Cumulative Thermonuclear AB-Reactor

Alexander Bolonkin
C&R, abolonkin@juno.com

Abstract

In last sixty years, the scientists spent the tens billion dollars attempting to develop useful thermonuclear energy. But they cannot yet reach a stable thermonuclear reaction. They still are promising publically, after another 15 – 20 years, and more tens of billions of US dollars to finally design the expensive workable industrial installation, which possibly will produce electric energy more expensive than current heat, wind and hydro-electric stations can in 2015.

The author offers a new, small cheap cumulative inertial thermonuclear reactor, which increases the pressure and temperature of its nuclear fuel by thousands of times, reaches the required ignition stage and, ultimately, full constant contained thermonuclear reaction. Cumulative A-B Reactor contains several innovations to achieve its product

Chief among them is using moving explosives (rocket thrust), which allows to accelerate the special piston to very high speed (more 30 km/s) which (as shown by integral computations) compresses the fuel capsule a million times and heats up the millions degrees of temperature.

Keywords:*Micro-thermonuclear reactor, Cumulative AB-thermonuclear reactor, transportation thermonucler reactor, aerospace thermonuclear engine, nuclei fuse.*

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, JET, has resulted in fusion power production somewhat larger than the power put into 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. The unrealized production of net electrical power from fusion machines is planned for the next generation experiment after ITER.

Unfortunately, this task is not easy, as 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 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 pressures.

At present, D-T is used by two main methods of fusion: inertial confinement fusion (ICF) and magnetic confinement fusion (MCF)--for example, tokomak device.

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 focused laser or ion beams are used for compression of pellets. The 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 enough to cause pellet 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 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.

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

Where T is temperature, [KeV], 1 eV = $1.16\times10^{4\,o}$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 in any 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 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 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 $T^{3/2}/\langle\sigma v\rangle$ (here σ is Boltzmann constant, v is ion speed). This condition is traditionally expressed in terms of the mass density ρ:

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

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.

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 ~ $n^2\langle\sigma v\rangle T^{-1/2} / n$ ~ $(nT)\,(\langle\sigma v\rangle/T^{3/2})$

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. 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 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 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, commenced being constructed at LLNL in 1997. Originally intended to start construction in the early 1990s, the NIF is now six years behind schedule and over-budget by some $3.5 billion. Nevertheless many of the 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 "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.

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.
- *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 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" 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 lasers. This research will be carried out on the (currently being built) OMEGA EP petawatt 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).

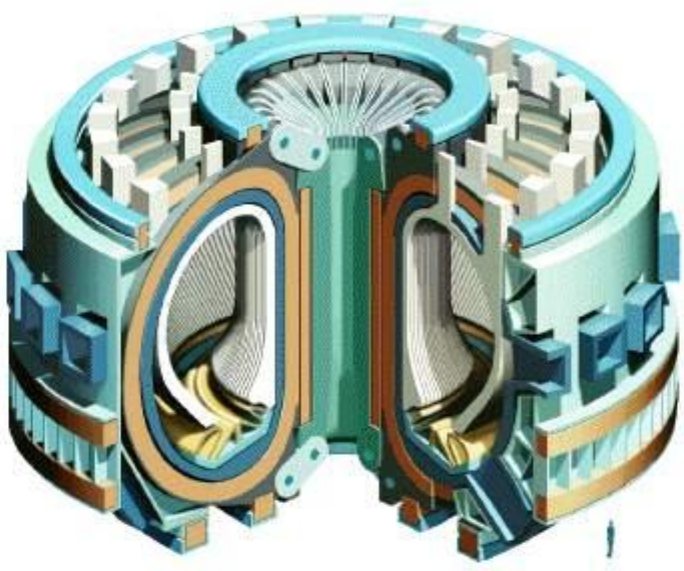

Fig. 2. Magnetic thermonuclear reactor. The size of the installation is obvious if you compare it with the “Little Blue Man” inside the machine at the bottom. Cost is some tens of billions of dollars.

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 *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.*

The magnetic fusion energy (MFE) program seeks to establish the conditions to sustain a nuclear fusion reaction in plasma that is contained by magnetic fields to allow the successful production of fusion power. 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 tokomak) have a Lawrence criterion that is tens of times lower than is necessary (Figure 3).

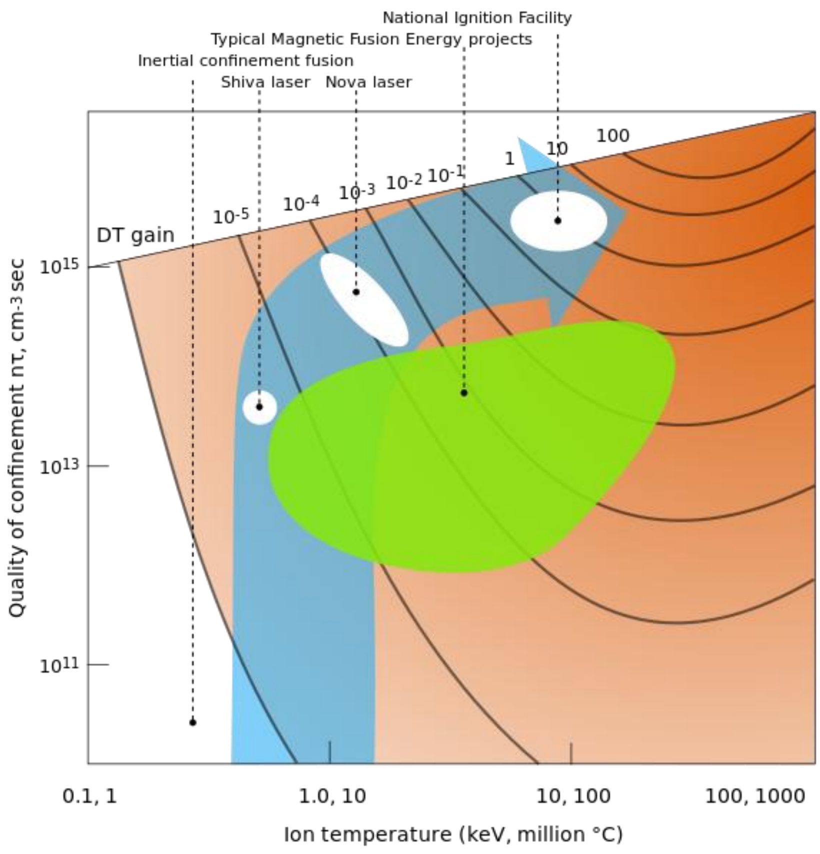

Fig. 3. Parameter space occupied by inertial fusion energy and magnetic fusion energy devices. The regime allowing thermonuclear ignition with high gain lies near the upper right corner of the plot.

Data of same current inertial laser installations:

1. NOVA uses laser NIF (USA), has 192 beams, impulse energy up 120 kJ. One reach density 20 g/cm^3, speed of cover is up 300 km/s.

NIF has failed to reach ignition and is, asof 2013, generating about 1/3rd of the required energy levels. NIF cost is about $3.5B.

2. YiPER (EU) has impulse energy up 70 kJ.
2. OMEGA (USA) has impulse energy up 60 kJ.
3. Gekko-XII (Japon) has impulse energy up 20 kJ. One reaches density 120 g/cm^3.
4. Febus (France) has impulse energy up 20 kJ.
5. Iskra-5 (Russia) has impulse energy up 30 kJ.

Description and Innovations of Cumulative AB reactors

Description.
Laser method. Disadvantages.
Thermonuclear reactors and, in particular, Laser methods are have been under development for about 60 years. Governments have already spent tens billions of US dollars, but it is not yetseen asan industrial application of thermonuclear energy for the coming 10-15 years time period. The laser has very low efficiency (1- 1.5%), high pressure acts very shot time (10^{-9}– 10^{-10} s), enough energy not delivered to the center of the spherical fuel pellet, there are a lot of future problems the radioactivity and converting the thermonuclear energy into useful energy.

Cumulative method. Author offers the new method, which is cheaper by thousands of times, more efficiency and does not have many disadvantages of the laser and magnetic methods. Detailed consideration of advantages the new method and computation proofs will be in next paragraph.

Description of new reactor and method.
The most comfortable version 1 of the Cumulative AB thermonuclear reactor is presented in figures 4 – 6. The new thermonuclear reactor contains (Fig.4): strong sphere 1, fuse 2, six (or more) explosive injectors 3, piston 4 from heavy appropriate material, fuel pellet 5 and tube 6 for loading and primary acceleration.

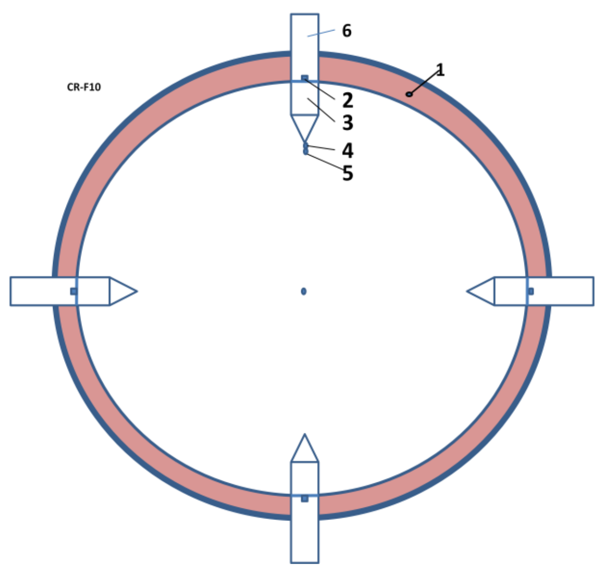

Fig.4. Impulse Cumulative AB-thermonuclear reactor (Version 1). *Notations:* 1 – strong sphere, 2 – fuse, 3– explosive, 4 - piston from heavy material, 5 – capsule (pellet) of nuclear fuel; 6 – tube for loading and additional initial acceleration.

The Cumulative AB reactor works in the following way (figs. 5 – 7):
The net fuses 2 (six or more) (Fig.4) simultaneously blows an nearest layer of the explosive 3(shoot, fire off) and an explosive gas is pushing the explosive 3 to center of sphere (Fig.5a). The explosive 3 is burning, produces gas jet 8 (fig.5a) and create jet rocket thrust 7 which is moving, accelerating, pistons4 in direction to center of sphere 1.

Note: It is very important to *simultaneously* ignite *all* fuses 2 of explosive 3. In only this case, the explosive begin to move at the same time into target mass and reach simultaneously its center. They work like rocket engine, accelerate the pistons 4 (having small mass from heavy material) for high speeds in tens times more that in conventional cumulative explosive. That is main innovation in offered method.

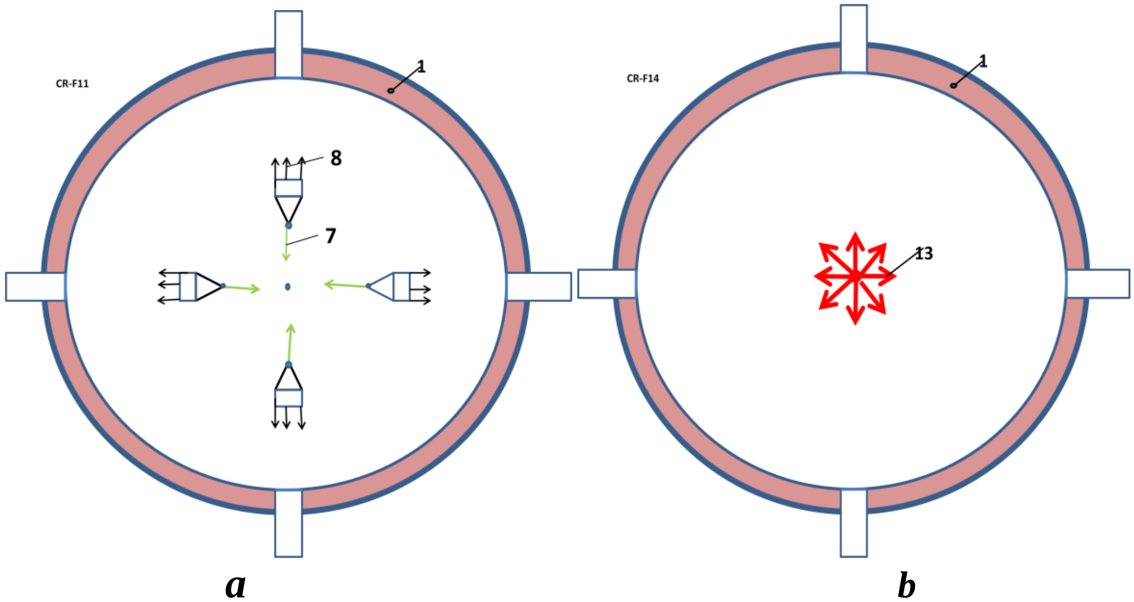

Fig. 5. Work of AB thermonuclear reactor (Version 1). Notations: ***a*** – rocket acceleration of pistons, ***b*** – nuclear explosion;7 is moving of explosive and pistons(force from rocket thrust), 8 is flow of rocket explosive gas. 13 – Thermonuclear explosion.

The collision of heavy piston sin the center creates a big compression and the temperature in the fuel capsule that initiates the nuclear ignition (Fig. 5b).Nuclear energy heats the explosive gas and increases pressure which a magneto hydrodynamic generator (MHD) converts to electric energy, or gas (or steam) turbine converts the gas pressure to the mechanical energy (Fig. 6a), or gas flows to a rocket nozzle and produces a rocket thrust(Fig. 6b).

Cumulative AB Reactor is cooling unseal method or an injection of water into sphere (fig. 9b).

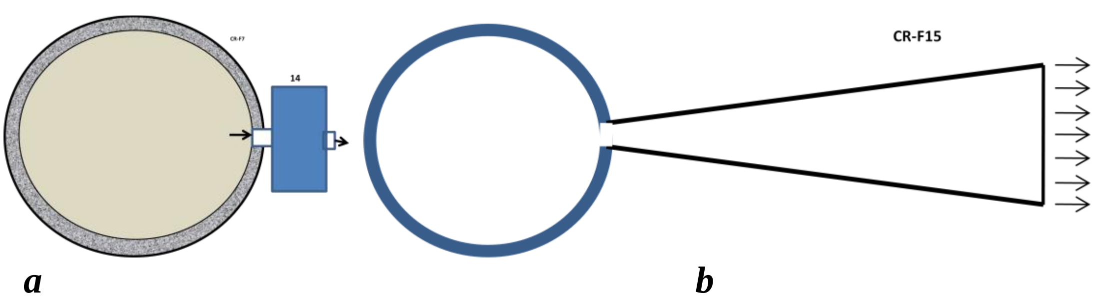

Fig. 6. Final (industrial) work of Cumulative AB thermonuclear reactor. Compressed gas from sphere runs to the magneto hydrodynamic (MHD) generator and produces electric energy or runs to gas turbine and produces useful work (Fig. 6a).*Notation*: 14 – conversion of hot gas pressure to electric or mechanical energy, for example, by the magneto hydrodynamic generator (MHD together with condenser), gas (steam) turbine (Fig. 6a) or moving to a rocket nozzle and produces a rocket thrust (Fig. 6b).

The second version is described below. This Version 2Cumulative AB Reactor is more suitable for use as a deadly weapon.

The new thermonuclear reactor contains (Fig. 7): strong sphere 1, net fuse 2, explosive 3, thin film 4 from heavy material (piston) and fuel pellet 5 into center of sphere.

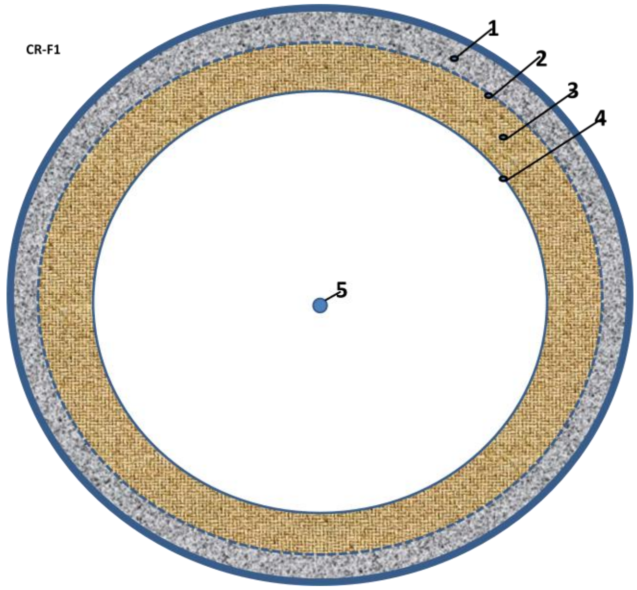

Fig.7. Impulse Cumulative AB-thermonuclear Reactor (Version 2). *Notations*: 1 –strong sphere, 2 – net fuse, 3 – explosive,4 - film (piston) of heavy material, 5 – nuclear fuel.

Note: It is very important to *simultaneously* ignite the *all* outer surface of explosive 3. In only this case the explosive begin to move towards mass center and works as rocket engine, accelerate and compress the explosive and film 4 (having small mass) for high speeds in tens times more that in conventional explosive. That is main innovation in offered method.

We can reach the simultaneously ignition all outer surface of explosive by electric net with a small cells. The electric impulse will ignite the entire outer surface of explosive.

The Cumulative AB Reactor works the following way (figs. 7 – 9):

The net fuse 2 (Fig.8a) simultaneously blows an outer layer of the explosive 3 and an explosive gas 6 is pushing the explosive 3 to center of sphere. The outer surface of explosive 3 is burning 8 (fig.8b) and create jet rocket thrust 7 which is moving, accelerating, compressing the explosive and thin film 4 in direction to center 5 of sphere 1.

As the result the film (piston) made from heavy material bumps with high speed (about 30 km/s) and produced a high pressure (millions atmospheres). This pressure is acting more time than laser pressure and reaches to center of fuel capsule (Fig.9a). The thermonuclear fuel capsule explodes (Fig.9b). The heavy material brakes the explosion, increases the time and efficiency of the thermonuclear reaction. If installation is used as reactor, after MHD or turbine the cooling liquid (for example, water) is injected into strong sphere. One is converted to hot gas (steam) and rotates the turbine blades (Fig.6a).

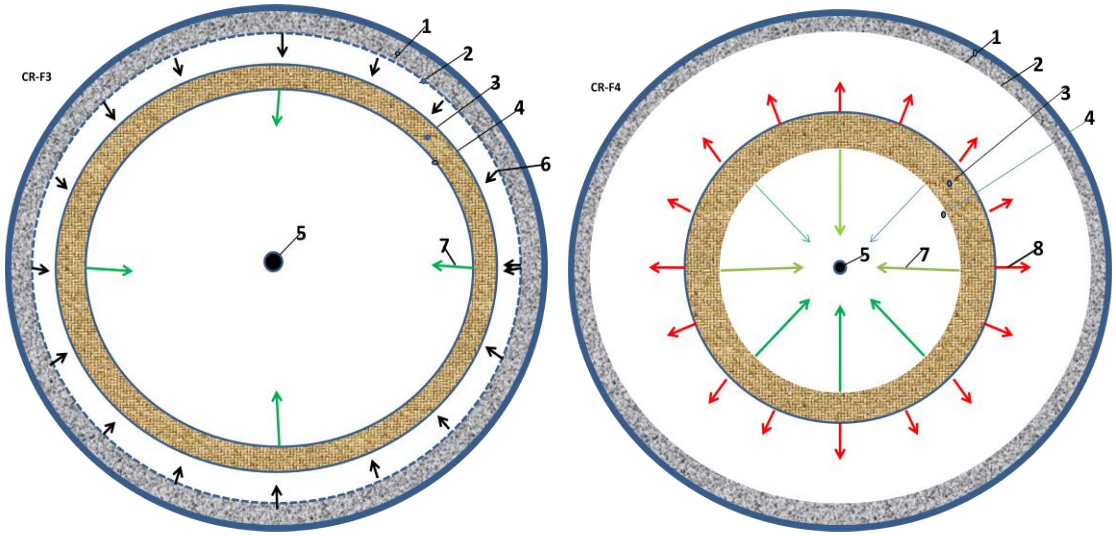

Fig. 8. Work of Cumulative AB thermonuclear reactor (Version 2). *Notations*: ***a*** – initial layer explosive, ***b*** – rocket part of explosive.1 -5 are same with Fig.7, 6 is pressure of initial layer of explosion, 7 is moving of explosive (force from jetted gas rocket thrust) , 8 is flow of reactive explosive gas.

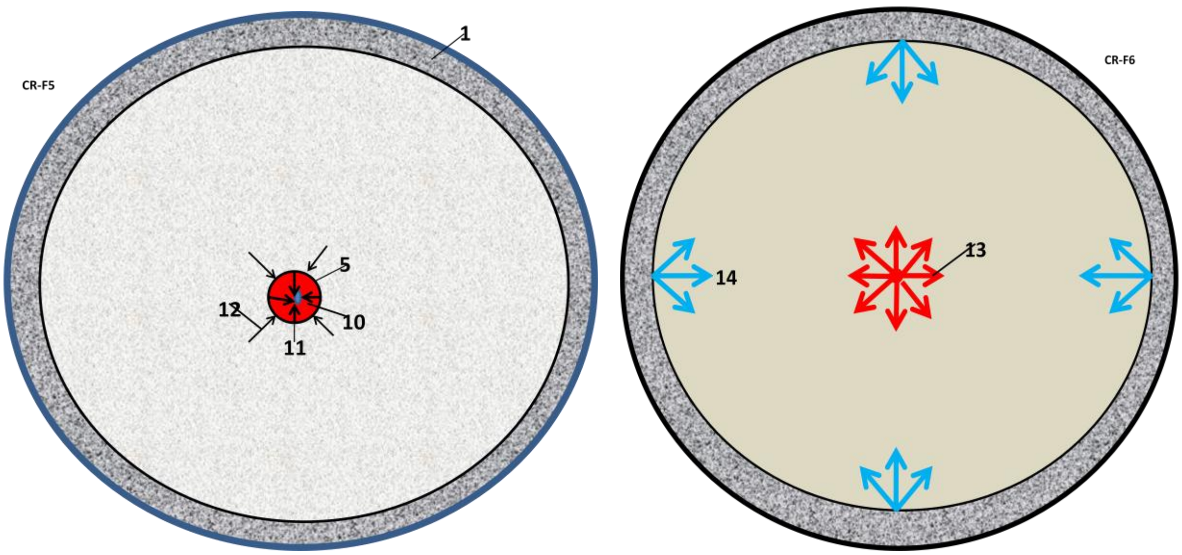

Fig 9. Work of Cumulative AB thermonuclear reactor(Version 2). *Notations*: ***a*** – final of a fuel compression, ***b*** – thermonuclear explosion and injection of work and cooling liquid (for example, water). 10 is heavy piston (one is in final presses), blocks fuel and increases time for nuclear reaction; 11 **-** brake pressure; 12 – outer pressure (shock wave from explosive); 13 – thermonuclear exposure of fuel; 14 – injection of a work and cooling liquid (for example, water after MHD).

If Version 2 is used as reactor, when gas is finished, the top semi-sphere opens, embeds a new explosive and process is repeated. We may to have 2 -3 the explosive spheres for continuous work.

Advantages of the suggested reactor and method in comparison with Laser method.

The offered reactor and method have the following advantages in comparison with the conventional laser reactor:

1. Cumulative AB-reactor is cheaper by thousands of time because one does not have the gigantic very expensive laser installations (see Fig.1).
2. One more efficiency because the laser efficiency convert only 1 -1.5% the electric energy into the light beam. In suggested AB reactor the all underused (for compression) explosive energy remains in the spherical tank and utilized in MGD or turbine. AB reactor cannot have coefficient Q significantly less 1. Moreover one has heat efficiency more than conventional heat engines because it has very high compression ratio. One can use as the conventional very high power engine in military transportation.
3. The offered very important innovation (accelerating of the explosive by the rocket thrust) allows to increase the top speed of the piston mass 4 from the conventional sound (shock wave) speed 3 – km/s up about 30 km/s. Only this innovation increases the thermonuclear ignition criterion in 100 times in comparison with conventional cumulative explosion (see computation). This makes this method available for thermonuclear reaction.
4. Cumulative AB-reactor gives compression of the fuel capsule much more than the current laser installations.
5. This compression is longer time(up to 10^{-3} – 10^{-5} s) than a light beam pressing (impulse 10^{-9} – 10^{-12} s), because heavy mass 4 (piston) is many times (10 ÷ 30) more than mass of a capsule (pellet, micro balloon) 5. This pressure is supported by rocket gas and shock wave coming from moving explosive gas. This pressure reaches the center of capsule with high speed of heavy mass 4, (not sound speed as in laser pressure) increases the temperature, compressing and probability of thermonuclear reaction in the fuel capsule.
6. The heavy mass 4 (piston)(having high nuclear numbers A and Z) not allow the nuclear particles easily to fly apart. That increases the reaction time and reactor efficiency.
7. The suggested AB-thermonuclear reactor is small (diameter about 1÷1.3 m or less up 0.3 m) light (mass about 1.7 ton or less up 150 kg for Version 2) and may be used in the transport vehicles and aviation.
8. The water may protect the material of the sphere from neutrons.
9. It is possible (see computations) the efficiency of AB reactor will be enouph for using as fuel only the deuterium which is cheaper then tritium in thousands times (1 g tritium cost about 30,000 US dollars).

Theory, computation and estimation of Cumulative AB-reactor and comparison one with current ICF.

Estimation of Laser method (ICF).

For comparison the laser and offer cumulative AB method, we estimate the current laser method.

Typical laser installation for ICF has the power 5 MJ and deliver to pellet about 20÷50 kJ energy. The pullet has the 1 – 10 mg liquid (frozen) fuel D+T (density 200 kg/m^3), diameter of the fuel pullet about1- 2 mm, diameter of an evaporative coating 4 – 10 mm.

Let us take the delivered energy E = 50 kJ, volume of the coating v = 5 mm^3, specific weight of coating γ = 400 kg/m^3 (molar weight μ = 10).

For these data and instant delivery of laser energy the maximum pressure in cover is

$$p=\frac{E}{v}=\frac{5\times10^4}{5\cdot10^{-9}}=10^{13}\,\frac{N}{m^2}=10^8\text{atm} \qquad (1)$$

But we don't know what part this pressure transfer to the fuel pellet.

Number of nuclear in 1 m^3 of covering is

$$n=\frac{\gamma}{\mu m_p}=\frac{0.4\cdot10^3}{10\cdot1.67\cdot10^{-27}}=2.4\cdot10^{28}\quad[m^{-3}] \qquad (2)$$

Here m_p=1.67·10^{-27} is mass of nucleon(proton) [kg].

Temperature of evaporating cover is

$$T = \frac{p}{n\,k} = \frac{10^{13}}{2.4\cdot 10^{28} 1.38\cdot 10^{-23}} = 3\cdot 10^{7} \quad [K] \tag{3}$$

Here k = 1.38×10^{-23} Boltzmann constant, J/^{o}K.

Speed of evaporated covering is

$$V = \left(\frac{8kT}{\pi\,\mu\,m_p}\right)^{0,5} = \left(\frac{8\cdot 1.38\cdot 10^{-23} 3\cdot 10^{7}}{3.14\cdot 10\cdot 1.67\cdot 10^{-27}}\right)^{0.5} = 2.51\cdot 10^{5}\ m/s = 251\,km/s \tag{4}$$

Time of evaporating for thickness of covering l = 2·10^{-3} m is

$$t = \frac{l}{V} = \frac{2\cdot 10^{-3}}{2.51\cdot 10^{5}} = 8\cdot 10^{-9} \quad s \tag{5}$$

Let us to consider now the process into pellet.

The density of fuel particles is

$$n_f = \frac{\gamma}{\mu\,m_p} = \frac{200}{2.5\cdot 1.67\cdot 10^{-27}} = 4.8\cdot 10^{28} \quad \frac{1}{m^3} \tag{6}$$

where μ = 2.5 is average molar mass of fuel D+T.

The frozen (liquid) fuel, after converting in gas, has a temperature of about T = 4 K.

The pressure average speed V_n of particles after conversion of the fuel into gas (plasma) and sound speed V_f to fuel gas at temperature 4K are:

$$p_f = n_f kT = 4.8\cdot 10^{28} \times 1.38\cdot 10^{-23} \times 4 = 2.65\cdot 10^{6} \quad N/m^2 = 26.5 \quad atm,$$

$$V_n = \left(\frac{8kT}{\pi\,\mu m_p}\right)^{1/2} = \left(\frac{8\cdot 1.38\cdot 10^{-23}\cdot 4}{3.14\cdot 2.5\cdot 1.67\cdot 10^{-27}}\right)^{1/2} = 183\ \frac{m}{s}, \tag{7}$$

$$V_f = \left(\frac{p_f}{\rho_f}\right)^{1/2} == \left(\frac{2.65\cdot 10^{6}}{200}\right)^{1/2} = 115 \quad m/s.$$

Additional fuel pressure in ***center*** of pellet from two opposing sound wave bump-up is

$$p_s = \rho_f (2V_f)^2/2 = 200\cdot(2\cdot 115)^2/2 = 5.3\cdot 10^{6} \quad N/m^2 = 53 \quad atm. \tag{8}$$

Fuel temperature in ***center*** of small mass pellet where two opposing sound (shock) wave bump-up happens is

$$T = \frac{\pi\,\mu\,m_p (V_n + V_f)^2}{8k} = \frac{3.14\cdot 2.5\cdot 1.67\cdot 10^{-27}(183+115)^2}{8\cdot 1.38\cdot 10^{-23}} = 10.5\,K \tag{9}$$

In reality, the full pressure and temperature in center of capsule is much more. We compute ONLY the sound wave. Any shock wave becomes fast at short distance the sound wave. But in our case this computation is very complex.

Current inertial reactors have the maximal rate of fuel compressing in center of pellet about

$$\xi \approx 600 \quad . \tag{10}$$

Criterion of ignition (for radius of pullet R_o = 0.02 sm and solid or liquid fuel ρ_o= 0.2 g/cm^3) is

$$\rho R = \rho_o R_o \xi^{2/3} = 0.2\cdot 0.02\cdot (600)^{2/3} = 0.28 < 1 \tag{11}$$

where ρ in g/cm^3, R in cm. That value is not useful enough.

You can imagine – with just a small effort and we will fulfill the criterion of ignition! Look your attention in very low temperature of fuel (9). For this temperature the criterion may be wrong, or area of the ignition located into center of pullet may be very small, that energy is very few for ignition of all fuel?

Estimation of Cumulative AB reactors.

The proposed Cumulative AB Reactor is an internal rocket engine which accelerates the small piston from heavy material by cumulative explosion (Figs. 4-7). This piston bumps into pellet of contained nuclear fuel, compresses and heats the pellet up to very high values, producing a nuclear reaction. Most important innovation is in design, the cumulative explosion which works as rocket engine and produces a final speed of the small piston in 15 (and more, from 2 km/s to 30 km/s) times and piston energy in $(15)^2$ = 225 times more than a convention explosion. Below is not project, below the estimations of the typical parameters of AB reactors.

1. **Final speed of the piston.** Let us to estimate the offered design. It is well known the final speed V of rocket is

$$V = -W_e \ln \frac{M_k}{M} = -W_e \ln \mu_k \quad , \qquad (12)$$

where W_e is speed exhaust gas of rocket, m/s; M_k is final mass of rocket, kg; M is initial mass of rocket, kg; $\mu_k = M_k/M$ is ratio the final and initial mass of rocket.

The distance L(acceleration way) of rocket is

$$L = g_0^{-1} W_e^2 v_0 [1 - \mu_k (1 - \ln \mu_k)] \quad \text{if} \quad \mu_k < 0.05 \quad \text{then} \quad L \approx g_0^{-1} W_e^2 v_0 \qquad (13)$$

In (12) – (13) it is used the notations: g_o = 9.81 m/s^2~ 10 m/s^2 is Earth acceleration, $v_o = Mg_o/P_o$ is an initial thrust-to-weight, N/N.

The rocket engine uses the solid fuel W_e = 2400 ÷ 2800 m/s, liquid fuel W_e = 3000 ÷ 3400 m/s, hydrogen-oxygen up W_e = 4000 m/s.

The explosive matters have:

TNT: specific energy E_s= 4.184MJ/kg≈ 4.2 MJ/kg, density ρ = 1,650 kg/m^3, speed of detonation 6900 m/s;
Dynamite: specific energy up E_s= 7 MJ/kg, standard*s* = 5.3 MJ/kg, density ρ= 1,400 kg/m^3 , speed of detonation 6000 m/s.

From $E = mV^2/2$ we get the average speed of exhaust gas for TNT:

$$W_e = (2E_s)^{1/2} = (2 \cdot 4.184 \cdot 10^6)^{1/2} = 2893 m/s \qquad (14)$$

Maximum pressure of explosive is

$$p = \frac{E}{v} = \frac{E\,m}{m\,v} = E_s \rho = 4.184 \cdot 10^6 \cdot 1650 = 6.9 \cdot 10^9 \ \frac{N}{m^2} = 6.9 \cdot 10^4 \text{ atm} \quad , \qquad (15)$$

where v is volume of explosive, m^3; $E_s = E/m$ is specific energy of explosion, J/kg.

Density of particles and temperature of TNT explosion initial moment of explosion (exhause gas has averageμ = 20):

$$n = \frac{\rho}{\mu m_p} = \frac{1650}{20 \cdot 1.67 \cdot 10^{-27}} = 4.94 \cdot 10^{28} \quad \text{m}^{-3}, \quad T = \frac{p}{n k} = \frac{6.9 \cdot 10^9}{4.94 \cdot 10^{28} 1.38 \cdot 10^{-23}} = 10.1 \cdot 10^3 \quad K, \qquad (16)$$

Let us estimate final speed of the piston for data: mass of explosive is M = 2 kg, mass of piston M_k = 20 mg = $2\cdot10^{-5}$ kg, W_e = 2650 m/s.

$$V=-W_e\ln\frac{M_k}{M}=-2650\ln\frac{2\cdot10^{-5}}{2}=2650\cdot5\cdot2.3\approx30475\quad m/s\approx30\quad km/s \quad . \qquad (17)$$

Let us to find the minimal acceleration distance L of piston (minimal distance from lower part of explosive to center of sphere). For Version 1 we receive:

$$\text{From } L=g_0^{-1}W_e^2v_o\ ,\ v_o=Mg_0/F,\ m_c=\rho V_d S\ ,$$
$$F=ma=m_cW_e=\rho V_d SW_e\ ,\ v_o=Mg_0/\rho V_d SW_e\ , \qquad (18)$$
$$\text{we get}\quad L=\frac{MW_e}{\rho V_d S}=\frac{2\cdot2.6\cdot10^3}{1.65\cdot10^3\cdot30\cdot0.2}=0.46\quad m$$

where g_o= 9.81 m/s^2 is gravitation; $W_e$is speed of rocket exhaust gas, m/s; ρ is rocket fuel density, kg/m^3;$V_d$is rate (speed) of combustion of rocket fuel, m/s; S is initial area of the combustion created rocket thrust, m^2; F is initial rocket thrust, N/m^2, M is mass of rocket fuel, kg. We can change speed V_d to add special additives.

2. Temperature T and pressure *p* in pellet after compressing by piston is (for piston speed $V = 3\cdot10^4$ m/s and density of piston $\rho = 2\cdot10^4$ kg/m^3, μ = 200):

$$p=\frac{\rho(2V)^2}{2}=\frac{2\cdot10^4(2\cdot3\cdot10^4)^2}{2}=3.6\cdot10^{13}\quad\frac{\text{N}}{\text{m}^2}=3.6\cdot10^8\quad\text{atm} \quad . \qquad (19)$$

We take here piston speed 2V because we have two opposed pistons.

Temperature

$$\text{From}\quad E=\frac{\mu m_p V^2}{2}=\frac{3kT}{2}\quad\text{we}\quad\text{have}\quad T=\frac{\mu m_p V^2}{3k} \quad . \qquad (20)$$

The mixture D+T hasμ = 2.5 , piston about μ = 200 (for example: tungsten has $\rho = 19.34\cdot10^3$ kg/m^3, μ =184; uran-238 has $\rho = 19.1\cdot10^3$ kg/m^3 , μ = 238 ; lead has $\rho = 11.35\cdot10^3$ kg/m^3 , μ = 207).

The temperature of mixture D+T is:

$$\text{For}\quad\text{fuel}\quad D+T\quad T=\frac{\mu m_p V^2}{3k}=\frac{2.5\cdot1.67\cdot10^{-27}(3\cdot10^4)^2}{3\cdot1.38\cdot10^{-23}}=91\cdot10^3\quad K=7.84\quad eV,$$
$$\text{For}\quad\text{piston}\quad T=\frac{\mu m_p V^2}{3k}=\frac{200\cdot1.67\cdot10^{-27}(3\cdot10^4)^2}{3\cdot1.38\cdot10^{-23}}=7{,}26\cdot10^6\quad K=626\quad eV, \qquad (21)$$

The mass of the piston is in 10 ÷ 30 times more then mass of fuel and the piston has direct contact to fuel. That means the fuel will has temperature about 7 millions degree. That is less the need value 10 keV but in thousands of time more than in a laser method. In offered method we have also very more pressure that in laser method. The high-pressure significantly decreases the need temperature because one decreases the need distance between nuclear particles.

3. **Estimation the Criterion of ignition the Cumulative AB Reactor.**

The process of compression converted the solid-liquid fuel into gas. In according (7) the initial pressure this gas is p_o= 26.5 atm. In accordance(19), the final pressure is about $p = 3.6\cdot10^8$ atm. The rate of fuel compression is

$$\xi = \frac{p}{p_0} = \frac{3.6 \cdot 10^8}{26.5} \approx 1.37 \cdot 10^7 \qquad (22)$$

(compare this reached value with maximum ξ = 600 in laser method. The Cumulative AB Reactor has compression many times more than laser method).

That means the liner size of fuel pellet will be in $(\xi)^{1/3}$= 240 times less. If capsule has initial diameter D = 0.1 cm (fuel mass = $21 \cdot 10^{-6}$ mg, ρ_o = 0.2 g/cm^3), one has R = 0.05/240 = $2.08 \cdot 10^{-4}$ cm. The offered Cumulative AB thermonuclear reactor produced *direct* compression almost a thousands times greater than the usual shock wave laser compression machines at the center of a fuel pullet. The density of the fuel will be $\rho = \rho_o \xi = 0.2 \cdot 1.4 \cdot 10^7 = 2.8 \cdot 10^6$ g/cm^3.

The criterion of the inertial ignition is

$$\rho R = 2.8 \cdot 10^6 \cdot 0.208 \cdot 10^{-3} = 585 > 1 \qquad (23$$

One is in half thousand times MORE than needed. That means we can use instead of very expensive tritium the deuterium which is the thousands times cheaper. The corresponding reactions are:

D + T → ^{4}He (3.5MeV) + n (14.1MeV);

D + D →T (1.01MeV) + p (3.02MeV) 50%

D + D →^{3}He(0.82MeV) + n (2.45MeV) 50%

The deuterium cannot be used in the laser reactor because one requests in 100 times more ignition criterion then D + T. But, as you see in (23), one may be used in AB reactor (Fig.10).

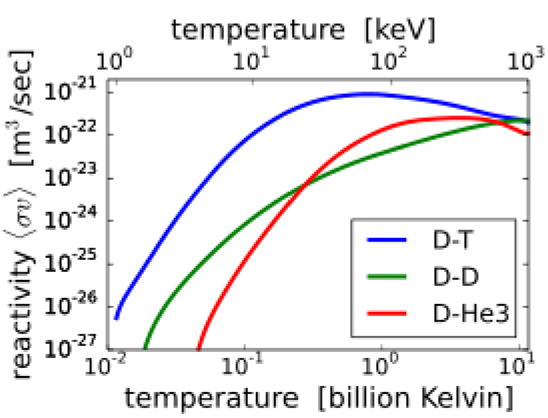

Fig.10. Reactivity is requested for thermonuclear reaction.

The ^{3}He is received in deuterium reaction may be used in next reactions:

D + ^{3}He →^{4}He ((3.6MeV) + p (14.7MeV);

^{3}He + ^{3}He →^{4}He +2p (12.9MeV).

They produce only high energy protons which can be directly converted in electric energy. Last reactions do not produce radio isotopic matters (no neutrons).

Reaction D + D has the other distinct advantages:

1. One produces the protons which energy can be converted directly to electric energy.
2. One produces the tritium which is expensive and may be used for thermonuclear reaction.

3. One produces less and low energy neutrons which create radioactive matters.

The other important advantage is using the pellets with compression gas fuel. Let us take a micro-balloon having fuel gas with p_o= 100 atm., radius 0.1 cm., temperature 300K. The mass fuel will be 4.19 mg.

The compression rate is $\xi = p/p_o$ =3.6·10^8/100 = 3.6·10^6. Liner size decreases by $(\xi)^{1/3}$ = 153 times. The radius of compressed fuel pellet will be R = 0.1/153 = 0.65·10^{-3} cm. The initial density is

$$\rho_0 = \frac{\mu m_p p_0}{kT_0} = \frac{2.5\cdot 1.67\cdot 10^{-27}10^7}{1.38\cdot 10^{-23}300} = 10\,\frac{kg}{m^3} = 10^{-2}\,\frac{g}{cm^3}, \qquad (24)$$

and inertial criterion is

$$\rho R = \rho_0 R_0 \xi^{2/3} = 10^{-2} 0.1\cdot(3.6\cdot 10^6)^{2/3} = 23.5 > 1. \qquad (25)$$

Criterion is good for solid (liquid) fuel D+T, but it is small for fuel D+D. For fuel D+D we must decrease pressure in pellet up 400 atm or increase diameter (and power) our installation.

Compressed micro-balloon is more comfortable for laboratory working because it is unnecessary to store fuel at lower temperature.

Estimation of other parameters the Cumulative AB Reactor.

1. *Thermonuclear energy*. One mg (10^{-6} kg) of thermonuclear fuel D+T has energy:

Number of nucleus:

$$n_1 = \frac{M}{\mu m_p} = \frac{10^{-6}}{2.5\cdot 1.67\cdot 10^{-27}} = 2.4\cdot 10^{20} \qquad (26)$$

One pair of nuclear D+T produces energy E_1 = 17.6 MeV. The n_1 nuclear particles contain the energy

$$E = 0.5\, n_1 E_1 = 0.5\cdot 2.4\cdot 10^{20} 17.6\cdot 10^6 = 21.1\cdot 10^{26}\ eV = 21.1\cdot 10^{26} 1.6\cdot 10^{-19} = 3.38\cdot 10^8\ \mathrm{J} \qquad (27)$$

If coefficient efficiency of the Cumulative AB Reactor is η = 0.3, one mg of fuel produces the energy 100 millions joules. If we make one explosion per sec, installation has the power of 100 million watts. The part of this energy will be produced inside fuel micro-capsule fuel pellet (3.5 Me V from ^{4}He, E = 6.72·10^{7}J) the most of energy (14.1 Me V from neutrons) will be produced into the big containment sphere.

Conventional coefficient of nuclear reactor efficiency is about 0.3, the steam (gas) turbine is about 0.9.

2. *Energy is delivered by piston to fuel capsule* is $E = mV^2/2$. For m = 30 mg, piston speed V = 3·10^4 m/s final piston energy is E = 13.5·10^3 J. That is less then typical energy 20 ÷ 50 kJ delivered by laser installation. But laser energy is spent in vaporizing the cover of the fuel pellet and only small part as shock wave reaches the center of fuel pellet mass. In Cumulative AB Reactor, all piston energy passes directly into the target fuel pellet. The piston energy is easy to increase up 100 kJ by increasing the piston mass and piston speed (also by using more explosive). The piston mass hinders the fuel micro-balloon and increases the nuclear reaction time many times.

Part of this energy will be used for ionization of the fuel. One mg of fuel, for its ionization, requests E = n_1·13.6 e V =522 J, compression of solid fuel about E = 624 J, compression of gas fuel from p = 100 atm E = 105 J. That is a small part of the derived piston energy.

3. *Pressure and temperature in sphere after chemical explosive***.**

Let us take the volume of sphere as 1 m^3, the mass of explosive TNT 2 kg. The energy from chemical explosive is $E_{ch} = mE_s = 2\cdot 4.2\cdot 10^6 = 8.4\cdot 10^6$ J. Here $E_s = 4.2\cdot 10^6$ J/kg is specific energy of TNT explosive J/kg. The final pressure of TNT gas after acceleration of piston is

$$p = E_{ch}/v = 8.4\cdot 10^6/1 = 8.4\cdot 10^6 \text{ N/m}^2 = 84 \text{ atm.} \qquad (28)$$

The temperature is

$$T = \frac{p}{n_0 k}, \quad \text{where} \quad n_0 = \frac{M}{\mu m_p} = \frac{2}{20\cdot 1.67\cdot 10^{-27}} = 5\cdot 10^{25} \quad \frac{1}{m^3}, \quad T = \frac{8.4\cdot 10^6}{5\cdot 10^{25} 1{,}38\cdot 10^{-23}} = 10\cdot 10^3 \quad K, \qquad (29)$$

Here $\mu = 20$ for exhaust gas of TNT. Reaction of TNT is $2C_7H_5N_3O_6 = 3N_2 + 5H_2O + 7CO + 7C$.

4. *Estimation of pressure and temperature after nuclear explosion*.

Let us to find the pressure and temperature after thermonuclear explosive the one mg fuel D+T. Number of nuclear particles in sphere 1 m^3 is

$$n_n = \frac{M}{\mu m_p} = \frac{10^{-6}}{2.5\cdot 1.67\cdot 10^{-27}} = 2.4\cdot 10^{20} \quad \frac{1}{m^3} \qquad (30)$$

Full thermonuclear energy

$$E_n = 0.5 n_n E_1 = 0.5\cdot 2.4\cdot 10^{20} 17.6\cdot 10^6 = 21.1\cdot 10^{26} \text{ eV} = 3.38\cdot 10^8 \text{ J} \qquad (31)$$

If coefficient efficiency of thermonuclear reaction is $\eta = 0.3$ in volume 1 m^3:

$$p = \frac{\eta(E_n + E_{ch})}{v} = \frac{0.3(3.38\cdot 10^8 + 8.4\cdot 10^6)}{1} = 1.038\cdot 10^8 \approx 10^8 \ \frac{\text{N}}{\text{m}^2} = 1000 \text{atm} \qquad (32)$$

Total pressure– nuclear explosive together with chemical explosive - is $p \approx 1000$ atm. Temperature of gas mixture of explosive plus nuclear fuel is

$$T = \frac{p}{(n_0 + n_n)k} = \frac{10^8}{(2.6\cdot 10^{25} + 2.4\cdot 10^{20})\cdot 1.38\cdot 10^{-23}} = 279\cdot 10^3 \text{ K} \qquad (33)$$

As you see the temperature is high. But that is impulse engine. This temperature may be active just a very short time. Between explosions, the installation is cooling from non-use.

5. *Thickness of sphere cover*. Assume the sphere is made from conventional steel having safety tensile stress $\sigma = 50$ kg/mm^2 = $5\cdot 10^8$ N/m^2. The full tensile force is $F = \pi r^2 p = 3.14\cdot 0.5^2\cdot 10^8 = 0.785\cdot 10^8$ N. Requested area of steel is $S_r = F/\sigma = 0.785\cdot 10^8/5\cdot 10^8 = 0.157$ m^2. The thickness of sphere wall is $\delta = S_r/2\pi r = 0.157/2\cdot 3.14\cdot 0.5 = 0.05$ m. Mass of sphere is $M_c \approx \gamma S_s \delta = 7800\cdot 4.536\cdot 0.05 = 1769$ kg. Here S_s is average surface of sphere.

If we use the more strong material for sphere wall, for example: 1μm iron whisker having safety tensile stress $\sigma \approx 400$ kg/mm^2 = $4\cdot 10^9$ N/m^2, we decrease the sphere's mass by 4 – 8 times. We can also make the sphere wall from composite materials (example: an artificial fiber carbon or glass having safety stress σ ≈ 100 ÷ 150 kg/mm^2 and density $\gamma = 1500 \div 2700$ kg/m^3).

6. *Cooling the sphere by water*. If explosions are very frequent, we then can decrease the wall or/and gas temperature by injection of the chilled or room-temperature water. The water also protects our installation from high energy protons in other words, it behaves as a shielding materials.

Let us estimate the amount of water which decreases the temperature and pressure of gas (at most steam H_2O) into sphere for magnitudes acceptable for current steam turbines: $T = 400^oC = 672$ K. The critical point of water (triple point) is $T = 273^oC$, $p = 22$ MPa.

Heating 1 kg water from 20^oC to 100^oC requests energy $E = C_p\Delta T = 4.19\cdot 80 = 333$ kJ, evaporation $- r = 2260$ kJ, heating of steam up 400^oC - $E = C_p\Delta T = 1.05\cdot 300 = 315$ kJ. Total amount of water heat energy is $E_w = 333 + 2260 + 315 = 2908$ kJ/kg. Total mass of water for nuclear efficiency $\eta = 1$ equals $M_w = E/E_w = 3.4\cdot 10^8/2.9\cdot 10^6 = 117$ kg. For $\eta = 0.3$ $M_w = 35$ kg. The 2 – 3 cm of water thickness protects the instellation fron high energy of neutrons produced by reaction D+T.

Unfortunately, the injection of water before decompressing strongly decreases the efficiency of installation.

7. *Run protons and heavy nuclear particles*.

The physic directory by Kikoin, Moscow, 1975, p. 953 gives the following equation for running the protons and charged heavy particles inside gas at pressure 1 atm

$$R_x(E) = \frac{m_x}{m_p} R_p\left(\frac{m_p}{m_x}E\right) \quad , \qquad (34)$$

Where R_x is runof the investigated particles, m_x is mass of investigated particles, $m_p$is mass of proton, R_p is run of known particles in a known environment, E is energy of particles in MeV. The run of proton in H_2 at pressure 1 atm is in the Table 1:

Table 1. Run (range) of proton in gas H_2 at pressure 1 atm

Energy E [MeV]	1	10	100
Run R[cm]	10	$5\cdot 10^2$	$2\cdot 10^4$

For particles ^{4}He (3.5 MeV) in reaction D+T under the piston pressure $p = 10^8$ atm the run is

$$R_x(E) = \frac{m_x}{m_p} R_p\left(\frac{m_p}{m_x}E\right)/p \approx \frac{4}{1} R_p\left(\frac{1}{4}1\cdot 3.5\right)/10^8 \approx 4\cdot 10/10^8 = 4\cdot 10^{-7}\ cm \approx 4\cdot 10^{-6}\ \text{mm} \qquad (35)$$

The closed run has proton.

That means the all energy of the charges particles after nuclear reaction is used for heating other “cold” particles. If probability of an initial reaction is more than 10 keV/3500 ke V= 1/ 350, the chain reaction and ignition will occur .

In the Cumulative AB Reactor these conditions are in *whole* fuel capsule, in laser reactor of many times lower conditions may be *only* in center of fuel capsule (collision of the imposed shock waves). If reacted particles run out the center of capsule, its energy will wasted.

The run way of neutrons is large and very complex function of energy and conditions. Environment.

8.*Converting the nuclear energy of Cumulative AD Reactor to electric, mechanical energy or a rocket thrust.*

The best means for converting a Cumulative AB Reactor nuclear energy is magneto hydrodynamic electric generator (MHD-generator) which converts with high efficiency the high temperature and high pressure plasma directly in electric energy. Together with capacitors one can produces continuous electric currency. Short impulse work of reactor allows to cool the reactor by impulse injection the cooler (or conventional cooling) and protect the Cumulative AB Reactor installation from very high temperature.

The second way for converting an Cumulative AB Reactor nuclear energy is conventional heat exchanger and gas turbine. As cooler may be used the FLiBe – melted mix of fluoride salts of lithium and beryllium.

The third way is injection of water inside sphere and steam turbine as description over.

8. *Using the Cumulative AB reactor as an impulse space rocket engine.*

There are good prospects (possibility) to use the suggested Cumulative AB Reactor as an impulse rocket engine.

If plasma will flow from sphere to space the average speed V of jet is

$$\text{From} \quad E=\frac{mV^2}{2} \quad \text{we get} \quad V=\left(\frac{2E}{m}\right)^{1/2}=\left(\frac{2\cdot10^8}{2}\right)^{1/2}=10^4 \ \frac{\text{m}}{\text{s}}. \qquad (36)$$

Here E is nuclear energy in one impulse one mg nuclear fuel, J; m is the mass injected to outer space (together with conventional explosive), kg.

Received speed V = 10 km/s is in three times more than a current exhaust chemical speed (it may be up 25 km/s). If space apparatus has mass 1 tonn the ship speed changes in $V_2 = (m_1/m_2)\ V_1$ = 20 m/s in one strong impulse.

More importantly, the next possibility is of the rocket powered by the Cumulative AB Reactor. Any matter from any planets, asteroids, space body may be used as fuel used for increasing the derivation of impulses. For example, assume the captured solid object moving through spaceis composed of some water, and we filled rocket tanks using that mined planet, comet or asteroid water. From (35) and Law of equal impulse we have from every impulse

$$V_1=(2Em_1)^{1/2}/m_2=(2\cdot10^8\cdot16)^{1/2}/10^3=56.6 \quad m/s. \qquad (37)$$

Here V_1 is add speed m_1 mass jet kg, m_1 = 14 kg of water + 2 kg of explosive; m_2 is mass of space apparatus.

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 humankind's aerospace activities. Using such reactor, aircraft could undertake flights of very long distance and for extended periods and that, of course, decreases a significant cost of aerial transportation, allowing the saving of ever-more expensive imported oil-based fuels. (As of mid-2006, the USA DoD has a program to make aircraft fuel from domestic natural gas sources). The temperature and pressure required for any particular fuel to fuse is known as the Lawson criterion L. Lawson criterion relates to plasma production temperature, plasma density and 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. They cannot stably achieve the nuclear ignition and the Lawson criterion. In future, they will have a lot of difficulties with acceptable cost of nuclear energy, with converting the nuclear energy to conventional energy, with small thermonuclear installation suitable for transportation or space exploration. Scientists promise an industrial application of thermonuclear energy after 10 – 15 years additional researches and new billions of US dollars in the future. But old methods not allow to reach it 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 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 vaporarization 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 offer method does not have these disadvantages. One directly presses fully the fuel capsule to high pressure and temperature by piston, one covers the capsule by piston mass in 10 – 30 times more them mass of fuel, protects the fuel by the heavy elements having high number of nucleons A and charges Z. They reflect the light protons, D, T, repels high-energy reacted particles (^{4}He, p) back to fuel and significantly (in hundreds time) increasing the conformation time.

It is important also that all chemical (explosive) energy not used for compression of the fuel capsule remains into sphere and may be used for useful work.

The cumulative idea cannot be used for thermonuclear reaction in its classical form. Produced pressure and temperature are not enough for thermonuclear reaction. The main author innovation is using the rocket thrust of explosive for acceleration piston for very high speed (from 2 km/s up 30 km/s and more), That increases the kinetic energy the piston in 225 times.

Author noted that the mass of fuel and piston is very small and allows reaching the high rocket speed of pressing by piston.

The method possible allows to use reaction D+D (instead D+T) with cheap nuclear fuel D (Tritium is very expensive – about 20,000 USD for 1 g). One also allows using the compressed fuel-gas at room temperature.

The method also be used for getting the metal hydrogen, which has super-conductivity at room temperature and high thermal capacity.

Conclusion

The author offers a new small cheap cumulative inertial thermonuclear reactor, which increases the pressure and temperature of a nuclear fuel in thousands times, reaches the ignition and full thermonuclear reaction. Cumulative AB Reactor, herein offered by its originator, contains several innovations.

Main of them is using a moved explosive, which allows to accelerate the special piston to very high speed (more than 30 km/s) which (as it is shown by computations) compresses the fuel capsule in million times and heating up the million degrees of temperature.

The offered reactor is small, cheap, may be used for cheap electricity, as engine for Earth transportation (train, truck, sea-going ships, aircraft), for space apparatus and for producing small and cheap and powerful weapons. Closed ideas are in [1]-[8].

Acknowledgement

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