AN UPDATE on DIVERTOR STUDIES and HEAT LOAD ANALYSIS

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ARIES-CS Project Meeting

November 17-18, 2005

UCSD, La Jolla, CA

OUTLINE

- CS Configurations for divertor study.
- Update on divertor study:
  - Tools update
  - Strategy for optimizing divertor configuration
  - Setting up trial divertor plate configuration
- Update of alpha heat load studies
- Summary and future work

CS Configurations for Divertor Study

- ARIES/NCSX:
  - NCSX-ARE has been made a reference configuration, because of favorable □ loss characteristics. However, it does not have a self-consistent coil set, thus no free-boundary equilibrium.
  - For now, divertor study will continue with the old configuration as its magnetic topology is very similar to ARE.

- ARIES/MHH2:
  - MHH2-K14 is available with a complete set of VMEC-related equilibrium files and optimized coil set data.
  - A 3-D grid of B-field components needs to be generated with MFBE before carrying out divertor analysis.

A Recap from Previous Results -- McGuinness

- Used NCSX-like equilibrium with <R> = 8.25 m, A = 4.5.

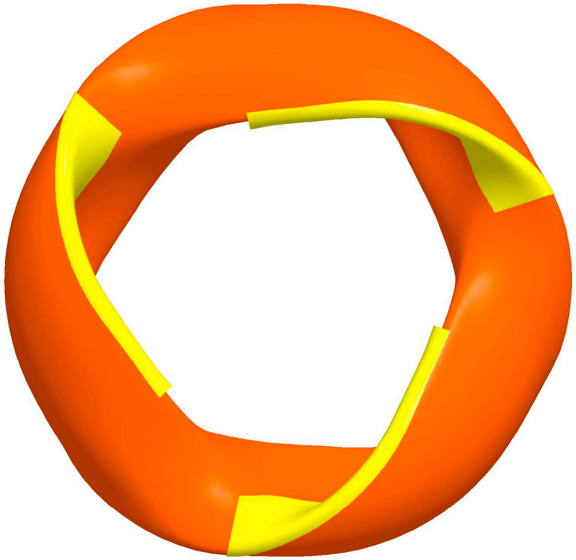
- Example divertor has one plate per period, with 40 m^2 per plate, with load peaking factor of 14-15.

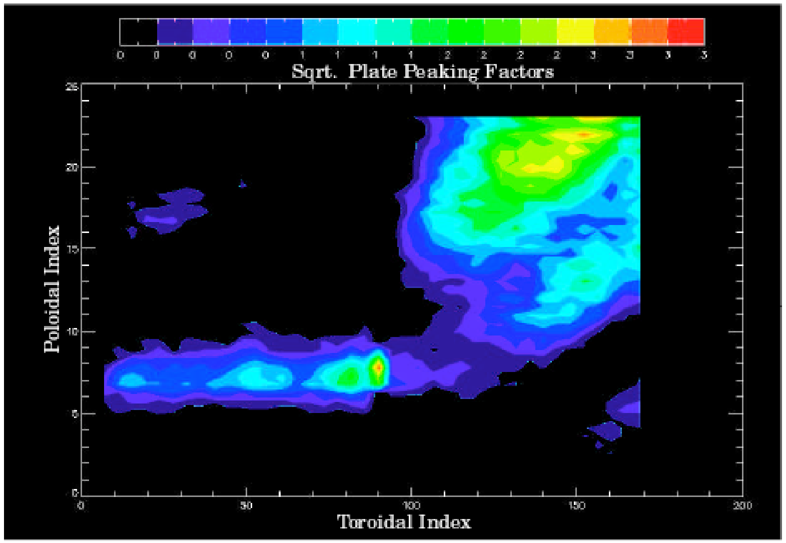
  Can handle max. heat load of 86 MW.

- Divertor configuration not satisfactory:
  - Peaking factor too large
  - Surface coverage (~15%) is too large
  - Heat load is highly non-uniform
  - Flux expansion zone not fully utilized

- Results presented in SOFE05.

- Further optimization of location, geometry, and size to be carried out.





Reduction of Divertor Heat Load

- Using the previous example divertor with a peak heat load limit of 10 MW/m^2, the target plates can handle a maximum of 86 MW only, including conduction loss, core radiation and neutron flux.

- To reduce heat, several methods can be considered:
  - Create plasma radiative mantle inside LCMS by injecting medium-Z impurity
  - Operate divertor in "conventional" high-recycling regime, relying on reionization of neutrals near the target to radiate the power
    - Requires high density, low temperature near target
  - Operate divertor in semi-detached or detached mode by:
    - Strong gas puffing (enhances intrinsic impurity radiation)
    - Combination of impurity seeding (N, He, Ar) and gas puffing

    Requires high density and low temperature

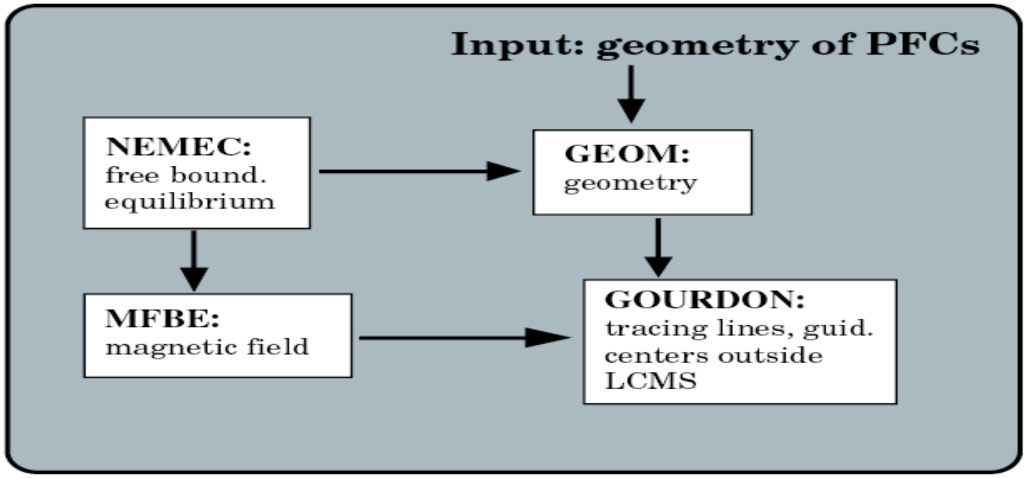
    Experiments observed reduction of peak heat flux to divertors by a factor of > 5.

    LHD recently reported detached divertor operation.

- Operating the divertor in these modes can greatly reduce the engineering design requirement for the target plates.

Tools for Divertor Design

- **NEMEC+MFBE** : Calculates magnetic field including finite-beta effects both inside and outside the LCMS.
- **GOURDON** : Traces magnetic field lines inside and outside of LCMS.
- **GEOM** : Creates a 3-D grid of the device geometry, and provides labels for surfaces such as LCMS, first wall, divertor and baffle plates, and for regions such as the plasma, SOL, and divertor.
- **GOURDON/GEOM :** Determines (1) locations where field lines intersect the divertor plates and first wall, (2) angles of intersection and (3) field line lengths from LCMS to first wall. It also calculates normalized heat load distribution.
- A **suite of codes** to calculate the Fourier representation of first wall, and plate location and surface topology. [Lots of tedious work]
- A **suite of visualization softwares** (IDL, GNUPLOT) for displaying results. [To be implemented]

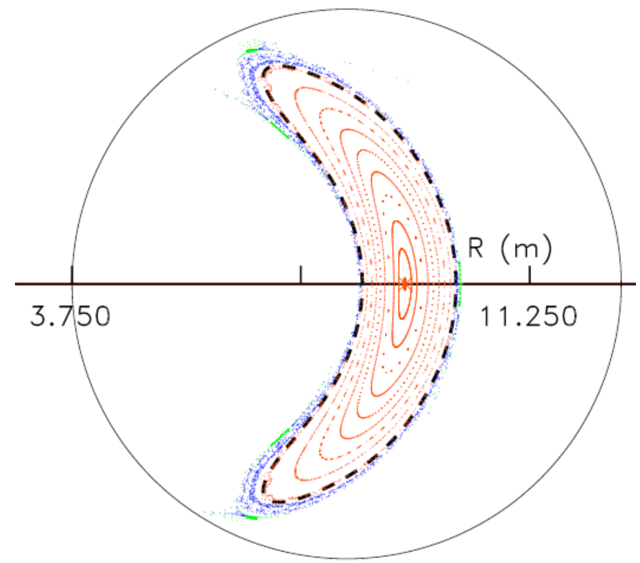


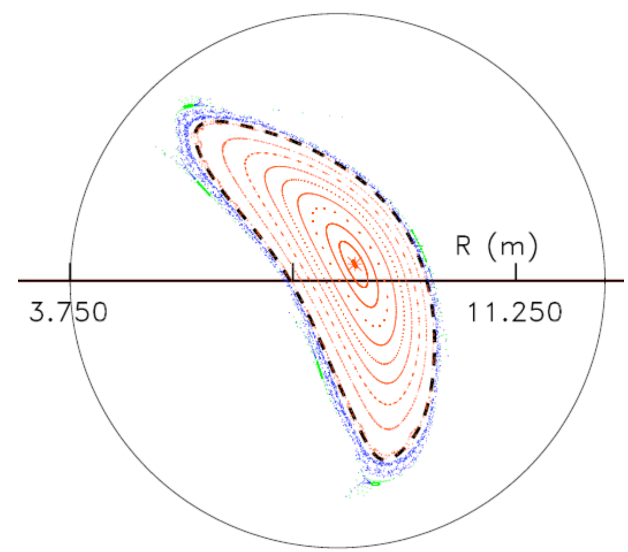
Poincaré Plot of Field Lines Outside LCMS Provides Guidance for Placement of Divertor Plates

- Most desirable poloidal location: outside regions of LCMS with sharp curvature:

  - Local flux expansion zone ensures spreading of field lines (and heat load).

  - Much larger number of field lines passing through the region increases chance of intercepting divertor plates located there.





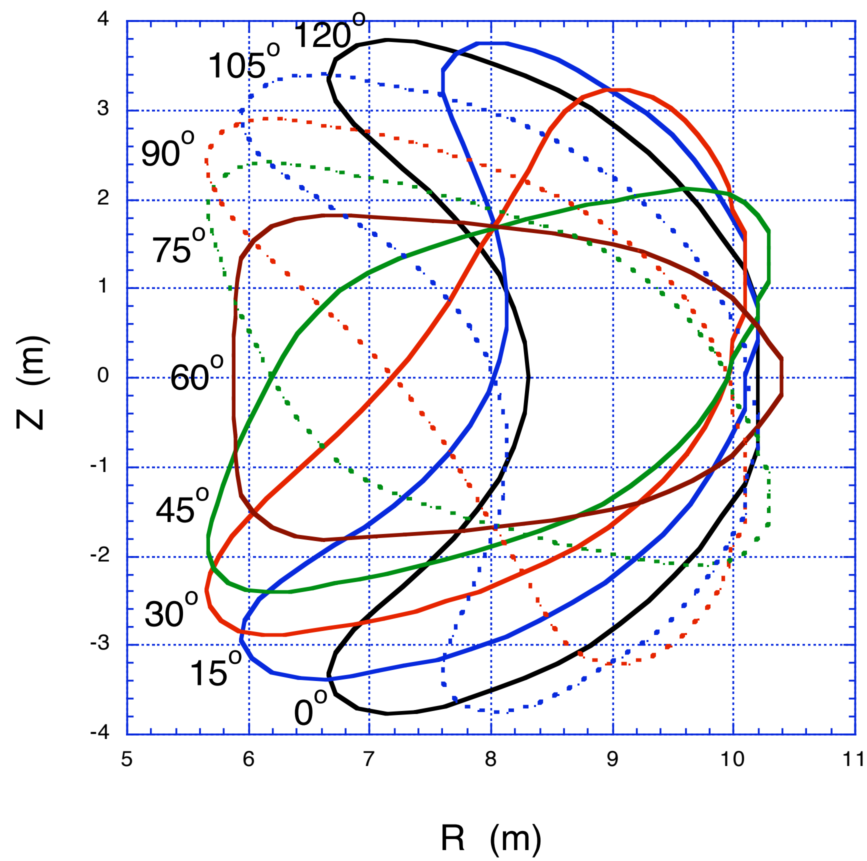
Starting Location of Divertor Plate

- To take advantage of flux expansion, take the following divertor plate location:

  In each field period, center of plate at

  - Lower corner for 0º < □ < 60º
  - Upper corner for 60º < □ < 120º

  Poloidal and toroidal extents are to be adjusted to minimize plate area, if possible.

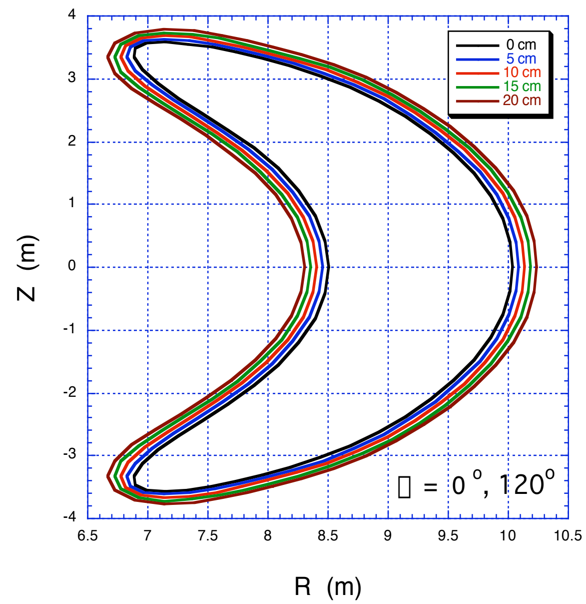


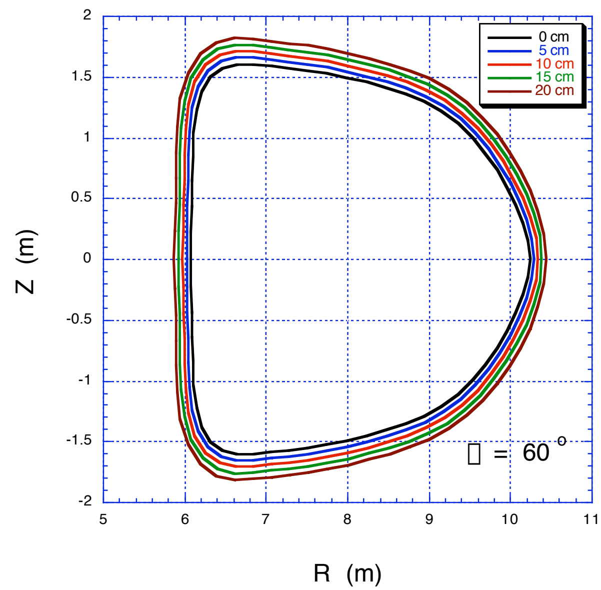
Starting Shape of Plate Surface

- To ensure field lines intersecting the plate at a shallow angle (for better load spreading), the initial plate surface is approx'ly conformal to the LCMS.

- The surface can be made locally inward-convex to capture more field lines while keeping surface area small.

- Two other adjusting options:
  - Plate center line
  - Offset distance from LCMS



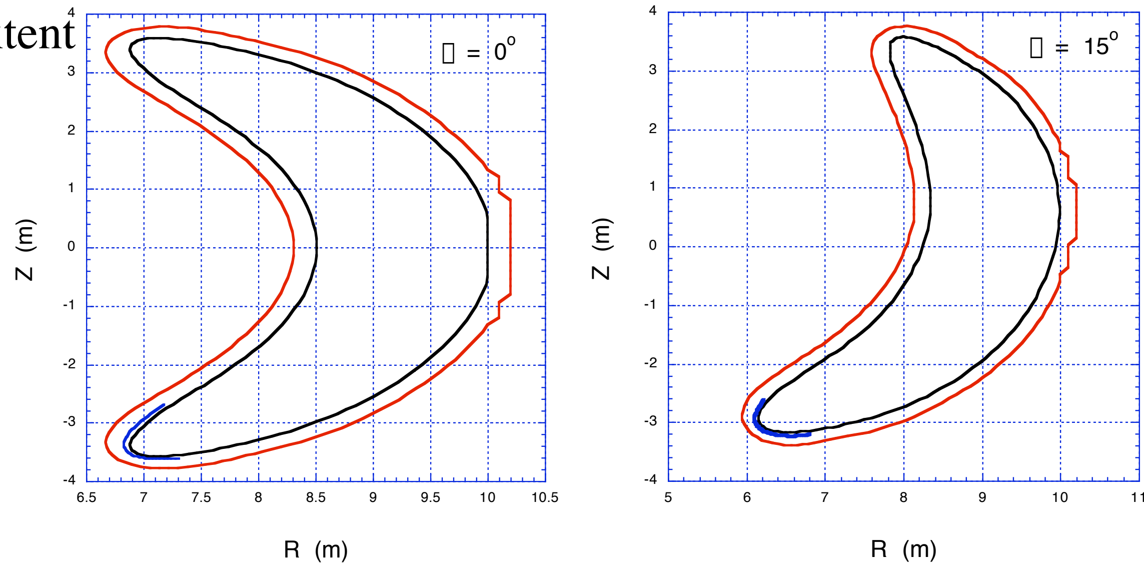


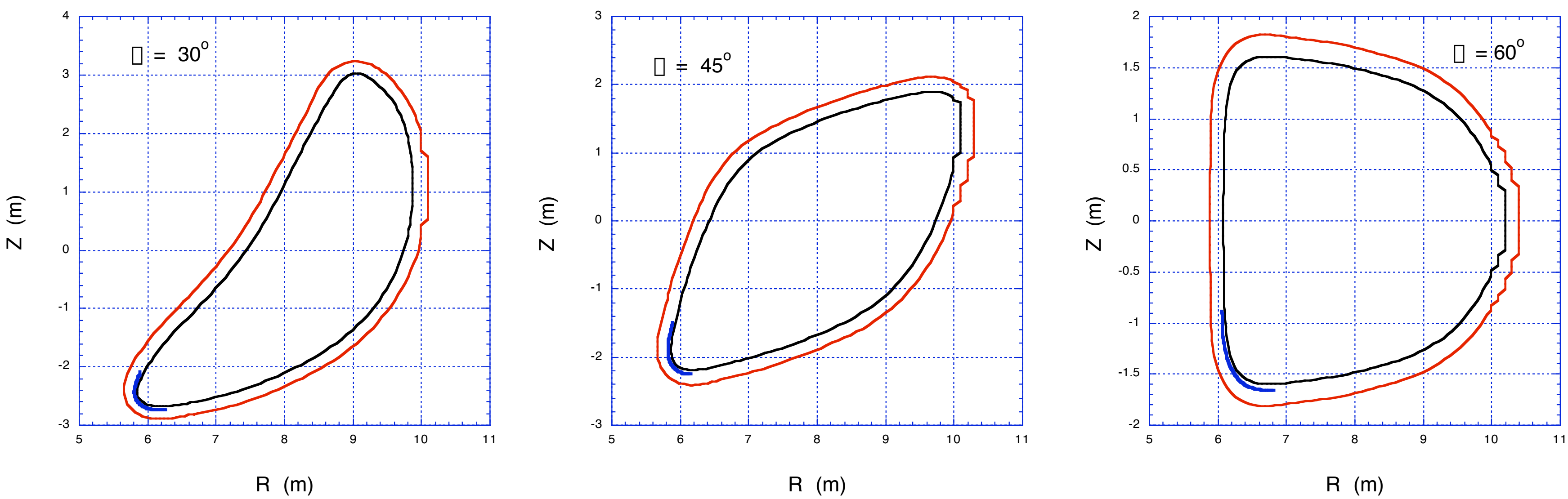
Trial Lower Divertor Plate Configuration

- Here, plate poloidal extent is □□ = 40°, and toroidal extent is □□ = 60°.

- The plate offset from LCMS is 5 cm.

- First wall offset from LCMS is 20 cm.





Issues for the GOURDON/GEOM Code

- The GOURDON/GEOM code is still undergoing test as the divertor configuration is being developed. There are three issues that need to be addressed.

- An error in the code causes a few % of the lines to “leak” through the target plate, without registering the strike points. Presently these points are simply thrown out.

- Another error causes strike points within $\pm 0.5^{o}$ of a period boundary, at □ = 0, 120 and 240^{o}, to be determined incorrectly. Presently, such field lines are simply re-launched, causing a lack of data near the boundaries.

- The implementation of cross-field diffusion in the code must be carefully re-examined, as it appears to have a much stronger effect on field line distribution on the plates and wall than indicated in previous studies (W7-AS, NCSX).

Update of Alpha Particle Heat Load Study

- Since the reference NCSX-ARE configuration lacks a free-boundary equilibrium, it is suggested that we map the alpha particle exit data from ARE onto the old NCSX-like equilibrium.

  Strictly speaking, this process requires an inversion of Boozer coordinates to VMEC coordinates for the old equilibrium, which will require some work.

  For the time being and as an approximation, we will just use the Boozer coordinates on the LCMS to directly calculate the alpha exit points.

- Incorporation of GYRO into GOURDON has been partially suspended so that more time can be devoted on optimizing the divertor configuration.

- When a reasonably optimized divertor geometry is obtained, an assessment of alpha particle heat load on the target and first wall will then be carried out.

Summary

- Because a previous calculation of a divertor configuration has yielded unsatisfactory results (high peaking factor, large plate area, and non-uniform load distribution), a more systematic approach has been mapped out in order to find a better solution to the problem.

- Various parameters can be varied to optimize the plate configuration. These include:
  - Location of plate center
  - Plate poloidal and toroidal extent
  - Inward convex-ness of plate surface
  - Plate offset distance from LCMS

- A trial divertor plate configuration has been obtained that will be tested fully with GOURDON/GEOM soon.

- It has been determined that alpha exit points from ARE be mapped onto the old NCSX-like configuration. The related heat load on the PFCs can then be assessed.

Future Work

- Further optimize the divertor configuration by following the strategy outlined.
- Address the three listed issues on GOURDON/GEOM, particularly the effect of diffusion on field line evolution.
- Calculate alpha particle exit points on LCMS NCSX-like finite beta equilibrium with favorable loss fraction.
- Finish the incorporation of GYRO into GOURDON/GEOM, and determine heat load distribution on divertor plates and the first wall.
- So far, all divertor and alpha particle work has been focused on the NCSX-based configuration. In view of limited resources and slower-then-expected progress in this work, what priority and time should be devoted to the MHH2 case?