New ARIES Systems Code Development and Validation

Farrokh Najmabadi
UC San Diego

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The ARIES Pathways Study began in 2007 to evaluate R&D needs and gaps for fusion from ITER to Demo.

- R&D metrics to evaluate the status of the field and progress along the development path.
  - In this study we examined a methodology for evaluating R&D needs and gaps that is widely recognized and utilized outside the fusion community.

- A new systems-based approach to establish the importance of various power plant parameters and define metrics for prioritization.
Motivation for a New Approach to Systems Analysis

- Systems codes are critical tools in fusion design, because they integrate physics, engineering, design and costing.

- The approach taken by most (if not all) systems codes has been to produce an **optimal operating point**, which is often difficult to justify, **why is it optimal?**
  - For example, scans of COE vs one parameter around the design point usually shows a shallow minimum.

- This does not utilize the power of a systems code, which is to generate many operating points (**operating space approach**)
  - Scanning can be done with simple models
  - Results from detailed analysis can be incorporated for more specific searches
Experience indicates that “optimum” design points are usually driven by the constraints.

- In some cases, a large design window is available when the constraint is “slightly” relaxed with substantial improvements in COE.
- In other cases, COE changes slightly with changing the constraints, and operation away from the constraint allows a more “robust” and credible design with minim impact on COE.

Operating space approach to systems analysis makes the effect of constraints more transparent.

Many constraints carry a lot of uncertainty, which can be quantified.
Sequencing the analysis through 1) physics operating space, 2) engineering operating space, and 3) device build and cost, will provide a better explanation of available operating points and why they are desirable.
Features of the New ARIES Systems Code

- Objective oriented programming allows inclusion of many models for various systems.
- In the Operating Space mode, a large data base of possible power plant candidates is created which can be examined under different optimization constraints and criteria using modern data mining and visualization techniques.

Physics module:

- Originally developed in order to examine high field compact Tokamak burning plasmas for FIRE experiment.
- Generates a large database of viable steady state plasmas for advanced, high energy Tokamaks.
Features of the New ARIES Systems Code

Engineering module (new features):

- Modern CFD Mesh generation techniques are used to define the contours of all power core systems (starting from plasma separatrix). Surface and volumes have a very good agreement with CAD.

- Blanket module includes models for changes in the radial build and power conversion efficiency based on surface and neutron loading.
  - ARIES-AT type SiC blanket modules is operational, A DCLL blanket module is under development.

- New models for simple estimation of PF system which are quite accurate for costing purposes.
A detailed power flow system is included to estimate cycle efficiency and pumping requirements.
A new Costing model is under development (Accounting rules similar to Gen-IV reactors)

Accounts 20, Land and Land Rights

✓ Accounts 21, Structures and Site Facilities

• Partially Acct 22, Power Core Plant Equipment
  ✓ Acct 22.01, Fusion Energy Capture and Conversion (FWB, shielding)
  • Acct 22.02, Plasma Confinement
  • Acct 22.03, Plasma Formation and Sustainment
  • Acct 22.04, Vacuum, Power Core
  • Acct 22.05 Primary Structure and Support, Power Core
  • Acct 22.06 – 13 Power Supplies, Main HT&T, Cryo, Rad Matls, Fuel Handl, Maint, I&C, and Other Plant Equipment (yet to be done)

• Account 23 Turbine Plant Equipment To Be Done
• Account 24 Electric Plant Equipment To Be Done
• Account 25 Heat Rejection Equipment To Be Done
• Account 26 Misc Plant Equipment To Be done
• Account 27 Special Materials To Be Done
• Accounts 91, 92, 93, 94, 95, 96, 97, 98 Reported This Meeting
Physics and engineering modules have been developed and validated against previous ARIES designs (ARIES-AT SiC Blanket).

Costing is currently done using old ARIES system code models. Costing models are validated against ARIES-AT.

We are generating the data base of possible power plant embodiments.

Some sample results (based on partial data base) are shown.
Examples of Data Visualization

Data Point Locations

All Costs of Electricity

Optimal COE Versus 3 Parameters

Optimal COE Surface

arbitrary parameter varies across COE surface
Impact of divertor heat flux constraint on the design space.

- Divertor Heat flux $< 8$ MW/m$^2$
- $< 12$ MW/m$^2$
- $< 20$ MW/m$^2$

- Core radiation fraction is self-consistently calculated (typically 25-50%)
- Edge/divertor radiation fraction is assumed to be 75%
Impact of divertor heat flux constraint on the design space.

Divertor Heat flux $< 8 \text{ MW/m}^2$

- Core radiation fraction (typically 25-50%)
- Edge/divertor radiation $< 12 \text{ MW/m}^2$ $< 20 \text{ MW/m}^2$
Impact of divertor heat flux constraint on the design space.

- Divertor Heat flux < 8 MW/m²
- < 12 MW/m²
- < 20 MW/m²

Core radiation fraction is self-consistently calculated (typically 25-50%)
Edge/divertor radiation fraction is assumed to be 75%
Impact of divertor heat flux constraint on the design space.

- Divertor Heat flux < 8 MW/m²
  - < 5 MW/m²
  - 85% edge radiation

Core radiation fraction is self-consistently calculated (typically 25-50%)
Edge/divertor radiation fraction plays an important role in expanding available design space.
Example of physics parameters in the data base
A new ARIES Systems code is under development.

It can be operated in Design Space approach to allow understanding trade-off of various constraints.

Code development is completed (for SiC Blankets).

We are generating a large database of possible power plant embodiments.

Some sample results were presented.
Thank you!
Any Questions?