Fusion power for all ?

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There has been a great deal of buzz about the recent Lockheed Skunk Works announce reported as "Lockheed says makes breakthrough on fusion energy project" from Reuters[i]; or "Experts Skeptical Of Lockheed Martin's 'Nuclear Fusion Breakthrough" from Huffpost[ii] .

The skepticism went all the way from "not enough detail to make a judgment" to "strategy to get funds" to "why talk before it has been demonstrated". The more charitable comments emphasized the Skunk works record for amazing high tech systems.

I focused on the part of the announcement where they said that patents pending were going to become public. If they are being forced out of the closet and their competitor's will have some idea what they are up to, then they might as well get some publicity. Seems like a good reason to go public.

These days patent applications are published several years before they become patents. I searched the PCT data base for world patent applications, and there it was;

(WO2014165641) MAGNETIC FIELD PLASMA CONFINEMENT FOR COMPACT FUSION POWER REACTOR Published on 9/10/14, 4 days before the announcement. The sole inventor is Tomas McGuire, who received his PhD from MIT "Improved Lifetimes and Synchronization Behavior in Multi-grid Inertial Electrostatic Confinement Fusion Devices".

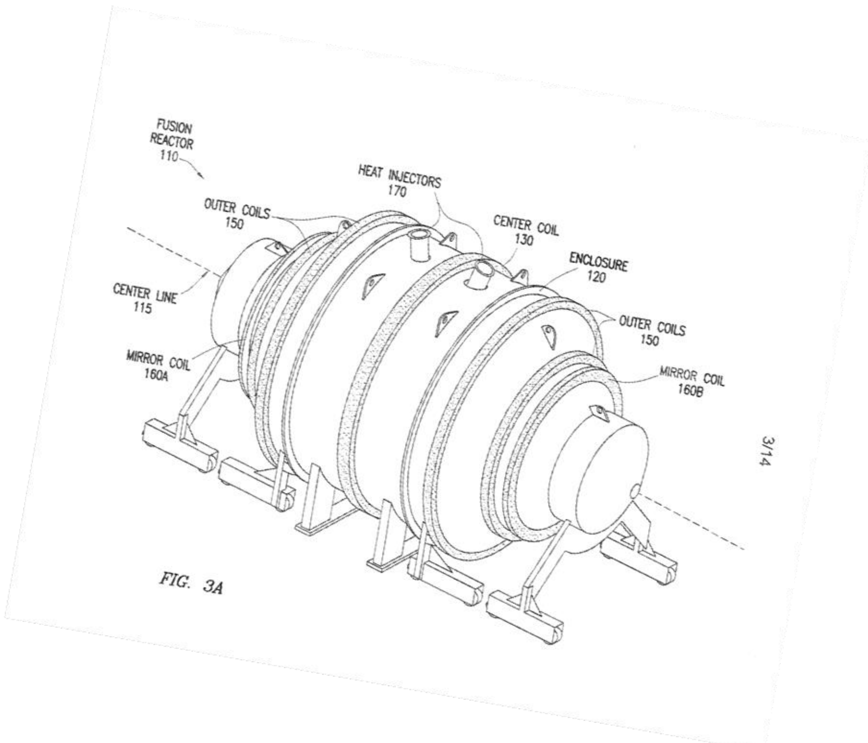
Now there are several disclaimers with patent applications; they do have to have been shown to work, and they do not have to show the final successful implementation. However they must disclose the favored design at the time of submission. The design can evolve after submission, but the claims must encompass the final successful implementation, if the implementation is to be covered by the patent. Finally, there may be other follow on patent applications that disclose other strategies, which may be in fact be the final implementation. That being said, there may be plenty to learn from the first patent application.

I am not a fusion guy, so I was just trying to get an overall impression. The first observation was that there is plenty of design detail, and that the detail was consistent with the press release generalities. The commentaries in italics are all direct quotes from the patent application. I have edited out the weird patent language so as to make the quotes easier to understand.

> *"In general, fusion reactor.. is a device that generates power by confining and controlling plasma that is used in a nuclear fusion process. Fusion reactor .. generates a large amount of heat from the nuclear fusion process that may be converted into various forms of power. For example, the heat generated by fusion reactor .. may be utilized to produce steam for driving a turbine and an electrical generator, thereby producing electricity."*

The outside of the chamber was shown in Figure 3A, *"The …. fusion reactor … may be approximately 10 m x 7 m and may have a gross heat output of approximately 100 MW."*

Heat is extracted though the walls of the chamber, by liquid metal coolant, steam or gas depending on the application.



The inside is shown in a cutaway drawing Fig 3B.

In general, fusion reactor .. is an encapsulated linear ring …. fusion reactor in which encapsulating magnetic coils .. are used to prevent plasma, that is generated using internal … magnetic coils, from expanding.

The main plasma confinement is accomplished…. by .. a center coil 130 with two … internal coils on either side 140). These confinement regions are then encapsulated with … coils 150 within a coaxial mirror field provided by mirror coils 160.

The mirror fields appear to be the strongest magnets in the system. Mirror containment designs are not new, they have been considered for several years[iii].

"Mirror coils 160 are magnetic coils that are …. close to the ends of enclosure 120 In general, ..(they)…… make all the recirculating field lines satisfy an average minimum- β , a condition that is not satisfied by other existing recirculating schemes."

"Beta" refers to the balance between plasma pressure and magnetic field pressure and effectively describes the containment of the plasma. In the talk that announced this development, the program manager emphasized that the strength of the containment magnetic field increased as the distance from the plasma increases.

In the words of the patent;

> *"Fusion reactor 110 is an improvement over existing systems in part because global MHD (Magnetic Hydro Dynamic) stability can be preserved and the losses through successive confinement zones are more isolated due to the scattering of particles moving along the null lines. This feature means that particles moving along the center line are not likely to pass immediately out of the system, but will take many scattering events to leave the system. This increases their lifetime in the device, increasing the ability of the reactor to produce useful fusion power "*

The need for multiple scattering events or "ion jumps" within the recirculation zone translates into some design metrics ;

> *"… the field geometry is sized to be the minimum size necessary to achieve adequate ion magnetization with fields that can be produced by simple magnet technology. …….at full 20 KeV plasma energy there are 6.5 ion jumps. This is the lowest to maintain a reasonable magnetic field of 2.2 T in the cusps and keep a modest device size ."*

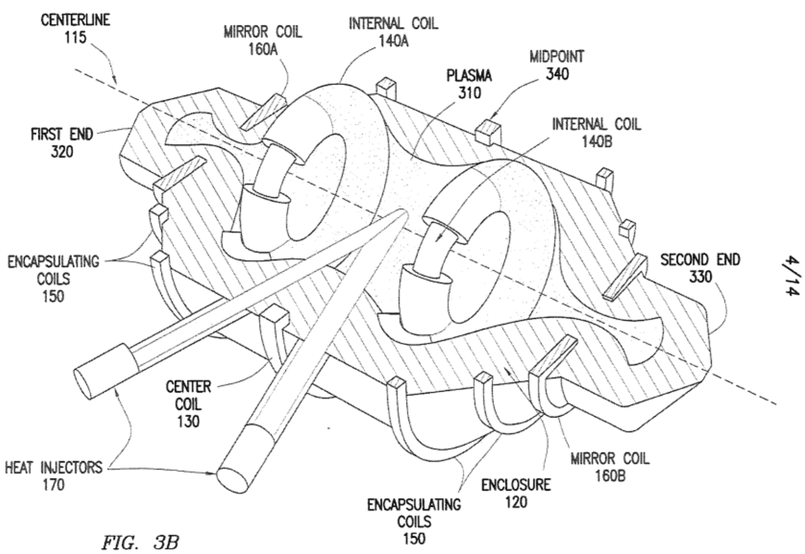


FIG. 3B

The claims all focus on the arrangement of the coils that creates a magnetic confinement of the plasma. In the patent they show what appears to be a magnetic field simulation of an implementation. It shows 3 magnetic wells, the magnetic field strength and the number of Mega amp turns (MA) of the coils.

> *"FIGURE 6 illustrates a magnetic field of certain embodiments of fusion reactor…. In general, fusion reactor …. is designed to have a central magnetic well that is desired for high beta operation and to achieve higher plasma densities. As illustrated in FIGURE 6, the magnetic field may include three magnetic wells. The central magnetic well can expand with high Beta, and fusion occurs in all three magnetic wells. "*

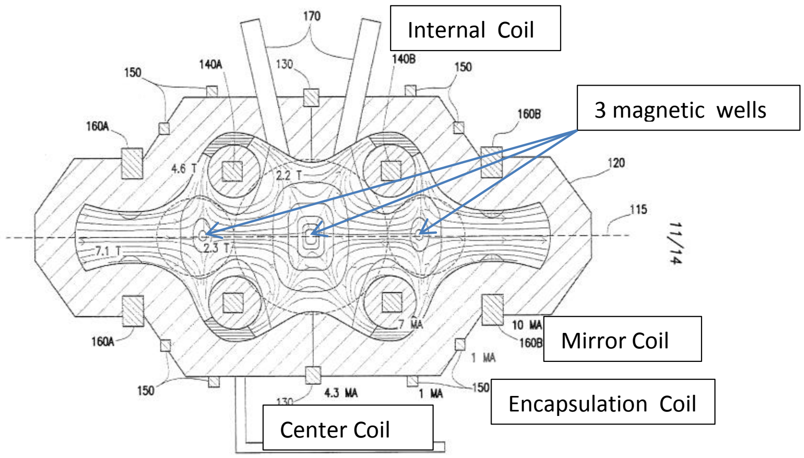


FIG. 6

A few more details of the plasma are also described;

> *"FIGURE 5 illustrates plasma 310 within enclosure 120 that is shaped and confined by center coil 130, internal coils 140, encapsulating coils 150, and mirror coils 160. As illustrated, an external mirror field is provided by mirror coils 160. The ring cusp flow is contained inside the mirror. A trapped magnetized sheath 510 that is provided by encapsulating coils 150 prevents detachment of plasma 310. Trapped magnetized sheath 510 is a magnetic wall that causes plasma 310 to recirculate and prevents plasma 310 from expanding outward. The recirculating flow is thus forced to stay in a stronger magnetic field. This provides complete stability in a compact and efficient cylindrical geometry. Furthermore, the only losses from plasma exiting fusion reactor"110 are at two small point cusps at the ends of fusion reactor ..along center line 115 This is an improvement over typical designs in which plasma detaches and exits at other locations."*

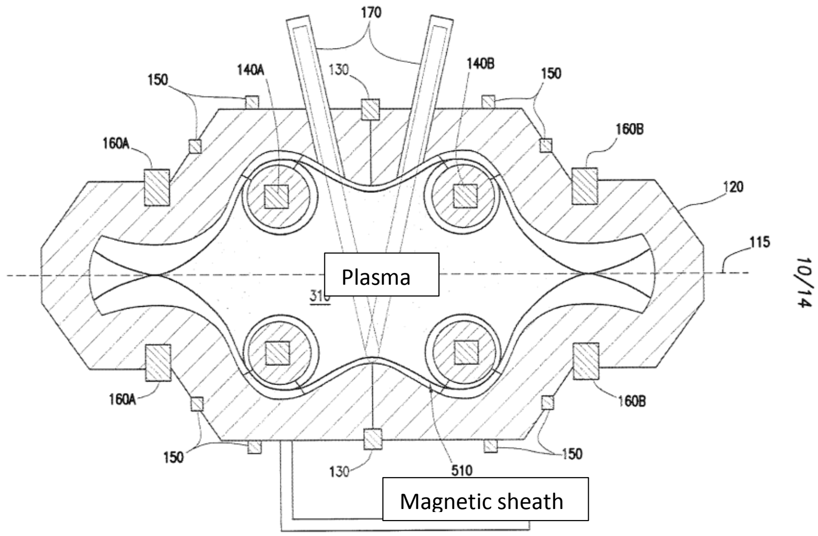


FIG. 5

The inventor recognizes the need to deal with high energy neutrons that are produced by the fusion reaction. Neutron damage has been a serious issue in recent fusion reactors[iv].

> *"(Inner) Coil windings form a superconducting coil and carry an electric current that is typically in an opposite direction from encapsulating coils, center coils, and mirror coils ....Coil windings may be surrounded by inner shield that provides structural support, reduces residual neutron flux, and shields against gamma rays due to impurities. Inner shield may be made of Tungsten or any other material that is capable of stopping neutrons and gamma rays. (The shield) may be made (surrounded by a layer) of lithium (e.g., lithium- 6) ….. (An) Outer shield may be made of FLiBe …*

The claims describe a fairly detailed arrangement of magnetic coils, also suggesting a high level of confidence in the basic architecture. I think we can assume that they have comprehensive simulations that are driving the design detail in the application.

How close are they to making this work ? As several commentators noticed, the press release also talked about the "T4 prototype" which implies that there are 3 previous generations, and certainly implies a significant program. As a long time engineering project manager, I completely agree with their assertion that the small size directly translates to rapid, low cost, development cycles and multiple cycles of learning.

For whatever its worth, my sense is that this is a really serious program from a really serious organization. These things never move as quickly as the engineering team hopes, so delays should be expected. This is an idea with a planetary impact if it works.

[i] http://www.reuters.com/article/2014/10/15/us-lockheed-fusion-idUSKCN0I41EM20141015ment

[ii] http://www.huffingtonpost.com/2014/10/17/lockheed-nuclear-fusion-energy_n_5990900.html

[iii] http://en.wikipedia.org/wiki/Fusion_power

[iv] http://en.wikipedia.org/wiki/Fusion_power