Summarized proposal of a Deuterium-Deuterium fusion reactor intended for a large power plant

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Abstract: even if a Deuterium-Deuterium (D-D) fusion reactor would be necessarily much bigger than a Deuterium-Tritium (D-T) reactor due to the much weaker fusion reactivity of the D-D fusion compared to the D-T fusion, a D-D reactor size would remain under an acceptable size. Indeed, a D-D power plant would be necessarily large and powerful, i.e. the net electric power would be preferably above 10 GWe. A D-D reactor is less complex than a D-T reactor as it is not necessary to obtain Tritium from the reactor itself. The goal of the original article is to create a physical model of the D-D reactor so as to estimate this one without the need of a simulator and finally to estimate the dimensions, power and yield of such D-D reactor for different net electrical powers. It is reminded that the Deuterium is relatively abundant on the sea water, and so it constitutes an almost inexhaustible source of energy.

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1. Introduction

The goal of this presentation is to briefly describe, a power plant using Deuterium-Deuterium (D-D) fusion rather than Deuterium-Tritium (D-T) fusion and to determine if the size of such machine would be compatible with an industrial power plant, let's say, less than 500 m.
It is an abstract (4 pages) of the original article (50 pages) available here:
https://zenodo.org/records/10479179
Note that this article has been published there: http://doi.org/10.4236/wjnst.2024.141001)

This reactor uses magnetic confinement and hosts two opposed beams of electrons and two opposed beams of ions. All these beams, initially directed axially, circulate inside a figure of "0" configuration, also called "racetrack", as shown in figure 1, on the next page.

On this figure, the reactor appears stocky for representation necessity, but it is rather long and narrow, the length of this reactor being, in fact, more than 10 times larger than the width.

This D-D reactor would produce nuclear fusions with a mechanical gain (Q), i.e. the ratio "fusion power / mechanical injection power", equal to about 17 for 20 GWe of net electric power.

The D-D reactor, which is mainly aimed to be part of a power plant (see figure 3), would produce electricity with a power amplification gain, i.e. the ratio "electrical energy supplied by the alternator / electric energy consumed (auxiliary equipment included)", equal to about 2.5.

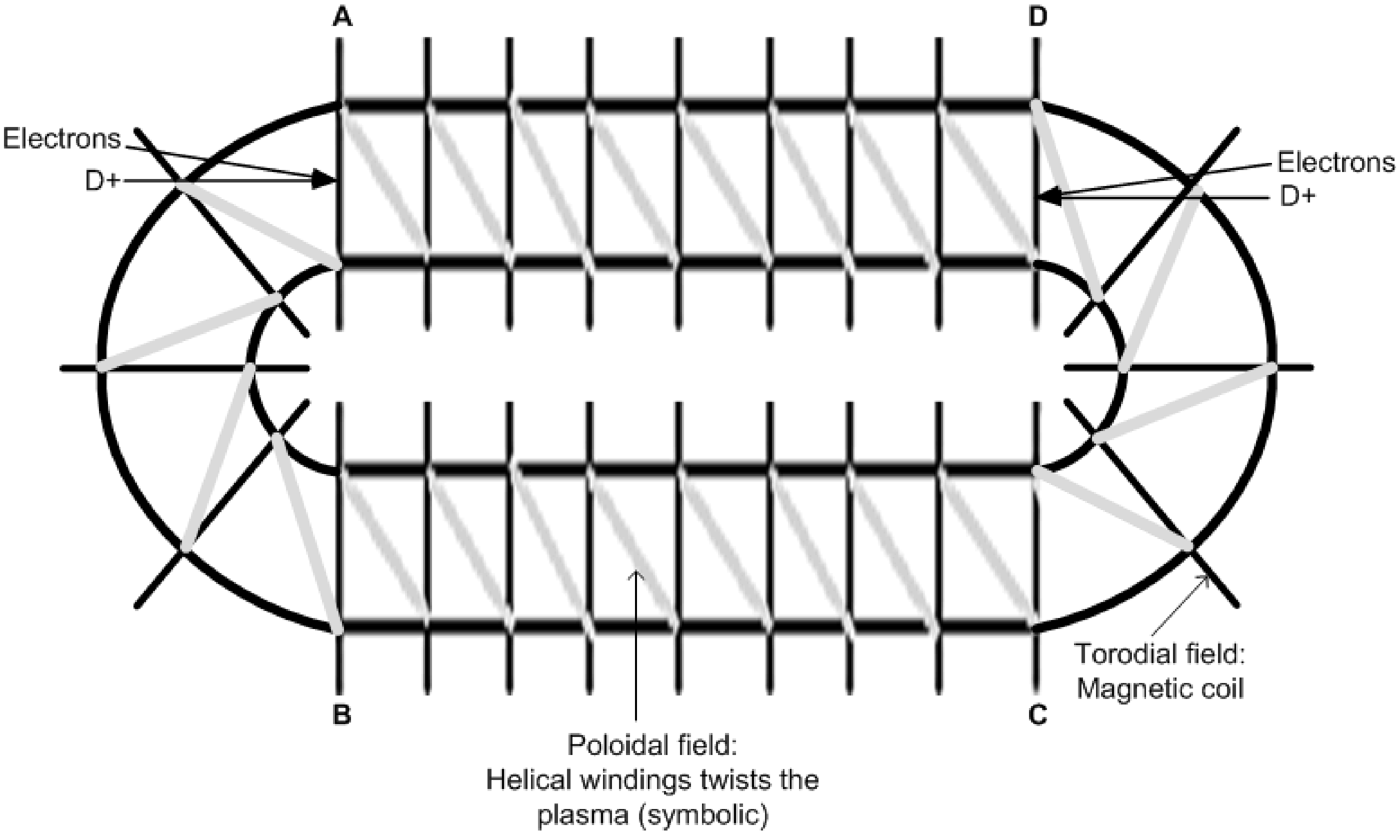

Figure 1. D-D fusion reactor principle diagram

2. Principle of the fusion D-D reactor

The proposed reactor pertains to the CBFR category of reactors, but with a Stellarator configuration. So it is much less complex than a Tokamak.

To have an important fusion power, the beam must be necessarily neutral so as to escape from the space charge problem which drastically prevents to have a reasonable density of ions (D+). So a mix of electrons and ions is proposed for neutrality.

D+ ions are injected in opposition at the same speed and form a neutral beam with the injected electrons.
The beam turns in a magnetic closed loop in form of figure of “0” (see the figure 1).
After isotropization (1.0 s), the particles will turn on the loop in one direction or the other, randomly.
Meanwhile, the particles (electrons and D+ ions) are progressively thermalized.

The plasma is heated by fusion products: T+, p, He3+ and He4+ ions and maintained at an equilibrium energy between 100 and 150 keV, where the primary and secondary fusions are numerous. This heating is sufficient to compensate the losses by radiations (mainly by Bremsstrahlung), the plasma cooling in the two half-toruses, and the particles losses.
The replacement particles are injected at a relatively low energy (i.e. about 45 keV) to replace lost particles.

The toroidal magnetic field (B) must be axial relatively to the pipe, and maximum to confine particles (electrons + ions). The present industrial maximum B limit for superconducting coils is 5 T (Tesla). So this 5 T field will be supposed, as the default value.
A poloidal field is indispensable to limit the particles shift inside loops (see the figure 1).

It is targeted a power plant generating 20 GW (20 000 MW) of net electric power to the grid. The global conversion will be such that at least 20 % of the thermal power issued from the D-D reactor will be converted in net electric power. So around 100 GW of thermal energy might be produced by the D-D reactor. The working is continuous.

The fusion reactions considered are given below.

Primary D-D fusion reactions

1) D+ + D+ ->T+ (+1.01 MeV) + p (+3.03 MeV) (at 50%)
2) D+ + D+ ->He3+ (+0.82 MeV) + n (+2.45 MeV) (at 50%)

Secondary D-T fusion reaction

D+ + T+ ->He4+ (+3.52 MeV) + n (+14.06 MeV)
This reaction uses the Tritium ions (T+) generated by the primary D-D fusion 1) given above.

Secondary D-He3 fusion reaction

D+ + He3+ ->He4+ (+ 3.67 MeV) + p (+ 14.67 MeV) (aneutronic fusion)
This reaction uses the Helium 3 ions (He3+) generated by the primary D-D fusion 2) given above.

As it can be seen in the figure 2 below, reactivities are relatively elevated between 100 keV and 300 keV.

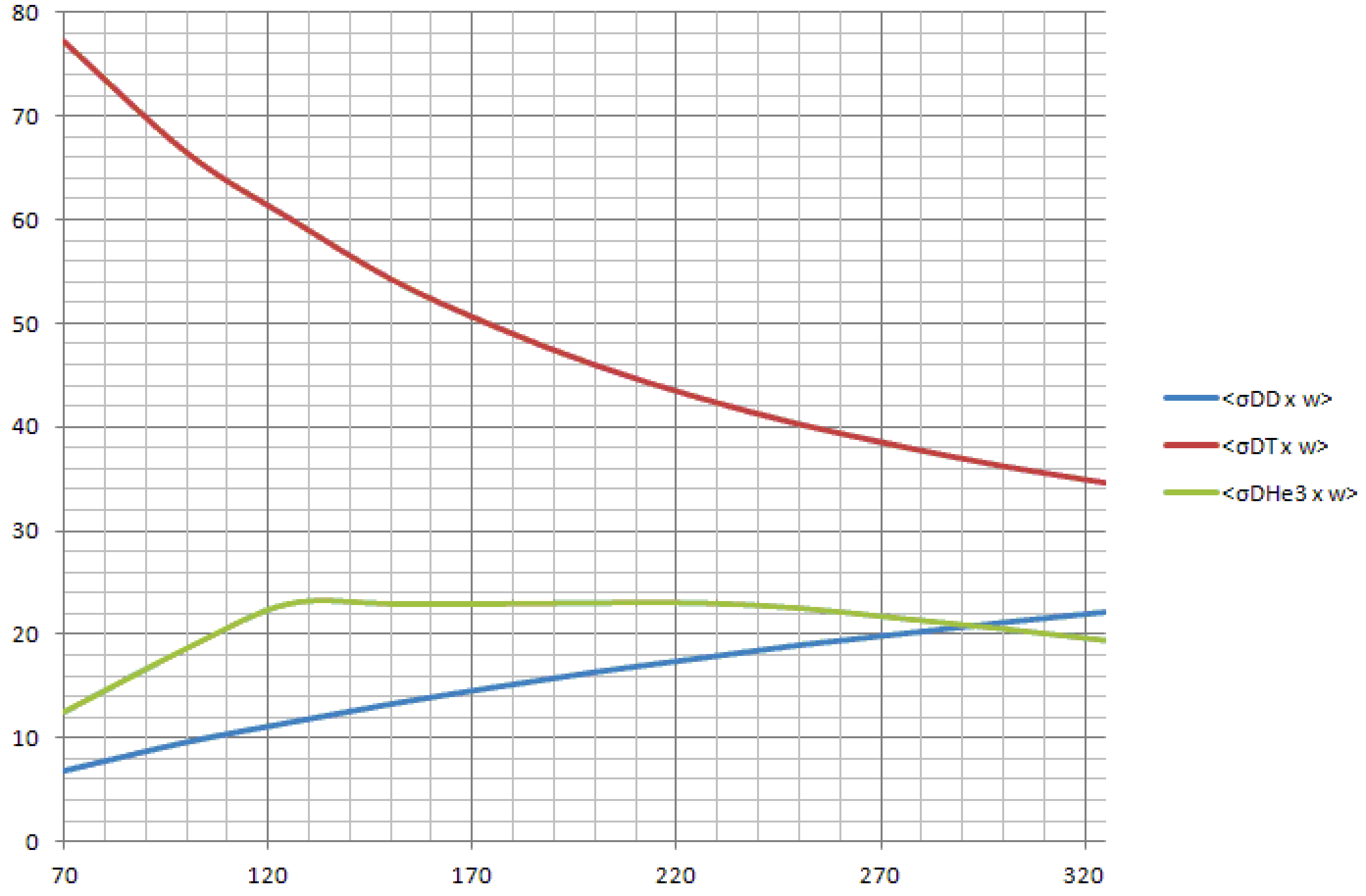

Figure 2. Reactivities of the D-D / D-T / D-He3 fusions.
The abscissa is the Center-of-Mass energy in keV and the ordinate is the reactivity in m^3/s x 1E-23

The physical model gives the following results for a plant supplying 20.2 GWe of net electric power: mechanical gain (Q) = 17.3, length of the reactor = 451 m, width of the reactor = 27 m, pipe radius = 4.5 m, volume of the reactor = 59358 m^3 and power amplification gain = 2.53.

The following figure 3 summarizes the reactor energy balance, from which the mechanical gain Q and the other parameters (dimensions, net electric power, power amplification gain, etc) are calculated.

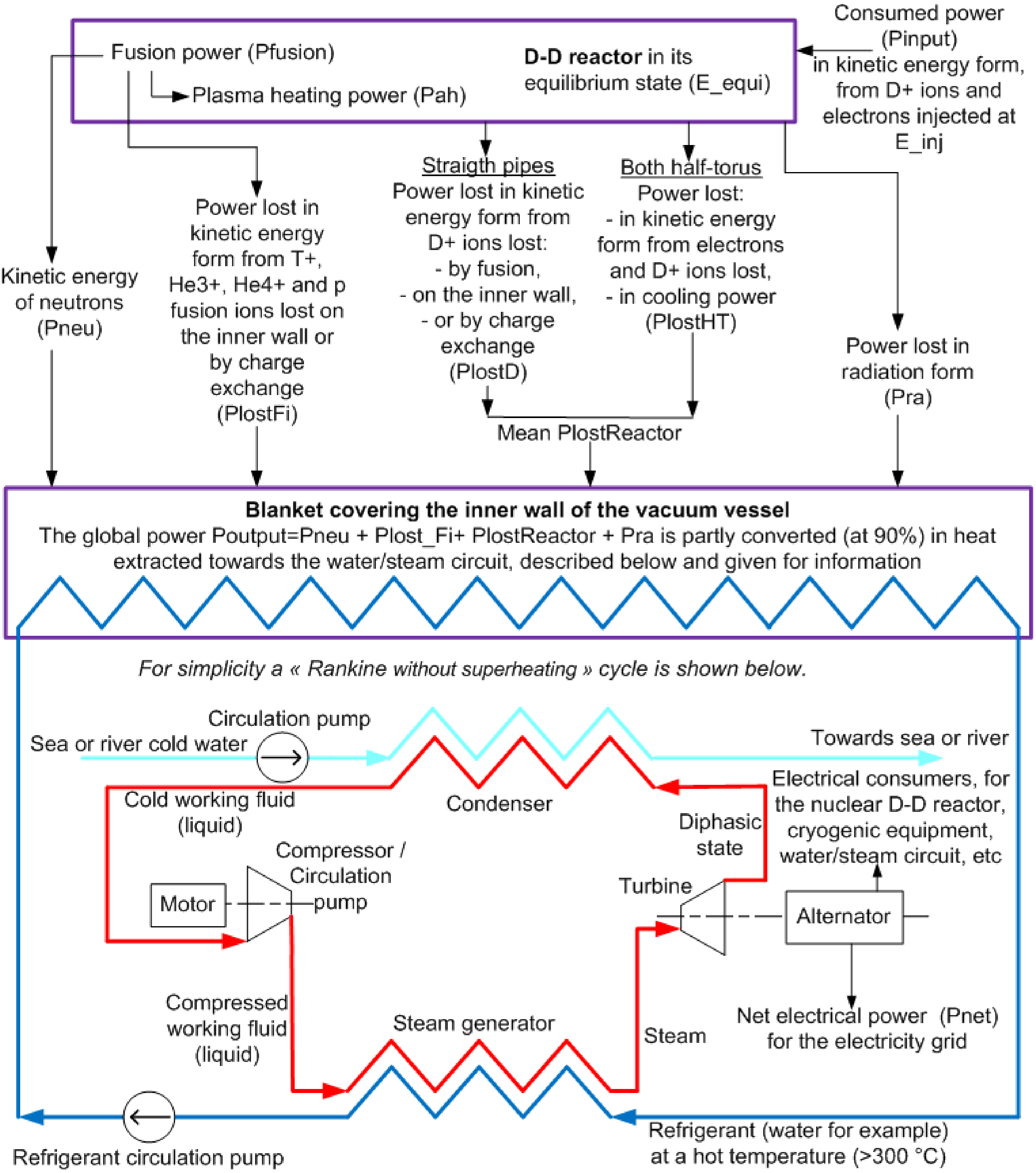

Figure 3 D-D reactor energy balance

3 Conclusion

This D-D reactor, synthesis of a Stellarator and a CBFR reactor, could, perhaps, be a solution for a massive electricity production, using the Deuterium extracted from the sea.
The results of the original article are orders of magnitude but sufficient to consider the possibility of a functional D-D fusion reactor, necessarily very powerful. Even if many points relative to this type of reactor would have to be detailed, it must be taken into account that Deuterium is an almost inexhaustible source of energy.