Memo:	ARIES-25
Date:	22 December 2005
Subject:	ARIES Project Meeting Minutes, 17-18 November 2005, University of California, San Diego
To:	ARIES Team
From:	L. Waganer

Organization	**ARIES Compact Stellarator**
ANL	
Boeing	Waganer
DOE	
FZK	
General Atomics	Turnbull
Georgia Tech	Abdel-Khalik
INL	Merrill
LLNL	
MIT	
NYU	
ORNL	Lyon
PPPL	Ku
RPI	Donavon (Mike)
UCSD	Dragejlovic (Zorin), Malang, Mau, Najmabadi, Raffray, Tillack, Wang (X.)
U of Wisc	El-Guebaly

Ref: Agenda and Links to Presentations: http://aries.ucsd.edu/ARIES/MEETINGS/0511/

Administrative

Welcome – Rene Raffray welcomed the ARIES Team to the University of California – San Diego and advised the team of the refreshments, facilities, safety instructions, and lunch arrangements. The University provided the morning and afternoon refreshments.

Status of ARIES Program – Farrokh explained the House and Senate have passed the FY06 Energy and Water budget, which is expected to be signed shortly by the President. A slight reduction of 2-4% is expected.

The next ARIES meeting is to be held in January just ahead of the US/Japan Power Plant Design Workshop at UCSD. Presentations at the Workshop are encouraged from the ARIES team on the basis, design, and analysis of the Compact Stellarator. The ARIES meeting will be on Monday, January 23 and the Workshop will be on January 24-25. One of the topics for the ARIES-CS meeting is to discuss areas to be considered for study following the completion of the CS in 2007 and beyond. The Compact Stellarator technical effort should be concluded by September 06 and the following 2-3 months would be devoted to writing the final report.

Farrokh said the ARIES team has been working to converge on a common technical baseline for the Compact Stellarator, but more work remains to establish a current and common baseline. Mike Donavon from RPI has joined the team working with Don Steiner.

Compact Stellarator Physics Basis

Recent Results of Configuration Studies – Long Poe Ku recapped his findings presented at the September 2005 Town Meeting. Three attractive reactor configuration families (NCSX, MHH2, and SNS) have been examined in some detail. The use of bootstrap currents will be examined. The recent discovery of biased components in the magnetic spectrum may improve plasma performance and may lead to improved configurations.

Long Poe showed his study of the NCSX configuration for a range of aspect ratios from 3.5 to 5.6. All have favorable MHD stability properties, good QA and low ε-eff. The favorable solution becomes more difficult to achieve as the Aspect Ratio decreases. The field properties were shown for the range of aspect ratios. Energy loss fraction of alpha particles and the collisionality parameter are most favorable in the range of aspect ratios around 4. The alpha loss tends to be smaller if the field is higher and/or the collisionality with the background ions is large. Calculations for the mirror-enhanced NCSX with an aspect ratio of 4.5 and beta of 4% show strong υ and B dependence.

Long Poe intends to continue to use biased magnetic spectrum to improve the configuration by adding iota constraint for surface quality improvement. He will also study the coil complexity and aspect ratio on these configurations. He will also optimize internal transforms by varying p and J profiles. He will examine physics aspects of the reference point design in the code. He will also add an SNS configuration to be added to the system code reference plasma configurations.

Update on Beta Limits for ARIES-CS – Alan Turnbull summarized the Town Meeting guidance on the applicability and stability on beta limits for stellarators:

- Ignore local stability criteria
- Check flux surface quality (with PIES)
- Check low order edge rationals
- Monitor linear global stability
- Research non-linear global stability

For the next year, he anticipates investigating the impact of variations from the baseline scaled NCSX and MHH2 configurations on system performance. He will also continue to monitor the developmental tools needed for the ARIES-CS design.

An Update on Divertor Studies and Heat Load Analysis – T.K. Mau said the NCSX ARE configuration is the reference baseline configuration due to its favorable alpha loss characteristics. But it does not have a self consistent coil set (no free boundary equilibrium). However, the existing NCSX should be sufficiently close to use as a surrogate configuration.

The MHH2 configuration is available with a complete set of VMEC coil equilibrium files and coil geometry data.

TK summarized the McGuinness divertor data previously provided. However, the divertor heat load peaking factor is too high for the present divertor design. TK outlined several methods to lower the peaking factor. Farrokh Najmabadi suggested setting divertor reference data points for further design work and base this on an alpha loss calculation. Farrokh suggested a new approach to map the heat load at all plasma surface locations and then incline or shape the divertor to have heat loads less than the 10 MW/m^2 heat load limit. Field lines in present analyses are much too short, hence high heat loads. Need to have a reference divertor design in 3 months with a list of intermediate milestones to reach the goal.

Compact Stellarator Reactor Integrated Systems Assessment

Analysis of Systems Code Results – Jim Lyon summarized the systems code concerns voiced at the September Town Meeting. Some costs and weights were not in agreement with similar subsystems from previous ARIES designs. Laila El-Guebaly has conducted an in-depth assessment of the volumes, weights, and costs as compared to prior designs (see following talk).

Jim explained the NCSX-ARE is the reference case for most system assessments. He described the plasma and coil parameters for the MHH2 and the NCSX-ARE designs. He highlighted areas of concern in his charts for more examination. The reference configuration is not consistent with the physics or engineering baseline, however, the code inconsistencies will be resolved before proceeding toward a common baseline is incorporated in the systems code. Farrokh is concerned about the high power alpha loss.

The design basis and method of calculating the coil structure was extensively discussed. This design basis is being modified by the engineering group to achieve a more cost-effective approach Also, the shield only region is being redesigned to eliminate the helium manifold behind the blanket and move it to the adjacent blanket regions. The coil winding pack costs are uncertain as discussed by Leslie Bromberg in his presentation.

There seemed to be an error in the use of the gross thermal efficiency, which should be the efficiency of the gross thermal power into gross electric power. The electrical pumping power and thermal power contribution from the pumping power friction losses were not being handled properly. Some cost accounts were not totaled correctly. The thermal conversion costs for the Brayton cycle and secondary HX were not being correctly computed.

Assessment of Power Core Parameters and Related Costs – Laila El-Guebaly assessed the volumes and costs for the ARIES-CS as compared to similar systems in the prior reactor designs. The ARIES-CS volumes of the components calculated by the CAD and the systems code did not compare well. The LiPb volume was too high as compared to ARIES-AT. The coil structure seemed high, but this may be due to the design being costed. The basis for the buildings, especially the Reactor Building, needs to be reassessed. The recirculating power also needs to be updated. The costing algorithm for the main heat transfer and transport system needs to be modified for the dual-coolant system.

Laila will work with Jim to make sure the code can predict volumes, masses, and cost values consistent with the ARIES-CS design concept.

Compact Stellarator Reactor Engineering Assessment

Status of Engineering Effort on ARIES-CS Power Core – Rene Raffray showed the power flow diagram for heat fluxes on the divertor and first wall. He then showed the analysis to determine the fractional power radiation from divertor region to maintain the heat load less than 10 MW/m^2. Three methods to lower the maximum divertor heat flux were to lower peaking factor or larger surface area, magnetically sweep the high heat flux regions from the plasma, and provide for higher radiation in the divertor region. Rene explained the frequency distribution of the alpha particles over the range of expected energies. The divertor PFC surface must accommodate the heat flux but also the high energy alphas. The higher energy alphas will erode the divertor surface and reduce the armor lifetime. Ion implantation in the tungsten armor is quite complex to model. Some experimental results have been accomplished and may be applicable to this application. A possible material modification is to use porous W and nano W microstructures to allow the generated helium to escape the W surface layer.

Rene explained the key parameters for the dual-cooled Brayton thermal conversion and the optimization of the cycle efficiency for the dual coolant thermal conversion system. He summarized the parameters for the dual coolant concept for a wall loading of 5 MW/m^2. An analysis was conducted on the self-cooled Pb-17 Li blanket with SiC/SiC and it determined the gross thermal cycle efficiency varied from 0.63 to 0.56 over a range of maximum neutron wall loading from 2 to 5.

Rene reported that the port-based maintenance scheme of modular replacement is recommended as the reference case. The field period-based scheme of removing an entire sector will be retained as an alternate scenario.

Rene reported good progress on the engineering of the divertor module to handle the anticipated divertor heat load. However the peaking must be reduced to more tolerable limits for the engineering design approach.

New Radial Build Data – Laila El-Guebaly noted the recent changes to the LiPb/FS configuration radial build. The Shield-Only Zones now accommodate the 20-cm thick helium manifolds that increase the machine size significantly, influence the re-weldability of the manifolds, and determine the needed local shielding. Design approaches are being considered to move the helium manifolds from this region as Laila suggested. At present, the high temperature shield has increased from 18 cm to 28 cm to protect the manifolds of the nominal blanket/shield. Additional local shields are required behind the He access tubes to protect the VV/magnet against streaming neutrons.

Laila has now modeled the new 4K magnet composition provided by Leslie Bromberg. The new magnet composition has no major impact on the definition of the radial build.

Laila provided new radial builds through the blanket/shield and shield-only regions as well as radial build through the helium access tubes. Laila suggested using LiPb to cool the shield-only regions. She also asked if all shields could be cooled by LiPb. One action item to UCSD Engineering Group was to investigate if the shield-only region could be cooled from the adjacent sections with no manifold in the shield-only region.

Status of the Modular- and Field-Period Replacement Maintenance – Xueren Wang noted the thickness of the high temperature (HT) shield increased from 18 cm to 28 cm. He has incorporated the 35-cm thick manifolds behind the typical HT shield. He also showed a possible solution for protecting the coolant welds at the rear of the shield. He illustrated the sequential steps needed to remove the blanket modules in the modular replacement scheme. He showed a possible solution for shield-only modular design that uses two modules per each zone. Weld protection solutions were also shown.

Xueren reviewed the weld protection approach for the protection of the weld behind the shield. 3-D drawings were provided to illustrate approach for connecting the coolant manifolds.

It was decided that the CAD model will be updated from the present major radius of 8 m to a more representative size of 7 m. This can be accomplished by linear scaling of all components from the present configuration.

Low Cost Fabrication Approach for ARIES-CS Coil Structure - Les Waganer reviewed the present coil structure cost estimate and suggested structure design approaches that might be more efficient. The continuous grooved coil structure shell is a good approach, but it is likely to be structurally inefficient. The new approach suggested by X. Wang is an improvement, but the in-plane loads are not efficiently transferred into a thinner coil structure section. Les suggested an even thinner continuous coil structure with strategically placed rib stiffeners. Immediately outside the coil, additional structure is provided to resist the radial loads. On the sides of the coil, structural material is added to resist the out-of-plane loads. This material and the continuous shell will be aligned with the coil so no bending loads are generated. The local out-of- plane and radial thicknesses would be tailored to the local coil forces, which results in the optimal sized and configured structure.

Les suggested a low-cost fabrication approach involving near-net shape with advanced metal deposition systems. This approach would deposit metals, probably ferrous, in accordance with the CAD definition. This approach has been demonstrated and is being used to fabricate flight-qualified aerospace structural components of a moderate size (10 feet or so in length). This approach yields a component requiring minimal machining, probably in the coil groove, the field-period interfaces, gravity support points, and miscellaneous hardware mounting surfaces. The fabricated cost would be a few multiples of the raw material cost. Les suggested the structural cost would be in the range of $10/kg. However, if the structural material has to be a material in plate or forged condition, such as Incoloy, this fabrication approach would not be feasible with present knowledge. More definition on the fabrication approach will occur after the coil structure is better defined.

ARIES-CS Magnet Definition – Leslie Bromberg said he is continuing to try to estimate the complexity of the coil and coil structure fabrication to determine an appropriate cost. He had previously thought high temperature superconductor (HTS) could not be applicable. However, recent advances in AMSC have been able to fabricate HTS YBCO conductors at a reasonable size that have a much higher strain tolerance (~1% as opposed to 0.1%). Thus, HTS should be reconsidered as a possible coil technology. This would allow the use of lower cost (non-Incoloy) structural materials. Leslie thought the cost of both Nb_3Sn and YBCO HTS would be around $1/kAm.

Status of Coil Structural Design and Magnetic-Structural Analyses – Xueren Wang presented updates to his ANSYS EM analysis of the NCSX coils. Don Williamson, ORNL, ran the stress calculations using the FEM data provided by Xueren. These analyses were for the 8-m major radius, which will be reduced to the 7-m range in accordance with the project baseline. The highest forces occurred at the regions of the minimal bend radii. Within the field period, all poloidal (□) and Z forces are cancelled to a net zero. The net radial coil forces exert a net inward force that is counteracted with the bucking cylinder. It was decided the bucking cylinder could be cryogenic as the force transfer across cryogenic/room temperature interfaces is too difficult in the port maintenance case. The EM forces were illustrated for the coil set. Xueren assumed Incoloy 908 as the coil structural material consistent with low temperature superconducting materials. See prior section for a possible change to HTS conductors and ferrous structural materials. The analysis analyzed the stresses and displacements. This would indicate where additional material is needed and where material can be removed, realizing that this is an interim solution pending new coil configurations. Xueren showed the earlier coils structural design as well as an updated approach similar to Les Waganer's. This will probably be the approach used in future analyses. The coil cross-section will be changed from the present square cross-section to the higher aspect ratio used by Jim Lyon. It was suggested Xueren model half a field period and assume mirror symmetry. Then send the model to Williamson for processing.

Action Items:

<u>**ALL**</u>

Use the machine dimensions and power flow per ARE strawman presented by Jim Lyon at Nov. Project Meeting

<u>**Jim Lyon**</u>

1. Correct arithmetic total of Account 21 and check all totals for arithmetic errors
2. Correct Systems Code to agree with general structure of previous ARIES Power Flow chart; see chart in Raffray's presentation (Gross Electric Too Low)
3. Modify Systems algorithms and input data to reflect the use of Gross Thermal Efficiency – Rene Raffray to supply new gross efficiency values and pumping power requirements (both electrical power and frictional thermal power) (Gross Electric Too Low)
4. Correct cost modeling (Acct 22.2) to account for dual coolant heat transfer and transport including heat exchangers (partially Nb) and the more costly Brayton turbines
5. Change data input for "Primary Structure" to reflect gravity supports (Account 22.1.5)
6. Include coil structure (strongback and inter-coil tube) in Coil volume and Cost (instead of Primary Structure)
7. Recheck Replaceable FWBS and divertor Annual cost as the reported value is too low
8. Cost for Impurity Control is too low - $7M should be more like $55M. ********(Not sure about this item # 8. It's 14 M$ for ARIES-RS, 4 M$ for ARIES-AT, and 12 M$ for SPPS. 7 M$ may not be too far off)********
9. All other issues identified in Laila's presentation:
    a. <u>Increase shield volume by 10% to account for penetration and local shields</u>
    b. Move "Heat Rejection System" out of Account 23 and list as separate Account 26
    c. Fix "Reactor Building" Account 21.2
    d. Include cryostat in Account 22.1.6 (get dimensions from UCSD)

10. Use ARIES-AT unit cost for WC
11. Add placeholder for divertor cost
12. Do not accept design changes until you and Laila have resolved code modeling errors
13. After modeling has been validated, correct coil structure modeling in the code should be based upon the then-current design basis
14. After modeling has been validated, generate parameters for advanced LiPb/SiC design with 58% thermal conversion efficiency
15. After modeling has been validated, generate parameters for 2 PF configurations (get radial build from Laila)

Laila El-Guebaly

1. Check blanket coverage and TBR for latest plasma-magnet separation contours
2. Continue to work with Jim to fix all identified modeling errors on volume, mass, and cost algorithms. Provide algorithms and test data. Validate all related modeling and code outputs (try to complete this before Laila goes on vacation from December 26 to January 17
3. Continue the verification role as future design changes are incorporated into the code
4. Update power distribution to blanket Pb-17Li coolant, blanket and shield He, shield-only zone He and divertor He. Get He pumping power from UCSD
5. Optimize local shield behind helium access tube
6. Provide radial build for 2 field period configuration

Long Poe Ku

1. Update Physics memo to include SNS case
2. Contact A. Brooks to provide X. Wang with coil coordinates (using ARE dimensions and coil sizes)
3. Interact with Mau re modeling of alpha loss for ARE strawman
4. Provide plasma-midcoil separation contours to Laila for 2 and 3 FP configurations

TK Mau

1. Test diffusion model in GOURDON code (Dec. 2)
2. Implement programs for displaying GOURDON results. [From Hayden, or explore using PGPLOT] (Dec. 16)
3. Obtain optimized divertor geometry for ARIES/NCSX configuration for R=8.25 m case, with heat load and peaking factor (Jan. 20)
4. Complete incorporation of GYRO into GOURDON (Feb. 10)
5. Produce alpha heat load on optimized divertor and wall for ARIES/NCSX. (Mar. 10)

6. Provide divertor coverage fraction to Laila to estimate overall TBR

Xueren Wang

1. Update CAD model with new ARE strawman dimensions. Provide volume data to Jim Lyon and Laila to check against systems code
2. Modeling of the coil cross-section should reflect what Jim is using in the Systems Code (obtain coil coordinates from A. Brooks and use for analysis)
3. Determine if we can run a solid model of the coils with our university version of ANSYS. Proceed accordingly
4. Perform coil displacement analysis for separate coil structure with bucking cylinder and compared to keyed structures without bucking cylinder to decide which way to go with port based maintenance (X. Wang)

Raffray et al. (Engineering group)

1. Design of shield only module with possible coolant connection from neighbouring module (S. Malang, X. Wang)
2. Start safety studies for port-based maintenance (B. Merrill)
3. Write-up on port-based maintenance and field-period-based maintenance (R. Raffray)
4. Details of manifold design and coolant routing (S. Malang, X. Wang)
5. Update divertor pressure drop and pumping power; redo cycle calculations and provide gross efficiency and pumping power values to Jim (R. Raffray)
6. Further study of alpha particles impact on armor lifetime (R. Raffray)
7. Estimate cryostat thickness based on simple hoop stress (R. Raffray)
8. Confirm possibility of cooling magnet structure at 10K (L. Bromberg).

Les Waganer

1. Develop a document describing all cost account items (what is in each account and formulas to be used). Obtain from Jim and Laila latest of what was in the ARIES systems code
2. Estimate volume and cost of He coolant