NCSX Machine Configuration Design Progress

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Abstract

A new experimental facility, the National Compact Stellarator Experiment, is being designed to support the development of high-beta, low aspect-ratio stellarators. To fulfill its mission, the facility design is required to: 1)be based on a stellarator magnetic configuration which enables it to address reactor physics issues, 2)have high probability of achieving its physics mission within the uncertainties of present-day physics models, and 3)provide access for experimental tools such as plasma heating systems and diagnostics. The most critical machine component is the coil system which determines the plasma configuration and its properties. To gain an understanding of the practical implications of the mission requirements and determine the optimum approach to satisfying them, a range of coil configuration options was investigated. To address requirement 1, each option was designed to reconstruct a common stellarator plasma configuration with desired stability and transport properties. To mitigate mission risk (requirement 2), magnetic configuration flexibility features, e.g., coils for inductive current drive and axisymmetric field shaping and an operating space exceeding the nominal magnetic field and pulse-length requirements, were included in all designs. To implement requirement 3, port access requirements for neutral-beam and radiofrequency heating systems, a diagnostic array, and vacuum pumping were determined and these were used to analyze the various designs. Differential costs were evaluated to provide a basis for assessing benefit/cost.

NCSX: An Experimental Facility to Support the Development of Compact Stellarators

Mission

Develop the knowledge base needed to assess the attractiveness of compact stellarators:

- Conditions for high-beta disruption-free operation.
- Beta limits.
- Neoclassical transport reduction by quasi-axisymmetry.
- Anomalous transport reduction by flow-shear control.
- Neoclassical tearing mode stabilization by magnetic shear.
- Power and particle exhaust compatibility.

Physics Requirements

- A reference plasma configuration designed to test compact stellarator physics principles:
  - High β (4-5%) with reactor-like profiles
  - Stable with no wall.
  - Quasiaxisymmetric for good orbit confinement and low flow damping.
  - Stellarator shear for neoclassical tearing mode stabilization.
  - Low aspect ratio ($R/\langle a \rangle \sim 4$).
- Flexibity to vary configuration to test physics.
- Robust against uncertainties in the physics.
- Well diagnosed.

Engineering Requirements

- Coil geometry and currents compatible with reference operating scenario: vacuum to reference high-beta state with good physics properties.
- Special coils and current headroom for flexibility.
- Access for heating, diagnostics, and pumping.
- Power and particle handling for good performance.

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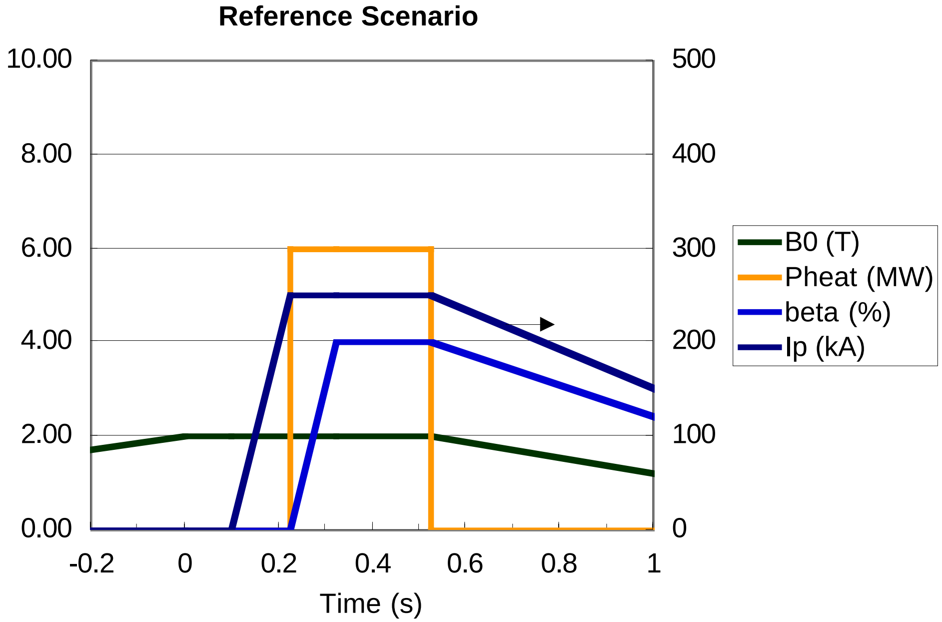
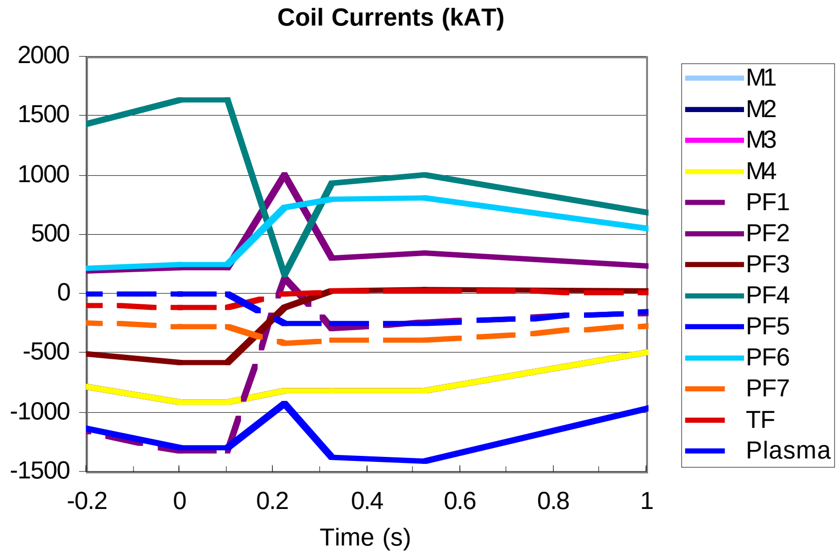
Design

Reference Scenario Defines Discharge Time Evolution





- Idealized pulse, design basis for coils and power supplies.
- B_0=2 T, I_p=250 kA, β=4%.
- Current ramped at 2 MA/s.
- 0.3 s heating pulse.

Physics Simulations of Startup: E. Lazarus, this session.

Choosing the Best Design: Several Options Were Compared

Plasma Configurations

- Surveyed a large configuration design space: $N_{periods}$ (2-4); $R/\langle a \rangle$ (3-5); κ (2.5-3.0); ι_a (0.47-0.78)

A. Reiman invited paper provides details.

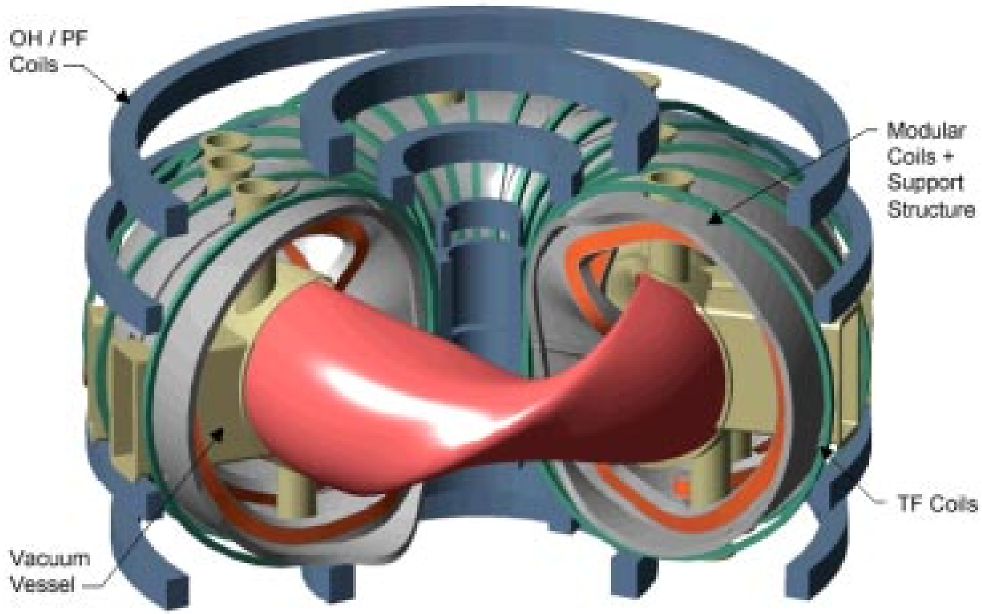
Coil Topologies

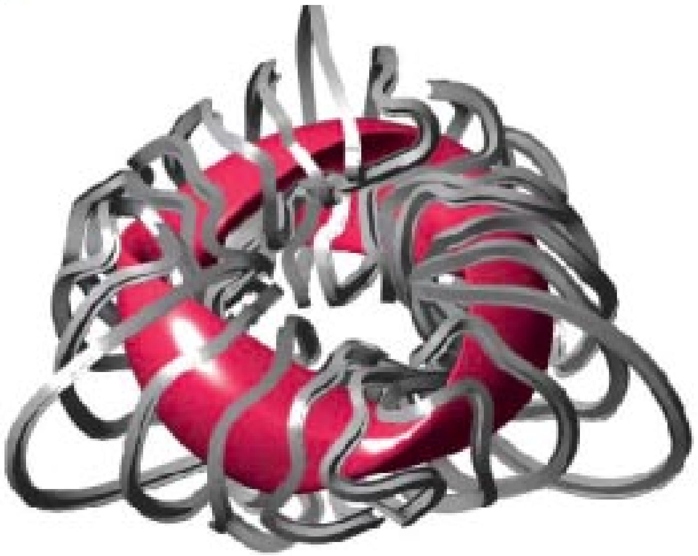
- Saddle coils (conformal) + 1/R background field (TF coils)
- Saddle coils (conformal) + optimized background field coils
- Modular coils

Comparison criteria

- Ability to produce equilibria with required physics properties
- Access for heating and diagnostics
- Engineering: constructability, maintainability, cost, risk

Modular Coil Option





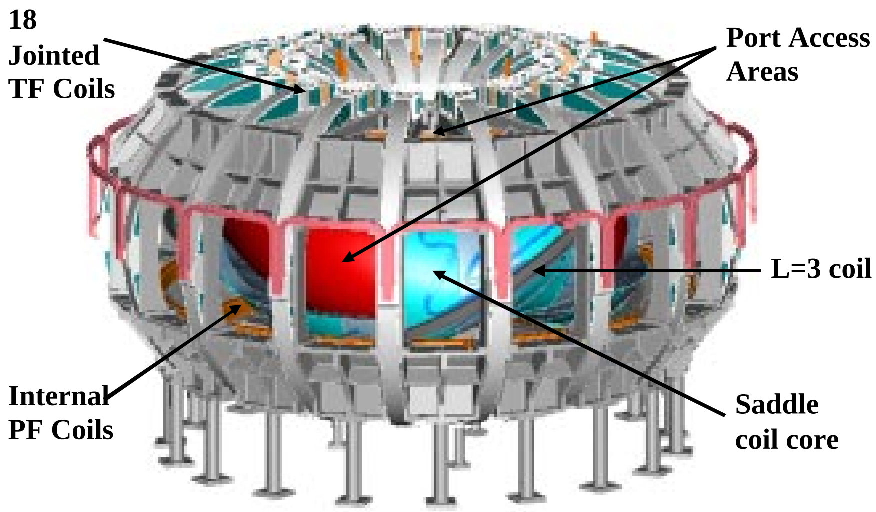
- LN-cooled cable wound on contoured coil support.
- External PF and supplementary TF.
- Conformal vacuum vessel.

Assessment

- **May provide best physics properties.**

Access-compatible structure concept being developed.

Saddle Coil Option



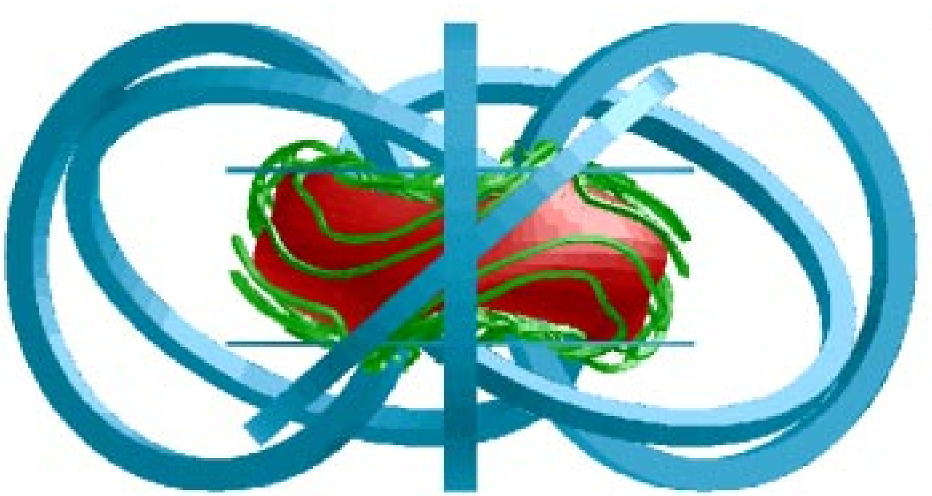
- Demountable TF coil
- Internal PF coil
- Helical field produced by saddle coils: LN-cooled cable in grooves on conformal support shell.
- Conformal vacuum vessel
- Three large openings.

Assessment

- **Good access**
- **Low power requirements**
- **Good constructability**

Coil modifications to improve physics properties being developed.

Optimized Background Coils + Conformal Coils



Motivation: Reduce current densities in saddle coils

- Simple, oversize coils form background field that approximates required helical field.
- Conformal coils provide detailed shaping.

Assessment

- **Reduced current density– compatible with room temperature operation, but…**
- **Access more restricted.**
- **Stray fields problematic for NBI.**
- **Currently tabled**

Status of Options Comparisons

Plasma Configuration: LI383 was selected

- Major improvement over predecessor (C82) in magnetic surfaces, coil compatibility, transport.
- R=1.7 m, $\langle a \rangle$=0.40 m, N=3, R/$\langle a \rangle$= 4.4, β=4.1%

Coil Topologies: Modulars and Saddles are Viable Options

- **Modulars** have exhibited best physics properties (esp., magnetic surfaces, flexibility, stability). Engineering development has just started. Is an access-compatible structure feasible?
- **Saddles** have an attractive machine configuration (good access, low power requirements) and perhaps lowest cost. Can physics properties match modulars? Coil design targeting good surfaces is in progress.
- Trim coils are planned for island reduction over a range of operation in both options.

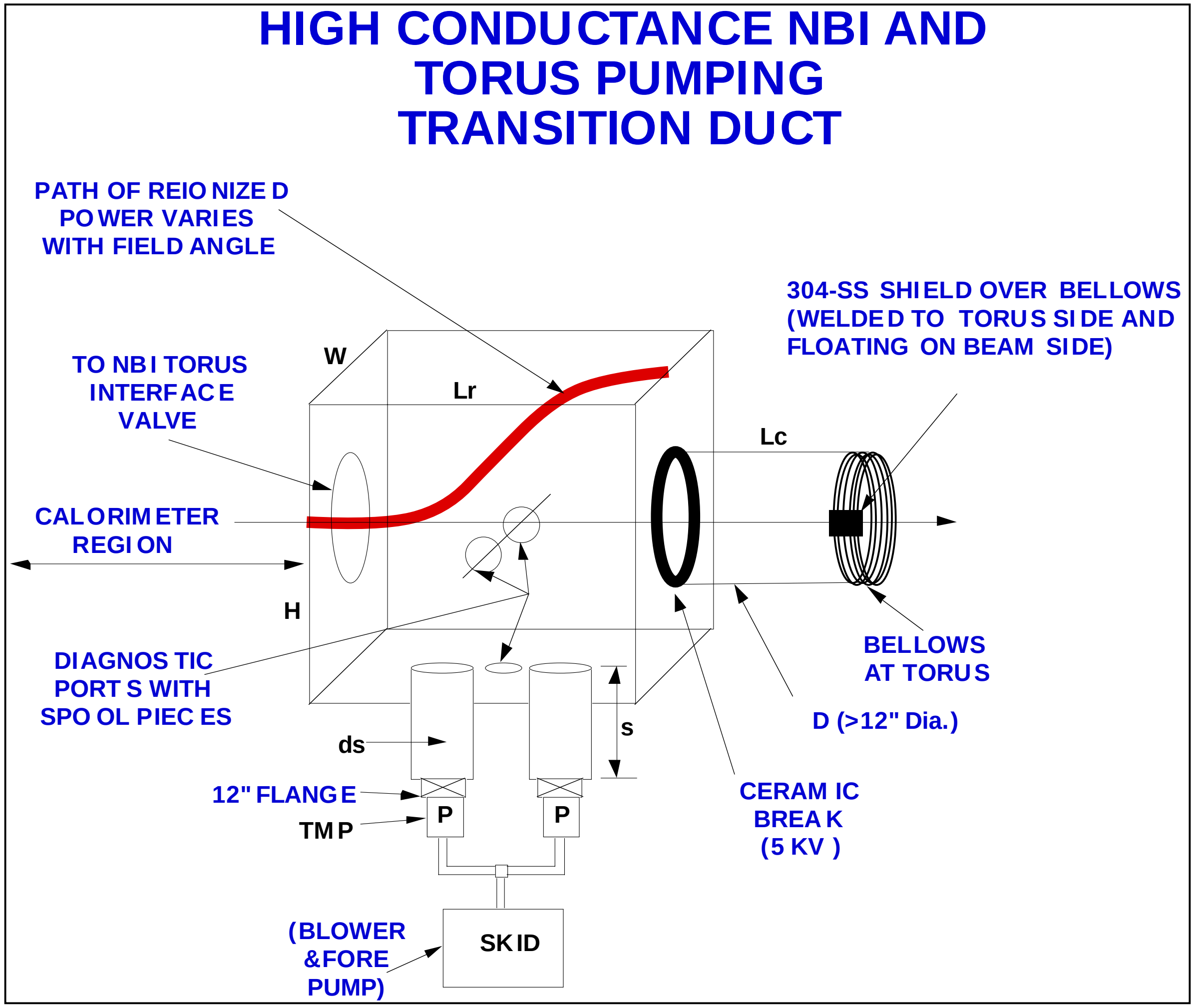
Access for Physics Tools

Requirements

- Heating
  - Neutral Beams (6 MW)
  - Ion Cyclotron RF (6 MW)
- Diagnostics
- Power and Particle Handling
  - Divertors and limiters
  - Vacuum pumping

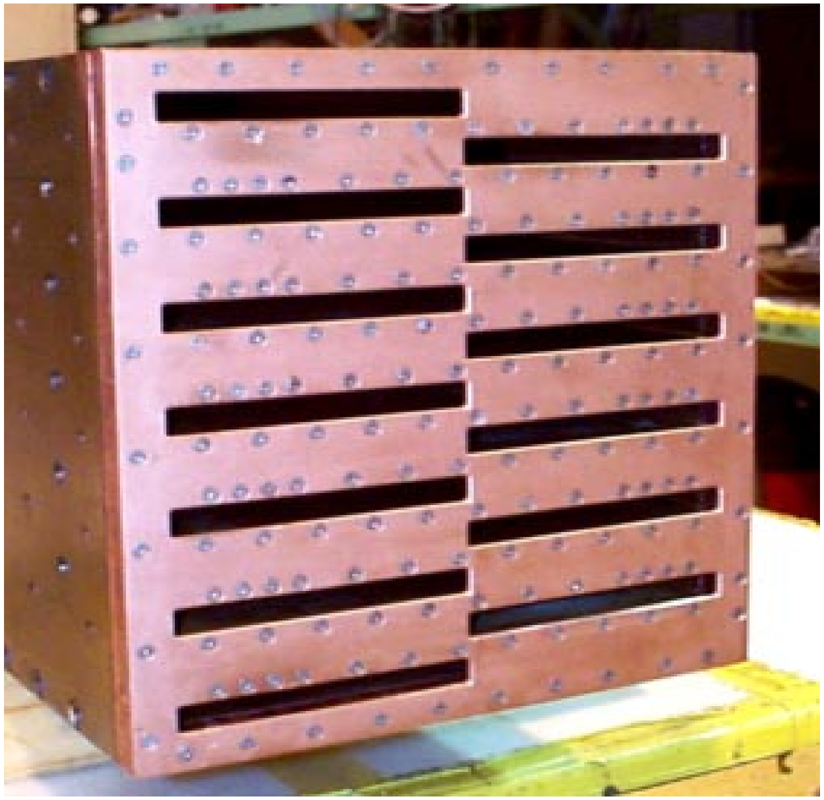
NCSX Neutral Beam and Torus Pumping Port Access Requirements

- Maximize W, H, D, ds
- Minimize duct s while not exceeding max fringe field
- Use electropolished 304-SS
- If possible, use rectangular ceramic break and bellows to maximize conductance
- Provide 150°C bakeout and operating capability
- Provide diagnostic ports with spool pieces
- Provide port for GDC electrode
- Far-wall beam armor should have beam diagnostics



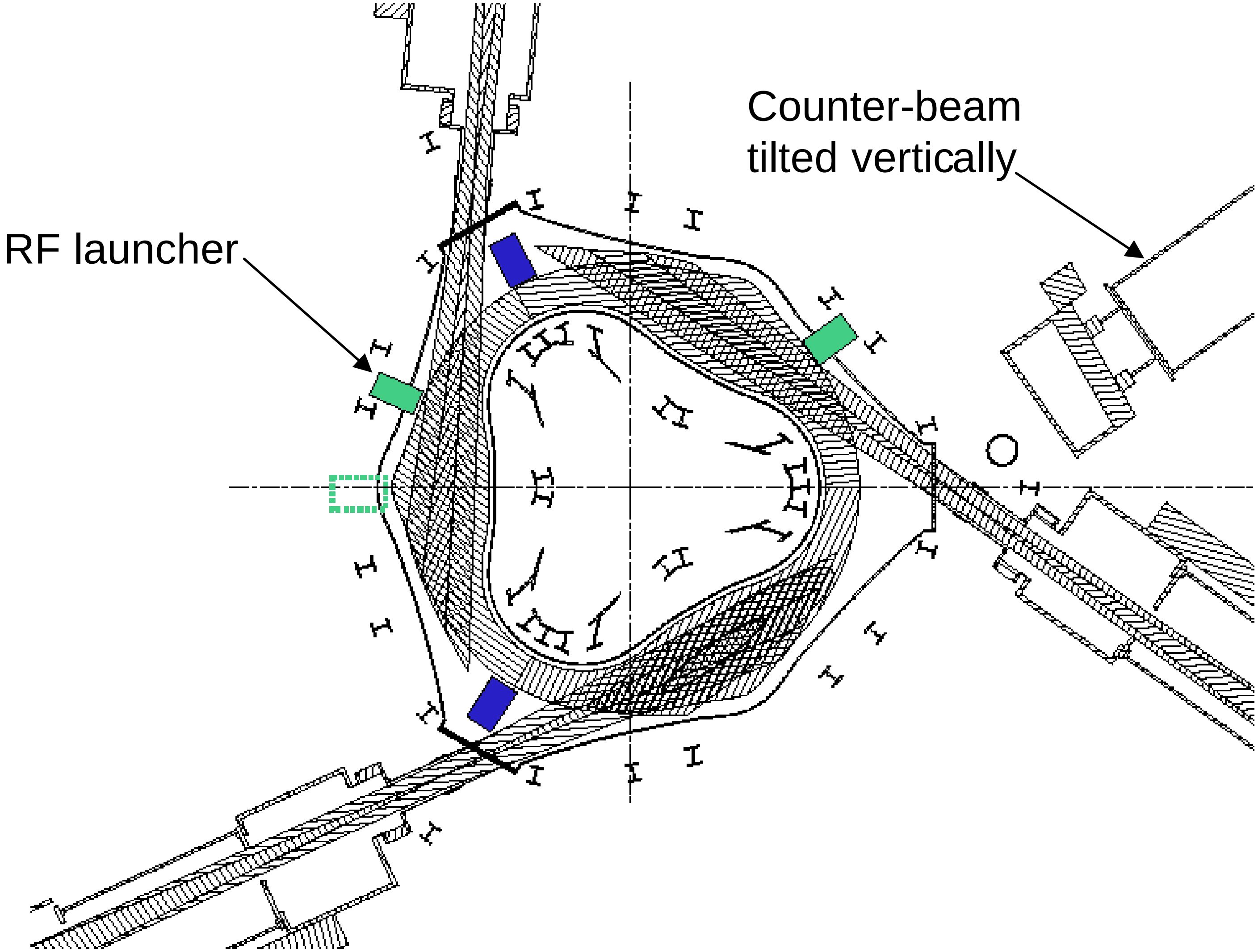
RF heating system port requirements

Prototype of ORNL folded-waveguide dipole launcher

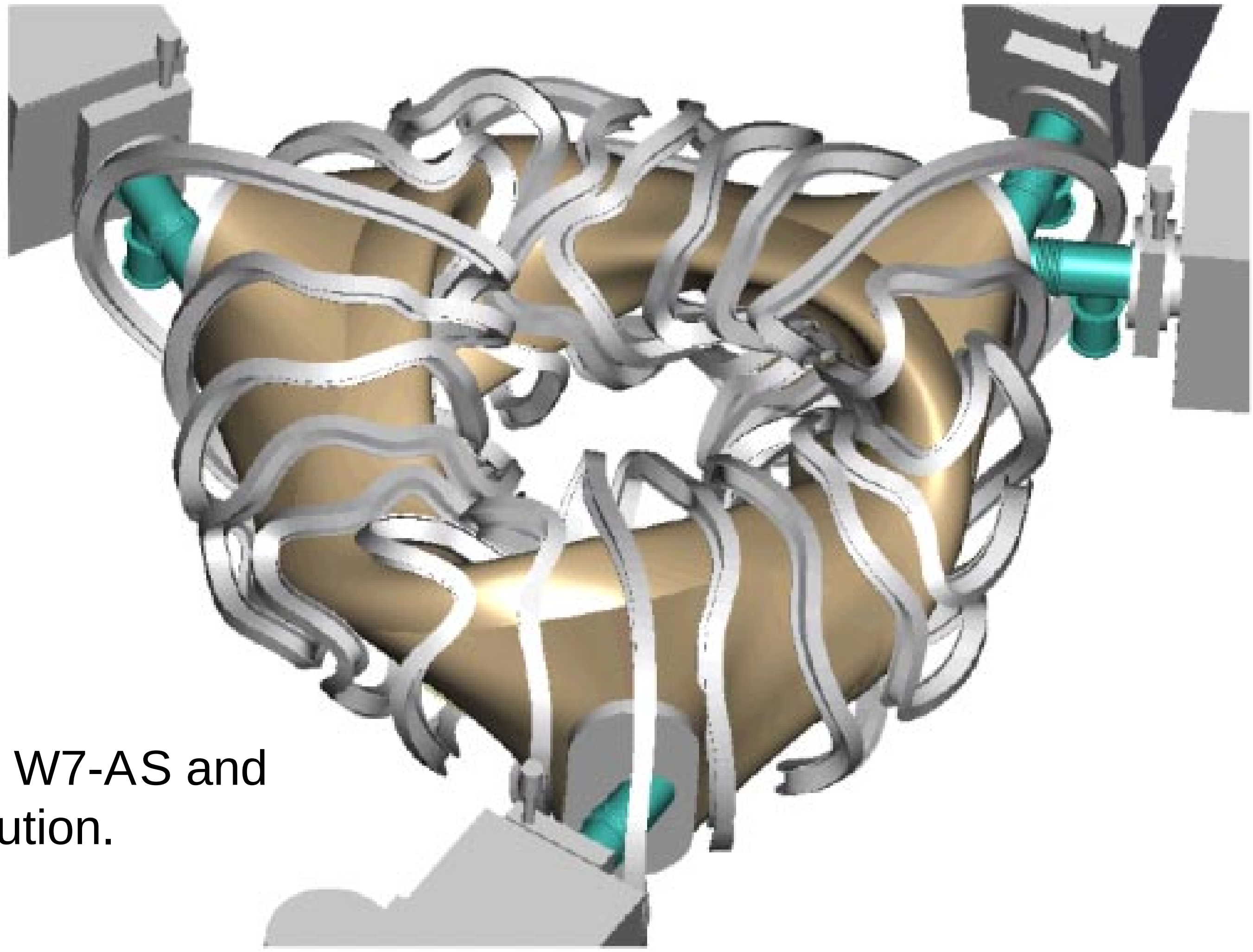


- Present focus is on high frequency fast waves (350 MHz) for RF heating
  - Folded waveguide launchers
  - Modeling predicts 80% per-pass absorption for $N_{\|} = 5\text{-}6$
  - Good absorption for $T_e > 300$ eV at $n_e(0) > 6 \times 10^{19}$ m^{-3}.
  - Insensitive to |B|, over range 1-2 T.
- Noninductive current drive capability
  - ~0.03 - 0.05 A/W
- Launcher complement for 6 MW coupled:
  - Four launchers in 4 ports.
  - Each launcher would be 24 cm in toroidal width, ~44 cm in poloidal height.

Plasma Geometry is Well Suited to Tangential NBI Access

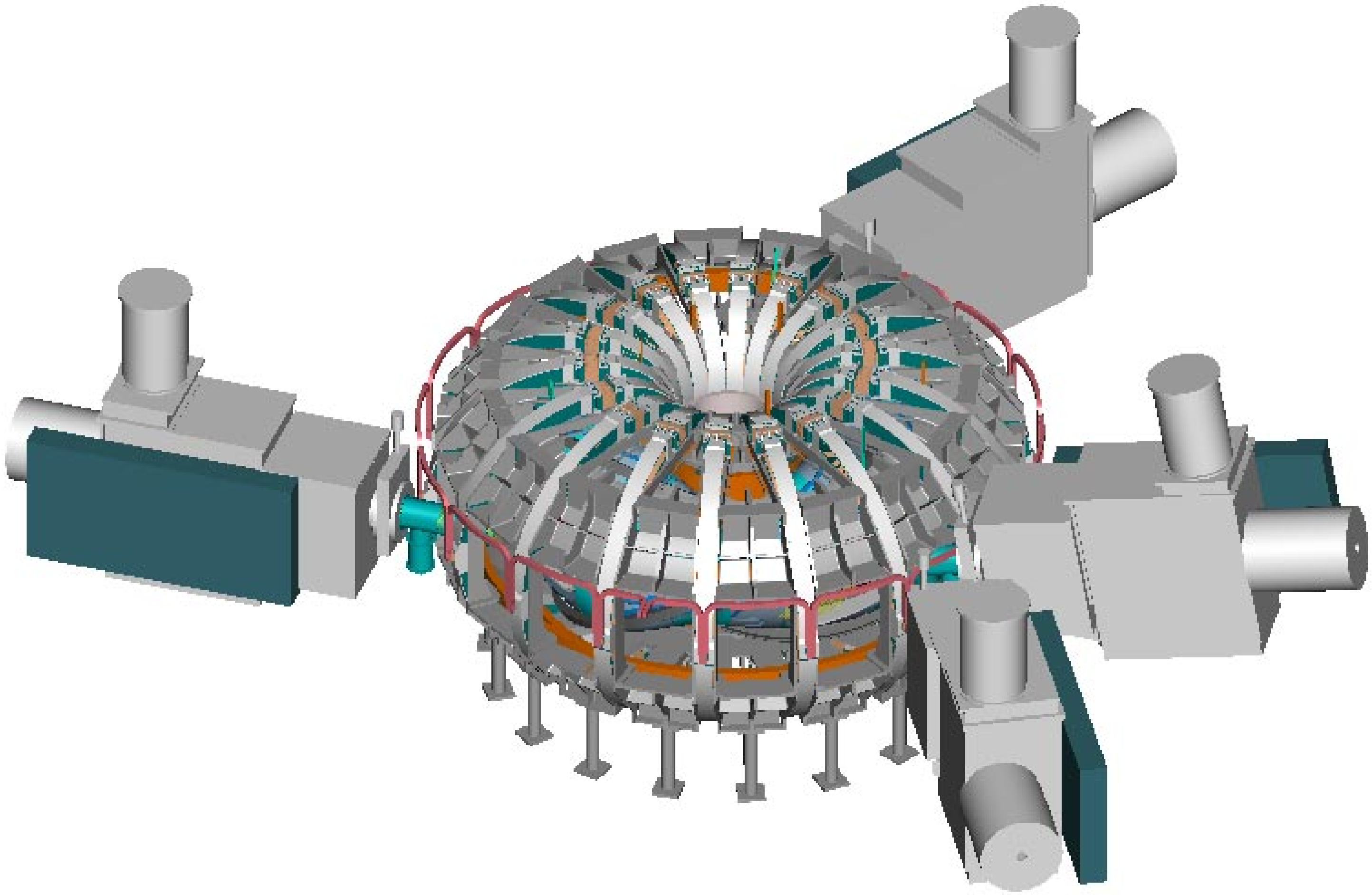


Extended Modular Coil Accommodates NBI Access



Similar to W7-AS and W7-X solution.

Saddle Coils Accommodate NBI Access Through Three Large Openings



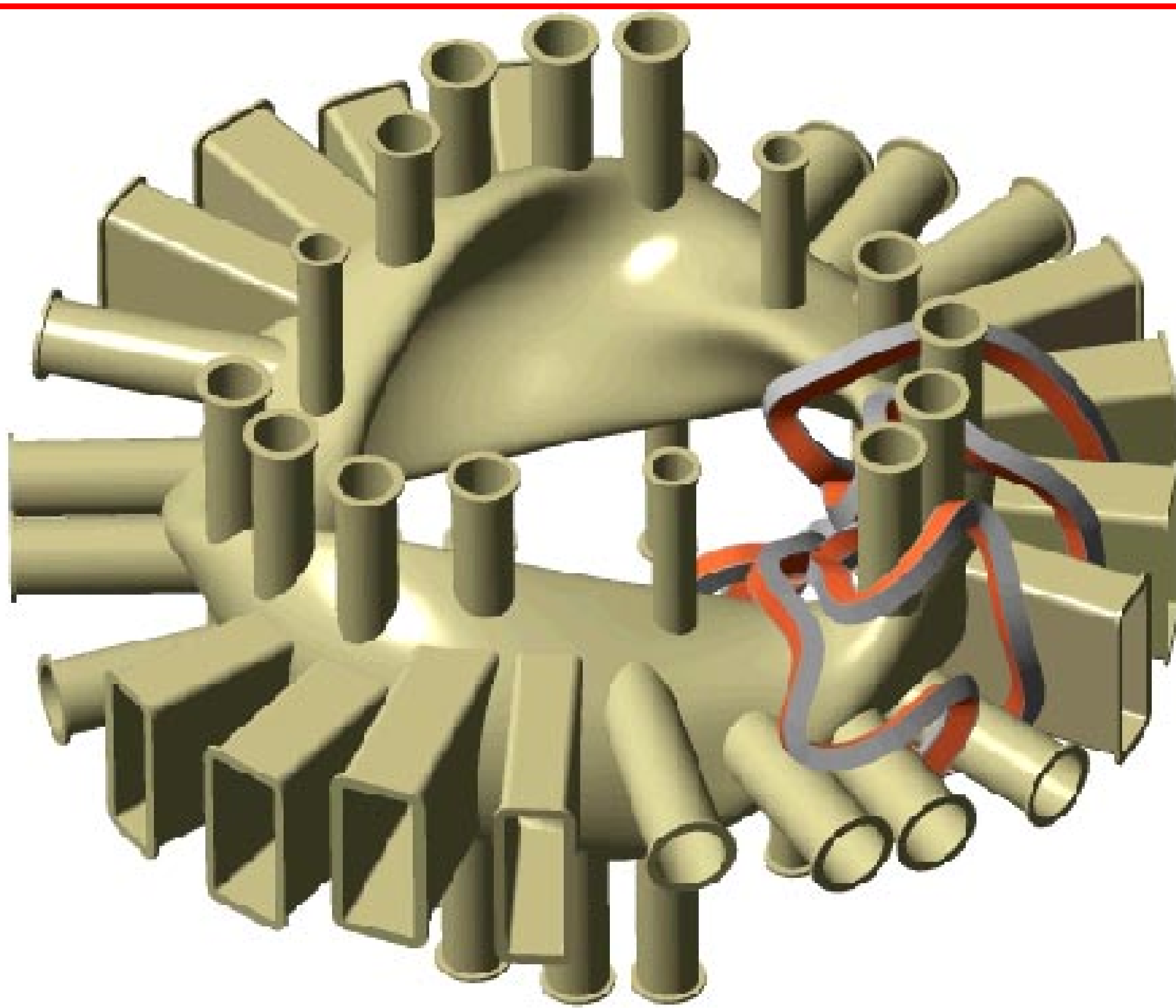
Preliminary Diagnostic Port Requirements (I)

diagnostic	#ports	size	comments
in-vessel sensors	30	2.75	location dependent on method for mounting sensors, protecting leads
visible cameras	3	6	assumes retractable periscopes for inspection, top best
IR cameras	6	4.5	provide sightlines to limiter, divertor regions, RF antenna, NB armor
interferometer	2	4.5	opposing on line through core will use commercial flapper shutter
x-ray imaging arrays	12	6	part of "tomography" complement
VB array	1	6	part of "tomography" complement
	1	2.75	will use commercial flapper shutter
bolometer arrays	3	6	part of "tomography" complement
VIPS, SPRED, filterscopes	4	6	part of "tomography" complement will use commercial flapper shutter
CHERS/MSE	1	10	shares large miplane slot with NB
	2	2.75	for shutter drive
BES	1	10	shares large miplane slot with NB
	2	2.75	for shutter drive
poloidal CHERS	2	4x10	racetrack shape above/below NB
	2	2.75	for shutter drive

Preliminary Diagnostic Port Requirements (II)

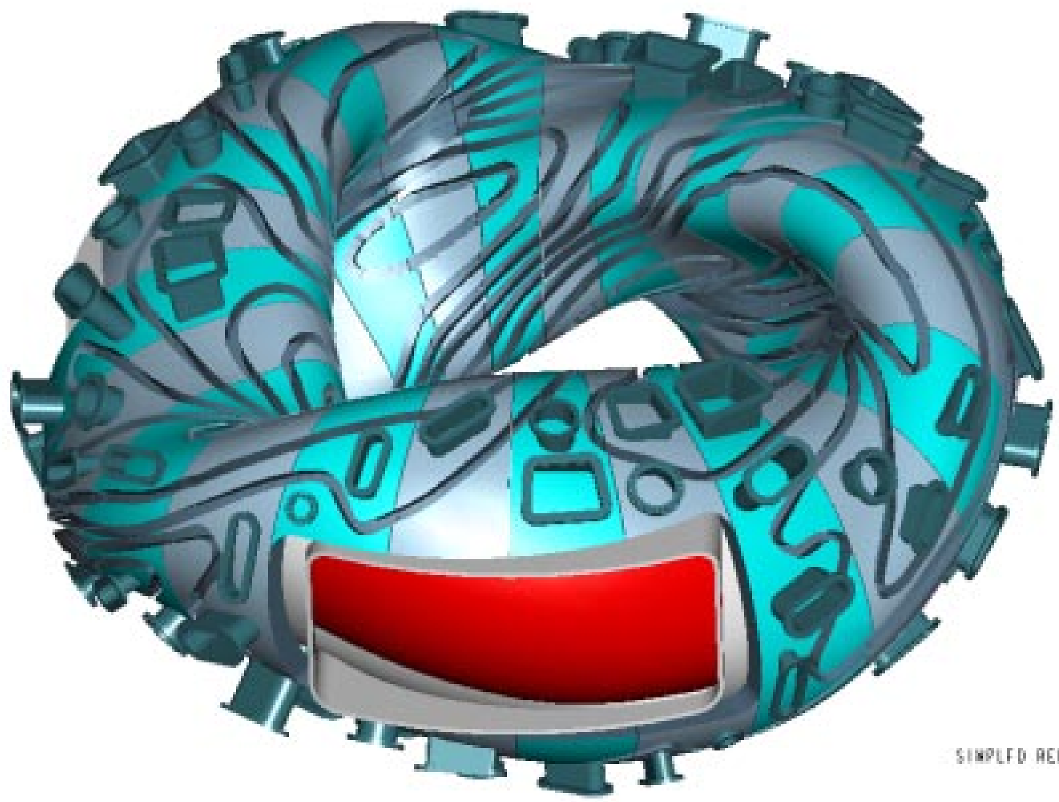
Thomson Scattering	1	2.75	outer midplane, oblate sym. plane
	1	10	top or midplane
	1	2.75	for shutter drive
ECE	2	8	outer midplane, symmetry plane
reflectometry	2	8	outer midplane, symmetry plane
x-ray PHA	1	6	horiz. or vert. flt. tube out of TF
NPA	1	6	horiz. or vert. flt. tube out of TF
fast ion loss probe	1	6	needs clear path to outside of TF
fast scanning probe	1	6	needs clear path to outside of TF
future needs	8	2.75	initially blanked
	4	4.5	part of “tomography” complement
	4	6	initially blanked
	2	8	initially blanked
	2	10	initially blanked
total	102		

Modular Coil Vacuum Vessel Provides Good Diagnostic Access



Saddle Coils Provides Good Diagnostic Access

No of ports	96
24	8” Dia
6	4” Dia
12	Trapezoidal 14*11*10
6	Trapezoidal 10*7*10
12	Oblong 10” long * 4” wide
12	Oblong 12” long * 4” wide
12	Oblong 8” long * 4” wide
12	Oblong 8” long * 6” wide
96	



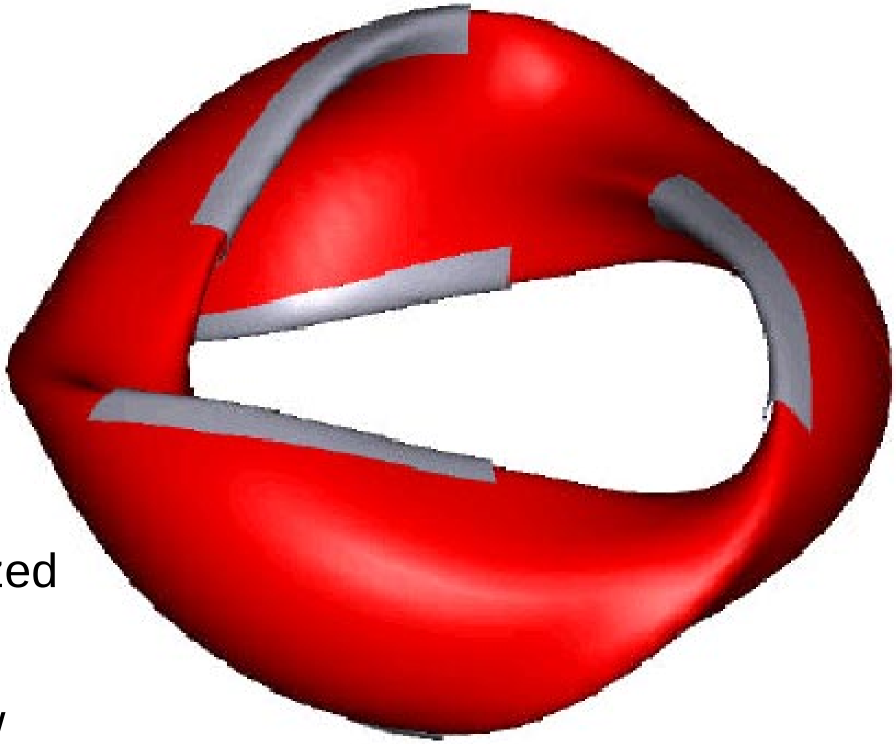
Power & Particle Handling

Requirements

- Remove heat.
- Control neutrals and impurities for good plasma performance.

Solutions

- Structures: divertors and limiters-staged implementation planned.
- Materials: Low-Z, e.g. bulk-boronized graphite, boronization.
- Conditioning: Baking (350 C), glow discharge cleaning.



NCSX Divertor Concept

Summary (I): NCSX Design Status

- Reference plasma configuration has been selected.
- Two viable coil options exist:
  - Saddle design is well developed and may be an attractive choice for a physics experiment because of its good access and adaptability. Coil modifications to improve physics properties are in progress.
  - Modular design is less developed but may provide the better physics performance. Design of an access-compatible support structure is in progress.
- Heating access is accommodated in both designs.
- Preliminary diagnostic requirements have been developed. Access solutions have been demonstrated in saddle option. Solutions are sensitive to details of the coil structure.
- Power and particle handling requirements are being developed.

Summary (II): NCSX Plan

- Continue to develop the design of the modular option.
- Try to improve physics performance of the saddle option, to see if it is a viable backup.
- Hold a Physics Validation Review in early 2001.