PRINCETON PLASMA PHYSICS LABORATORY

PPPL – Fusion Power Associates

Steve Cowley, Director

December, 2020

100 years of fusion. August 24th 1920 The British Association

- Arthur Stanley Eddington -- delivered the presidential address:

"The Internal Constitution of Stars"

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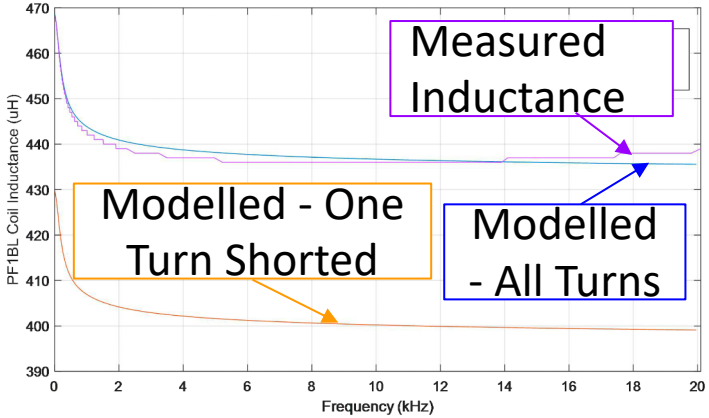
"This reservoir can scarcely be other than the sub-atomic energy which, it is known, exists abundantly in all matter; we sometimes dream that man (!) will one day learn how to release it and use it for his service. The store is well-nigh inexhaustible, if only it could be tapped".

Arthur Stanley Eddington 1920.

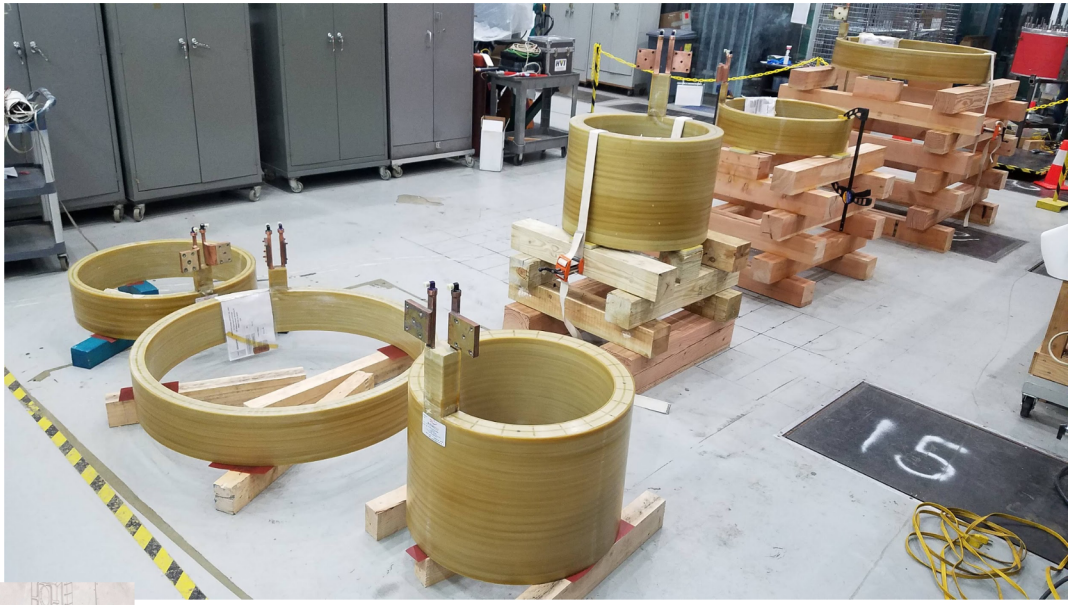
- Eddington proposed that the sun is transforming hydrogen into helium – thereby liberating "fusion energy". It is. He went on to estimate the sun's lifetime – surprisingly accurately (15 Billion years).

NSTX-U Fabrication and installation



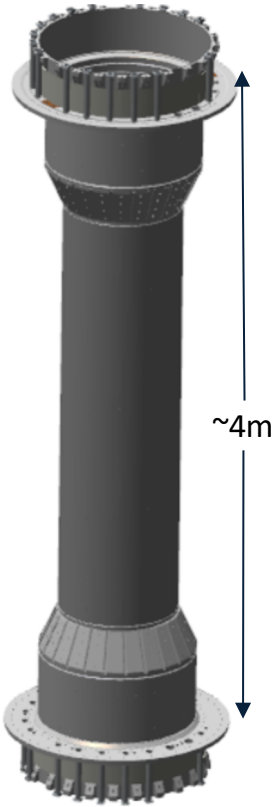
PF1B Coil Inductance vs. Frequency

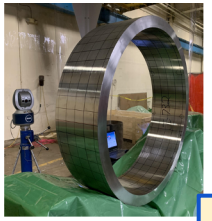
All 9 coils delivered – 3 spares

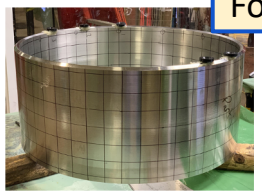


Tiles 50% complete

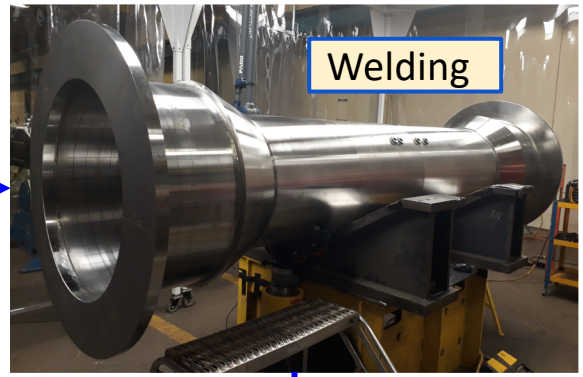
Casing Manufacture



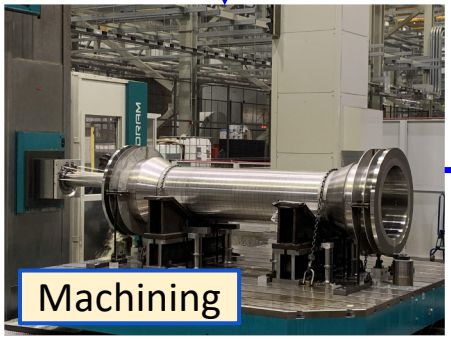




Forgings



Welding



Machining

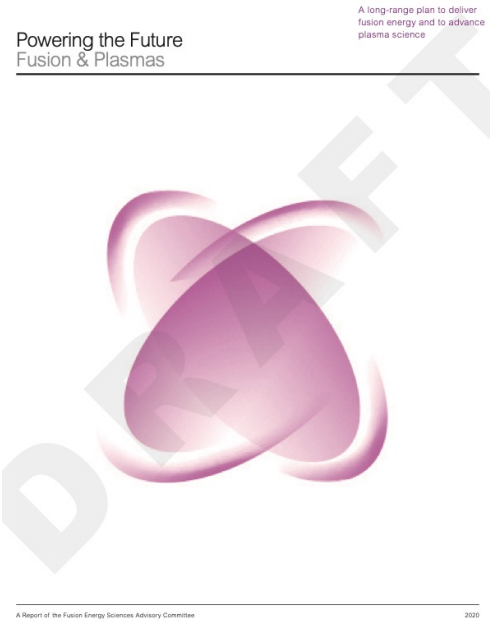
Welding

Machining

Finish Machining and Final Assembly

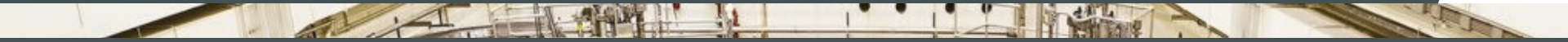
FESAC planning – and PPPL -- Welcomed by PPPL.

- Fusion strategy for PPPL. Two primary aims (since TFTR).
  - ITER – achieve a burning plasma. Diagnostics. PPPL wants to enable a strong US participation in burning plasma experiments.
    - Disruption prediction
    - Whole device model – and rapid analysis tools.
  - Innovate cheaper more efficient fusion reactor concepts. NSTX and Stellarator.
    - **Unit price must come down for fusion to enter the market. Industry spoke clearly. Cost in balance of plant.**
- Without innovation we don't have a plasma configuration that translates to a workable/cost effective/"small" reactor that can handle its power. Whatever the **B** field. e.g. Wade 2019 FPA.
- For ignition self-similar (e.g. Zohm 2018): $\beta H^3 B^4 R^3 = constant$



$$\mathcal{P}_{Fusion} \times Volume \propto \beta^2 B^4 R^3 \propto \frac{\beta}{H^3}$$

Disruption energy per unit area of wall $\propto \frac{\beta^{1/2}}{H^{3/2} R^{1/2}}$



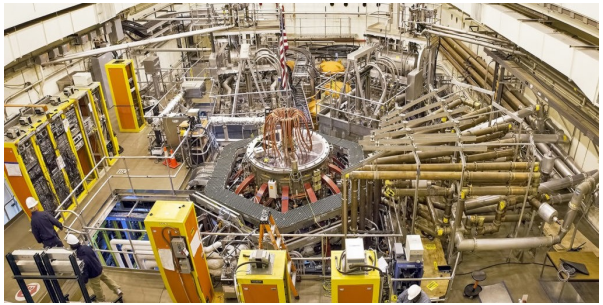
1. **Rebuild NSTX-U and advance the spherical tokamak as a reduced-cost fusion concept**

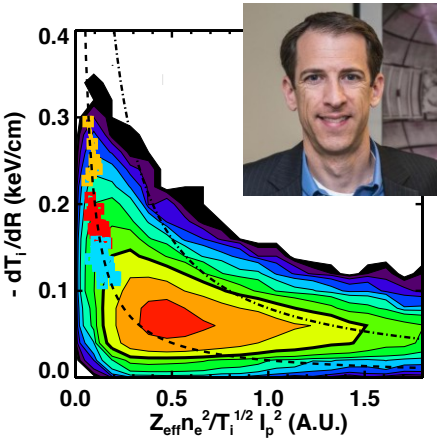
Two-Phase Science Mission:

1. *to evaluate the ST's potential as a reduced-cost fusion concept,*
   Key is confinement (H_{eff}) – can sphericals do better?
2. *to develop novel liquid metal power and particle exhaust solutions.*
   Power per unit area on divertor > 50MW/m^2?

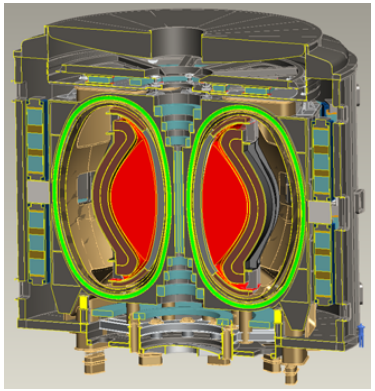
Five-year plan developed with FES:
Collaborators assembled into a team, diagnostic development.

Significant progress in NSTX-U research planning & analysis



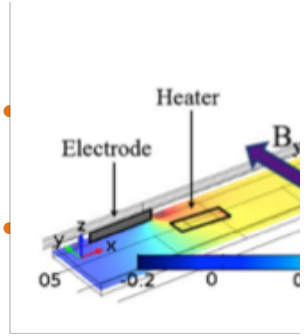


- NSTX-U 5 year research plan favorably reviewed
  - 3 Mission Objectives:
    1. Understand ST confinement and stability physics
    2. Sustain plasma current without transformer action
    3. Develop innovative power and particle exhaust handling
- New understanding of enhanced confinement
  - Ion energy confinement increases at higher temperature
  - Favorable result → supports compact ST reactor vision



Developing li

- Co-Leading initiative to for power e systems



LMX chute flowing ex

- Results fr NSTX-U

Jacob Schwartz

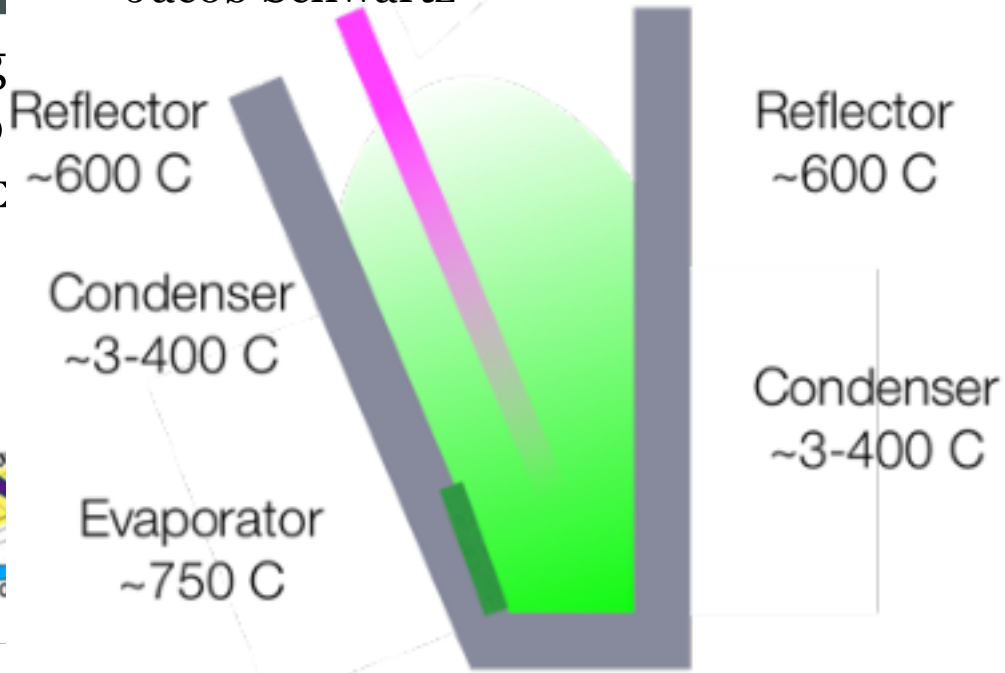
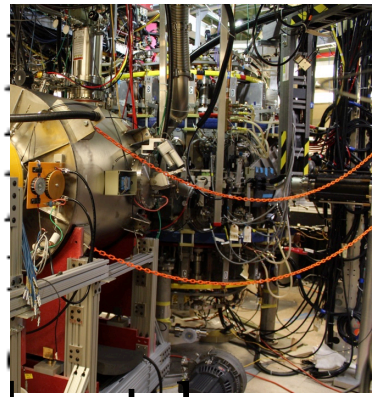


FIG. 3: Lithium vapor box divertor without baffles.

ow operational

ement w/ liquid Li



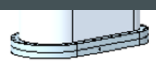
metals on

Matt Lucia
Dennis Boyle

Radical shifts

Improve fusion through innovations in 3D shaping, boundary composition, and magnets – enabling technology and science

- ARPA-E BETHE - FES program funded $4M development of permanent magnet array for stellarator. Partner with small company SABR-LLC on engineering. Co-funding from Stellar-Energy Foundation. Public Private.
- Partnering with ANSYS on virtual engineering, design and assembly.
- Simons “Hidden Symmetries” grant funding computational optimization.
- David Gate’s technical and political leadership, Mike Zarnstorff insight.
- Because of low recycling power Stellarators may make cheaper reactors. Menard 2016.



C. Zhu, et al., 2020 Nucl. Fusion **60** 076016,
P. Helander, et. al. Phys. Rev. Lett. **9,** 2020

Conclusion