ARIES Systems Code Status & Development

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Systems code has evolved into a design space scanning tool

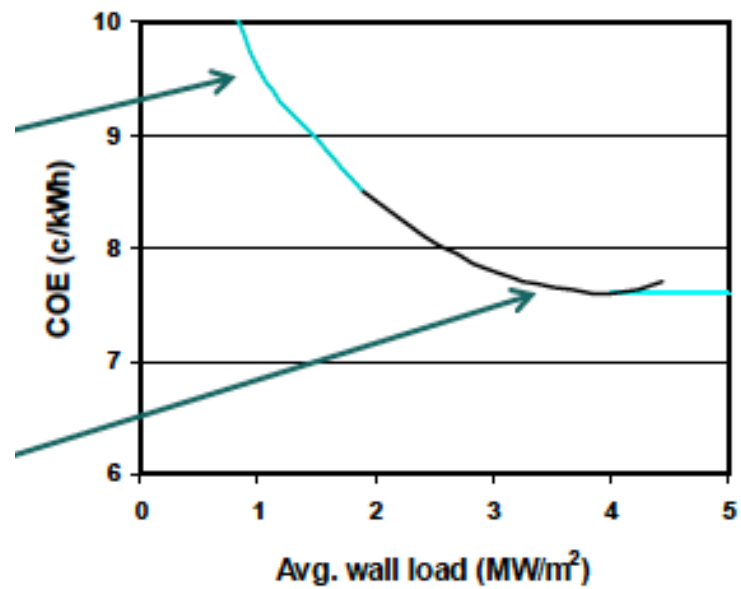
- Prior designs focused on defining and optimizing *about* specific design points
  - (ARIES-I, II, RS, AT, etc)
- The optimal operating point was often difficult to explain or justify why it was optimal.
- *New* approach scans a wide operating space for a *range* of possible design points.
- This allows for consideration of a wide range of feasible points and visualization of parameters.

Systems Code Applications

1. Large systems scans are possible (10^6 - 10^7 points)
2. Targeted systems scans around a region of interest
3. Operating point search and sensitivity scans, supported by detailed analysis

The operating space scan identifies steep or shallow constraints

- Want to better visualize slopes. Are we at a *steep* optimization point with no leeway or at a *shallow* point with a more relaxed constraint?
- Can some constraints be relaxed with minor influence on others?
- Experience indicates that "optimum" design points are usually driven by the constraints.
  - In some cases, a larger design window is available when a constraint is slightly relaxed, with substantial improvement in COE.
  - In other cases, COE changes slightly by changing the constraints, and operation away from the constraint allows for a more robust and credible design with minimum impact on COE.



(From F. Najmabadi)

ARIES systems code consists of three building blocks

- Systems code integrates physics, engineering, design, and costing.

Systems Code Analysis Flow

1. PHYSICS
Plasmas that satisfy power and particle balance

→

2. ENGINEERING FILTERS APPLIED

→

3. ENGINEERING & COSTING DETAILS
Power core, power flow, magnets, costing, COE

Filters include:

1. Toroidal magnetic fields
2. Heat flux to divertor
3. Neutron wall load
4. Net electric power

Modules include:

1. Blankets
2. Geometry
3. Magnets
4. Power flow
5. Costing

DCLL
SiC
ARIES-AT

Large database can be processed

- A large database of possible power plant candidates can be examined under different optimization constraints and through a range of input criteria.
- We have the capability to parallel process the engineering data on a cluster with hundreds of nodes, reducing computation time by number of nodes employed.
- Princeton Plasma Physics (PPPL) computer cluster:
  - *200+ processors*
  - *Quad-core CPUs*
  - *2-4 GB RAM each*
  - *1 gigabit ethernet*

2 GHz Core2 Duo ***laptop***	*AMD Quad-core* ***node***
~700 points/hr	**~2000 points/hr**
Time for 10^5 points = **142 hrs**	**= 50 hrs/node**
Time for 10^6 points = **1428 hrs**	**= 500 hrs/node**

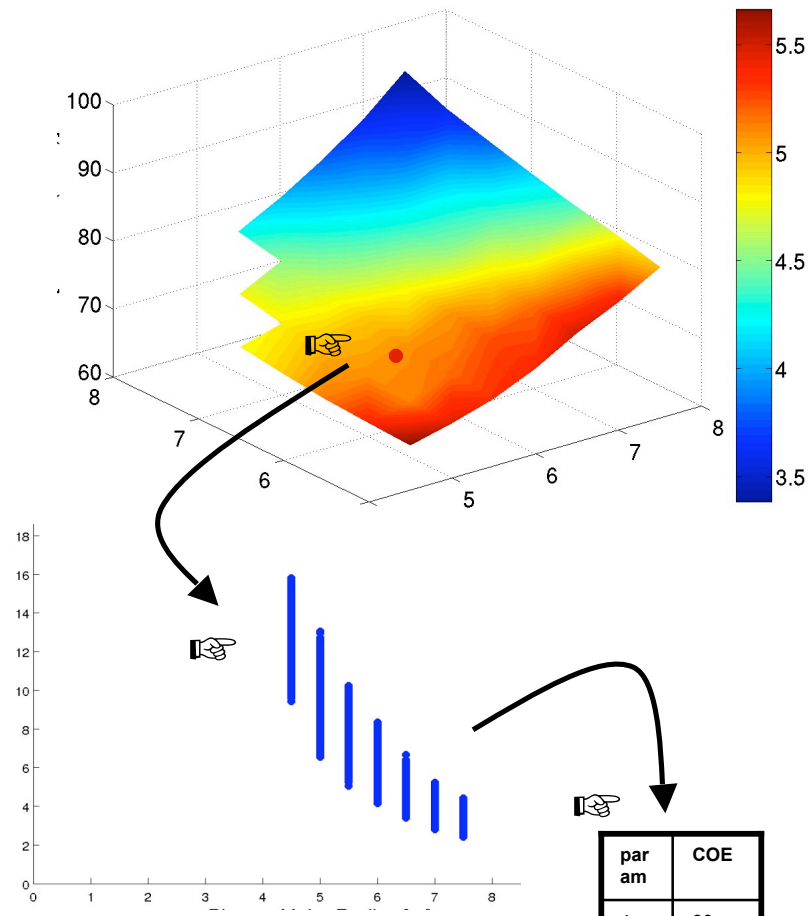
PPPL Cluster

Revision control is necessary

- Multiple users modifying multiple code versions of code creates confusion.
- Needful to control revisions to the code to keep track of changes and updates.
- Subversion (SVN) revision control software keeps the code centralized in a server repository.
- Users can “check out” the code, modify it, then commit it back to the central server as the most recent updated version.

It is a challenge to visualize large data sets

- *Possible visualization methods:*
  - **4D <=> 3D <=> 2D <=> table**
  - **ProEngineer-type fly-through**: fly through the n-dimensional space, slide along an axis, then zoom in or pan around to navigate and explore.
  - **Web-based, on-the-fly graphing**: accessible from any browser, would pull data from a server and display in HTML, may be too elaborate to begin with

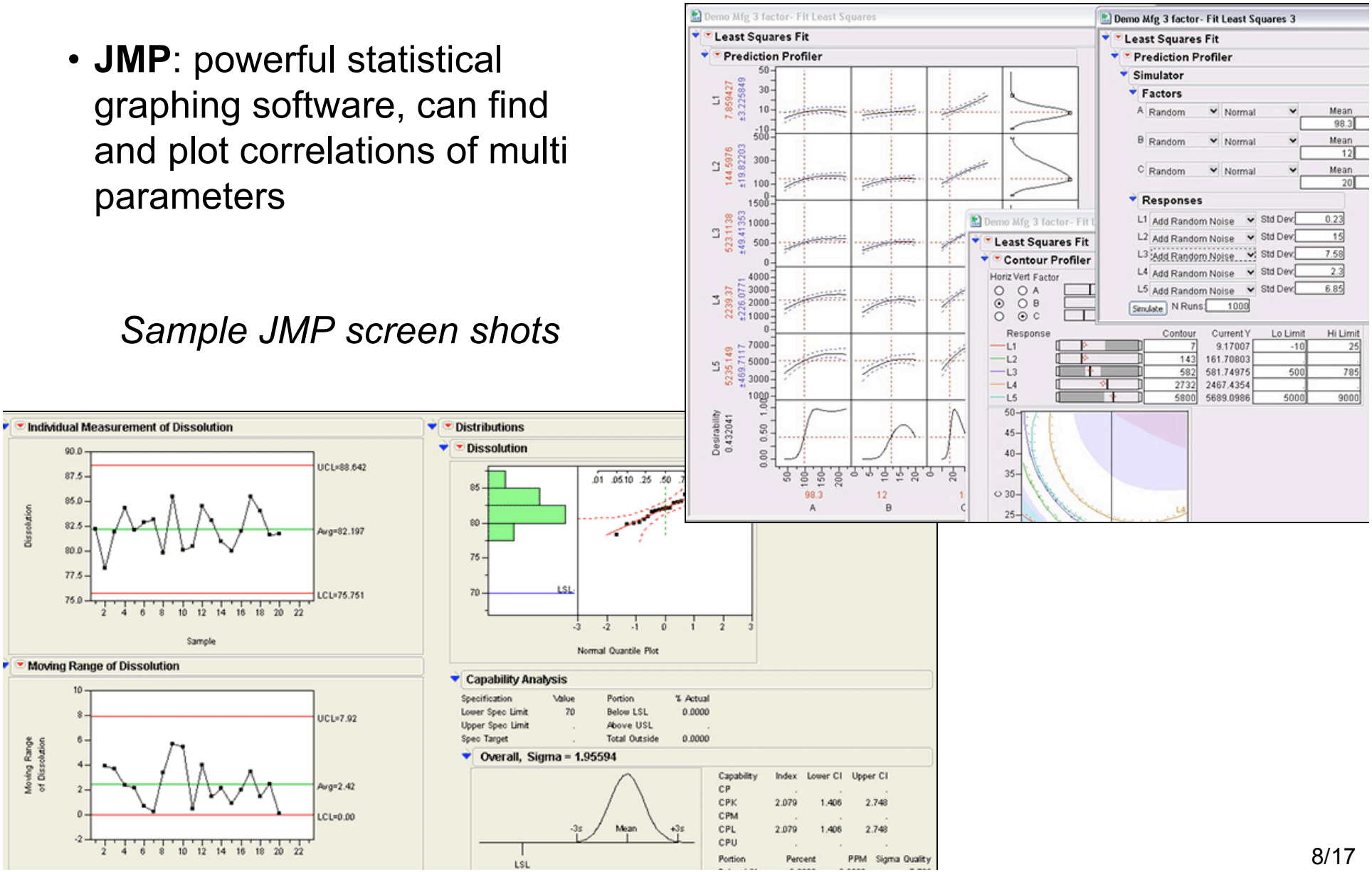


param	COE
4 m	30
5 m	35
6 m	40
7 m	45

Some possible visualization methods include:

- **JMP**: powerful statistical graphing software, can find and plot correlations of multi parameters

Sample JMP screen shots

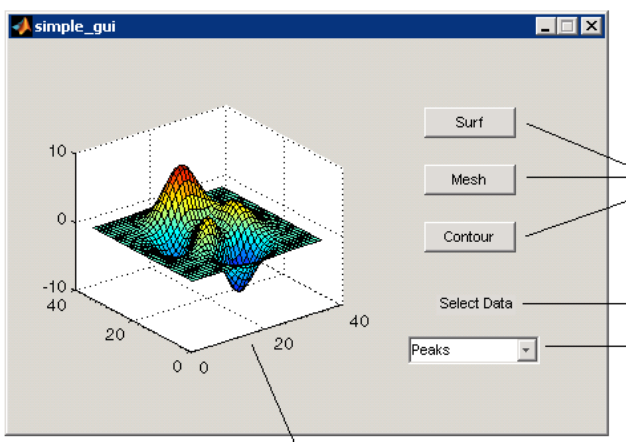


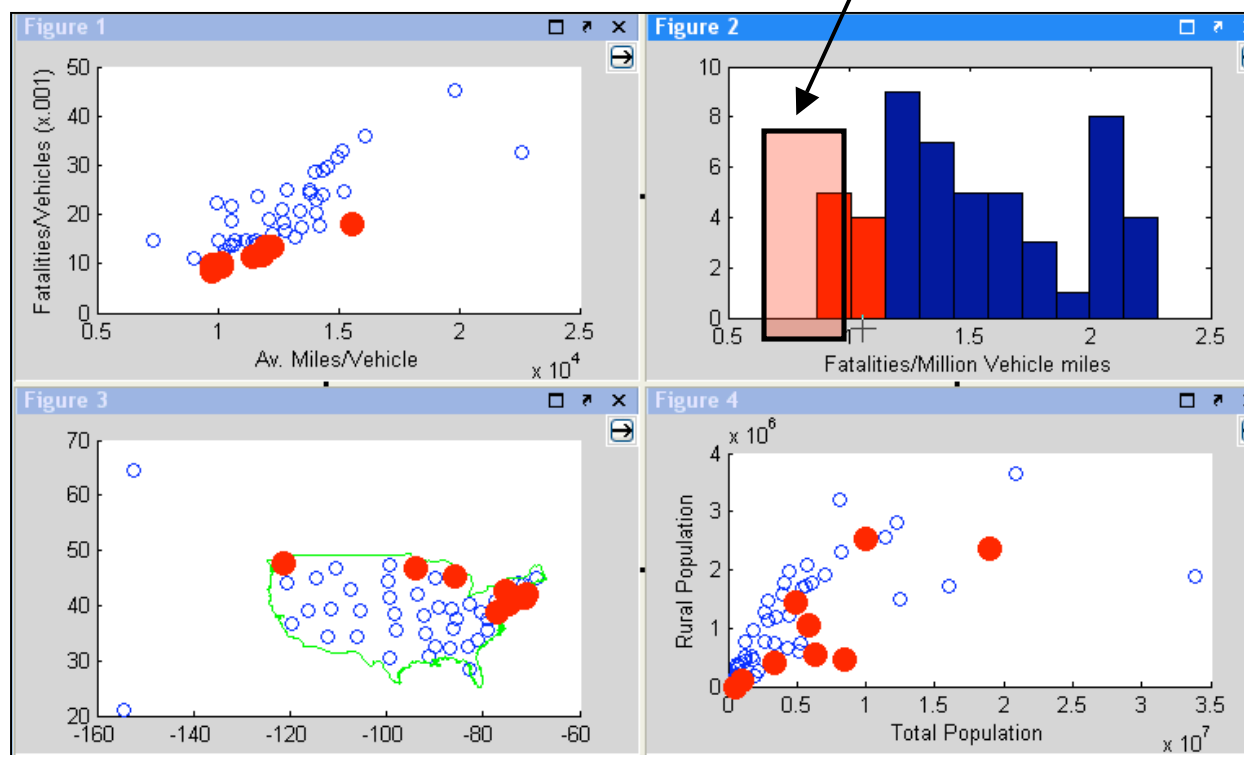
Some possible visualization methods include:

- **Matlab GUI**: a user-friendly graphical user interface can plot custom graphs and explore any parameter with real-time linking to the systems code database
- *Slider bar* to scan a parameter space and see its influence on others

Highlighting any parameter space would show real-time effect on other parameters

Sample Matlab GUI screen shots





Costing accounts have been updated and integrated into the code

- Much effort by L. Waganer to update and modernize our costing model.
- Some accounts date back to the 1980's and have never been updated.

- Some major updates include:
  - Main heat transfer and transport algorithms revised
  - Land acquisition and building costs settled
  - New TF coil estimates
  - Bucking cylinder
  - Cryostat
  - Heating and current drive
  - Electric plant equipment
  - Rad waste, fuel handling, maintenance
  - …

Level of Safety Assurance have been removed

- Level of Safety Assurance **(LSA)** - used to modify existing cost estimates for *fission* plants for use in varying levels of *less* hazardous materials and construction techniques for *fusion* systems.
- Prior ARIES studies used LSA=1,2
- LSA approach is confusing because it assumes fission costs are the basis for all new plant estimates. In reality, ARIES has developed many new fusion-based cost estimates and is based on fusion-specific materials on a system-cost basis, I.e. the LSA is already built into the cost.
- Use of inherent safety systems and low-activation materials are standard practices for the ARIES program and we are developing cost bases consistent with these practices and materials.

Four Levels of Safety Assurance

LSA = 4 Denotes active protection, not inherently safe.

LSA = 3 Safety is assured by passive mechanisms of release limitation as long as severe violations of small-scale geometry are avoided (e.g., large coolant pipe breaks).

LSA = 2 Safety is assured by passive mechanisms as long as severe reconfiguration of large-scale geometry is avoided.

LSA = 1 Safety is assured by passive mechanisms of release limitation for any accident sequence.

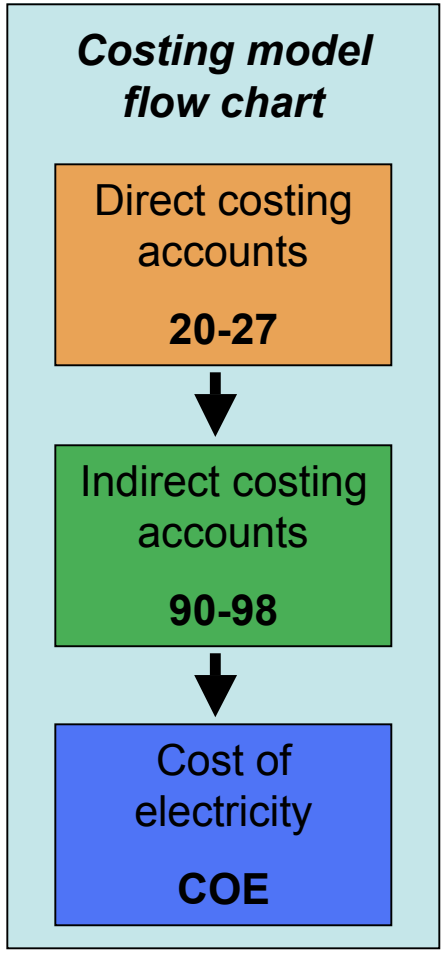
(From L. Waganer)

Costing accounts have been updated & detailed

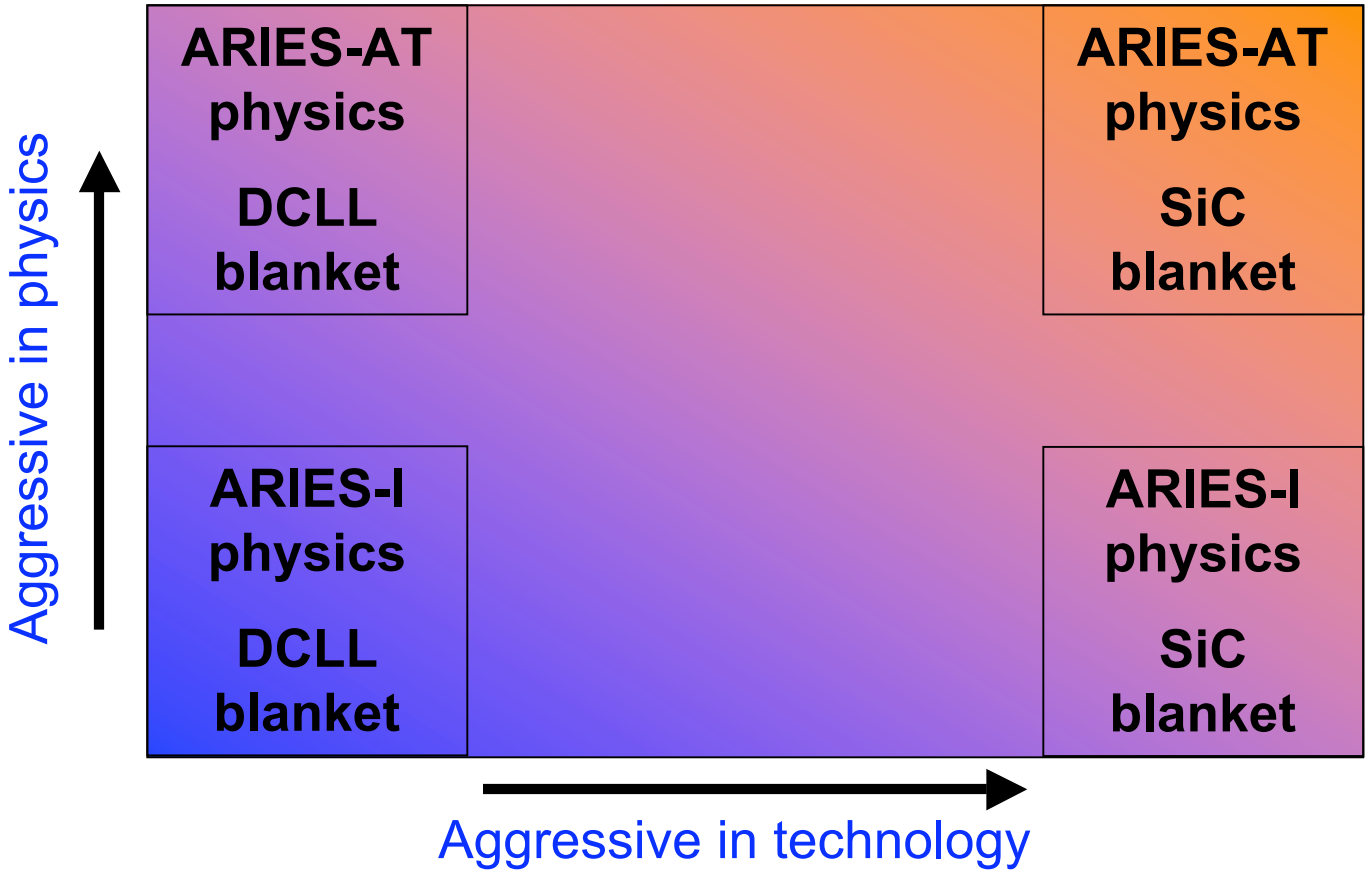
- For better costing accuracy, the geometry of the power core has been updated to more accurately reflect the engineering design.
- Volumes and masses of components are more carefully estimated, which enables a higher fidelity cost estimate.
- Special materials' costs (primarily enriched lithium) have been updated.

- Two DCLL *(dual-coolant, lead-lithium)* blanket modules are implemented:
  - one configuration has a LiPb/He manifold,
  - the other configuration is without a manifold
  - the "next step" module will feature a SiC blanket

- Costing algorithms still needing updating are:
  - Turbine plant equipment
  - Heat rejection equipment
  - Vacuum system, pumps, ducting

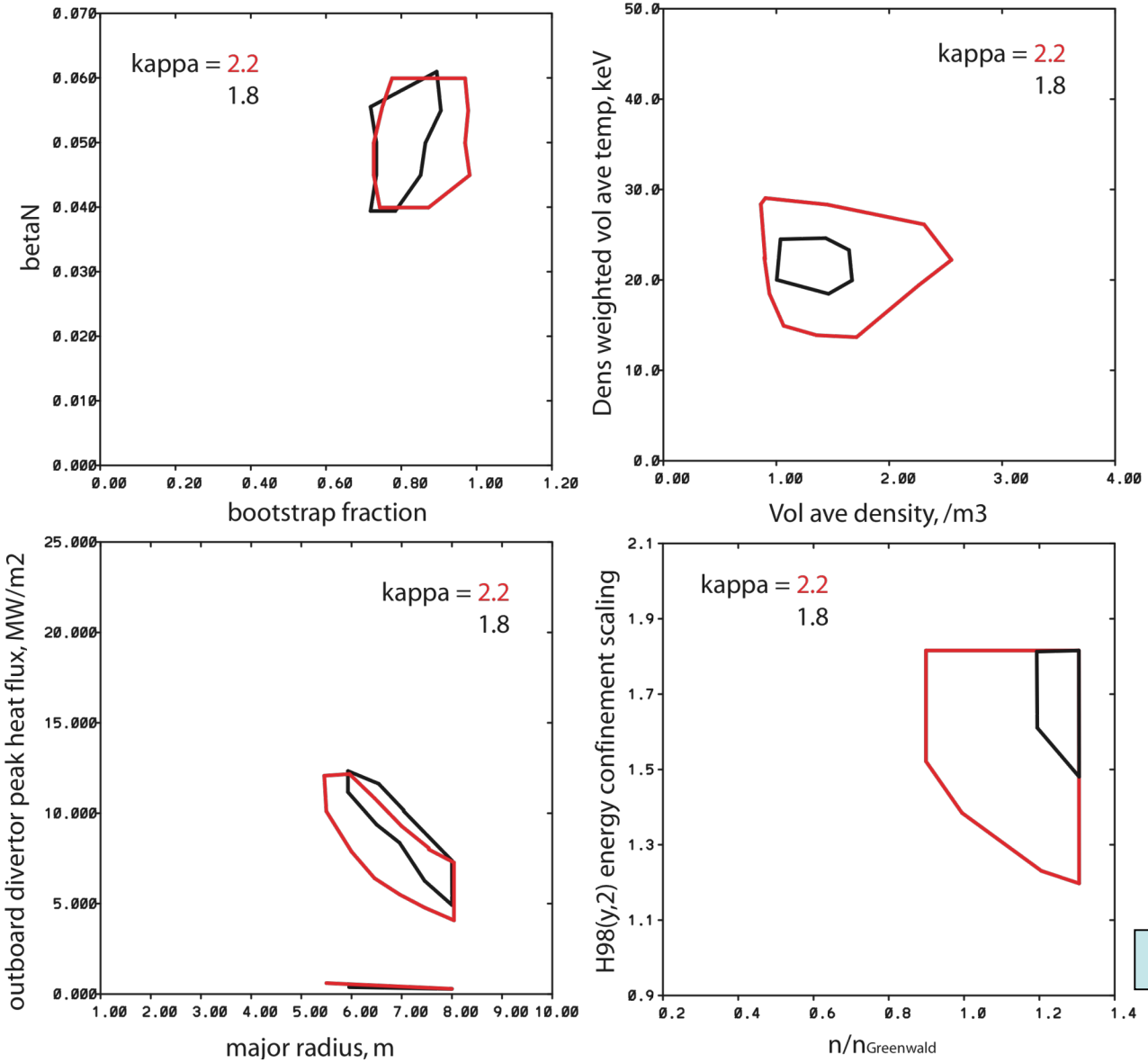


We have framed an operating space based on prior point designs



- Frame the parameter space for attractive power plants by considering four corners of aggressiveness.
- Use the systems code to understand the tradeoffs.
- Want to fill in this operating space with significant resolution with costing.

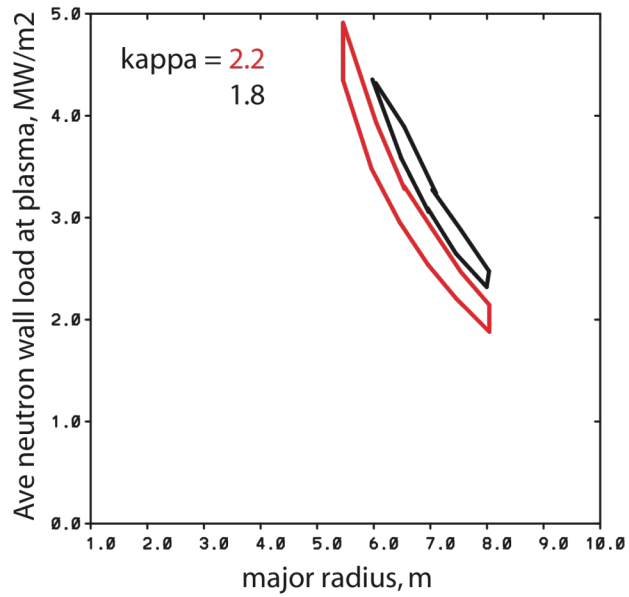
C. Kessel has taken a preliminary look at these four corners

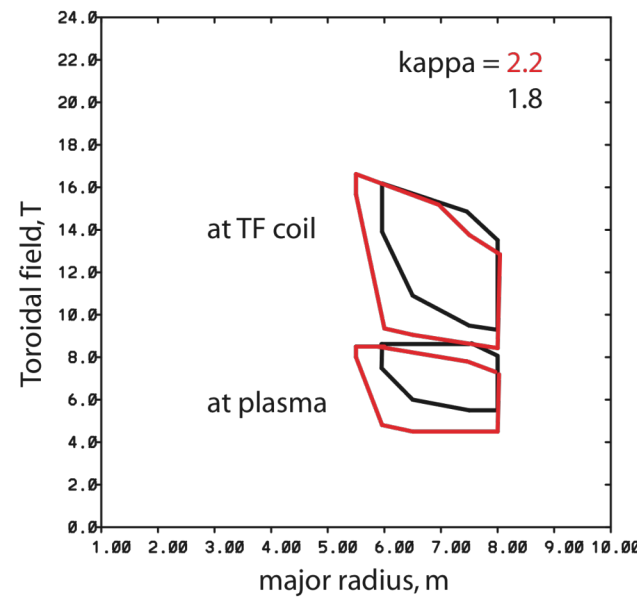


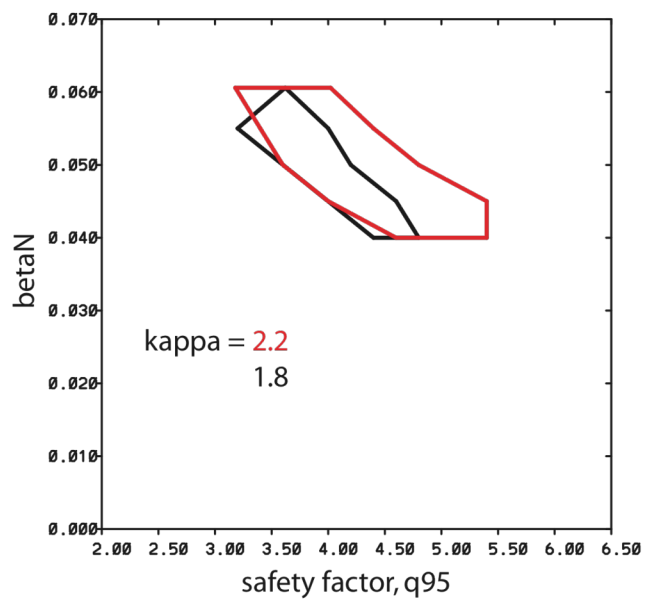
(From C. Kessel)

Comparison of kappa = 1.8 and 2.2 for DCLL blanket and ARIES-AT plasma

- An elongated plasma can provide smaller devices, but requires a stabilizer.
- A broader design space is achieved by varying this parameters.







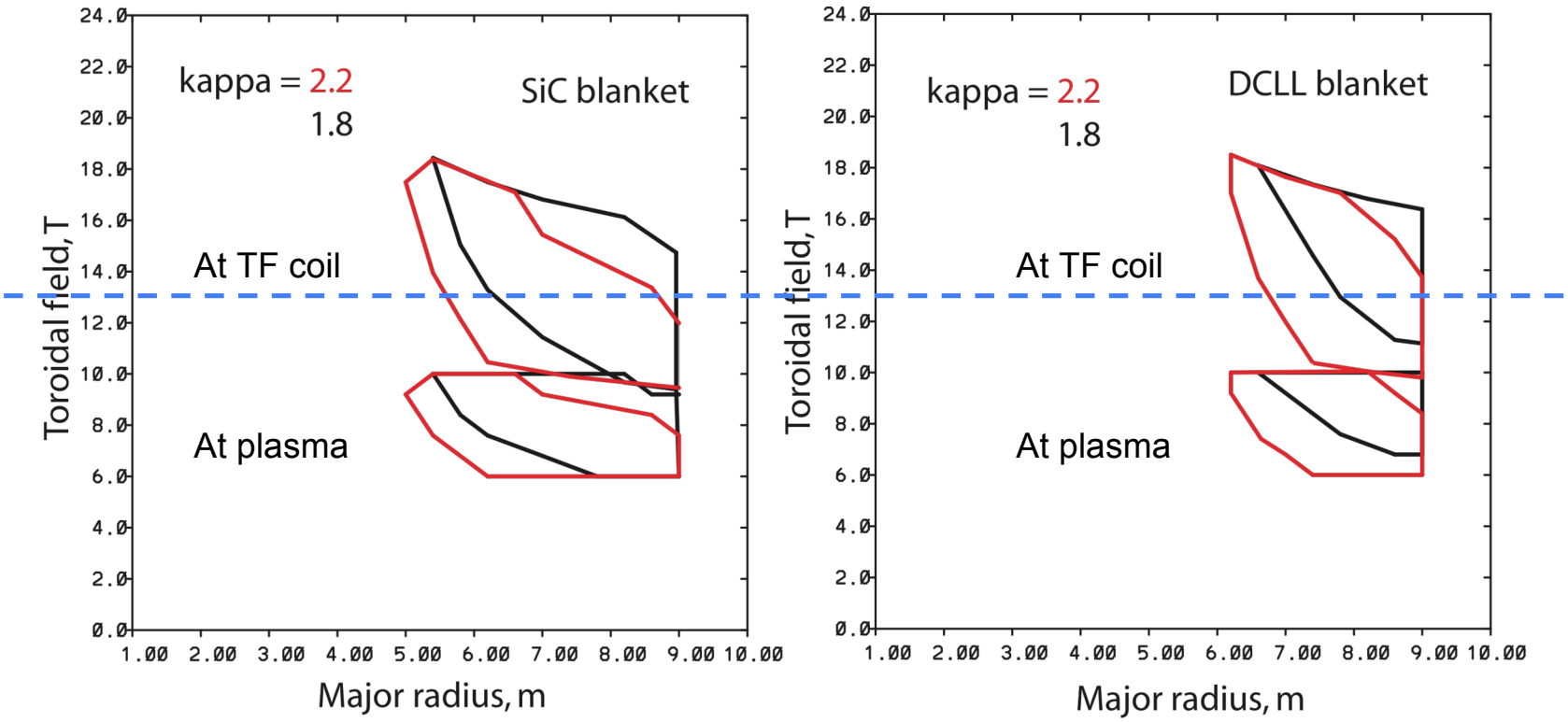
- Candidate operating points will be honed for consideration and evaluation.
- Costing will also be included.

Summary of results

- ✓ Initial results show promise of operating space scans.
- ✓ Updated costing algorithms are implemented.
- ✓ The systems code is operational and able to quickly scan and process a large design space.
- ✓ Revision control has been implemented.

Future work

- Re-examine the TF and PF coil j vs. B relationships.
- Prior SC magnets may be too optimistic - re-examine lower B fields for possible solutions.
- Develop solutions to the power balancing within the limits of materials/coolants - critical to accessing smaller power plants.
- Fill in the operating space of the four corners with sufficient resolution using updated costing algorithms.
- Improve visual display of the power plant data to allow the user more visualization interaction and explorative power.

Backup

ARIES-I plasmas, TF coil solutions, what is TF limit at the coil?