paper production to precisely measure and regulate material thickness [26].

c- These diverse applications highlight the critical role of nuclear chemistry in advancing technology and improving everyday life [27].

1.4. Nuclear decay:

Radioactive decay (also referred to as radioactivity, nuclear decay, radioactive disintegration, or nuclear disintegration) is the process in which an shaky atomic nucleus releases energy through radiation [28]. Any

material that contains unstable nuclei is classified as radioactive. The three most common types of decay are alpha, gamma, and beta decay. Beta decay is governed by the weak nuclear force, whereas alpha and gamma decay are influenced by the electromagnetic and strong nuclear forces.

At the atomic level, radioactive decay occurs randomly. According to quantum mechanics, it is fundamentally impossible to determine exactly when a specific atom will decay, regardless of how long it has existed [29]. However, when dealing with a large number of identical atoms, the decay rate can be quantified using either a decay constant or a half-life. The half-lives of radioactive isotopes vary widely, ranging from fractions of a second to durations exceeding the age of the universe.

The nucleus undergoing decay is known as the "parent radionuclide" (or "parent radioisotope"), and the process results in the formation of at least one "daughter nuclide." Except in cases of gamma decay or internal transformation from an excited nuclear state, radioactive decay leads to nuclear transmutation, producing a daughter nuclide with a different number of protons, neutrons, or both. If the number of protons changes, the resulting element is entirely different from the original one [30].

On Earth, there are 28 naturally occurring radioactive elements, comprising 35 radionuclides (with seven elements possessing two distinct radionuclides each). These radionuclides have existed since before the formation of the Solar System and are known as primordial radionuclides. Well-known examples include uranium and thorium, as well as naturally occurring long-lived isotopes like

potassium-40. Each of these heavy primordial radionuclides is involved in one of four radioactive decay chains [31,32].

The half-life (denoted as $t_{1/2}$) of a radioactive material is the time it takes for half of a given sample to decay. Every radioactive isotope has a unique half-life, which can range from fractions of a second to millions or even billions of years [33].

The equation governing radioactive decay follows an exponential pattern. The half-life remains constant, regardless of whether the sample is 1 gram or 1000 grams. It is a fixed property of each radioactive isotope, independent of the sample size [34].

1.5. Fusion and Fission:

Nuclear fusion reactions produces results that nuclei less heavy than nickel-62 or iron-56 will generally emit energy [35]. These elements have somewhat low mass and high nuclear binding energy per nucleon. Fusion of nuclei not as heavy as these emits (an exothermic process), whereas the fusion of more weight nuclei lead to energy being absorbed, making the reaction endothermic. The reverse process of fusion is nuclear fission, where a heavy nucleus splits apart. Fusion primarily involves lighter elements such as hydrogen and helium, which are more prone to fusion, while heavier elements like uranium, thorium, and plutonium are more likely to undergo fission [36].

In extreme astrophysical events, such as supernova explosions, there is enough energy to fuse nuclei into elements heavier than iron [37].

Nuclear fusion occurs when two or more atomic nuclei, typically deuterium and tritium (hydrogen isotopes),

combine to form new atomic nuclei along with subatomic particles (such as neutrons or protons). The difference in mass between the reactants and products results in either the release or absorption of energy, due to differences in nuclear binding energy before and after the reaction. Fusion is the energy source of stars, including those in the main sequence, where immense amounts of energy are generated [38].

Nuclear fission, on the other hand, occurs when a heavy atomic nucleus splits into two or more smaller nuclei. This process releases a significant amount of energy, often producing gamma radiation as well. The energy output of fission exceeds that of standard radioactive decay. In experiments conducted in Moscow by Kurchatov, researchers aimed to validate and confirm the principles of nuclear fission. The fission rate of uranium, in the absence of neutron bombardment, was negligible, as predicted by Niels Bohr, though not entirely insignificant [39].

The unpredictable nature of fission products, which vary in a probabilistic and somewhat chaotic manner, sets nuclear fission apart from purely quantum tunneling processes like proton emission, cluster decay and alpha decay that consistently produce the same byproducts. Nuclear fission serves as an energy source for nuclear power and is also responsible for nuclear weapon explosions. Both applications are feasible because specific materials, known as nuclear fuels, undergo fission when struck by neutrons and subsequently release more neutrons upon splitting [40]. This process enables a self-sustaining nuclear chain reaction, which can either be controlled in a nuclear reactor or occur rapidly and uncontrollably in a nuclear weapon. The energy released

from the fission of an equivalent amount of uranium-235 is a million times greater than that produced by burning methane or using hydrogen fuel cells [41].

However, the products of nuclear fission are generally far more radioactive than the heavy elements initially used as fuel, and they persist for long periods, creating a nuclear waste challenge. Nevertheless, the seven long-lived fission products constitute only a small portion of all fission products. Neutron absorption that does not result in fission leads to the formation of plutonium (from uranium-238) and minor actinides (from both uranium-235 and uranium-238), which are significantly more radiotoxic than long-lived fission products [42]. The concerns surrounding nuclear waste accumulation and the destructive potential of nuclear weapons counterbalance the interest in utilizing fission as an energy source. The thorium fuel cycle, however, generates minimal plutonium and fewer long-lived actinides. Minor actinides, including uranium-232 and its decay products, are significant gamma-ray emitters. All actinides are either fertile or fissile, and although fast breeder reactors can fission them, this is only possible under specific configurations. Nuclear reprocessing aims to recover valuable materials from spent nuclear fuel, extending the availability of uranium (and thorium) while also reducing nuclear waste. In the industry, a process that fissions nearly all actinides is referred to as a "closed fuel cycle" [43].

Fission produces energy when atoms are divided, whereas fusion releases energy when atoms combine. The energy output from fusion reactions is greater than that from fission [44].

Unlike fission, fusion does not produce long-term radioactive residue as a byproduct. However, fusion requires more energy to initiate than fission does. This high energy requirement has been a major obstacle to its widespread use for power generation [45].

The fundamental difference between the two processes is that fission involves splitting a heavy, unstable nucleus into two smaller nuclei, while fusion requires combining lighter nuclei to form a heavier one [46].

1.6. Nuclear weapons:

Nuclear weapons are powerful bombs that generate enormous energy through nuclear reactions. These reactions either involve nuclear fission, like in atomic bombs, or a combination of fission and fusion in thermonuclear bombs. Despite their small size, both types can release vast amounts of destructive energy [47].

The first test of a fission ("atomic") bomb produced energy equivalent to 20,000 tons of TNT (about 84 terajoules). Meanwhile, the first test of a thermonuclear ("hydrogen") bomb released energy equal to 10 million tons of TNT (around 42 petajoules). The explosive power of nuclear bombs ranges from 10 tons of TNT, as in the Nagasaki atomic bombing, to 50 megatons, as in the Tsar Bomba. Additionally, a thermonuclear weapon with a mass of 600 pounds (270 kg) can generate energy exceeding 1.2 megatons of TNT (equivalent to 5.0 petajoules) [48].

Although similar in size to conventional bombs, nuclear devices can cause massive destruction to entire cities through explosion, intense heat, and radiation. Their classification as weapons of mass destruction makes their spread a critical issue in global

diplomacy. These weapons have been used in warfare only twice—by the United States on Hiroshima and Nagasaki during World War II in 1945[49].

Nuclear weapons have been deployed in warfare on just two occasions, both by the United States against Japan towards the end of World War II. On August 6, 1945, the U.S. Army Air Forces (USAAF) dropped a uranium-based bomb, "Little Boy," on Hiroshima. Three days later, on August 9, a plutonium-fueled implosion bomb, "Fat Man," was used on Nagasaki. These attacks caused severe casualties, ultimately leading to the deaths of approximately 200,000 people, including both civilians and soldiers [50]. The moral debate surrounding these bombings and their role in Japan's surrender continues to this day.

Since the atomic bombings of Hiroshima and Nagasaki, nuclear weapons have been tested and demonstrated more than 2,000 times. Only a limited number of nations either possess these weapons or are suspected of seeking them. Countries that have officially acknowledged possessing and testing nuclear weapons, in order of their first detonation, include the United States, the former Soviet Union (now Russia), along with Britain, France, China, India, Pakistan, and North Korea. While Israel is believed to have nuclear capabilities, it maintains a policy of deliberate ambiguity and does not officially confirm possession. Additionally, Germany, Italy, Turkey, Belgium, the Netherlands, and Belarus take part in nuclear weapons-sharing programs. South Africa stands out as the only country to have independently developed nuclear weapons and later dismantled them [51,52].

The Non-proliferation of nuclear weapons agreement aims to restrict the spread of nuclear arms, but its effectiveness remains a subject of debate [53].

Nuclear weapons are classified into two main types: the first relies primarily on nuclear fission reactions to generate most of its energy, while the second uses fission reactions to initiate nuclear fusion, which significantly contributes to the total energy released [54].

1.6.1. Fission weapons:

All nuclear weapons generate at least some of their explosive energy through nuclear fission reactions. Those that rely entirely on fission for their destructive power are commonly known as atomic bombs or A-bombs. However, this term has been considered somewhat misleading since the energy originates from the atomic nucleus, similar to fusion-based weapons [55].

Fission weapons operate by bringing a quantity of fissile material, such as enriched uranium or plutonium, into a supercritical state, triggering a rapid chain reaction. This is achieved through two primary methods: the "gun" method, where one sub-critical mass is propelled into another, or the "implosion" method, which involves compressing a sub-critical sphere or cylinder of fissile material using explosive lenses. The implosion technique is more advanced and efficient, as it requires less fissile material, is more compact, and reduces overall mass [56].

A critical challenge in nuclear weapon design is maximizing the consumption of fuel before the device self-destructs. The energy yield of fission bombs varies significantly, ranging from less than a ton to over 500,000 tons (500

kilotons) of TNT, equivalent to 4.2 to (4.2 to 2.1×10^6 GJ) [57].

Every fission reaction produces byproducts, which are the remnants of split atomic nuclei. Some of these byproducts emit intense radiation but decay quickly, while others remain radioactive for extended periods. As a result, they contribute significantly to radioactive contamination. These fission products are the primary source of nuclear fallout. Additionally, the free neutrons released by the explosion can interact with surrounding materials, altering their nuclei and generating new radioactive isotopes [58].

The most frequently utilized fissile materials in nuclear weapons are uranium-235 and plutonium-239, with uranium-233 being used less often. Certain isotopes, such as neptunium-237 and americium, have theoretical applications in nuclear explosives, though there is no definitive evidence of their use. Their potential role in nuclear weapon development remains a subject of debate [59].

1.6.2. Fusion weapons:

The second main type of nuclear weapon generates most of its energy through nuclear fusion reactions. These are commonly known as thermonuclear weapons, or more informally as hydrogen bombs (H-bombs), since they depend on fusion reactions involving hydrogen isotopes like deuterium and tritium. A substantial amount of their energy originates from fission reactions, which serve as the trigger for fusion, and in turn, fusion reactions can initiate further fission processes [60].

Only six nations—the United States, Russia, the United Kingdom, China, France, and India—have conducted tests of thermonuclear weapons.

However, there is ongoing debate regarding whether India has successfully detonated a fully functional multi-stage thermonuclear device. In January 2016, North Korea claimed to have tested a fusion-based weapon, though this assertion remains contested. Thermonuclear weapons are significantly more complex to design and develop compared to basic fission bombs. Despite this, nearly all modern nuclear arsenals rely on thermonuclear designs, as they produce explosions that are hundreds of times more powerful than fission bombs of similar mass [61].

Thermonuclear bombs function by utilizing the energy from a fission bomb to compress and heat fusion fuel. The Teller-Ulam design, which is used in all multi-megaton hydrogen bombs, achieves this by placing a fission bomb and fusion fuel—such as tritium, deuterium, or lithium deuteride—inside a specialized radiation-reflecting container. Upon detonation of the fission bomb, the emitted gamma rays and X-rays first compress the fusion fuel before heating it to extreme temperatures required for thermonuclear fusion. This fusion process generates a vast number of high-energy neutrons, which can then trigger fission in materials that are typically resistant to it, like depleted uranium. Each part of this mechanism is referred to as a "stage", where the fission bomb acts as the "primary", while the fusion capsule serves as the "secondary". In large hydrogen bombs with yields in the megaton range, nearly half of the total explosive power results from the terminal fissioning of exhausted uranium [62,63].

Nearly all modern thermonuclear weapons follow a two-stage design, but additional fusion stages can be added, with each stage igniting a larger

quantity of fusion fuel than the previous one. This method allows for the creation of thermonuclear weapons with practically unlimited yields. Unlike fission bombs, whose explosive power is restricted due to the risk of criticality accidents—where excessive pre-assembled fissile fuel causes an uncontrolled chain reaction—thermonuclear weapons have no such limit. The most powerful nuclear device ever tested, the Tsar Bomba, developed by the Soviet Union, released energy exceeding 50 megatons of TNT (210 PJ) and utilized a three-stage design. However, most thermonuclear weapons are much smaller due to limitations in missile warhead size and weight. During the early 1950s, the Livermore Laboratory in the United States proposed testing two massive bombs, named Gnomon and Sundial, with explosive yields of 1 gigaton and 10 gigatons of TNT, consecutively [64,65].

Fusion reactions do not produce fission products, meaning they generate significantly less nuclear fallout than fission reactions. However, since all thermonuclear weapons include at least one fission stage—and many high-yield designs incorporate a final fission stage—they can produce fallout levels comparable to pure fission weapons. Additionally, large thermonuclear explosions, particularly ground bursts, can propel radioactive debris into the stratosphere, where the stable atmospheric conditions allow the material to travel vast distances before eventually settling, unpredictably contaminating regions far from the detonation site [66].

1.6.3. Other types of weapons :

Producing antimatter in sufficiently large amounts remains impractical, and

there is no indication that its use extends beyond theoretical military applications. However, during the Cold War, the U.S. Air Force funded research into antimatter physics and explored its potential role in weapons—not only as a trigger but as the primary explosive component. A proposed fourth-generation nuclear weapon follows principles similar to those of antimatter-catalyzed nuclear pulse propulsion [67].

Variations in nuclear weapon designs generally aim to tailor explosive yields for different operational needs. Adjustments in weapon structure also seek to reduce size, radiation vulnerability, and dependence on specialized materials, particularly fissile fuel or tritium [68].

Some nuclear weapons are engineered for specialized roles, primarily for non-strategic objectives rather than large-scale warfare. These are commonly known as tactical nuclear weapons and are designed for use in limited battlefield scenarios rather than as war-ending strategic weapons [69].

The neutron bomb, attributed to Sam Cohen, is a type of thermonuclear weapon designed to produce a limited explosion while generating a significant amount of neutron radiation. Military strategists suggest that such a weapon could cause extensive biological casualties while minimizing damage to physical structures and producing less radioactive fallout [70]. Due to the ability of high-energy neutrons to penetrate dense materials, including armored vehicles, neutron warheads were developed in the 1980s as tactical payloads for the U.S. Army's artillery rounds (200 mm W⁷⁹ and 155 mm W⁸²) and short-range rocket crops. At the same time, Soviet officials declared their own intentions to deploy neutron

warheads in Europe, asserting that they were the original inventors of the neutron bomb. However, there is no verifiable evidence confirming their actual deployment within the USSR's tactical nuclear forces [71]. A nuclear explosive device designed for use by ground special forces is the Special Atomic Demolition Munition (SADM), commonly referred to as a suitcase nuke. This type of nuclear bomb is man-portable or transportable by a vehicle, and while it has a relatively low yield of about one to two kilotons, it is still capable of destroying key tactical targets such as bridges, dams, tunnels, and critical military or commercial infrastructure. It can be deployed behind enemy lines or preemptively in areas at risk of enemy occupation. These weapons use plutonium fuel, making them highly radioactive, and they require strict security precaution for stockpiling and deployment [72].

2.Experimental:

New simple models from cartoon papers were made for hydrogen bomb and atomic bomb. These models are homemade and used in the class to simplify the concepts of nuclear chemistry and simplify the differences between hydrogen bomb and atomic bomb.

3.Methods of Research and the tools used:

The papers were collected from various sources from the Egyptian Knowledge Bank and Google.

4.Results of Research:

4.1.Nuclear Weapons:

Small-scale tactical nuclear weapons were developed for use in anti-aircraft defense. Examples include the USAF AIR-2 Genie, the AIM-26 Falcon, and the US Army Nike Hercules [73].

Additionally, missile interceptors like the Sprint and Spartan were equipped with compact nuclear warheads, designed to generate neutron or X-ray radiation, primarily to neutralize enemy strategic warheads [74].

Other tactical nuclear weapons were integrated into naval operations, particularly for antisubmarine warfare. These included nuclear depth charges and torpedoes armed with nuclear warheads. Furthermore, nuclear mines were explored as potential weapons for deployment on land and at sea [75].

The atomic bombs dropped on Hiroshima and Nagasaki were fission-based weapons, relying on the splitting of atomic nuclei. Each atomic nucleus is composed of protons and neutrons, with the number of protons determining the element (for example, carbon has 6 protons, while uranium has 92). The number of neutrons, however, determines the isotope of that element. While different isotopes of the same element share identical chemical properties, their nuclear behavior can vary significantly. Some isotopes are capable of undergoing fission, meaning they can break apart into lighter elements. Uranium (symbol U) is particularly significant in this regard [76].

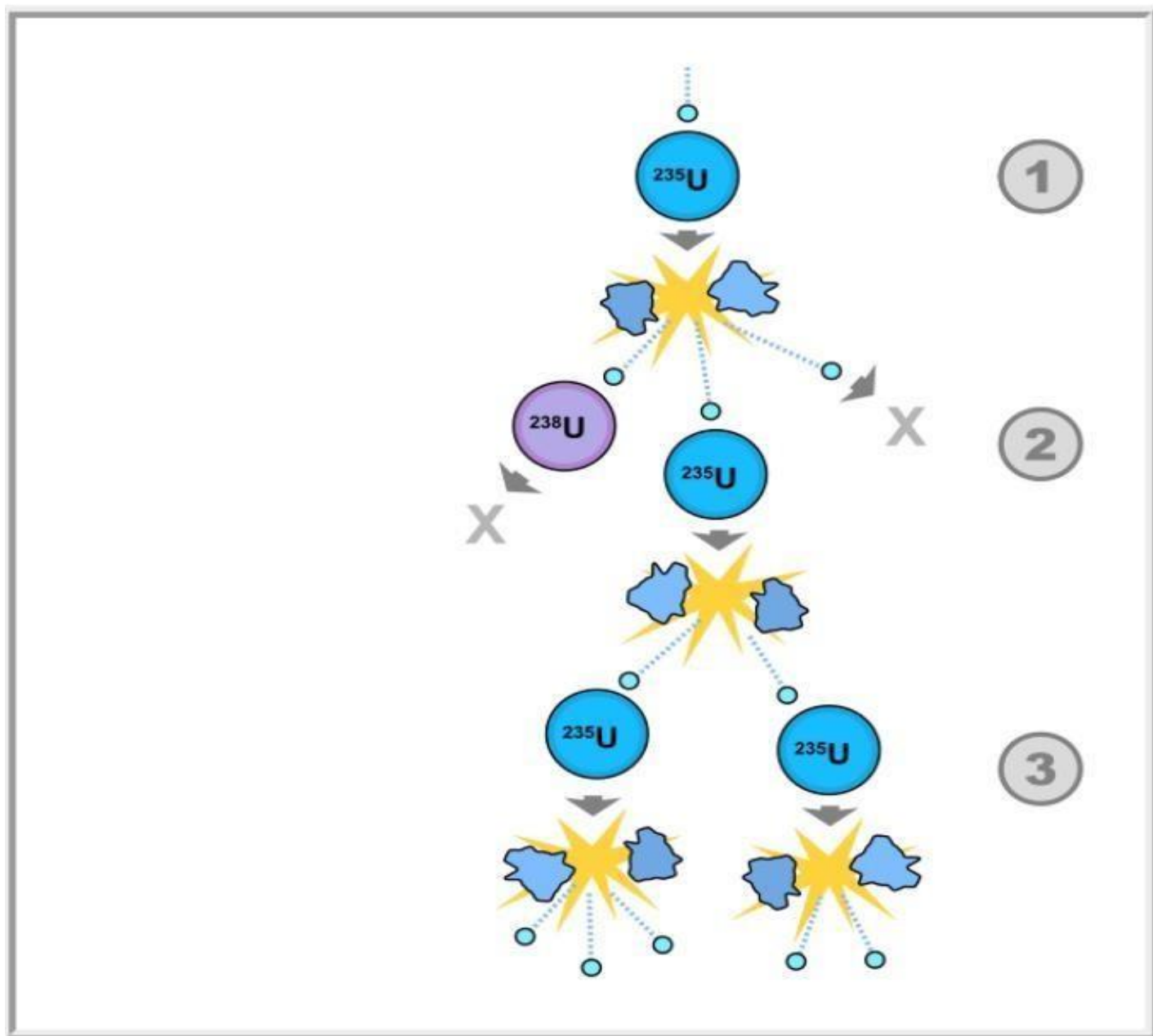


Figure (1): Illustrational of nuclear chain reaction.

All uranium atoms contain 92 protons, but U-238 is the most abundant isotope, making up 99.3% of naturally occurring uranium. The number 238 represents its atomic mass, which is the total of protons and neutrons in the nucleus. This means that U-238 has 146 neutrons ($238 - 92 = 146$). The isotope U-

235, on the other hand, contains 143 neutrons and accounts for only 0.7% of natural uranium. Another isotope, U-234, is even rarer, constituting just 0.005%, with other, even more uncommon isotopes existing, some of which have only been synthesized in laboratories [77].

From a nuclear energy and weapons perspective, U-235 is the most valuable isotope, as it serves as a primary fuel source for both reactors and atomic bombs, whereas U-238 cannot be used in the same way. As illustrated in the previous diagram, when a U-235 atom absorbs a neutron, it undergoes fission, splitting into two smaller atoms while releasing additional neutrons. This process releases a significant amount of atomic energy, which can either generate electricity or cause a powerful explosion. On average, the fission of a single U-235 atom produces approximately 2.5 new neutrons [78].

When neutrons are captured by fresh U-235 atoms, a rapidly intensifying chain reaction begins. The number of atoms undergoing fission multiplies exponentially—starting at 1, then 2.5 (on average), then $2.5^2 = 6.25$, and so forth. After 10 cycles, more than 10,000 atoms have split, and after 20 cycles, the count surpasses 100 million. However, as shown in the earlier diagram, some neutrons escape without contributing to the chain reaction (such as the neutron marked with an X on the right in step 2), while others are absorbed by U-238 atoms (the neutron marked with an X on the left in step 2), preventing further neutron production. (Once U-238 absorbs an additional neutron, it converts into U-239, which will be covered later. The key takeaway here is that this process does not generate more neutrons.) If each fission event, on average, results in more than one subsequent fission, the

reaction expands exponentially, unleashing immense energy [79,80].

The forces binding an atomic nucleus are vastly stronger than chemical bonds. Consequently, U-235 in a nuclear bomb delivers far more energy than an equal amount of TNT. The device detonated over Hiroshima contained roughly 50 kg (100 pounds) of U-235, yet its explosive force matched 15,000 tons (30 million pounds) of TNT. Had the entire U-235 supply undergone fission, the explosion could have reached 500 kilotons. However, only 3% of this potential was realized, as most of the U-235 scattered before absorbing neutrons necessary to continue the chain reaction [81].

The previous discussion emphasizes that what is often termed critical mass is, in reality, critical mass density. When a U-235 bomb detonates, most of the uranium remains, but it becomes too widely scattered to sustain the chain reaction. Too few neutrons interact with other U-235 atoms to keep the process going. This concept is fundamental to the "gun-type" atomic bomb, shown below [82]. In this design, two separate uranium masses, each below critical level, are placed at opposite ends of a barrel—one shaped like a projectile and the other as a hollow cylinder.

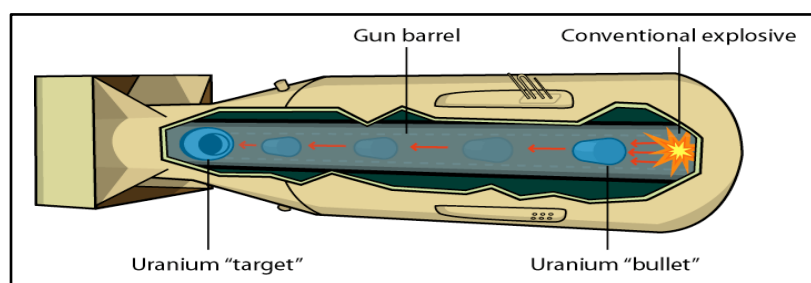


Figure (2): Gun-type nuclear bomb mechanism.

The target is specifically designed to snugly encase the projectile. When conventional explosives propel the projectile through the barrel, it merges with the target. This rapid assembly of two subcritical uranium masses results in a supercritical mass, initiating a chain reaction that culminates in a nuclear explosion. It's noteworthy that prior to detonation, the bomb contains more than a critical mass of uranium; however, it is divided into two separate pieces, spaced sufficiently apart to prevent neutrons from one piece from inducing fission in the other[83].

As previously mentioned, U-238 is generally not suitable as nuclear fuel, despite constituting 99.3% of naturally occurring uranium, with the remaining 0.7% primarily being U-235. Consequently, natural uranium cannot be directly utilized in weapons or most power plants and must first undergo enrichment to increase its U-235 content. The most prevalent nuclear reactors today are light water reactors (LWRs), which require uranium enriched to about 3-4% U-235, known as low-enriched uranium (LEU). In contrast, bomb-grade fuel necessitates further enrichment, preferably to 90% U-235, termed highly enriched uranium (HEU) [84].

Regrettably, the same technology employed to produce LEU for nuclear power—such as the gas centrifuges utilized in Iran's nuclear program—can be adapted to manufacture HEU for weapons. The Nuclear Non-Proliferation Treaty (NPT) obligates signatories, excluding the United States, Russia, the United Kingdom, France, and China, to refrain from developing nuclear weapons, while recognizing the "inalienable right" of all countries advancing nuclear technology for peaceful uses. The close

association between peaceful and military applications of nuclear technology makes distinguishing between these objectives exceedingly challenging, particularly concerning uranium enrichment [85]. Mohamed ElBaradei, the former Director General of the International Atomic Energy Agency (IAEA), has referred to enrichment as the "Achilles' heel" of non-proliferation efforts. For instance, Iran asserts that its enrichment program is essential for its domestic nuclear power agenda and does not contravene its NPT obligations. Nevertheless, its enrichment capability is likely to render it a "latent nuclear power" a nation capable of assembling a bomb in short order, should it choose to do so—in the near future [86].

HEU poses a significant proliferation risk because weapons utilizing it can function without prior testing. The HEU bomb dropped on Hiroshima on August 6, 1945, had never undergone a test before its use. In contrast, the nuclear test conducted on July 16, 1945, at Alamogordo, New Mexico—known as the Trinity test—involved a more intricate plutonium-based design. The scientists of the Manhattan Project were not sufficiently confident in this design to deploy it on Nagasaki without first conducting a full-scale trial. North Korea's two nuclear tests have both involved plutonium-based weapons, and the low yield of its first test, estimated to be around 1 kiloton, underscores the necessity of testing such weapons before actual deployment [87,88].

4.2 Uses of plutonium in nuclear weapons: Plutonium (chemical symbol Pu), a name originally proposed as a joke by Glenn Seaborg, has 94 protons, making it two

protons heavier than uranium. It has multiple isotopes, with Pu-239 being the most suitable for nuclear weapons. Plutonium is found in nature only in trace amounts but is artificially produced in nuclear reactors when U-238 absorbs a neutron and momentarily transforms into U-239. This isotope has a short half-life and decays into neptunium-239 (Np-239), which subsequently decays into Pu-239. The latter is much more stable, with a half-life of 24,000 years. Plutonium generated through this process is an exceptional nuclear fuel but is more challenging to ignite compared to HEU. Instead of using a straightforward gun-type assembly, plutonium-based bombs require a more complex implosion mechanism, as illustrated below [89].

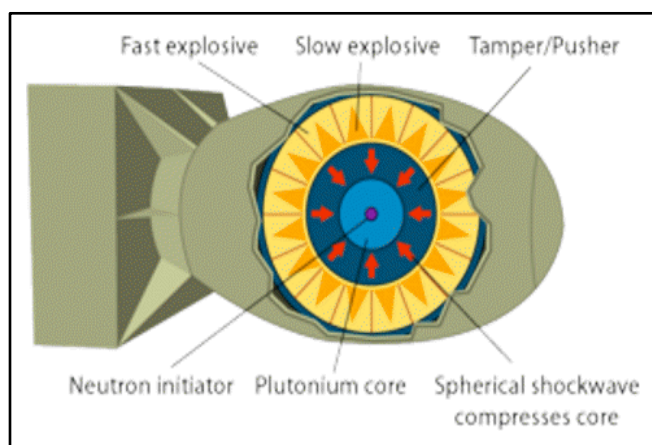


Figure (3): cross-sectional diagram of a plutonium-based implosion weapon.

Plutonium is shaped into a round core, referred to as a plutonium pit (similar to the seed inside a peach). This core is positioned within a hollow casing filled with conventional high explosives, known as an explosive lens. For the weapon to function properly, these explosives must detonate simultaneously, generating a spherical shockwave that compresses the core and decreases its critical mass. (Even metals like plutonium can be compressed under extreme force.) In its original state, before compression, the core remains below critical

mass. However, once detonated, the increased density shifts it into a supercritical state, triggering a nuclear explosion. The neutron initiator (or trigger, depicted in the diagram) plays a crucial role in the weapon's operation but does not require detailed discussion at this stage [90].

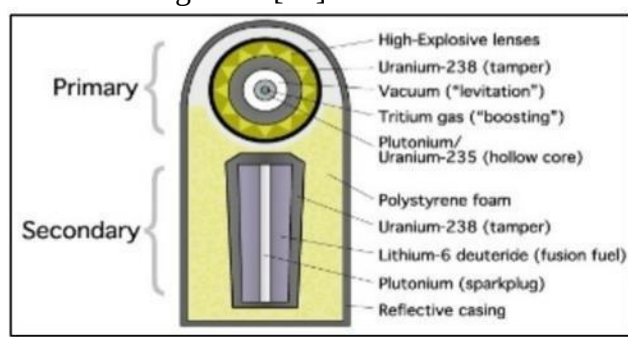
Despite their complexity, plutonium-based weapons are often preferred once a country masters their design. This preference arises because they require less than 10 kg of plutonium, whereas highly enriched uranium (HEU) weapons demand a significantly greater amount. Siegfried Hecker, former director of Los Alamos National Laboratory and now a professor at Stanford University, has pointed out that North Korea's uranium enrichment program is not as concerning due to its capability to develop more sophisticated (and militarily advantageous) plutonium weapons. Conversely, Iran's nuclear program raises concerns since it has not demonstrated the ability to create plutonium-based weapons [91].

Natural uranium, which contains only 0.7% U-235, is generally unsuitable for use in weapons or as a primary fuel for power plants, with one key exception: the Magnox reactor. This gas-cooled, graphite-moderated reactor operates using raw unenriched uranium and produces weapons-grade plutonium, which can be separated from uranium due to their distinct chemical characteristics. (In contrast, U-235 is much harder to separate from the more abundant U-238 because they share similar chemical properties.) North Korea relied on a small Magnox research reactor to generate all the plutonium used in its nuclear tests, as well as an estimated 4 to 8 remaining weapons. This approach allowed the country to bypass the complexities of the uranium enrichment process [92].

Given that low-enriched uranium (LEU) for light water reactors (LWRs) is supplied by a controlled provider, these reactors become more resistant to proliferation risks. This is because their fuel can be carefully monitored, and the plutonium generated within them is less suitable for nuclear weapons production. This elucidates why the 1994 Agreed Framework, designed to restrain North Korea's nuclear aspirations, proposed replacing its Magnox reactors with two light water reactors (LWRs). These points will be explored in greater depth later [93].

Fission-based nuclear weapons have an upper theoretical limit on their explosive power, with the most potent one ever built reaching 500 kilotons. Conversely, fusion weapons do not have such a restriction, as the largest one ever tested produced a 50-megaton detonation—equivalent to 50,000 kilotons, or 100 million pounds of TNT [94].

Due to their overwhelming destructive force, such massive weapons have limited strategic utility. Consequently, modern strategic nuclear weapons typically range between 100 and 500 kilotons, making them significantly more devastating than the bombs dropped on Hiroshima and Nagasaki. Meanwhile, tactical nuclear weapons, intended for battlefield deployment, have yields below one kiloton to prevent excessive collateral damage, which could impact allied forces and surrounding areas [95].



Figure(4):Cross-sectional diagram of a fusion weapon.

Fission weapons are sometimes referred to as atomic bombs, whereas fusion-based arms are known as hydrogen bombs or thermonuclear devices. The fundamental parts of a fusion bomb are illustrated in this diagram. The "primary" unit is a nuclear fission device that ignites the fusion process in the "secondary" stage [96].

Hydrogen exists in three isotopic forms: Protium (symbol H) consists of a single proton in its nucleus and lacks neutrons. It accounts for 99.985% of naturally occurring hydrogen. Light Water Reactors utilize ordinary water (H₂O) [97].

Deuterium (symbol D or ²H) has one proton and one neutron, making up nearly 0.015% of hydrogen found in nature. Heavy Water Reactors, which use deuterium oxide (D₂O), pose a greater risk for nuclear proliferation since they, like Magnox reactors, can operate with natural (unenriched) uranium as fuel[98].

Tritium (symbol T or ³H) contains one proton and two neutrons. It is radioactive with a half-life of roughly 12 years. Only minuscule amounts are naturally present, requiring artificial production for nuclear weapon applications [99].

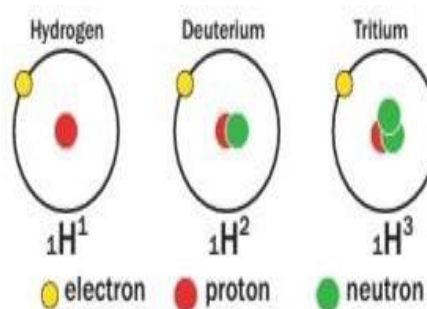


Figure (5): The three hydrogen isotopes—protium, deuterium, and tritium.

The most effective fusion reaction in nuclear weaponry involves the merging of a deuterium nucleus with a tritium nucleus. Combined, these two nuclei have two protons and three neutrons. When they fuse, they generate a helium nucleus composed of two protons and two neutrons, while an extra neutron is released. (This free neutron enhances the fission reaction, interacting with the uranium-238 shell shown in the diagram. This is an exception to the general principle that uranium-238 is unsuitable as bomb fuel. On its own, U-238 cannot function in a nuclear weapon and requires either highly enriched uranium or plutonium[100].

The fusion of deuterium and tritium releases an immense amount of energy, which drives the detonation. The first hydrogen bomb, codenamed "Ivy Mike," was far from a conventional bomb, as seen in the Image below. To grasp the scale of the apparatus, observe the individuals in the lower right-hand section [101].

To get a sense of the apparatus's scale, observe the men in the lower right corner of the image. It was designed purely as a proof of concept, a role it successfully fulfilled with a yield of just over 10 megatons [102].

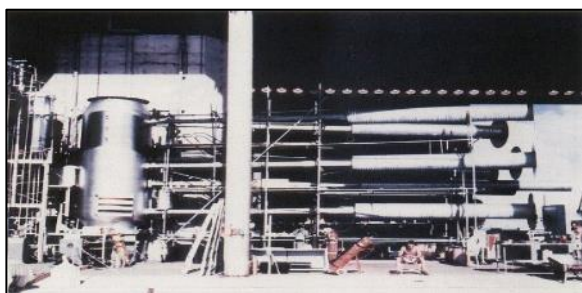


Figure (6): The ivy mike hydrogen bomb test apparatus.

For comparison, the "gadget" used in the Trinity test of July 1945 is shown below.

Although sizable, it was feasible to develop an airborne version [103].



Figure (7): The gadget used in the July 1945 trinity test.

Over the years, nuclear weapons have undergone significant miniaturization. It is astonishing to realize that the W87 warhead, with a yield of 475 kilotons, is compact enough to fit inside a backpack while still possessing the power to obliterate an entire city. However, this reality must be acknowledged [104].

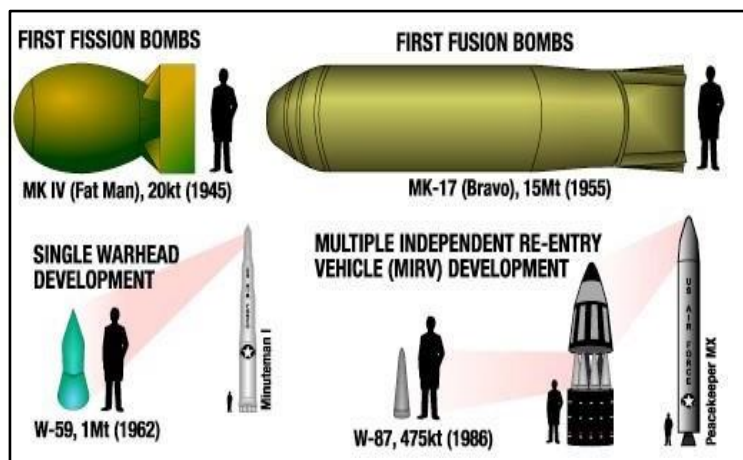


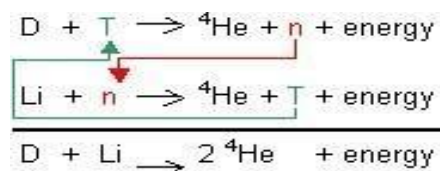
Figure (8): The progression of nuclear weapons over time.

The MX missile, shown in the lower right corner of the figure, is capable of carrying up to ten W87 warheads, each capable of striking a separate target. This technique, known as MIRV (Multiple Independently-targetable Reentry Vehicle), was initially seen as a cost-efficient method to expand nuclear arsenals. However, over time, it

became clear that MIRV-equipped missiles introduced instability and heightened the risk of a preemptive strike. Because a single enemy warhead (or a few, to ensure success) could eliminate a missile carrying multiple warheads, MIRV systems became prime targets in a nuclear conflict. This dynamic creates a dangerous scenario known as crisis instability, where there is an incentive to strike first. As a result, arms control treaties have sought to limit the use of highly MIRV'ed missiles. For instance, the New START Treaty, recently ratified by the Senate, caps the number of deployed launchers (missiles and bombers) for both the U.S. and Russia at 700, with a total of 1,550 deployed warheads, allowing only a modest level of MIRV deployment [105].

Another crucial aspect of nuclear weapons technology relates to fusion fuel. As previously mentioned, fusion reactions involve deuterium and tritium, which are isotopes of hydrogen. At standard temperature and pressure, hydrogen isotopes exist as gases, making them low in density and difficult to store efficiently. The first full-scale thermonuclear device, Ivy Mike, addressed this Issue by using liquid deuterium and tritium, but the required cryogenic systems contributed significantly to the size of the device. A breakthrough occurred when scientists discovered an alternative way to store fusion fuel in solid form under normal conditions [106].

This innovation involved combining lithium and hydrogen to form lithium hydride (LiH), a stable solid compound. When deuterium is substituted for hydrogen, the result is lithium deuteride (LiD), which



Figure(9): fusion reaction.

serves as an efficient fuel for fusion reactions. The fundamental fusion reaction begins with deuterium and tritium combining to produce helium, a free neutron, and a large amount of energy. The released neutron can then be absorbed by a lithium atom, triggering a fission reaction that generates more helium, tritium, and energy. The newly produced tritium can, in turn, continue the fusion process by reacting with additional deuterium[107].

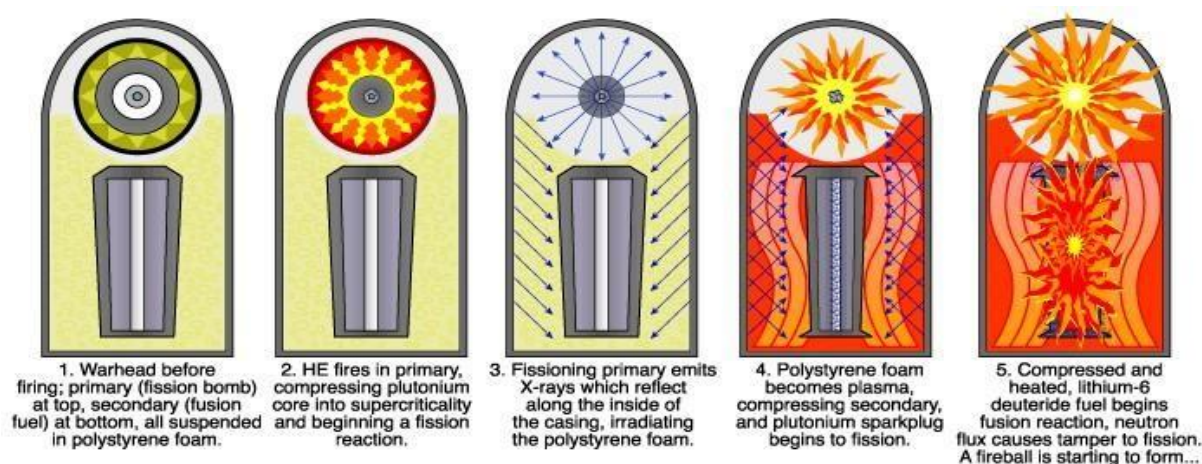
By utilizing lithium deuteride, nuclear weapons can effectively generate tritium as needed, eliminating the challenge posed by tritium's short half-life of 12 years. If tritium were used directly as fuel, It would require regular replenishment. In contrast, lithium deuteride is chemically stable and can remain viable for extended periods without the need for refueling, making it a highly practical solution for nuclear weapon design [108].

To break apart. The area under the curves represents the explosion's

yield. If neutrons are introduced too early, such as at zero alpha, the yield is relatively low, corresponding to the smaller triangular area on the left. However, if neutrons are introduced at peak alpha, the larger triangular area in the middle represents the

maximum yield. This is the optimal and highest possible yield [109].

The diagram below illustrates the stages of a thermonuclear weapon detonation using lithium deuteride. In the second stage, "HE" refers to High Explosive.



Figure(10): stages of a thermonuclear weapon detonation process.

4.3.the effects resulting from the explosion of nuclear bomb:

The effects of a nuclear bomb explosion refer to the consequences caused by the detonation process itself, rather than the thermal and radioactive effects that follow. Approximately 40% to 60% of the bomb's total energy is released in the form of intense heat and pressure, which rapidly displaces gases in the atmosphere away from the explosion site. This displacement generates immense pressure on the surrounding environment, producing successive circular shock waves that travel at speeds of hundreds of kilometers per hour [110].

At the moment of detonation, two primary types of pressure are generated:

1. High static pressure: This results from the sudden and intense pressure surge caused by the bomb's shockwave.

2. Dynamic pressure: This occurs due to the movement and vibration of atmospheric gases expanding outward in a circular pattern from the explosion center [111].

Beyond their impact on structures, these high-pressure waves also have severe effects on the human body. The intense pressure affects the points where different tissues meet, such as the junction between muscles and bones, leading to serious tissue tears. Additionally, organs containing gases, such as the lungs, intestines, and middle ear, are especially vulnerable, as the extreme pressure can cause them to rupture [112].

To quantify the explosive force of a nuclear bomb, its power is often compared to the energy released by TNT. A nuclear detonation is typically measured in kilotons or megatons of TNT. Based on this scale, a nuclear bomb's explosive force ranges from 10 to 20 kilotons of TNT. For perspective, a 10-kiloton explosion is sufficient to destroy a small

modern city, with its destructive effects extending up to 2.4 kilometers from the blast center [113].

4.3.1. The Initial Explosive Power of a Nuclear Bomb:

The explosive force of a nuclear bomb is determined by two key factors. The first is its energy output, typically measured in comparison to TNT. The second factor is the altitude at which the bomb is detonated above the ground [114]. Selecting the optimal detonation height is crucial for maximizing the bomb's impact

For instance, the atomic bomb dropped on Nagasaki, Japan, was detonated at an altitude of 580 meters. This bomb, a plutonium-based implosion-type device, had an explosive yield of 20 kilotons of TNT. The altitude required for detonation is directly proportional to the bomb's power. For example, a bomb with a yield of 30 kilotons would need to be detonated at a greater height to achieve maximum destructive effect [115].

4.3.2. Nuclear Fuel:

Nuclear fuel primarily consists of uranium oxide, which is shaped into cylindrical pellets approximately 2.5 cm in height and 0.9 cm in diameter. These pellets are encased in zirconium alloy tubes, which can endure high temperatures and absorb minimal neutrons. Each tube is about 4 meters long and is tightly sealed at both ends to prevent the escape of impurities during reactor operation [116].

Enriched uranium oxide typically contains up to 3.6% of the fissile isotope uranium-235, with the remaining 96.3% being uranium-238. Since natural uranium contains only

0.7% uranium-235, it must be enriched to between 2.5% and 4.0% for use in reactors that utilize ordinary water [117].

Water serves multiple critical functions in a nuclear reactor. It absorbs and transfers the intense heat produced by the fuel during operation, raising its temperature to around 500°C. The fuel and water units are housed within a thick steel reactor vessel, where high pressure builds due to the elevated temperature. Some of the water transforms into steam, which drives turbines to generate electricity [118].

Additionally, water acts as a neutron moderator, slowing down neutrons generated by the fission of uranium-235. This moderation is essential for sustaining the chain reaction. The 3.6% uranium-235 content in nuclear fuel produces neutrons, ensuring the continuation of the nuclear reaction and maintaining energy production [119].

4.4. Nuclear fission in the atomic bomb:



Figure (11):photo of little boy bomb.

4.4.1. Fission Process in the Atomic Bomb:

When a neutron collides with the nucleus of a uranium-235 or plutonium-239 atom, it triggers the nucleus to split into two smaller fragments, each containing approximately half the original protons and neutrons. This splitting process, known as nuclear fission, releases a significant amount of thermal

energy, along with gamma rays and additional neutrons [120].

Under specific conditions, the released neutrons go on to strike and split neighboring uranium nuclei, which in turn emit more neutrons. These neutrons continue to fission further nuclei in a rapidly accelerating chain reaction. Eventually, this process results in the near-complete consumption of the fissionable material, leading to the explosive energy release characteristic of an atomic bomb [121].

Uranium has several isotopes capable of undergoing fission, but uranium-235 is particularly important due to its natural occurrence at a ratio of approximately one part per 139 parts of uranium-238. It fissions more easily and emits more neutrons per reaction than many other isotopes. Plutonium-239 shares similar properties,

making both materials the primary fuels for nuclear weapons [122].

A small quantity of uranium-235—such as 0.45 kg (1 pound)—is insufficient to sustain a chain reaction and is referred to as a subcritical mass. In this state, the neutrons released by fission are more likely to escape the material without colliding with another nucleus, thereby preventing further fission. However, when more uranium-235 is added, the probability of a released neutron initiating another fission increases. This is because the escaping neutrons must traverse more uranium nuclei, raising the likelihood of one striking another nucleus and causing additional fission events [123]. Once the amount of uranium-235 reaches a level where, on average, each fission event produces at least one additional fission, critical mass is achieved. At this point, a self-sustaining chain.

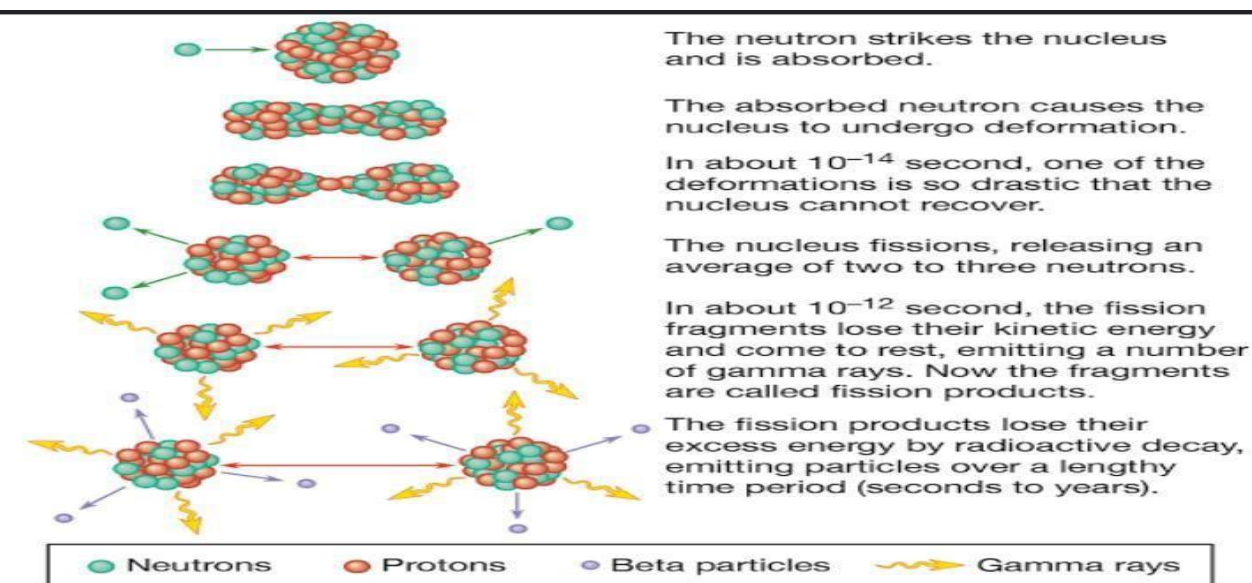


Figure (12): Stages of nuclear fission and energy

4.4.2. Stages of Nuclear Fission and Energy Release:

Nuclear fission releases an immense amount of energy relative to the material involved.

When 1 kg (2.2 pounds) of uranium-235 undergoes complete fission, it produces energy equivalent to 17,000 tons (or 17 kilotons) of TNT. The detonation of an atomic bomb generates vast amounts of thermal energy, reaching temperatures of

20

several million degrees at the core of the explosion [124].

This extreme heat creates a massive fireball, capable of igniting ground fires that can engulf an entire small city. The explosion also generates convection currents that pull dust and debris into the fireball, forming the distinctive mushroom-shaped cloud characteristic of nuclear detonations.

Additionally, the explosion produces an intense shockwave that spreads outward from the blast site, traveling several miles before gradually dissipating. This powerful blast wave can cause widespread destruction, leveling buildings and infrastructure miles away from the explosion's epicenter [125].

The detonation also releases large quantities of neutrons and gamma rays, emitting lethal radiation that diminishes rapidly over a distance of 1.5 to 3 km (1 to 2 miles) from the blast. The intense heat vaporizes materials within the fireball, which then condense into fine radioactive particles known as fallout. This radioactive debris is carried by atmospheric winds in the troposphere or stratosphere, spreading contamination over vast areas [126].

Among the hazardous materials in nuclear fallout are long-lived radioactive isotopes such as strontium-90 and plutonium-239. Even brief exposure to fallout in the first few weeks after a detonation can be fatal, while prolonged exposure significantly increases the risk of developing cancer [127].

The fission process can be better understood by examining the composition and stability of atomic nuclei. Nuclei are composed of nucleons (neutrons and protons). The conversion of mass to energy follows Einstein's equation, $E = mc^2$, where E is the

energy equivalent of a mass, m , and c is the velocity of light. This difference is known as the mass defect and is a measure of the total binding energy (and, hence, the stability) of the nucleus. Here's a revised version of the provided text with improved clarity and readability [128].

4.4.3. Binding Energy and Nuclear Stability:

The difference between the actual mass of a nucleus and the sum of the masses of its individual nucleons is known as the mass defect [129].

This difference corresponds to the binding energy, which is released when a nucleus is formed from its constituent nucleons. The relationship between mass and energy follows Einstein's famous equation:

$E = mc^2$ where E represents energy, m is mass, and c is the speed of light. The binding energy is a measure of the total energy holding a nucleus together, determining its overall stability. To break a nucleus into its individual protons and neutrons, an amount of energy equal to the binding energy must be supplied [130].

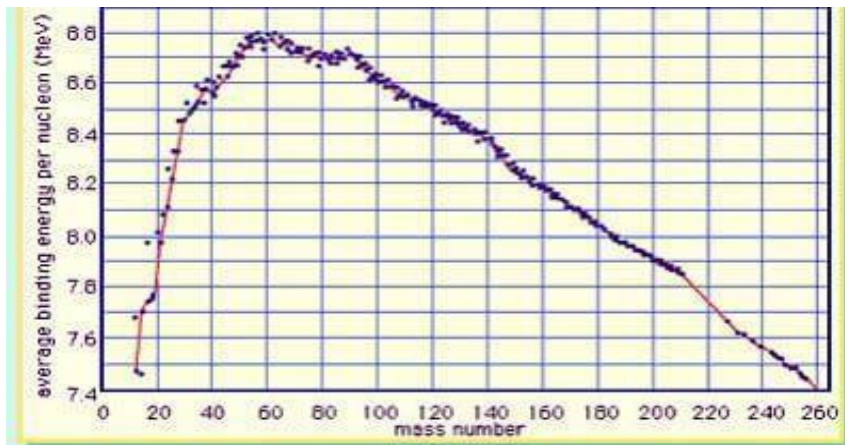


Figure (13): Relationship between binding energy and mass number.

A graph illustrating the average binding energy per nucleon as a function of nuclear mass number reveals key trends in nuclear stability. The highest binding energy—indicating the greatest stability—is found around mass number 56, which corresponds to iron [131].

This suggests that nuclei heavier than mass number 56 tend to become more stable by splitting into lighter nuclei with higher binding energy, a process that releases energy—this is the principle behind nuclear fission. Conversely, nuclei lighter than mass number 56 gain stability by fusing together to form heavier nuclei with greater mass defects, also releasing energy in the process. This fusion process, particularly involving hydrogen nuclei, is responsible for the immense energy produced by the Sun and serves as the basis for the hydrogen bomb. Scientists continue to explore ways to harness fusion as a sustainable power source [132].

4.5. Hydrogen bomb:



Figure (14): photo of fatman bomb.

A thermonuclear bomb initiates its explosive sequence with the detonation of the primary stage, which consists of a limited quantity of conventional explosives. This explosion compresses a sufficient amount of fissile uranium, triggering a fission chain reaction.

The energy from this reaction leads to another explosion, generating extreme temperatures of several million degrees. The heat and force produced are reflected back by a uranium casing and directed toward the secondary stage, which contains lithium-6 deuteride. The immense heat sets off nuclear fusion, resulting in an explosion powerful enough to rupture the uranium casing. The fusion process releases neutrons that induce further fission in the uranium, producing a significant portion of the explosion's energy and leading to radioactive fallout [133].

A neutron bomb, which is a variation of a thermonuclear weapon, lacks the uranium casing. This results in a smaller explosion but an intensified neutron radiation effect. The entire chain of explosions in a thermonuclear bomb unfolds within a fraction of a second [134].

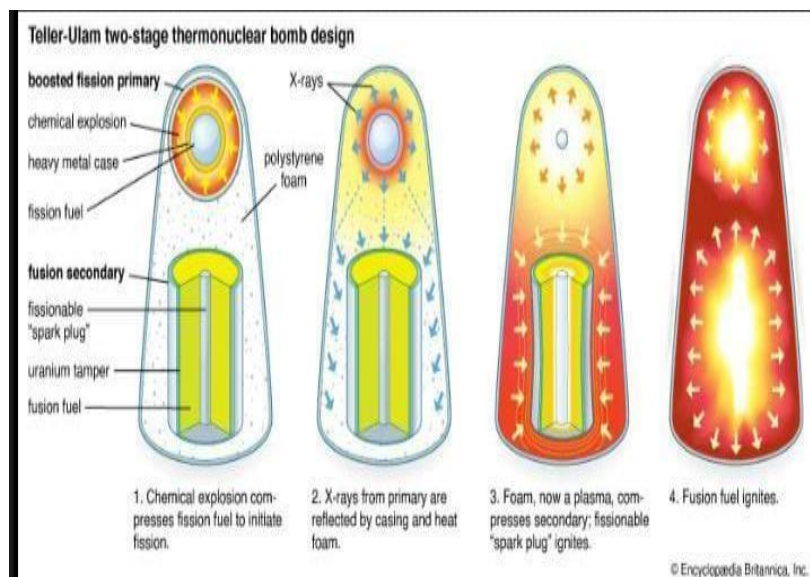


Figure (15): Schematic diagram of a teller-ulam two-stage thermonuclear bomb.

4.6. Effects of a Thermonuclear Explosion:

The detonation of a thermonuclear device unleashes intense heat, bright light, a powerful blast wave, and radioactive fallout. The shockwave generated by the explosion expands outward at supersonic speeds, devastating buildings within several miles. The blinding white flash can cause permanent vision loss for individuals even miles away. Extreme temperatures ignite flammable materials, creating widespread fires that can merge into a massive firestorm. The radioactive debris contaminates air, land, and water, persisting in the environment for years and spreading globally [135].

4.7. Evolution of Nuclear Weapon Designs:

4.7.1. Gun-Type Fission Bomb (1945):

Mechanism: Combines two sub-critical uranium-235 masses through conventional explosives to achieve a supercritical state and trigger a nuclear explosion

Example: "Little Boy" bomb dropped on Hiroshima [136].

4.7.2. Implosion-Type Fission Bomb (1945):

Design: Uses symmetrical explosives around plutonium-239 to compress it rapidly, reaching a supercritical condition

Example: "Fat Man" bomb detonated over Nagasaki [137].

4.7.3. Two-Point Implosion Design (1960s):

Concept: Employs opposing explosive lenses to compress the fissile core more efficiently, allowing for a more compact weapon
Historical Context: The Nth Country Experiment (1964-1967) demonstrated that even individuals without weapons expertise could create a working nuclear device using publicly available knowledge [138].



Figure (16): Cross-section of a thermonuclear warhead.

4.7.4. Boosted Fission Weapons (1950s - Present):

Advancement: Incorporates a small amount of deuterium and tritium fusion fuel into the fission bomb, significantly increasing efficiency and yield without enlarging the weapon's size [139].

4.8. Factors affecting the explosive yield of hydrogen bombs:

4.8.1. Bomb Design:

The overall design of the weapon, typically involving two stages—an initial fission explosion (atomic bomb) followed by a fusion reaction (hydrogen bomb)—plays a crucial role in determining the yield [140].

4.8.2. Amount of Fusion Fuel:

The quantity and type of fusion fuel used in the secondary stage (such as deuterium and tritium) significantly impact the energy released during the fusion process [141].

4.8.3. Compression Efficiency:

The effectiveness with which the fusion fuel in the secondary stage is compressed by the fission explosion affects the efficiency of the fusion reaction and thus the final yield [142].

4.8.4. Casing Materials:

The casing, which often includes materials that reflect neutrons back into the core, helps boost the fusion process, thereby increasing the yield [143].

4.8.5. Temperature and Pressure:

High temperatures and pressures are required to initiate nuclear fusion, and the fission explosion creates the necessary conditions for these extreme environments[144].

4.8.6. Tritium Production:

In some designs, tritium is produced from lithium deuteride, which contributes additional fuel for the

fusion process, impacting the overall yield [145].

4.8.7. Size and Weight of the Weapon:

Larger bombs tend to have more fusion fuel, potentially increasing the yield, though this is constrained by practical limits related to size and weight [146].

4.8.8. Fusion Boosting:

Some designs utilize the fission explosion to enhance the secondary stage, increasing the amount of fusion fuel that undergoes fusion, thus boosting the yield1 [147].

4.8.9. Efficiency of Energy Transfer:

The efficiency of transferring energy from the fission reaction to the fusion reaction plays a significant role in determining the total explosive yield [148].

Table (1): Factors affecting the explosive yield of hydrogen bombs:

Factor	Description	Effects on Explosive Yield
Fusion Fuel Composition [149]	The hydrogen isotopes (deuterium and tritium) used in the fusion stage are critical for initiating fusion reactions.	A higher proportion of deuterium and tritium increases the intensity of the fusion reaction, resulting in a stronger explosion. The amount of fusion fuel directly correlates with the bomb's total yield.

Fission Trigger [150]	The fission explosion that initiates the fusion process is crucial. It generates the necessary heat and pressure.	A more efficient or powerful fission reaction generates sufficient energy to trigger the fusion phase effectively, leading to a much higher explosive yield.
Design Complexity [151]	The arrangement of the fission and fusion stages in the bomb's design significantly influences the amount of energy harnessed.	A well- designed bomb maximizes the transfer of energy from the fission stage to the fusion stage, optimizing the final explosive power. Poor design can lead to wasted energy and a reduced yield.
Temperature and Pressure [152]	Extreme temperature and pressure are necessary for fusion. The bomb must create and sustain these conditions.	Achieving and maintaining high temperatures and pressures ensures that fusion reactions occur more efficiently, enhancing the bomb's overall yield. A failure to reach these conditions limits the explosion's power.
Environmental Factors [153]	External conditions like altitude and atmospheric pressure can influence the bomb's impact.	Environmental factors play a secondary role; while atmospheric pressure can slightly affect the intensity of the blast, the primary determinant of yield remains the internal fusion and fission processes.

4.9. Comparison between the atomic bomb and the hydrogen bomb:

During World War II in 1945, Japan witnessed unprecedented devastation when the United States dropped atomic bombs on Hiroshima and, three days later, on Nagasaki. The attacks resulted in the deaths of over 200,000 people and ultimately led to Japan's surrender [154]. However, nuclear experts explain that hydrogen bombs are significantly more powerful—potentially up to 1,000 times stronger than atomic bombs. The United States first tested a hydrogen bomb in 1954, demonstrating its immense destructive capacity [155].

Unlike atomic bombs, which rely solely on nuclear fission, hydrogen bombs generate energy through a combination of fission and fusion, leading to a much larger explosion. As a result, the blast radius, shock waves, heat, and radiation effects of a hydrogen bomb extend far beyond those of an atomic bomb. Experts estimate that while the bomb dropped on Nagasaki destroyed everything within a one-mile radius, a hydrogen bomb could impact an area spanning 5 to 10 miles, causing significantly higher casualties [156].

4.9.1. Differences Between Hydrogen and Atomic Bombs:

Hydrogen bombs are considered a more advanced and powerful version of atomic bombs. While atomic bombs function by splitting heavy atomic nuclei such as uranium or plutonium, hydrogen bombs require additional isotopes—deuterium and tritium—to trigger a nuclear fusion reaction. This fusion process releases significantly more energy, amplifying the bomb's destructive force [157,158]. Due to their advanced technology, hydrogen bombs typically yield between 100,000 and several million kilotons of TNT—far exceeding the destructive power of the atomic bombs used in World War II, which had an estimated yield of 10,000 kilotons of TNT. Additionally, hydrogen bombs are more efficient in terms of weight and can be deployed over greater distances using missiles.

4.9.2. Similarities Between Hydrogen and Atomic Bombs:

Despite their differences, both hydrogen and atomic bombs share common traits. Both produce extreme destruction, with the ability to kill tens of thousands instantly and cause long-term radiation-related illnesses. Their explosions generate intense heat and pressure waves capable of leveling buildings, setting entire areas ablaze, and making roads impassable due to debris and craters. Furthermore, radiation exposure from both types of bombs can lead to severe health

effects, including cancer and genetic mutations, with environmental contamination lasting for decades [159].

4.9.3. Modern Advancements in Hydrogen Bomb Technology:

Recent technological advancements have further enhanced the destructive capabilities of hydrogen bombs:

Multiple Independently Targetable Reentry Vehicles (MIRVs): A single missile can carry multiple hydrogen warheads, each targeting different locations [160].

Miniaturization: Advanced engineering allows for smaller, more compact bombs that can be delivered via missiles, aircraft, or submarines [161].

High Yield-to-Weight Ratio: Hydrogen bombs maximize their destructive potential while remaining lightweight enough for modern deployment systems [162].

Although atomic bombs caused catastrophic devastation in the past, hydrogen bombs pose an even greater threat due to their immense power and technological advancements, making them among the most dangerous weapons ever developed [163].

5. Conclusion:

Hydrogen bomb is the more advanced version of an atomic bomb. An atomic bomb uses either uranium or plutonium and relies on fission, a nuclear reaction in which a nucleus or an atom breaks apart into two pieces. To make a hydrogen bomb, one would still need uranium or plutonium as well as two other isotopes of hydrogen, called deuterium and tritium. The hydrogen bomb relies on fusion, the process of taking two separate atoms and putting them together to

form a third atom. The way the hydrogen bomb works, it's really a combination of fission and fusion together.

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