Memo: ARIES-24

Date: 29 November 2004
Subject: ARIES Project Meeting Minutes, 4-5 November 2004, UCSD
To: ARIES Team
From: L. Waganer

Organization	**ARIES Compact Stellarator**
ANL	
Boeing	Waganer
DOE	
FZK	Malang
General Atomics	Turnbull
Georgia Tech	Abdel-Khalik
INL	Merrill
MIT	Bromberg
NYU	
ORNL	Lyon
PPPL	Ku
RPI	McGuinness
UCSD	Grossman, Mau, Najmabadi, Raffray, Sze, Wang (Xueren)
U of Wisc	El-Guebaly, Martin (Carl)

Ref: Agenda and Links to Presentations: http://aries.ucsd.edu/ARIES/MEETINGS/0411/

Administrative

Welcome – René Raffray welcomed the ARIES team to the University of California – San Diego campus. Les Waganer reviewed the agenda. Due to the small number of presentations, it was hoped to conclude the meeting in one day.

Next Meeting/Conference Call – The next conference call will be on Wednesday, December 1. Les Waganer will provide a conference call number. The next ARIES meeting will be held in San Diego (Update: GA will host the meeting) on February 24 (Thursday) and half a day February 25 (Friday). The following two meetings will be tentatively scheduled in June and September 2005 with the locations TBD. There will be a US/Japan workshop in Naka, JA, 11-13 January 2005 with several ARIES team members attending. There is also a socio-economics conference to be held during the week of April 22, 2005 at Culham, UK. A SOFE meeting is scheduled during the week of September 26, 2004 in Nashville, TN.

Status of ARIES Program – Farrokh Najmabadi said the OFES briefing in September 2004 went well and DOE was very complementary of the ARIES work. Farrokh also noted we had a good showing of technical papers at the September TOFE meeting in Madison. So far, Farrokh has only received 2/3 of the ARIES-specific papers to be installed on the ARIES web. Please forward him the remaining papers. Farrokh is updating the ARIES roster – please examine the roster on the web and confirm names.

Farrokh stressed that we need to make good technical progress in our interim design and evaluation phase by September 2005 to initiate the detailed design phase and publish that work by September 2006. In the interim before the final report, we need to publish progress reports and papers to document our progress. We have been doing a good job on the engineering area (TOFE, et.al.), but the physics and systems work needs to be documented (action: Ku, Turnbull and Lyon when results are available)).

Compact Stellarator Reactor Engineering Assessment

Heat Flux Gradient Limits for Liquid-Protected Divertors - Said Abdel-Khalik noted that the ALPS and APEX projects have been investigating the temperature limits on liquid metal and metal salt surface coolants for divertors for some time. His work is focused on the thermal gradients that might invoke more stringent limits for the liquid surfaces on a divertor. At the June ARIES meeting, Don Steiner suggested that heat flux gradients might also be a useful parameter. So Said has been expanding his field of investigation. Specifically, he is looking at a non-uniform heat flux that translates into a non-uniform temperature distribution resulting in a local thinning of the surface film. Depending on the surface film thickness, heat flux gradient, and other conditions, the film may rupture and expose the underlying surface with very adverse consequences. The heat distribution is a cosine function and the film surface is modeled with a third order partial differential equation.

Said illustrated his results with several candidate materials with flibe having the most restrictive performance (lowest tolerable heat and temperature gradients) and gallium the least restrictive. He noted that these analytical investigations are concluded. Experiments are being planned to verify the analytical results.

Radial Build Definition for Modified LiPb/FS/He System with SiC Inserts – Laila El-Guebaly showed her list of blanket, shield, and vacuum vessel (VV) concepts. She added a LiPb blanket concept with SiC inserts as proposed by Raffray and Malang to provide thermal and electrical (MHD) insulation for the FS structure. For this concept, Laila showed the radial build and the layer composition. Within the blanket region, there are two breeding zones (I and II), each 25-cm thick. Zone I provides approximately 70% of the tritium breeding capability. She indicated an approach to vary the thickness of Zone II in the transition areas surrounding the shield-only zones. In summary, the modified LiPb/FS/He system with SiC inserts has no change in Δ_{min}, a 2 cm-thickness reduction in $\Delta_{nominal}$, and a slight change in material composition values compared to the previous LiPb/FS/He design. For the 2-field period configuration, a uniform breeding blanket must be used everywhere as compared to using the WC shield locally in the 3-FP cases.

Laila compared the six different blanket, shield, and VV concepts for their key performance parameters as a precursor to the systems code analysis. These have been posted on the FTI web at http://fti.neep.wisc.edu/aries-cs/builds/build.html.

Neutron Wall Load Updates – Laila El-Guebaly noted the higher fidelity CAD neutron wall load (NWL) model used for the 3-FP case with neutrons tallied in discrete bins over the plasma surface. The peak NWL was ~3.1 MW/m^2 on the FW with a peak to average ratio of 1.62. The peak occurs above and below the outboard midplane within ± 1 m. She compared the results obtained with both simple (shorter run time) and more complex models. The simple model results were within 20% of the peak value and within a factor of 2 of the minimum value.

Laila also compared the UW ARIES-CS, 3-FP results with the HSR, 4-FP German results. The HSR results predicted a peak to average of 1.8 versus the ARIES-CS calculation of 1.6 for the 3-FP configuration.

Future efforts will focus on speeding up the calculations while maintaining necessary accuracy.

Code Integration for Efficient Divertor Design – Hayden McGuinness described the code elements (GOURDON, ORBIT3D, and GEOM) that are being used to define and develop the ARIES-CS divertor. GEOM is a geometric mapping code that identifies all the surface elements with tags for mapping. GOURDON reads the GEOM tagged maps and traces the field maps with characteristic lengths (Lc) to determine local heat fluxes. If the characteristic lengths are too long, guiding centers may be substituted. The ORBIT3D will be used to determine the gyro-radius for the GEOM code.

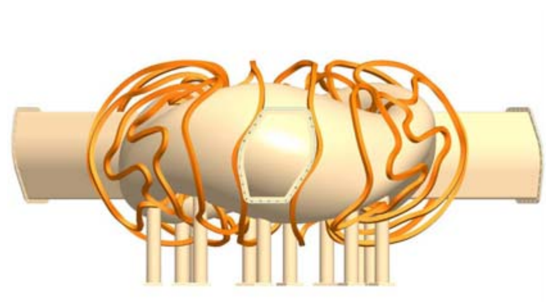
LOCA/LOFA Analyses for LiPb/FS/He System - Carl Martin has been working on the LOFA/LOCA analyses with Jake Blanchard. Early results were presented at the September 2004 meeting. A recommendation from the September meeting specified that the plasma would continue for 3 seconds after the incident. This continued heating condition was added to the LOFA/LOCA analyses and the results are reported. Radial builds and thermal boundary conditions were reviewed. A key assumption is that the back of the VV is an adiabatic boundary. Thermal responses for a complete LOCA of all coolants were shown. There was an early peak at 3.6 hours, followed by cooling period, and then a gradual steady thermal rise in all elements. A LOCA in blanket and shield and a LOFA in VV has the early peak with a gradual cooling of all elements. The inverse condition, a LOFA in blanket and shield and LOCA in the VV has a slightly lower peak temperature compared to the complete LOCA with an early peak, cooling period, and a gradual steady temperature increase (no heat transfer outside the power core). This analysis assumed the LiPb was stagnant and not moving – this assumption was questioned for future resolution. For the case of a LOFA of LiPb and VV water and LOCA for helium coolant showed a peaking and gradual cooling of all elements.

In the model used there were two gaps between elements with heat transfer by radiation only (one gap between blanket and shield, the other one between shield and VV. In the discussion, it was mentioned that we do not intend to have the first gap (blanket and shield are bolted together since they will have nearly the same operating temperature, making the heat resistance between the two elements close to zero). This can lead to considerably lower temperatures in the blanket during a severe accident, and this should be quantified by an analysis.

Future work will focus on removing the blanket-shield gap and improved modeling of the structure between power core elements and supporting structures. The capability of LiPb to slowly flow under convective heating will be researched. It was stated that the addition of surface and nuclear heating for 3 seconds raised the peak temperature by 2.5°C. The team thought this value was too small and would result in difficulty to heat the power core from a cold start.

Update of the ARIES-CS Power Core Configuration and Maintenance - Xueren showed the external vacuum vessel approach with three large outer VV doors that can be radially moved to the outer edges of a maintenance corridor, one at a time. These doors connect to a hollow central post and floor disk. It was suggested the hollow central post be eliminated in favor of simple disks above and below, connected with structure internal to the vacuum vessel (replacing a complicated torus structure with a sphere having flat surfaces top and bottom.) Prior to removing the VV door, a large containment enclosure would be positioned over one of the field periods (1/3 of reactor). This enclosure would be a thin, light-weight, non-permeable material to form a containment boundary around 1/3 of the VV. This enclosure would be capable of being moved to other locations for maintenance of other field periods.

For the modular maintenance approach, the VV is internal to the coils. One or two ports per field period pass through the bioshield, between the coils, and through the vacuum vessel to access the back of the shield. The VV also serves as a part of the shield, thus there will be a port shield in place when the reactor is operating. Xueren Wang reviewed the ARIES-RS maintenance approach and the Waganer/Malang design for contamination and tritium control. A similar scheme is proposed modular maintenance approach for ARIES-CS. Typical cross-sections and a plan view were shown. This maintenance allows a smaller radius bio-shield. Three-D views showed the vacuum vessel with the coils shown in position (without the cryogenic coil structure), see figure to the right. The VV is constructed as 60 deg segments inserted into the coil structures as field period assemblies. Then the FP assemblies are welded together. Maintenance flasks, similar to ARIES-RS, are used for maintenance.



Summary of Power Core Materials & Fabrication Unit Costs - Les Waganer reminded the team of the material costs provided for one power core concept. All concepts were shown to illustrate the common and uncommon materials. This power core concept chart is expanded to show the fabricated and installed cost per kg and theoretical density (contained in two sheets). A new cost quote for beryllium from Brush Wellman is significantly lower than previous estimates. These costs assume there will be a much larger production capability already amortized. The enriched lithium costs provided in September 2004 were incorrect as it should have been calculated with the atom percentage. Previous estimates on lithium and lithium orthosilicate were escalated to 2004$. Les showed the historical cost databases used in these calculations.

Les showed an illustrative trade study matrix containing the key performance parameters. He noted he should have added the energy multiplication and thermal conversion efficiency to the evaluation parameters. Rene Raffray suggested combining several power-related parameters into a single parameter and Laila suggested changing the blanket thickness into radial build standoff and the TBR into Li enrichment and Be content.

Power Core Options for Phase II and Focus of Engineering Effort – Rene Raffray summarized the power core options being explored for the ARIES-CS. These options are being narrowed to two for a more in-depth analysis in Phase II. Rene summarized the key performance and evaluation factors for the maintenance schemes and blanket/shield/VV. He noted Les' trade study matrix. He then discussed the key factors in the selection process.

Rene summarized the engineering activities in Phase II that defines the divertor, dual coolant LiPb blanket design, coil cross-section definition, and integration of all power core components.

CS Coil Design Definition/Fabrication Definition – Leslie Bromberg reported feedback from an ORNL meeting, mainly the need to update a systems code to provide additional and more detailed coil design data (current density and structural definition). Additional coil concepts may be needed to provide more parametric database and provide the capability to obtain a more detailed magnet structure. Leslie suggested making the superconductor pack as wide as possible to decrease the thickness of the conductor to meet the superconductor load line. Leslie provided an algorithm to calculate the required structure properties and geometries. In the conductor pack, strong ribs will be needed to resist the load with acceptable strains.

Leslie provided some example performance and cost calculations on baseline configurations. He said the strains would be the most challenging aspect of the design. Local strengthening of the coil structure will be required at the maintenance breaks to minimize distortion of the coil support structure. Some discussion of approaches was voiced. There was a feeling that the novel features of our "supporting tube structure" compared to designs with separate coil cases are not sufficiently taken into account by this analysis.

Compact Stellarator Reactor Physics Basis

Recent Development of QHS and QAS Configurations – Long Poe Ku described the advantages of QHS as compared to QAS: good particle drive orbits, large rotational transform, lower bootstrap current, and small Shafranov shift (higher equilibrium beta limit). The downside is that typically QHS has to have a larger aspect ratio, but this limit is not known. Hopefully, aspect ratios of 6 or less can be achieved. Long Poe found and analyzed two A = 6 and two A = 4.5 configurations. Excellent confinement properties may be attained for A = 6, but at A = 4.5 the energetic particles are not well confined. The ballooning beta limit is quite low. The QH properties are compromised. A vacuum well of a few percent would stabilize the interchange modes. The A = 6 configuration might be attractive if it proves to be cost competitive and "good" coils can be found.

The QHS A = 6 JI6 case is compared to the QAS, A = 6 KJC167 cases. The QHS has better confinement, but QAS has better MHD stability characteristics. QHS may have a better equilibrium beta limit and surface flux quality, excluding low order islands. There are three QAS classes of configurations: MHH2 (typically 2FP), NCSX, and new approaches that emphasize equilibrium surface quality.

The focus in the next period is to work on both 2 and 3 field period cases to improve the physics, design, and optimize the coils and complete the parameter trade space of R, B, beta, and aspect ratio.

Overview and Progress on Divertor Heat load Assessment and Design - T. K. Mau described his approach to define and assess the ARIES-CS divertor, including the type of divertor (island, ergodic, swept, radiative, and gas target). He added to the set of tools described earlier by McGuinness. He intends to calculate the magnetic fields inside and outside the last closed magnetic surface (LCMS), trace the field lines, and redetermine and reconcile the LCMS. Then the GOURDON code can determine the divertor locations and trace field lines to divertor plates. TK then outlined specific tasks to be accomplished during the next few months.

TK explained the reassessment of the alpha heat load on the first wall surfaces. The alpha particle exit points from the LCMS were converted from Boozer coordinates to toroidal coordinates, which showed definite patterns. Almost all alpha particles are lost through the outboard lower quadrant of the LCMS. He also showed an alpha heat load distribution on the LCMS.

Progress Toward Beta Limits for Compact Stellarators - Alan Turnbull noted the status of the ARIES-CS equilibrium and stability analyses. There is a general (though not yet universal) agreement on the meaning of MHD stability limits in stellarators, but the value and a predictive theory are unknown at present.

Alan discussed his and Paul Garabedian's papers at the EPS2004 conference and his collaboration at Lausanne. He noted that the linear stability calculations need to be benchmarked against the experimental results. For each mode type, nonlinear calculations must be completed to be able to fairly interpret the results.

The problems and limitations of the TERPSICHORE code have largely been resolved. Previously, the key parameters for the NCSX 3-FP and the MHH2 2-FP cases are compared. Using these data, he scaled the pressure profile and showed scaled values for both cases. Alan now showed a convergence test for both configurations involving many surfaces. This confirmed the conclusions obtained from the earlier study. Alan also showed completed calculations for stability with a wall close to the plasma, which were not possible before.

Modeling of Particle and Power Control for Compact Stellarators – Arthur Grossman used computer generated figures of the plasma surface and field lines to visually illustrate the regions where islands form on NCSX and ARIE-CS plasmas shown in several cross-sections. Many have small islands that could be used for a set of island divertors. He showed representative divertor concepts in the reactor cross-section that showed divertor baffles and pumping zones. The GOURDON code is capable of optimizing the island divertor. It is important to model the entire power core to accurately show the locations of the divertors.

Compact Stellarator Reactor Integrated Systems Assessment

Status of Systems Code Studies – Jim Lyon reiterated that the systems code is basically a 0-D code that can minimize on several parameters, primarily the cost of electricity. There are also a number of optimization variables, along with a large number of constraints. Jim explained the power core geometry being used and how the code uses the geometry - currently it is incorrect in that there is no gap between the shield and the outer leg of the coil (no space).

Jim outlined the code output, approach, and underlying assumptions. He has now obtained good agreement between the systems code and benchmarking codes. There remains a bug in the optimizing routine. He is using the power core costing data from Les and the coil cost data from Leslie. He ran some sample cases and generated preliminary data for comparison and evaluation. He was requested to provide more detailed data on the ARIES web site for detailed evaluation. Some output data looked suspicious and it was recommended to further analyze these data (Structure costs are too low, Blanket and Shield are too high (should put coolants into Special Materials), and Blanket replacement are too low).

Action Items for Phase II Engineering Effort

- Run LOCA/LOFA case with low contact resistance between blanket and hot shield (UW)
- Check effect of local radial conductance in blanket and between shield and vacuum vessel (UW)
- Do we need to consider any other accident scenario, such as LOVA? (INEL/UW)
- Structural analysis of coil support to have a better definition of required thickness for cases with separate coil structure for each field period (MIT)
- Details of module attachment and replacement (choice between “single” module maintenance or “series” module maintenance) (FNTC/UCSD)
- Port maintenance including all pipes and lines (realistic 3-D layout including accommodation of all penetrations) (UCSD)
- Coolant lines coupling to the heat exchanger (choice of HX material, e.g. W-coated FS vs. refractory alloy such as niobium alloy) (FNTC/UCSD)
- Tritium extraction system for Pb-17Li + tritium inventories (FNTC/UCSD/INEL)
- How high can we push the Pb-17Li/FS interface temperature based on corrosion limits? (FNTC/UCSD)
- External vacuum vessel design (thickness and configuration) (FNTC/UCSD)
- Divertor design and analysis (T. Ihli/UCSD)