Harnessing Fusion Power: Compact Tori

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Useful suggestions from Charlie Baker, John Sheffield

ReNeW
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Outline

Greenwald: research Gaps 10-15, Theme IV panels.

Over-arching comments: dev path cost, cost of *plant,* innovation

Thrust I. Fuel Cycle

Thrust II. Power Extraction

Thrust III. Materials

Thrust IV. Safety

Thrust V. Reliability, Availability, Maintainability, Integrate-ability

Technology gaps for making practical fusion energy systems *

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*G-10. Understanding of the use of low activation solid and liquid **materials,** joining technologies and cooling strategies sufficient to design robust first-wall and **divertor components** in a high heat flux, steady-state nuclear environment.*

*G-11. Understanding the elements of the complete **fuel cycle** particularly tritium breeding and retention in vessel components.*

*G-12. An engineering science base for the effective **removal of heat** at high temperatures from first wall and breeding components in the fusion environment.*

*G-13. Understanding of the evolving properties of low activation materials in the fusion environment necessary for **structural and first wall components.***

*G-14. The knowledge base for fusion systems sufficient to guarantee **safety** over the plant life cycle - including licensing and commissioning, normal operation, off-normal events and decommissioning/disposal.*

*G-15. The knowledge base for efficient **maintainability** of in-vessel components to guarantee the availability goals of Demo are achievable.*

* Greenwald Report

Theme IV organized into 5 panels to address gaps

Thrust I. Fuel Cycle

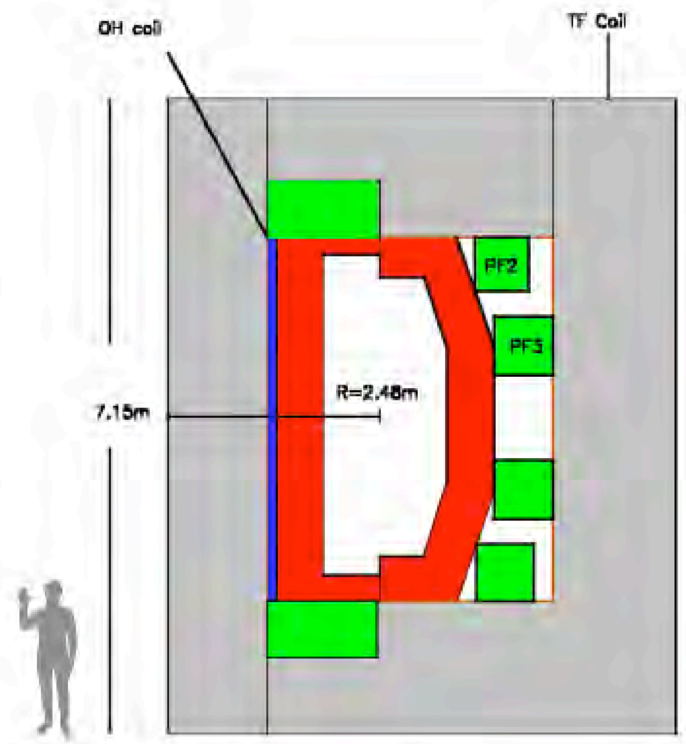
Thrust II. Power Extraction

Thrust III. Materials

Thrust IV. Safety

Thrust V. Reliability, Availability, Maintainability, Inspectability (RAMI)

Present visions of DEMO: perhaps tokamak variations, but there are opportunities for CT researchers to contribute.



Tokamak

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Various ideas put forward: ST, tokamak, etc. for CTF.

Goldston plan indicates opportunity for innovative approaches.

*Stambaugh, Fusion Development Facility

Some over-arching comments

Core is only one component of power plant: for a DT system, the cost of the core is only 30% of total capital costs.

So don’t rate your concept-specific innovation highly unless it impacts every other component in the plant.

Total cost	
Direct cost	65%
indirect cost	25%
Contingency	10%
	100%

Direct cost	
Reactor	50-60%
Conventional plant	35-30%
Structures	15-10%
	100%

Reactor Cost	
Coils	30%
Shield	10%
Blanket	10%
Heat Transfer	15%
Auxilliary power	15%
Other compnents	20%
	100%

Some over-arching comments

Innovation is needed in all areas: CT researchers have an advantage here - we are **highly** innovative:

- ‘Radical design change’ in one community might be construed as pretty conservative by another community: omitting TF and OH coils is totally outside the frame of reference to some, as are different fuel cycles, and fundamentally different ways to deal with heat, fuel etc.

- We have an opportunity to keep options on the table and not narrow the options just yet: this may well be important later.

1 Fusion fuel cycle

This thrust examines how the fuel is put into the system, how it is bred, and how it is extracted from the breeding process and recovered from the surfaces of the vessel, how it is monitored and accounted.

The critical issues here are that large scale production facilities are needed to actually make enough of it for a DEMO, and these don’t exist: TSTA generates 6l/minute of Tritium, where 120l/minute will be needed for ITER and DEMO.

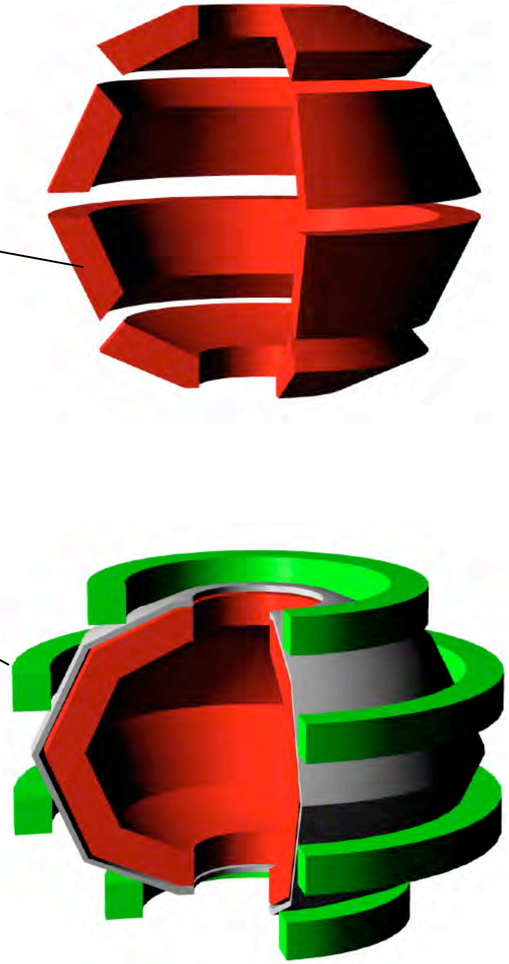
Next, the tritium that is produced is difficult to extract both from the blanket and from the first wall. There are no known ways to fully extract Tritium from the wall once it is in there, and control of the breeding needs to be very carefully done (no over-production!).

1 Fusion fuel cycle: how do CTs contribute?

Blankets can be much simpler:
annular blankets, rather than wedge sections possible: reduces the system complexity, hence cost.

One component of magnetic field
to interact with - B_pol.

By use of a difference fuel cycle,
it is possible to avoid many issues posed by the D-T cycle [4]. --> Think also about advanced fuels (e.g. D-^{3}He).



2 Power extraction

This thrust examines how the heat is extracted from the plasma by use of blankets and divertors, but also entails other subsystems, such as baffles, 1st wall shield, coolant loops, heat exchangers and power conversion components.

Main issues are to not only to understand thermal fluid dynamics and generation of tritium, but also to understand how the system integrates into the fusion core. Understanding thermal gradients in the coolant flow, means for controlling coolant chemistry and effects of fusion environment with strong magnetic field remain to be resolved.

2 Power extraction: how do CTs contribute?

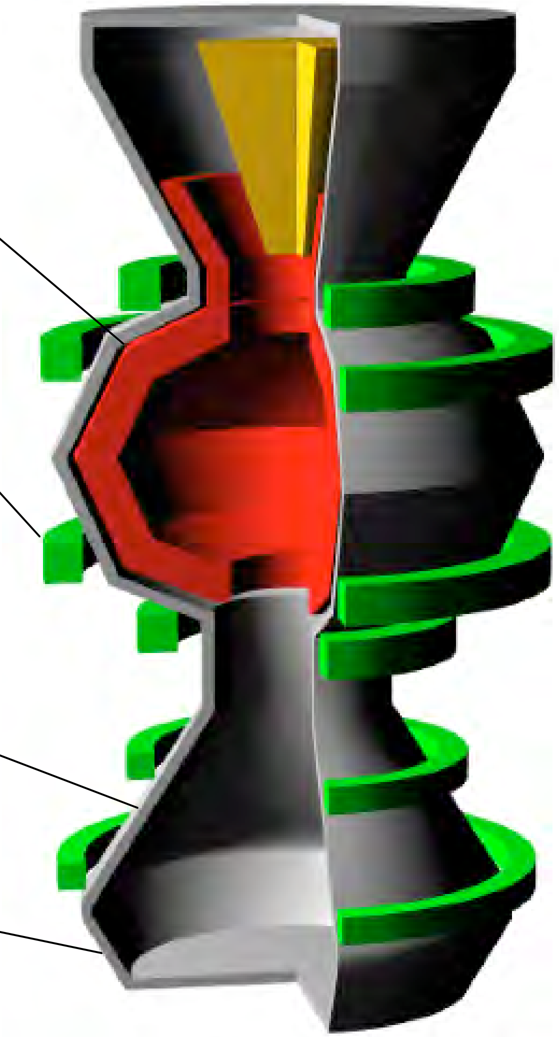
By simplifying the geometry, particularly by omission of the central blanket, a CT blanket may be easier to fabricate, though most issues will remain.

Fluid flow parallel to magnetic field possible - only one component of field to interact with.

Divertors can be mounted some distance from the reactor core, so that means the size of the divertor is independent from the size of the plasma.

External divertors are easier to pump.

Lots of room for Super X or Snowflake.



3 Materials

This thrust examines which materials can be used in a system with high heat and neutron fluxes to surfaces.

The fusion environment does not remain still on any scale-length, and so thermal and mechanical stresses have to be considered on all scale lengths. Largely, the call is to extend the database of materials from samples to components. A testing facility would be needed to do the large-scale materials testing.

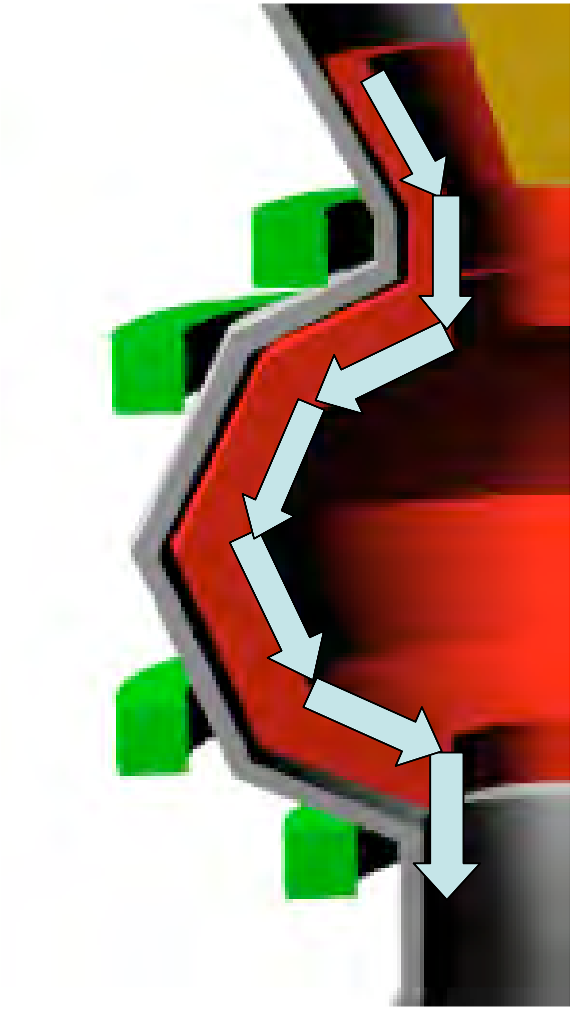
Currently, the tokamak / ST CTF are thought to be the only possible candidates for volumetric sources, although a mirror-CTF based on the GDT is discussed [5]. Spallation sources are also proposed.

3 Materials: how could CTs contribute?

A possible advantage of a simply connected volume and simple flow pattern might be that liquid first walls can be used to protect other surfaces (see e.g. Majeski's white paper [6]).

Fewer joints, all possible components that could fail external to the blanket.

Lower requirements for external divertors.



4 Safety

This thrust examines how one maintains an inherently safe device. The Greenwald report summarized these as:

(1) ability to not require an evacuation plan;
(2) generate only low-level waste;
(3) ability to not disturb the public's day-to-day activities;
(4) ability to not expose workers to a higher risk than other power plants; and
(5) demonstrate a closed tritium fuel cycle.

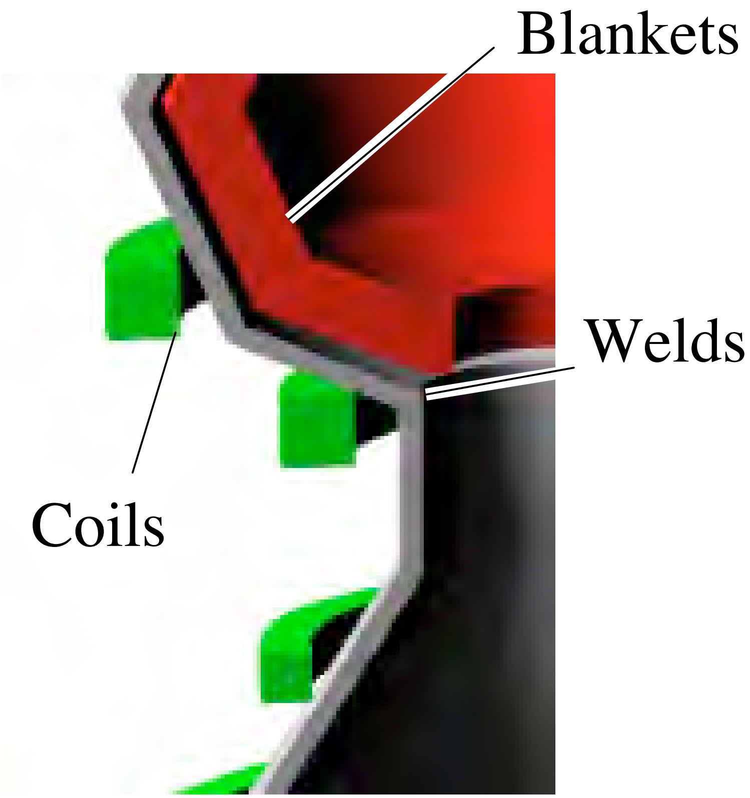
4 Safety: how could CTs contribute?

With a simpler system it is possible that the safety issues are reduced also.

More compact - possibly lower current / energy system.

Failure modes will be fewer with fewer major components (no TF, no OH).

Failure mode analysis could proceed by starting with a critique of existing Tokamak safety analysis (e.g. Holdren’s 1986 ESECOM).



5 Reliability Availability Maintainability Inspectability (RAMI)

Ultimately, the power core will be installed as a power producing plant, generating electricity in an economic manner. This theme examines how the core and subsystem design impacts the CoE, and poses categories for assessing economy.

5 Reliability Availability Maintainability Inspectability

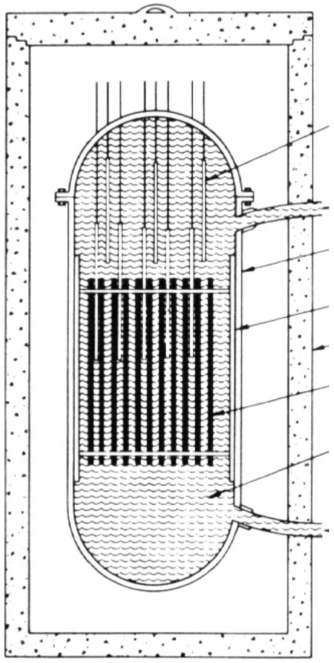
(RAMI)

How to make a system as reliable as possible?

Comparisons are made between the fusion and a fission power cores of similar output power.

The subsystems are also increasingly high tech, not low, and so the issue of reliability of a highly complex system is questionable.

CTs have few components, so less likely to fail, lower tech components that are less complex.



Fission

CT

5 Reliability **Availability** Maintainability Inspectability

(RAMI)

In the event of a failure, how will the system be repaired expediently?

The cost of electricity scales inversely with availability, so down-time has to be minimized. To be taken seriously by the utilities there has to be a minimum of 50% plant availability, that pushes the fusion core to need at least 80% availability.

The GA FDF facility proposes to address this issue by making the system highly modular (mountable annular sections, not wedges, demountable toroidal coils).

No interlocking coils means that system will be easy to take apart.

5 Reliability Availability Maintainability Inspectability (RAMI)

How to perform maintenance?

The view of a reactor being constructed as a ‘ship in a bottle’ no longer is valid as highly modular systems are being designed – with either wedge or annular sections.

Simply connected systems will have advantages here, particularly if the coils are not interlocking, which would allow for easy annular construction.

Entire system can be built from annular modules that can be demounted easily.

5 Reliability Availability Maintainability **Inspectability** (RAMI)

An effective inspection and maintenance system that is proficient in monitoring equipment health, detecting and isolating failures, providing spares, effecting and verifying repair, refurbishing failed components, and processing radwaste.

Summary

Although many of the issues remain common, by omitting the OH and TF coils, the **system becomes simpler, more compact and hence easier to maintain and repair**, which should allow for higher availability.

Fewer complicated components perhaps means that the system will be more reliable.

A simply-connected system could lend itself to the exploration of liquid first walls.