Trade-Off Studies and Engineering Input to System Code

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Focus of Engineering Effort

- Development of system code including engineering input on various parameters

- Trade-off studies in conjunction with providing input to system code
Action Items from April 07 Meeting

1. Continue system code development including incorporation of engineering input and cost algorithms (UCSD, PPPL)

2. Provide updated cost algorithms as input to system code (Boeing, UW)

3. Provide blanket definition and parameters (including coupling to power conversion system) as input to system code for DCLL and self-cooled Pb-17Li with SiC/SiC (thermal-hydraulic parameters (UCSD), radial build (UW))

4. Assess impact of heat flux accommodation on choice of materials and grade level of heat extraction for divertor (UCSD, GIT)

5. Provide input on coil material and parameters to system code (MIT)

6. Assess implications of waste treatment on power plant design requirements (UW)

7. Assess impact of power core component design choice on reliability, availability and maintainability (RAM) (Boeing/INL)

8. Evaluate impact of tritium breeding and recovery on fuel management, safety and cost (INL/UW)
Power Conversion Trade-Off Studies and Input to System Code

- Impact of coolant temperature on choice of materials and grade level of heat extraction

Coolant Exit temperature (°C): 420  500  620  800  1000

<table>
<thead>
<tr>
<th>Power Cycle configuration:</th>
<th>Low-Perf. Rankine</th>
<th>High-Perf. Rankine</th>
<th>Brayton W-alloy</th>
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<tbody>
<tr>
<td>Possibility of H₂ production</td>
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Cycle Efficiency: 35%  40%  45%  50%  60%
Example Brayton Cycle Considered

Set parameters for example calculations:
- Blanket He coolant used to drive power cycle
- Minimum He temperature in cycle (heat sink) = 35°C
- 3-stage compression
- Optimize cycle compression ratio (but < 3.5; not limiting for cases considered)
- Cycle fractional ΔP ~ 0.07
- Turbine efficiency = 0.93
- Compressor eff. = 0.89
- Recuperator effective = 0.95
Brayton Cycle Efficiency as a Function of Neutron Wall Load and Surface Heat Flux for Self-Cooled Pb-17Li + SiC\textsubscript{f}/SiC Blanket (based on ARIES-AT)

- Fusion power = 1.74 GW
- Neutron wall load peaking factor = 1.5
- Heat flux peaking factor = 1.25

Constraints:
- Max. allowable combined stress = 190 MPa
- Max. allowable SiC\textsubscript{f}/SiC temp. = 1000 °C
- Max. allowable CVD Sic temp. = 1000 °C
- Turbine efficiency = 0.93
- Compressor efficiency = 0.89
- Recuperator effectiveness = 0.96

![Graph showing Brayton cycle efficiency as a function of neutron wall load and surface heat flux](image)
Brayton Cycle Efficiency as a Function of Neutron Wall Load and Surface Heat Flux for DCLL Blanket (based on ARIES-CS)

- Fusion power = 2.37 GW
- Neutron wall load peaking factor = 1.5
- Heat flux peaking factor = 1.25

Constraints:
RAFS $T_{\text{max}} < 550 \, ^\circ\text{C}$; ODS $T_{\text{max}} < 700 \, ^\circ\text{C}$
$T_{\text{max}} \text{ Pb-17/FS} < 500 \, ^\circ\text{C}$
Turbine efficiency = 0.93
Compressor efficiency = 0.89
Recuperator effectiveness = 0.95

$q'' = \text{avg. heat flux (MW/m}^2\text{)}$
Blanket Pumping Power and Brayton Cycle Net Efficiency as a Function of Neutron Wall Load and Surface Heat Flux for DCLL Blanket (based on ARIES-CS)

- Need to confirm pumping power jump for increase of $q''$ from 0.4 to 0.6 MW/m²
Impact of Tritium Breeding on Fuel Management, Safety and Cost

• Controllability is a key issue
  - Need to be able to adjust TBR definitely within 1% and most probably within 0.1%
  - Even 1% change in TBR results in ~1.5 kg of T per year for a 2.3-3 GW fusion plant
  - At steady state only need to breed enough to cover decay losses (~0.4%)
  - Need to be able to provide for initial hold-up inventory and startup inventory of another reactor (e.g. ~2% for 2 year doubling time)

• TBR is not like your “typical” design parameter (as compared to stress, temperature, dose rate….)
  - E.g can overestimate stress to be conservative
    - If operating stress is as predicted ---> no consequences
    - If operating stress is lower than predicted ---> still no consequences
    - For TBR, overestimating has consequences (what do you do with extra T?)

• Need consistent TBR definition
  - We should design for an operation TBR (1.01) and show it as such with upper and lower bound margins
Example Tritium Breeding Design Operation Point for ARIES-AT

Questions
- At which $^6$Li level do we start?
- How easy is it to adjust $^6$Li level?
- How long does it take?
- What are the implications on breeder inventory, cost and safety issues?

Uncertainty band in predicting operating TBR (calculation and operation)

Design operation TBR (1.01)

Additional margin for hold-up inventory and/or start-up tritium inventory as required

Highest confidence estimate within uncertainty range (from experts)

$^6$Li enrichment (%)