Small, Non-Expensive Electric Impulse Thermonuclear Reactor with Collising Jets

Alexander Bolonkin
C&R, abolonkin@gmail.com

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 the new, small cheap electric cumulative thermonuclear reactors, which increases the temperature and pressure of its nuclear fuel by millions of times, reaches the required ignition stage and, ultimately, constant contained thermonuclear reaction. Electric Cumulative AB Reactors contain several innovations to achieve its product.

Chief among them in electric thermonuclear reactors are using electric voltage 50 ÷ 1000 kV (an electric condenser discharge), which allows to heat the compressed fuel in special pellet by electric impulse up hundreds millions degrees of temperature.

In electric cumulative vertion of AB thermonuclear reactors the fuel nucleus are heated by high electric voltage (50 ÷ 1000 kV) up the hundreds millions degree and cumulative compressed into center of the special cylindrical fuel cartridge. The additional compressing and combustion time the fuel nucleus may have from electric pinch-effect and heavy nucleus of the fuel cartridge cover. The main advantages of the offered method are very small electric fuel cartridge (11-18 mm) and small of the full reactor installation (reactor has the spherical diameter 0.3 - 3 m), using the many thermonuclear fuels at room temperature and possibility of using the offered thermonuclear reactor for transportation (ships, trains, aircrafts, rockets, etc.). Author gives theory and estimations of the suggested reactors.

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

Offered small micro-reactors may be used as heaves (ignition, fusee) for small artillery nuclear projectiles and bombs.

Keywords: *Micro-thermonuclear reactor, Impulse electric thermonuclear reactor, Impulse thermonuclear reactor, transportation thermonuclear 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, for example NOVA - laser driver) and magnetic confinement fusion (MCF)--for example, tokomak device. However, tritium is very expensive.

Data of some current inertial laser installations:

1. NOVA uses laser NIF (USA), has 192 beams, impulse energy up 120 kJ. One reach fuel 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 research author offers the new cheap thermonuclear reactors and fusees for nuclear projectales. In early different versions of this method was described in [1] – [5]. Below are cheaper and simpler reactors.

Description and Innovations of Electric 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. The laser has very low efficiency (2-3%), high-pressure acts every shot time (10^{-9}– 10^{-10} s), enough energy not delivered to the center of the spherical fuel pellet (low temperature), there are many future problems the radioactivity and converting the thermonuclear energy into useful energy.

Electric impulse method. Early author offered five the new methods (reflex, cumulative, impulse, ultra-cold, electric)[1 ÷ 5], 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 a version of the electric impulse improved reactor. Detailed consideration of advantages the new methods and computation proofs are in next paragraphs.

Outline of the new electric impulse reactors and method.

The improved version of the electric impulse AB thermonuclear reactor is presented in figures 1 – 3.

The new thermonuclear reactor contains: 1) Small cilindrical thermonuclear cartridge (cylindrical fuel ampule (granule, beat, pellet) having two cameres, Fig.1). For fuel mass $M = 10^{-7}$ kg, the internel diameter is about 1 mm, the camera length is about 1 mm; pressure of gas fuel is up 200 ÷1000 atm);

2) The thermonuclear reactor (sphere diameter is 0.3 – 3 m. Fig.2). Reactor has two Version 1 - 2. In Version 1 the reactor has the additional installations for converting the nuclear energy into an electric, mechanical energy, in Version 2 the reactor converts the thermonuclear energy in a rocket thrust (fig. 3).

The fuel cartridge has (fig.1): the strong cylindrical shell from non-conductive heavy matter (A ≈ 200); left fuel camera 1, right fuel camera 2, thermonuclear fuel in left camera 3, themonuclear fuel in right camera 4 (one may be different from left camera), power electric condenser 5 (50÷150 kJ, voltage 100 ÷1000 kV), negative electric contact 6, two positive electric contacts 7, thin electric conductivity partition 8 delete the left and right fuel cameras. Partition is burned by electric impulse.

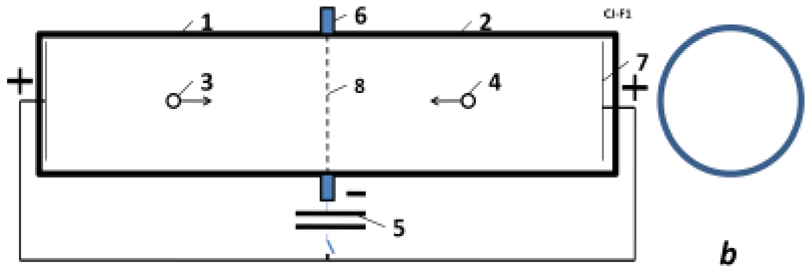


Fig.1. Principal schema of the fuel cartrige. *Notation:* ***a*** – side view; ***b*** – forward view. 1- left fuel camera, 2 - right fuel camera, 3 – thermonuclear fuel in left camera, 4 – themonuclear fuel in right camera (one may be different from left camera), 5 – power electric condenser (50÷150 kJ, voltage 100 ÷1000 kV), 6 – negative electric contact, 7 –two positive electric contacts, 8 – thin elastic electric conductivity partition.

Body of nuclear reactor is shown in Fig.2. One contains: strong spherical body (shell) of reactor 1 (diameter about 0.3 – 3 m); the fuel cartridge 2 (It is described in Fig.1); holder (electric conductor) 3 of fuel cartridge; enter of compressed air (gas) 4; exit of a hot compressed air (gas) after thermonuclear heating 5; electric voltage from condenser 6.

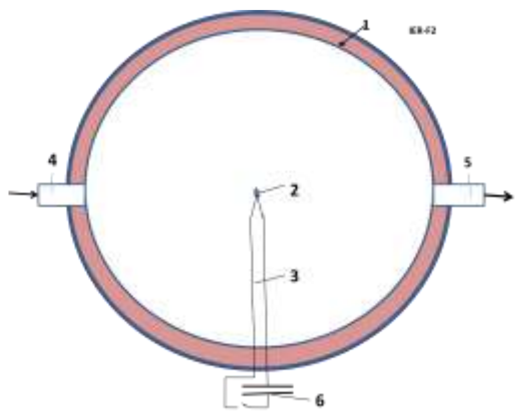


Fig. 2. AB thermonuclear electric impulse reactor. *Notations*: 1 - strong spherical body (shell) of reactor (diameter about 0.3 – 3 m); 2 - the fuel cartridge (it is described in Fig.1); 3 - holder of fuel cartridge; 4 – enter of compressed air (gas); 5 – exit of a hot compressed air (gas) after thermonuclear heating; 6 – electric conductor.

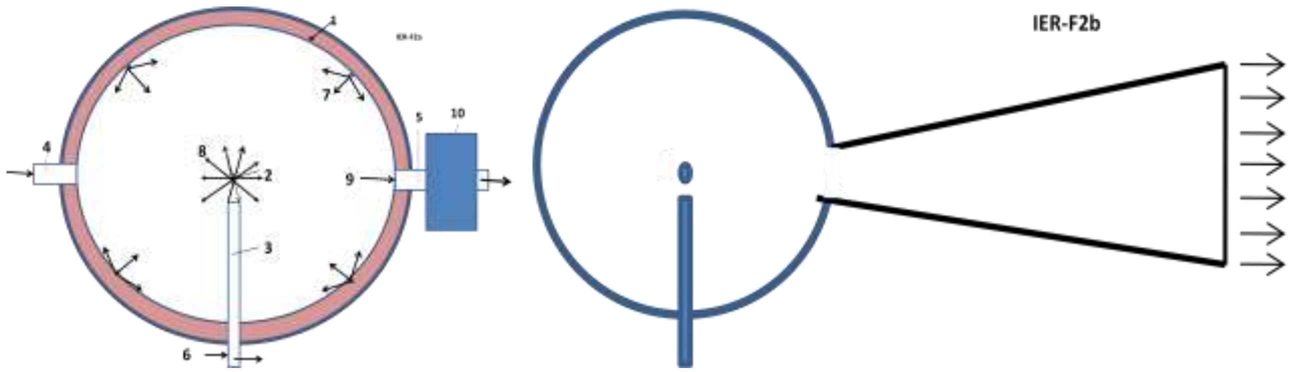
The offered thermonuclear reactor works the next way (Figs. 1 – 3):

1) Version 1 for an electric or mechanic energy.

The internal volume of reactor body is filled the atmospheric or compression air (enter 4 of Fig.2).

The fuel cartridge (Fig.1) lifts by holder 3 (Fig.2) into reactor body. Turn on the charged (up 50 -500 kV) electric condenser 6 (Fig 2). The electrons from the contacts 6-7 (Fig.1) are ionised the fuel molecules (fig.1) into the left and right cameras. In particule, they positive ionize and dissociate the fuel molecules (for example, D and T are contained into cameras 3 – 4 of catrige). The positive ionized nucleus of the thermonuclear fuel (having small mass) are quick collectively accelerated up very high temperature (up 50 – 500 keV) and collide the collectively mooving nucleus of opposed camera. Partition 8 is burned. The high electric currency produses the strong pinch effect, delete the charged particles from the pellet walls and compress the thermonuclear fuel. The cover from heavy molecules (mass $A \approx 200$) reflect the light ($A \approx 2 \div 3$) fuel nucleus and increase the fusion (reaction) time of the fuel nucleus. In results (as show computation) the fuel nucleus merge and produce a thermonuclear reaction. The thermonuclear reaction (explosive) heats the air into reactor body. For increasing the efficiency, work mass, decreasing explosive temperature and protection from neutrons, the liquid 7 (for example, water, fig.3a) may be injected into reactor.

After thermonuclear explosion the hot gas flow out into the magneto-hydrodynamic generator (MHG) 10 and produces electric energy or runs to the gas, steam turbine and produces an useful work (Fig. 3a). Or the hot compressed gas runs to rocket nozzle and produces the rocket trust (fig. 3b).



a *b*

Fig.3. Final (industrial) work of Impulse Electric 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. 3a). ***b***) Hot compressed gas runs to rocket nozzle and produces the rocket trust. *Notation*: 1 – 6 are same Fig.2; 7 – injection the cooling liquid (for example, water)(option); 8 – thermonuclear explosive of fuel pellet; 10 – MHG or gas (steam) turbine; 11 - exit of hot gas.

The main difference the offered electric reactor from the published cumulative reactors [2, 5] is type of explosive for getting the temperature, pressure and cumulative effect in fuel. On [1 - 2] author used the chemical explosive. The offered reactor uses the strong electric field for acceleration, getting high temperature and cumulative effect. The electric method leads to practically unlimited cheap power. In [2, 4] the explosive is located into main spherical body 1 (fig.1) (or gun in [2]). In [4] version 1 (fig.2, [4]) the explosive 3 is small and located in the special fuel cartridge (fig.2, [4]). In current version (and [5]) no special compression explosive. The pressure and high temperature of the fuel are reached the high voltage condenser. It is easier and it is more comfortable in using.

The version [5] and current cartridge the fuel pullet is filling by the compressed gas fuel (up 200÷600 atmosphere or more) has not the explosive for an additional compressing of fuel. The fuel is compressed primery and heating only by strong electric charge of a condenser. The computation shows that is possible. We can also use the conventional pellet with frozen fuel.

AB Reactors are cooled using well-known methods between explosives or by an injection of water into sphere (fig. 3a).

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

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

1. The high voltage electric condenser allows reaching the needed thermonuclear temperature.
2. Cumulative, Impulse Electric AB-reactors are cheaper by thousands of time because they do not have the gigantic very expensive laser or magnetic installations (see [1]-[5]).
3. They more efficiency because the laser installation converts only 1 - 2.5% the electric energy into the light beam. In suggested AB reactors, the all underused energy remains in the spherical reactor and utilized in MHG or turbine. AB reactors cannot have coefficient *Q* (used energy) significantly less 1. Moreover, one has heat efficiency more than conventional heat engines because it has very high

temperature and 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 exhaust rocket gas) allows increasing the top speed of the exhaust mass up very high speed. This makes this method available for thermonuclear rockets.
5. Electric AB-reactors give temperature of the fuel much more than the current ICF laser installations.
6. The compression has longer time (up to $10^{-3} – 10^{-6}$ s) than a laser beam pressing ($10^{-9} – 10^{-12}$ s), because molar mass ($\mu \approx 200$) of heavy molecules (cover of cartridge in fig.1) is many times (50 ÷ 100) heavier than fuel molar mass ($\mu = 2 \div 3$).This pressure is supported by shock wave coming from moving gas and pinch effect. This pressure increases the temperature, compressing and probability of thermonuclear reaction.
7. The heavy mass of the cover of cartrige (fig.1) (having high nuclear numbers Z ≈ 80 and A ≈ 200) 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 is about some ton or less up 100 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 enough for using as fuel only the deuterium (or others) which is cheaper then tritium in thousands times (One gram of tritium costs about 30,000 US dollars. One gram of deuterium costs 1$) (see Estimations of a fuel cost).
11. The offered AB reactors have high limits in temperature. That allowes to use the fuels do not give the heutrons and gamma-radiation. These fuels are safety for humanity and installetions.
12. Offered reactor may be used for synteze elements.

Theory of the current Thermonuclear Reactors

1. The following reactions are suitable for thermonuclear fusion:

Table 1. Sutable reactions for thermonuclear fusion

#	Syntezis	Result (received Energy, MeV)	%
1	D+T→	^{4}He(3.5)+n(14.1)	
2a	D+D→	T(1.01)+p(3.02)	50%
2b	D+D→	^{3}He(0.82)+n(2.45)	50%
3	D+^{3}He→	^{4}He(3.06)+p(14.7)	
4	T+T→	^{4}He+2n(+11.3)	
5	^{3}He+^{3}He→	^{4}He+2p(+12.9)	
6a	^{3}He+T→	^{4}He+p+n(+12,1)	51%
6b	^{3}He+T→	^{4}He(4.8)+D(9.5)	43%
6c	^{3}He+T→	^{5}He(2.4)+p(+11.9)	6%
7	p+^{6}Li →	^{4}He(1.7)+^{3}He(2.3)	
8a	p+^{7}Li →	2^{4}He(17.3)	20%
8b	p+^{7}Li →	^{7}Be+n(1.6)	80%
9	D+^{6}Li→	2^{4}He(22.4)	
10	p+^{11}B→	3^{4}He(+8.7)	
11	n+^{6}Li→	^{4}He(2.1)+T(2.7)	
12	^{3}He+^{6}Li→	2^{4}He+p(+16.9)	

Here are: p = ^{1}H (protium), D = ^{2}H (deuterium), and T = ^{3}H (tritium) are shorthand notation for the main three isotopes of hydrogen. ^{4}He = ά –alpha particle.

Very important value is the cross section of thermonuclear reaction. The **nuclear cross section** of a nucleus is used to characterize the probability that a nuclear reaction will occur. The concept of a nuclear cross section can be quantified physically in terms of "characteristic area" where a larger area means a larger probability of interaction. The standard unit for measuring a nuclear cross section (denoted as σ) is the barn, which is equal to 10^{-28} m² or 10^{-24} cm². Nuclear cross section very strong depent from kinetic energy of particles. Typical thermonuclear cross section main fuel particles are shown in fig.4.

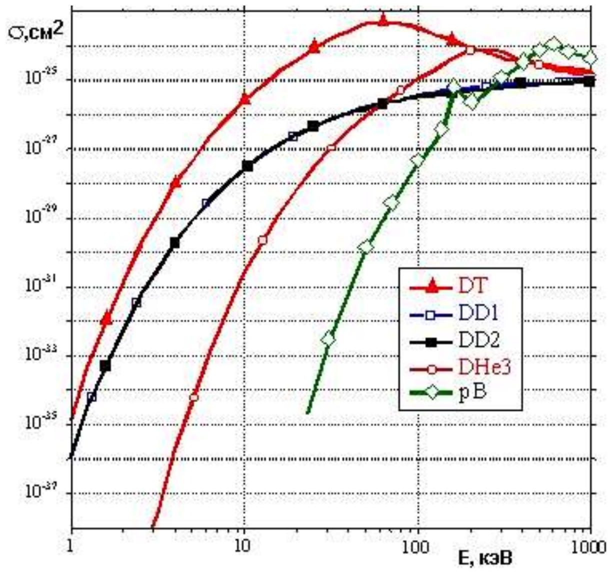


Fig.4. Thermonuclear cross section reation D+T, D+D (2a), D+D (2b), D+^{3}He, and p+B vs kinetis energy E [keV] of the light particles.

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.

Typical nuclear radii are of the order 10^{-14} m. Assuming spherical shape, we therefore expect the cross sections for nuclear reactions to be of the order of πr^2 or 10^{-28} m² (i.e. 1 barn). Observed cross sections

vary enormously - for example, slow neutrons absorbed by the (n,   ) reaction show a cross section much higher than 1,000 barns in some cases (boron-10, cadmium-113, and xenon-135), while the cross sections for transmutations by gamma-ray absorption are in the region of 0.001 barn.

The some cross sections and coppesponding energy are shown in Table 2. In Table 2 we use the shortly notation the nuclear reaction. For exemple D+T → ^{4}He + n as ^{2}H(t,n)^{4}He. If result has many products canales) we do not wright them.

Table 2. Cross section and correcponding energy of some thermonuclear reaction

Fig. #	Reaction	Reaction Energy MeV	Temperat. ≈10 kV and **σ**	Temperat. ≈10^2 kV and **σ**	Temperat. ≈10^3 kV and **σ**	Temperat. ≈10^4 kV and **σ**	Temperat. and **σ**=max

43-1(2)	^{2}H(d,n)^{3}H	4.033	10kV, σ=10^{-29}	10^{2}kV, σ=$1.1{\cdot}10^{-26}$	10^{3}kV, σ=$7{\cdot}10^{-26}$	10^{4}kV, σ=$7{\cdot}10^{-26}$	10^{3}kV, σ=$7{\cdot}10^{-26}$
43-1(7)	^{6}Li(p,ά)^{3}He	4.021	-	10^{2}kV, σ=$8{\cdot}10^{-27}$	10^{3}kV, σ=10^{-26}	10^{4}kV, σ=$2{\cdot}10^{-22}$	-
43-1(8)	^{6}Li(t,n)$^{\cdots}$	16	-	-	10^{3}kV, σ=$3{\cdot}10^{-25}$	-	-
43-1(3)	^{2}H(t,d)^{4}H	4.321	-	10^{2}kV, σ=$1.1{\cdot}10^{-26}$	10^{3}kV, σ=$7{\cdot}10^{-26}$	10^{4}kV, σ=$7{\cdot}10^{-26}$	10^{3}kV, σ=$7{\cdot}10^{-26}$
43-1(4)							
43-2(2)	^{3}H(d,n)^{4}He D+T→^{4}He+n	17,6	10kV, σ=$2{\cdot}10^{-27}$	10^{2}kV, σ=$5{\cdot}10^{-24}$	10^{3}kV, σ=$2{\cdot}10^{-25}$	10^{4}kV, σ=$6{\cdot}10^{-26}$	10^{2}kV, σ=$5{\cdot}10^{-24}$
43-2(1)	^{2}H(d,n)^{3}He	7.3	10^{1}kV, σ=$1.1{\cdot}10^{-29}$	10^{2}kV, σ=$5{\cdot}10^{-26}$	10^{3}kV, σ=$0.9{\cdot}10^{-25}$	10^{2}kV, σ=$0.8{\cdot}10^{-25}$	10^{2}kV, σ=$0.9{\cdot}10^{-25}$
43-2(4)	^{3}H(d,p)^{4}He	18.35	-	10^{2}kV, σ=$3{\cdot}10^{-27}$	10^{3}kV, σ=$3{\cdot}10^{-26}$	10^{4}kV, σ=$5{\cdot}10^{-27}$	$4{\cdot}10^{2}$kV, σ=$9{\cdot}10^{-26}$
43-2(5)	^{3}H(t,pn)^{4}He	12	-	10^{2}kV, σ=$7{\cdot}10^{-28}$	10^{3}kV, σ=$6{\cdot}10^{-26}$	-	-
43-2(6)	^{6}Li(d,p)^{7}Li	5.028	-	10^{2}kV, σ=$6{\cdot}10^{-28}$	10^{3}kV, σ=10^{-25}	-	-
43-3(4)	^{6}Li(d,ά)^{4}He	22.375	-	10^{2}kV, σ=$7{\cdot}10^{-28}$	$7{\cdot}10^{2}$kV, σ=$7{\cdot}10^{-26}$	-	-
43-4(6)	^{9}Be(p,ά)^{6}Li	2.126	-	$5{\cdot}10^{2}$kV, σ=$3{\cdot}10^{-26}$	$1.1{\cdot}10^{3}$kV, σ=$3{\cdot}10^{-25}$	-	-

Source: [12] pp. 947-950.

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:

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

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 3. 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 (7) and (12). The ^{3}He from reaction (7) can react with ^{6}Li in reaction

(12) before completely thermalizing. This produces an energetic proton which in turn undergoes reaction (7) 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 4. 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.

Below aresome equation useful for computation:

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

$$d_p = \frac{c}{\omega_{pe}} = 5.31\cdot 10^5 n_e^{-1/2} \quad . \text{[cm]} \qquad (1\text{-}1)$$

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 resistivity

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

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

8. Reaction rates $<\sigma v>$ (in cm^3 s^{-1}) averaged over Maxwellian 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 $<\sigma v>$ (in cm^{-3} s^{-1}) averaged over Maxwellian distributions

Tempera-ture, keV	D+D, (2a + 2b)	D+T , (1)	D+^{3}He, (3)	T+T, (4)	T+^{3}He, (6a-c)
1.0	1.5×10^{-22}	5.5×10^{-21}	10^{-26}	3.3×10^{-22}	10^{-28}
2.0	5.4×10^{-21}	2.6×10^{-19}	1.4×10^{-23}	7.1×10^{-21}	10^{-25}
5.0	1.8×10^{-19}	1.3×10^{-17}	6.7×10^{-21}	1.4×10^{-19}	2.1×10^{-22}
10.0	1.2×10^{-18}	1.1×10^{-16}	2.3×10^{-19}	7.2×10^{-19}	1.2×10^{-20}
20.0	5.2×10^{-18}	4.2×10^{-16}	3.8×10^{-18}	2.5×10^{-18}	2.6×10^{-19}
50.0	2.1×10^{-17}	8.7×10^{-16}	5.4×10^{-17}	8.7×10^{-18}	5.3×10^{-18}
100.0	4.5×10^{-17}	8.5×10^{-16}	1.6×10^{-16}	1.9×10^{-17}	7.7×10^{-17}
200.0	8.8×10^{-17}	6.3×10^{-16}	2.4×10^{-16}	4.2×10^{-17}	9.2×10^{-17}
500.0	1.8×10^{-16}	3.7×10^{-16}	2.3×10^{-16}	8.4×10^{-17}	2.9×10^{-16}
1000.0	2.2×10^{-16}	2.7×10^{-16}	1.8×10^{-16}	8.0×10^{-17}	5.2×10^{-16}

Sourse: AIP, Desk Reference, Thied Edition, p.644.

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

Estimation of Laser method (ICF).

For comparison the laser and offer Electric, 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 spherical 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/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

$$n_f = \frac{\gamma}{\mu m_p} = \frac{200}{2.5\cdot 1.67\cdot 10^{-27}} = 4.8\cdot 10^{28} \quad \frac{1}{m^3} \tag{6-2}$$

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:

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

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

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

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

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

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

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

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

$$\xi \approx 600. \tag{10-2}$$

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

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

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 some parameters the Electric Impulse AB reactor.

The proposed Electric Impulse AB Reactor accelerates the fuel 3-4 (fig.1) by a strong electric field (100÷1000 keV) and heats the fuel up 100÷1000 keV. The counter-flows and electric pinch-effect compresses and additional heats the fuel up to very high values, producing a nuclear reaction. Inlike [1 – 3] the cumulative explosionis produced not chemical explosive but a strong electric impulse.

Below is not mega-project. Instead, below, is the estimations of the typical parameters of electric impulse AB reactors.

1. Suitable thermonuclear reactions.

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 D+D may be used in AB reactors with an additional heating by electric field.

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>200 atm., radius 0.05 cm., temperature 300K. The mass fuel will be less 1 mg.

Compressed micro-balloon (pellet) is more comfortable for working because it is unnecessary to store the fuel at lower (frozen)) temperature.

2. Cumulative nucleus speed, temperature and pressure in the fuel cartridge afterelectrc impulse.

When we turn on the high voltage electric impulse, the power electron flows into pellet vaporize, ionize and dissociate the fuel.

The average ion (nuclear) temperature. The average voltage U = 15 kV, 100 kV of condenser is accelerated fuel ion in vacuum . The ion temperatureis

$$T = 15\cdot 10^3\cdot 1.18\cdot 10^4 = 177\cdot 10^6\ K, \quad T = 10^5\cdot 1.18\cdot 10^4 = 1.18\cdot 10^9\ K\,.$$

This temperature will have the fuel gas is filled the cartrige. The energy of ionization and dissociation is small (3 ÷ 15 eV) in comparison with energy from acceleration (15 ÷ 100) keV. We can neglect it. The full ionized ions are moving as one whole.That means no gas resistance for fuel ion acceleration (electron mass is only 1/1836 of mass proton) . Any atom in internal space of cartridge will be ionized and accelerated in two counter-flow direction.

The average speed of ionsand ion and electrons for U = 15 kV is:

$$V_i = \sqrt{\frac{2eU}{\mu m_p}} = \sqrt{\frac{2\cdot 1.6\cdot 10^{-19} 15\cdot 10^3}{2.5\cdot 1{,}67\cdot 10^{-27}}} \approx 10^6\ \frac{m}{s}, \quad V_e = \sqrt{\frac{2eU}{\mu m_e}} = \sqrt{\frac{2\cdot 1.6\cdot 10^{-19} 15\cdot 10^3}{2.5\cdot 9.1\cdot 10^{-31}}} \approx 4.6\cdot 10^7\ \frac{m}{s} \quad ,(13=2)$$

Here e =1.6·10^{-19} is charge of ion, C; U is condenser voltage, V; μ is relative mass of molar fuel D+T; m_p= 1.67·10^{-27}is proton weight, kg, m_e= 9.1·10^{-31} is electron mass, kg.

The average time of ion and electron moving in distance L = 1 mm and speed V = 10^6 m/s are:

$$T_i = \frac{L}{V_i} = \frac{1\cdot 10^{-3}}{10^6} = 1\cdot 10^{-9}\ s, \quad T_e = \frac{L}{V_e} = \frac{1\cdot 10^{-3}}{4.6\cdot 10^7} = 2.17\cdot 10^{-11}\ s \quad , (14\text{-}2)$$

3.Maximal deviation of fuel ion from cartridge centeris

$$r_a = V_0 T_i = 1750\cdot 1\cdot 10^{-9} = 1.75\cdot 10^{-6}\ m\,, \qquad (15\text{-}2)$$

Where V_0 is speed of nucleon for temperature at 300 K.

4. Ion free path in the center of the cartridge

$$l = \frac{1}{\sqrt{2}\pi n_0 \sigma^2} = \frac{1}{\sqrt{2}\cdot 3.14\cdot 2.4\cdot 10^{25}(5\cdot 10^{12})^2} = 3.76\cdot 10^{-4}\ cm \quad . (16\text{-}2)$$

Here $n_o = N/v$ = 2.4·10^{19}/10^{-6}cm^{-3} is density of fuel ion in center of cartridge (v is volume 1 cm^3), σ is cross-section ion diameter, cm^2. Than means, the ions will collisions many times at center of the cartridge.

5. *Thermonuclear energy*. One/tenth mg (10^{-7} kg) of thermonuclear fuel D+T has energy:
Number of nucleus:

$$n_1 = \frac{M}{\mu m_p} = \frac{10^{-7}}{2.5\cdot 1.67\cdot 10^{-27}} = 2.4\cdot 10^{19} \qquad (17\text{-}2)$$

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

$$E = 0.5\ n_1 E_1 = 0.5\cdot 2.4\cdot 10^{19} 17.6\cdot 10^6 = 21.1\cdot 10^{25}\ eV = 21.1\cdot 10^{25} 1.6\cdot 10^{-19}\ J = 3.38\cdot 10^7\ \text{J} \qquad (18\text{-}2)$$

One pair of nuclear D+D produces energy E_1 = 3.64 MeV. The $n_1 = 3\cdot 10^{19}$ nuclear particles contain the energy

$$E = 0.5\ n_1 E_1 = 0.5\cdot 3\cdot 10^{19} 3.64\cdot 10^6 = 5.46\cdot 10^{25}\ eV = 5.46\cdot 10^{25} 1.6\cdot 10^{-19} \approx 8.74\cdot 10^6\ \text{J} \qquad (19\text{-}2)$$

If coefficient efficiency of the Electric Cumulative AB Reactor is η = 0.3, 0.1 mg of fuel T+D produces the energy 10 million joules, D+D produced 2.62 million joules. If we make one explosion per sec, installation has the power of 10 million watts (T+D). The part of this energy will be produced inside fuel microcapsule-fuel pellet (3.5 MeV from ^{4}He, $E = 6.76\cdot 10^6$ J) the most of energy (14.1 MeV from neutrons, $E = 2.7\cdot 10^7$ J) 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.

6. *Estimation of pressure and temperature after nuclear explosion in reactor (more precisely, inside reactor sphere).*

Let us to find the pressure and temperature after thermonuclear explosive the 0.1 mg fuel D+T into reactor having sphere 1 m^3 filled by air.

Number of nuclear particles in sphere 1 m^3 is

$$n_n = \frac{M}{\mu m_p} = \frac{10^{-7}}{2.5\cdot 1.67\cdot 10^{-27}} = 2.4\cdot 10^{19} \quad \frac{1}{m^3} \qquad (20\text{-}2)$$

Full thermonuclear energy (η = 1):

$$E_n = 0.5 n_n E_1 = 0.5\cdot 2.4\cdot 10^{19} 17.6\cdot 10^6 = 21.1\cdot 10^{25}\ \text{eV} = 3.38\cdot 10^7\ \text{J} \qquad (21\text{-}2)$$

Number of air particles with air density ρ = 1.225 kg/m^3 in pressure p = 1 atm. $\mu \approx 28$ is

$$n_o = \frac{M}{\mu m_p} \approx \frac{1.225}{28\cdot 1.67\cdot 10^{-27}} = 2.6\cdot 10^{25} \quad \frac{1}{m^3}\ . \qquad (22\text{-}2)$$

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

$$p = \frac{\eta E_n}{v} = \frac{0.3\cdot 3.38\cdot 10^7}{1} = 1\cdot 10^7 \approx 10^7\ \frac{\text{N}}{\text{m}^2} = 100\,\text{atm} \qquad (23\text{-}2)$$

Total pressure– nuclear explosive is $p \approx 100$ atm.

Temperature of gas mixture of explosive plus nuclear fuel is

$$T = \frac{p}{(n_0 + n_n)k} = \frac{10^7}{(2.6\cdot 10^{25} + 2.4\cdot 10^{19})\cdot 1.38\cdot 10^{-23}} = 27.9\cdot 10^3\ \text{K} \qquad (24\text{-}2)$$

If we increase the initial pressure into reactor body up 10 atm, that the temperature decreases 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 installation body or any garbage material in a space ship.

7. Possibility charging the condenser .

If we use the fuel D+D in our reactor can directly produce protons having E_1 = 3.03 MeV. For fuel 10^{-7} kg ($N = 3\cdot 10^{19}$) in one explosion (cycle) and efficiency η = 0.5 that gives the electric energy

$$E = 0.5\eta E_1 eN = 0.5\cdot 0.5\cdot 3.03\cdot 10^6\cdot 1.6\cdot 10^{-19} 3\cdot 10^{19} = 3.6\cdot 10^6\ J$$

This energy in 50 times more than energy $72\cdot 10^3$ J, which is requests for heating fuel for thermonuclear reaction.

8. *Thickness of sphere cover*. Assume the spherical cover of reactor is made from conventional steel having safety tensile stress σ = 50 kg/mm^2= $5\cdot 10^8$ N/m^2, pressure is 100 atm. The full tensile force is $F = \pi r^2 p$=$3.14\cdot 0.5^2\cdot 10^7$ = $0.785\cdot 10^7$ N. Requested area of steel is $S_r = F/\sigma$ = $0.785\cdot 10^7/5\cdot 10^8$ =0.0157 m^2. The thickness of sphere wall is $\delta = S_r/2\pi r$ = 0.0157/2·3.14·0.5 = 0.005 m. Mass of sphere is $M_c \approx \gamma S_s \delta$ = 7800·3.14·0.005 = 122.5 kg. Here S_s=$4\pi r^2$ = $4\cdot 3.14\cdot 0.5^2$=3.14 m^2 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). There are many other reqests to sphere cover.

9. *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 $E = C_p \Delta T$ = 4.19·80 = 333 kJ, evaporation – r = 2260 kJ, heating of steam up 400^{o}C - $E = C_p \Delta T$ = 1.05·300 = 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 $M_w = E/E_w$ = $3.4\cdot 10^7/2.9\cdot 10^6$ = 11.7 kg. For η = 0.3 M_w = 3.5 kg. The 2 – 3 cm of water thickness protects the installation from high energy of neutrons produced by reaction D+T.

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

10. *Run protons and heavy nuclear particles*.

The physic directory by Kikoin, Moscow, 1975, p. 953[12] gives the following equation for running the protons and charged heavy particles inside gas at pressure 1 atm

$$R_x(E) = \frac{m_x}{m_p} R_p\left(\frac{m_p}{m_x} E\right) , \qquad (25\text{-}2)$$

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 atmosphere is in Table 6:

Table 6. Run (range) of proton in gas H_2 at pressure 1 atmosphere

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 pressure p = 10^7atmosphere the run is

$$R_x(E) = \frac{m_x}{m_p} R_p\left(\frac{m_p}{m_x} E\right)/p \approx \frac{4}{1} R_p\left(\frac{1}{4} 1\cdot 3.5\right)/10^8 \approx 4\cdot 10/10^7 = 4\cdot 10^{-6}\ cm \approx 4\cdot 10^{-5}\ \text{mm} \qquad (26\text{-}2)$$

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 keV = 1/ 350, the chain reaction and ignition will occur .

In the Electric Impulse 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 is very complex function of energy and conditions of Environment.

11.*Converting the nuclear energy of Electric Impulse AB reactor to electric, mechanical energy or a rocket thrust.*

The best means for converting the nuclear energy of the offered Reactor 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 Electric Cumulative AB Reactor installation from very high temperature.

The second way for converting an Electric 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.

12. *Using the Electric Impulse reactor as an impulse space rocket engine.*

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

Assume the fuel energy is 10^8 J and mass of cartridge is 5 gram. If plasma will flow from reactor to space the average speed V of jet is

$$\text{From} \quad E=\frac{mV^2}{2} \quad \text{we get} \quad V=\left(\frac{2E}{m}\right)^{1/2}=\left(\frac{2\cdot 10^8}{5\cdot 10^{-3}}\right)^{1/2}=2\cdot 10^5 \ \frac{\text{m}}{\text{s}}=200\,km/s \,. \qquad (27\text{-}2)$$

Here E = 10^8 is nuclear energy in one impulse one mg nuclear fuel, J; m = 5 g is the mass injected to outer space (fuel cartridge), kg.

Received speed V = 200 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 ton, the ship speed changes in $V_2 = (m/m_2)V$ = 1 m/s in one impulse. If we spend 10 kg of fuel cartridges, the apparatus get speed 2 km/s.

More importantly, the next possibility is of the rocket powered by the Electric Impulse AB Reactor. Any matter from any planets, asteroids, space body may be used as fuel (or addition to emission) 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 (27-2) and Law of equal impulse we have from every impulse

$$V_2 \approx (2Em_1)^{1/2}/m_2=(2\cdot 10^8\cdot 16)^{1/2}/10^3=56.6 \quad m/s \,. \qquad (28\text{-}2)$$

Here V_2 is additional speed of space ship; m_1 mass jet, kg, m_1 = 16 kg of water; m_2 is mass of space apparatus.

13. *Estimation of the neutron penetration*

$$l=1/n\sigma, \qquad (29\text{-}2)$$

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 neutron. For steel l = 12 cm, for compressed air up 200 atm the l = 205 cm.

14. *Requested thickness of the cylindrical "c" and spherical "s" shell* is

$$\left(\frac{D}{d}\right)_c = \left(1+\frac{p}{\sigma}\right), \quad \left(\frac{D}{d}\right)_s = \left(1+\frac{p}{\sigma}\right)^{0.5}. \qquad (30\text{-}2)$$

Where D is outer diameter of shell, d is inner diameter of shell, p is pressure, atm; σ is safety tensile stress kg/cm^2. Example, if p = 10 kg/mm^2, σ = 50 kg/mm^2, then $(D/d)_c \approx 1.2$.

Detail Estimation of Electric Impulse Reactors for transportation engine

1. **Estimation of nuclear energy (power).** Let us make more detail estimation the Electric Impulse Reactors for engine of transport vehicle having the fuel pellet 0.1 mg ($M_f = 10^{-7}$ kg) with fuel D+T and D+D.

Estimation of energy the D+T fuel for the coefficient efficiency η =0.5 is;
The couple nuclei T+D produces nuclear energy E_1 = 17.6 MeV.
Number N of fuel nuclei's 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 average relative (molar) mass of D+T; m_p is mass of proton, kg.
The nuclear energy of 0.1 mg D+T fuel in 1 Hz for efficiency η = 0.5 is

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

Here $e = 1.6\cdot 10^{-19}$ is charge of electron, C.

That is power energy of the 2 ÷ 5 power aviation turbo-engines. If one cycle in second (1Hz) is not enough, we can decrease the frequency. 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 = 3.15 MeV , μ = 2, $N = 3\cdot 10^{19}$ the nucler energy

$$E = 0.5E_1 eN\eta = 0.5\cdot 3.15\cdot 10^6\cdot 1.6\cdot 10^{-19} 3\cdot 10^{19}\cdot 0.5 = 3.8\cdot 10^6 \approx 3.8\, MJ/Hz$$

is aproximetely in 4.5 times less because E_1 is less.

2. **Size of cartridge and pellet**. Let us estimate the size of the electric impulse cartrige having an internal diameter d = 1 mm. The thickness δ of the cartrige wall is 0.5 mm.

Let us estimate the compressed pellet having gas mass $M = 10^{-7}$ kg, pressure p = 1000 atm =10^8 N/m^2 and T = 300 K. Specific density the gas D+D, D+T in compression p = 1atm is ρ_o= 0.1 kg/m^3.
The relative outer diameter of spherical pellet for pressure p = 10 kg/mm^2 and the safety tensile stress of the pellet cover σ = 50 kg/mm^2 with according (30-2) is

$$\frac{D}{d} = \left(\frac{p}{\sigma}+1\right) = \left(\frac{10}{50}+1\right) = 1.2.$$

Outer diameter of cartridge for safety tensile stress 50 kg/mm^2 is $D \approx 1.2$ mm.

3. Estimation of requested an acceleration time, electric currency, energy for fuel heating.

Let us take the fuel D+D, mass $M = 10^{-7}$ kg, the full fuel camera has internel diameter d = 1 mm, length l = 2 mm separated in two subcameres 1x1 mm having volume $v \approx 1$ mm^3 (fig.1) each.

The number nucleus in subcamera is $N = 1.5\cdot 10^{19}$, density in 1 cm^3 (m^3) is

$$n = \frac{N}{v} = \frac{1.5\cdot 10^{19}}{10^{-3}} = 1.5\cdot 10^{22}\ \frac{1}{cm^3} = 1.5\cdot 10^{28}\ \frac{1}{m^3}$$

The pressure at temperature T = 300 K is

$$p = nkT = 1.5\cdot 10^{28}\cdot 1.38\cdot 10^{-23}\cdot 300 = 6.21\cdot 10^7\ N/m^2 = 621\, atm.$$

Electric charge located in every subcamera

$$Q = Ne = 1.5\cdot 10^{19}\cdot 1.6\cdot 10^{-19} = 2.4\ \ C\ .$$

Let us take average voltage of condenser U = 50 kV and the length of subcamera l = 1 mm =10^{-3} m. Then averege intensity of electric field is

$$E_e = U/l = 5\cdot 10^4/10^{-3} = 0.5\cdot 10^{-8}\ \ \text{V/m}.$$

The force acting on the charge is

$$F = QE = 2.4\cdot 0.5\cdot 10^8\ \ N = 1.2\cdot 10^8\ N.$$

Acceleration of charge is

$$a = \frac{F}{M} = \frac{1.2\cdot 10^8}{0.5\cdot 10^{-7}} = 2.4\cdot 10^{15}\ \ \frac{m}{s^2}.$$

Acceleration time is

$$t = \left(\frac{2l}{a}\right)^{0.5} = \left(\frac{2\cdot 0.5\cdot 10^{-3}}{2.4\cdot 10^{15}}\right)^{0.5} = 0.42\cdot 10^{-9}\ \ s\ .$$

Here l = 0.5 mm is average distanse of the charge acceleration.
Average charge speed in end of acceleration is

$$V = at = 2.4\cdot 10^{15}\cdot 0.42\cdot 0^{-8} = 10^6\ \ m/s\ .$$

Kinetic energy of fuel is

$$E = \frac{MV^2}{2} = \frac{10^{-7}\left(10^6\right)^2}{2} = 0.5\cdot 10^5\ \ J\ .$$

Electric currency is

$$I = \frac{Q}{t} = \frac{2.4}{0.42\cdot 10^{-9}} = 5.7\cdot 10^9\ \ A\ .$$

Energy of electric currency is

$$E = IUt = 5.7\cdot 10^9\cdot 5\cdot 10^4\cdot 0.42\cdot 10^{-9} = 1.2\cdot 10^5\ \ J\ .$$

Here $U = 5\cdot 10^4$ V is everage voltage of the condenser.
Estimation of evarage magnetic pressure (pinch effect).
Intensity H of magnetic field is

$$H = \frac{I}{2\pi r} = \frac{5.7\cdot 10^9}{2\cdot 3.14\cdot 0.5\cdot 10^{-3}} = 1.8\cdot 10^{12}\ \ \frac{A}{m}.$$

Here r = 0.5 mm is the internel radius of fuel pellet.
Pressure p of magnetic field is

$$p = \mu_o\frac{H^2}{2} = \frac{4\pi 10^{-7}\left(1.8\cdot 10^{12}\right)^2}{2} = 20\cdot 10^{17}\ \ \frac{N}{m^2} = 2\cdot 10^{13}\ \ atm.$$

Here $\mu_o = 4\pi\cdot 10^{-7}$ is the magnetic constant.

This pressure increases the fuel density in n_{mag} times and separated nucleus from the capsule walls

$$N_{mag} = p/p_o = 2\cdot 10^{13}/621 = 3.22\cdot 10^{10},\quad n_{mag} = nN_{mag} - 1.5\cdot 10^{22} 3.22\cdot 10^{10} = 4.83\cdot 10^{32}\ \ 1/cm^3\ .$$

The probability P of te nucleus collision for temprature (voltage) =10^5 eV (cross section σ = $4\cdot 10^{-26}$ fig.4), nucleos density $n = n_{\text{mag}}$ and the length of the opposed jet δ = 0.05 cm) is

$$P = \sigma n\delta = 4\cdot 10^{-26}\cdot 4.83\cdot 10^{32}\cdot 0.5\cdot 10^{-1} = 9.7\cdot 10^5 \geq 1\ .$$

In reality the probability is less 1, because the number of reactive nucleus decrease as result of reactions

$$N(\delta) = N_0(1 - \exp(-\sigma n\delta))\ .$$

After collising the left and right collections of charges, the shock wave will move in a cylindrical capsule reflected from its ends. That occilation may be support by electric impulses and increase the reaction time.

Evaluation time retaining a high temperature and pressure.

Rate of collising the plasma iones after avarage electric heating $T = 10^5$ eV is

$$\nu = 4.8\cdot 10^{-8} Z^4 \mu^{-1/2} n \cdot \ln\Lambda \cdot T^{-3/2} \quad [1/s] = 4.8\cdot 10^{-8}\cdot 1^4 \cdot (2)^{-1/2} 1.5\cdot 10^{22}\cdot 10\cdot 10^{-7.5} = 1.6\cdot 10^8 \quad [1/s].$$

Here Z = 1 is charge state, $\mu = m_i/m_p = 2$ is molar mass expressed in units of the proton mass, $n = 1.5\cdot 10^{22}$ is ion density, 1/cm^3, T is temperature expressed in eV.

If the cover of pellet has $\mu \approx 200$ and ion has $\mu \approx 2$, the fuel ion can pass its energy to the cover ion after ≈200/2 = 100 collisions (impacts). That means the time of the ion transfer its energy encreses in 100 times and will be less 10^{-6} sec. In reality for need mass of fuel cover the additional reactivity time tie may be $10^{-3} \div 10^{-5}$ seconds.

Estimation of received energy and the energy contained in the fuel.

Let us to estimate the received energy from D+D fuel having mass $M = 10^{-7}$ kg (without energy of the first hit) and energy containing in fuel for selected $T = 10^5$ eV and the capcule pressure 620 atm = fuel density $n = 1.5\cdot 10^{22}$ 1/cm^3.

The thermonuclear power is

$$P_{DD} = 3.3\cdot 10^{-13} n^2 \cdot (\overline{\sigma v})_{DD} = 3.3\cdot 10^{-13}\cdot (1.5\cdot 10^{22})^2 \cdot 4.5\cdot 10^{-17} = 3.34\cdot 10^{15} \quad W/cm^3.$$

Here $(\overline{\sigma v})_{DD} = 4.5\cdot 10^{-17}$ is taken from Table 5.

The energy getting in time $t = 10^{-6}$ sec is

$$E = P_{DD}\cdot v\cdot t = 3.34\cdot 10^{15}\cdot 2.10^{-3}\cdot 10^{-6} = 6.68\cdot 10^6 \quad J.$$

Here $v = 2.10^{-3}$ cm^3 is volume of fuel pellet.

The fusion energy of couple D+D nucleus is

$$E_1 = 3.65 \text{ MeV} = 3.65\cdot 10^6\cdot 1.6\cdot 10^{-19} = 5.84\cdot 10^{-13} \quad J$$

Full energy $M = 10^{-7}$ kg of fuel D+D is

$$E_f = 0.5\cdot N\cdot E_1 = 0.5\cdot 1.5\cdot 10^{19}\cdot 5.84\cdot 10^{-13} = 4.4\cdot 10^6 \quad J.$$

We get the full energy is less than the received energy E_1. That means the time of themonuclear fusion is less them 10^{-6} sec. In fact the fusion time will be significantly smaller 10^{-6} sec because a pinch magnetic effect is strong compressed the gas fuel.

Loss the heat throw a thermal conductivity.

The loss the heat throw pallet wall is

$$Q = \alpha(p) F\cdot \Delta T\cdot \Delta t = 100\cdot 621\cdot 7.8\cdot 10^{-6}\cdot 1.16\cdot 10^9\cdot 10^{-6} = 0.562 \quad kJ/Hz$$

Here $\alpha = 100$ W/(m$^2\cdot$K$\cdot$s); $p = 621$ atm; F = internel surface of pallet; m^2; $T = 10^5$ eV = $1.16\cdot 10^{19}$ K is avarage temperature, K; t is time, sec.

That is small part from the spent electric energy ≈ 100 kW.

Bremsstrahlung radiation P_{Br} of a hot plasma having temterature T=10^5 eV.

$$P_{Br} = \frac{16\alpha^3 h^2}{\sqrt{3} m_e^{3/2}} n_e^2 T_e^{1/2} Z_{eff} = 1.69\times 10^{-32} n_e^2 T_e^{1/2} Z_{eff} = 1.69\cdot 10^{-32}\cdot (1.5\cdot 10^{22})^2 (10^5)^{1/2}\cdot 1 = 1.2\cdot 10^{15} \left[\frac{\text{W}}{\text{sm}^3}\right].$$

Here α is the fine structure constant, h is Planck's constant, m_e is mass of electron, n_e is electron density, 1/cm^3; T_e is electron temperature, eV, Z_{eff} is "effective" ion charge.

The loss of energy by volume v = 0.002 cm^3 in time $t = 10^{-7}$ sec is

$$E_{br} = P_{Br} \cdot v \cdot \Delta t = 1.2 \cdot 10^{15} 2 \cdot 10^{-3} \cdot 10^{-7} = 0.24 \cdot 10^{6} \quad \text{J}.$$

That is 5.4% from full enery.

4.**Estimation of electric condenser**. For heating of fuel we use the short strong electric impulse. For impulse the electric condenser may be used. Let us to estimate the condenser parameters for getting the fuel temperature T = 15 keV (plasma temperature is 30 keV for opposet jets) .

If fuel mass is M = 0.1 mg = 10^{-7}kg, the number of nucleus 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 $N = 3 \cdot 10^{19}$.

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

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

For heating D+D fuel is W = 72 kJ.

The minimal specific energy of conventional conductor according [9] p. 368 is γ = 2 kJ/kg. Consequently, the requested mass of condenser is about 30 – 36 kg. But if we can use the advanced supercapacitor (γ = 10 kJ/kg) or ultra-capacitor (γ = 20 kJ/kg) or capacitor EEStor, having claimed capacity γ = 1000 kJ/kg, we can decreased the capacitor mass. In any case, the capacitor mass is small part of thermonuclear engine.

5. **Estimation of capacitor discharge**. The electric schema of connection the condenser to fuel pellet is present in fig.5. That contains: the condenser 1, the source of high voltage 2 (high voltage electric generator or or battery), fuel cartrige (pellet) R_1, and connection wires having the electric resistance R_2.

The source charges the condenser has voltage up 50 ÷ 200 kV, energy 70 ÷ 200 kJ. The condenser connects to fuel cartrige.

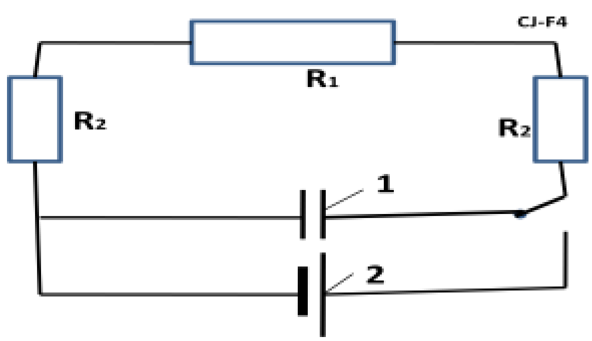


Fig.5. Electric schema of connection the condenser to the fuel pellet. *Notation*: R_1 is the resistance of fuel pellet, R_2 is resistance of the connection wires from condenser to the fuel pellet, 1 is condenser , 2 is high voltage electric generator (battery).

Electric resistance of a copper wires connected condenser to cartidgeis (fuel pellet) is

$$R_2 = \rho \frac{l_0}{s} = 1.75 \cdot 10^{-6} \frac{200}{5} = 7 \cdot 10^{-5} \quad \Omega.$$

Where l_0 = 200 cm is length of one wire, cm; s = 5 cm^2 is cross-section area of wire, sm^2; ρ= 1.75.10^{-6} is a coefficient electric resistance of cupper.

Estimation the plasma resistance into cartridge. The plasma resistance coefficients are:

$\eta_\perp = 1.03\cdot 10^{-2} Z\cdot \ln\Lambda\cdot T^{-3/2}$.

$For\ T = 10\,\mathrm{eV} \quad \eta_\perp \approx 1.03\cdot 10^{-2}\cdot 1\cdot 10\cdot 10^{-3/2} = 3.16\cdot 10^{-4}\ \Omega\cdot\mathrm{cm}.$

$For\ T = 10^5\ \mathrm{eV} \quad \eta_\perp \approx 1.03\cdot 10^{-2}\cdot 1\cdot 10\cdot 10^{-7.5} = 3.2\cdot 10^{-9}\ \Omega\cdot\mathrm{cm}.$

Here: Z = 1 is ion charge of fuel D, T; lnΛ = 10 is Columbu's logarithm; T is temperature, eV. The plasma electric resistance for fuel cameres l_o = 1 mm, area s = 1 mm^2 are:

$$For\ T = 10\,eV \quad R_1 = \eta_\perp \frac{l_0}{s} = 3.16\cdot 10^{-4}\frac{0.1}{2\cdot 0.01} \approx 1.6\cdot 10^{-3}\ \ \Omega\,,$$

$$For\ T = 10^5\ eV \quad R_1 = \eta_\perp \frac{l_0}{s} = 3.2\cdot 10^{-9}\frac{0.1}{2\cdot 0.01} \approx 1.6\cdot 10^{-8}\ \ \Omega\,.$$

Let us take the evarage electric resistance $R = R_1 + 2R_2 = 10^{-3}$ Ω. The condenser energy E = 60 kJ.

Time of the condenser discharge for initial voltage U = 30 kV

$$t = \frac{RE}{U^2} = \frac{10^{-3}60\cdot 10^3}{(30\cdot 10^3)^2} = 6.67\cdot 10^{-8}\ s$$

The time of discharge is about time of the full thermonuclear reaction (10^{-9} s).

The average electric currency in cartridge

$$I = \frac{E}{Ut} = \frac{6\cdot 10^4}{3\cdot 10^4 6.67\cdot 10^{-8}} = 0.3\cdot 10^8\ A.$$

Capacity of condenser

$$C = \frac{t}{R} = \frac{6.67\cdot 10^{-8}}{10^{-3}} = 6.67\cdot 10^{-5}\ F.$$

The specific energy weight γ_c [J/kg] of the condenser may be estimated by formulas

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

Where ε_o= 8.85·10^{-12} F/m is electric constant; $\boldsymbol{\varepsilon}$ **≈** 3 dielectric constant; E_q≈ 160 ÷ 640 MV/m is safety electric stress of isolator; γ ≈ 1000 ÷ 3000 kg/m^3 is specific weight of isolator. The γ_c ≈ 3 kJ/kg.

6. **Electric breakdown**. For starting fusion reaction the spark gap into the fuel pellet must be less the definite value. According [13] p.123, fig.51for plates in compressed hydrogen the voltage 10^5 volts has the spark gap pd = 10^4 kPa·mm (here p is pressure, kPa; d is distance between plates, mm). That means for 10^5 volts and a length fuel camera d = 1mm the maximum hydrogen pressure can be less p = 10^7/(5· 10^4·1) = 200 atm. That is not problem because the plates we can change the spearheads which decrease the need distance in 5 times or put in fuel a conductive yarns .

7. Cost of the thermonuclear fuel.

Deuterium. The sea water contains deuterium about 1.55·10^{-4} %. The World produces about tens thousand 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 isotope. The Helium-4 contains 1.3·10^{-6}/1 of the Helium-3. Cost is 30K $/g. One project offers to extract it on Moon and delivery to Earth.

Lithium 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 thermonuclear fuel D+D is the cheapest, but D+T has the lowest temperature for thermonuclear reaction. All the current experimental thermonuclear installations are using the D+T. Look your attention, the offered method allow to get very high thermonuclear temperature. We take $U = 15 \div 50$ kV, but no limit take U = 100, 200, 500 kV. The 200 kV produce the temperature $T = 200 \cdot 10^{3} \cdot 1.18 \cdot 10^4 = 2.36 \cdot 10^9$ K (two billions!). As you see in fig. 4 and estimations over, that significantly increase the probability of thermonuclear reaction and produce a fuel for the other reactor**.**We can use the cheap fuel produced few neutrons, many protons, expensive elements, which can be a fuel for thermonuclear reactors.

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 do not allow us to reach an industrial or transport engine 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 vaporization the cover of fuel capsule does not allow to delivery big energy. After laser beam, the fuel capsule is "naked" capsule. Capsule cannot to keep the high-energy particles of the nuclear ignition and loss them. Producing the power laser beam is very expensive and has very low efficiency (1 - 2.5%).

The offer method EIF (Electric Impulse Fusion) does not have these disadvantages. One uses the primery high pressed gas fuel ampules and directly heats them to need high temperature by special electric impulse in special cartridge. The shell of cupsule protects the fuel by the heavy elements (μ = 200) having high number of nucleons A and charges Z. They reflect the light protons, D, T, repels high-energy reacted particles (D, T, ^{3}He, ^{4}He, p) back to fuel and significantly increasing the pressure and conformation time.

The laser ICF, MCF ideas cannot be used for thermonuclear reaction in its classical form. Produced temperature and pressure by laser ICF and magnetic MCF are not enough for thermonuclear reaction. The main author innovation is using the electric field [5] for rearching the need temperature (up 1000 MeV) and using the primery compressing the gas fuel (up 1000 atm) in special ampules. That increases the intensity of nuclear reaction (and temperature) in hundreds times.

Author noted that the mass of fuel is very small and allows reaching the high speed by opposed high intensity electric fields.

The impotent innovations are the compressed the fuel gas into fuel cartridge at room temperature and an electric impulse for heating of fuel up the thermonuclear temperatures. The current ICF uses the frozen 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, deuterium costs 1 \$/g). One also allows using the compressed fuel-gas at room temperature. We can use the nuclear reactions which do not produce the neutrones and gamma radiation. They are dangerous for people.

Conclusion

The author offers a new small very cheap electric impulse thermonuclear reactors, which increases the temperature of a primery compressed nuclear fuel in thousands times, reaches the ignition and full thermonuclear reaction. Electric Impulse AB Reactor, herein offered by its originator, contains several innovations and inventions.

Main of them is using a electric field, which allows to accelerate the thermonuclear fuel to very high speed which (as it is shown by computations) heating up the hundreds million degrees of temperature. Important innovation is compressed gas fuel at room temperature, instellation for electric and mechanical energy and thermonuclear rocket.

The offered reactor is small, very cheap, may be used for non-expencive 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]-[11].

Acknowledgement

The author wishes to acknowledge R.B. Cathcart for correcting the author's English and offering useful advices and suggestions.

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., Cumulative and Impulse Mini Thermonuclear Reactors. 3 30 16, http://viXra.org/abs/1605.0309, https://archive.org/download/ImpulseMiniThermonuclearReactors ,

[5] Bolonkin A.A., Electric Cumulative Thermonuclear Reactors. https://archive.org/download/abolonkin_gmail_201610, http://vixra.org/abs/1610.0208 .

[6] 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,

[7] 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,
[8] 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,
[9] 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/
[10] 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.
[11] 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,
[12] Kikoin I.K., Tables of Physical Values, Moscow, Atomizdat, 1975 (Russian).
[13] Koshkin N.I., Shirkevich M.G., Handbook of elementary physics, Moscow, Nauka, 1982 (Russian).
[14] AIP, Physics Desk Reference, 3-rd Edition. Springer, AIP PRESS. Third Edition.

17 July 2016

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; Femtotechnology and Revolutionary {rojectsts, Lambert, 2011, p.530; New Methods of Optimization and their Application, Moscow High Technical University named Bauman (in Russian: Новыеметодыоптимизацииихприменение. МВТУим. Баумана, 1972г., 220 стр). List and linksof Bolonkin's publication: http://viXra.org/abs/1604.0304.Homepage: http://Bolonkin.narod.ru