Inexpensive Mini Thermonuclear Reactor

By Alexander Bolonkin
abolonkin@juno.com

New York, April 2012

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C&R Co., abolonkin@juno.com

Abstract

This proposed design for a mini thermonuclear reactor uses a method based upon a series of important innovations. A cumulative explosion presses a capsule with nuclear fuel up to 100 thousands of atmospheres, the explosive electric generator heats the capsule/pellet up to 100 million degrees and a special capsule and a special cover which keeps these pressure and temperature in capsule up to 0.001 sec. which is sufficient for Lawson criteria for ignition of thermonuclear fuel. Major advantages of these reactors/bombs is its very low cost, dimension, weight and easy production, which does not require a complex industry. The mini thermonuclear bomb can be delivered as a shell by conventional gun (from 155 mm), small civil aircraft, boat or even by an individual. The same method may be used for thermonuclear engine for electric energy plants, ships, aircrafts, tracks and rockets.

Key words: Thermonuclear mini bomb, thermonuclear reactor, nuclear energy, nuclear engine, nuclear space propulsion.

Introduction

It is common knowledge that thermonuclear bombs are extremely powerful but very expensive and difficult to produce as it requires a conventional nuclear bomb for ignition. In stark contrast, the Mini Thermonuclear Bomb is very inexpensive. Moreover, in contrast to conventional dangerous radioactive or neutron bombs which generates enormous power, the Mini Thermonuclear Bomb does not have gamma or neutron radiation which, in effect, makes it a "clean" bomb having only the flash and shock wave of a conventional explosive but much more powerful (from 1 ton of TNT and more, for example 100 tons). This means that using this weapon may not be forbidden by international treaties. Not only is it inexpensive, but it can easily be modified to the field situation by varying the type and power of the bomb. These changes require only changing the small capsule with nuclear fuel which then would convert the bomb to any of the following: long or short radioactive, gamma radiation, neutron, "clean" or electromagnetic bomb. The mini thermonuclear bomb may be delivered by shell from 152 mm gun (or more) and any small rocket or civil aircraft because it is small and would weigh only15 kg.

While all counties may dream of having this super weapon, its preeminent beneficial side is that it is one way to produce cheap energy. In the past 60 years, the United States and other governments spent tens of billions of dollars in futile attempts to create an inertial thermonuclear reactor. The main problem is designing a mechanism which can attain the required compression, temperature and time span for thermonuclear ignition. The author has invented the devices which make it possible to reach the hundreds of millions degrees of temperatures, up to a million atmospheres of pressure in a few milliseconds using only a small volume of materials. This designed device provides more than enough power for thermonuclear reactions using cheap thermonuclear fuel.

Brief Information about Thermonuclear Reactors

Fusion power is useful energy generated by nuclear fusion reactions. In this kind of reaction two light atomic nuclei fuse together to form a heavier nucleus and release energy. In the largest contemporary experiment to date, JET, fusion power production was somewhat larger than the power expended to create the plasma but was maintained for only a few seconds. An experimental reactor, ITER, was designed to produce several times more fusion power than the power into the plasma over many minutes. Construction of the facility began in 2007, and the first plasma is expected in 2019. The production of net electrical power from fusion is planned for the next generation experiment after ITER.

Unfortunately, this task is not as easy as scientists previously thought. Fusion reactions require a very large amount of energy to initiate a reaction in order to overcome the so-called *Coulomb barrier* or *fusion barrier energy*.

In order to create the required conditions, the fuel must be heated to at least tens of millions of degrees, and/or compressed to immense pressures. The temperature and pressure required for any particular fuel to fuse is known as the Lawson criterion. In nuclear fusion research, the Lawson criterion, first derived by John D. Lawson in 1957, is an important general measure of a system that defines the conditions needed for a fusion reactor to reach *ignition*, that is, that the heating of the plasma by the products of the fusion reactions is sufficient to maintain the temperature of the plasma against all losses without external power input. As originally formulated the Lawson criterion gives a minimum required value for the product of the plasma (electron) density n_e and the "energy confinement time" τ. Later analyses suggested that a more useful figure of merit is the "triple product" of density, confinement time, and plasma temperature T. The triple product also has a minimum required value, and the name "Lawson criterion" often refers to this inequality.

The key to practical fusion power is to select a fuel that requires the minimum amount of energy to start, that is, the lowest barrier energy. The best fuel from this standpoint is a one-to-one mix of deuterium and tritium; both are heavy isotopes of hydrogen. The D-T (Deuterium and Tritium) mix has a low barrier. In order to create the required conditions, the fuel must be heated to tens of millions of degrees, and/or must be compressed to immense pressures. To accomplish this, at present, D-T is used by two main methods of fusion: inertial confinement fusion (ICF) and magnetic confinement fusion (MCF) (for example, tokamak).

In inertial confinement fusion (ICF), nuclear fusion reactions are initiated by heating and compressing a target. The target is a pellet that most often contains deuterium and tritium (often only micro or milligrams). Intense laser or ion beams are used for compression. The beams explosively detonate the outer layers of the target. That accelerates the underlying target layers inward, sending a shockwave into the center of pellet mass. If the shockwave is powerful enough and if the center has high enough density, some of the fuel will be heated enough to cause fusion reactions. In a target which has been heated and compressed to the point of thermonuclear ignition, energy can then heat surrounding fuel to cause it to fuse as well, potentially releasing tremendous amounts of energy.

Magnetic confinement fusion (MCF). Since plasmas are very good electrical conductors, magnetic fields can also confine fusion fuel. A variety of magnetic configurations can be used, the basic distinction being between magnetic mirror confinement and toroidal confinement, especially tokamaks and stellarators.

For the D-T reaction, the physical value is about

$$\begin{array}{l} L = n_e T\tau > (10^{14} \div 10^{15}) \quad \text{in} \quad \text{"cgs"} \quad \text{units} \\ \text{or} \quad L = nT\tau > (10^{20} \div 10^{21}) \quad \text{in} \quad \text{CI} \quad \text{units} \end{array},$$

where T is temperature, [KeV], 1 eV = 1.16×10^4 °K; n_e is matter density, [1/cm^3]; n is matter density, [1/m^3]; τ is time, [s]. Last equation is in metric system. The thermonuclear reaction of $^2H + ^3D$ realizes if $L > 10^{20}$ in CI (meter, kilogram, second) units or $L > 10^{14}$ in 'cgs' (centimeter, gram, second) units.

This number has not yet been achieved in any reactor, although the latest generations of machines have come close. For instance, the reactor TFTR has achieved the densities and energy lifetimes needed to achieve Lawson at the temperatures it can create, but it cannot create those temperatures at the same time. Future ITER aims to do both.

The Lawson criterion applies to inertial confinement fusion as well as to magnetic confinement fusion but is more usefully expressed in a different form. Whereas the energy confinement time in a magnetic system is very difficult to predict or even to establish empirically, in an inertial system it must be on the order of the time it takes sound waves to travel across the plasma:

$$\tau \approx \frac{R}{\sqrt{kT/m_i}}$$

where τ is time, s; R is distance, m; $k = 1.38 \cdot 10^{-23}$ *J/K* is Boltzmann constant; m_i is mass of ion, kg.

Following the above derivation of the limit on $n_e\tau_E$, we see that the product of the density and the radius must be greater than a value related to the minimum of $T^{3/2}/\langle\sigma v\rangle$ (here σ is Boltzmann constant, v is ion speed). This condition is traditionally expressed in terms of the mass density ρ: $\rho R >$ 1 g/cm² .

To satisfy this criterion at the density of solid D+T (0.2 g/cm³) would require implausibly large laser pulse energy. Assuming the energy required scales with the mass of the fusion plasma ($E_{laser} \sim \rho R^3 \sim \rho^{-2}$), compressing the fuel to 10^3 or 10^4 times solid density would reduce the energy required by a factor of 10^6 or 10^8, bringing it into a realistic range. With a compression by 10^3, the compressed density will be 200 g/cm³, and the compressed radius can be as small as 0.05 mm. The radius of the fuel before compression would be 0.5 mm. The initial pellet will be perhaps twice as large since most of the mass will be ablated during the compression.

The fusion power density is a good figure of merit to determine the optimum temperature for magnetic confinement, but for inertial confinement the fractional burn-up of the fuel is probably more useful. The burn-up should be proportional to the specific reaction rate ($n^2\langle\sigma v\rangle$) times the confinement time (which scales as $T^{1/2}$) divided by the particle density n: burn-up fraction ~ $n^2\langle\sigma v\rangle T^{-1/2} / n \sim (nT)\ (\langle\sigma v\rangle/T^{3/2})$

Thus the optimum temperature for inertial confinement fusion is that which maximizes $\langle\sigma v\rangle/T^{3/2}$, which is slightly higher than the optimum temperature for magnetic confinement. Confinement refers to all the conditions necessary to keep plasma dense and hot long enough to undergo fusion:

- *Equilibrium:* There must be no net forces on any part of the plasma, otherwise it will rapidly disassemble. The exception, of course, is inertial confinement, where the relevant physics must occur faster than the disassembly time.
- *Stability:* The plasma must be so constructed that small deviations are restored to the initial state, otherwise some unavoidable disturbance will occur and grow exponentially until the plasma is destroyed.
- *Transport:* The loss of particles and heat in all channels must be sufficiently slow. The word "confinement" is often used in the restricted sense of "energy confinement".

To produce self-sustaining fusion, the energy released by the reaction (or at least a fraction of it) must be used to heat new reactant nuclei and keep them hot long enough that they also undergo fusion reactions. Retaining the heat generated is called energy *confinement* and may be accomplished in a number of ways.

The hydrogen bomb weapon has no confinement at all. The fuel is simply allowed to fly apart, but it takes a certain length of time to do this, and during this time fusion can occur. This approach is called *inertial confinement* (Figures 1 - 2). If more than about a milligram of fuel is used, the explosion would destroy the machine, so controlled thermonuclear fusion using inertial confinement causes tiny pellets of fuel to explode several times a second. To induce the explosion, the pellet must be compressed to about 30 times solid density with energetic beams. If the beams are focused directly on the pellet, it is called *direct drive*, which can in principle be very efficient, but in practice it is difficult to obtain the needed uniformity. An alternative approach is *indirect drive*, in which the beams heat a shell, and the shell radiates x-rays, which then implode the pellet. The beams are commonly laser beams, but heavy and light ion beams and electron beams have all been investigated and tried to one degree or another.

They rely on fuel pellets with a "perfect" shape in order to generate a symmetrical inward shock wave to produce the high-density plasma, and in practice these have proven difficult to produce. A recent development in the field of laser-induced ICF is the use of ultra-short pulse multi-petawatt lasers to heat the plasma of an imploding pellet at exactly the moment of greatest density after it is imploded conventionally using terawatt scale lasers. This research will be carried out on the (currently being built) OMEGA EP petawatt and OMEGA lasers at the University of Rochester and at the GEKKO XII laser at the Institute for Laser Engineering in Osaka Japan which, if fruitful, may have the effect of greatly reducing the cost of a laser fusion-based power source.

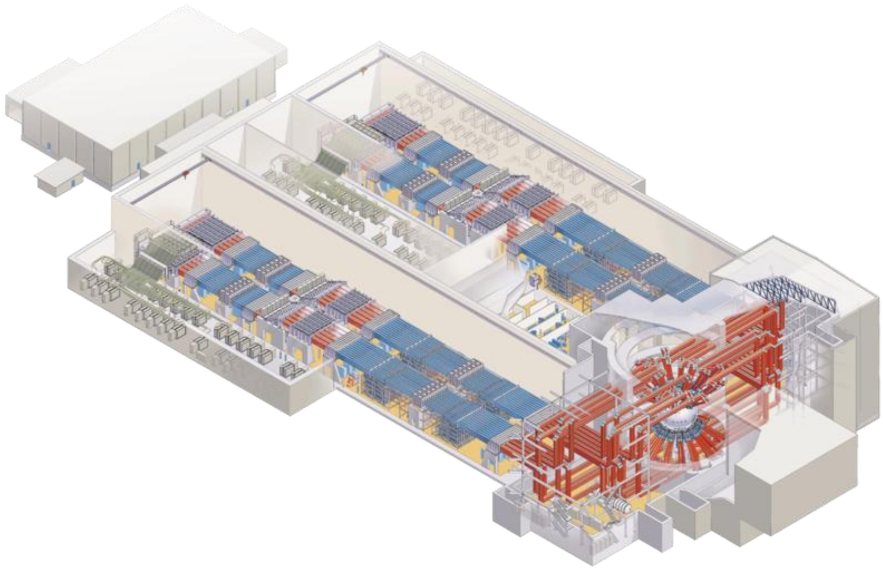

Fig.1. NIF's basic layout. The laser pulse is generated in the room just right of center, and is sent into the beamlines (blue) on either side. After several passes through the beamlines the light is sent into the "switchyard" (red) where it is aimed into the target chamber (silver).

Fig. 2. Laser installation for NOVA inertial thermonuclear reactor. Look your attention in the man and gigantic size of laser installation for reactor. Cost is some billions of dollars.

At the temperatures required for fusion, the fuel is in the form of plasma with very good electrical conductivity. This opens the possibility to confine the fuel and the energy with magnetic fields, an idea known as *magnetic confinement*. Much of this progress has been achieved with a particular emphasis on tokomaks.

In fusion research, achieving a fusion energy gain factor $Q = 1$ is called *breakeven* and is considered a significant although somewhat artificial milestone. *Ignition* refers to an infinite *Q*, that is, a self-sustaining plasma where the losses are made up for by fusion power without any external input. In a practical fusion reactor, some external power will always be required for things like current drive, refueling, profile control, and burn control. A value on the order of $Q = 20$ will be required if the plant is to deliver much more energy than it uses internally.

In a fusion power plant, the nuclear island has a *plasma chamber* with an associated vacuum system, surrounded by a plasma-facing components (first wall and diverter) maintaining the vacuum boundary and absorbing the thermal radiation coming from the plasma, surrounded in turn by a blanket where the neutrons are absorbed to breed tritium and heat a working fluid that transfers the power to the balance of plant. If magnetic confinement is used, a *magnet* system, using primarily cryogenic superconducting magnets, is needed, and usually systems for heating and refueling the plasma and for driving current. In inertial confinement, a *driver* (laser or accelerator) and a focusing system are needed, as well as a means for forming and positioning the *pellets.*

In thirty years, scientists have increased the Lawson criterion of the ICF and tokamak installations by tens of times. Unfortunately, all current and some new installations (ICF and totamak) have a Lawrence criterion that is tens of times lower than is necessary (Figure 3).

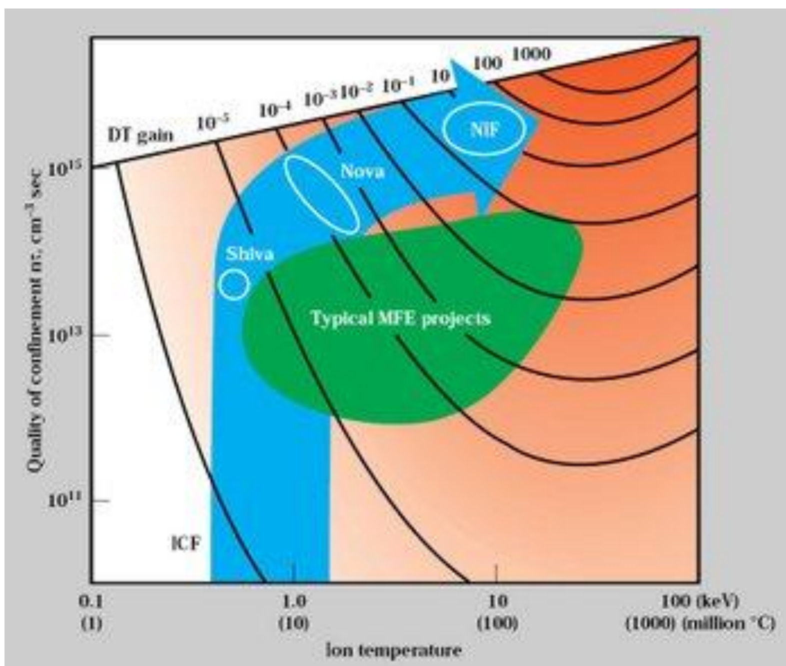

Figure 3. Parameter space occupied by inertial fusion energy and magnetic fusion energy devices. The regime allowing thermonuclear ignition with high gain lies near the upper right corner of the plot.

Present nuclear and thermonuclear bombs.

A **nuclear weapon** is an explosive device that derives its destructive force from nuclear reactions, either fission or a combination of fission and fusion. Both reactions release vast quantities of energy from relatively small amounts of matter. The first fission ("atomic") bomb test released the same amount of energy as approximately 20,000 tons of TNT. The first thermonuclear ("hydrogen") bomb test released the same amount of energy as approximately 10,000,000 tons of TNT.

A modern thermonuclear weapon weighing little more than 2,400 pounds (1,100 kg) can produce an explosive force comparable to the detonation of more than 1.2 million tons (1.1 million tonnes) of TNT. Thus, even a small nuclear device no larger than traditional bombs can devastate an entire city by blast, fire and radiation. Nuclear weapons are considered weapons of mass destruction, and their use and control have been a major focus of international relations policy since their debut.

The **Teller–Ulam design** is the nuclear weapon design concept used in most of the world's nuclear weapons. It is colloquially referred to as "the secret of the **hydrogen bomb**" because it employs hydrogen fusion, though in most applications the bulk of its destructive energy comes from uranium fission, not hydrogen fusion. It is named for its two chief contributors, Edward Teller and Stanisław Ulam, who developed it in 1951 for the United States, with certain concepts developed with the contribution of John von Neumann. It was first used in multi-megaton-range thermonuclear weapons. As it is also the most efficient design concept for small nuclear weapons, today virtually all the nuclear weapons deployed by the five major nuclear-armed nations use the Teller–Ulam design.

Its essential features, which officially remained secret for nearly three decades, are: 1) separation of stages into a triggering "primary" explosive and a much more powerful "secondary" explosive, 2) compression of the secondary by X-rays coming from nuclear fission in the primary, a process called the "radiation implosion" of the secondary, and 3) heating of the secondary, after cold compression, by a second fission explosion inside the secondary.

The radiation implosion mechanism is a heat engine exploiting the temperature difference between the secondary's hot, surrounding radiation channel and its relatively cool interior. This temperature difference is briefly maintained by a massive heat barrier called the "pusher", which also serves as an implosion tamper, increasing and prolonging the compression of the secondary. If made of uranium—and it usually is—it can capture neutrons produced by the fusion reaction and undergo fission itself, increasing the overall explosive yield. In many Teller–Ulam weapons, fission of the pusher dominates the explosion and produces radioactive fission product fallout.

The first test of this principle was the "Ivy Mike" nuclear test in 1952, conducted by the United States. In the Soviet Union, the design was known as Andrei Sakharov's "**Third Idea**", first tested in 1955. Similar devices were developed by the United Kingdom, China, and France, though no specific code names are known for their designs.

Explosively electric generator

The first work on these generators was conducted by the VNIIEF center for nuclear research in Sarov at the beginning of the 1950s followed by Los Alamos National Laboratory in the United States. In the spring of 1952, R.Z. Lyudaev, E.A. Feoktistova, G.A. Tsyrkov, and A.A. Chvileva undertook the first experiment with this type of generator, with the goal of obtaining a very high magnetic field.

MK-1 Hollow tube generators. The first experiments were able to attain magnetic fields of millions of gauss (hundreds of teslas, given an initial field of 30 kG (3 T which is in the free space "air" same as B/u0 = H --> 3 Vs/m^2 / 4pi10^-7 Vs/Am = 2.387x10^6 A/m so it is about 2.4 M A/m).

Mk-2. Helical generators. The MK-2 generator is particularly interesting for the production of intense currents, up to 10^8 A (100 MA), as well as a very high energy magnetic field, as up to 20% of the explosive energy can be converted to magnetic energy, and the field strength can attain 2×10^6 gauss (200 T).

Disc generators. Systems using up to 25 modules have been developed at VNIIEF. Output of 100 MJ at 256 MA have been produced by a generator a meter in diameter composed of three modules

The practical realization of high performance MK-2 systems required the pursuit of fundamental studies by a large team of researchers; this was effectively achieved by 1956, following the production of the first MK-2 generator in 1952, and the achievement of currents over 100 mega-amperes from 1953.

Cumulative explosion (shaped charge).

A **shaped charge** is an explosive charge shaped to focus the effect of the explosive's energy. Various types are used to cut and form metal, to initiate nuclear weapons, to penetrate armor, and to "complete" wells in the oil and gas industry. A typical modern lined shaped charge can penetrate armor steel to a depth of 7 or more times the diameter of the charge (charge diameters, CD), though greater depths of 10 CD and above have been achieved. Contrary to a widespread misconception, the shaped charge does not depend in any way on heating or melting for its effectiveness, that is, the jet from a shaped charge does not melt its way through armor, as its effect is purely kinetic in nature.

The maximum achievable jet velocity is roughly 2.34 times the sound velocity in the material. The speed can reach 10 km/s, peaking some 40 microseconds after detonation; the cone tip is subjected to acceleration of about 25 million g. The jet tail reaches about 2–5 km/s. The pressure between the jet tip and the target can reach one terapascal. The immense pressure makes the metal flow like a liquid, though x-ray diffraction has shown the metal stays solid; one of the theories explaining this behavior proposes molten core and solid sheath of the jet. The best materials are face-centered cubic metals, as they are the most ductile, but even graphite and zero-ductility ceramic cones show significant penetration.

THE EXPLOSIVE.

For optimal penetration, a high explosive having a high detonation velocity and pressure is normally chosen. The most common explosive used in high performance anti-armor warheads is HMX (octogen), though it is never used in pure form, as it would be too sensitive. It is normally compounded with a few percent of some type of plastic binder, such as in the polymer-bonded explosive (PBX) LX-14, or with another less-sensitive explosive, such as TNT, with which it forms Octol. Other common high-performance explosives are RDX-based compositions, again either as

PBXs or mixtures with TNT (to form Composition B and the Cyclotols) or wax (Cyclonites). Some explosives incorporate powdered aluminum to increase their blast and detonation temperature, but this addition generally results in decreased performance of the shaped charge. There has been research into using the very high-performance but sensitive explosive CL-20 in shaped-charge warheads, but, at present, due to its sensitivity, this has been in the form of the PBX composite LX-19 (CL-20 and Estane binder).

OTHER FEATURES

A **waveshaper** is a body (typically a disc or cylindrical block) of an inert material (typically solid or foamed plastic, but sometimes metal, perhaps hollow) inserted within the explosive for the purpose of changing the path of the detonation wave. The effect is to modify the collapse of the cone and resulting jet formation, with the intent of increasing penetration performance. Waveshapers are often used to save space; a shorter charge can achieve the same performance as a longer one without a waveshaper.

Description of Innovation

The principal schema of the offered mini thermonuclear bomb/shell is illustrated in fig.4. Bomb contains: body 1, high detonation explosive 2, closed loop conductivity liner 3 connected to a fuel capsule 6, empty toroidal cavity 4, capsule with compressed thermonuclear explosive 5, device for initial electric impulse 6, detonator 7.

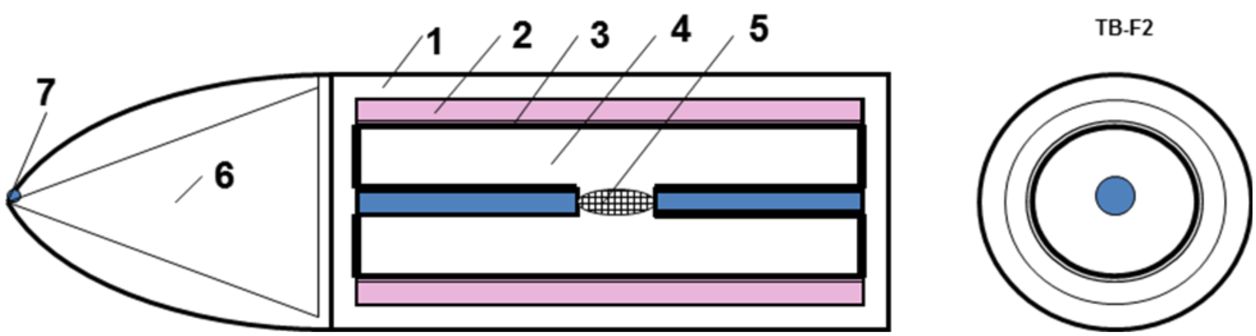

Fig.4. Mini thermonuclear Bomb. Notations: 1 - body of bomb, 2- high detonation explosive, 3 - closed loop conductivity liner connected to a fuel capsule (pellet) 6, 4 - empty toroidal cavity, 5 - capsule with compressed thermonuclear explosive, 6 - device for initial electric impulse, 7- detonator.

The bomb works in the following way. Detonator turns on the device 7 which creates the initial electric impulse. This impulse heats the thermonuclear fuel into capsule for converting it in conductive plasma (temperature 2 – 5 eV, 20,000- 50,000 ^{o}K) and creates the strong magnetic field into cavity 4. Devices simultaneously ignite the explosive 2. Explosive 2 explosives, moves the liner with high speed (3- 10 km/s) in cavity 4 to fuel capsule 5 , increases and compressing the magnetic field into cavity 4. That produces the very powerful electric impulse which heats the thermonuclear fuel up 2-5 keV (10 – 200 million ^{o}K). Simultaneously powerful electric impulse produces a strong pinch effect which keeps and compresses the fuel plasma into capsule. When the liner reaches the capsule, one inhibits and creates very much pressure up 100,000 atmospheres. Simultaneously the liner mass prevents the rapid expensive of the fuel plasma and increases the time of nuclear reaction. As the result we increase all three components of Lawson criteria and reach the request value. All processes take some micro seconds.

The innovations are: using the new impulse electric generator simultaneously for creating, high heating, compressing, plasma confinement and increasing the time of thermonuclear reaction. That is only principal schemes of new mini thermonuclear bomb. Many important details missed because they also are the inventions. The thermonuclear reactor used the closed schema but contains the additional devices for utilization the nuclear energy.

THEORY OF CURRENT THERMONUCLEAR REACTOR

Methods of Confinement in Current Reactors

Magnetic confinement. Magnetic fields can confine fusion fuel because plasma is a very good electrical conductor. A variety of magnetic configurations can be used, the most basic distinction being tokamaks and stellarators.

Inertial confinement. A third confinement principle is to apply a rapid pulse of energy to a large part of the surface of a pellet of fusion fuel, causing it to simultaneously "implode" and heat to very high pressure and temperature. If the fuel is dense enough and hot enough, the fusion reaction rate will be high enough to burn a significant fraction of the fuel before it has dissipated. To achieve these extreme conditions, the initially cold fuel must be explosively compressed. Inertial confinement is used in the hydrogen bomb, where the driver is x-rays created by a fission bomb. Inertial confinement is also attempted in "controlled" nuclear fusion, where the driver is a laser, ion, or electron beam.

Some other confinement principles have been investigated, such as muon-catalyzed fusion, the Farnsworth-Hirsch fusor (inertial electrostatic confinement), and bubble fusion.

In man-made fusion, the primary fuel is not constrained to be protons and higher temperatures can be used, so reactions with larger cross-sections are chosen. This implies a lower Lawson criterion, and therefore less startup effort. Another concern is the production of neutrons, which activate the reactor structure radiologically, but also have the advantages of allowing volumetric extraction of the fusion energy and tritium breeding. Reactions that release no neutrons are referred to as *aneutronic*.

In order to be useful as a source of energy, a fusion reaction must satisfy several criteria. It must:

- *be exothermic* - This may be obvious, but it limits the reactants to the low Z (number of protons) side of the curve of binding energy. It also makes helium ^{4}He the most common product because of its extraordinarily tight binding, although ^{3}He and ^{3}H also show up.
- *involve low Z nuclei* - This is because the electrostatic repulsion must be overcome before the nuclei are close enough to fuse.
- *have two reactants* - At anything less than stellar densities, three body collisions are too improbable. It should be noted that in inertial confinement, both stellar densities and temperatures

are exceeded to compensate for the shortcomings of the third parameter of the Lawson criterion, ICF's very short confinement time.

- *have two or more products* - This allows simultaneous conservation of energy and momentum without relying on the (weak!) electromagnetic force.
- *conserve both protons and neutrons* - The cross sections for the weak interaction are too small.

Few reactions meet these criteria. The following are those with the largest cross-sections:

Table 1. Suitable reactions for thermonuclear fusion

(1)	D	+	T			^{4}He	(3.5 MeV)	+		n	(14.1 MeV)					
(2i)	D	+	D			T	(1.01 MeV)	+		p	(3.02 MeV)					*50%*
(2ii)						^{3}He	(0.82 MeV)	+		n	(2.45 MeV)					*50%*
(3)	D	+	^{3}He			^{4}He	(3.6 MeV)	+		p	(14.7 MeV)					
(4)	T	+	T			^{4}He		+	2	n	+ 11.3 MeV					
(5)	^{3}He	+	^{3}He			^{4}He		+	2	p	+ 12.9 MeV					
(6i)	^{3}He	+	T			^{4}He		+		p		+	n	+ 12.1 MeV		*51%*
(6ii)						^{4}He	(4.8 MeV)	+		D	(9.5 MeV)					*43%*
(6iii)						^{4}He	(0.5 MeV)	+		n	(1.9 MeV)	+	p	(11.9 MeV)		*6%*
(7)	D	+	^{6}Li		2	^{4}He	+ 22.4 MeV									
(8)	p	+	^{6}Li			^{4}He	(1.7 MeV)	+		^{3}He	(2.3 MeV)					
(9)	^{3}He	+	^{6}Li		2	^{4}He		+		p	+ 16.9 MeV					
(10)	p	+	^{11}B		3	^{4}He	+ 8.7 MeV									

p (protium), D (deuterium), and T (tritium) is shorthand notation for the main three isotopes of hydrogen.

For reactions with two products, the energy is divided between them in inverse proportion to their masses, as shown. In most reactions with three products, the distribution of energy varies. For reactions that can result in more than one set of products, the branching ratios are given.

Some reaction candidates can be eliminated at once. The D-^{6}Li reaction has no advantage compared to p-^{11}B because it is roughly as difficult to burn but produces substantially more neutrons through D-D side reactions. There is also a p-^{7}Li reaction, but the cross-section is far too low except possible for T_i > 1 MeV, but at such high temperatures an endothermic, direct neutron-producing reaction also becomes very significant. Finally there is also a p-^{9}Be reaction, which is not only difficult to burn, but ^{9}Be can be easily induced to split into two alphas and a neutron.

In addition to the fusion reactions, the following reactions with neutrons are important in order to "breed" tritium in "dry" fusion bombs and some proposed fusion reactors:

$$n + {}^6\mathrm{Li} \rightarrow T + {}^4\mathrm{He}\ ,$$

$$n + {}^7\mathrm{Li} \rightarrow T + {}^4\mathrm{He} + n\ .$$

To evaluate the usefulness of these reactions, in addition to the reactants, the products, and the energy released, one needs to know something about the cross section. Any given fusion device will have a maximum plasma pressure that it can sustain, and an economical device will always operate near this maximum. Given this pressure, the largest fusion output is obtained when the temperature is selected so that $<\sigma v>/T^2$ is a maximum. This is also the temperature at which the value of the triple product $nT\tau$ required for ignition is a minimum. This chosen optimum temperature and the value of $<\sigma v>/T^2$ at that temperature is given for a few of these reactions in the following table 2.

Table 2. Optimum temperature and the value of $<\sigma v>/T^2$ at that temperature

fuel	T [keV]	$<\sigma v>/T^2$ [$m^3/s/keV^2$]
D-T	13.6	1.24×10^{-24}
D-D	15	1.28×10^{-26}
D-^{3}He	58	2.24×10^{-26}
p-^{6}Li	66	1.46×10^{-27}
p-^{11}B	123	3.01×10^{-27}

Note that many of the reactions form chains. For instance, a reactor fueled with T and ^{3}He will create some D, which is then possible to use in the D + ^{3}He reaction if the energies are "right". An elegant idea is to combine the reactions (8) and (9). The ^{3}He from reaction (8) can react with ^{6}Li in reaction (9) before completely thermalizing. This produces an energetic proton which in turn undergoes reaction (8) before thermalizing. A detailed analysis shows that this idea will not really work well, but it is a good example of a case where the usual assumption of a Maxwellian plasma is not appropriate.

Any of the reactions above can, in principle, be the basis of fusion power production. In addition to the temperature and cross section discussed above, we must consider the total energy of the fusion products E_{fus}, the energy of the charged fusion products E_{ch}, and the atomic number Z of the non-hydrogenic reactant.

Specification of the D-D reaction entails some difficulties, though. To begin with, one must average over the two branches (2) and (3). More difficult is to decide how to treat the T and ^{3}He products. T burns so well in a deuterium plasma that it is almost impossible to extract from the plasma. The D-^{3}He reaction is optimized at a much higher temperature, so the burn-up at the optimum D-D temperature may be low, so it seems reasonable to assume the T but not the ^{3}He gets burned up and adds its energy to the net reaction. Thus we will count the D-D fusion energy as E_{fus} = (4.03+17.6+3.27)/2 = 12.5 MeV and the energy in charged particles as E_{ch} = (4.03+3.5+0.82)/2 = 4.2 MeV.

Another unique aspect of the D-D reaction is that there is only one reactant, which must be taken into account when calculating the reaction rate.

With this choice, we tabulate parameters for four of the most important reactions (table 3).

Table 3. Parameters of the most important reactions

Fuel	Z	E_{fus} [MeV]	E_{ch} [MeV]	neutronicity
D-T	1	17.6	3.5	0.80
D-D	1	12.5	4.2	0.66
D-^{3}He	2	18.3	18.3	~ 0.05
p-^{11}B	5	8.7	8.7	~ 0.001

The last column is the *neutronicity* of the reaction, the fraction of the fusion energy released as neutrons. This is an important indicator of the magnitude of the problems associated with neutrons like radiation damage, biological shielding, remote handling, and safety. For the first two reactions it is calculated as $(E_{fus}-E_{ch})/E_{fus}$. For the last two reactions, where this calculation would give zero, the values quoted are rough estimates based on side reactions that produce neutrons in a plasma in thermal equilibrium.

Of course, the reactants should also be mixed in the optimal proportions. This is the case when each reactant ion plus its associated electrons accounts for half the pressure. Assuming that the total pressure is fixed, this means that density of the non-hydrogenic ion is smaller than that of the hydrogenic ion by a factor $2/(Z+1)$. Therefore the rate for these reactions is reduced by the same factor, on top of any differences in the values of $\langle\sigma v\rangle/T^2$. On the other hand, because the D-D reaction has only one reactant, the rate is twice as high as if the fuel were divided between two hydrogenic species.

Thus, there is a "penalty" of $(2/(Z+1))$ for non-hydrogenic fuels arising from the fact that they require more electrons, which take up pressure without participating in the fusion reaction. There is, at the same time, a "bonus" of a factor 2 for D-D due to the fact that each ion can react with any of the other ions, not just a fraction of them. We can now compare these reactions in the following table 4.

Table 4. Comparison of reactions

fuel	$\langle\sigma v\rangle/T^2$	penalty/ bonus	reactivity	Lawson criterion	power density
D-T	1.24×10^{-24}	1	1	1	1
D-D	1.28×10^{-26}	2	48	30	68
D-^{3}He	2.24×10^{-26}	2/3	83	16	80
p-^{11}B	3.01×10^{-27}	1/3	1240	500	2500

The maximum value of $\langle\sigma v\rangle/T^2$ is taken from a previous table. The "penalty/bonus" factor is that related to a non-hydrogenic reactant or a single-species reaction. The values in the column "reactivity" are found by dividing (1.24×10^{-24} by the product of the second and third columns. It indicates the factor by which the other reactions occur more slowly than the D-T reaction under comparable conditions. The column "Lawson criterion" weights these results with E_{ch} and gives an indication of how much more difficult it is to achieve ignition with these reactions, relative to the difficulty for the D-T reaction. The last column is labeled "power density" and weights the practical reactivity with E_{fus}. It indicates how much lower the fusion power density of the other reactions is compared to the D-T reaction and can be considered a measure of the economic potential.

Bremsstrahlung (Brake) Losses.

Bremsstrahlung, (from the German *bremsen*, to brake and *Strahlung*, radiation, thus, "braking radiation"), is electromagnetic radiation produced by the acceleration of a charged particle, such as an electron, when deflected by another charged particle, such as an atomic nucleus. The term is also used to refer to the process of producing the radiation. Bremsstrahlung has a continuous spectrum. The phenomenon was discovered by Nikola Tesla (1856-1943) during high frequency research he conducted between 1888 and 1897.

Bremsstrahlung may also be referred to as free-free radiation. This refers to the radiation that arises as a result of a charged particle that is free both before and after the deflection (acceleration) that causes the emission. Strictly speaking, bremsstrahlung refers to any radiation due to the acceleration of a charged particle, which includes synchrotron radiation; however, it is frequently used (even when not speaking German) in the more literal and narrow sense of radiation from electrons stopping in matter.

Table 5. Rough optimum temperature and the power ratio

of fusion and Bremsstrahlung radiation lost

Fuel	T_i (keV)	$P_{fusion}/P_{Bremsstrahlung}$
D-T	50	140
D-D	500	2.9
D-^{3}He	100	5.3
^{3}He-^{3}He	1000	0.72
p-^{6}Li	800	0.21
p-^{11}B	300	0.57

The ions undergoing fusion will essentially never occur alone but will be mixed with electrons that neutralize the ions' electrical charge and form a plasma. The electrons will generally have a temperature comparable to or greater than that of the ions, so they will collide with the ions and emit Bremsstrahlung. The Sun and stars are opaque to Bremsstrahlung, but essentially any terrestrial fusion reactor will be optically thin at relevant wavelengths. Bremsstrahlung is also difficult to reflect and difficult to convert directly to electricity, so the ratio of fusion power produced to Bremsstrahlung radiation lost is an important figure of merit. This ratio is generally maximized at a much higher temperature than that which maximizes the power density (see the previous subsection). The following table shows the rough optimum temperature and the power ratio at that temperature for several reactions.

The actual ratios of fusion to Bremsstrahlung power will likely be significantly lower for several reasons. For one, the calculation assumes that the energy of the fusion products is transmitted completely to the fuel ions, which then lose energy to the electrons by collisions, which in turn lose energy by Bremsstrahlung. However because the fusion products move much faster than the fuel ions, they will give up a significant fraction of their energy directly to the electrons. Secondly, the plasma is assumed to be composed purely of fuel ions. In practice, there will be a significant proportion of impurity ions, which will lower the ratio. In particular, the fusion products themselves *must* remain in the plasma until they have given up their energy, and *will* remain some time after that in any proposed confinement scheme. Finally, all channels of energy loss other than Bremsstrahlung have been neglected. The last two factors are related. On theoretical and experimental grounds, particle and energy confinement seem to be closely related. In a confinement scheme that does a good job of retaining energy, fusion products will build up. If the fusion products are efficiently ejected, then energy confinement will be poor, too.

The temperatures maximizing the fusion power compared to the Bremsstrahlung are in every case higher than the temperature that maximizes the power density and minimizes the required value of the fusion triple product (Lawson criterion). This will not change the optimum operating point for D-T very much because the Bremsstrahlung fraction is low, but it will push the other fuels into regimes where the power density relative to D-T is even lower and the required confinement even more difficult to achieve. For D-D and D-^{3}He, Bremsstrahlung losses will be a serious, possibly prohibitive problem. For ^{3}He-^{3}He, p-^{6}Li and p-^{11}B the Bremsstrahlung losses appear to make a fusion reactor using these fuels impossible.

In a plasma, the free electrons are constantly producing Bremsstrahlung in collisions with the ions. The power density of the Bremsstrahlung radiated is given by

$$P_{Br} = \frac{16\alpha^3 h^2}{\sqrt{3}\, m_e^{3/2}} n_e^2 T_e^{1/2} Z_{eff} \quad .$$

T_e is the electron temperature, α is the fine structure constant, h is Planck's constant, and the "effective" ion charge state Z_{eff} is given by an average over the charge states of the ions:

$$Z_{eff} = \Sigma\,(Z^2\, n_Z)\,/\,n_e$$

This formula is derived in "Basic Principles of Plasmas Physics: A Statistical Approach" by S. Ichimaru, p. 228. It applies for high enough T_e that the electron deBroglie wavelength is longer than the classical Coulomb distance of closest approach. In practical units, this formula gives

$$P_{Br} = (1.69\times10^{-32}\ /\mathrm{W\ cm}^{-3})\,(n_e/\mathrm{cm}^{-3})^2\,(T_e/\mathrm{eV})^{1/2}\,Z_{eff} =,$$

$$(5.34\times10^{-37}\ /\mathrm{W\ m^{-3}})\ (n_e\,/\mathrm{m^{-3}})^2\ (T_e\ /\mathrm{keV})^{1/2}\ Z_{eff}\ ,$$

where $\mathrm{Wcm^{-3}}$, $\mathrm{cm^{-3}}$, eV, $\mathrm{Wm^{-3}}$, $\mathrm{m^{-3}}$, keV are units of corresponding magnitudes. For very high temperatures there are relativistic corrections to this formula, that is, additional terms of order $T_e/m_e c^2$.

List of Main Equations

Below are the main equations for estimation of benefits from the offered innovations.

1. Energy, E, is needed for Thermonuclear Reaction

$$F = k\frac{Q_1Q_2}{r^2},\quad E=\int_{r_0}^{\infty} F\,dr,\quad E=\frac{kZ_1Z_2e^2}{r_0},\quad 1J = 0.625\cdot10^{19}eV$$
$$r_i = (1.2\div1.5)\cdot10^{-15}\sqrt[3]{A},\quad A = Z+N,\ \ r_0 = r_1 + r_2 \qquad (1)$$

where $k = 9\times10^9$ constant; Z_1, Z_2 are charge state of 1 and 2 particles respectively; $e = 1{,}6\times10^{-19}$ C is charge of electron; $r_o = r_1 + r_2$ is sum of radius of nuclear force, m; A is number of element; F is force, N; E is energy, J; Q is charge of particles.

For example, for reaction H+H (hydrogen, $Z_1 = Z_2 = 1$, $r_o \approx 2\times10^{-15}$ m) this energy is ≈ 0.7 MeV or 0.35 MeV for every particle. This energy nuclear has in temperature $T_k = 1.16\cdot10^4\ T_e = 4\cdot10^8$K . The real energy is about 30 times less because part of the particles has more average speed and there is a tunnel effect.

2. Energy Needed for Ignition. Figure 5 shows a magnitude $n\tau$ (analog of Lawson criterion) required for ignition.

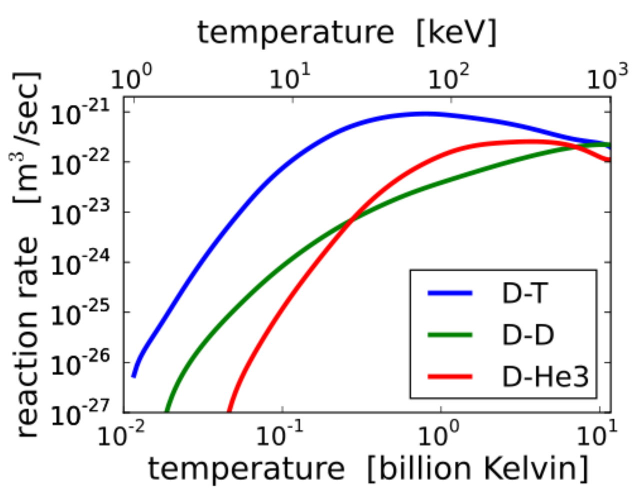

Fig. 5. Ration rate versus temperature in K.

3. Radiation energy from hot solid black body is (Stefan-Boltzmann Law):

$$E = \sigma T^4 \,, \qquad (2)$$

where E is emitted energy, W/m^2; $\sigma = 5.67\times10^{-8}$ - Stefan-Boltzmann constant, W/m^2 $^oK^4$; T is temperature in ^{o}K.

4. Wavelength corresponded of maximum energy density (Wien's Law) is

$$\lambda_0 = \frac{b}{T}, \quad \omega = \frac{2\pi}{\lambda_0} \qquad (3)$$

where $b = 2.8978\times10^{-3}$ is constant, m ^{o}K; T is temperature, ^{o}K; ω is angle frequency of wave, rad/s.

5. Pressure of light for Single Full Reflection is

$$F = 2E/c \,, \qquad (4)$$

where F - pressure, N/m^2; $c = 3\times10^8$ is light speed, m/s, E is radiation power, W/m^2. If plasma does not reflect radiation the pressure equals

$$F = E/c. \qquad (5)$$

6. Pressure for Plasma Multi-Reflection [23-25] is

$$F = \frac{2E}{c}\left(\frac{2}{1-q}\right) \,, \qquad (6)$$

where q is plasma reflection coefficient. For example, if $q = 0.98$ the radiation pressure increases by 100 times.

We neglect losses of prism reflection.

7. The Bremsstrahlung (Brake) Loss energy of plasma by radiation is ($T > 10^6$ ^{o}K)

$$P_{Br} = 5.34\cdot10^{-37} n_e^2 T^{0.5} Z_{eff}, \quad \text{where} \quad Z_{eff} = \sum (Z^2 n_z)/n_e \qquad (7)$$

where P_{Br} is power of Bremsstrahlung radiation, W/m^3; n_e is number of particles in m^3; T is a plasma temperature, KeV; Z is charge state; Z_{eff} is cross-section coefficient for multi-charges ions. For reactions H+D, D+T the Z_{eff} equals 1.

That loss may be very much. For some reaction they are more than useful nuclear energy and fusion nuclear reaction may be stopped. The Bremsstrahlung emission has continuous spectra.

8. Electron Frequency in Plasma is

$$\omega_{pe} = \left(\frac{4\pi n_e e^2}{m_e} \right)^{1/2}, \quad \text{or} \quad \omega_{pe} = 5.64 \times 10^4 (n_e)^{1/2}$$
$$\text{in "cgs" units, or} \quad \omega_{pe} = 56.4(n)^{1/2} \quad \text{in CI units} \qquad (8)$$

where ω_{pe} is electron frequency, rad/s; n_e is electron density, [1/cm^3]; n is electron density, [1/m^3]; $m_e = 9.11\times10^{-28}$ is mass of electron, g; $e = 1.6\times10^{-19}$ is electron charge, C.

The plasma is reflected an electromagnet radiation if frequency of electromagnet radiation is less than electron frequency in plasma, $\omega < \omega_{pe}$. That reflectivity is high. For $T > 15\times10^6$ ^{o}K it is more than silver and increases with plasma temperature as $T^{3/2}$. The frequency of laser beam and Bremsstrahlung emission are less than electron frequency in plasma.

9. The Deep of Penetration of outer radiation into plasma is

$$d_p = \frac{c}{\omega_{pe}} = 5.31\cdot10^5 n_e^{-1/2} \ . \ [\text{cm}] \qquad (9)$$

For plasma density $n_e = 10^{22}$ 1/cm^3 $\quad d_p = 5.31\times10^{-6}$ cm.

10. The Gas (Plasma) Dynamic Pressure, p_k, is

$$p_k = nk(T_e + T_i) \quad \text{if} \quad T_e = T_k \quad \text{then} \quad p_k = 2nkT \qquad (10)$$

where $k = 1.38\times10^{-23}$ is Boltzmann constant; T_e is temperature of electrons, ^{o}K; T_i is temperature of ions, ^{o}K.

These temperatures may be different; n is ion density, 1/m^3; p_k is plasma pressure, N/m^2.

11. The gas pressure, p, is

$$p = \frac{2}{3} nkT, \qquad (11)$$

Here n is gas density in 1/m^3.

12. The magnetic p_m and electrostatic pressure, p_s, are

$$p_m = \frac{B^2}{2\mu_0}, \quad p_s = \frac{1}{2}\varepsilon_0 E_S^2 \qquad (12)$$

where B is electromagnetic induction, Tesla; $\mu_0 = 4\pi\times10^{-7}$ electromagnetic constant; $\varepsilon_0 = 8.85\times10^{-12}$, F/m, is electrostatic constant; E_S is electrostatic intensity, V/m.

13. Ion thermal velocity is

$$v_{Ti} = \left(\frac{kT_i}{m_i}\right)^{1/2} = 9.79 \times 10^5 \mu^{-1/2} T_i^{1/2} \quad \text{cm/s} \quad , \tag{13}$$

where $\mu = m_i / m_p$, m_i is mass of ion, kg; $m_p = 1.67 \times 10^{-27}$ is mass of proton, kg.

14. Transverse Spitzer plasma resistivity

$$\eta_\perp = 1.03 \times 10^{-2} Z \ln \Lambda T^{-3/2}, \quad \Omega \text{ cm} \quad \text{or} \quad \rho \approx \frac{0.1\text{Z}}{\text{T}^{3/2}} \quad \Omega \text{ cm} \quad , \tag{14}$$

where ln $\Lambda = 5 \div 15 \approx 10$ is Coulomb logarithm, Z is charge state.

15. Reaction rates $<\sigma v>$ (in $\text{cm}^3\ \text{s}^{-1}$) averaged over Mexwellian distributions for low energy (T < 25 keV) may be represent by

$$\begin{aligned}(\overline{\sigma v})_{DD} &= 2.33 \times 10^{-14} T^{-2/3} \exp(-18.76\, T^{-1/3}) \quad \text{cm}^3\text{s}^{-1}, \\ (\overline{\sigma v})_{DT} &= 3.68 \times 10^{-12} T^{-2/3} \exp(-19.94\, T^{-1/3}) \quad \text{cm}^3\text{s}^{-1},\end{aligned} \tag{15}$$

where T is measured in keV.

16. The power density released in the form of charged particles is

$$\begin{aligned}P_{DD} &= 3.3 \times 10^{-13} n_D^2 (\overline{\sigma v})_{DD} , \quad \text{W cm}^{-3} \\ P_{DT} &= 5.6 \times 10^{-13} n_D n_T (\overline{\sigma v})_{DT} , \quad \text{W cm}^{-3} \\ P_{DHe^3} &= 2.9 \times 10^{-12} n_D n_{He^3} (\overline{\sigma v})_{DHe^3} , \quad \text{W cm}^{-3}\end{aligned} \tag{16}$$

Here in P_{DD} equation it is included D + T reaction.

Theory of mini thermonuclear bomb/reactor. Estimations.

The parameters of the offered installation may be estimated the equation above and below.

1. Energy is needed for heating of plasma for nuclear reaction is computed by equation (1). For fuel D+T it is about T_e = 0.34MeV. This energy nuclear has in temperature $T_k = 1.16 \cdot 10^4\ T_e = 4 \cdot 10^8$K. In reality this temperature is less in some times (see fig. 3).

2. Energy of nuclear explosion E_n , [MeV]

$$E_n = (1/2)\, n V E_1 , \quad n = \frac{M}{(A_1 + A_2) m_p} , \tag{17}$$

where n is number of nuclears into unit of volume, m^{-3} or cm^{-3} (for example, 1 cm^3 fuel mixture D+T contains about about 10^{21} nuclears in room temperature under 100 atm pressure); V *is* volume before nuclear reaction, m^3 or cm^3; E_1 is energy couples of nuclear in MeV. For example, couple nuclears D+T gives E_1 = 3.5+14.1 = 17.6 MeV energy (see. Table 1, line 1). It is in 52 times more than energy needs for reaction; M is mass of the nuclear fuel in unit of volume, kg/cm^3 or kg/m^3 ; A is number nucleons in reactants (A = 2 for D, A = 3 for T); $m_p = 1.67\cdot 10^{-27}$ kg is mass of nucleon.

2. Maximal pressure and energy for high speed (6 km/s) detonation explosive (for example TNT):

$$p = E_s\gamma\,, \quad T = \frac{pv}{R_u} = \frac{pM}{\gamma R_u}\,, \quad R_u = \frac{8314.2}{\mu}\,, \qquad (18)$$

where p is gas pressure N/m^2; v is gas volume, m^3; T is gas temperature, K; M is explosive mass, kg; E_s is specific energy of explosive, J/kg (for TNT E_s = 5.4 MJ/kg); γ is specific weight of explosive, kg/m^3; R_u is heat constant, J/kg$\cdot$K; μ is average molar weight (for CO_2 μ = 46, for H_2O μ = 18; w is outer work (energy of process, J). For example, TNT can produce in explosion p = 10^{10} N/m^2 = 10^5 atm and temperature 20,000^{o}K; E is energy, J; η is coefficient efficiency.

3. For computation of explosion extension in the impulse electric generator may be used the equations of adiabatic process in gas:

$$p_1v_1^k = p_2v_2^k\,, \ \frac{p_1}{p_2} = \left(\frac{v_2}{v_1}\right)^k, \quad \frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{k-1} = \left(\frac{p_1}{p_2}\right)^{\frac{k-1}{k}}, \quad E = pv\,, \quad \eta = \frac{E_0 - E}{E_0}\,,$$

$$w = \frac{p_1v_1}{k-1}\left(1 - \frac{T_2}{T_1}\right), \quad w = \frac{R_u}{k-1}(T_1 - T_2), \quad w = \frac{R_u}{k-1}\left[1 - \left(\frac{v_1}{v_2}\right)^{k-1}\right], \quad w = \frac{p_1v_1}{k-1}\left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}}\right], \qquad (19)$$

where lower index "$_1$" means the first state of gas, "$_2$" means the second state of gas; $k \approx 1.4$ is adiabatic constant, for very high temperature k → 1.

4. Estimation the explosive electric generator:

$$\Phi = B_nS, \quad W = i(\Phi_1 - \Phi_2)\,, \quad E = -\frac{d\Phi}{dt}\,, \quad i = \frac{E}{R}\,, \quad R = \rho\frac{l}{s}\,, \quad L = \mu_0\frac{N^2S_s}{l_s}\,, \quad \frac{d}{dt}(Li) + iR = 0\,, \qquad (20)$$

where Φ is magnetic flux throw area S, Wb; B_n magnetic induction (intensity) perpendicular S, T; W is work of magnetic flow, J; i is electric current, A; E is electromotive force (voltage), V; R is electric resistance, Ω; ρ if specific electric resistance, for copper $\rho = 1.75.10^{-6}$ Ω$\cdot$cm; l is length of wire, cm; s is cross-section of wire, cm^2; L is inductance of solenoid; $\mu_0 = 4\pi\cdot 10^{-7}$ is magnetic constant; N is number of coils in solenoid; l_s is length of solenoid, m; S_s is cross-section of solenoid, m^2; t is time, s.

5. Increasing and decreasing current in the electric circuit

$$For\ turn on\ i = \left(\frac{E}{R}\right)\left[1 - \exp\left(-\frac{t}{T}\right)\right], \quad for turn of \quad fi = i_0\left(-\frac{t}{T}\right), \quad where \quad T = \frac{L}{R}\,, \quad W = L\frac{i^2}{2}\,, \qquad (21)$$

where i_o is initial current, A; W is work for state permanent current, J.

6. Ion collision rate and the mean free path

$$\nu_i = 4.8\cdot 10^{-8}Z^4\mu^{-1/2}n_i\ln\Lambda\cdot T_i^{-1/2}, \quad l = \frac{V_i}{\nu_i} = 2.04\cdot 10^{13}\frac{T_i^2}{Z^4n_i\ln\Lambda}\,, \qquad (22)$$

where lower index "$_i$" means ion.

7. Safety electric current in wire:

$$j = \left\{ \frac{\gamma \left[C_{pm}\Delta T + \left(C_p \Delta T + r \right) m_w / m \right]}{\rho t} \right\}^{0.5} , \qquad (23)$$

where j is electric current density, A/m^2; γ – mass density of wire, for cupper γ = 8320 kg/m^3; C_{pm} is heat capacity, for cupper C_{pm} = 0.39 kJ/kg·K; ρ is electric resistance, for cupper $\rho = 1.75 \cdot 10^{-8}$ Ω·m; ΔT is safety temperature, K; C_p is heat capacity of cooling liquid, for water C_p = 4.19 kJ/kg; r is heat evaporation of the cooling liquid, for water r = 2260 kJ/kg·K; t is safety time, sec; m_w/m is mass ratio of cooling liquid to wire mass. Example: for t = 0.003 sec, ΔT = 80 ^{o}K, we get j = $3.26 \cdot 10^3$ A/mm^2 without cooling.

8. Estimation of neutron penetration:

$$l = 1/n\sigma_n , \qquad (24)$$

where l is path of penetration, cm; n is density of material, cm^{-3}; σ is cross section area of nuclear, $\sigma_n \approx 10^{-24}$ cm^2.

9. Required thickness of the shell:

$$\delta = \frac{pd}{2\sigma} , \qquad (25)$$

where p is pressure, N/m^2; d is diameter of cylinder, m; σ is safety tensile stress, N/m^2.

Discussion

The offered mini-thermonuclear bomb, as with any innovations, are needed in further more detailed theoretical research, R&D, product development and testing. However, the new mini-bomb/reactor has gigantic advantages over present-day thermonuclear bombs:

(1) They are cheaper by many hundreds of times. That means not only non-industrial countries but middle-size companies can undertake R&D and production of perfected new thermonuclear weapon.

(2) They have a small weight and size but they have enough power (up 100 k. tons). That idea and design can also be used as engine of land vehicles, small ships, aircraft, manned and unmanned spacecraft, space propulsion and community power utilities.

(3) They are not limited in high temperature regime as are all existing reactors. That means they can use inexpensive fuel (not deuterium, helium-3, plutonium, or uranium as do extant reactors).

The parameters of the proposed mini thermonuclear bomb and Reactors are considered in given article very far from optima. They are only examples utilized to vividly illustrate the enormous possibilities of the innovative bombs and reactors.

The suggested mini thermonuclear bomb/reactor has Lawson criterion more than conventional current (2012) inertial thermonuclear reactors (ICF). That strongly increases either of three multipliers in Lawson criterion. That increases the density n. It increases the temperature T, because it is strait heating the fuel. It increases the time of reaction τ because create a mass cover for the pellet (capsule).

The suggested mini thermonuclear reactors (A-B Reactors) may be a revolutionary jump in energy industry. The importance of this innovation can be highlighted in the context of previous attempts.

History of failed attempts to initiate thermonuclear fusion. One of the earliest (in the late 1970's and early 1980's) serious attempts at an ICF design was *Shiva*, a 20-armed neodymium laser system built at the Lawrence Livermore National Laboratory (LLNL) that started operation in 1978. Shiva was a "proof of concept" design, followed by the *NOVA* design with 10 times the power. Funding for fusion research was severely constrained in the 80's, but NOVA nevertheless successfully gathered enough information for a next generation machine whose goal was ignition. Although net energy can be released even without ignition (the breakeven point), ignition is considered necessary for a *practical* power system.

The resulting design, now known as the National Ignition Facility (NIF), was completed three years ago at a cost of $3.5 billion. It is a huge lab, 10 stories high and bigger than a football field. Its massive building, heavily guarded and highly classified, stands on isolated ground inside the Lawrence Livermore National Laboratory. Scientists associated with the ignition effort predicted at first they would achieve ignition in 2010, and again last year. Ed Moses, leader of the NIF program, and his colleagues next set the goal of ignition for this October, and now the aim is to achieve it by the end of the year. Moses is not making any firm predictions now.

"The scientific and technological progress in inertial confinement fusion has been substantial during the past decade. However, many of the technologies needed for an integrated inertial fusion energy system are still at an early stage of technological maturity," the committee said in a statement. "For all approaches to inertial fusion energy there remain critical scientific and engineering challenges."

Stephen Bodner, retired director of the laser-fusion program at the Naval Research Laboratory in Washington and a longtime public critic of the ignition project, said he was highly skeptical of the significance of the latest development. Bodner has advocated a completely different approach to creating the unimaginably high temperatures and pressures required for achieving fusion.

In April, 2012 their team of physicists and engineers said they fired an array of 192 laser beams, focused "in perfect unison," and created a single pulse of energy that for 23 billionths of a second generated a thousand times more power than the entire United States consumes in a single second. The experiment March 15 delivered to the center of the facility's target chamber 1.87 megajoules of ultraviolet light, amounting to 100 times more energy than any other laser system in the world.[1]

[1] http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2012/04/10/MN2N1O0UJP.DTL&type=science

"Was it just a gimmick shot, achieved without any real progress ... and done only to demonstrate some sort of program progress?" he asked in an e-mail. "It appears that they are just floundering about as they try to solve the many basic problems with their ignition target design."

Many scientists have long voiced doubts that the experiments could ever yield enough energy to achieve ignition, and it's still an open question whether thermonuclear reactions can ever be achieved in the laboratory. Last month a committee of experts preparing a report on the future of fusion research for the National Academy of Sciences expressed continued doubts.

The other very expensive European failed attempt is HiPER (High Power laser Energy Research) facility which has yet to demonstrate the scientific proof of principle, but claims that their facility will move from the scientific proof of principle stage to a commercial fusion reactor.

In light of the skepticism that a fusion reactor will ever be commercially viable, these innovations may be long awaited quantum leap to make this commercially viable, The proposed A-B Reactor is different from present magnetic confinement reactor. That is smaller because AB-self-magnetic reactor works a small fuel capsule and does not require laser confinement. In present-day MCF reactor, the rare fuel gas (D+T) fills all volume of large chamber. In AB-Reactor the fuel is located into small capsule under high pressure (or, as solid, liquid or frizzed fuel under conventional pressure). In this case the fuel density can reach $n = 10^{26} \div 10^{27}$ 1/m^3 (or solid, liquid, frozen fuel may be inside conductive matter, $n = 10^{28} \div 10^{29}$ 1/m^3). That is enough for thermonuclear ignition and keeping plasma under the radiation pressure and magnetic pressure. For current MCF the magnetic intensity is 5 T. For AB-Self-MCF the magnetic intensity may be about 10 T and more. For AB-reactor the shaper pressure is about $10^{10} \div 10^{11}$ N/m^2 (0.1 – 1 million atm). We can neglect the outer magnetic force in AB-Reactor and we may design AB-Self-MCF/ICF reactor without very complex and expensive superconductivity magnetic system.

Note: The offered AB-Reactor can also have problems. The experimenters may have problems with fast high-intensity electric impulse through small capsule. As any innovation the offered reactor needs further perfecting R&D. Many innovations-inventions not described in this work are components of the AB-Reactor and will be delineated in future papers.

Some other relevant ideas of the author can be found in References [1–34].

Acknowledgement

The author wishes to acknowledge Professor Shmuel Neumann and Joseph Friedlander (of Shave Shomron, Israel) for correcting the English and offering useful advice and suggestions.

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24 April 2012.