# UCSD Contributions to First-Wall Battle Plan

**Farrokh Najmabadi, Rene Raffray**

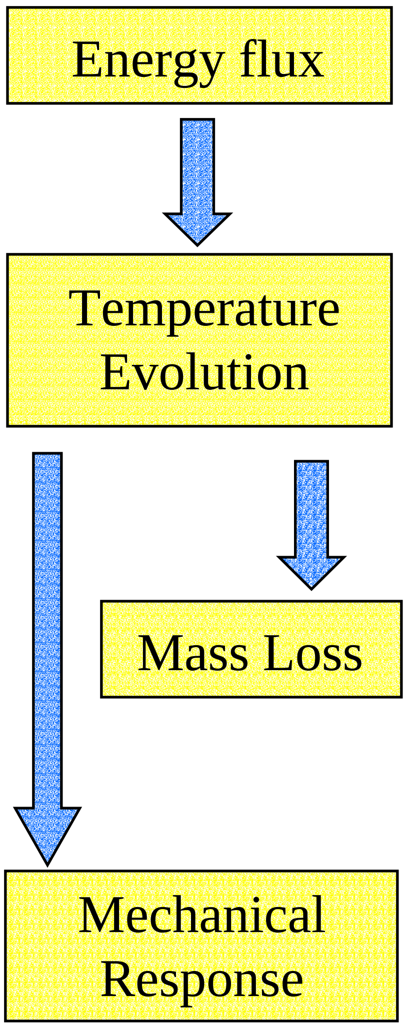
HAPL Meeting

April 8-10, 2003
Sandia National Laboratory, Albuquerque, NM

Electronic copy: http://aries.ucsd.edu/najmabadi/TALKS
UCSD IFE Web Site: http://aries.ucsd.edu/IFE

# Wall Survival Critically Depends on Its Thermo-Mechanical Response

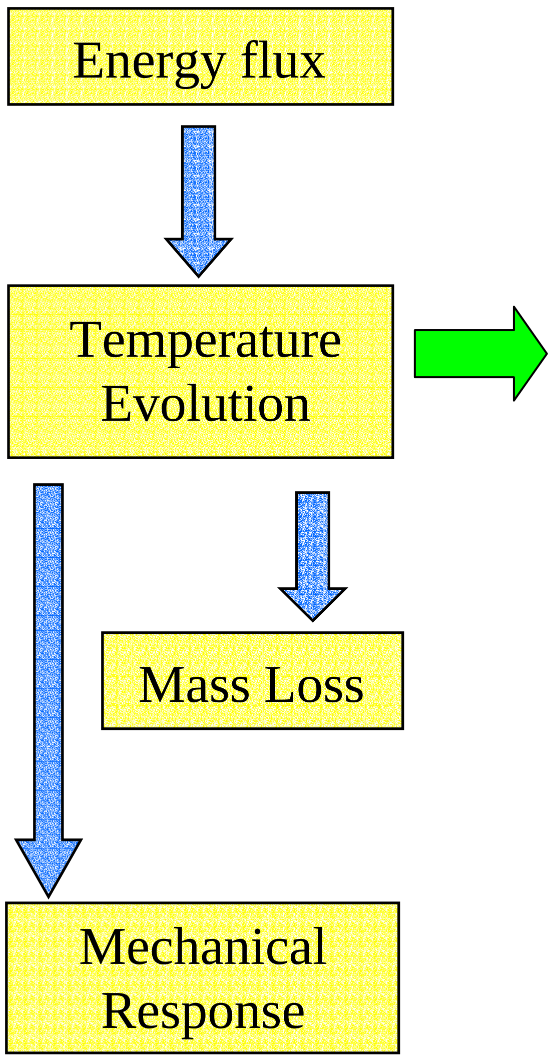
## Physical Phenomena




**Capabilities of UCSD Laser Facility**

- Max laser energy = 1.3 J
  (600 mJ is sufficient to melt 1 $cm^2$ sample)
- Capable of large no. of shots ($10^5$ to $10^6$ shots)
- Rep rates from single shot to 10 Hz
- Very accurate control of source energy
- Excellent control of irradiation environment
  - ✓ Chamber can be evacuated to $10^{-8}$ torr
- A suite of diagnostics
  - ✓ MCFOT
  - ✓ QMS, RGA
  - ✓ Surface examination

# Measurement of Temperature Evolution Is a Key Ingredient

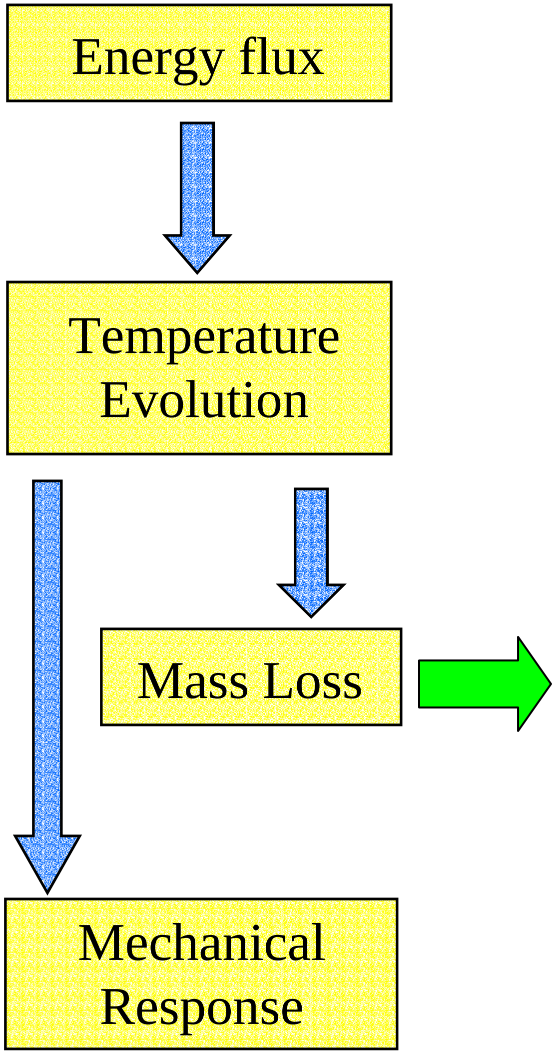



- Temperature variation mainly in a thin (~10-20 μm) region. Large temperature spikes only in the first few μm. Surface features are probably >> 10-20 μm due to manufacturing tolerances, *etc.* This will lead to non-uniform temperature profiles. Impurities and contaminants can cause hot spots.
- At a minimum, surface temperature should be monitored.

**Plan:**

- Measure thermal response of W samples and compare with ANSYS calculations:
  - ✓ Polished and "sculptured" surfaces;
  - ✓ Addition of contaminants;
  - ✓ Surface examination for hot spots;
  - ✓ "Near-melting" behavior.

# Is Avoidance of Melting a Good Criteria for Avoidance of Mass Loss?

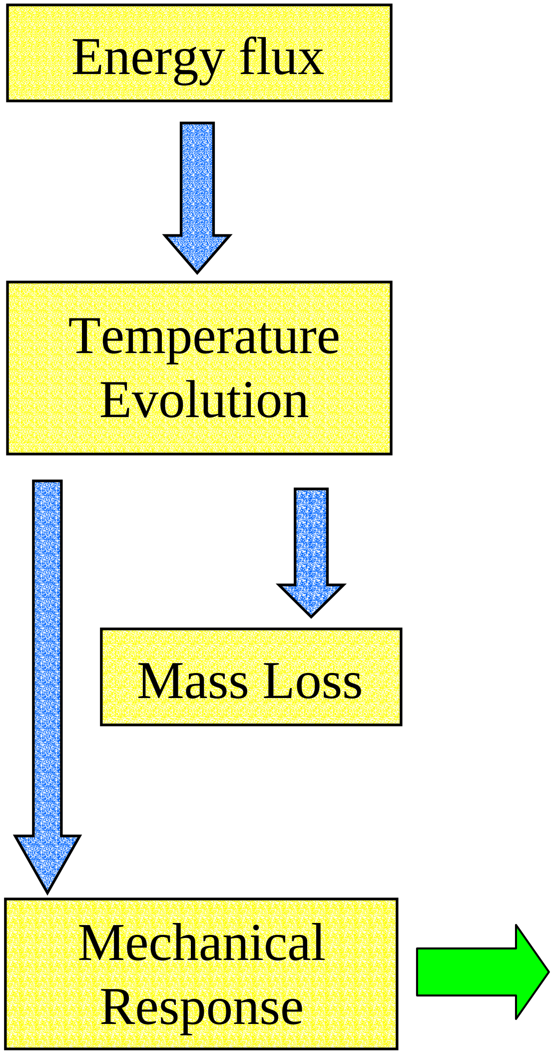



- ➢ Sublimation can be important near the melting point.
- ➢ Steady-state data for sublimation rates may not be applicable.
  - ✓ Sublimation rates also depends on the atomic form of sublimated species;
  - ✓ Sublimation at local hot spots (contaminants, surface morphology) may dominate.
- ✓ Is avoidance of melting a good criteria?

**Plan:**

- ➢ Measurement of mass loss rate with QMS (per shot basis) and with RGA for large no. of shots;
- ➢ Spectroscopic measurement of sublimated species
- ➢ Impact of contaminants.

# Mechanical Response May Be The Most Restricting Constraint




**Plan:**

- Expose samples to
  - ✓ Different laser energies
  - ✓ Different shot rates
  - ✓ Different temporal profile of the laser pulse (to examine the effects of strain rate).
  - ✓ Different surface roughness
  - ✓ Addition of contaminants.
- Surface examination of samples.
- Field samples on RHEPP to compare response to laser pulse versus ion beam
- Field special samples to measure thermo-mechanical properties of sample (post irradiation).

# Careful Characterization of Experiments Is Essential in Comparing Our Results and Developing a Predictive Capability

- Our experiments, specially intercomparison of the data, will provide a wealth information. Some suggestions that can enhance our chances of developing a predictive capability:
- Develop a common format to report experimental results:
  - Sample condition, its thermophysical properties, how it was handled, etc.
  - “Energy source” characterization
  - Temperature evaluation of the sample during the test (calculated/measured)
  - Test conditions (background temperature, test environment, etc.)
  - Post-test analysis
  - …
- Material working group can provide some feedback on the other needed info?
- Post results on a Web site (or any other means for dissemination)

# Scoping of IFE Power Plant with W/FS Armor/First Wall

- Identify possible blanket designs from past MFE work(e.g. FS/LiPB with possible SiC coating, similar to ARIES-AT design or He-cooled box with LiPb coolant/breeder as for ARIES-ST)

- Aim at designing for maximum cycle efficiency based on material constraint (max. temp. and stress limits)

- Simple trade-off study based on yield, rep rate, and chamber size for example designs

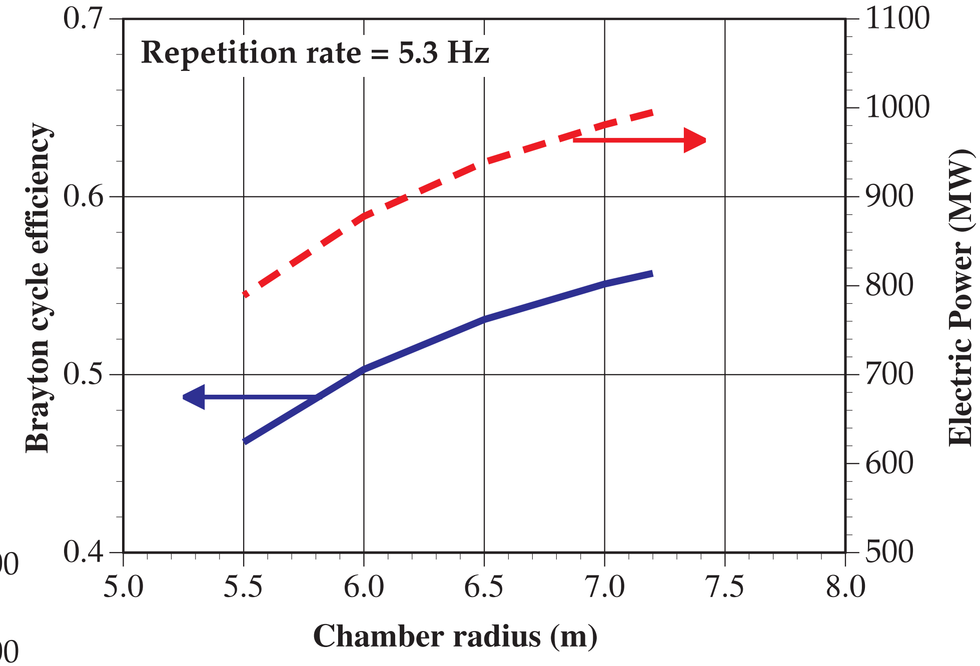
- Utilize ARIES-IFE parametric studies as example

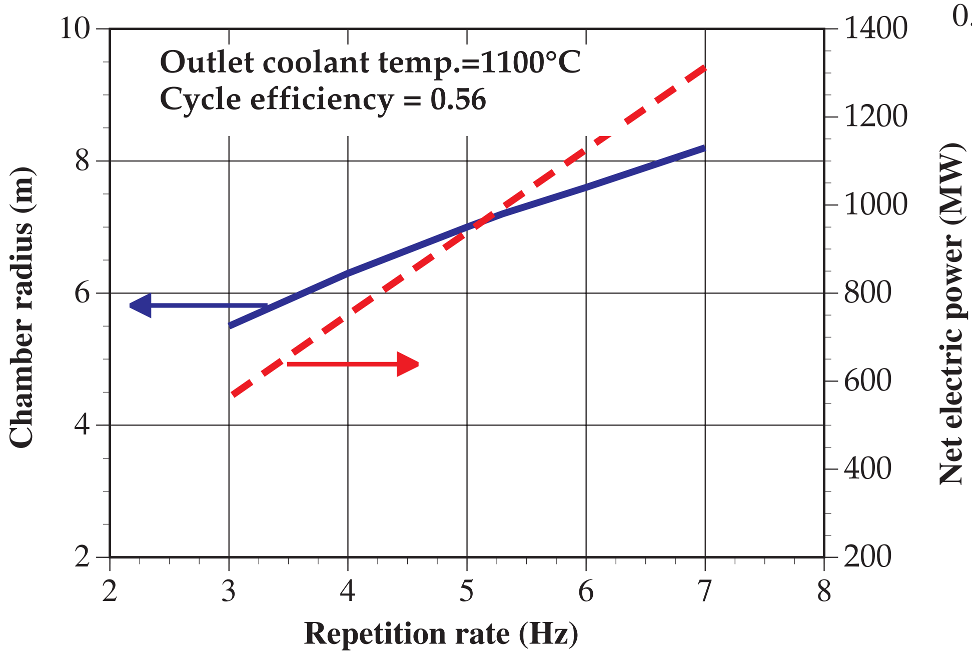
# Example Scoping Analysis (from ARIES-IFE)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Driver Energy (MJ) | 2.9 | | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |
| Gain | 138 | | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 | 138 |
| Yield (MJ) | 400.2 | | 400.2 | 400.2 | 400.2 | 400.2 | 400.2 | 400.2 | 400.2 | 400.2 | 400.2 | 400.2 |
| Driver Efficiency | 0.07 | | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| **Rep-rate (Hz)** | **5.3** | | **3** | **4** | **5** | **5.3** | **6** | **7** | **5.3** | **5.3** | **5.3** | **5.3** |
| | | | | | | | | | | | | |
| **Cycle** | | | | | | | | | | | | |
| Total compression ratio | 4.51773911 | | 4.51773911 | 4.51773911 | 4.51773911 | 4.51773911 | 4.51773911 | 4.51773911 | 4.51773911 | 4.51773911 | 4.51773911 | 4.51773911 |
| **Power cycle efficiency** | **0.55054244** | | **0.55670676** | **0.55670676** | **0.55670676** | **0.55670676** | **0.55670676** | **0.55670676** | **0.46257929** | **0.50324098** | **0.53082478** | **0.55054244** |
| | | | | | | | | | | | | |
| **Power** | | | | | | | | | | | | |
| **Fusion Power (MW)** | **2121.06** | | **1200.6** | **1600.8** | **2001** | **2121.06** | **2401.2** | **2801.4** | **2121.06** | **2121.06** | **2121.06** | **2121.06** |
| Power in neutrons (MW) | 1505.9526 | | 852.426 | 1136.568 | 1420.71 | 1505.9526 | 1704.852 | 1988.994 | 1505.9526 | 1505.9526 | 1505.9526 | 1505.9526 |
| Non neutron-power on first wall region (MW) | 615.1074 | | 348.174 | 464.232 | 580.29 | 615.1074 | 696.348 | 812.406 | 615.1074 | 615.1074 | 615.1074 | 615.1074 |
| Fraction of neutron power on first wall | 0.075 | | 0.075 | 0.075 | 0.075 | 0.075 | 0.075 | 0.075 | 0.075 | 0.075 | 0.075 | 0.075 |
| Neutron energy multiplication factor | 1.1 | | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| Total power on FW region (MW) | 739.34849 | | 418.499145 | 557.99886 | 697.498575 | 739.34849 | 836.99829 | 976.498005 | 739.34849 | 739.34849 | 739.34849 | 739.34849 |
| **Effective heat flux on first wall (MW/m2)** | **1.04480755** | | **0.95797106** | **0.97349877** | **0.9856675** | **0.98756887** | **1.00341498** | **1.00560367** | **1.69241554** | **1.42209917** | **1.21172947** | **1.04480755** |
| Total thermal power (MW) | 2271.65526 | | 1285.8426 | 1714.4568 | 2143.071 | 2271.65526 | 2571.6852 | 3000.2994 | 2271.65526 | 2271.65526 | 2271.65526 | 2271.65526 |
| Gross electric power (MW) | 1250.64262 | | 715.837264 | 954.449685 | 1193.06211 | 1264.64583 | 1431.67453 | 1670.28695 | 1050.82069 | 1143.19002 | 1205.85091 | 1250.64262 |
| Auxiliary Power (4%) = 52 MWe | 50.0257047 | | 28.6334905 | 38.1779874 | 47.7224842 | 50.5858333 | 57.2669811 | 66.8114779 | 42.0328275 | 45.7276008 | 48.2340363 | 50.0257047 |
| Laser power (MW) | 219.571429 | | 124.285714 | 165.714286 | 207.142857 | 219.571429 | 248.571429 | 290 | 219.571429 | 219.571429 | 219.571429 | 219.571429 |
| **Net electric power (MW)** | **981.045485** | | **562.918059** | **750.557412** | **938.196765** | **994.488571** | **1125.83612** | **1313.47547** | **789.216431** | **877.89099** | **938.045442** | **981.045485** |
| | | | | | | | | | | | | |
| **Thermal-Hydraulics (Pb-17Li)** | | | | | | | | | | | | |
| **Inlet temperature (C)** | **518.764635** | | **529.912422** | **529.912422** | **529.912422** | **529.912422** | **529.912422** | **529.912422** | **390.565091** | **443.517077** | **485.321276** | **518.764635** |
| FW outlet temp.(C) | 701.428143 | | 715.457032 | 715.457032 | 715.457032 | 715.457032 | 715.457032 | 715.457032 | 540.095925 | 606.733146 | 659.341478 | 701.428143 |
| **Blanket outlet temperature (C)** | **1080** | | **1100** | **1100** | **1100** | **1100** | **1100** | **1100** | **850** | **945** | **1020** | **1080** |
| Total mass flow rate (kg/s) | 2.17E+04 | | 1.21E+04 | 1.61E+04 | 2.01E+04 | 2.13E+04 | 24144.5244 | 2.82E+04 | 2.63E+04 | 2.41E+04 | 2.27E+04 | 2.17E+04 |
| | | | | | | | | | | | | |
| **Chamber Wall + Channel geometry** | | | | | | | | | | | | |
| **Chamber radius (m)** | **7** | | **5.5** | **6.3** | **7** | **7.2** | **7.6** | **8.2** | **5.5** | **6** | **6.5** | **7** |
| FW channel dimension (m) | 5.00E-03 | | 5.00E-03 | 5.00E-03 | 5.00E-03 | 5.00E-03 | 0.005 | 5.00E-03 | 5.00E-03 | 5.00E-03 | 5.00E-03 | 5.00E-03 |
| FW channel length (m) | 2.20E+01 | | 1.73E+01 | 1.98E+01 | 2.20E+01 | 2.26E+01 | 23.864 | 2.57E+01 | 1.73E+01 | 1.88E+01 | 2.04E+01 | 2.20E+01 |
| SiC/SiC wall thickness (m) | 4.00E-03 | | 4.00E-03 | 4.00E-03 | 4.00E-03 | 4.00E-03 | 0.004 | 4.00E-03 | 4.00E-03 | 4.00E-03 | 4.00E-03 | 4.00E-03 |
| W armor thickness (m) | 1.00E-03 | | 1.00E-03 | 1.00E-03 | 1.00E-03 | 1.00E-03 | 0.001 | 1.00E-03 | 1.00E-03 | 1.00E-03 | 1.00E-03 | 1.00E-03 |
| **Velocity in FW channel (m/s)** | **2.20E+00** | | **1.56E+00** | **1.82E+00** | **2.05E+00** | **2.11E+00** | **2.26150867** | **2.45E+00** | **3.30E+00** | **2.81E+00** | **2.46E+00** | **2.20E+00** |
| | | | | | | | | | | | | |
| **Heat Transfer Coefficient** | | | | | | | | | | | | |
| Re Number | 2.16E+05 | | 1.57E+05 | 1.82E+05 | 2.05E+05 | 2.11E+05 | 226578.439 | 2.45E+05 | 2.44E+05 | 2.37E+05 | 2.27E+05 | 2.16E+05 |
| Peclet Number | 5.02E+03 | | 3.56E+03 | 4.15E+03 | 4.67E+03 | 4.81E+03 | 5157.40526 | 5.58E+03 | 7.81E+03 | 6.56E+03 | 5.68E+03 | 5.02E+03 |
| Nusselt Number (Lubarsky and Kaufman) based or | 1.89E+01 | | 1.65E+01 | 1.75E+01 | 1.83E+01 | 1.86E+01 | 19.0920481 | 1.97E+01 | 2.25E+01 | 2.10E+01 | 1.98E+01 | 1.89E+01 |
| h (Lubarsky and Kaufman) based on $T_{bulk}$ (W/m$^2$-K | 1.38E+04 | | 1.21E+04 | 1.28E+04 | 1.34E+04 | 1.36E+04 | 13988.2377 | 1.44E+04 | 1.65E+04 | 1.54E+04 | 1.45E+04 | 1.38E+04 |
| | | | | | | | | | | | | |
| FW Film drop (°C) | 7.99E+01 | | 8.40E+01 | 8.03E+01 | 7.76E+01 | 7.68E+01 | 75.8886247 | 7.37E+01 | 1.08E+02 | 9.77E+01 | 8.82E+01 | 7.99E+01 |
| SiC/SiC Temp. drop (°C) | 2.17E+02 | | 1.99E+02 | 2.02E+02 | 2.05E+02 | 2.05E+02 | 208.610243 | 2.09E+02 | 3.52E+02 | 2.96E+02 | 2.52E+02 | 2.17E+02 |
| W Temp. drop (C) | 1.06E+01 | | 9.68E+00 | 9.84E+00 | 9.96E+00 | 9.98E+00 | 10.1398464 | 1.02E+01 | 1.71E+01 | 1.44E+01 | 1.22E+01 | 1.06E+01 |
| **Approx. SiC/SiC thermal stress (MPa)** | **2.00E+02** | | **1.84E+02** | **1.86E+02** | **1.89E+02** | **1.89E+02** | **192.219438** | **1.93E+02** | **3.24E+02** | **2.72E+02** | **2.32E+02** | **2.00E+02** |
| **Approx. quasi-steady state SiC/SiC Tmax (°C)** | **9.98E+02** | | **9.99E+02** | **9.98E+02** | **9.98E+02** | **9.98E+02** | **999.955899** | **9.98E+02** | **1.00E+03** | **1.00E+03** | **9.99E+02** | **9.98E+02** |
| **Approx. quasi steady-state W Tmax (°C)** | **1.01E+03** | | **1.01E+03** | **1.01E+03** | **1.01E+03** | **1.01E+03** | **1010.09575** | **1.01E+03** | **1.02E+03** | **1.01E+03** | **1.01E+03** | **1.01E+03** |
| **Average W surface temp. (°C)** | **9.18E+02** | | **9.16E+02** | **9.15E+02** | **9.15E+02** | **9.15E+02** | **917.32344** | **9.16E+02** | **9.43E+02** | **9.33E+02** | **9.25E+02** | **9.18E+02** |
| | | | | | | | | | | | | |
| **Friction Factor** | | | | | | | | | | | | |
| Darcy-Weisbach friction factor for rough tubes | 1.77E-02 | | 2.09E-02 | 1.92E-02 | 1.81E-02 | 1.78E-02 | 0.01725805 | 1.66E-02 | 1.67E-02 | 1.69E-02 | 1.73E-02 | 1.77E-02 |
| **Pressure Drop (MPa)** | **8.83E-01** | | **4.15E-01** | **5.92E-01** | **7.83E-01** | **8.42E-01** | **0.98760089** | **1.20E+00** | **1.55E+00** | **1.22E+00** | **1.02E+00** | **8.83E-01** |
| **FW Pumping Power (MW)** | **2.37E+00** | | **6.23E-01** | **1.18E+00** | **1.96E+00** | **2.23E+00** | **2.96259106** | **4.20E+00** | **4.90E+00** | **3.59E+00** | **2.84E+00** | **2.37E+00** |

# Example Parametric Analysis (from ARIES-IFE)

**400 MJ yield case**
**In this case SiC/SiC max. temp.< 1000°C**



# Example Parametric Analysis (from ARIES-IFE)

**154 MJ yield case**
**SiC/SiC max. temp. < 1000°C**