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Impulse Mini Thermonuclear Reactors

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Abstract

In last sixty years, the scientists spent the tens billion dollars attempting to develop useful thermonuclear energy. However, 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 hydroelectric stations can in 2015.

The author offers two types (cumulative and impulse) the new, small cheap inertial thermonuclear reactors, 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 and impulse AB Reactors contain several innovations to achieve its product.

Chief among them in cumulative reactor is using moving explosives (rocket thrust) and an electric descharge, which allows to accelerate the special piston to very high speed (more 20 km/s) which (as shown by integral computations) compresses the fuel capsule a million times and additional heating fuel by electric impulse up hundreds millions degrees of temperature.

In impulse vertion of AB therbonucler reactor the gas fuel, praimery high compressed into a pellet heationg by an electric impulse up the needed temperature in hundred of millions degrees, produces the thermonucler reaction. Author gives theory and estimations of the suggested reactors.

Author also is descussing the problems of converting the received thermonucler energy into mechanical (electrical) energy and into rocket thrust.

Offered small micro-reactors may be used as heaves (ignition) for small artillery atomic projectiles and bomb.

Keywords: *Micro-thermonuclear reactor, Cumulative thermonuclear reactor, Impuls thermonuclear reactor, transportation thermonucler reactor, aerospace thermonuclear engine, nuclei fusee.Thermonuclear rocket.*

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 (D –T); both are heavy isotopes of hydrogen. The D-T 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. However, tritium is very expensive.

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 D –T (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.

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 known fuel from this standpoint is a one-to-one mix of deuterium and tritium; both are heavy isotopes of hydrogen. The D-T 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

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

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

This number has not yet been achieved in any 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.

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 and R-radius of fuel pellet:

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

To satisfy this criterion at the density of solid D+T (0.2 g/cm³) would require implausibly large laser pulse energy. Assuming the energy required scales with the mass of the fusion plasma ($E_{laser} \sim \rho R^3 \sim \rho^{-2}$), compressing the fuel to 10^3 or 10^4 times solid density would reduce the energy required by a factor of 10^6 or 10^8, bringing it into a realistic range. With a compression by 10^3, the compressed density will be 200 g/cm³, and the compressed radius can be as small as 0.05 mm. The radius of the fuel before compression would be 0.5 mm. The initial pellet will be perhaps twice as large since most of the mass will be ablated during the compression 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 ($n^2<\sigma v>$) times the confinement time (which scales as $T^{1/2}$) divided by the particle density n: burn-up fraction ~ $n^2<\sigma v>T^{-1/2} / n \sim (nT)(<\sigma v>/T^{3/2})$

Thus the optimum temperature for inertial confinement fusion is that which maximizes $<\sigma v>/T^{3/2}$, 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 (NIF), 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. Never the less 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* . 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.

Data of some 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, as of 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.

In given reseach author offers the new cheap termonuclear reactors and fusees for nuclear projectales. In early this method was described in [1] – [3]. Below are cheaper and simpler reactors.

Description and Innovations of Cumulative and Impulse 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 yet seen as an industrial application of thermonuclear energy for the coming 10-15 years time. 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 many future problems the radioactivity and converting the thermonuclear energy into useful energy.
Cumulative method. Author offered three the new methods [1 – 3], which is cheaper by thousands of times, more efficiency and does not have many disadvantages of the laser and magnetic methods. In given article the author offers two (cumulative and impulse) impruved reactors. Detailed consideration of advantages the new methods and computation proofs are in next paragraph.
Description of new cumulativr reactor and method.
The impruved version 1 of the Cumulative AB thermonuclear reactor is presented in figures 1 – 4. The new thermonuclear reactor contains (Fig.1): strong spherical body of reactor 1; cartridge (holder) of fuel pellet (or pellet inVersion 2) 2; holder (electric conductor) of fuel cartridge (pellet) 3; enter of compressed air (gas) 4; exit of a hot compressed air after thermonuclear heating, 5; contacts of voltage 6 for electric condenser.

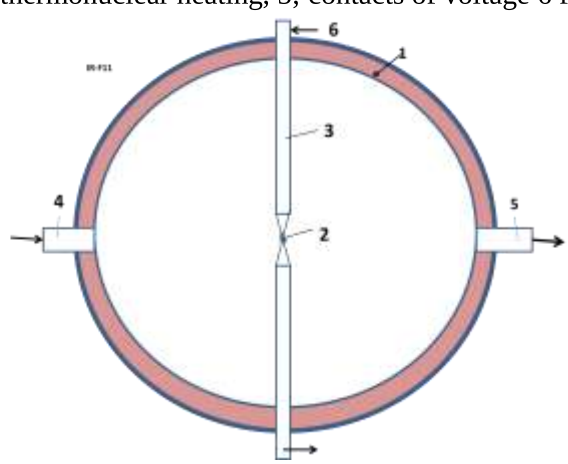


Fig. 1. AB thermonuclear cumulative reactor (Version 1). *Notations*: 1- strong spherical body of reactor, diameter about 0.5 – 5 m ; 2 – catridge (holder) of fuel pellet, diameter 1÷ 2 cm (or pellet inVersion 2, diameter 2 ÷ 3 mm); 3 – holder (electric conductor) of fuel pellet; 4 – enter of compressed air (gas); 5 – exit of a hot compressed air (gas) after thermonuclear heating; 6 – electric voltage.

The fuel cartrige 6 has diameter about 10 – 20 mm and the next design (fig.2): strong sphere 1; net fusee (electric net 2 for ignition of explosive 3, fig 2), explosive 3, film (piston) of heavy material 4, ampoule of nuclear fuel (pellet) 5, electric conductors 6.

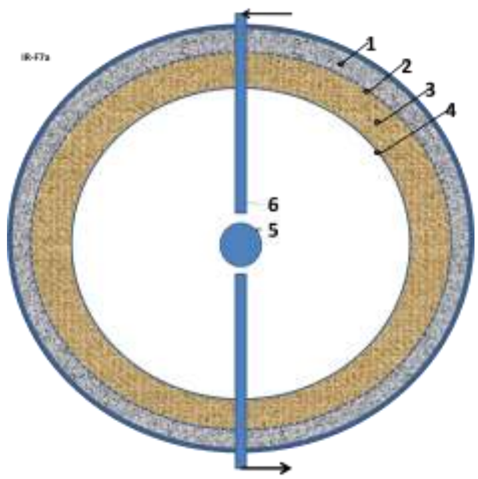
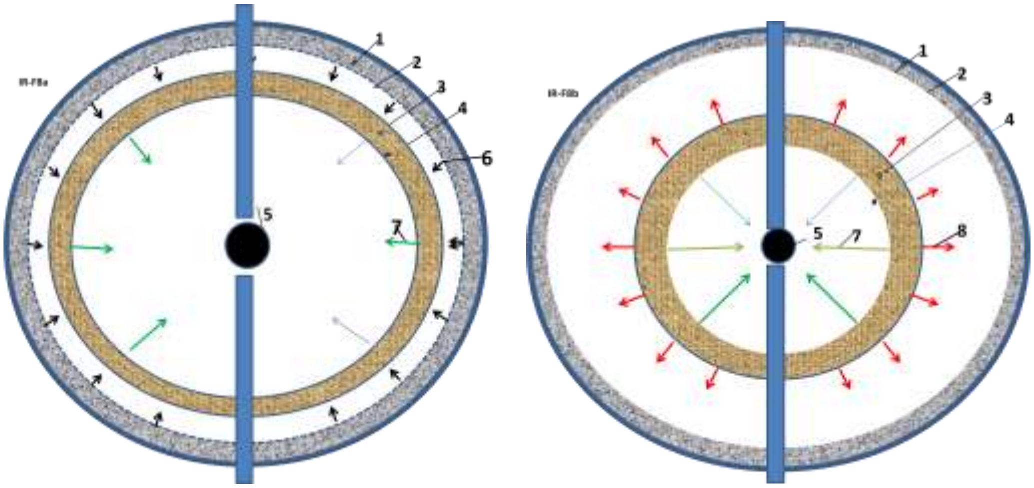


Fig.2. Catridge of Cumulative AB-thermonuclear Reactor (Version 1). *Notations*: 1 –strong sphere, 2 – net fusee (electric net), 3 – explosive, 4 - layer (piston) of heavy material, 5 – nuclear fuel (pellet), 6 - electric conductor.

In shortly the reactor works the following way: The lasting sphere 1of reactor (fig.1) is filled the compressed gas (for example, air). Electric signal is sended across the electric conductor 3 (fig.1) and blow up the explosive 3 (fig.2) into fuel cartridge (fig.3a). The cumulative explosive works as rocket engine (fig.3b) and presses the layer (piston) of heavy material 4 around the fuel pullet 5 (fig.3) and high presses (and heating) the fuel pullet 5. The strong electric impulse from condenser, sending across the insulated conductors 3 (fig.1) and 6 (fig.2) into pellet, additional heats the fuel up the need thermonucler temperature. The fuel exploves.

Note: It is very important to *simultaneously* ignite the *all* outer surface of explosive 3 (fig.2). In only this case the explosive begin to move towards mass center and works as rocket engine, accelerate and compress the explosive and layer 4 (having small mass) for high speeds in tens times more that in conventional explosive. That is main innovation in offered method.

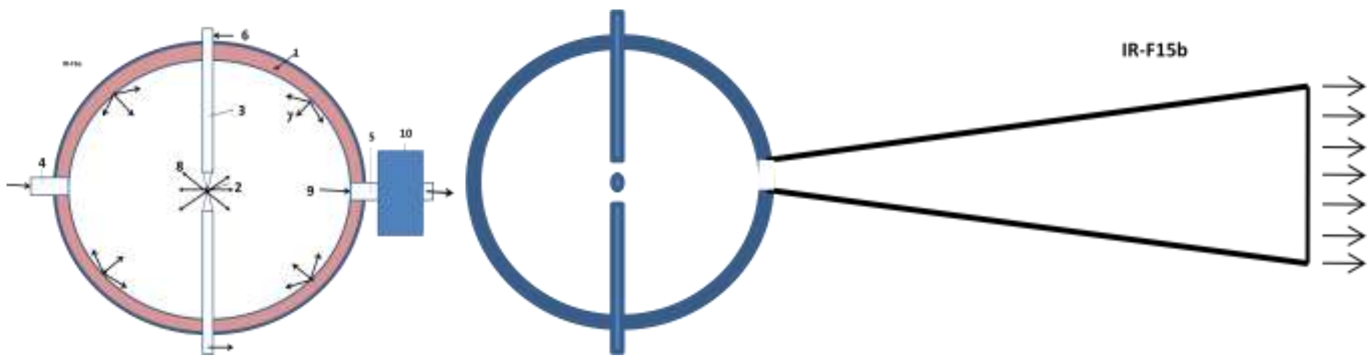
We can reach the simultaneously ignition all outer surface of explosive by electric net having a small cells of net. The electric impulse will ignite the entire outer surface of explosive.



a *b*

Fig. 3. Cumulative canridge of thermonuclear fuel. Work of Cumulative thermonuclear catridge (Version 1). *Notations*: ***a*** – initial layer explosive, ***b*** – rocket part of explosive. 1 - 5 are same with Fig.3; 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.

Simultaneouly (or early) into the big sphere of reactor body may be injected the water 7 (fig.4a) (optional). The compressed air (or injected water) is heating by the thermonuclear explosive 8 (fig.4a) and go out across a hole 9 (fig.4a) into MHG (or gas-, steam turbine) and produses the electric or mechanical energy. In rocket engine, the gas flow out across the nozzle and creates the rocket trust (fig.4b).



a *b*

Fig. 4. Final (industrial) work of Cumulative and Impulse AB thermonuclear reactors. ***a***) Hot compressed gas from sphere runs to the magneto-hydrodynamic generator (MHG) 10 and produces electric energy or runs to gas turbine and produces an useful work (Fig. 2a). ***b***) Hot compressed gas rans to rocket nozzle and produces the rocket trust. *Notation*: 1 – 6 are same Fig.1; 7 – injection the cooling liquid (for example, water)(option); 8 – themonuclear explosive of fuel pellet; exit of hot gas; 10 – MHG or gas (steam) turbine.

The main difference the offered reactor from cumulative reactors (versions 1, 2) [1] is location of compressed exposive. In [1] the explosive is located into main spherical body 1 (fig.1) (or gun in [2]). In curent version 1 (fig.2) the explosive 3 is small and located in the special fuel cartridge (fig.2). It easer and it is more camfortable in using.

The versions 1, 2 of current reactors the fuel pullet is filling by the compressed gas fuel (up 1000 atmosphere or more) and version 2 not has the explosive for an edditional compressing of fuel. The fuel pellet is heating only by strong electric charge. The pullet has an edditional feachures (fig.5). The computation shows that is possible. This method needs in eddisional research. In cumulative version 1, we can use the coventional pellet with frozen fuel.

AB Reactors are cooled well-known methods between explosives or by an injection of water into sphere (fig. 4a).

In more details the Cumulative AB Reactor works the following way (figs. 3 – 5):

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

As the result the layer 4 (piston) made from heavy material bumps with high speed (about 20 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.3a). The strong electric impulse increases the fuel temperature up need value.The thermonuclear fuel capsule explodes (Fig.3b). The heavy material of layer brakes the nuclear explosion, increases the conformation time and efficiency of the thermonuclear reaction. If installation is used as reactor for MHG 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.4a).

Note: It is very important to *simultaneously* ignite the *all* outer surface of explosive 3 (fig.2). In only this case the explosive mass begin to move towards to center and works as rocket engine, accelerate and compress the explosive and layer 4 (having small mass) for high speeds in tens times more that in conventional explosive. That is main innovation in offered method.

Compressed gas pellet for Cumulative and Impulse thermonuclear reactors is shown in fig.5. One has a compressed up 300 – 1000 atm thermonuclear gas fuel 5, the insulater spherical cover 2, the contacts connect the inside and outside electric contacts 2-3; and thin internel electric conductor 4 (only for Impulse reactor) which produces the initial ion canal for an electric currency.

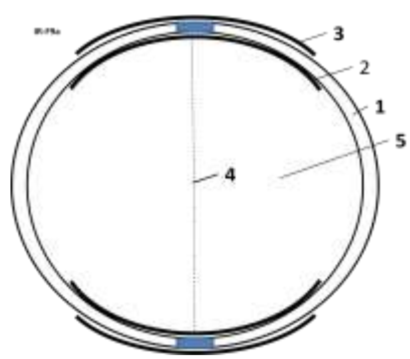


Fig.5. Compressed gas pellet for Cumulative and Impulse Thermonuclear reactors. *Notations*: 1- isolator cover; 2, 3 – iternel and externel ejectric contacts; 4 – initial hot ioniser; 5 – compressed gas thermonucler fuel.

Advantages of the suggested reactors in comparison with ICF Laser method.

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

1. The additional electric heating allows reaching the needed thermonuclear temperature.
2. Cumulative and Impulse AB-reactors are cheaper by thousands of time because they do not have the gigantic very expensive laser installations (see [1]-[3]).
3. They more efficiency because the laser istellation converts only 1 -1.5% the electric energy into the light beam. In suggested AB reactors, the all underused (for compression) explosive energy remains in the spherical tank and utilized in MDG or turbine. AB reactor cannot have coefficient *Q* (used energy) 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 civil and military transportation.

4. The offered very important innovation (accelerating of the explosive by the rocket thrust) allows increasing the top speed of the piston mass 4 from the conventional sound (shock wave) speed 3 – km/s up about 20 km/s. Only this innovation increases the thermonuclear ignition criterion in 50 times in comparison with conventional cumulative explosion (see computation). This makes this method available for thermonuclear reaction.
5. Cumulative AB-reactor gives compression of the fuel capsule much more than the current ICF laser installations.
6. This compression has longer time (up to 10^{-3} – 10^{-5} s) than a laser beam pressing (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.
7. 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.
8. The suggested AB-thermonuclear reactor is small (diameter about 0.5÷3 m or less up 0.3 m) light (mass about some ton or less up 150 kg) and may be used in the transport vehicles and aviation.
9. The water may protect the material of the sphere from neutrons.
10. It is possible (see computations) the efficiency of AB reactors will be enouph for using as fuel only the deuterium which is cheaper then tritium in thousands times (One gram of tritium costs about 30,000 US dollars. One gram of deuterium costs 1$.).

Theory of current Thermonucler Reactor

1. The following reactions are sutable for thermonuclear fusion:

Table 1. Sutable reactions for thermonuclear fusion

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

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

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

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

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

$$n + {}^{6}Li \rightarrow T + {}^{4}He, \quad n + {}^{7}Li \rightarrow T + {}^{4}He + n.$$

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

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

fuel	T [keV]	$\langle\sigma v\rangle/T^2$ [m³/s/keV²]
D-T	13.6	1.24×10^{-24}
D-D	15	1.28×10^{-26}
D-^{3}He	58	2.24×10^{-26}
p-^{6}Li	66	1.46×10^{-27}
p-^{11}B	123	3.01×10^{-27}

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

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

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

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

With this choice, we tabulate parameters for four of the most important reactions.

Table 3. Parameters of the most important reactions

Fuel	Z	E_{fus} [MeV]	E_{ch} [MeV]	neutronicity
D-T	1	17.6	3.5	0.80

D-D	1	12.5	4.2	0.66
D-^{3}He	2	18.3	18.3	~0.05
p-^{11}B	5	8.7	8.7	~0.001

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

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

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

We can now compare these reactions in the following table 4.

Table 4. Comparison of reactions

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

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

Below are some equation useful for computation:

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

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

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

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

$$p_k = nk(T_e + T_i) \quad \text{if} \quad T_e = T_k \quad \text{then} \quad p_k = 2nkT \qquad (2\text{-}1)$$

where $k = 1.38\times10^{-23}$ is Boltzmann constant; T_e is temperature of electrons, ^oK; T_i is temperature of ions, ^oK. These temperatures may be different; n is plasma density, $1/m^3$; p_k is plasma pressure, N/m^2.

4. The gas (plasma) ion pressure, p, is

$$p = \frac{2}{3} nkT, \qquad (3\text{-}1)$$

Here n is plasma density in $1/m^3$.

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

$$p_m = \frac{B^2}{2\mu_0}, \quad p_s = \frac{1}{2}\varepsilon_0 E_S^2 \qquad (4\text{-}1)$$

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

6. Ion thermal velocity is

$$v_{Ti} = \left(\frac{kT_i}{m_i}\right)^{1/2} = 9.79\times10^5 \mu^{-1/2} T_i^{1/2} \quad \text{cm/s} \;, \qquad (5\text{-}1)$$

where $\mu = m_i/m_p$, m_i is mass of ion, kg; $m_p = 1.67\times10^{-27}$ is mass of proton, kg.

7. Transverse Spitzer plasma resistivety

$$\eta_\perp = 1.03\times10^{-2} Z \ln \Lambda T^{-3/2}, \quad \Omega\ \text{cm} \quad \text{or} \quad \rho \approx \frac{0.1\text{Z}}{\text{T}^{3/2}} \quad \Omega\ \text{cm} \quad , \qquad (6\text{-}1)$$

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

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

$$(\overline{\sigma v})_{DD} = 2.33\times10^{-14} T^{-2/3} \exp(-18.76\, T^{-1/3}) \quad \text{cm}^3\text{s}^{-1}, \qquad (7\text{-}1)$$

$$(\overline{\sigma v})_{DT} = 3.68\times10^{-12} T^{-2/3} \exp(-19.94\, T^{-1/3}) \quad \text{cm}^3\text{s}^{-1},$$

where T is measured in keV.

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

$$P_{DD} = 3.3\times10^{-13} n_D^2 (\overline{\sigma v})_{DD}\,, \quad \text{W cm}^{-3}$$

$$P_{DT} = 5.6\times10^{-13} n_D n_T (\overline{\sigma v})_{DT}\,, \quad \text{W cm}^{-3} \qquad (8\text{-}1)$$

$$P_{DHe^3} = 2.9\times10^{-12} n_D n_{He^3} (\overline{\sigma v})_{DHe^3}\,, \quad \text{W cm}^{-3}$$

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

10. Reaction rates are presented in Table 5 below:

Table 5. Reaction rates <σv> (in $cm^{-3}\ s^{-1}$) avereged over Maxwellian distributions

Tempera-ture, keV	D+D, (1a + 1d)	D+T , (2)	D+He, (3)
1.0	1.5×10^{-22}	5.5×10^{-21}	10^{-26}
2.0	5.4×10^{-21}	2.6×10^{-19}	1.4×10^{-23}

5.0	1.8×10^{-19}	1.3×10^{-17}	6.7×10^{-21}
10.0	1.2×10^{-18}	1.1×10^{-16}	2.3×10^{-19}
20.0	5.2×10^{-18}	4.2×10^{-16}	3.8×10^{-18}
50.0	2.1×10^{-17}	8.7×10^{-16}	5.4×10^{-17}
100.0	4.5×10^{-17}	8.5×10^{-16}	1.6×10^{-16}
200.0	8.8×10^{-17}	6.3×10^{-16}	2.4×10^{-16}
500.0	1.8×10^{-16}	3.7×10^{-16}	2.3×10^{-16}
1000.0	2.2×10^{-16}	2.7×10^{-16}	1.8×10^{-16}

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

Estimation of Laser method (ICF).

For comparison the laser and offer cumulative and Impulse AB methods, we estimate the current ICF 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

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

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

Number of nuclear in 1 m^3 of covering is

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

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

Temperature of evaporating cover is

$$T=\frac{p}{nk}=\frac{10^{13}}{2.4\cdot10^{28}1.38\cdot10^{-23}}=3\cdot10^7\quad[K] \qquad (3\text{-}2)$$

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

Speed of evaporated covering is

$$V=\left(\frac{8kT}{\pi\mu m_p}\right)^{0,5}=\left(\frac{8\cdot1.38\cdot10^{-23}3\cdot10^7}{3.14\cdot10\cdot1.67\cdot10^{-27}}\right)^{0.5}=2.51\cdot10^5\ m/s=251\,km/s \qquad (4\text{-}2)$$

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

$$t=\frac{l}{V}=\frac{2\cdot10^{-3}}{2.51\cdot10^5}=8\cdot10^{-9}\quad s \qquad (5\text{-}2)$$

Let us to consider now the process into pellet.

The density of fuel particles is

$$n_f=\frac{\gamma}{\mu m_p}=\frac{200}{2.5\cdot1.67\cdot10^{-27}}=4.8\cdot10^{28}\quad\frac{1}{m^3} \qquad (6\text{-}2)$$

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:

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

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

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

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

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

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

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

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. However, in our case this computation is very complex.

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

$$\xi \approx 600 \,. \qquad (10\text{-}2)$$

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

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

where ρ in g/cm^3, R in cm. That value is not enough (0.28 < 1).

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 (9-2). 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 reactor.

The proposed Cumulative AB Reactor is an internal rocket engine, which accelerates the small piston (layer) from heavy material by cumulative explosion (Figs. 1-3). 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 10 (and more, from 2 km/s to 20 km/s) times and piston energy in $(10)^2$ = 100 times more than a convention explosion. The second important innovation is the additional heating the fuel by the strong electric impulse. Below is not project; below is the estimations of the typical parameters of AB reactors.

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

$$V = -W_e \ln\frac{M_k}{M} = -W_e \ln \mu_k \,, \qquad (12\text{-}2)$$

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 path) of rocket is

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

In (12-2) – (13-2) 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 weight-to-thrust, N/N.

The rocket engine has 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:

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

Maximum pressure of explosive is

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

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 average μ = 20, TNT reaction) is:

$$n = \frac{\rho}{\mu m_p} = \frac{1650}{20\cdot 1.67\cdot 10^{-27}} = 4.94\cdot 10^{28}\quad \text{m}^{-3},$$

$$T = \frac{p}{n\,k} = \frac{6.9\cdot 10^9}{4.94\cdot 10^{28} 1.38\cdot 10^{-23}} = 10.1\cdot 10^3\quad K, \qquad (16\text{-}2)$$

Let us estimate the final speed of the piston (layer) for data: mass of explosive is $M = 10^{-3}$ kg, mass of piston (layer) M_k = 1 mg = 10^{-6} kg, W_e = 2650 m/s.

$$V = -W_e \ln\frac{M_k}{M} = -2650\ln\frac{10^{-6}}{10^{-3}} = 2650\cdot 3\cdot 2.3 \approx 18300\, m/s \approx 18\, km/s\,. \qquad (17\text{-}2)$$

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

From $L = g_0^{-1}W_e^2 v_o$, $v_o = Mg_0/F$, $m_c = \rho V_d S$,

$$F = ma = m_c W_e = \rho V_d S W_e\ , v_o = Mg_0/\rho V_d S W_e\ , V_d = W_e. \qquad (18\text{-}2)$$

we get $L = \dfrac{M}{\rho S} = \dfrac{10^{-3}}{1.65\cdot 10^3\cdot 6\cdot 10^{-4}} = 0.1\cdot 10^{-2} m = 1\, mm$

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 $V = 1.8\cdot 10^4$ m/s and density of piston $\rho = 2\cdot 10^4$ kg/m^3, μ = 200):

$$p = \frac{\rho(2V)^2}{2} = \frac{2\cdot 10^4(2\cdot 1.8\cdot 10^4)^2}{2} = 1.36\cdot 10^{13}\ \frac{\text{N}}{\text{m}^2} = 1.36\cdot 10^8\ \text{atm}\,. \qquad (19\text{-}2)$$

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

Temperature

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

The mixture D+T has μ = 2.5 , piston about μ = 200 (for example: tungsten has $\rho = 19.34\cdot 10^3$ kg/m^3, μ =184; uran-238 has $\rho = 19.1\cdot 10^3$ kg/m^3 , μ = 238 ; lead has $\rho = 11.35\cdot 10^3$ kg/m^3 , μ = 207).

The temperature of mixture D+T is:

$$\text{For fuel D+T} \quad T = \frac{\mu m_p V^2}{3k} = \frac{2.5\cdot 1.67\cdot 10^{-27}(1.8\cdot 10^4)^2}{3\cdot 1.38\cdot 10^{-23}} = 34.5\cdot 10^3 K \approx 3.14 eV,$$

$$\text{For piston} \quad T = \frac{\mu m_p V^2}{3k} = \frac{200\cdot 1.67\cdot 10^{-27}(1.8\cdot 10^4)^2}{3\cdot 1.38\cdot 10^{-23}} = 2.61\cdot 10^6 K = 225 eV, \qquad (21\text{-}2)$$

The mass of the piston is in 5 ÷ 20 times more then mass of fuel and the piston has direct contact to fuel. That means the fuel will has temperature about 3 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 (7-2) the initial pressure this gas is p_o= 26.5 atm. In accordance(19-2), the final pressure is about p = 1.44·10^8 atm. The rate of fuel compression is

$$\xi = \frac{p}{p_0} = \frac{1.44\cdot 10^8}{26.5} \approx 5.43\cdot 10^5 \qquad (22\text{-}2)$$

(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 $(\xi)^{1/3}$= 82 times less. If capsule has initial diameter D = 0.1 cm (fuel mass = 21·10^{-6} kg, ρ_o = 0.2 g/cm^3), one has R = 0.05/82 = 6.1·10^{-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 $\rho = \rho_o\xi$ = 0.2·5.43·10^5= 1.1·10^5 g/cm^3.

The criterion of the inertial ignition is

$$\rho R = 1.1\cdot 10^5 \cdot 6.1\cdot 10^{-4} = 67 > 1 . \qquad (23\text{-}2)$$

One is in 67 times MORE than needed (67 > 1> 0.28) . 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 (23-2), one may be used in AB reactor (Fig.6) with an additional heating by electric charge.

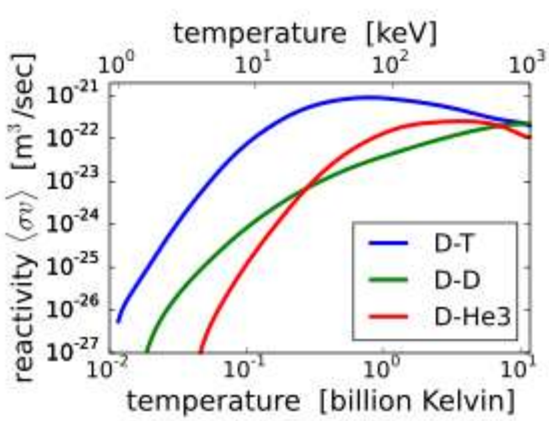

Fig.6. Reactivity is requested for thermonuclear reaction.

The ^3He is received in deuterium reaction may be used in next reactions:
D + $^3He \rightarrow {}^4He$ (3.6MeV) + p (14.7MeV);
^3He + $^3He \rightarrow {}^4He$ +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 (pellet) 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 $\xi = p/p_o = 1.44 \cdot 10^8/100 = 1.44 \cdot 10^6$. Liner size decreases by $(\xi)^{1/3}$ = 113 times. The radius of compressed fuel pellet will be R = 0.1/113 = $0.88 \cdot 10^{-3}$ cm. The initial density is

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

and inertial criterion is

$$\rho R = \rho_0 R_0 \xi^{2/3} = 10^{-2} 0.1 \cdot (1.44 \cdot 10^6)^{2/3} = 12.7 > 1. \quad (25\text{-}2)$$

Criterion is good for compressed fuel D+T, but it is small for fuel D+D. For fuel D+D we must decrease pressure in pellet up 400÷1000 atm or increase diameter (and power) our installation or use the additional heating of fuel by strong electric impulse.

Compressed micro-balloon (pellet) is more comfortable for working because it is unnecessary to store the 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:

$$n_1 = \frac{M}{\mu m_p} = \frac{10^{-6}}{2.5 \cdot 1.67 \cdot 10^{-27}} = 2.4 \cdot 10^{20} \quad (26\text{-}2)$$

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

$$E = 0.5\, n_1 E_1 = 0.5 \cdot 2.4 \cdot 10^{20} 17.6 \cdot 10^6 = 21.1 \cdot 10^{26}\ eV = 21.1 \cdot 10^{26} 1.6 \cdot 10^{-19} = 3.38 \cdot 10^8 \text{ J} \quad (27\text{-}2)$$

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 microcapsule fuel pellet (3.5 MeV from ^4He, $E = 6.72 \cdot 10^7$J) the most of energy (14.1 MeV from neutrons) will be produced into the big containment sphere.

Conventional coefficient of nuclear reactor efficiency is about 0.3÷ 0.5, the steam (gas) turbine is about 0.9.

2. *Energy is delivered by piston to fuel capsule* is $E = mV^2/2$. For m = 5 mg, piston speed $V = 2 \cdot 10^4$ m/s final piston energy is $E = 2 \cdot 10^3$ J. That is less then typical energy 20 ÷ 50 kJ delivered by laser installation. However, 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 20 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 in many times.

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

3. *Reaction of explosive* 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

$$n_n = \frac{M}{\mu m_p} = \frac{10^{-6}}{2.5 \cdot 1.67 \cdot 10^{-27}} = 2.4 \cdot 10^{20} \quad \frac{1}{m^3} \tag{28-2}$$

Full thermonuclear energy

$$E_n = 0.5 n_n E_1 = 0.5 \cdot 2.4 \cdot 10^{20} 17.6 \cdot 10^6 = 21.1 \cdot 10^{26} \text{ eV} = 3.38 \cdot 10^8 \text{ J} \tag{29-2}$$

Number of air particles with air density ρ = 1.225 kg/m^3 in pressure p = 1 atm is

$$n_o = \frac{M}{\mu m_p} = \frac{1.225}{28 \cdot 1.67 \cdot 10^{-27}} = 2.6 \cdot 10^{25} \quad \frac{1}{m^3}. \tag{30-2}$$

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

$$p = \frac{\eta E_n}{v} = \frac{0.3 \cdot 3.38 \cdot 10^8}{1} = 1 \cdot 10^8 \approx 10^8 \ \frac{\text{N}}{\text{m}^2} = 1000 \, \text{atm} \tag{31-2}$$

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

$$T = \frac{p}{(n_0 + n_n)k} = \frac{10^8}{(2.6 \cdot 10^{25} + 2.4 \cdot 10^{20}) \cdot 1.38 \cdot 10^{-23}} = 279 \cdot 10^3 \text{ K} \tag{32-2}$$

If we increase the initial pressure into reactor body up 100 atm, that the temperature desreases to 2790K. The same temperature is in a combustion chamber of conventional engine of the internal combustion. We can use the conventional cooling system.

The same method may be used for estimation of injection water into instellation body or any garbige material in a space ship (or asteroid).

5. *Thickness of sphere cover*. Assume the spherical cover is made from conventional steel having safety tensile stress σ = 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 γ = 1500 ÷ 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 neutrons 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^{o}C = 672 K. The critical point of water (triple point) is T = 273^{o}C, p = 22 MPa.

Heating 1 kg water from 20^{o}C to 100^{o}C requests energy $E = C_p \Delta T$ = 4.19$\cdot$80 = 333 kJ, evaporation – r = 2260 kJ, heating of steam up 400^{o}C - $E = C_p \Delta T$ = 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 η = 1 equals $M_w = E/E_w$ =

$3.4 \cdot 10^8/2.9 \cdot 10^6$ = 117 kg. For η = 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 [10] gives the following equation for running the protons and charged heavy particles inside gas at pressure 1 atm

$$R_x(E) = \frac{m_x}{m_p} R_p\left(\frac{m_p}{m_x} E\right) , \quad (33\text{-}2)$$

Where R_x is run of 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 6:

Table 6. 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

$$R_x(E) = \frac{m_x}{m_p} R_p\left(\frac{m_p}{m_x} E\right)/p \approx \frac{4}{1} R_p\left(\frac{1}{4} 1 \cdot 3.5\right)/10^8 \approx 4 \cdot 10/10^8 = 4 \cdot 10^{-7}\ cm \approx 4 \cdot 10^{-6} \text{ mm} \quad (34\text{-}2)$$

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 of Environment.

8.*Converting the nuclear energy of Cumulative AB 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. Impulse work of reactor allows to cool the reactor by 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

$$\text{From} \quad E = \frac{mV^2}{2} \quad \text{we get} \quad V = \left(\frac{2E}{m}\right)^{1/2} = \left(\frac{2 \cdot 10^8}{5 \cdot 10^{-3}}\right)^{1/2} = 4 \cdot 10^5 \ \frac{\text{m}}{\text{s}} . \quad (35\text{-}2)$$

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

Received speed V = 400 km/s is in many times more than a current exhaust chemical speed 3 km/s. If of space apparatus has mass m_2 = 1 tonn, the ship speed changes in V_2 = (m/m$_2$) V_1 = 2 m/s in one impulse. If we spend 10 kg of fuel cartriges, the apparatus get speed 10 km/s.

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 (35-2) and Law of equal impulse we have from every impulse

$$V_1 = (2Em_1)^{1/2}/m_2 = (2\cdot 10^8\cdot 16)^{1/2}/10^3 = 56.6 \quad m/s \quad . \qquad (36\text{-}2)$$

Here V_1 is add speed m_1 mass jet kg, m_1 = 16 kg of water; m$_2$ is mass of space apparatus.

9. *Estimation of the neutron penetration*

$$l = 1/n\sigma, \qquad (37\text{-}2)$$

Where l is path of penetration, cm; n is density of material, 1/cm^3; $\sigma = 10^{-24}$ cm^2 is cross section of the nuclear. For steel l = 12 cm, for compressed air up 100 atm the l = 410 cm.

10. *Requested thickness of the spherical shell* is

$$\frac{D}{d} = \left(\frac{p}{\sigma} + 1\right)^{0.5} , \qquad (38\text{-}2)$$

Where D is outer diameter of spherical shell, d is inner diameter of spherical shell, p is pressure, atm; σ is safety tensail stress kg/cm^2. Exemple, if p = 10 kg/mm^2, σ = 50 kg/mm^2, then D/d ≈ 1.1.

Detail Estimation of Cumulative and Impulse reactors for transportation engine

1. **Estimation of nuclear energy (power).** Let us make more detail estimation the Cumulative and Impulse reactors for engine of transport vinicle having the fuel pellet 0.1 mg ($M_f = 10^{-7}$ kg) with fuel D+T or D+D. The Impulse reactor has pressure into pellet 300 atm.

Estimation of energy (power) this D+T pellet if the coefficient efficiency is $\eta = 0.5$.
The couple nuclei T+D produses nuclear energy E_1 = 17.6 MeV
Number N_f of nucleis in pellet is:

$$N = \frac{M_f}{\mu m_p} = \frac{10^{-7}}{2.5\cdot 1.67\cdot 10^{-27}} = 2.4\cdot 10^{19} .$$

Here μ is averege moliar mass of D+T; m_p is mass of proton, kg.

The nucler energy of 1 mg D+T fuel in 1 Hz is

$$E = 0.5E_1 N\eta = 0.5\cdot 17.6\cdot 10^6\cdot 1.6\cdot 10^{-19} 2.4\cdot 10^{19}\cdot 0.5 = 16.9\cdot 10^6 \approx 17\, MJ/Hz .$$

That is power energy of the 2-5 power aviation turbo-engines. If one cycle in second (1 Hz) is not enough, we can decrease the friquency. The piston engine has up 50-70 revolution per second, the high speed aviation gun up 30 shots in second.

If we use the D+D fuel having single energy E_1 = 3.65 MeV , μ = 2, the nucler energy is aproximetely in 5 times less because E_1 is less.

2. **Size of cartridge and pellet**. Let us estimate the size of the cumulative cartrige for mass the explosive TNT M_e = 1 gram ($M_e = 10^{-3}$ kg, energy E_e = 4.2 NJ, density ρ = 1650 kg/m^3) and internel diameter cartridge is d = 10 mm. The thickness δ of explosive is:

$$\delta \approx \frac{M_e}{4\pi r^2 \rho} = \frac{1}{4\cdot 3.14\cdot 0.5^2\cdot 1.65} = 0.2\, cm$$

Outer diameter of cartidge for safety tensile stress 100 kg/mm^2 is D = 16 mm.

Let us estimate the compressed **pellet** having gas mass M = 10^{-7} kg, pressure p = 300 atm =3·10^7 N/m^2 and T = 300 K. Specific denfity the gas D+D, D+T in compession p = 1 atm is ρ_o = 0.1 kg/m^3,atm. The internel radius of gas pellet is:

$$r=\left(\frac{3M}{4\pi p\rho_0}\right)^{1/3}=\left(\frac{3\cdot 10^{-7}}{4\cdot 3.14\cdot 3\cdot 10^2 0.1}\right)^{1/3}\approx 0.926\cdot 10^{-3}m\approx 1\,mm$$

The reletive outer diameter of pellet for pressure p = 3 kg/mm^2 and the safety tensile stress of the pellet cover σ = 50 kg/mm^2 with according (38-2) is

$$\frac{D}{d}=\left(\frac{p}{\sigma}+1\right)^{0.5}=\left(\frac{3}{50}+1\right)^{1/2}=1.03 .$$

Nuclear prosses in to pellet. After cumulative explosive into cartridge the density of fuel D+T into pellet after cumulative compressing is

$$n=\frac{3p}{\mu m_p V_p^2}=\frac{3\cdot 1.36\cdot 10^{13}}{2.5\cdot 1.67\cdot 10^{-27}(18\cdot 10^3)^2}=3\cdot 10^{25}cm^{-3} ,$$

Where p is pressure after cumulative compressing, N/m^2, V_p is final speed of piston, m/s , m_p is mass of proton, kg. Density of D+D fuel is n = 3.75·10^{25} cm^{-3}.
Time of fuel combustion for T = 15 keV is

$$\text{For D+T}\quad t=\frac{0.5\eta E_1}{5.6\cdot 10^{-13}n<\sigma v>}=\frac{0.5\cdot 0.5\cdot 2.82\cdot 10^{-12}}{5.6\cdot 10^{-13}3\cdot 10^{25}2.65\cdot 10^{-16}}=1.58\cdot 10^{-10}\ s,$$

$$\text{For D+D}\quad t=\frac{0.5\eta E_1}{3.3\cdot 10^{-13}n<\sigma v>}=\frac{0.5\cdot 0.5\cdot 0.58\cdot 10^{-12}}{5.6\cdot 10^{-13}3.75\cdot 10^{25}3.2\cdot 10^{-18}}=3.7\cdot 10^{-9}\ s,$$

Where η is coefficient efficiency, E_1 is energy couple nucleis (for D+T E_1 = 17.6MeV·1.6·10^{-19}= 2·82.10^{-12} J; for D+D E_1=3.65MeV= 0.58·10^{-12} J). Here we used Eq. (8-1) and Table 5.

For primery compressed gas fuel pellet p = 300 atm without cumulative compressing, the density of the fuel gas into pellet for T = 300K is

$$n=\frac{p}{kT}=\frac{3\cdot 10^7}{1.38\cdot 10^{-23}300}=2.25\cdot 10^{21}cm^{-3} ,$$

Where k = 1.38·10^{-23} - is Bolzman constant.

The time of nucler fuel combustion for T = 15 keV is

$$\text{For D+T}\quad t=\frac{0.5\eta E_1}{5.6\cdot 10^{-13}n<\sigma v>}=\frac{0.5\cdot 0.5\cdot 2.82\cdot 10^{-12}}{5.6\cdot 10^{-13}2.25\cdot 10^{21}2.65\cdot 10^{-16}}=2.1\cdot 10^{-6}\ s,$$

$$\text{For D+D}\quad t=\frac{0.5\eta E_1}{3.3\cdot 10^{-13}n<\sigma v>}=\frac{0.5\cdot 0.5\cdot 0.58\cdot 10^{-12}}{5.6\cdot 10^{-13}2.25\cdot 10^{21}3.2\cdot 10^{-18}}=6.14\cdot 10^{-5}\ s,$$

As you see, the combustion time significently is increased but it is enough for reaction. We can decrease it if we increases density of fuel.

Estimation of electric condenser. For heating of fuel we use the short strong electric impulse. For impulse the electric conderser may be used. Let us to estimate the condenser parameters for getting the fuel temperature T = 15 keV.

If fuel mass is M = 1 mg = 10^{-7} kg, the number of nucleis for D+T is

$$N=\frac{M}{\mu m_p}=\frac{10^{-7}}{2.5\cdot 1.67\cdot 10^{-27}}=2.4\cdot 10^{19} .$$

For D+D the N = 3.10^{19}.

The energy is needed for heating the fuel D+T up T = 15 keV is

$$W = NT \cdot 1.6 \cdot 10^{-19} = 2.4 \cdot 10^{19} 15 \cdot 10^{3} 1.6 \cdot 10^{-19} \approx 60\, kJ \ .$$

For heating D+D fuel is W = 72 kJ.
The minimal specific weight of conventional conductor according [7] p. 368 is γ = 2 kJ/kg. Consequently, the requeted mass of condenser is about 30 – 36 kg. But if we can use the advanced supercapacitor (γ = 10 kJ/kg) or ultracapacitor (γ = 20 kJ/kg) or capacitor EEStor, having claimed capasity γ = 1000 kJ/kg, we can decreased the capacitor mass. In any case, the capacitor mass is small part of themonuclear engine.

Estimation of capacitor descharge.

a) Need condenser *after cumulative compressing* of pellet for heating fuel up T = 15 keV.

Assume the initial temperature of cumulative compresed gas fuel is T = 3.14 eV, mass of fuel $M = 10^{-7}$ kg, initial pressure p = 300 atm, initial diameter of pellet d = 0.2 cm..

The specific electric Spitzer resistance of plasma is

$$\rho = \eta_{\perp} = 1{,}03 \cdot 10^{-2} Z \ln \Lambda \cdot T^{-3/2} .$$

Where Z is rate of charge, lnΛ = (5÷15) is Columbus logariphm. For lnΛ = 10 we have

$$\rho = 1.03 \cdot 10^{-2} 1 \cdot 10 / 3.14^{3/2} = 1.85 \cdot 10^{-3}\ \Omega \cdot cm .$$

Diameter of the cumulative compressed pellet having initial gas pressure p_o = 300 atm and l_o = 0.2 cm is

$$l = l_0 \left(\frac{p_0}{p} \right)^{1/3} = 0.2 \left(\frac{300}{3.24 \cdot 10^7} \right)^{1/3} = 4.2 \cdot 10^{-3}\ cm, \quad s = \frac{3.14}{4} l^2 = 1.4 \cdot 10^{-5}\ cm^2$$

Electric resistance is

$$R = \rho \frac{l}{s} = 1.85 \cdot 10^{-3} \frac{4.2 \cdot 10^{-3}}{1.4 \cdot 10^{-5}} = 0.555\ \Omega \cdot cm \ .$$

Where l is diameter of pellet, cm; s is cross-section area, sm^2.

Needed inisial voltage and currency of condenser for time of recharde $t = 10^{-5}$ second is

$$U = \left(\frac{RW}{t} \right)^{1/2} = \left(\frac{0.555 \cdot 6 \cdot 10^4}{10^{-5}} \right)^{1/2} = 57.7\, kV, \quad I = \left(\frac{W}{Rt} \right)^{1/2} = \left(\frac{6 \cdot 10^4}{0.555 \cdot 10^{-5}} \right)^{1/2} = 104\, kA .$$

Capasity of condenser

$$C = \frac{t}{R} = \frac{10^{-5}}{0.555} = 18 \cdot 10^{-6}\ \ F \ .$$

. b) Need condenser *without* cumulative compressing of pellet. Initial data: Initial temperature is T = 0.1eV, mass of fuel $M = 10^{-7}$ kg, pressire p = 300 atm, diameter of pellet d = 0.2 cm, final temperture T = 15 keV.

$$\rho = 1.03 \cdot 10^{-2} 1 \cdot 10 / 0.1^{3/2} = 3.16\ \ \Omega \cdot cm .$$

Cross-section area of the pellet having fuel gas pressure p_o = 300 atm and diameter of pellet $d_o = l_o$ = 0.2 cm is

$$s = \pi d_0^2 / 4 = 0.0314 cm^2 \ .$$

Electric resistance is

$$R = \rho \frac{l_0}{s} = 3.16 \frac{0.2}{0.0314} = 20\ \ \Omega \cdot cm \ .$$

Where l is diameter of pellet, cm; s is cross-section area, sm^2.

Needed initial voltage and currency of condenser for time of recharde $t = 10^{-5}$ second is

$$U = \left(\frac{RW}{t}\right)^{1/2} = \left(\frac{20\cdot 6\cdot 10^4}{10^{-5}}\right)^{1/2} = 346\,kV, \quad I = \left(\frac{W}{Rt}\right)^{1/2} = \left(\frac{6\cdot 10^4}{20\cdot 10^{-5}}\right)^{1/2} = 54.8\,kA.$$

Capasity of condenser

$$C = \frac{t}{R} = \frac{10^{-5}}{20} = 7\cdot 10^{-7}\ F.$$

The specific energy weight γ_c [J/kg] of the condenser my be estimate by formules

$$\gamma_c = \frac{\varepsilon_0 \varepsilon E_q^2}{\gamma}.$$

Where $\varepsilon_o = 8.85 \cdot 10^{-12}$ F/m is electric constant; $\varepsilon \approx 3$ dielectric constant; $E_q \approx 160 \div 640$ MV/m is safety electric stress of isolator; $\gamma \approx 1000 \div 3000$ kg/m^3 is spesific weight of isolator.

Initial magnetic pressure from charged currency is

a) Pellet having cumulative compressing has initial currency I = 104 kA, radous of pellet after compressing $r = 2.1 \cdot 10^{-5}$ m has magnetic intensity H and magnetic pressure p:

$$H = \frac{I}{2\pi r} = \frac{104\cdot 10^3}{2\cdot 3.14\cdot 2.1\cdot 10^{-5}} = 7.9\cdot 10^8\ \frac{A}{m},$$

$$p = \frac{\mu_0 H^2}{2} = \frac{4\pi\cdot 10^{-7}(7.9\cdot 10^8)^2}{2} = 4\cdot 10^{11}\ \frac{N}{m^2} = 4\cdot 10^6\ atm.$$

That is closed to piston pressure $3.4 \cdot 10^7$ atm.

b) Without cumulative pressure $H = 0.87.10^7$ A/m and p = 477 atm.

Cost of the nuclear fuel.

Deuterium. The sea water contains about $1.55 \cdot 10^{-4}$ %.The World produces about tens thousend tons in year. Cost 1 $/g.

Tritium. The special nuclear reactors can produced it. Now the cost is 30,000 $/g. In future an expected cost will be from 100K÷200K $/g.

Helium-3. Very rare isotop. The Helium-4 contains $1.3 \cdot 10^{-6}$/1 of the Helium-3. Cost is 30K $/g. One project offers to extract it on Moon and delivery to Earth.

Litium 6 -7. Nature mixture cost 150 $/kg.

Uranium-238 contains 0.7% of Uranium-235. It cost 90÷250 $/kg.

Plutonium-239. Cost 5600 $/g.

As you see the thermonucler fuel D+D is the cheapest, but D+T has the lowest temperature for themonucler reaction. All the current experimental thermonuclear instellations are using the D+T.

Table 7. Properties of some material suitable for the offer instellation**.**

Material	Tensile strength kg/mm^2	Density g/cm^3	Fibers	Tensile strength kg/mm^2	Density g/cm^3
Steel A514	76	7.8	S-Glass	471	2.48
Aluminum alloy	45.5	2.7	Basalt fiber	484	2.7
Titanium alloy	90	4.51	Carbon fiber	565	1,75
Steel Piano wire	220-248	7.8	Carbon nanotubes	6200	1.34

Issue: [7] p.370.

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 pressure, time and temperature 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 an industriel or tranport engine 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 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 20 km/s and more), That increases the kinetic energy the piston in hundreds 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 impotent innovatins are the compressed gas pellets at room temperature and electric impulse for heating of pellet up the themonuclear temperatures. The current ICF uses the frizen fuel about absolute zero. That is not acceptable for practice. Author also suggested the transport nuclear engine and nuclear rocket.

The method possible allows to use reaction D+D (instead D+T) with cheap nuclear fuel D (Tritium is very expensive – about 30,000 USD per 1 g, deiterium costs 1 $/g). One also allows using the compressed fuel-gas at room temperature.

The cumulative method also may 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 and impulse inertial thermonuclear reactors, which increases the pressure and temperature of a nuclear fuel in thousands times, reaches the ignition and full thermonuclear reaction. Cumulative and Impulse AB Reactor, herein offered by its originator, contains several innovations and inventions.

Main of them is using a moved explosive, which allows to accelerate the special piston to very high speed (more than 20 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 second main innovation is the additional heating the fuel pellet by electric impulse to up temperature in 15keV and more (hundreds millions of degrees). Important innovtion is compressed pellet at room temperature, instellation for electric and mechanical energy and thermonuclear rocket.

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]-[9].

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References

(Reader can find part of these articles in WEBs: https://archive.org/details/List5OfBolonkinPublications,http://Bolonkin.narod.ru/p65.htm, http://arxiv.org/find/all/1/au:+Bolonkin/0/1/0/all/0/1, http://vixra.org).

[1] Bolonkin, A.A., "Inexpensive Mini Thermonuclear Reactor". International Journal of Advanced Engineering Applications, Vol.1, Iss.6, pp.62-77 (2012) . http://viXra.org/abs/1305.0046 http://archive.org/details/InexpensiveMiniThermonuclearReactor,

[2] Bolonkin A.A. , Cumulative Thermonuclear AB-Reactor.. Vixra 7 8 2015, http://viXra.org/abs/1507.0053 https://archive.org/details/ArticleCumulativeReactorFinalAfterCathAndOlga7716

[3] Bolonkin A.A., Ultra-Cold Thermonuclear Synthesis: Criterion of Cold Fusion. 7 18 2015. http://viXra.org/abs/1507.0158, GSJornal: http://gsjournal.net/Science-Journals/%7B$cat_name%7D/View/6140

[4] Bolonkin, A.A., "Non Rocket Space Launch and Flight". Elsevier, 2005. 488 pgs. ISBN-13: 978-0-08044-731-5, ISBN-10: 0-080-44731-7 . http://vixra.org/abs/1504.0011 v4,

[5] Bolonkin, A.A., "New Concepts, Ideas, Innovations in Aerospace, Technology and the Human Sciences", NOVA, 2006, 510 pgs. ISBN-13: 978-1-60021-787-6. http://viXra.org/abs/1309.0193,

[6] Bolonkin, A.A., Femtotechnologies and Revolutionary Projects. Lambert, USA, 2011. 538 p. 16 Mb. ISBN:978-3-8473-0839-0.http://viXra.org/abs/1309.0191,

[7] Bolonkin, A.A., Innovations and New Technologies (v2).Lulu, 2014. 465 pgs. 10.5 Mb, ISBN: 978-1-312-62280-7. https://archive.org/details/Book5InnovationsAndNewTechnologiesv2102014/

[8] Bolonkin, A.A., Stability and Production Super-Strong AB Matter. International Journal of Advanced Engineering Applications. 3-1-3, February 2014, pp.18-33. http://fragrancejournals.com/wp-content/uploads/2013/03/IJAEA-3-1-3.pdf The General Science Journal, November, 2013, #5244.

[9] Bolonkin, A.A., Converting of Any Matter to Nuclear Energy by AB-Generator. American Journal of Engineering and Applied Science, Vol. 2, #4, 2009, pp.683-693. http://viXra.org/abs/1309.0200,

[10] Kikoin I.K., Tables of Physical Values, Moscow, Atomizdat, 1975 (Russian).

[11] AIP, Physics Desk Reference, 3-rd Edition. Springer, AIP PRESS.

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Short biography of Bolonkin, Alexander Alexandrovich

Alexander A. Bolonkin was born in the former USSR. He holds doctoral degree in aviation engineering from Moscow Aviation Institute and a post-doctoral degree in aerospace engineering from Leningrad Polytechnic University. He has held the positions of senior engineer in the Antonov Aircraft Design Company and Chairman of the Reliability Department in the Clushko Rocket Design Company. He has also lectured at the Moscow Aviation Universities. Following his arrival in the United States in 1988, he lectured at the New Jersey Institute of Technology and worked as a Senior Scientist at NASA and the US Air Force Research Laboratories.

Bolonkin is the author of more than 250 scientific articles and books and has 17 inventions to his credit. His most notable books include The Development of Soviet Rocket Engines (Delphic Ass., Inc., Washington , 1991); Non-Rocket Space Launch and Flight (Elsevier, 2006); New Concepts, Ideas, Innovation in Aerospace, Technology and Human Life (USA, NOVA, 2007); Macro-Projects: Environment and Technology (NOVA, 2008); Human Immortality and Electronic Civilization, 3-rd Edition, (Lulu, 2007; Publish America, 2010): Life and Science. Lambert Academic Publishing, Germany, 2011, 205 pgs. ISBN: 978-3-8473-0839-3. http://www.archive.org/details/Life.Science.Future.biographyNotesResearchesAndInnovations; New Methods of Optimization and their Application, Moscow High Technical University named Bauman (in Russian: Новые методы оптимизации и их применение. МВТУ им. Баумана, 1972г., 220 стр). http://vixra.org/abs/1504.0011 v4.

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