1) Disruption heat loading
2) Progress on time-dependent modeling

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ARIES Project Meeting, Bethesda, MD, 4/4/2011

Continuing the loading description for PFCs

	nominal	nominal transient	off-normal transient
divertor/heat	$P_{SOL(rad+cond)}$	ELMs	disruption
divertor/particle	DT,He,Ar	ELMs	disruption
FW/heat	P_{rad},core CX neutrals stationary core MARFE stationary X-pt MARFE	ELMs	disruption runaway electrons fast confinement loss fast alpha particles
FW/particle	DT flux CX flux	ELMs	disruption runaway electrons fast confinement loss fast alpha particles

Disruption basics

- Plasma drifting (vertical motion for VDE)
- Plasma transitions from H to L mode (partial loss of plasma stored energy)
- Thermal quench (plasma losses its stored energy)
- Plasma current quench (plasma loses its poloidal magnetic energy)
- Disruption types
  - Vertical displacement events (VDE, plasma motion then disrupt)
  - ITB or ideal MHD disruptions (fast disruption)
  - Resistive MHD disruptions (slower disruption)
  - Mitigated disruptions (particle injected to radiate stored energy on fast time scale)
- Significant heat footprint broadening on divertor during disruption, 5-10 x relative to H-mode
- Time scale for thermal quench, ~ 1 ms, time scale for power to appear on divertor, ~ 1-2.5 ms, time scale for current quench ~ 15-40 ms or ~ 1 s

Vertical Displacement Event (VDE)

- Plasma drifts until contact with FW, plasma in H-mode
- Plasma transitions from H to L-mode, loses ~½ its stored energy, $\tau_E^L \sim ½\ \tau_E^H$
- Thermal quench occurs when q_{edge} reaches ~ 1.5-2, power flux broadening occurs, time scale is ~ 1 ms
  - Change in current profile, $\Delta li \sim -(0.15\text{-}0.2)$
  - Energy released is ½ $W_{plasma}^{H\text{-}mode}$
  - Time duration 1.5-3 ms rise, and 1.5-6 ms fall
  - Power SOL width is 2.5-5.0 cm (5-10 x our regular 0.5 cm)
- Current quench results in the poloidal magnetic energy being radiated to the FW, with peak to average of ~ 2-3 (peaking on inboard) (like a MARFE)
  - Fast current quench is 36 ms long for linear rampdown or 16 ms exponential
  - Slow current quench is 0.6-1 s
  - Energy radiated ~ 300-600 MJ for ITER (poloidal magnetic energy need to calculate for ARIES) over 8-10 ms
- Split between divertor and first wall is not specified clearly for ITER, depends on disruption type
  - Plasma touching the FW?
  - Conducted vs radiated power

Major disruptions (ITB or ideal MHD)

- Plasma disrupts at its nominal location for regular operation
- Thermal quench releases all plasma stored energy, over ~ 1 ms
  - It can be ½ or 1 x the stored energy in the flattop (H-mode)
  - Since plasma is still diverted, need to watch expanded power width and deposition on other surfaces like the throat of the divertor or FW near this area
- Power scrape-off width would be 5-10 x the normal value in flattop H-mode
- Power deposition time on divertor is 3-9 ms, similar prescription as for VDEs
- Current quench behavior is same as VDE, poloidal magnetic energy is radiated to FW

Disruptions and thermal quench power split

- VDEs are in contact with the FW when they have their thermal quench, so the heat load should be dominated by FW deposition? This will be localized to the location where the plasma is in contact, so it will NOT involve the large surface area of the total FW

- Major disruptions that are not VDEs would disrupt near the normal plasma location and would likely send a large portion of the energy at thermal quench to the divertor, with some to the FW depending on plasma motion and wall contact

NSTX VDE, plasma is touching passive plate and divertor floor

Runaway electrons

- The electric fields generated during the current quench phase can give rise to runaway electrons with energies as high as 10's -100's of MeV

- ITER specs
  - Total runaway current = 10 MA
  - Energy spectrum of electrons ~ $e^{-(E/Eo)}$, E_o = 12.5 MeV
  - Angle of incidence on FW, ~ $1\text{-}1.5^0$
  - Total energy deposition, ~ 20 MJ
  - Average energy density, ~ 1.5 MJ/m^2 over 100 ms
  - Maximum energy density, ~ 25 MJ/m^2, over 10 ms
  - Frequency is every major disruption or VDE

- Strategies include trying to 1) avoid their creation, 2) confine the runaways and slowly bring their current down, or 3) use methods to get them to leak out a little at a time

Mitigated disruptions

- Various approaches have been proposed and examined in experiments for reducing local high heat fluxes from disruptions and runaway electrons, mainly by injecting a lot of particles

- These can cause the plasma current to drop faster than a typical disruption

- ITER specs
  - All stored energy is radiated
  - Average heat load to FW, ~ 0.5 MJ/m^2, peaking factor of 3
  - Duration 1 ms
  - Same current quench behavior as other disruptions

Time-dependent modeling of ARIES plasmas with the Tokamak Simulation Code and PTRANSP

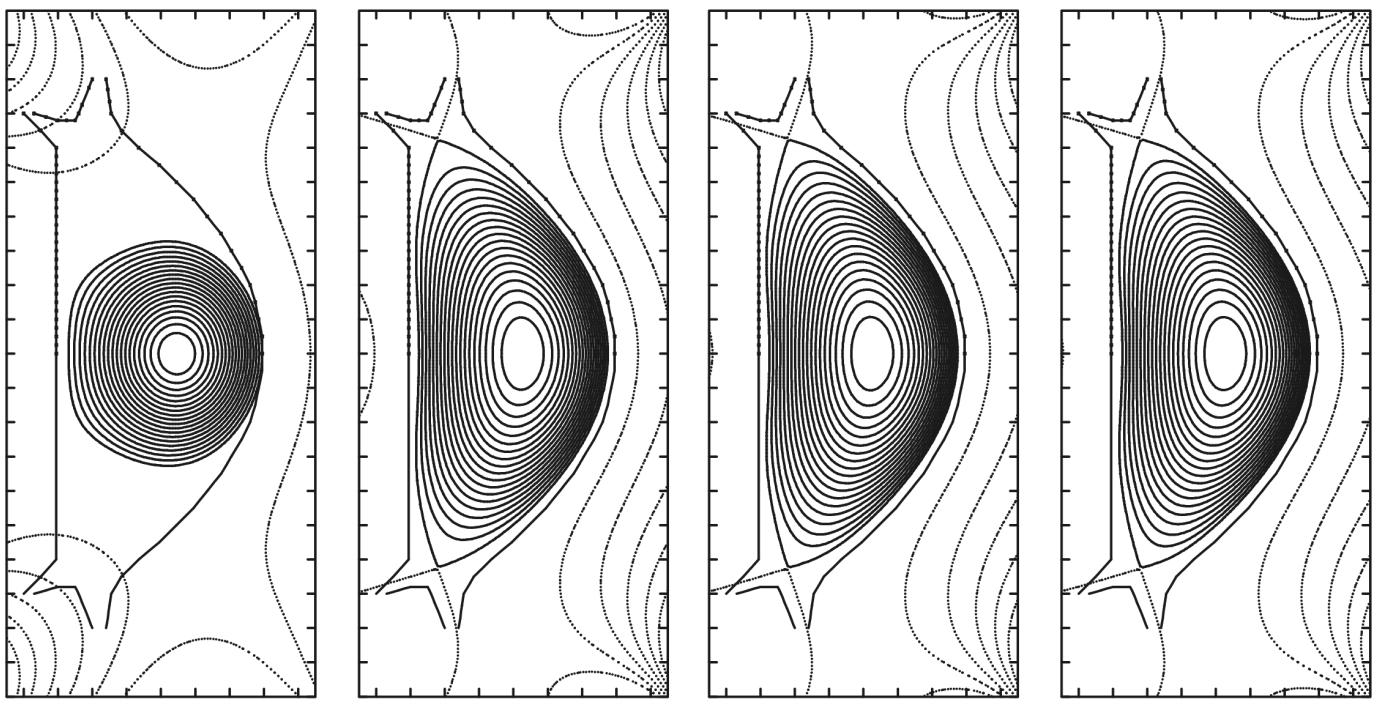
- Model disruptions in coordination with Univ. of Wisc
  - TSC will do drift, thermal quench, current quench and halo current modeling
  - Pass currents, fields, vector potential, and plasma motion & current distribution to structure codes
  - Can work with structure modelers to create 2D equivalent of 3D structures
- Model rampup and establishment of flattop configurations
  - Utilize PTRANSP source modeling with TSC free-boundary evolution
- Contribute to physics configuration studies
  - Flattop plasma configurations

Fiducial equilibria thru rampup

From systems output, using aggr phys / aggr tech

R = 5.5 m, a = 1.375 m, κ = 2.2, β_N = 4.5, B_T = 5.5 T, $q_{div,out}$ < 7.5 MW/m2

t = 1+ s	t = 20 s	t = 100 s	t = 150 s
Ip = 0.5 MA	Ip = 3.0 MA	Ip = 6.5 MA	Ip = 10.5 MA
β_N = 0.25	β_N = 0.80	β_N = 2.65	β_N = 4.5
$l_i(1)$ = 1.17	$l_i(1)$ = 0.83	$l_i(1)$ = 0.66	$l_i(1)$ = 0.65
Ψ = -60 Wb	Ψ = -20 Wb	Ψ = 10 Wb	Ψ = 40 Wb
q_{95} = 28	q_{95} = 12	q_{95} = 5.8	q_{95} = 3.6



Fiducial equilibria pressure and j-toroidal profiles

L-mode plasma to start

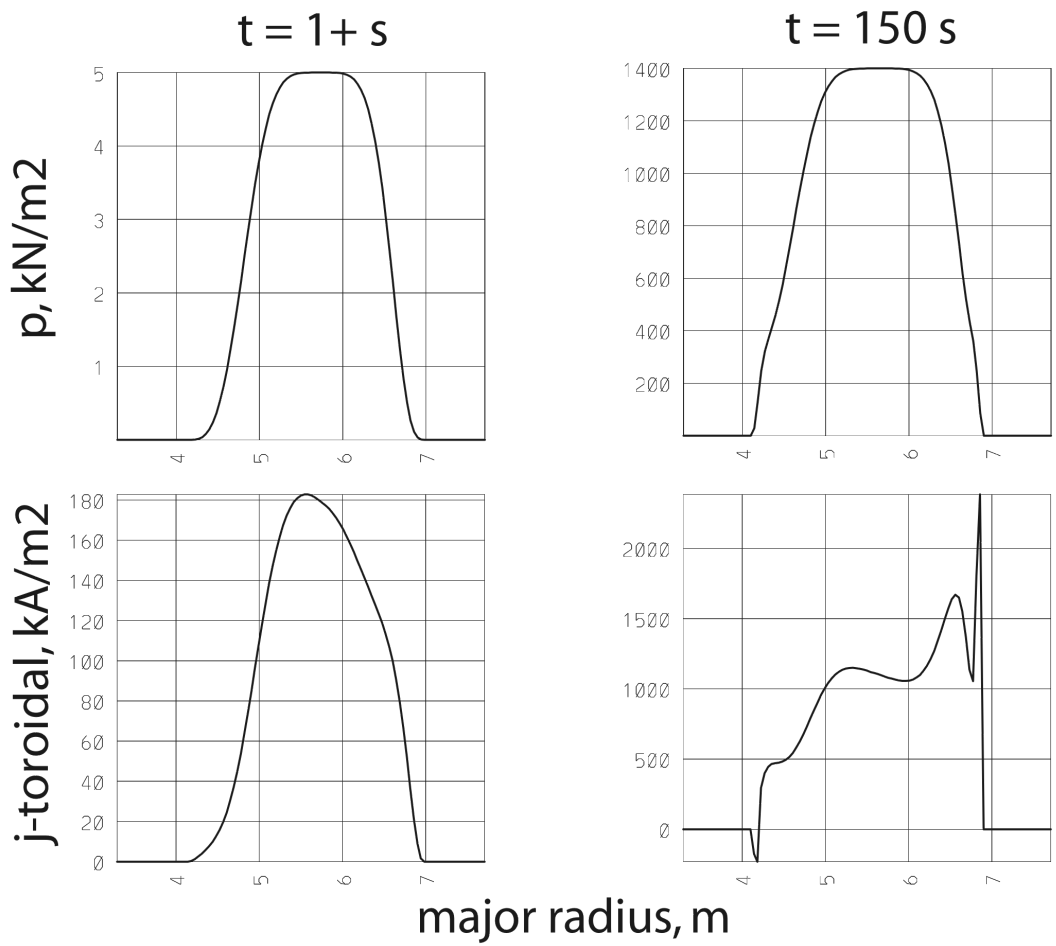
Low beta

High li, peaked current profile

H-mode plasma with broad current density

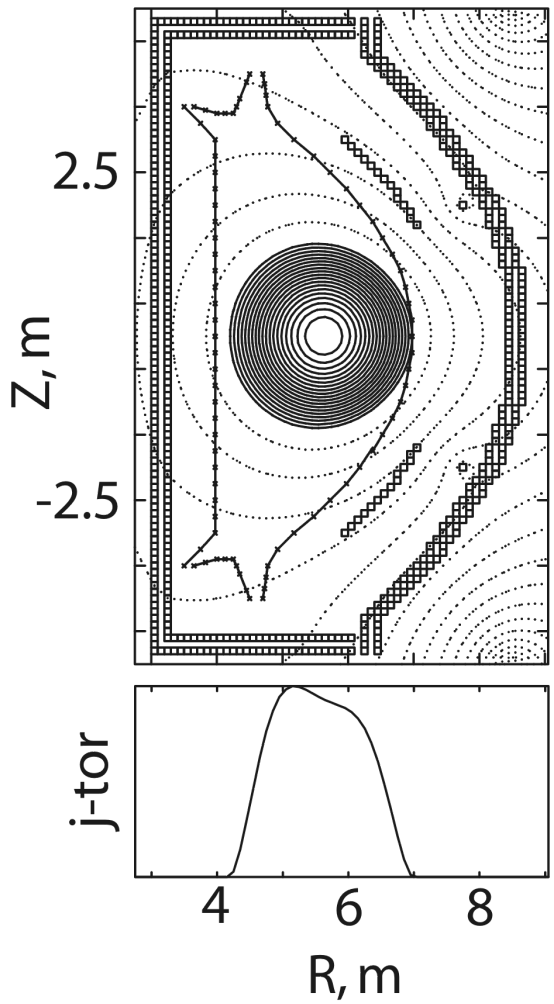
High beta

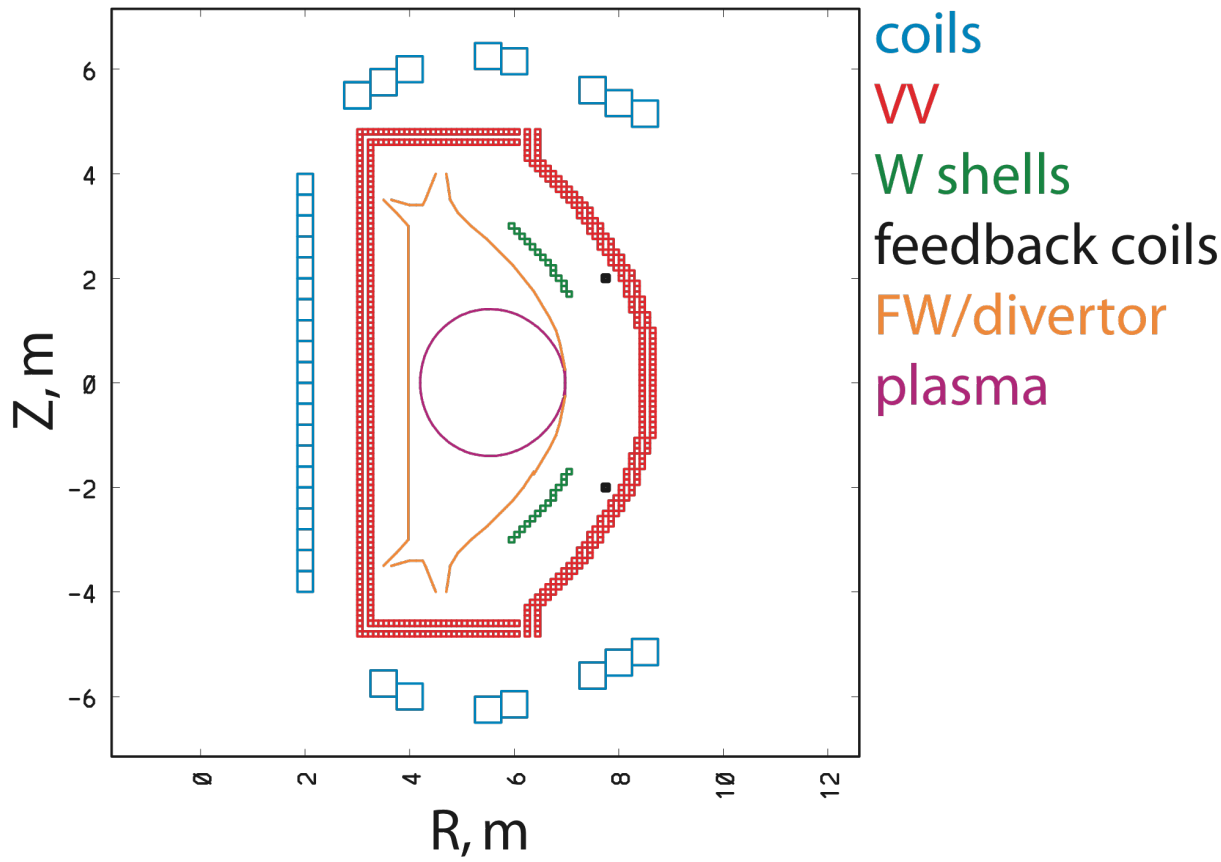
Low li broad current profile



Building structure model based on ARIES-RS, AT

Toroidally continuous structures for stabilizing (W) and for strength (steel)





Future Work

- Continue getting disruptions described in a form that can be used for heat loading FW and divertor analysis
  - Need to address particle loading if we are going to address erosion
- Input is welcome on the table for heat and particle loading description – what's missing, what can be ignored….
- Beginning to get time-dependent simulations in TSC set up for disruption analysis and mechanical analysis
  - Free-boundary equilibria are available for those who may need them
- Will also begin discharge simulations with plasma evolution and flattop configurations
- An aggressive and a conservative plasma strawman is pretty much available for analysis, so we can use these in our analysis