NCSX

WBS 1 Torus systems Design Progress and Status

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Outline of Presentations

- WBS 1 Goals, Status and plans — Nelson
- Non-Axisymmetric Coil and Structure Design — Williamson

  Design Parameters, Design / Fabrication Options, Issues
- Vacuum Liner — Goranson

  Requirements and Design Criteria, Fabrication Options, Status and Issues
- Design Integration — Cole

  Neutral Beam Injection layouts

Torus Systems (WBS-1) Scope

Torus systems includes everything inside the vacuum vessel, as well as integration of these components with each other and the rest of the machine

PFCs, Vacuum Vessel   Paul Goranson
tiles, armor, limiters, R&D

Interface Structures   Fred Dahlgren
mods/refurbishment of existing structure and interfaces with new structure

Axisymmetric Coil Systems
existing PBX coils, refurbishment and relocation

Non-Axisymmetric Coil Systems   Dave Williamson
Saddle coils and winding structure

In-Vessel Measurement Systems   Doug Loesser
geometric and magnetic measurements

Baseline parameters for design study

- Pre-assembled, “drop in “ stellarator core, consisting of vacuum vessel, saddle coils, and saddle coil structure

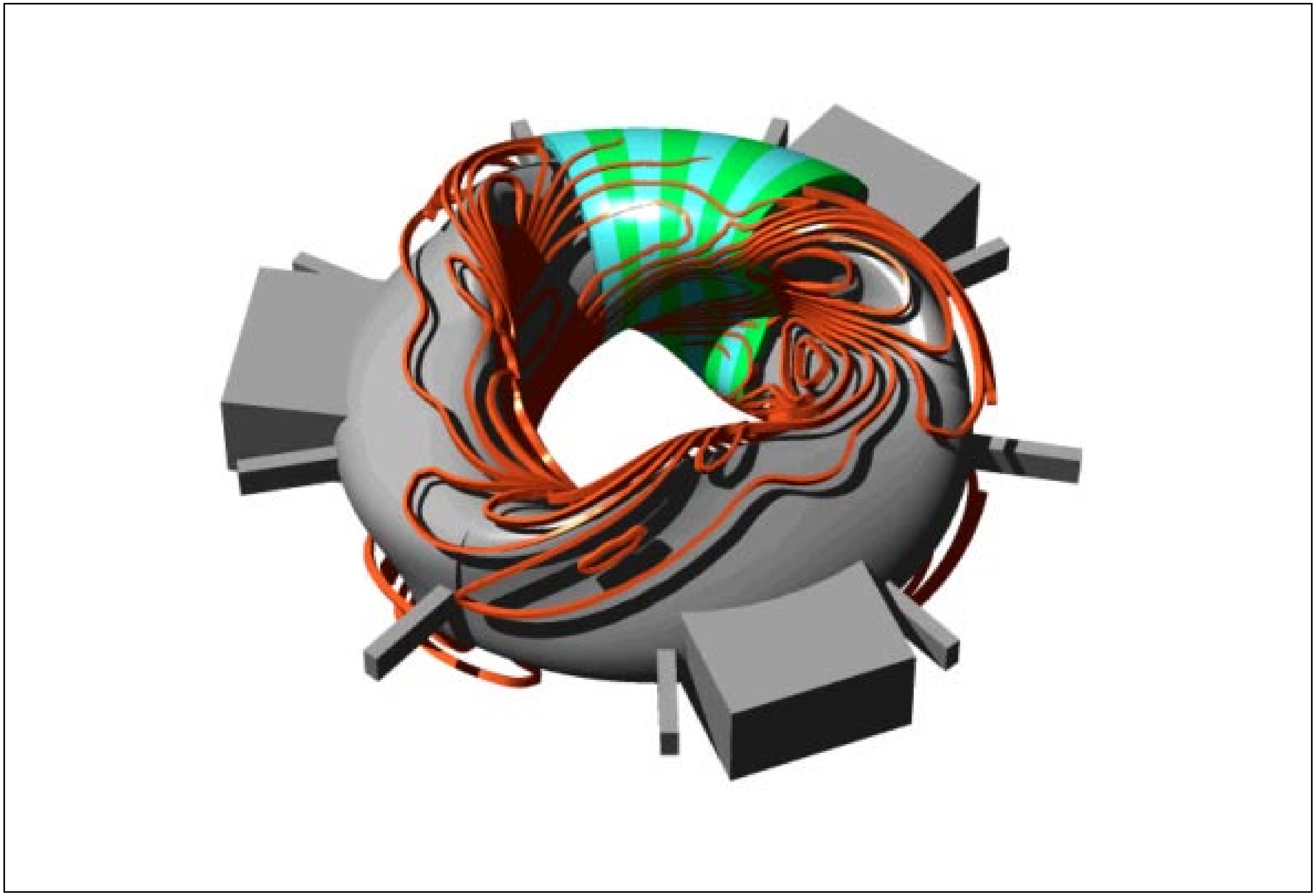
  Option 2C - Re-use PBX TF, PF coils and structure
  Option 3B – New TF, PF coils, structure

- C10 plasma with SAD18.5_16 coil set, LN cooled

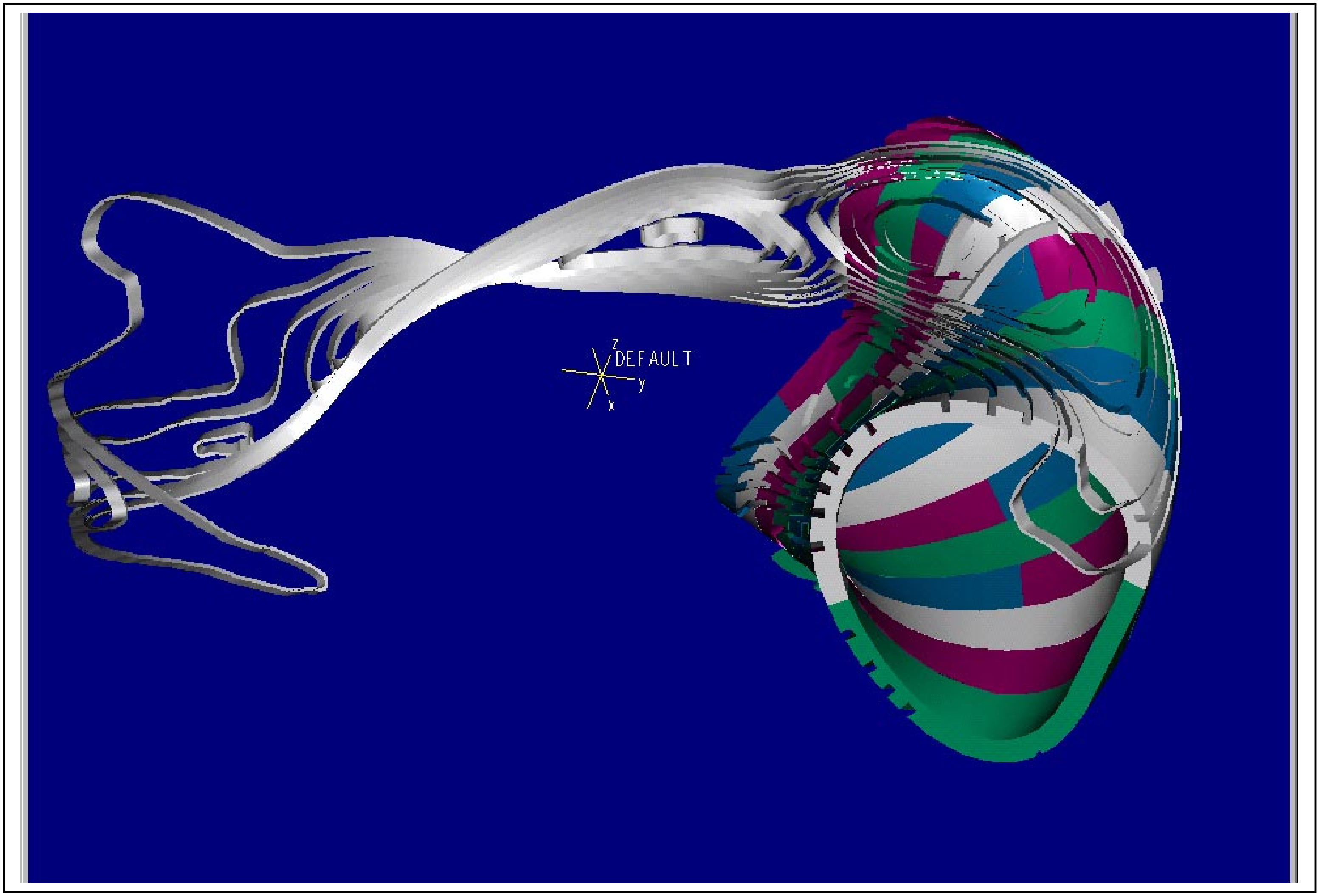
  25,000 A/ cm ^2 current density at 2 Tesla field on axis
  2.1 cm minimum spacing between saddle coil windings
  10 turns per saddle coil

- Vacuum vessel is stand-alone, structural vessel that can be baked to 350C

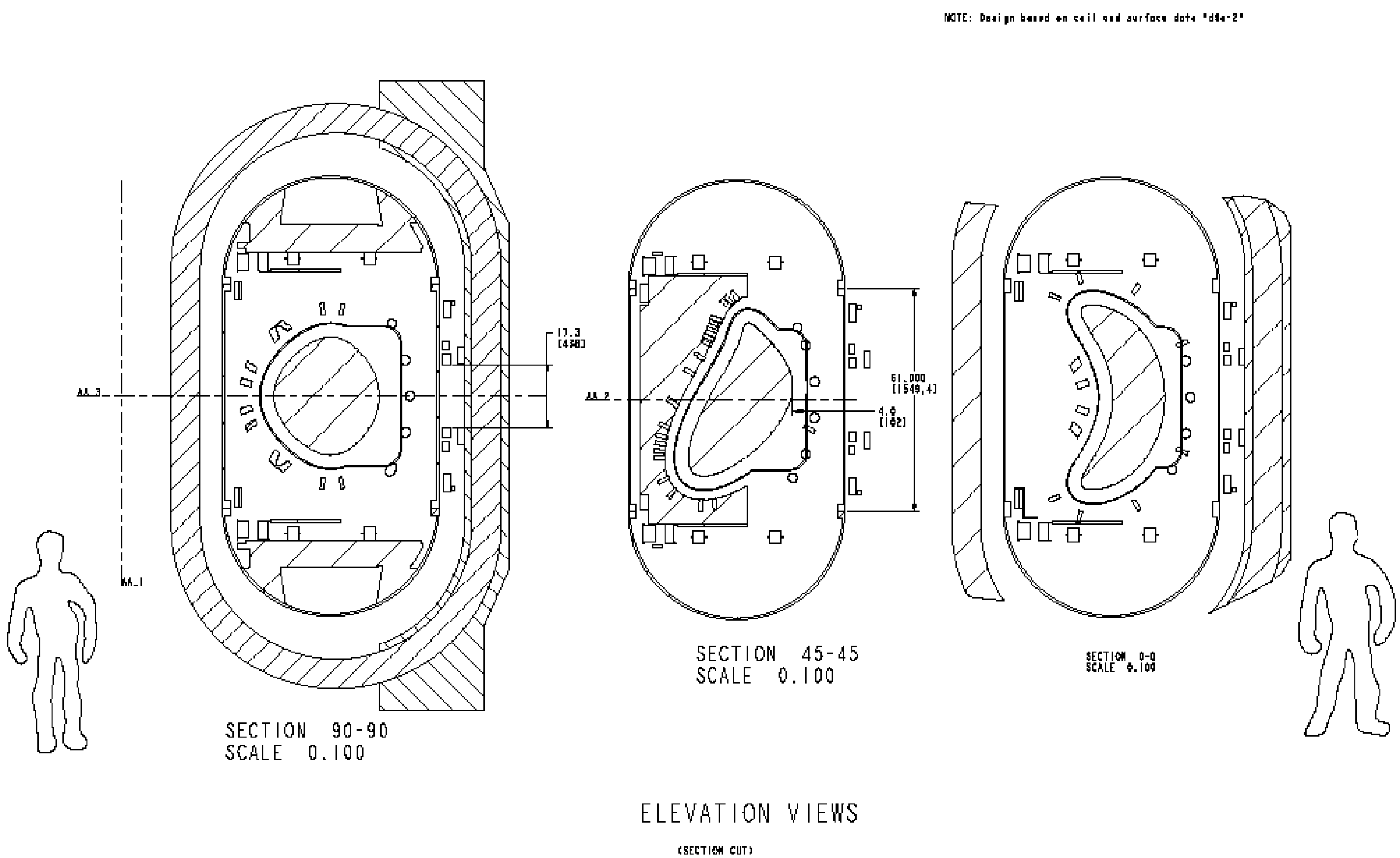
Winding set , SAD185-8 with vacuum vessel and partial shell



Winding set , one field period, SAD185-16 with partial shell



Sections through machine for D9E in PBX



WBS-1 Goals for January 1 to February 23

- Develop design criteria and requirements to proceed with CDR
  - Identify issues (eg, what lead and crossover configurations are acceptable? what is minimum time constant for shell?)
  - List requirements in working document

- Vacuum vessel
  1. Scoping analysis for vacuum and em loads, calculate time constant
  2. Develop envelope, fabrication concept

- Saddle coils
  1. Calculate forces/fields and develop structural, electrical, thermal criteria
  2. Develop and select fabrication / winding / structure concept

- Develop tools for analysis and for iterating 3-D coil designs between physics and engineering

Progress since December

Progress has been made in several areas since December PAC meeting

- Pre-conceptual Design Cost Estimate for 4 major WBS-1 options,

    Selected option 2C or 3B, "Drop-in core"

- Design and Fabrication Concepts Narrowed- *Primarily Saddle coils and Liner*
- Tool Development *Field and force calculations, PRO-E modeling semi-automated*
- Continued refinement / expansion of design criteria / parameter list
- Scoping calculations performed

    Stresses in liner due to vacuum and em loads
    Fields and forces in saddle coils

What are primary open issues?

System or component	Issue	Options	Comments	Resolution
Vacuum vessel	Material	316L stainless	Current baseline, Permeability could be issue	Sharpen magnetic permeability requirement, **Check cost**
		Inconel 625	Stronger, thinner, more costly	
	Fabrication process	Break bending	Current baseline like WVII-AS	Work with vendor for lowest cost option, after selecting material
		Explosive forming	like HSX	
		Casting, other process	like ??	
	Assembly	Procured and installed in one piece	Current baseline, best procurement option	Decide in conjunction with shell assembly concept
		3 pieces joined from inside	Offers more flexibility for shell assembly	
	Cooling / Heating fluid	Water / Steam	Should be cheaper, if corrosion not an issue	Resolution based on cost only
		Dowtherm	Used for NSTX	

What are primary open issues?

System or component	Issue	Options	Comments	Resolution
Saddle Coils	Conductor current density is too high due to close spacing of coils 3-D effects make grooves even tighter at root of bends	Reduce temperature of coil to increase pulse length	Expensive to sub-cool LN	Check cost
		Reduce number of turns to increase packing fraction	Increases field errors, Conductor is harder to wind	Check feasibility of winding
		Fewer coils	Poor reconstruction	Must be resolved by physics
		Put coils closer to plasma	Can't go much closer than 18 cm	Check feasibility of reducing insulation thickness, gaps, etc.
		Put two saddles in one groove in tight regions	May have second order benefit, but cooling, winding accuracy may suffer	Must be resolved by physics
	Cooling of conductor	Conduction to shell	Better use of space, depends on material of shell	Total cost for effective system
		Conduction to strap	Works for any material	

Issue: Current Density and Pulse Length

- Coil geometry pushes design to higher current density

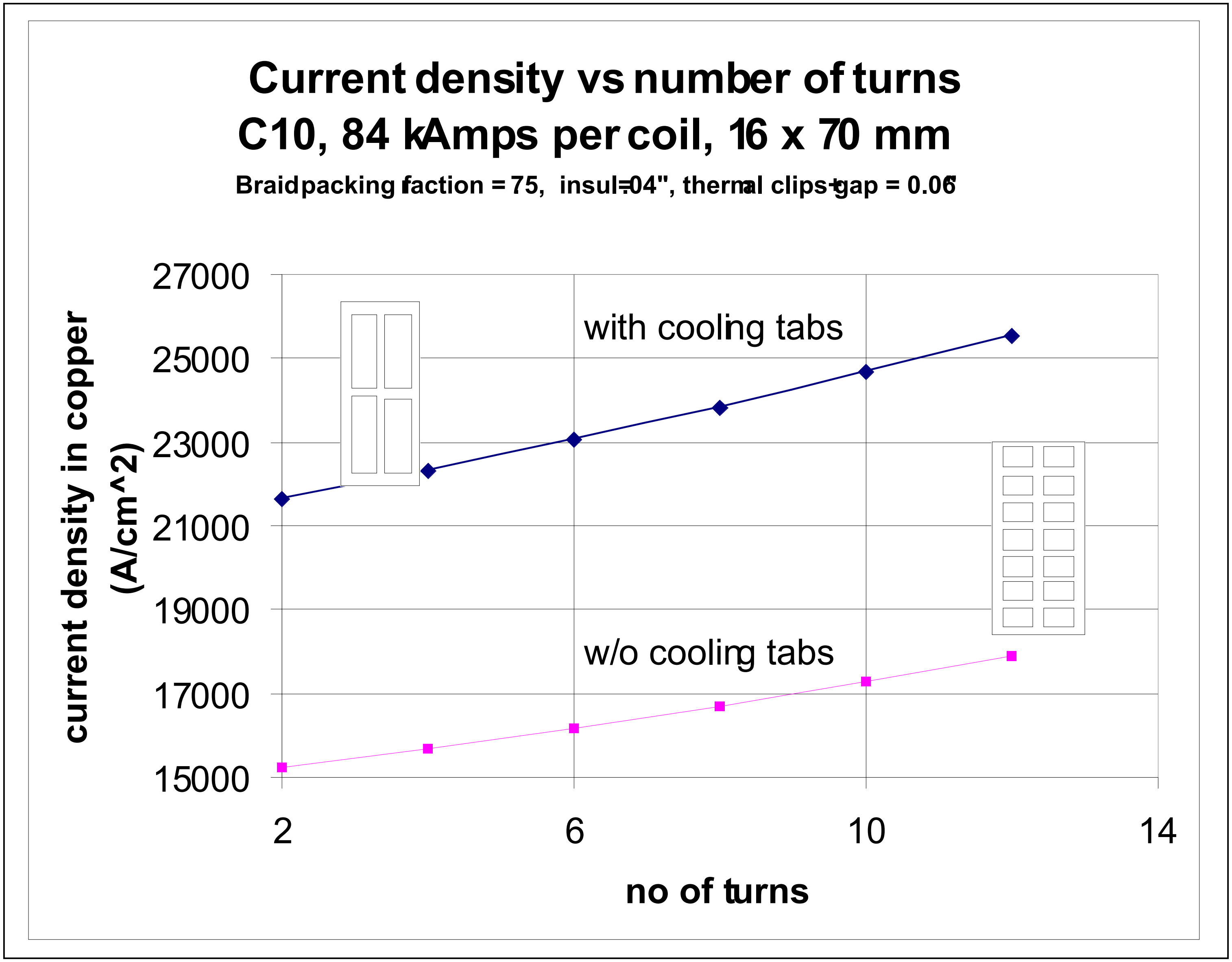
  - -Winding centers can be closer to plasma surface
  - Adjacent windings can be closer to each other

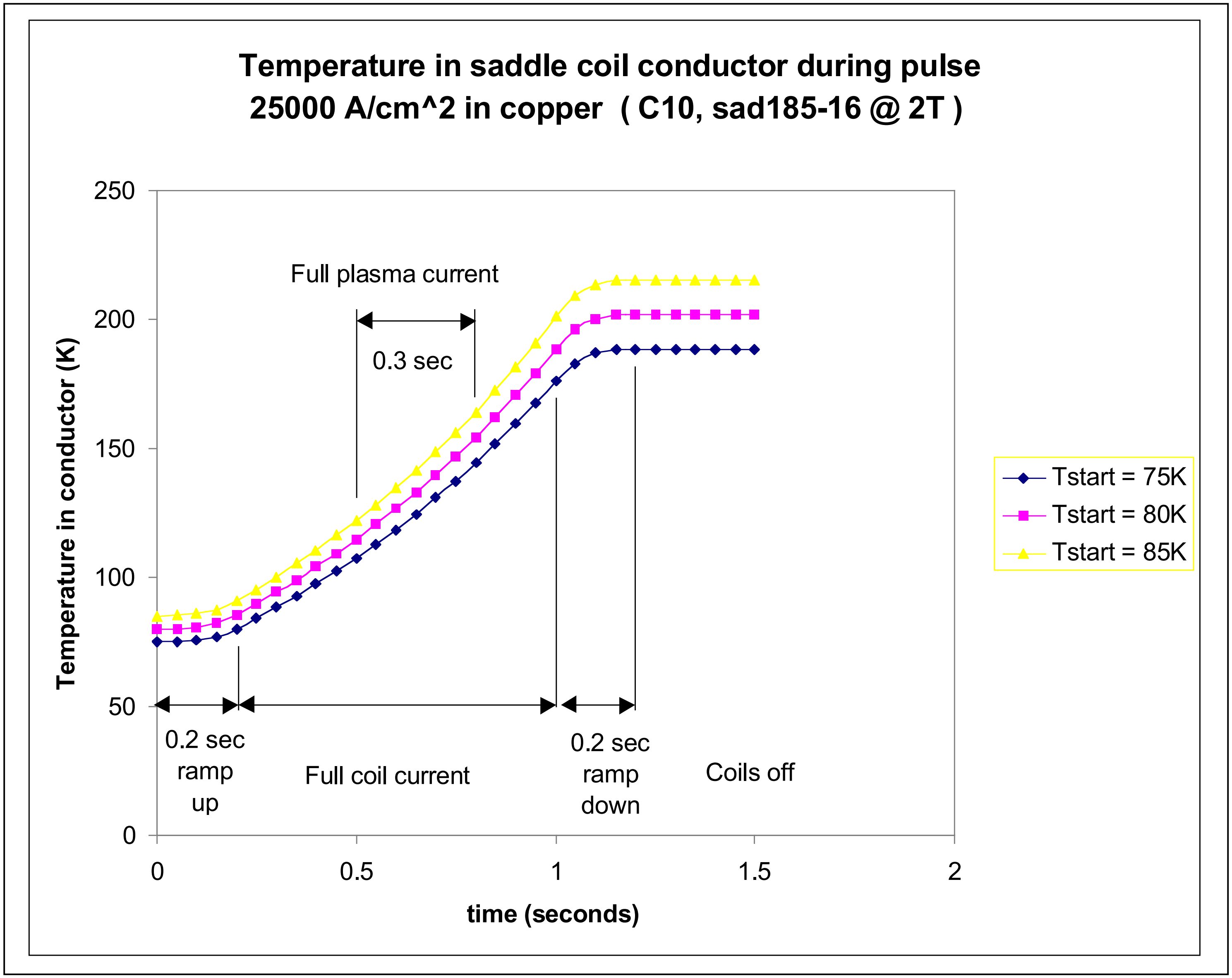
- Current density determines pulse length for adiabatic heating

- Current density is a function of number of turns, packing fraction in braided conductor

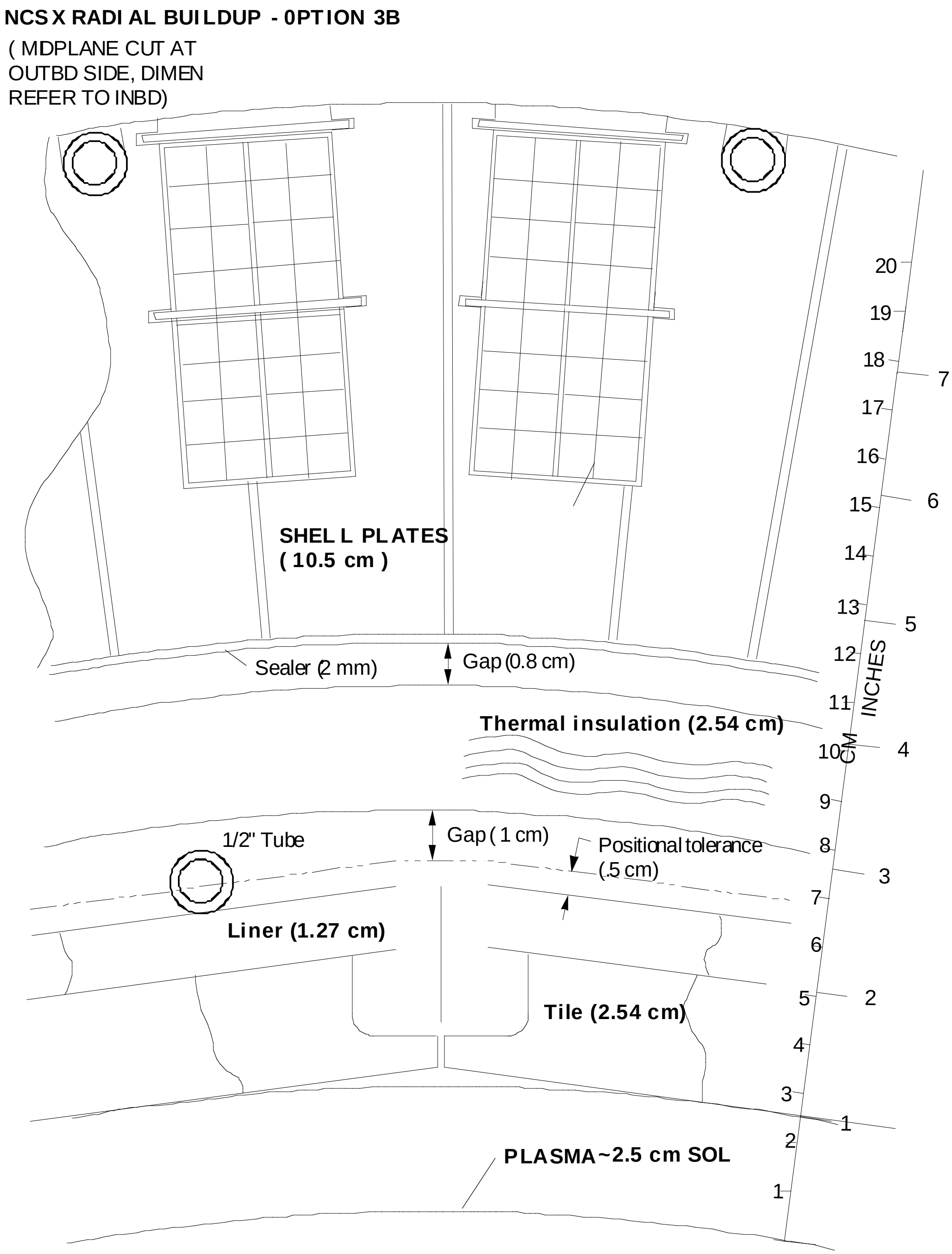
- Baseline design

  - Number of turns per saddle coil = 10
  - Current density in copper **~25 kA/cm^2 at 2 T**
  - Pulse length for 80 to 210 K rise = ~**1 second** (equivalent square wave)
  - Power at end of pulse ~80 MW


Current density vs number of turns
C10, 84 kAmps per coil, 16 x 70 mm
Braid packing fraction = 75, insul=.04", thermal clips+gap = 0.06"
27000
25000
23000
21000
19000
17000
15000
current density in copper (A/cm^2)
with cooling tabs
w/o cooling tabs
2
6
10
14
no of turns


Temperature in saddle coil conductor during pulse
25000 A/cm^2 in copper (C10, sad185-16 @ 2T)
Temperature in conductor (K)
250
200
150
100
50
0
0
0.5
1
1.5
2
time (seconds)
Full plasma current
0.3 sec
0.2 sec ramp up
Full coil current
0.2 sec ramp down
Coils off
Tstart = 75K
Tstart = 80K
Tstart = 85K

Two saddle coils merged into one groove



What are primary open issues (cont'd)?

System or component	Issue	Options	Comments	Resolution
Saddle Coils	Fabrication option	Wedges	Material Fastening wedges together	Must be resolved by combination of cost, risk, after defining consistent thickness parameters for each option
		Ribs with epoxy fill	Material properties, fastening ribs together, behavior of composite structure at LN temperature	
		Structural shell with epoxy fill	Material properties, cost of two nested shells	
	Shell material	304L stainless	Good except for machining and thermal conductivity	Work with fab shops for lowest total cost option
		Bronze alloy	Good, but hard to weld, may have permeability problem	
		G-10	Low electrical conductivity, hard to machine, bad CTE	
		Graphite epoxy	Not clear	
	Cooling	Closed loop	Safer, more complicated	Total cost for safe system
		Open loop	Like Alcator C-Mod	

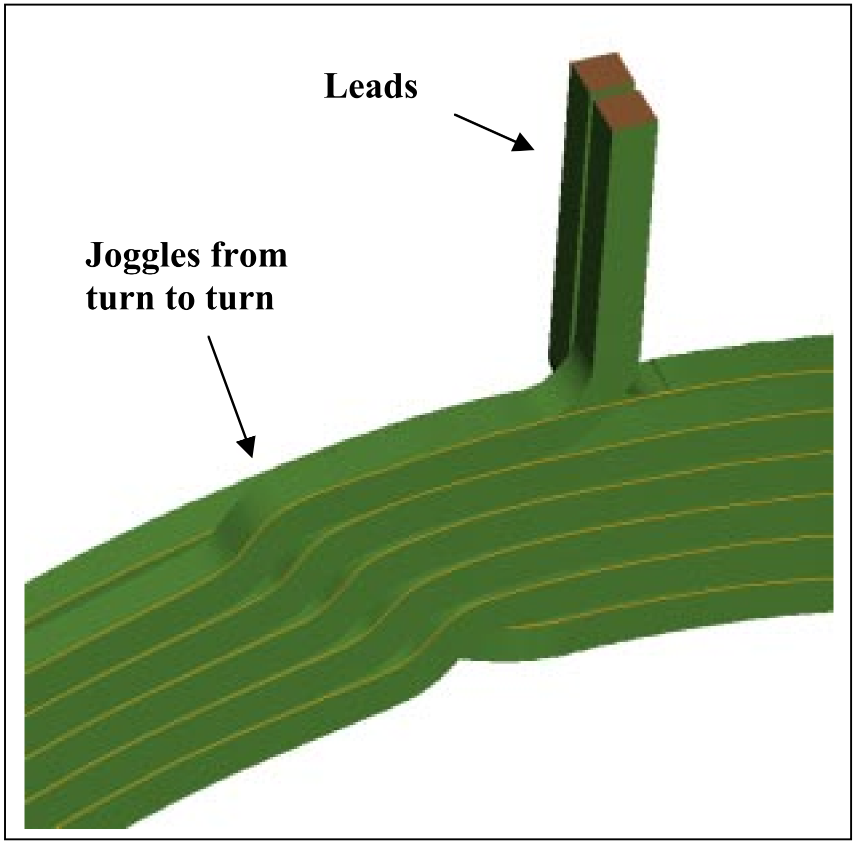
Crossovers and leads for saddle coils

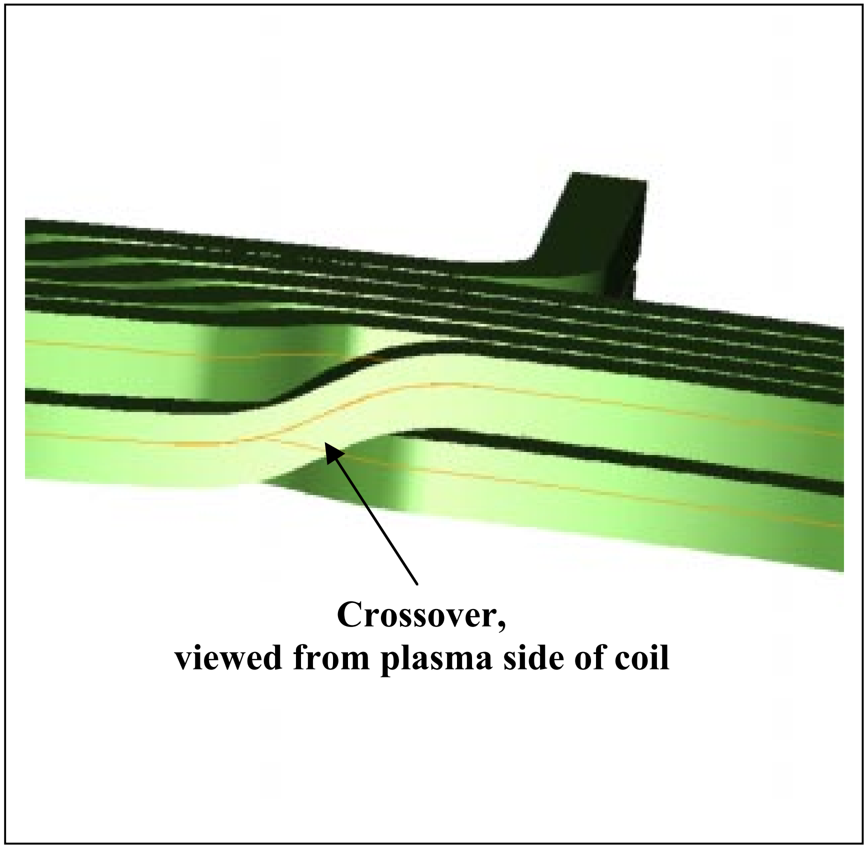
- Leads and crossovers can be source of large field errors
- Each saddle coil will be multi-turn and independently powered (78 lead pairs)
- Aleksandr (Sasha) Georgiyevskiy calculated the field errors from various crossover and lead topologies and lead locations. Basic conclusions were: [1]

1. Keep the conductor current as low as possible (less than 10KA, if possible).
2. Locate the leads on the inboard midplane rather than on the top or bottom
3. Spiral wind the first turn, do not use an abrupt joggle.
4. Lead curvature of .5 m exiting coil ok, we can do better with braided conductor
5. Use coax or twisted pairs after leads exit coil

[1] paraphrased from Wayne Reiersen's summary

Crossovers and joggles





What do we need for PVR?

From January 15 memo by Wayne Reiersen:

- System requirements are defined
- The initial system level design of the stellarator core is complete

  Saddle coil windings, structure, vacuum vessel, axisymmetric coils
- The system level design addresses the technical requirements
- The system level design can be fabricated and assembled
- The stellarator core can accommodate the required ancillary systems
- The system level design meets cost and schedule objectives

How do we get there from here? Near term plans

- Develop self-consistent designs for each shell option
  - Top level layouts and drawings
  - Basic parameters: Wt., amount of machining, assembly sequence, cooling
- Solicit input from vendors
  - Contacts from design show in Chicago
  - Local shops around Oak Ridge and Princeton
  - Other contacts from previous jobs
  - Y-12 shops and Oak Ridge Center for Manufacturing Technology
- Develop fabrication and assembly schedule for each option, assess schedule risk
- Develop best guess at relative cost
- Select best option