Ultra-Cold Thermonuclear Synthesis: Criterion of Cold Fusion

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Abstract

All scientists know well: to achieve nucleus fusion, a temperature of hundreds of millions of degrees is required. Only in this case, the kinetic energy of nucleus overcomes the repulsive electric force of nucleus and connects two initial nucleuses into a single nucleus. In the last sixty years, scientists have spent tens of billion US dollars attempting to develop useful thermonuclear fusion energy.Yet, today they still cannot reach a stable long-period thermonuclear reaction. They still are promising publically, after many years of effort, and additional tens of billions of US dollars to finally design the expensive but ultimately workable industrial installation, which possibly will produce electric energy more expensive than current heat, wind and hydro-electric stations can in 2015.

Author, instead, uses well-known physical laws and shows the other andcheaperway: very low temperatures (0.01 ÷ 10K) and high-pressure (some thousands or millions of atmospheres) allows reaching the same results: thermonuclear fusion.He does not use kinetic energy of nucleus again repulsive force of nucleus, as in the long-touted conventional plasma confinement method. Instead, he uses the blocking the repulsive forces of nucleus by electrons (sphere Debya), very low-temperatureand high-pressure. In current time to reach these temperature and pressure are easily than hundreds millions degrees by magnetic or inertial confinement. New method for thermonuclear fusion is relatively cheap and allows use of other thermonuclear fuel which are less expensive and which produce theaneutronic reaction. Author offers new criterion for Ultra Cold Thermonuclear Fusion.

Keywords:*Ultra-cold thermonuclear fusion,Micro-thermonuclear reactor, AB-thermonuclear reactor, transportation thermonuclear reactor, aerospace thermonuclear engine, nucleus fusion.*

INTRODUCTION

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. The largest current nuclear fusion experiment, abbreviated as JET, has resulted in fusion power production somewhat larger than the power input to the plasma, maintained for a few seconds. In June 2005, the construction of the experimental reactor ITER, designed to produce several times more fusion power than the power into it generating the plasma over many minutes, was announced. Ten years later, the unrealized production of net electrical power from fusion machines is delayed to the next generation experiment after ITER.

Unfortunately, this task is not easy, as some scientists thought early on. Fusion reactions require a very large amount of energy to initiate in order to overcome the so-called *Coulomb barrier* or *fusion barrier energy*. The key to practical fusion power is to select a fuel that requires the minimum amount of energy to start, that is, the lowest possible commencement 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 suitable low barrier energy. In order to create the required conditions, the fuel must be heated to tens of millions of degrees, and/or compressed to immense plasma pressures. At present, D-T is used by two main methods of fusion: inertial confinement fusion (ICF) and magnetic confinement fusion (MCF)—for example, in a tokomak device.

With*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 focused laser or ion beams are used for compression of pellets. The focused beams explosively detonate the outer material layers of the target pellet. That accelerates the underlying target layers inward, sending a shockwave into the center of each pellet's mass. If the shockwave is powerful enough, and if high enough density at the center is achieved, some of the fuel will be heated sufficiently to cause target pellet fusion reactions. In a target pellet 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 be configured to safely confine fusion fuel. A variety of magnetic configurations can be used, the basic distinction being between magnetic mirror confinement and toroidal confinement, especially tokomaks and stellarators.

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* stage, that is, 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 important 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. To reiterate, the best known 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 compressed to immense pressures. The temperature and pressure required for any particular fuel to fuse is known as the Lawson criterion. For the D-T reaction, the physical value is about

$$L = n_e T\tau > (10^{14} \div 10^{15}) \quad \text{in} \quad \text{"cgs"} \quad \text{units}$$

$$\text{or} \quad L = nT\tau > (10^{20} \div 10^{21}) \quad \text{in} \quad \text{CI} \quad \text{units} \quad ,$$

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 ^{2}H + ^{3}D 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 by any working fusion reactor, although the latest generations of fusion-making machines have come significantly close to doing so. For instance, the reactor TFTR has achieved the densities and energy lifetimes needed to achieve Lawson criterion 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 traverse the plasma cloud:

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

where τ is time, s; R is distance, m; k is Boltzmann constant; T is temperature, K; 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 $T^{3/2}/<\sigma v>$ (here σ is Boltzmann constant, v is ion speed). This condition is traditionally expressed in terms of the mass density ρ:

$$\rho R > 1 \text{ g/cm}^2 .$$

To satisfy this criterion at the density of solid D+T (0.2 g/cm^3) 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/cm^3, 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 stage by a symmetrical energy input bath. Some scienists think the inequality $\rho R > 1$ g/cm^2 must be $\rho R > 6.9$ g/cm^2.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 $\sim n^2\langle\sigma v\rangle T^{-1/2} / n \sim (nT)\,(\langle\sigma v\rangle/T^{3/2})$.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.

*Short history of thermonuclear fusion R&D.*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) in central California 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 1980's, but NOVA nevertheless successfully gathered enough information for a next generation machine whose stated goal was ignition. Although net energy can be released even without ignition (the break-even point), ignition is considered necessary for a *practical* power system.The resulting design, now known as the National Ignition Facility, commenced being constructed at LLNL in 1997. Originally intended to start construction in the early 1990s, the NIF is now years behind schedule and over-budget by some $3.5 billion and has not achieved its design results. Nevertheless many of the macro-problems appear to be due to the "Big Science Laboratory" mentality, and shifting the focus from pure ICF research to the nuclear stewardship program, LLNLs traditional nuclear weapons-making role. NIF finally"burned" in 2010, when the remaining lasers in the 192-beam array were finally installed. Like those earlier experiments, however, NIF has failed to reach ignition and is, as of 2015, generating only about 1/3rd of the required energy levels needed to reach full fusion stage of operation.

Elsewhere, laser physicists in Europe have put forward plans to build a £500m facility, called HiPER, to study a new approach to laser fusion. A panel of scientists from seven European Union countries believes that a "fast ignition" laser facility could make a significant contribution to fusion research, as well as supporting experiments in other areas of physics. The facility would be designed to achieve high-energy gains, providing the critical intermediate step between ignition and a demonstration reactor. It would consist of a long-pulse laser with energy of 200 kJ to compress the fuel and a short-pulse laser with energy of 70 kJ to heat it.

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 and equipment damaged significantly.
- *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.Hydrogen bomb weapons require 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*(Figure 1). 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 targeted pellets of fuel to explode several times a second. To induce the explosion, each pellet must be compressed to about 30 times its solid material density with energetic focused impinging beams. If the bathing beams are focused directly on the target 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 "spherically perfect" globular 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 focused lasers. This research will be carried out on the (currently being built) OMEGA EP peta-watt and OMEGA lasers at the University of Rochester in New York 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. One laser installation of NIF

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*(Figure 2).Much of this progress has been achieved with a particular emphasis on tokomaks (Figure 2).

In fusion research, achieving a fusion energy gain factor$Q$ = 1 is called *break-even* and is considered a significant, although somewhat artificial milestone. *Ignition* refers to an infinite Q, that is, a self-sustaining plasma cloud wherein the losses are made up by fusion power without any external input. In a practical thermonuclear fusion reactor, some external power will always be required for operations like current drive, refueling, profile control, and burn control. A value on the order of Q = 20 will be required if the perfected 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 as well as absorbing the thermal radiation emitted by 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 targeted*pellets.*

The magnetic fusion energy (MFE) program seeks to establish the conditions to sustain a thermonuclear fusion reaction in plasma that is contained by magnetic fields to allow the successful production of commercially viable fusion power.

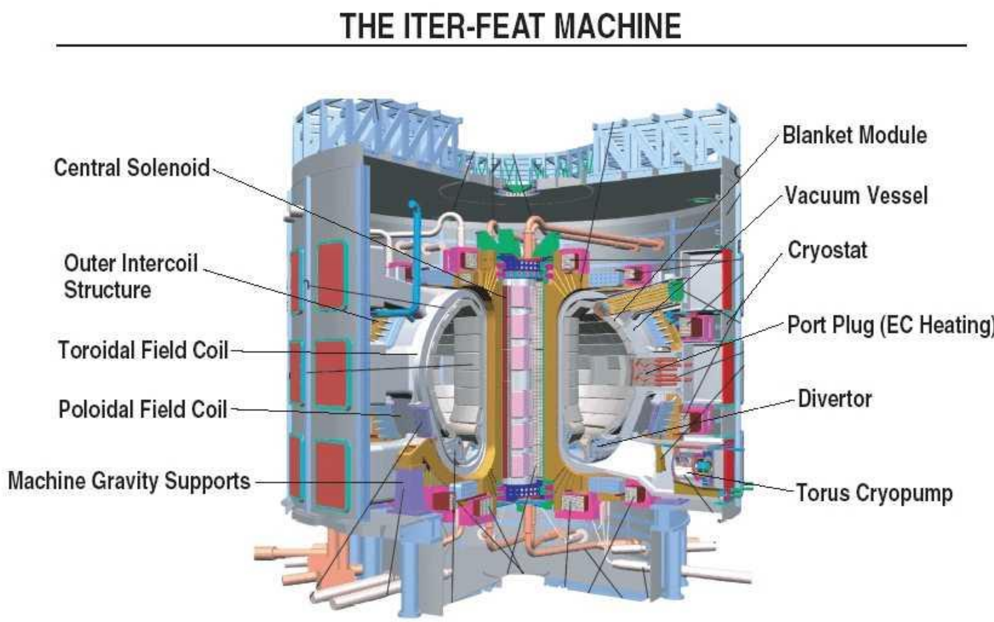

Fig. 2.Magnetic thermonuclear reactor ITER. Cost is some tens of billions of dollars.

In thirty years, scientists have increased the Lawson criterion of the ICF and tokomak installations by tens of times. Unfortunately, all current and some new installations (ICF and variously-sited tokomaks) have a Lawson criterion that is tens of times lower than is necessary for a successful machine (Figure 3).

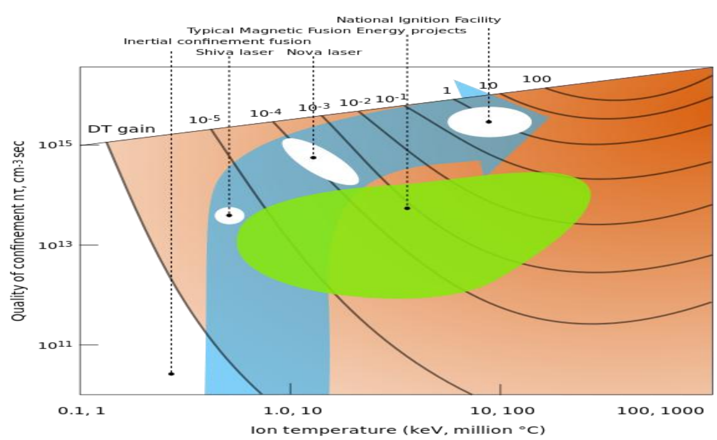

Fig. 3. Parameter space occupied by inertial fusion energy and magnetic fusion energy devices. The regime allowing thermonuclear ignition with high gain lies near the upper right corner of the plot.

Main Idea: Theory, Estimations, Criteria of Cold Fusion

Main Idea: Theory, Estimation.Plasma is the mixture the positive (nucleus) and negative (electrons) charges. The energy givesonly the fusion of positive (nucleus) charges. The repulsiveelectric force overcomes the fusion of nucleus. The plasma is used in current nuclear reactors is rare and scientistsconventionallyneglectits influence of electrons in fusion of nucleus.The nucleus pulseone other but if between them is electron, one blocks the repulsive force. For example, the electrons in atoms and molecules block the negative nucleus charge and atom (molecules) became neutral. The atoms can overcome one to the other. The electrons connect them in molecules.Decreasing the distance between nucleous by negative charges is used in muon catalyzer. The heave negative muon has orbit radius 207 times less than conventional electron. One decreases the distance (and energy for association) nucleus andallows to connect nucleus. In conventional fusion, the distance between nucleuses the scientists try to overcome by high kinetic energy (temperature). The offer method tries to overcome by electrons and compression of a fuel.

Criterion of Cool Fusion. However, if temperature is very low and pressure is very high, electron effect becomes significant. In plasma physics there is Debye radius – distance the charge can come to othersame charge (nucleus to nucleus) not fills its charges (the other electrons are blocked the positive charge of nucleus). Debye radius is (in SU)

$$\lambda_D \approx \sqrt{\frac{\varepsilon_0 k}{e^2}}\sqrt{\frac{T}{n}} = a\sqrt{\frac{T}{n}} = \left(\frac{8.85\cdot10^{-12}\cdot1.38\cdot10^{-23}}{1.6^2\cdot10^{-19\times2}}\right)^{1/2}\left(\frac{T}{n}\right)^{1/2} = 69\left(\frac{T}{n}\right)^{1/2}\ [\mathrm{m}]\,, \qquad (1)$$

where ε_0 is electric constant, $C^2/N{\cdot}m^2$; $k = 1.38\cdot10^{-23}$ is Bolzmann constant, J/K; e is charge of electron $1.6\cdot10^{-19}$ C; T is temperature of electrons, K; n is number of electrons into 1 m^3. In typical conditions (hydrogen at 1 atm, ρ = 0.1 kg/m^3, T = 300K) the $n = \rho/\mu{\cdot}m_p = 0.1/1\cdot1.67\cdot10^{-27} = 6\cdot10^{25}$ 1/m^3.λ_D=$1.54\cdot10^{-10}$ m.This is usual radius of atomH (it is closed to electron radius of molecule H_2 $r = 1.25\cdot 10^{-10}$ m).

The radius (length, sphere) of Debye is distance which the nucleus can approach (overcome) one to other without the repulsive force of same charges. The outer electrons blockade the repulsive forces of nucleus.The strong nucleus attractive force of nucleus begins from distance less than

$$d \approx 2\cdot10^{-15}\ \mathrm{m}. \qquad (2)$$

If researchers can ever consistently bring together two nuclei in this distance, then we can reach repeatable thermonuclear fusion. Let us substitute this value (2) to equation (1) and estimate the ratio *T/n* requested for it.

$$\frac{T}{n} < \frac{\lambda_D^2}{69^2} = \frac{(2\cdot10^{-15})^2}{4761} \approx 8.4\cdot10^{-34}. \quad \text{Final} \quad B = \frac{T}{n} < 8.4\cdot10^{-34}. \qquad (3)$$

Here B is new critereon, T is temperature of fuel electrons, K; n is number (density) of electrons into 1 m^3 the fuel.

Final equation $B$is the first version of the ***criterion of the Ultra-Cool Fusion***. It is in principal different from criterion of the inertial fusion$\rho R > 1$ (where ρ is density of fuel. g/cm^3, R is radius of fuel pellet-capsule, cm.). The inertial criterion depends from density and RADIUS of capsule and request hundred millions of fuel temperature. The offered criterion depends from density and temperature, not from pellet-capsule size.The LOWER temperature is best for cool fusion!It is more comfortable for estimation when $n$is presented through the pressure of fuel:

$$n = \frac{p}{kT}\,, \quad p = 10^5 p_a\,, \qquad (4)$$

where p is fuel pressure, N/m^2; p_a is fuel pressure in atmospheres; $k = 1.38\cdot10^{-23}$ J/K is Bolzmann constant.Substitute (4) to (3) we get the criterion (3) in form:

$$B = \frac{T^2}{p_a} < 0.6 \cdot 10^{-5}. \qquad (5)$$

For example, if we cool the fuel D+T at 0.7 K and pressure of 100,000 atmospheres, we can reach thermonuclear fusion.We can write criterion (2) through density of fuel:

$$n = \frac{\rho}{\mu m_p}, \qquad (6)$$

whereinρ is density of fuel, kg/m^3; $\mu = m/m_p$ is molar mass (for hydrogen Hμ=1, for deuterium D μ = 2, fo tritium T μ = 3); $m_p = 1.67 \cdot 10^{-27}$ kg is mass of proton. Substitute (6) to (2) we receive Criterion of Cool Fusion in form:

$$B = \frac{T}{\rho} < 0.25 \cdot 10^{-6}. \qquad (7)$$

Method for reaching the needed low-temperature.

Let us consider the possibility of current technology to reach the temperature and pressure requested for thermonuclear fusion.The low temperature up 0.7K may be reached bypumping of helium vapor.The temperature low 0.3K up 0.001K is reached by magnetic refrigeration. The *nuclear* magnetic refrigeration allow to get temperature about 10^{-6}K.The mixing Helium-3 and Yelium-4 allows to get temperatures low 0.3K.

In several laboratories, a record low temperature of 100 pK, or 1.0×10^{-10} K was obtained as long ago as1999.The current apparatus for achieving low temperatures has two stages. The first utilizes a helium dilution refrigerator to get to temperatures of millikelvins (mK) whilst the next stage uses adiabatic nuclear demagnetization to reach pico-kelvins.There are many available methods for getting low temperatures. For example, Dilution refrigerator: A ^{3}He/^{4}He dilution refrigerator is a cryogenic device that provides continuous cooling to temperatures as low as 2 mK, with no moving parts in the low-temperature region. The cooling power is provided by the heat of mixing of the Helium-3 and Helium-4 isotopes. It is the only continuous refrigeration method used for reaching temperatures below 0.3 K.

Methods forreaching the needed high-pressure.

In inertial fusion the scientists try to reach the high-pressure by shock-wave from bathing laser target pellet-capsule evaporation. This method is very expensive and not suitable for us. One requests the gigantic installation (1 ÷ 15B $), enormous energy expenditure, since it has only 1÷1.5% efficiency,and works a short time (10^{-8} s). Author offersto use cheap, simple method described below (Fig.4). This method explodes the super hard allows widely used in industry.

The date (maximum pressure) of superhard allows are presented in Table 1.

Table 1.Vickers hardness some materials.

Material	Pressure in atm.	Material	Pressure in atm
Diamond	1150,000	B_4C	300,000
c-BC_2N	760,000	WB_4	300,000
c-BN	480,000	ReB_2	200,000
O_5B_2	370,000	Steel 40X	40,000

As you see from (5) we needpressure p_a = 100,000 atmospheres for fuel temperature T = 0.7K.

Description and Innovations of Thermonuclear reactor (fuel cupsule)

*Description and work****Version 1.***The suggested thermonuclear fusion installation (more exactly: work capsule) is presented in Fig.4. The work capsule has astrong outer cover 1, explosive 2, pressure segments 3 (they convert low pressure of explosive 2 to high pressure of segment tip 5), fuel capsule 4, tip 5 of segment 3 from hardness material, canals for direct cooling of fuel capsule 6, elastic material between pressure segment 7.

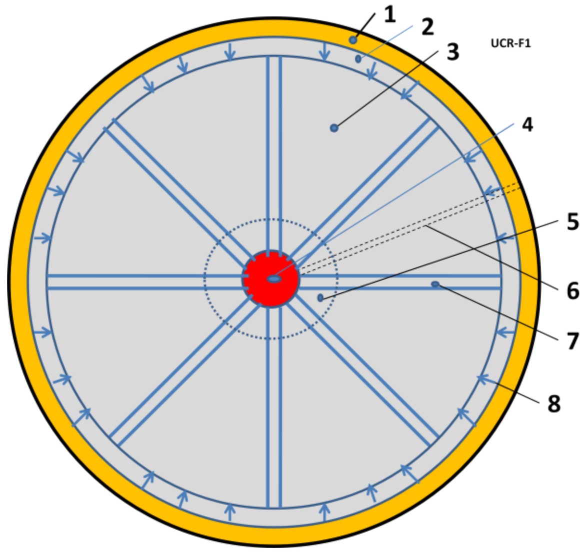

Fig.4. Ultra-Cold Thermonuclear Fusion Reactor (fuel capsule). **Version 1**.*Notations*: 1 - outer strong cover; 2 – layer of explosive; 3 – compess segment; 4 – target fuel pellet; 5 – the tip from the super-hard alloy; 6 – canal for cooling fuel pelletby cooling liquid or gas; 7 -viscous grease (gasket from elastic material); 8 – pressure from explosive.

Version 1 (fuel capsule) works this way. The fuel capsuleskept in cryogenics vessel (for example liquid air). Before explosion the target pellet getsan additional cooling through canal 6. After explosion the explosive layer 2, the explosive gas 8 presses to segments 3. The segments 3 increases this ambient pressure by hundreds times and press by the hardness tips 5 the fuel pellet 4. After explosion the thermonuclear energy are used as it is described in [1] in thermonuclear reactor, or rocket engine, or even a potentially infrastructure devastating new explosive weapon of war and terrorism.

*Description and work**Version 2***(Fig.5). This version contains the outer cover 1, heat protection 2 (it may be vacuum);strong cover3 (it can keep pressure from conventional explosive); fuze net 4; explosive 5; heat protection 6; thermonuclear fuel pellet 7; cooling canal 8.

Version 2 (fuel capsule) works the next proposed way. The fuel capsules arekept into the cryogenics vessel (for exemple, inliquid helium). Before using, the pellet gets an additional cooling through canal 8. After explosion the explosive 5, the explosive gas presses to pellet 7. After thermonuclear explosion the thermonuclear energy are used as it is described in [1] in thermonuclear reactor, or MHD generator, or in rocket engine, or weapon.

The first version allows to get more high pellet pressure up the 1 million atmosphere and relatively high temperature up 2 K, but capsule has more size (diameter up 2 ÷ 4 sm), mass (5 ÷ 35 g) and needs a significantly more complex operational design, having the pressure segments. The second version needs less temperature (up 0.6 K) because it produces the lower pressure (up 70,000 atm). But Version 1 is simplest and has less physical size (diameter 0.7 ÷ 1.5sm), as well as less mass (0.5 ÷ 8 g) (see estimation below).

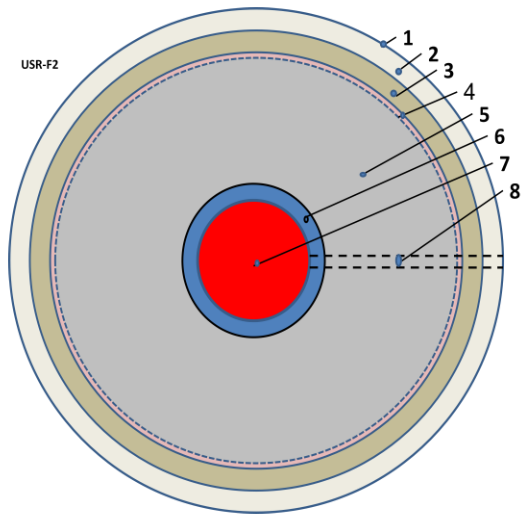

Fig.5. Ultra-Cold Thermonuclear Fusion Reactor (fuel capsule). **Version2**.*Notations*: 1 - outer cover; 2 –heat protection (it may be vacuum); 3 – strong cover; 4 – fuze net; 5 – explosive; 6 – heat protection; 7 – fuel pellet; 8 – cooling canal.

Estimation.

Let us estimate the suggested thermonuclear reactor. That is not optimal version. We demonstrate the method of estimation.

Version 1.Assume the target fuel pellet has diameter 2 mm (r = 1 mm). Fuel is D+T. The fuel volume is

$$V = \frac{4}{3}\pi r^3 = 4.189 \times 1^3 \approx 4.2\ mm^3 \quad (8)$$

Fusion energy of couple nucleus D+Tis E_1 = 17.6 MeV, density offrizen fuel D+T is d = 0.2 g/sm^3 = 200 kg/m^3, mass of appropriate fuel is $m = \rho V = 8.4 \cdot 10^{-6}$ kg. Number of fuel nucleus and energy is:

$$n = \frac{M}{\mu m_p} = \frac{8.4 \cdot 10^{-6}}{2.5 \cdot 1.67 \cdot 10^{-27}} = 2.5 \cdot 10^{21},$$
$$E_2 = 0.5 n E_1 = 0.5 \cdot 2.5 \cdot 10^{21} \cdot 17.6 \cdot 10^6\ eV = \quad (9)$$
$$= 22 \cdot 10^{27} 1.6 \cdot 10^{-19} = 35 \cdot 10^8\ J.$$

For efficiency coefficientη = 0.3 the received energy is

$$E = \eta E_2 = 0.3 \cdot 35 \cdot 10^8 \approx 10^9\ J. \quad (10)$$

If installationproduced one explosion in one second, the power is P = 1 Million kW. That is the power output of anaverage urban electric generation station!

If installation is used as a rocket engine and fuel capsule has mass m = 40 g = 0.04 kg, the speed V of exhaust gas and thrust T is

$$V = \left(\frac{2E}{m}\right)^{1/2} = \left(\frac{2 \cdot 10^9}{0.04}\right)^{0.5} = 225\ km/s, \quad T = m \cdot \Delta V = 0.04 \cdot 2.25 \cdot 10^5 = 9 \cdot 10^3\ N = 900\, kgf \quad (11)$$

Conventional rocket has speed of exhaust gas about 3 km/s. Offer thermonuclear reactor has exhaust speed in 75 times greater. Increasing the frequency the fuel explosive, we can increase the rocket engine thrust greatly. That means space flight can be made easier to any planets of our Solar system.

If fuel capsule is used as weapon, its energy equals the 250 kg TNT (for specific energy of TNT ≈ $4.2 \cdot 10^6$ J).

The initial pressure into pellet, when frozen fuel converted into gas is

$$p = n_0 kT, \quad \text{where} \quad n_0 = \frac{\rho}{\mu m_p} = \frac{200}{2.5 \cdot 1.67 \cdot 10^{-27}} = 4.8 \cdot 10^{28}\ \frac{1}{m^3}.$$
$$\text{For } T = 0.7\ K, \quad p = 4.64 \cdot 10^5\ \frac{N}{m^2} \approx 5\, atm \quad (12)$$

Here$k$ =1.38·10^{-23} is Bolzmann constant,J/K; n_o is number nucleus in 1 m^3; ρ = 200 kg/m^3 is density of frizzed(liquid) fuel in pellet. If compression is made in T = constup p = 100,000 atm, the ratio of volume compression is ε = 10^5/5 =20,000 . Final radius of pellet from 1 mm decreases to $r = 1/\varepsilon^{1/3}$= 1/27 = 0.037 mm.The full diameter of the fuel capsule will be about 1÷1.5 cm.

Estimation of ***Version 2*.**

If we can produce the temperature lower T = 0.6K we can make the more simple fuel capcule (Fig.5). Conventional explosive be capable of pressure p_a = 60,000 ÷ 80,000 atm. For example, pressure of the explosive TNT having the specific energy E_e = 4.2 MJ/kg and densityρ_e = 1654 kg/m^3 is:

$$p = E_c\rho_c = 4.2\cdot10^6 \times 1654 \approx 7\cdot10^9\ \frac{N}{m^2} = 70{,}000\,atm\,. \qquad (13)$$

That means criterion (5)can be applied and the fuel capsule may be made without additional segments 3 (Fig.4). Example: For T = 0.5K from (5) we get B-criterion

$$B = \frac{T^2}{p_a} = \frac{0.25}{7\cdot10^4} = 0.357\cdot10^{-5} < 0.6\cdot10^{-5}\,. \qquad (14)$$

The Version 2 has the pellet radius of 0.5 mm. That means one produces in 8 times less power. But fuel capsule has less size (about 1 cm), less mass (about 3 g) and very simple design for manufacturing.

Other data and problems.

*Compressing.*In our consideration we assumed, the compressing the fuel pellet after explousion is isothermal process (T = const). In reality one may be closed to adiabatic process (no adding and deleting heat from environment). For example, let us estimate the heating the pullet cooled up T_2 = 0.01K and pressed from p_1 = 5 atm up p_2 = 70,000 atmospheres. The adiabatic process gives in end compressing the temperature

$$T_1 = T_2\left(\frac{p_1}{p_2}\right)^{\frac{k-1}{k}} = 0.01\left(\frac{7\cdot10^4}{5}\right)^{\frac{1.67-1}{1.67}} = 0.446\,\text{K}\,. \qquad (15)$$

Here k is adiabatic rate. This value is from 1 up 1.67. One depends from structure of moleculs and temperature. For isothermal process k = 1, for air at room temperature one equals$k$ = 1.4. We take the worst value k = 1.67.If cover 6 (fig. 5) of the pellet contains the small granules having Helium-3 and Helium-4, they mixture in pressing and produce the mixture which has lower temperature than an initial components and not allows increasing temperature the fuel pellet.Themelting and boiling of Helium and fuel request a lot of energy. The ionization and dissociation of atom and molecules request the very big energy. That means one melting of Helium (T = 0.95K) stops the father increasingtemperature.

We must use the explosive with low speed of burning;press speed must be less than the sound speed in fuel mixture in pellet. We must avoid the shock wave, use deeper cooling and protect the pellet fromoverheating, for example, by mixture of helium-3 and helium-4.Below are some data which may be used for estimation.

Helium-3.

Helium-3 boils at 3.19 K compared with helium-4 at 4.23 K, and its critical point is also lower at 3.35 K, compared with helium-4 at 5.2 K. Helium-3 has less than one-half of the density when it is at its boiling point: 59 gram per liter compared to the 125 gram per liter of helium-4—at a pressure of one atmosphere. Its latent heat of vaporization is also considerably lower at 0.026 kilojoules per molecompared with the 0.0829 kilojoules per mole of helium-4. Cost of Helium-3 was 930 USA/Liter in 2009. The cost of Helium-4 was 23 Euro/Liter during 2012.

Helium-4

Ionization energies	1st: 2372.3 kJ/mol 2nd: 5250.5 kJ/mol
Physical properties	
Phase	gas
Melting point	0.95 K (−272.20 °C, −457.96 °F) (at 2.5 MPa)
Boiling point	4.222 K (−268.928 °C, −452.070 °F)
Densityat stp (0 °C and 101.325 kPa)	0.1786 g/L
when liquid, at m.p.	0.145 g/cm^3
when liquid, at b.p.	0.125 g/cm^3
Triple point	2.177 K, 5.043 kPa
Critical point	5.1953 K, 0.22746 MPa
Heat of fusion	0.0138 kJ/mol
Heat of vaporization	0.0829 kJ/mol
Molar heat capacity	20.78 J/(mol·K)
Speed of sound	972 m/s
Thermal conductivity	0.1513 W/(m·K)
Magnetic ordering	diamagnetic

Hydrogen

Ionization energies	1st: 1312.0 kJ/mol
Phase	gas
Melting point	13.99 K (−259.16 °C, −434.49 °F)
Boiling point	20.271 K (−252.879 °C, −423.182 °F)
Densityat stp (0 °C and 101.325 kPa)	0.08988 g/L
when liquid, at m.p.	0.07 g/cm^3 (solid: 0.0763 g·cm^{-3})[4]
when liquid, at b.p.	0.07099 g/cm^3
Triple point	13.8033 K, 7.041 kPa
Critical point	32.938 K, 1.2858 MPa
Heat of fusion	(H_2) 0.117 kJ/mol
Heat of vaporization	(H_2) 0.904 kJ/mol
Molar heat capacity	(H_2) 28.836 J/(mol·K)

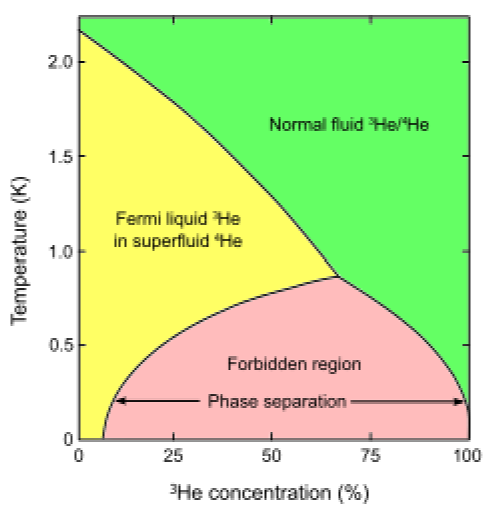

Fig.6. Phase diagram of liquid ^{3}He–^{4}He mixtures showing the phase separation.

Thickness of sphere cover.

Variant 2 is useful if the sphere's outer cover can hold the pressure a long time. According the

Lawson criterion the received energy is proportional the time of reaction. If we can keep our pressure and temperature a long time, the probability thermonuclear reaction is increased. It is better, if the cover of fuel capsule must keep the internal pressure after conventional explosion.

While it is not difficult to get needed equation for estimation of the thickness and mass *M*for the needed cover. The author conceived the following equations:

$$\bar{R}=\frac{R}{r}=\left(\frac{p}{\sigma}+1\right)^{0.5}, \quad M=\frac{4}{3}\pi\gamma r^3\left[\left(\frac{R}{r}\right)^3-1\right], \qquad (16)$$

where*r* is internal radioscover sphere, m; *R* is external radius of sphere, m; γ is density of cover, kg/m^3; *p* is pressure after conventional explosive, N/m^2; σ is safety tensile stress, N/m^2.

Property of some materials in Table 4.

Table 4.Property some material which can be used for cover.

Material	Ultimatetensile stress, MPa	Density, g/sm^3	Material	Ultimatetensile stress, MPa	Density, g/sm^3
Steel (AISI AII)	5205	7.45	Silicon (m-S1)	7000	2.33
Carbon fiber (Torey +100G)	6370	1.80	Carbon nanotube	11,000÷63,000	0.037÷1.34
Zylon	5800	1.56	Graphene	130,000	1

Example estimation of capsule cover for explosive press $p = 7\cdot10^9$ N/m^2 and tensile stress $\sigma = 2.5\cdot10^9$ N/m^2, r = 2 mm.

$$\bar{R}=\frac{R}{r}=\left(\frac{p}{\sigma}+1\right)^{0.5}=\left(\frac{7\cdot10^9}{2.5\cdot10^9}+1\right)^{0.5}3.8^{0.5}\approx 2, \quad R=4\text{ mm},$$

$$M=\frac{4}{3}\pi\gamma r^3\left[\left(\frac{R}{r}\right)^3-1\right]=\frac{4}{3}3.14\cdot7450\cdot(2\cdot10^{-3})^3[2^3-1]=1.75\cdot10^{-3}\,kg\approx 2\,g. \qquad (16)$$

Consequently, the diameter cupsule-2 is about 8 mm.

Discussion

About sixty years ago, scientists conducted Research and Development of a thermonuclear reactor that promised then a true revolution in the energy industry and, especially, in the field of modern humankind's Twenty-first Century aerospace activities. Using such reactor, aircraft could undertake flights of very long distance and for extended time periods and that, of course, decreases by a significant monetary cost the price of aerial transportation, allowing the saving of ever-more expensive, and possibly depleting, imported oil-based fuels. The temperature and pressure required for any particular fuel to fuse is known as the Lawson criterion,*L*. Lawson criterion relates to plasma cloud production temperature, plasma cloud density and sustainable time. The thermonuclear reaction is realized when *L* is more certain magnitude. There are two main methods of nuclear fusion: inertial confinement fusion (ICF) and magnetic confinement fusion (MCF).

Existing thermonuclear reactors are very complex, expensive, large, and heavy. They cost many billions of US dollars and require many years for their design, construction and prototype testing. For example,formation of the ITER Tokomak started in 2007 and the building costs are now over US$14 billion as of June 2015, some 3 times the original figure. The facility is expected to finish its construction phase in 2019 and will start commissioning the reactor that same year and initiate plasma experiments in 2020 with full deuterium-tritium fusion experiments starting in 2027. If ITER becomes operational, it will become the largest magnetic confinement plasma physics experiment in use, surpassing the Joint European Torus. The first commercial demonstration fusion power plant, named DEMO, is proposed to follow on from the ITER project. The resulting design, now known as the National Ignition Facility, started construction at LLNL in 1997. NIF's main objective will be to operate as the flagship experimental device of the so-called nuclear stewardship program, supporting LLNLs traditional bomb-making role. Completed in March 2009, NIF has now conducted experiments using all 192 beams, including experiments that set new records for power delivery by a laser. The first credible attempts at ignition were initially scheduled for 2010, but ignition had not been achieved as of September 30, 2012! As of October 7, 2013, the facility is understood to have achieved an important milestone towards commercialization of thermonuclear fusion, namely, for the first time a targeted fuel capsule gave off more energy than was applied to it. This is still a long way from satisfying the Lawson criterion, but is a major step forward in terms of progress.Many other magnetic reactors cannot stably achieve the nuclear ignition and the Lawson criterion. In future, they will have a lot of difficulties with finding an acceptable cost of nuclear energy production, with converting the nuclear energy to conventional energy, with small thermonuclear installation suitable for transportation or outer space exploration. Scientists promise an industrial application of thermonuclear energy after 10 – 15 years additional researches—that is, to 2015 or 2030 AD—and more billions of US taxpayer dollars in the future. But old methods will not allow them to reach that goal in nearest future.

In inertial confinement many scientists thought that short pressure (10^{-9} – 10^{-12} s), which they can reach by laser beam, compress the target fuel capsule, but this short pressure only create the shock-wave which produced the not large pressure and temperature in a limited range area in center of fuel capsule. The scientists try to reach it by increasing NIF, but plasma from initial vaporization the cover of fuel capsule does not allow to delivery big energy. After laser beam, the fuel capsule is "naked" capsule. Capsule cannot to keep the high-energy particles of the nuclear ignition and loss them. Producing the power laser beam is very expensive and has very low efficiency (1 - 1.5%).

The author offers a new method for the fusion of nuclei. The old method was to try to reach very high-speed of nucleus (very high temperature – in hundreds millions degree). The high kinetic energy of nucleus must overcome the repulsive force of nucleus. Author's scheme will block the repulsive force of nucleus by sphere Debya which, thereby, allows to approach the nucleus distance when nucleus force to produce the desired fusion. The very low-temperature and high-pressure decreases the Debye length for need value. Nucleus oscillations do not depend upon temperature and help the fusion.The offered method possible allows to use reaction D+D (instead D+T) with cheap nuclear fuel D (Tritium is very expensive – about 20,000 USDollarsfor 1 g).

Conclusion

The author offers a new Method fusion in thermonuclear reaction and Installation for it. Author uses the well-known physical laws and shows the other opposed cheap way: very low temperatures (0.01 ÷ 10K) and high pressure (some thousands or millions of atmospheres) allow to reaching the same results inthermonuclear fusion. He uses not kinetic energy of nucleus again repulsive force of nucleus, as in all R&D conventional methods. He uses the blocking the repulsive forces of nucleus by electrons (sphere Debya), very low temperature and high pressure. In current time to reach these temperature and pressure are easily than hundreds millions degrees by Magnetic or Inertial Confinement. New method the thermonuclear fusion very cheap and allows to use other thermonuclear fuel which are cheaper and produce the aneutronic reaction. The offered fusion reactor is small in bulk, cheap to construct and operate, may be used for the copious production of very cheap electricity, can be used as an engine for Earth-biosphere transportation (train, truck, sea-going ships, aircraft), for outer space apparatus propulsion and for producing small, cheap and powerful deadly explosive weapons. In brief, the author has offered a comprehensive new Criterion for Ultra Cold Thermonuclear Fusion! Useful data for estimation are in [1]-[14].

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