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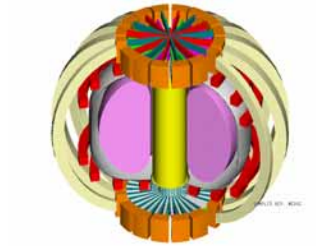

Status Report of Next-Step ST (NSST) Scoping Study

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For the NSTX National Team and the NSST Working Group (LPDA)

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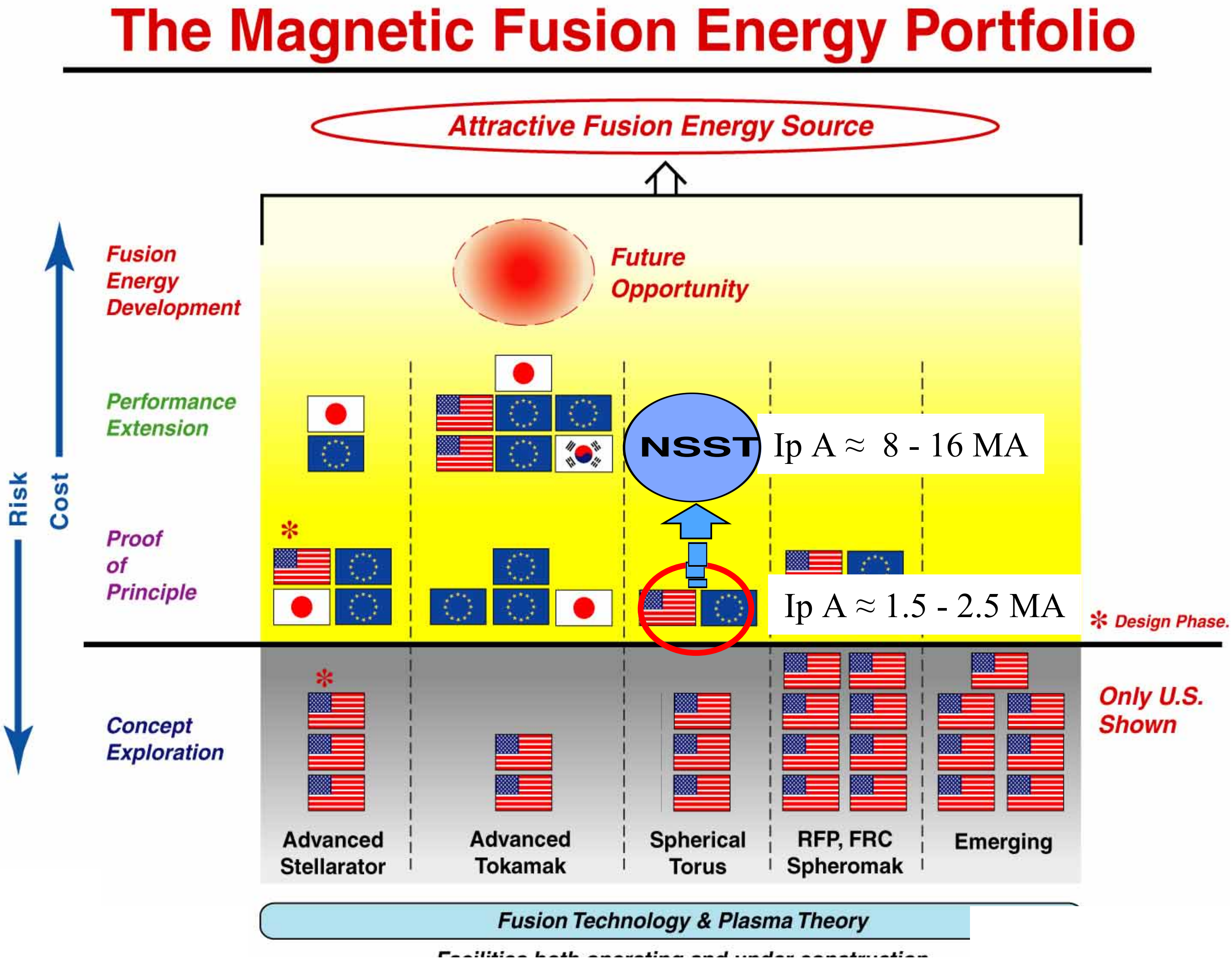
PPPL

Talk Outline

- ST Performance Extension Experiment
  Next-Step ST (NSST)
- Mission and Approach of NSST
  - Scientific Opportunities of NSST
- NSST Device Design Point
- Summary

The Next-Step-ST will be in the Performance Extension Phase



What is Performance Extension?

Criteria, Goals and Metrics for FESAC (10/8/99)

NSST

- Explored physics of the concept at or near the fusion-relevant regime absolute parameters.
- Achieved dimensionless parameters approaching those of a fusion power system.
- Deployed a variety of auxiliary systems at significant scale for control and optimization.
- Extensive diagnostics provided thorough coverage in space and time.
- Integrated physics and technology elements into single demonstrations.
- Theory and modeling provided a predictive capability of the concept.
- Generated sufficient confidence that absolute parameters needed for a fusion development can be achieved and a fusion program with a reasonable cost can be implemented.
- Conduct as a National Program.

In addition (not specifically in the report),

- DT Operation will be clearly an additional benefit.

Mission of NSST

NSST

- Explore physics of non-inductively sustained ARIES-ST-like regimes at mid-current range (5-10 MA)

- Contribute to the MFE science data base for low aspect-ratio / high beta toroidal plasmas at fusion reactor parameters.

- Develop non-Ohmic start-up techniques at Multi-MA level for ST (and AT) reactors.

- Provide sufficient physics basis for design and construction of Fusion Energy Development devices (e.g., VNS and/or ST-pilot plant.)

NSST Device and Plasma Parameters

NSST

Parameters	Unit	NSTX	DIII-D	JET	NSST	ARIES-ST
R	m	**0.85**	1.65	3	**1.5**	3.2
a	m	**0.65**	0.62	1	**0.94**	2
A(R/a)		**1.3**	2.5	3	**1.6**	1.6
V	m^3	**12**	25	100	**77**	950
B_T	T	**0.3(0.6)**	2.1	3.5	**2**	2
Ip	MA	**0.8- 1.6**	2-3	3-3.8	**5-10**	28
A Ip	MA	**1-2**	5-7.5	9-12	**8 - 16**	45
q_x		**10**	3	3	**10**	10
q*		**3**	2	2	**3**	3
κ		**1.6-2.4**	1.8-2.4	1.7	**2.7**	3.6
δ		**0.2-0.6**	0.6 - 0.8	0.2-0.3	**0.6**	0.67
Config.		**SN/DN**	SN/DN	SN	**SN/DN**	DN
τ–flat top	sec	**5 (1)**	6-10	30	**4 - 50**	SS
Paux	MW	**11**	23	40	**40**	27

NSST Would Achieve Dimensionless Plasma Parameters

NSST

	NSTX	NSST	ARIES-ST
ν^*	0.2	0.04	0.015
a/ρ_i	35	130	140
β_T	0.4	0.4	0.5
$\varepsilon\beta_T$	1	1	1
q_{95}	10	10	10
F_{bs}	0.7	0.85	0.95
n_e/n_G	0.7	0.7	0.7
V_{NBI}/V_{Alfven}	3	0.7	
V_α/V_{Alfven}		4.4	5

"Achieved dimensionless parameters approaching those of a fusion power system. FESAC, PE"

ST Research at Fusion Parameters (10 keV, 10^{14}cm^{-3})

"Explored physics of the concept at or near the fusion-relevant regime absolute parameters. FESAC - PE"

NSST

- Plasma confinement: Understanding and Improvements
  - Confinement physics for L-mode, H-mode and ITBs at fusion temperatures, high beta and low collisionality
  - H-mode physics including L-H transition power threshold at multi-MA level.

- MHDs: Understanding and avoidance
  - Resistive-wall mode and plasma rotation
  - NTM and stabilization
  - High frequency MHDs (TAE, CAE, etc.)

- Non-inductive plasma sustainment at multi-MA level using bootstrap current and current drive.

- Non-OH Start-Up at multi-MA, representing an order of magnitude increase from 0.5 MA NSTX CHI goal.

- Heating & Particle Handling: With anticipated 30 MW of heating power up to twice τ_{skin} (≈ 20-30 sec), the challenge will be significantly greater.

- Energetic particle physics including α-particle effects.

R&D of Non-Ohmic Start-up for ST

NSST

ST Reactors (ARIES-ST, VNS, etc.) require non-OH Start-up.

	HIT-II	NSTX	NSST	ARIES-ST
Ip (MA)	0.2	0.5	5	28
R(m)	0.3	0.8	1.5	3.2

On NSTX, CHI (a fast start-up technique) making steady progress. .

- CHI has already produced 390 kA of toroidal current with current multiplication of 14. (Goal is Ip = 500 kA)
- CHI discharge quality is improving (n=1 oscillations, higher temperature, etc.)

For NSST, the start-up requirement is a significant extrapolation even with complete success of CHI on NSTX.

⇒ Development of non-OH start-up at multi-MA level will be an essential element of the NSST research program.

Non-OH Start-Up Research on NSST

• ARIES-ST and ARIES-AT assume bootstrap overdrive for a (slow) start-up. For steady-state devices, the required ramp up time is not a limiting factor.
• Fast start-up such as CHI is attractive for a limited pulse length ST devices including NSST.

$\Rightarrow$ The NSST Non-OH Start-Up research should include slow-start-up techniques.

• NSST to investigate fast start-up techniques including CHI and poloidal field utilization to demonstrate non-OH multi-MA start-up.

• NSST to investigate slow start-up techniques using bootstrap current over drive + CD to establish physics basis for mulit-MA start-up feasibility.

Non-Inductive Sustainment Research on NSST

NSST

• ARIES-ST and ARIES-AT assume largely bootstrap current sustained (95%) discharges. It is clear the NSST non-inductively sustained plasmas should maximize the bootstrap current fraction.
• On NSTX, HHFW induced H-mode produced high $\varepsilon\beta_{pol} \approx 0.8$ with nearly zero loop voltage in the heating mode. ⇒ The current was believed to be sustained mainly by bootstrap current.

• NSST to investigate techniques to maximize the bootstrap current fraction including some degree of pressure profile modification (H-mode, advanced fueling, etc.).

• NSST to investigate efficient non-inductive current drive techniques including EBW. Gyrotrons are available in this frequency range.

Possible Heating and Current Drive Systems

NBI: Use existing 4 NBI Injector 30 MW System from TFTR

- Bulk plasma heater
- Impart toroidal momentum for toroidal rotation for wall mode stabilization and sheared flow for improved confinement.
- "Core" Fueling
- Facilitate plasma diagnostics
- Increase DT reactivity.
- Current Drive

ICRF: Use existing 10 MW RF systems (8 Transmitters)

- Core ion and electron heating. (2 Ω_T)
- Mode-conversion CD and NTM stabilization
- IBW for transport barrier formation for pressure and bootstrap current profiles

EBW (10 MW)

- Non-inductive start-up assist, NTM stablization and CD.

"Deployed a variety of auxiliary systems at significant scale for control and optimization. FESAC, PE"

Scientific Benefit of DT Operations

NSST

- Energetic particle physics is an exciting area of research for ST.
  - NSTX NBI heated discharge with $V_{NBI}/V_{alfven} >> 1$, high Ti regime was observed.
  - Stochastic ion heating via CAE proposed to explain the high Ti regime in NSTX. (D. Gates, et al., PRL 2001)
  - V_{α}/V_{alfven} is expected to be large (≈ 5) for ARIES-ST.
  - Comparable V_{α}/V_{alfven} (≈ 4)an be obtained on NSST.

- DT Operations could help access higher performance plasmas through increased alpha-heating power and isotope effect.

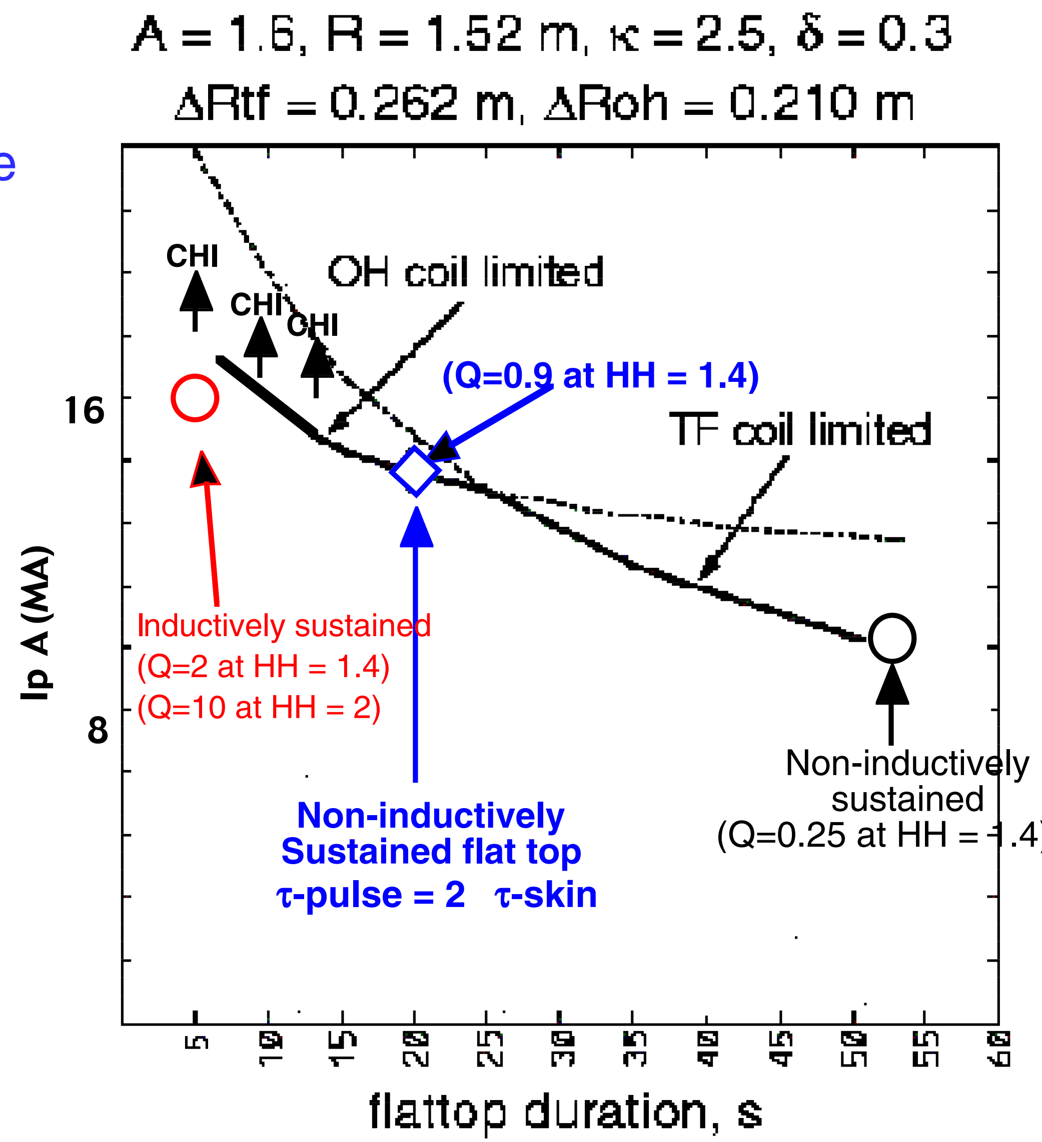
- α-particle confinement and effects on plasma stability and confinement behavior are important scientific issues for FED ST devices.

NSST Can Access A Wide Parameter Range

NSST

A Flexible Systems Code developed to explore possible device parameters within the following constraints*

- Available site power.
- Fit within the Exp. Hall.
- TF/OH coil temperature limits.
- P_{aux} = 30 MW



* Work carried out with the FIRE effort.

* Code benchmarked with TSC.

NSST Operational Scenarios

NSST

Aiming toward ARIES-ST vision:

- OH to ramp-up to Ip ≈ 5-8 MA with half-swing.

- Non-inductive current drive and heating power to sustain Ip ≈ 5 -8 MA (by bootstrap + CD) for twice τ-skin (≈ 20 sec).

- Non-OH start-up capability to investigate start-up techniques (both fast and slow) at multi-MA level.

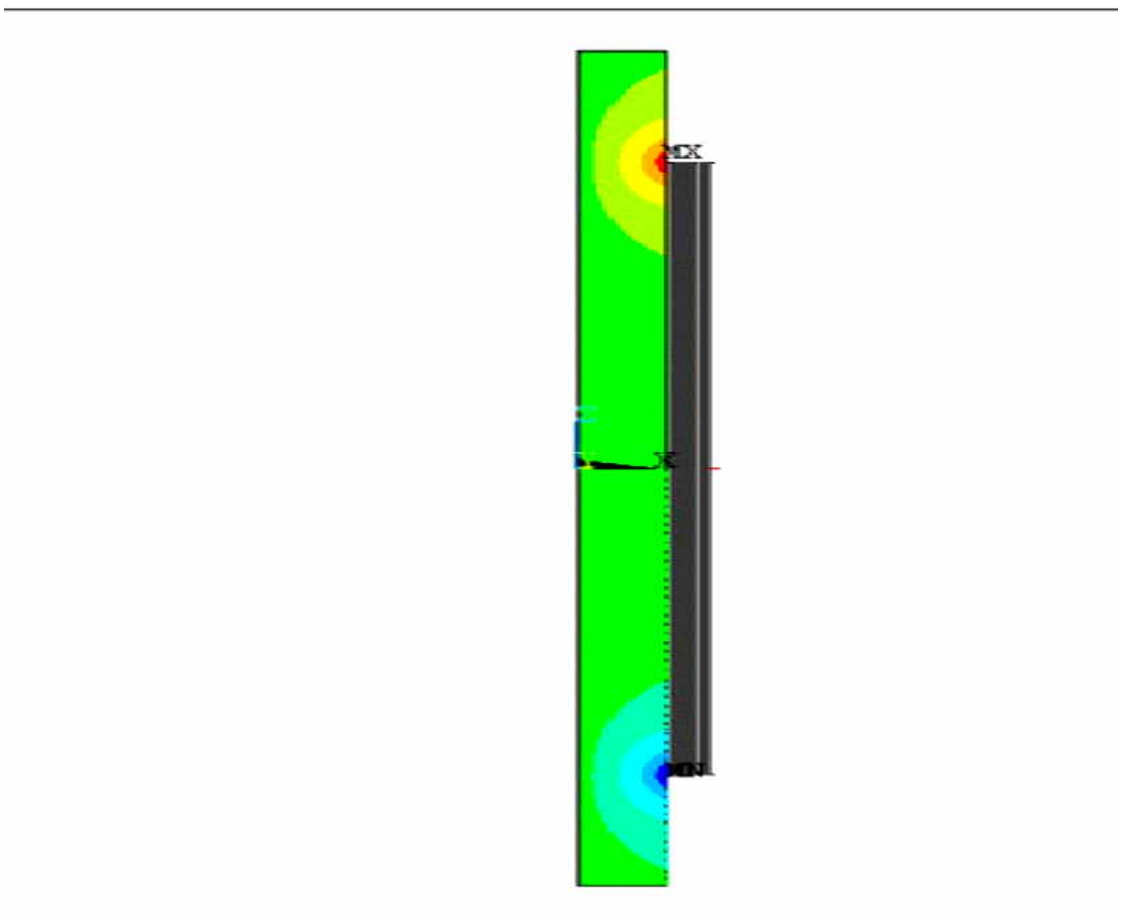
- Full OH swing to access ≈ 10 MA range for purely inductively driven pulse ≈ 5 sec >> τ_E.

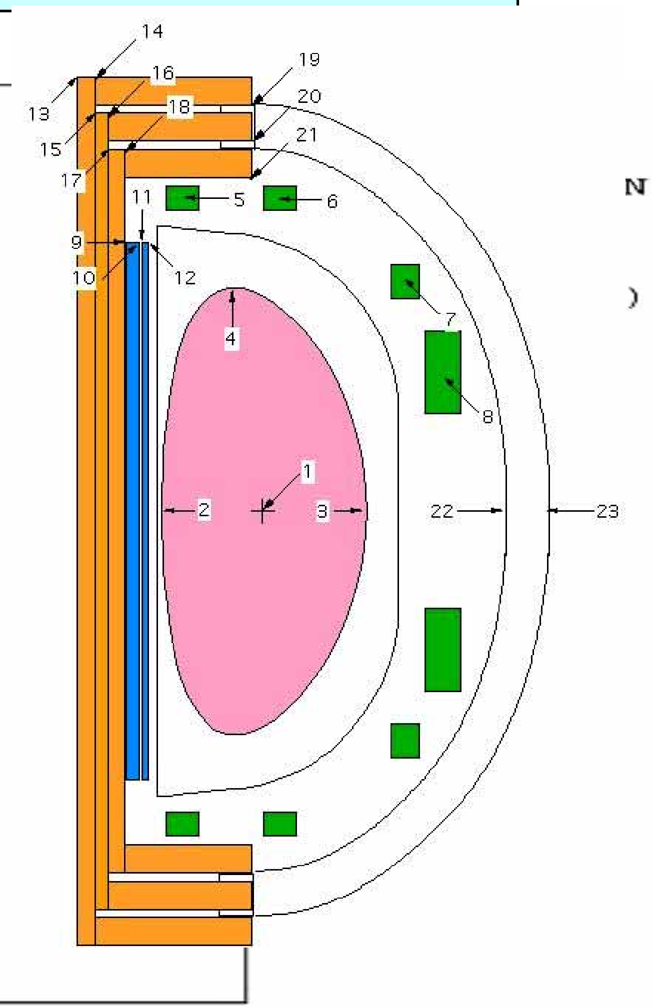
- Facility to be tritium capable for α-particle physics investigation.

OH Is Feasible for NSST

NSST

Torque on TF by OH the major engineering challenge:



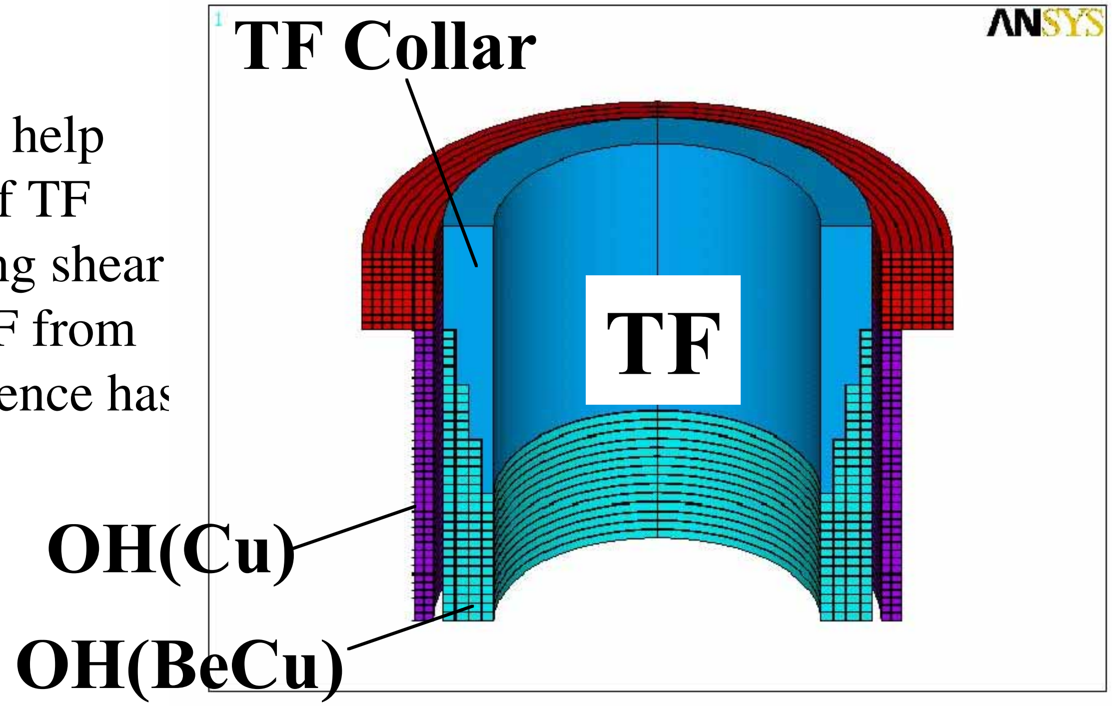


• Liquid nitrogen cooled coils to minimize the power and energy requirements.

A Viable OH Design Possible Through Engineering Innovations

NSST

• Tailoring ends of OH coil can help reduce B_r and increase length of TF support collar, further decreasing shear stresses due to the torsion on TF from OH radial field. (NSTX experience has been very valuable.)



• A novel 2 part OH coil was developed to optimize use of available space resulted in 50% flux increase

- outer part is OFHC Cu operated to both stress and thermal limits.
- inner part is BeCu operated to thermal limit (but typically still below stress limit)

NSST to Utilize NSTX Organizational Model

NSST

- Designed and constructed by a multi-institutional national team.
- Cost effective utilization of existing site-credit and infrastructure.
- Flexible design to facilitate upgrades / maintenance / and repair.
- Emphasize physics capabilities including state-of-the-art diagnostics.
- Experiments to be carried out by a national research team selected through the DOE peer-review process.
- A key element of the national fusion energy science program with extensive theory/modeling while promoting international cooperation.

Summary

NSST

- NSST will provide physics data base for Ip A ≈ 8 - 16 MA class toroidal plasmas at lower aspect ratio and higher toroidal beta regimes.

- A Performance Extension (PE) step toward ARIES-ST and VNS is a logical NSST goal. If successful, NSST will provide sufficient physics basis for the construction of VNS/ST-Pilot Plant.

- The NSTX Organizational and Research Program Model seems to apply well to NSST.

- Research Opportunities:
  - Non-inductive start-up (slow & fast) development at multi-MA level.
  - Non-inductive current sustainment at multi-MA level
  - Plasma confinement and stability investigation at high temperature, high beta and in the presence of α-heating.
  - Particle and Power Handling at high heating power and longer duration.

This is a draft NSST scoping study.
Your advice and comments are greatly appreciated.