Target Engineering

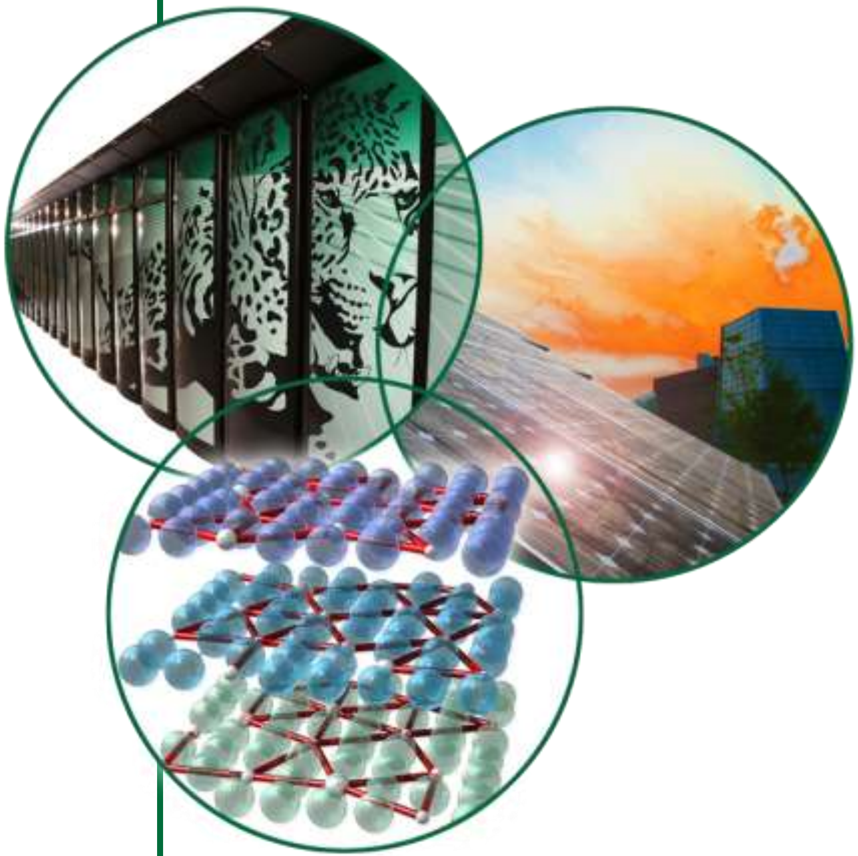
Patrick Geoghegan

Kim Handy

Jim Janney

David Lousteau

Peter Rosenblad



U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Topics

- Goal / Purpose of Target Design Group
- Target Procurement Strategy / Status
- Current Analysis State
- Additional Leak Detection
- Potential Alternate Manufacturing Technique
- Future Target Designs

Target Design Group Goal / Purpose

- Provide engineering, manufacturing, and operational support for the SNS Target System, considering the following:
  - Beam power – Target System (specifically target module) shall not be the limiting component in SNS
  - Target Consumption - sufficient stock of spare targets shall be available
  - Supply – one (preferably more) target module suppliers shall consistently remain proficient in manufacturing units so that supply is not delayed by repeating the learning curve
  - Design – Considering the above, the design shall be continually improved to improve performance, manufacturability, and cost

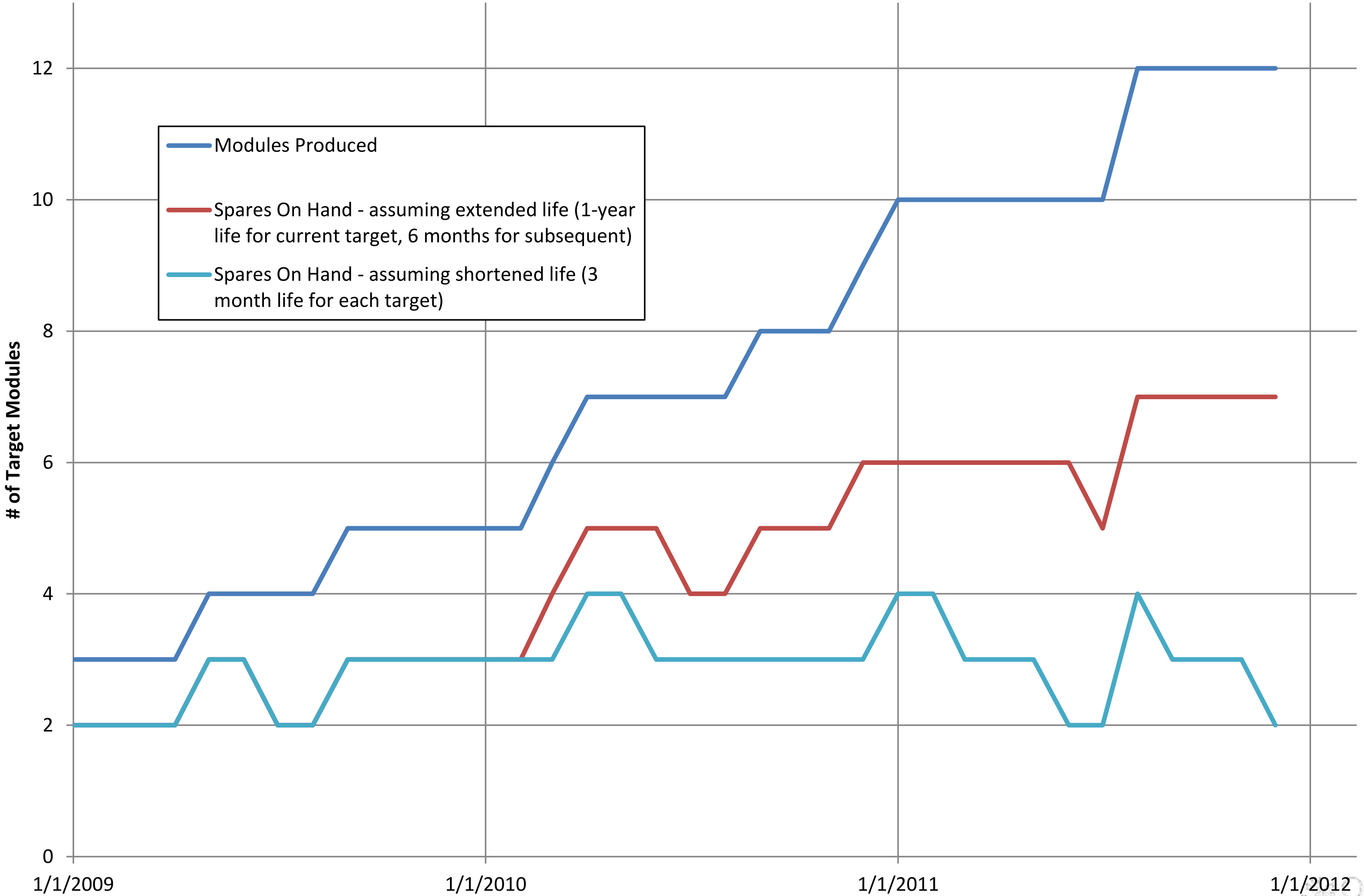
Procurement Strategy / Status

- Initial contract in 2004-2006 provided 2 units from one source (Metalex, Cincinnati, OH)
- Performance was very good, however single source for long term supply is not ideal
- Solicitation in 2007 with goal of awarding targets redundant suppliers and key sub-tier suppliers (EB welding)
- Awards made to Metalex, Oak Ridge Tool and Engineering, and Major Tool and Machine (Indianapolis)

Procurement Strategy / Status

- Metalex has delivered 3 more targets (5 total) and will deliver one more in March, 2010
- Major Tool and Machine is scheduled to deliver their first target in March of 2010, second in September of 2010, and third in November of 2010
- Oak Ridge Tool is scheduled to deliver their first target in January of 2011, second and third in June of 2011

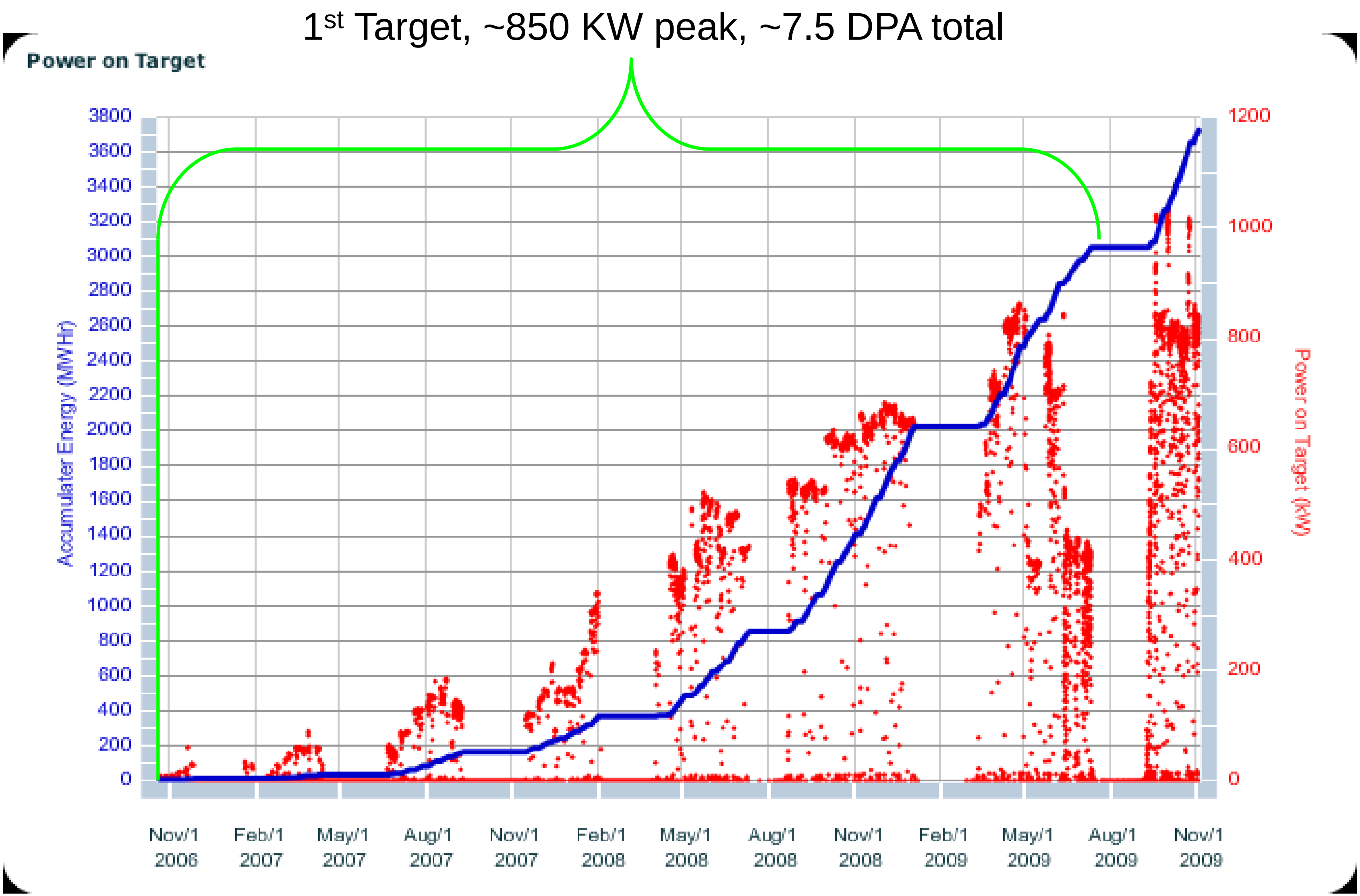
Procurement Strategy / Status



Analysis prior to SNS Operation

- Mercury Vessel analyzed to 1 MW – loads include:
  - Dead weight
  - Static pressure
  - Steady state temperature profile
  - Pressure pulse
  - Low cycle (thermal + pressure pulse) and high cycle (pressure pulse) fatigue evaluated
- Water Cooled Shroud analyzed to 2 MW
  - Limited amount of off normal cases were studied
- All analysis assumes initial material condition
  - No thinning due to cavitation damage
  - No radiation damage effects

SNS Operation on First Target



Analysis After Initial SNS Operation

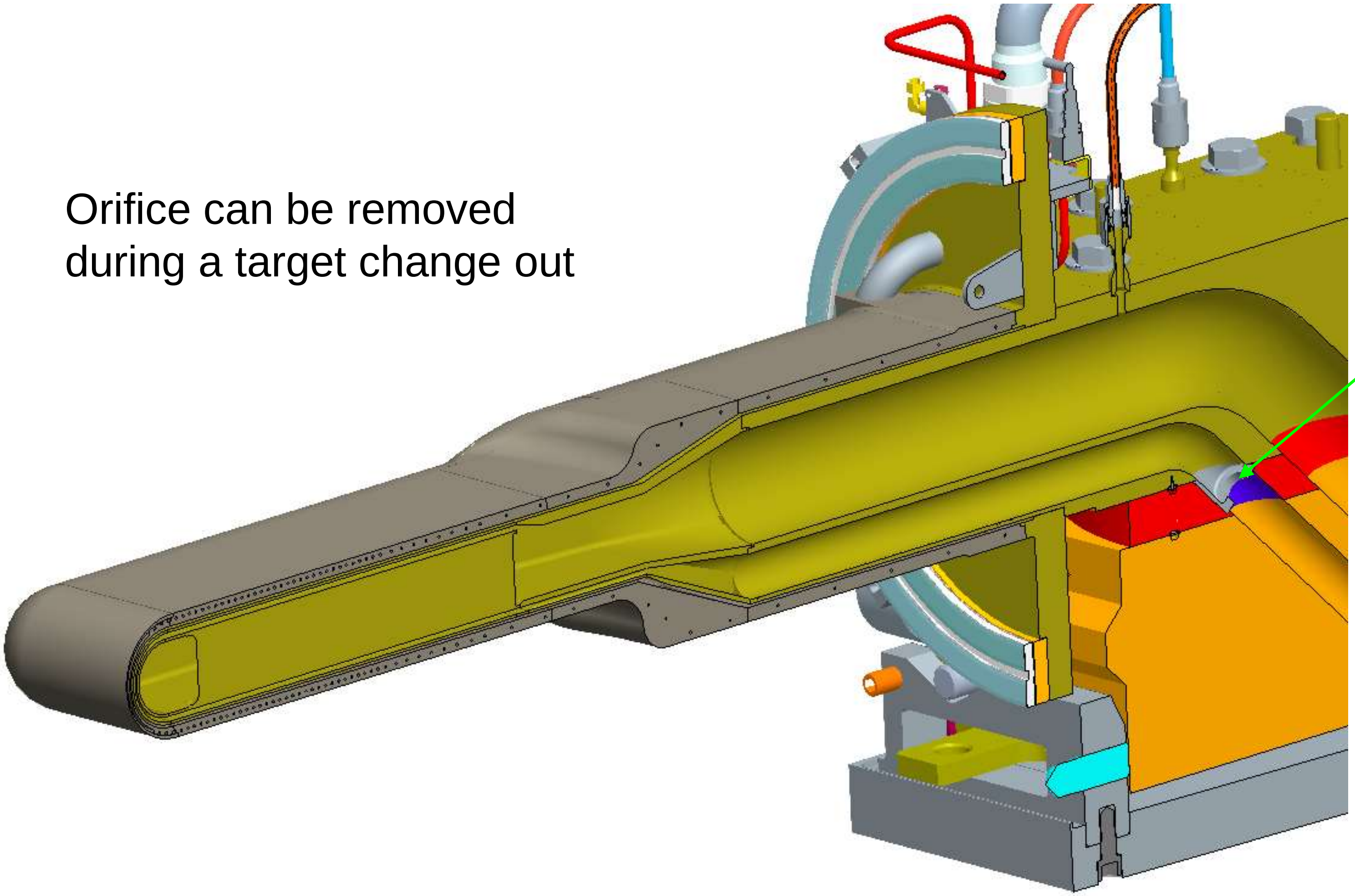
- GOAL: To determine the practical beam power/intensity limit for present target design and identify design changes which would allow additional power and or design margin. Beam power goal is 1.4+ MW.
- Because the Water Cooled Shroud was analyzed to 2 MW, initial emphasis was on the Mercury Vessel

Mercury Vessel Analysis

- Mercury Vessel has been analyzed with the SNS nominal beam at a power of 1.4*1.1 MW
  - 1.1 factor is included to simulate peaking over the entire profile
- 4 different flow conditions studied (due to pump limitations)
  - Pump at 270 rpm with window flow orifice
  - Pump at 270 rpm without window flow orifice
  - Pump at 400 rpm with window flow orifice
  - Pump at 400 rpm without window flow orifice
- Loads Included (same as pre-operation):
  - Dead Weight
  - Static Pressures
  - Steady State Temperature Profile
  - Pressure/Temperature Pulse
  - Low cycle (thermal + pressure pulse) and high cycle (pressure pulse) fatigue evaluated

Mercury Vessel – Window Flow Orifice

Orifice can be removed during a target change out



Mercury Vessel Analysis, 1.4*(1.1) MW - Results

- **There is less than 10% difference among the peak stress between all four flow conditions.**

	Limiting Peak Stress, Secondary (Mpa)	Allowable at limiting location, Secondary, $3*S_m$ (Mpa)**	Stress/Allowable
270 rpm with orifice	395.2	413.6	0.96
270 rpm without orifice	351.6	413.6	0.85
400 rpm with orifice	371.9	481.1	0.77
400 rpm without orifice	372.1	484.0	0.77

- **Due to desire to limit pump speed, the orifice will be removed and pump will remain ~270 rpm**
- **Conclusion: The existing Mercury Vessel design is capable of operating in excess of 1.4 MW, allowing for 10% peaked beam. Further improvement could be made by thinning the outer window if cavitation is not life limiting at these power levels.**

****Allowable secondary stresses are based on actual material properties for the present target using ASME criteria (S_m = 2/3*yield strength). Values vary based on local temperature and the strength of individually supplied heats.**

Water Shroud Analysis

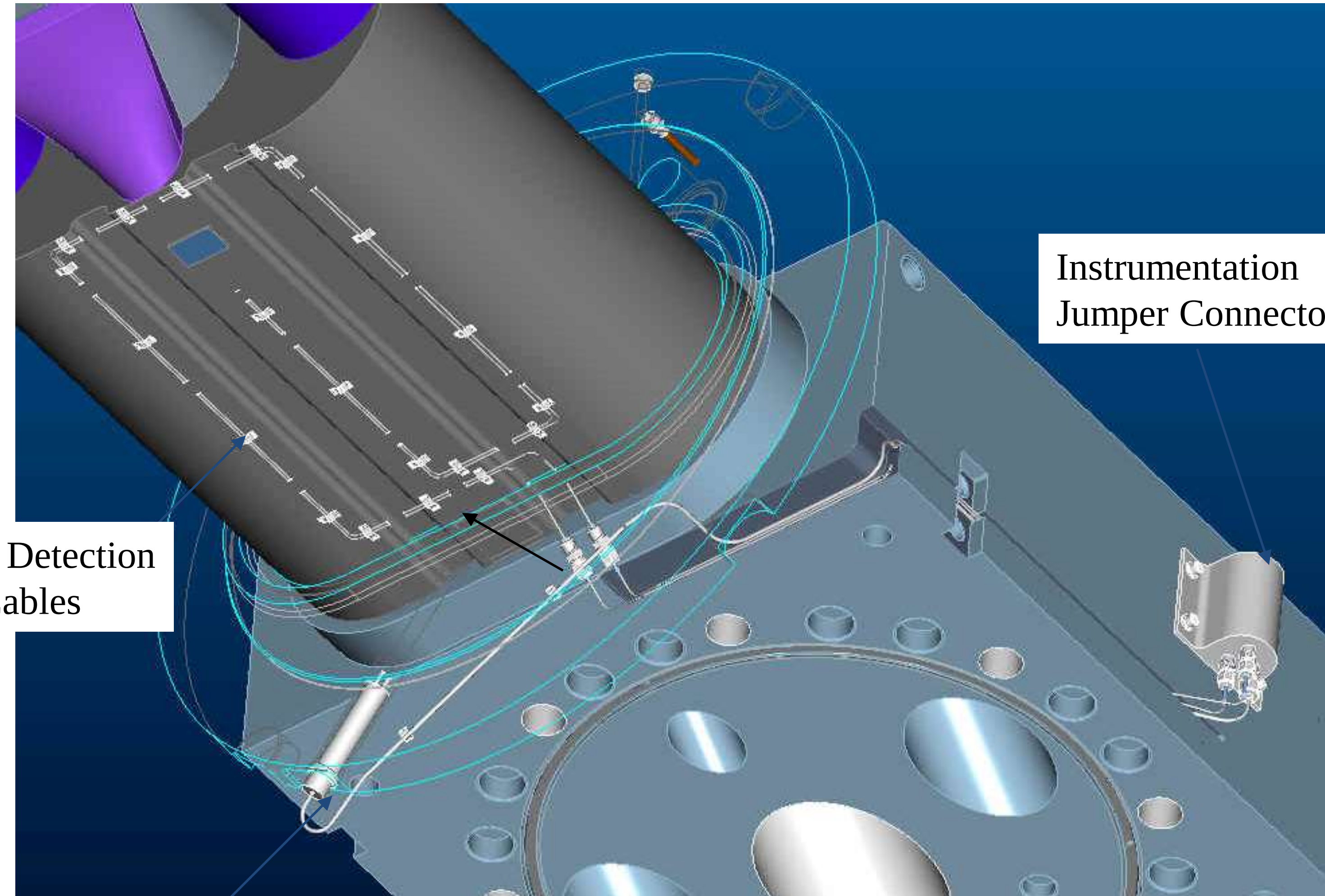
- Water Shroud Analysis prior to SNS operation was done at 2 MW. Therefore, the component was not previously considered power limiting.
- However, off-normal analysis only considered:
  - Static pressure due to Hg leak from vessel
  - Pressure pulse due to Hg leak from vessel
- No steady state thermal stress calculation from temperature profile following Hg leak from vessel
- This level of analysis assumes that the leak detectors will function properly

Leak Detectors Currently on Targets

- Mercury leaking from the mercury vessel is expected to be detected by the redundant leak detectors in the interstitial
  - Continuity probes (2) – checked periodically for continuity throughout operation
  - Heated thermocouple junction, calibrated for Hg and H_2O
- Testing was performed prior to construction which showed that mercury will drain to the bottom of the interstitial so that it will contact the detectors and the detectors worked as intended

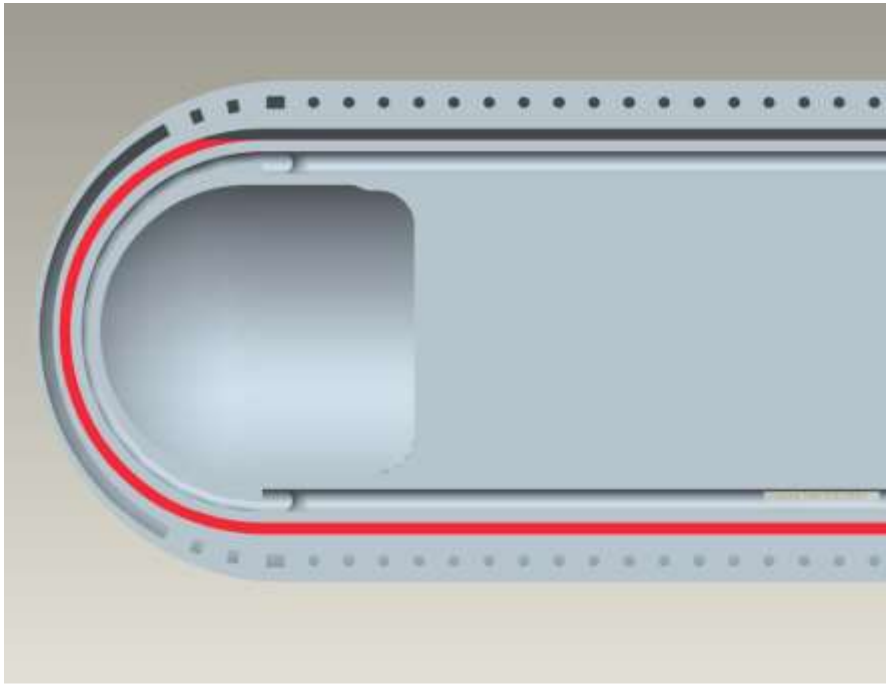
Target Module – Leak Detectors

- Located in Gap Between Hg Vessel and Shroud



Leak Detectors – what if they don't work, or don't work quickly enough?

- Mercury fills the interstitial until the it equalizes with the helium, or forces the helium back through the system
- Even at low pump speed (270 RPM) mercury would fill to above the front windows of the shroud and mercury vessel
- Interstitial space becomes a stagnant metal layer of Hg that receives energy deposition and is only cooled by conduction through the SS



Leak Detectors – Response time Requirements

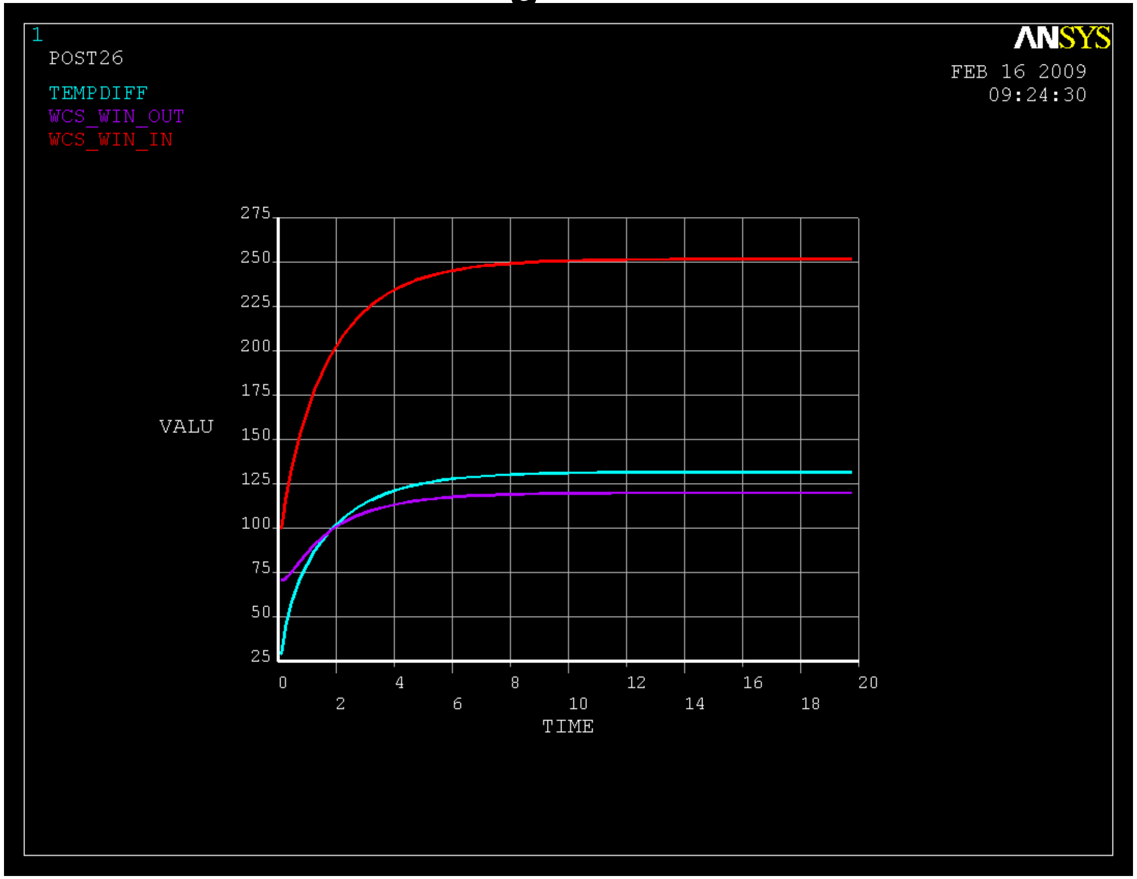
- Elevated stress and temperature is reached after roughly 5 seconds
- Beam shut off is set to 1 second following leak detection

Legend

Inside of WCS inner Window – Red

Outside of WCS inner window – purple

Temperature difference between inside and outside - teal



Water Shroud Analysis - Hg leak

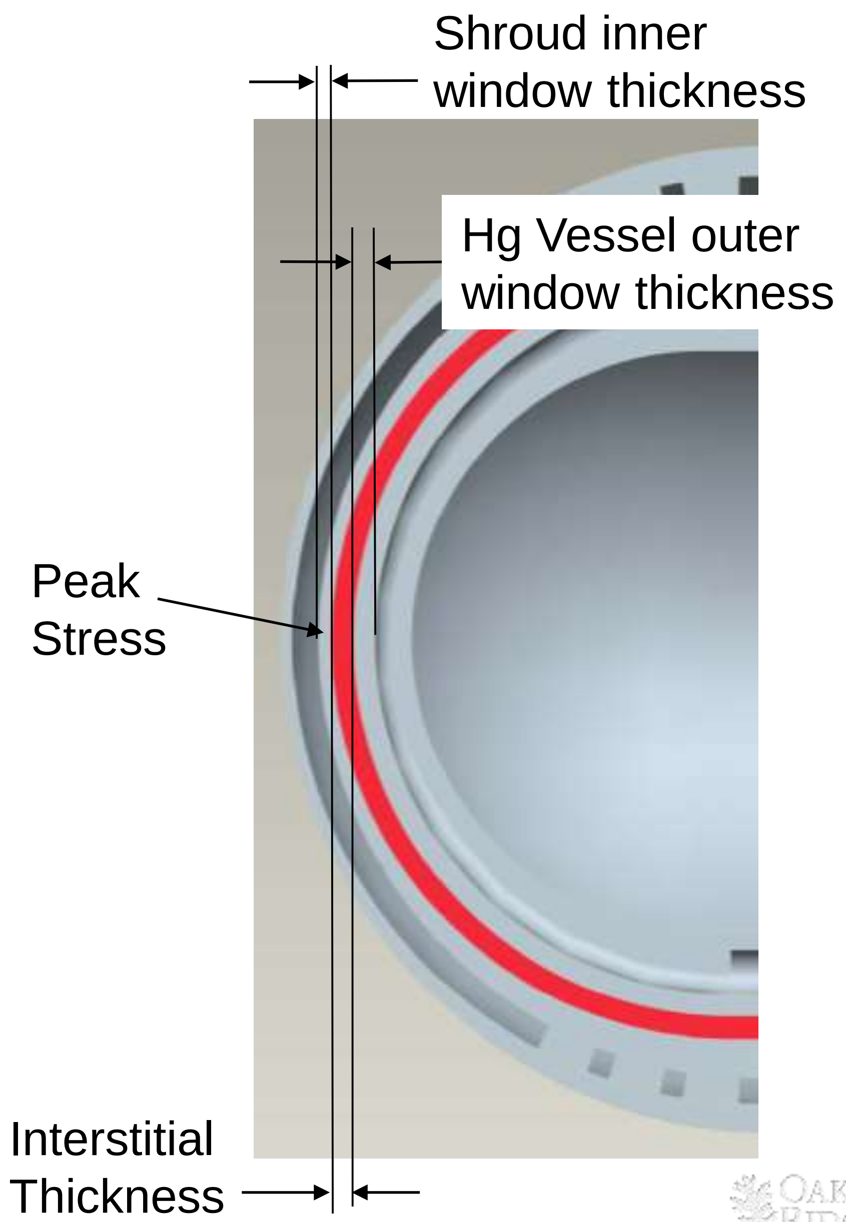
- Loads – 1 MW beam
  - Dead Weight
  - Static Pressures
  - Steady State Thermal Stresses – new
  - Pressure Pulse
- All are based on mercury completely filling interstitial
- Analysis assumes that flow within the mercury vessel remains in the normal operating condition despite the leak

Water Shroud Analysis - Hg leak

- The secondary stress combination at center of the beam in the shroud inner window is the limiting factor
- Result is heavily driven by local through the wall thermal stress
- Ratio of allowable stress / calculated stress = 1.37
- Preliminary Conclusion: The current water shroud design limits operation to roughly 1.37 MW operation due to this off-normal load case, with no allowance for a peaked beam.
- If this load case is to be considered, design changes are required to increase the power level to 1.4+ MW

Water Shroud Analysis - Hg leak

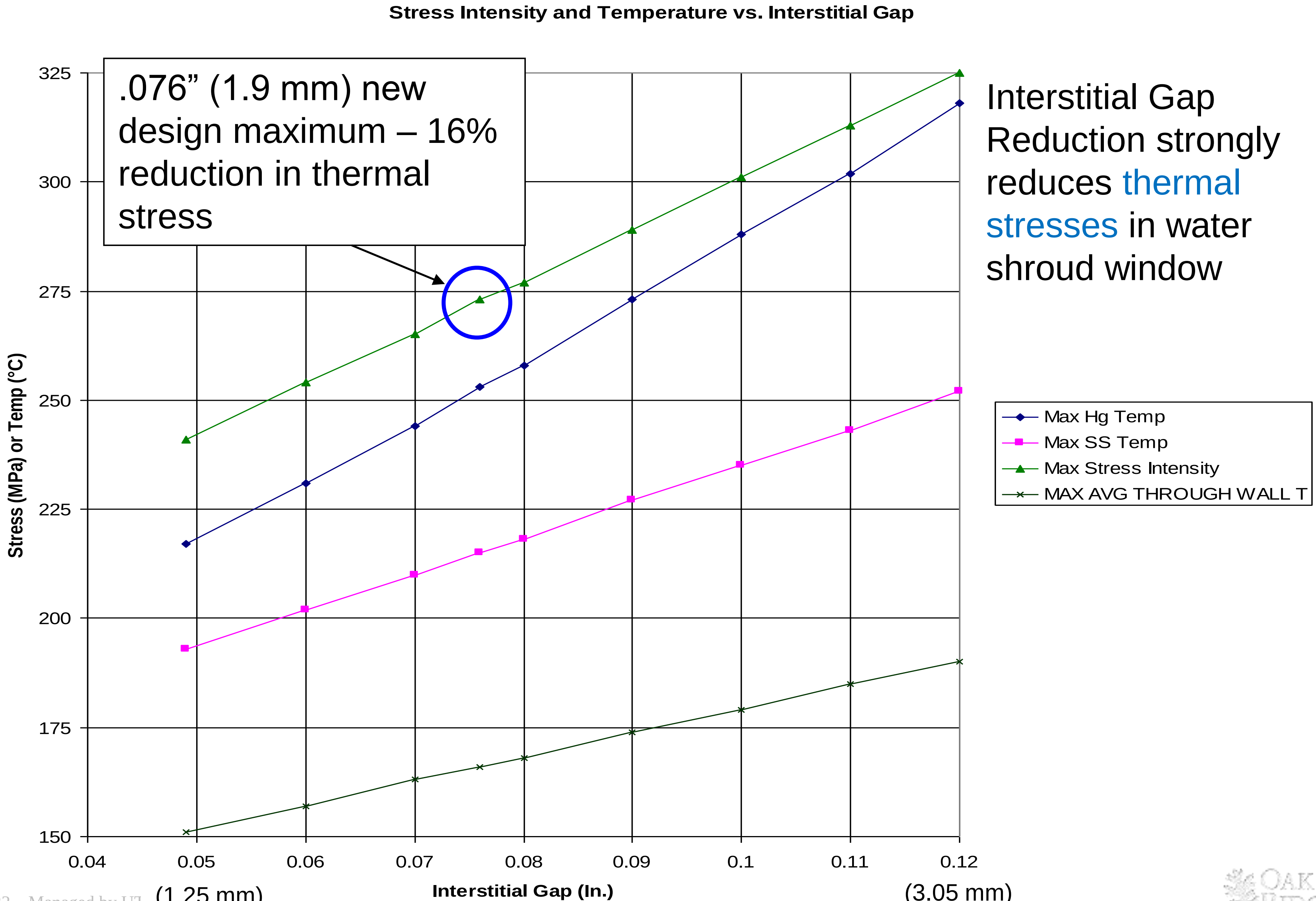
- **Evaluation of Analysis**
  - **The limiting stress is at the center of the beam in the inner window of the water shroud.**
  - **The stress state is heavily driven by the high temperature and temperature gradient through this window**
  - **There are three adjustments which could lower the stress state:**
    - **1. reduce the thickness of the *interstitial gap*, or the distance between the mercury vessel and the water shroud**
    - ***2.* reduce the thickness of the inner window of the water shroud.**
    - **3. reduce the thickness of the outer window of the Hg vessel**



Water Shroud Analysis - Hg leak

- Three parametric studies have been performed
  - 1. Study the effect of reducing the interstitial gap – performed with a simplified 2-D model
  - 2. Study the effect of reducing the thickness of the water shroud inner window – performed with a simplified 3-D model
  - 3. Study the effect of reducing the thickness of the Hg vessel outer window – performed with a simplified 2-D model

Water Shroud Analysis - Hg leak, Parametric Study #1

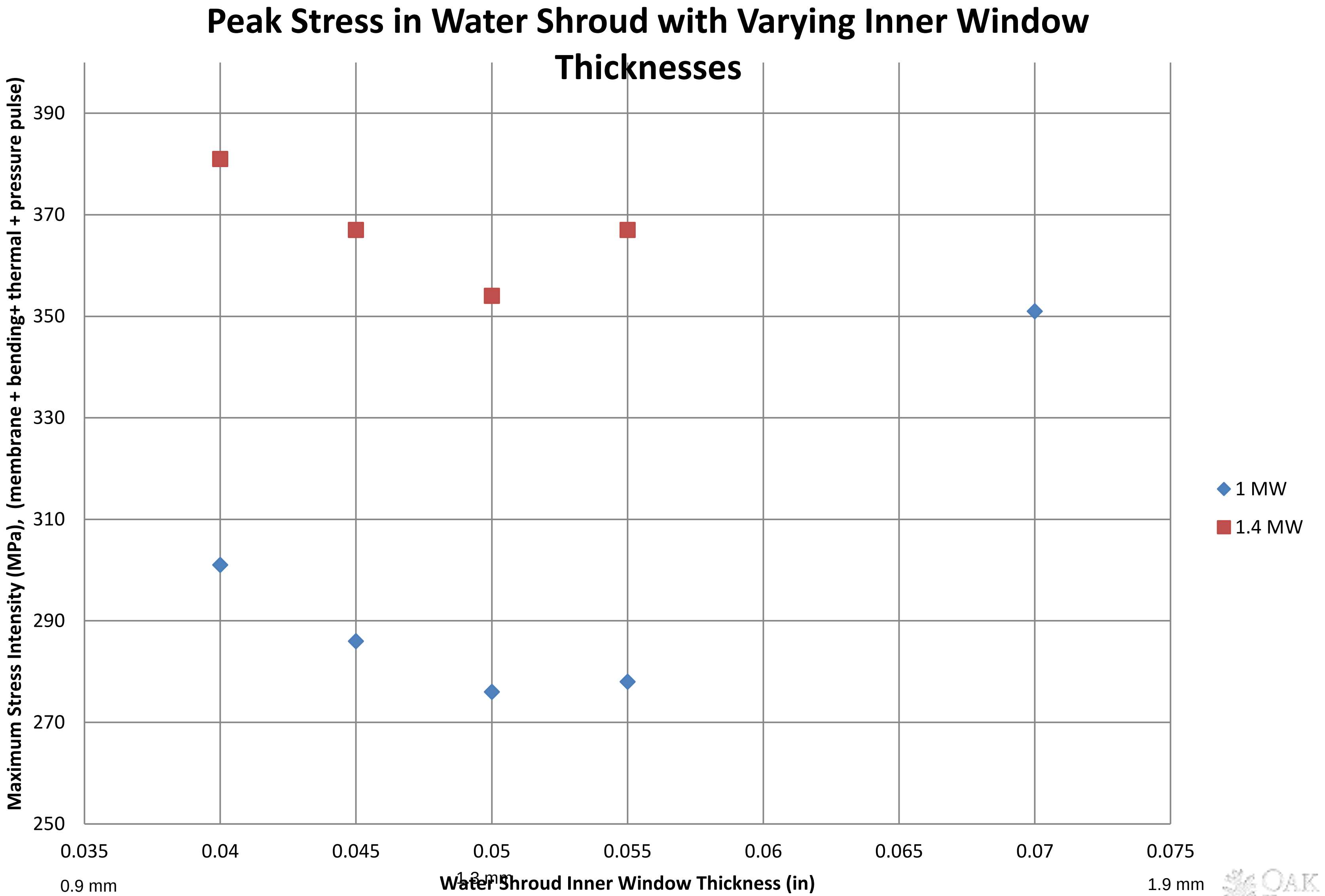


Interstitial Gap Reduction strongly reduces thermal stresses in water shroud window

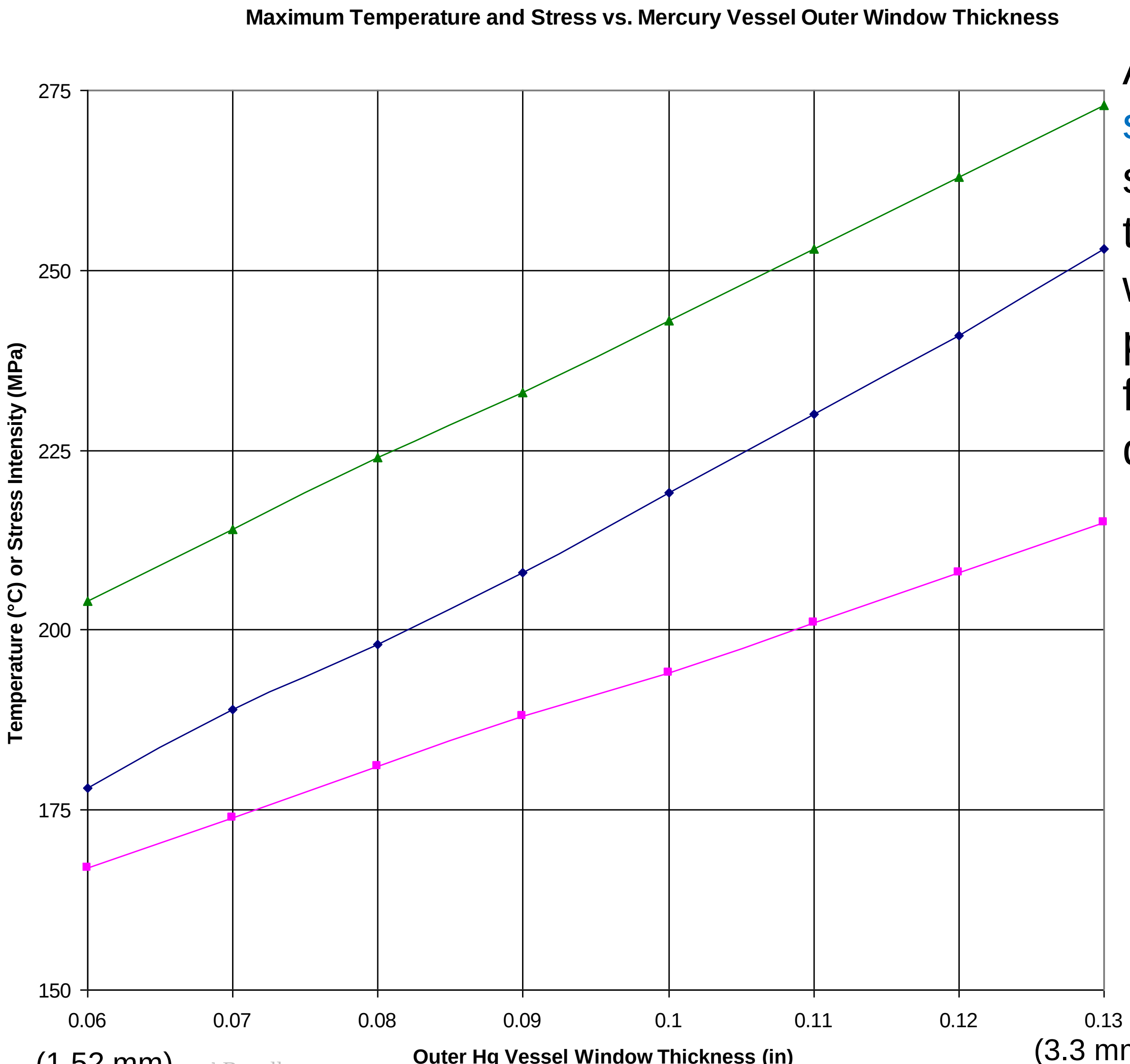
Water Shroud Analysis - Hg leak, Parametric Study #2

- Reduce thickness of the water shroud inner window
- Current design thickness is .070” (1.78mm)
- As thickness is reduced, static pressure and pressure pulse stresses increase, but thermal stresses are reduced.
- New design thickness will be .050” +/- .005” (1.27 mm)

Water Shroud Analysis - Hg leak, Parametric Study #2



Water Shroud Analysis - Hg leak, Parametric Study #3



(1.52 mm)

(3.3 mm)

Although significant thermal stress reductions in the water shroud could be obtained by thinning the outer Hg vessel window, this option is on hold pending a more clear path forward for mitigating cavitation damage.

Current Analysis Summary

- Varying power levels are based on actual material properties and measured interstitial gaps
- The listed values are derived by scaling full 3-D results using simplified parametric analyses
- Targets # 4 and beyond will have reduced maximum interstitial gap (~15% improvement)
- Target # 6 and targets # 8 and beyond will have the thinned water shroud inner window (~ 20% improvement)

Scaled Power Limits	
Target # 2	1.61 MW
Target # 3	1.53 MW
Target # 4	1.85 MW
Target # 5	1.85 MW
Targets # 6 and beyond*	TBD*

- Current targets shown to be good for 1.4 MW with nominal beam profile. Operational limit now at 1.2 MW to allow for analysis and beam uncertainties. This limit can be adjusted when the beam profile is better understood and more analysis is completed

*Actual power limits will depend on material and manufacturing

Continuing Analysis

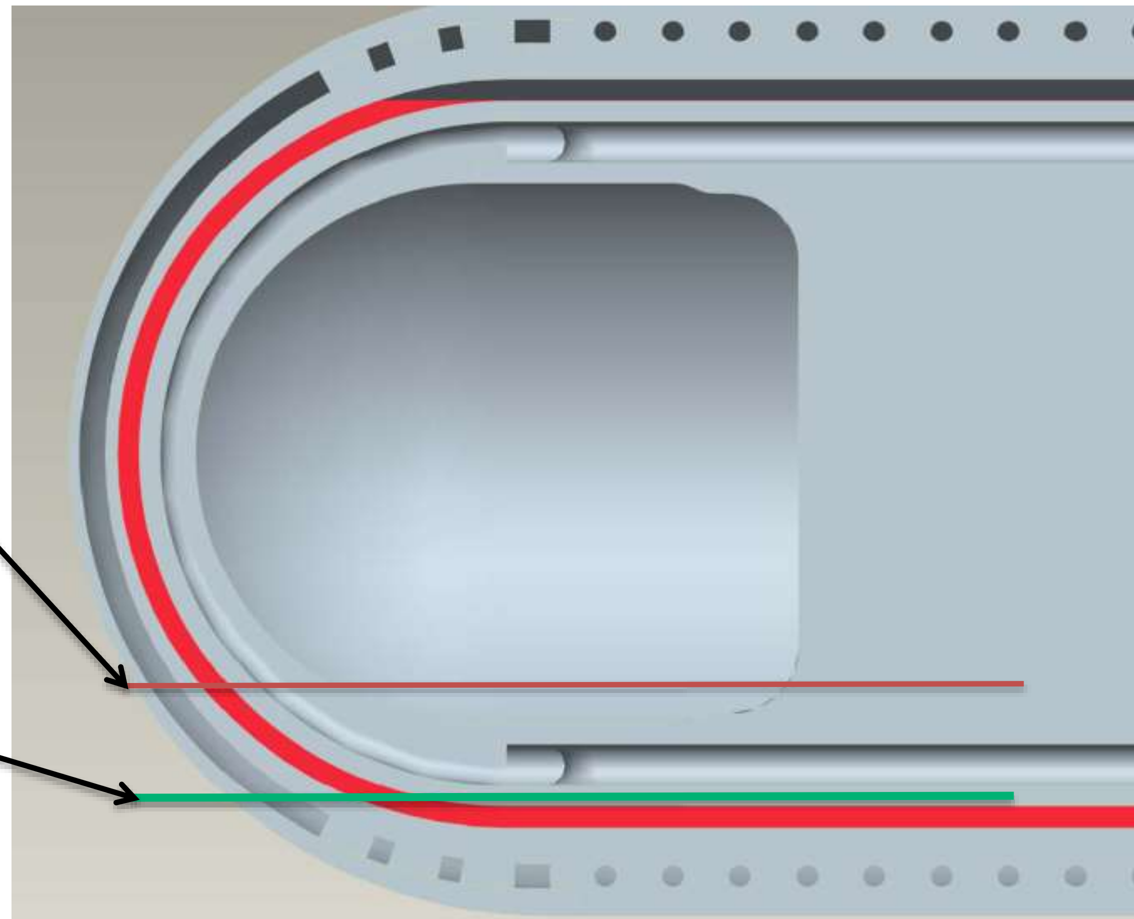
- Complete full 3-D analysis which accounts for synergistic effects of the reduced interstitial and window thicknesses (.076”/1.9mm maximum interstitial and .050”/1.3mm water shroud inner window)
- Analysis is being performed with 10% peaked beam, to approximate historical conditions.
- This analysis will eliminate some of the uncertainty in the current estimates for each target.

Additional Leak Detection

- Goal: Increase confidence in leak detection so that the steady state condition of mercury in the interstitial does not have to be considered.
  - Current Hg Vessel design is then capable of 1.4 MW+
  - Current water shroud design is capable of 2 MW
- Proposal: Burst Disk with indicator mounted to the manifold block of each target module
- Alternate or additional option: Gas analysis
  - Could be continuous system or operated in a batch mode
  - Requires more extensive system changes
- Additional leak detector can reduce uncertainty with mixed signals from existing 3 detectors and could eliminate need to retract carriage to test target module

Additional Leak Detection – Burst Disk

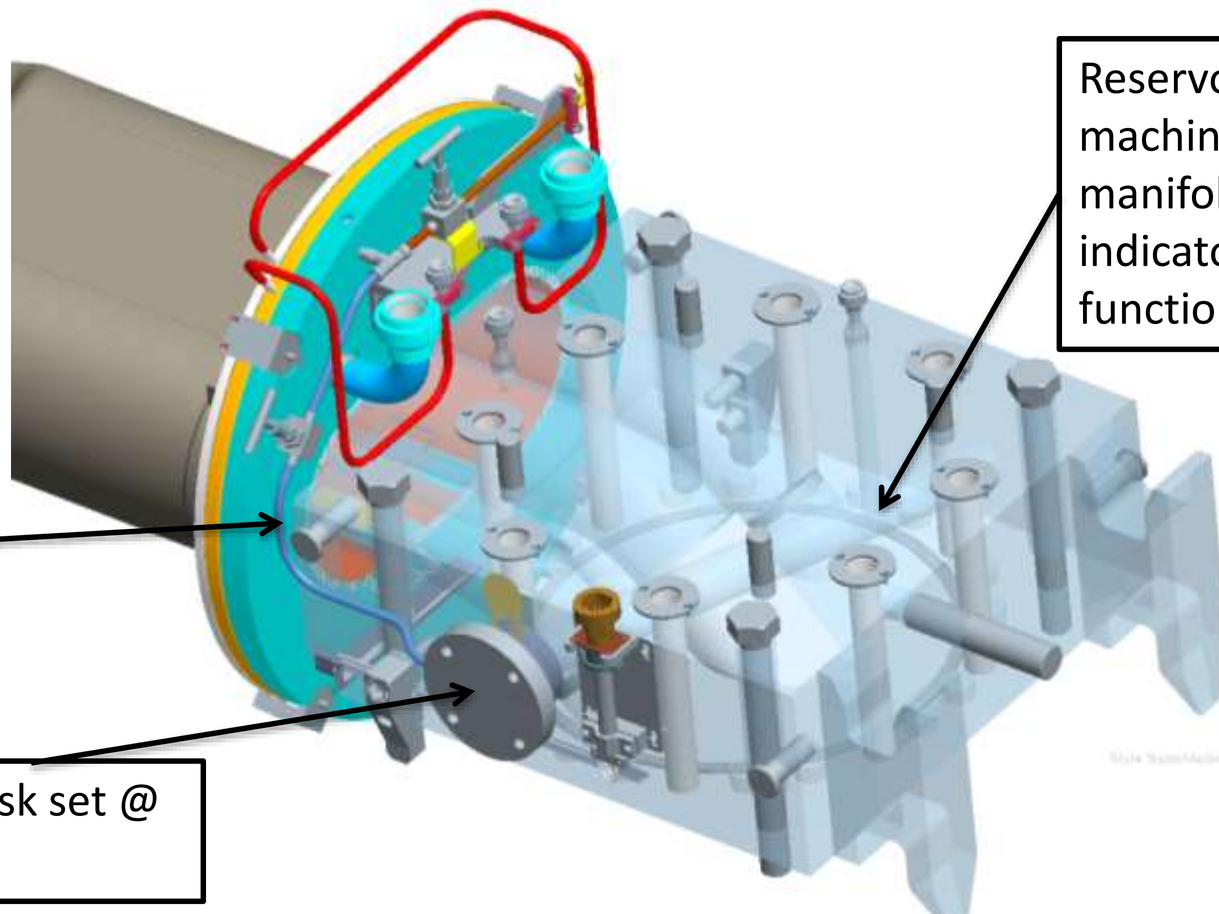
- Interstitial is backfilled w/ Helium @ 1 atma
- Bulk Hg pressure in target is 2.7 atma @ 270 rpm
- Disk will burst before Hg is able to fill into the highly heated volume



Hg fill level @ 1.82 atma (tolerance on burst disk)

Hg fill level @ 1.54 atma (burst disk set point)

Additional Leak Detection – Burst Disk, Preliminary Concept



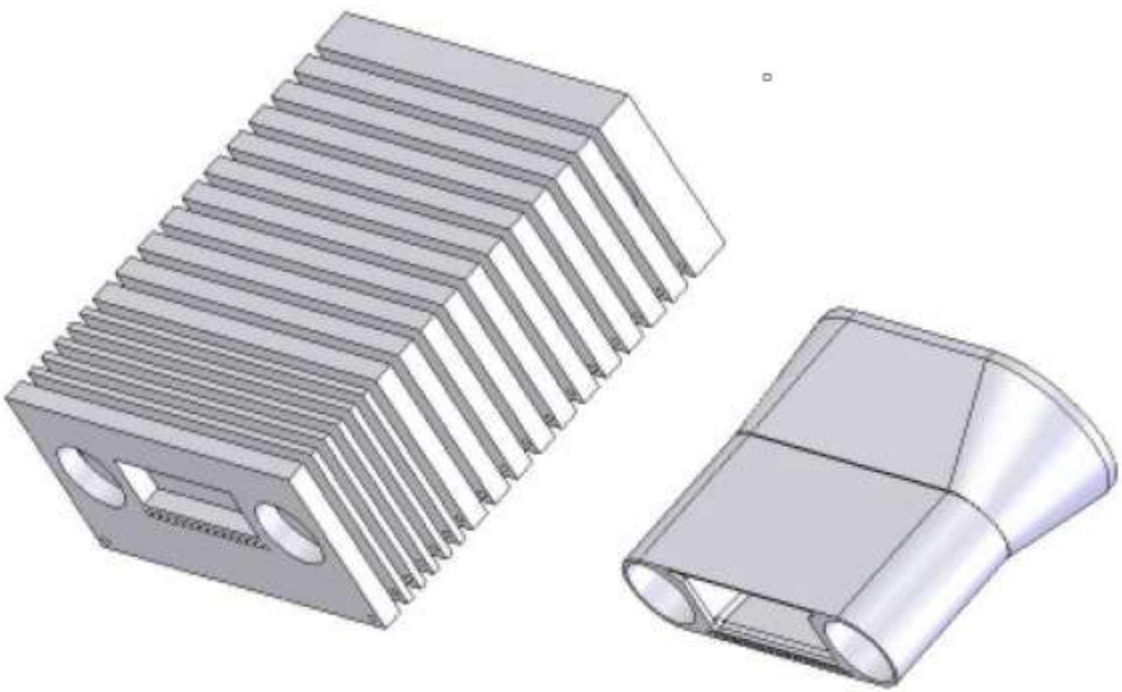
-Testing will be performed to ensure that the indicator will function with only small reservoir behind it.

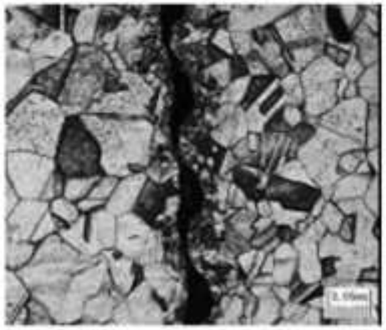
-Can be installed on spare targets – maybe in time for next change-out

-Can use existing spare wiring on carriage for burst signal

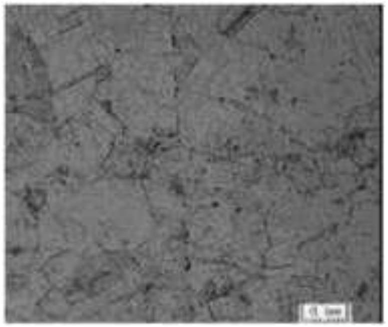
Potential Alternate Manufacturing Technique – Diffusion Bonding

- Allows complex cross sections – flow patterns not limited by more conventional wire EDM method
- Potential large cost savings
- Design changes can be more readily accommodated





Before



After

Future Design Work

- Target
  - Damage in the first target was limited to the low net flow region. Therefore, design work will look at a new target with revised flow pattern.
  - Initially efforts will be directed toward a cross flow design. The cross flow design is also convenient for gas wall mitigation if required in the future
- System
  - Cavitation mitigation via gas injection is considered a real possibility. As such, effects of this gas on the remainder of the system must be considered and, as necessary, mitigated. Initial efforts directed toward identifying gas effect on heat exchanger.

Questions / Comments