The 30 Second Elevator Speech

Introduction:

A friend of mine – who is completely new to the polywell – asked me to describe it. “Can you sum it up in a few words?” Jeez, I don’t know. Glossing over details is bad. But we do need a “30 second elevator speech” otherwise we cannot gather interest. Below is my attempt. There are probably mistakes in it. It is meant for a busy person who just wants the highlights about the reactor. If they have questions, a reading list is included – and there are lots of people on Talk-Polywell available for discussions and corrections. Enjoy the summary.

At the start, I was excited when I heard about this. The whole world is looking for new energy sources – and if they are not now they will soon. If you can invent something that produces cheap, clean abundant, green energy, you have ended the energy crisis and solved global warming. I have since relaxed a lot – it is unclear how this will go. It is still very exciting.

History:

The idea surfaced, in literature, ‘91 or ‘92. But its roots go back to June 1950. A handful of famous physicists in the plasma community looked at it. A few papers were published that showed theoretically that it would be difficult. The critic who understood the idea best was an MIT PhD student named Todd Rider. His PhD thesis showed it theoretically would be very difficult [3]. That was in ‘95. But the inventor, Robert Bussard kept experimenting with prototypes and navy funding. In 2005, he claimed to have a break through and went public to promote the idea. He died in 2007. This generated allot of buzz on the internet, and some scientists decided it was worth doing experiments. The previous work had been theoretical. So far, experiments have gone well – because project funding has reached close to 10 million dollars. We are waiting to see how the Navy works goes. A paper could emerge sometime next year.

There are technical problems – sure, but I do not know how much more difficult they are from the problems other fusion efforts are facing. The tokamak idea has lots of technical challenges, so does ICF. This Polywell concept has a number of technical problems too – are they as insurmountable as other ideas? Are they device killing? These machines always look easy from the outset. Tokamaks work by racing plasma around in a ring. The polywell idea uses magnets, a vacuum chamber and some injectors. This is basic technology. But, as you get closer to power generation, the problems get bigger and more complex. You have to move to more and more exotic solutions and materials, as well as more complicated models. I do not know how this will turn out. This may yet be a bad idea.

The Basics:

The basic mechanism is: you use the electric force to speed up hydrogen and get it to slam together and fuse. That is a gross, gross, oversimplification - but that is the basic idea. You have 6 rings. Each ring is an electromagnet. They are in a vacuum. All the poles point into the center. In the center there is a zone of no magnetic field. You inject electrons into the center. Supposedly the electrons swell and push back against the magnetic field. They form a big negative point charge. Now you inject ions. The ions are attracted to the center – speed up and slam into the center. Lots of things happen in the center, but sometimes the ions can hit hard enough to fuse. Two downsides are: under no configuration is this device radioactive free and, a working reactor would still give off lots of heat – which is not good for global warming.

Criticism:

Rider, Dolan and Nevins published critique papers in ‘94 and ’95 [1-5]. Rider used theory to show how difficult this was. Rider used order of magnitude arguments: showing that one effect may be 100 times too high for another effect; to make his case. Here is a summary of the big problems:

1. Energy: When particles fly past each other, x-rays are made. This sucks away energy and cools down the reactor. This is a big hurdle.

2. Energy: If the particles go to a bell curve, Rider made a strong case that the machine would fail.

3. Containment: High energy particles escape. This kills you because the high energy ions are those needed for fusion.

4. Cloud focusing: ions side swipe the cloud, this disperses the particles.

5. Scattering: particles get trapped, lost, or stuck – clogging the cusps or in a useless orbit.

6. Charge Distribution: the separation of charge – though it is supposed to be the driving force behind fusion – can also create instabilities. This is bad - but I do not know why.

7. Neutrons: Fusion reactions make neutrons. The more neutrons you detect, the better you are doing. But neutrons will cook the magnets and over a period of months and years break your machine down. They also make things radioactive.

Response to Criticism:

There are claims and there are facts. Below is a list of claims and ideas about the reactor. These are not proven. However, some ideas are connected to well studied phenomena in nature. Concepts like magnetic mirrors, resonance and diamagnetism.

1. Magnetic Mirrors: The magnetic fields act like a mirror rejecting the particles. We now have scientific evidence backing this phenomenon in Polywells [13] – but this is not really much of a surprise.

2. Containment: The electron cloud generates its' own magnetic field. This pushes back against the ring fields. This is called diamagnetism. This pinches off the holes – increasing containment. This is the Whiffle Ball idea. We do not know if it really happens.

3. Internal Structure: Bussard claimed that the charges inside the cloud result in a structure being formed inside the center. That the ions clump in the middle – held in by the surrounding electron cloud. This idea is called the virtual anode. Instabilities can form around this, such as Weibel instabilities [4].

4. Recirculation: Electrons need a high recirculation from the center to the edges - without hitting metal, or the device fails. Rider points this out as needed for success; but very difficult to achieve. Bussard claimed his device did this.

5. Pulsing: Can the reactor be pulsed, fast enough to avoid the particles inside it from going to a bell curve of energy? We have no published data on this. Nevins' paper looked at this [2].

6. Tuning: The system may resonate. The system is complex; many complex systems with competing factors have resonate conditions. A paper from Australia hinted at this [11]. There are seven input variables: containment strength, the geometry, the amount and energies of electron injection, the amount and energies of the ions and confinement time. It would be interesting to see if dimensional analysis could be used to simply the variable space.

7. Collection: Some people have speculated about using direct conversion to recovery energy from the machine. This technology was tested in the 80's, but is hardly mature [12]. It is supposed to have a very efficient recover rate.

8. Design: Bussard claimed the reactor may work better with 12 or 24 or more rings. It is unclear what effect this would have.

9. Size: Bussard claimed that the energy recovered scaled as the 5th power of the radius.

<u>Predictions:</u>

It is hard to make a prediction on this. Much depends on what the Navy finds and publishes. Things need to run their course - and that takes time. This kind of thing should be in a physics journal before it is on The Discovery Channel. If results are great, the project could get allot more attention, both good and bad. If results are mixed, this could turn into an extended government project. If results are terrible, then the technology dies and people stop pursuing it. People have speculated about taking the idea in lots of different directions: startups, academic research, military applications, space flight and power production. I do not know – we will see what happens.

Appendix - Terminology:

Hydrogen – Theoretically, you can fuse anything. The easiest reaction is deuterium and tritium, but the tritium is radioactive. The next easiest is deuterium and deuterium. This is the fuel used by amateurs. These are both isotopes of hydrogen. The ideal reaction is proton, boron-11. That is considered an Advanced Fuel.

Diamagnetism – Under a strong external field, non-magnetic materials can become magnetic. All protons and electrons, even at rest, have magnetic moments. This means that: under the right conditions, these particles can behave like bar magnets. Since these elementary particles are in living tissue – it allowed scientists to levitate a mouse in 2009. The mouse had gone diamagnetic, rejecting the externally applied field. These materials have a magnetic permeability less than vacuum. It is unclear whether a cloud of electrons would behave this way.

Bremsstrahlung Radiation – This is another word for x-ray cooling. In plasma, electrons can slingshot around ions. When this happens the electron slows down. The lost energy has to go somewhere. It leaves as an x-ray. This can happen anytime a charged particle flies by another charged particle. A plasma cloud with 10 billion particles can make lots of x-rays. These x-rays leak energy away from the cloud, cooling it down. This is a major concern.

Maxwellian, Thermalized – Plasma clouds experience this over time. Assume all the particles start at the same energy. The particles collide. One particle gains energy while the other loses energy. Over time the clouds' energy spreads out. Eventually this reaches a bell curve. The cloud has now thermalized. This is a major issue for the Polywell.

Quasineutral – This is an assumption that physicists use. It assumes that there is almost no net charge in a volume of plasma. A plasma can be locally charged, but globally quasineutral. An example of this is when plasma meets a solid surface. The plasma near the solid may have an excess of positive ions. The plasma is locally charged, but globally quasineutral. The reference length used to measure "local" verses "global" distances is the Debye screening length. In his paper, Rider starts by assuming the polywell plasma is quasineutral [1].

Debye Screening Length – The maximum distance over which a particle can interact with another particle. If particle B is outside the Debye length, particle A cannot "see" it. Particle A cannot kinetically or electrostatically interact with particle B;

not directly. If the density and temperature is known; Debye lengths can be estimated for plasma. People have claimed that the Debye length was higher than the radius of containment inside the Polywell. This claim needs to be verified.

Particles – This term means both ions and electrons. Read carefully where the word is used above. Each instance that refers to particle behavior means that both ions and electrons behave this way. This includes mirror reflection, energy distributions and trapping.

Direct Conversion – This is a method to recovery electricity from fusion. It uses alpha nuclei to kick up an electric current. It has a very high theoretical efficiency. Ideally, helium nuclei from the boron fusion reaction fly up a voltage gradient. When they reach the wall they draw two electrons at that voltage. This could be used to electrify the reactor chamber. The idea is attributed to Dick Post. Basic tests on the mechanism were done in the 80's.

Virtual Anode – This is a claim made by Dr. Bussard. The idea is the center of the device has a clump of positive ions. This was mentioned in Bussards 1989 patient. The anode is supposed to arise out of the fact that the center is space charge limited. A number of instabilities could arise from this.

Whiffle Ball – This a claim made by Dr. Bussard. It relates to the cloud of electrons going diamagnetic. An empty polywell has a zone of no magnetic field in the center. The zone is shaped like a 14 point star. You inject electrons. Once enough electrons are in the center, it is believed the cloud goes diamagnetic. The cloud develops its own magnetic field. The cloud field pushes back the external field. The “star” swells. It eventually takes the shape of a sphere. This sphere still has leaks where the typical particle may be able to get out. Therefore, containment now looks like a whiffle ball – a sphere with holes. Proof of this is needed. How big and where these holes would be, as well as the size of containment, are all open questions.

ICF – Inertial Confinement Fusion, this is a scheme for a fusion power plant currently being pursued by the US Department of Energy. Lasers are blasted on to a hydrogen pellet. This compresses the pellet to conditions where fusion occurs. The effort can trace its roots to the 1960’s. Current efforts are centered at the National Ignition Facility.

Weibel Instability - This happens in plasmas made of charged particles. It happens when one part of the plasma all moves in one direction. Typically this is the electrons, because they are smaller and move faster. When all the electrons move in one direction, it creates electrostatic waves in the plasma. These waves fight the tendency of the electrons to move in that direction. In Polywells, electrons supposedly recirculate along field lines generally pointed in one direction. It is unclear how this effect would play out, in a working polywell.

Cusps – This is where two or more magnetic fields meet. Cusps can be holes in containment and yet have a magnetic field. There are three kinds: point cusps, line cusps and funny cusps. The number of cusps would change with geometry.

Recommended Reading:

1. Criticism – Rider, Todd H. "A General Critique of Inertial-electrostatic Confinement Fusion Systems." Physics of Plasmas 6.2 (1995): 1853-872. Print.

2. Criticism – Nevins, W. M. "Can Inertial Electrostatic Confinement Work beyond the Ion-ion Collisional Time Scale." Physics of Plasmas 2.10 (1995): 3804-820. Print.

3. Criticism – Rider, Todd H. Fundamental Limitations on Plasma Fusion Systems Not in Thermodynamic Equilibrium. Thesis. Massachusetts Institute of Technology, 1995. Print.

4. Criticism – Rider, Todd H. "Is There a Better Route to Fusion?" April 1rst 2005. Presentation.

5. Confinement - Dolan, T. J. "Magnetic Electrostatic Plasma Confinement." Plasma Physics and Controlled Fusion 36 (1994): 1539-593. Print.

6. Confinement – PJ Catto and X Z Li. "Particle loss rates from electrostatic wells of arbitrary mirrors." Physics of Fluids 28, 352 (1985)

7. Confinement – Grossmann, William. "Particle Loss in a

Three-Dimensional Cusp." The Physics of Fluids 9.12 (1966). Print.

8. Response – Turner, Leaf, and D. C. Barnes. "Brillouin Limit and Beyond: A Route to Inertial -electrostatic Confinement of a Single-species Plasma." Physical Review Letters 70.3 (1993): 798-801. Print.

9. Response – Bussard, Robert W. "The Advent of Clean Nuclear Fusion: Superperformance Space Power and Propulsion." 57th International Astronautical Congress (2006). Web.

10. Response – Should Google Go Nuclear? Clean, Cheap, Nuclear Power. Perf. Dr. Robert Bussard. Google Tech Talks. YouTube, 9 Nov. 2006. Web. 15 Sept. 2011. .

11. Experimental – Carr, Matthew, and Joe Khachan. "The Dependence of the Virtual Cathode in a Polywell™ on the Coil Current and Background Gas Pressure." Physics of Plasmas 17.5 (2010). American Institute of Physics, 24 May 2010. Web.

12. Direct Conversion - Barr, W. L., R. W. Moir, and G. W. Hamilton. "Experimental Results from a Beam Direct Converter at 100 KV." Journal of Fusion Energy 2.2 (1982). Print.

13. Possibilities - Bussard, R. W. "Fusion as Electric Propulsion." Journal of Propulsion 6.5 (1990): 567-74. Print.