Future generation of tokomaks with super-high magnetic fields

This my presentation it is mainly based on Prof Dennis Whyte's talk

"**Magnetic Fusion Reactor Design**

& The Role of Technology"

which was at the Frontiers in Fusion workshop.

However many others scientific works were used to cover this topic.

What actually Prof Whyte and his team claim? Or to simplify, what is his presentation about?

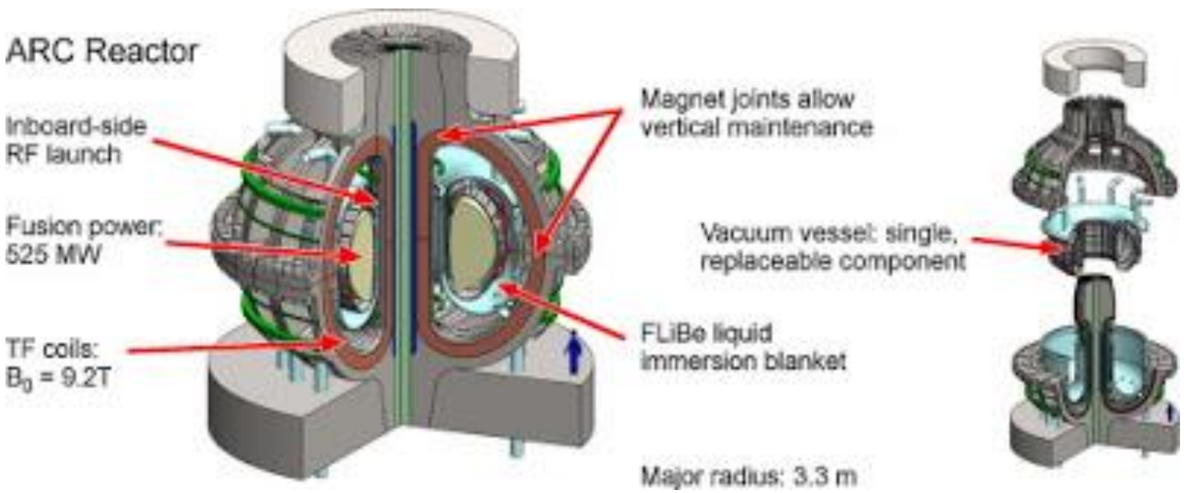
1. All previous MCF devices had one main problem, it's their huge size and therefore huge cost, which became the biggest obstacle in R&D of fusion energy .

2. All these tokomaks were not fit to produce fusion energy because they did not have magnets generating magnetic fields high enough.

3. Recently, few years ago, high-field magnets made of HTS materials were completed and commercially available.

4. Fusion Energy plants supplying electricity to the grid are feasible right now with the current technologies available.

They designed ARC (Affordable Robust Compact) Reactor.



I was really impressed by his talk that fusion energy is possible in the foreseeable future with the current technologies available.

But as every proper scientist honestly I became suspicious about such an ambitious claim.

I decided to carry out research on this subject on my own to prove or disprove this claim.

First of all, what I did is I obtained and studied the original paper where the tokomak reactor was described.

"ARC: A compact, high-field, fusion nuclear science facility and demonstration power plant with demountable magnets" by B.N. Sorbom, J. Ball, T.R. Palmer, F.J. Mangiarotti, J.M. Sierchio, P. Bonoli, C. Kasten, D.A. Sutherland, H.S. Barnard, C.B. Haakonsen, J. Goh, C. Sung, and D.G. Whyte in Fusion Engineering and Design Volume 100, November 2015, Pages 378–405

My impression was it is a proper but complicated paper describing in detail a new type of MCF device.

In addition I was studying other papers on this subject published in proper scientific journals

For example:

[12] “35.4 T field generated using a layer-wound superconducting coil made of $(RE)Ba_2Cu_3O_{7-x}$ (RE = rare earth) coated conductor” by Ulf P. Trociewitz, Matthieu Dalban-Canassy, Muriel Hannion, David K. Hilton, Jan Jaroszynski, Patrick Noyes, Youri Viouchkov, Hubertus W. Weijers and David C. Larbalestier , published in Appl. Phys. Lett. 99, 202506 (2011)

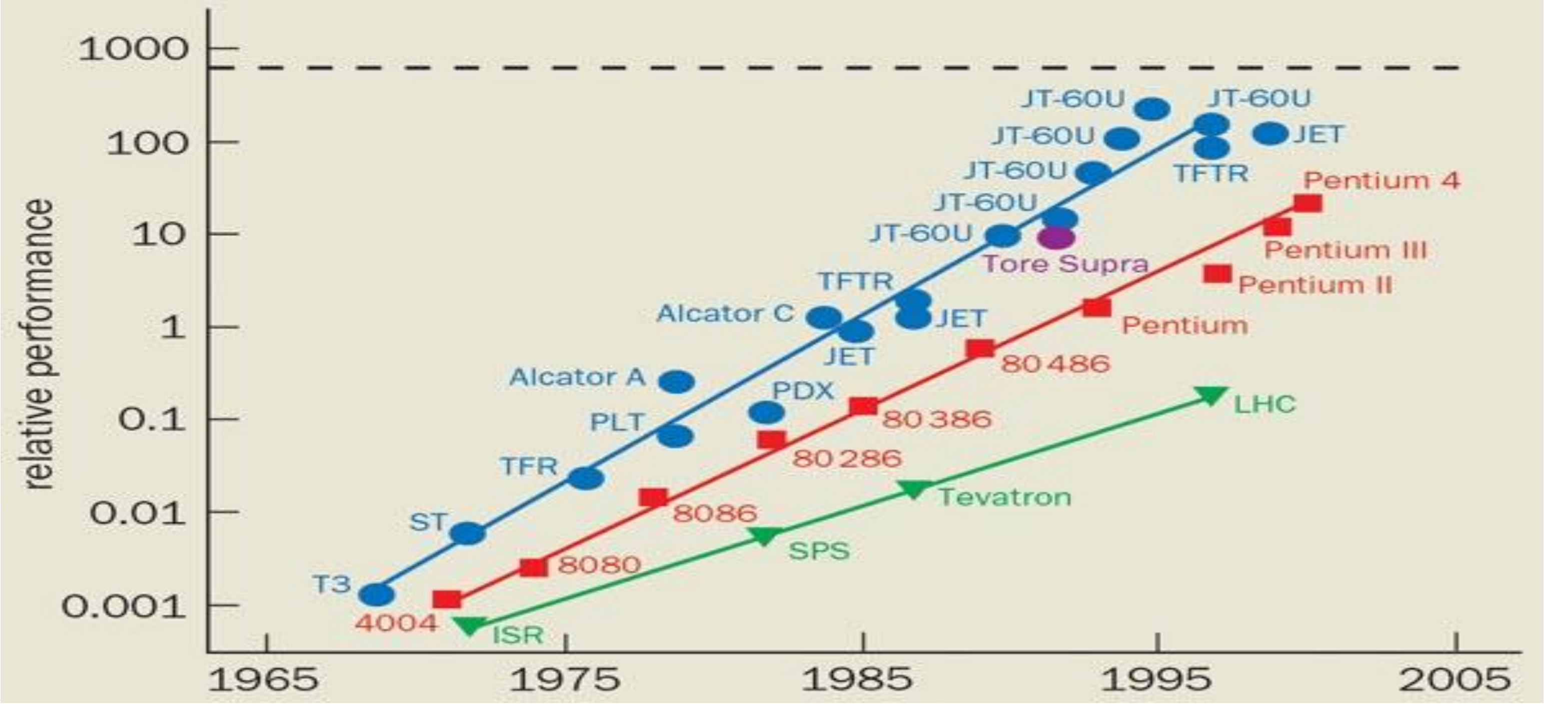
[13] “Design of a Superconducting 32 T Magnet With REBCO High Field” by Coils W. Denis Markiewicz, David C. Larbalestier, Hubertus W. Weijers, Adam J. Voran, Ken W. Pickard,William R. Sheppard, Jan Jaroszynski, Aixia Xu, R obert P. Walsh, Jun Lu, Andrew V. Gavrilin, andPatrick D. Noyes, published in IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 22, NO. 3, JUNE 2012

[14] “SPARC Soonest/Smallest Private-Funded Affordable Robust Compact A small high field torus for changing climates”, Presentation at MIT by B. Mumgaard, Z. Hartwig, B. Sorbom, D. Brunne

Studying these external materials helped me independently to develop a clear picture what actually happens with R&D in magnetic confinement fusion.

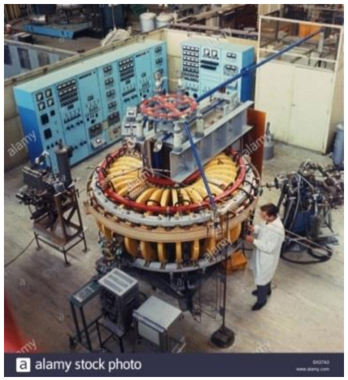
So what did I discover?

Remarkable results in R&D fusion power



Since the 1950's, when first tokomak was built, fusion energy research was developing very quickly, at exponential rate even faster than computers. We can say that the Moore law applied for this trend. It was remarkable result but MCF devices became bigger and bigger.

MCF devises became bigger and bigger



This figure shows Tokomak T 6 built in late 60's

This figure shows one of 24 ITER coils.

What actually we achieved in MCF in 60 years is making MCF devices in thousands times more expensive.

The size of ITER coil is impressive. But it is clear that something is missed in these MCF devises. This is ability of magnets to generate high magnetic field.

All these MCF devises were not fit for purpose because

"MCF, as its names implies, requires high magnetic fields"

J P Freidberg

But copper magnets were not able to generate high magnetic fields. And this was a problem!

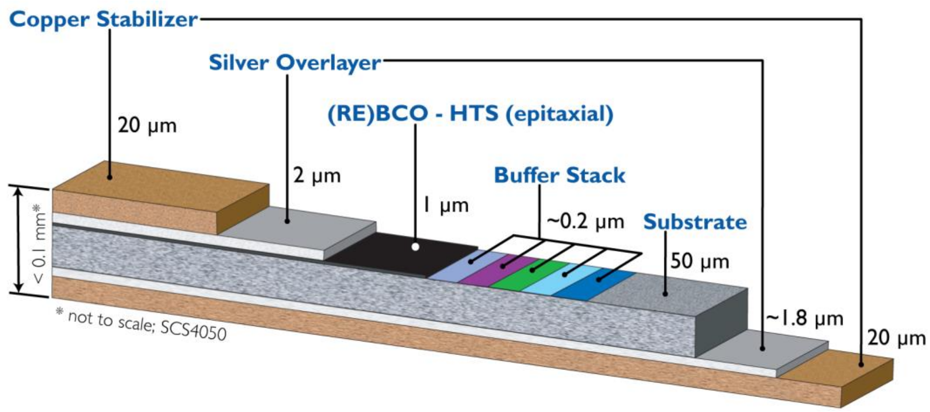
The discovery of HTS in 1986 year changed the situation.

High Temperature Super (HTS) conductors are materials that behave as superconductors at unusually high temperature. HTS were discovered by IBM researchers Georg Begnoez and Alex Muller, who were awarded the 1987 Nobel Prize in Physics.

HTS materials had unique “magic” properties which make them ideal for creating magnets with super-high magnetic fields.

HTS materials were discovered in 1986.

However it took 25 years of R&D to fabricate electrical wires made of these materials, called REBCO.



And then complete magnets with this wire (REBCO) generating super-high magnetic fields, 20 Tesala, 32 Tesla and even higher.

Next step is obvious to use these magnets in MCF devices

As solid proof that this wire REBCO and high field magnets already exists and can be found in

in reliable scientific journals.

[12] “35.4 T field generated using a layer-wound superconducting coil made of (RE)$Ba_2Cu_3O_{7-x}$ (RE = rare earth) coated conductor” by Ulf P. Trociewitz, Matthieu Dalban-Canassy, Muriel Hannion, David K. Hilton, Jan Jaroszynski, Patrick Noyes, Youri Viouchkov, Hubertus W. Weijers and David C. Larbalestier , published in Appl. Phys. Lett. 99, 202506 (2011)

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Scaling factor

What actually will happen with tokomaks performance,
If we increase magnetic fields?
Authors of the paper provides the following formula

$$\frac{\mathrm{P_f}}{\mathrm{V_p}} \propto \left(\frac{\beta_N \epsilon (1+k^2)}{4q_a}\right)^2 \mathrm{B_0}^4$$

This formula means the higher magnetic fields,
the smaller size of MCF device is required.

This formula $\frac{P_f}{V_p} \propto \left(\frac{\beta_N \epsilon (1+k^2)}{4q_a}\right)^2 B_0{}^4$ means the higher magnetic fields, the smaller size of MCF device is required.

So by increasing magnetic field in tokomak we can decrease its size.

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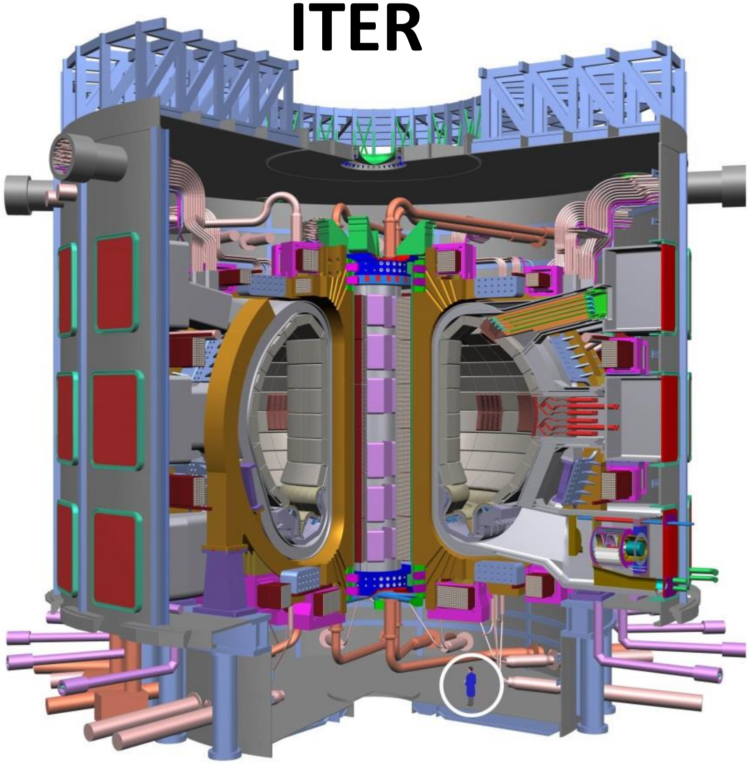
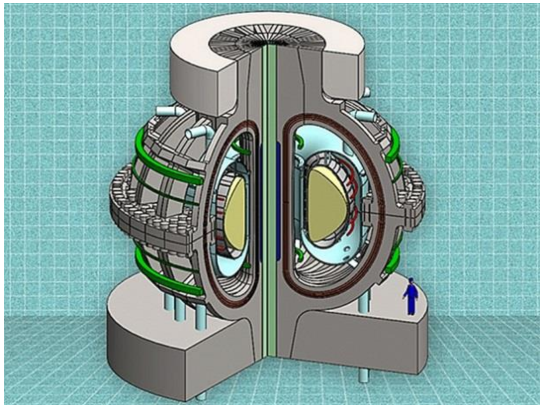


ARC Reactor



These pictures are at the same scale.

The both reactors have the same performance.

But ARC reactor is much smaller because oh having higher magnetic fields!!!

Derivation of the formula is really complicated

$$\frac{P_f}{V_p} \propto \left(\frac{\beta_N \epsilon (1+k^2)}{4 q_a}\right)^2 B_0{}^4$$

However I have asked some experts about this formula who have been working for in fusion energy for ages.

They said me that the formula is correct, and core physics described in the paper looks okay.

From my independent investigation I can conclude:

1. High-field magnets are already completed and really exist.
2. MCF devices with high-field magnets made of HTS materials will be significantly efficient and smaller.
3. Prof Whyte's claim is credible, and his proposal of a new small tokomak-reactor is based on strong scientific evidence.
4. Fusion energy is feasible now (in few years, not 50 years) with the current technologies available and with right approach.

Thank you for attention.

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