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Planned Mu2e Target Test at AP0

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Potential Fermilab Muon Campus & Storage Ring Experiments

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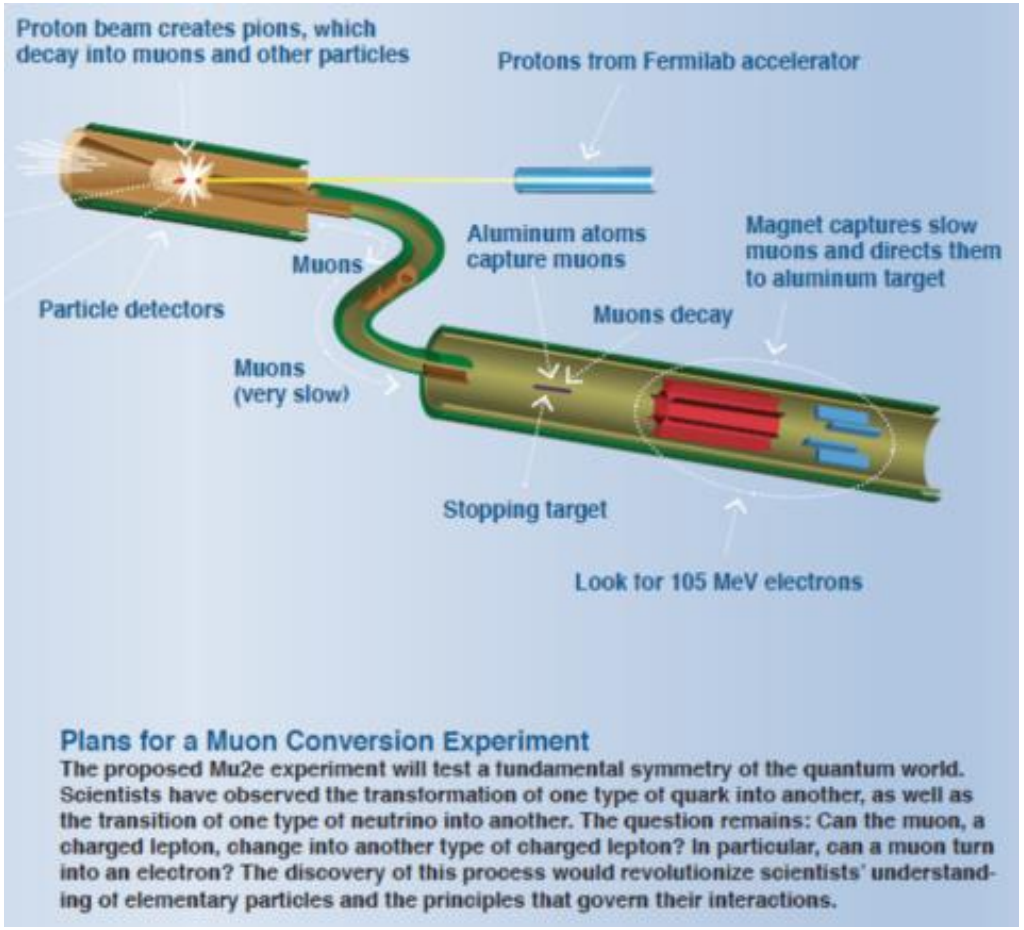
Background:

Mu2e has a Radiative Cooled target:

- 8 GeV Protons from Delivery Ring
- Eight 43 msec long spills during 380 ms. Then, 1020 msec of no beam.
- Operate for 1 year (2 x 10^7 seconds ~ 5555 hrs ~ 33 weeks)
- Goal is to make pions which decay to muons, and the muons transported to and absorbed in a stopping target.
- Beam Power is 7.3 kW for the design intensity running
- About 700 Watts absorbed in the target.



Scope and Motivation

Target is Unique and Multiple Failure Modes Exist:

- Differential Thermal Stress could cause cracks
- Low stresses at elevated temperature could lead to Creep
- Residue Oxygen or Water vapor in the vacuum can lead to tungsten oxidation at elevated temperature.

Mu2e is a $200M+ experiment which depends on this target successfully lasting 1 year.

- *Does it really make sense to put a unique, un-tested target in the experiment?*

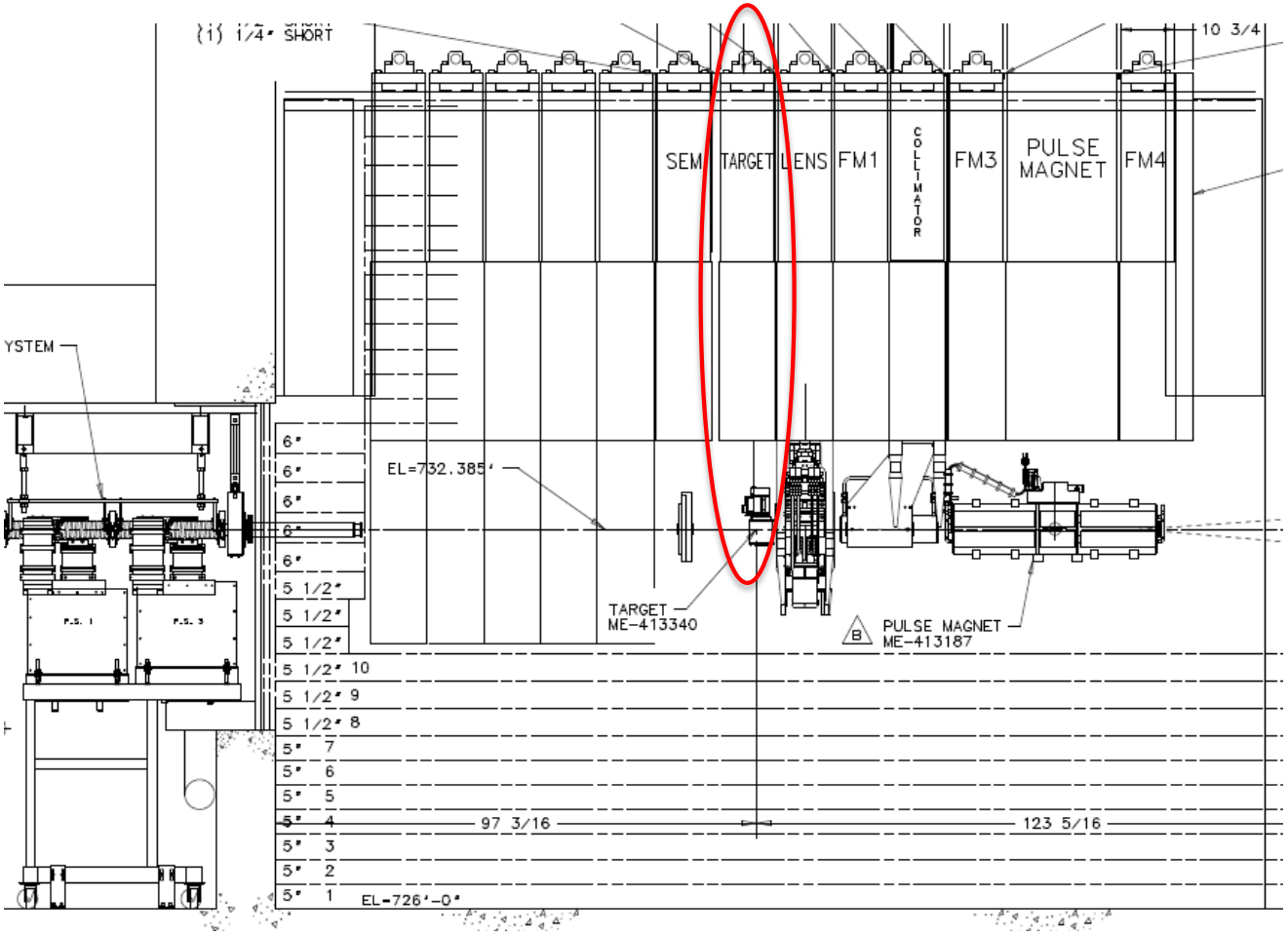
Why AP0?

- Protons at 8 GeV, same as in Mu2e
- Spot size and delivery different than Mu2e
  - Mu2e Resonant Extraction
  - AP0 Not resonant (Actually, a more severe thermal shock)
  - Spot sizes (beam sigma) differ slightly

- The complication:
  - Testing the Mu2e target means removing the g-2 target and ceasing beam delivery to g-2.
  - Ideally performed when g-2 is otherwise unable to take beam.
  - Involves significant effort in the AP0 target hall, best to occur at the end of an operating period.

Test Target Taking Position of g-2 target in AP0:

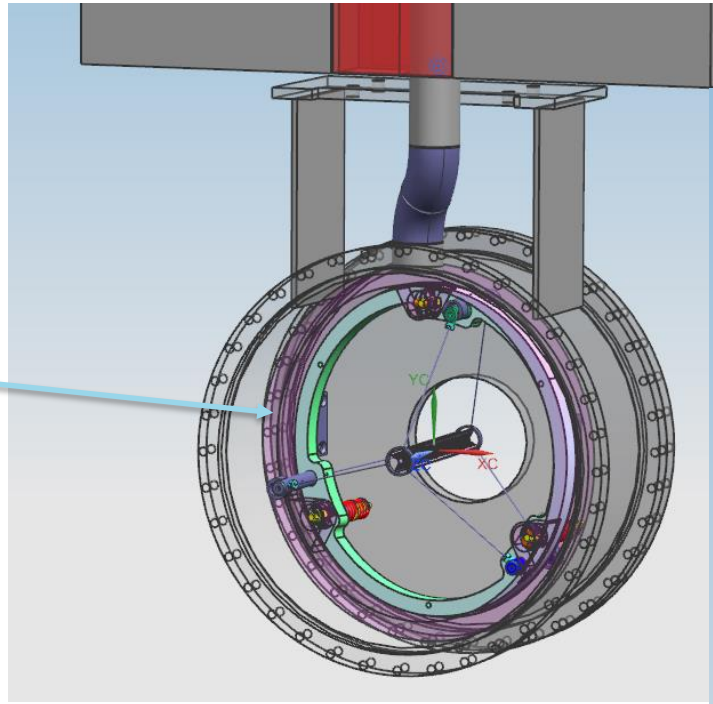
- Existing Target and Shielding Module Removed.
- Test target and Module inserted in place of target used for g-2
- Instrumentation and vacuum utilities connected to top of module.

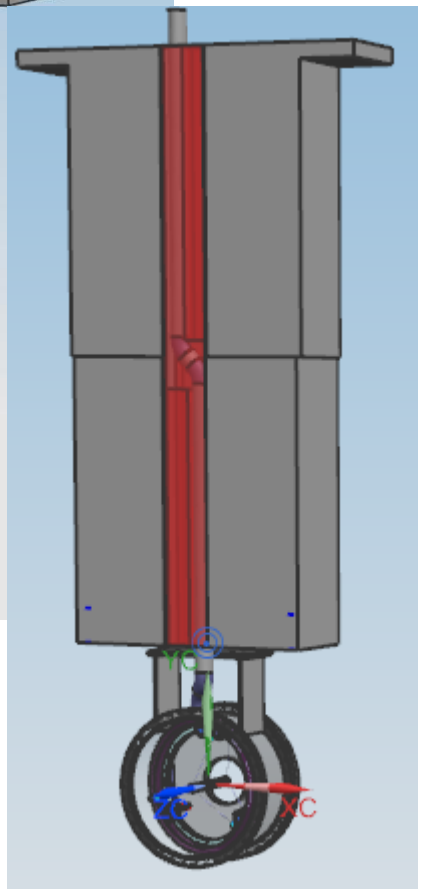


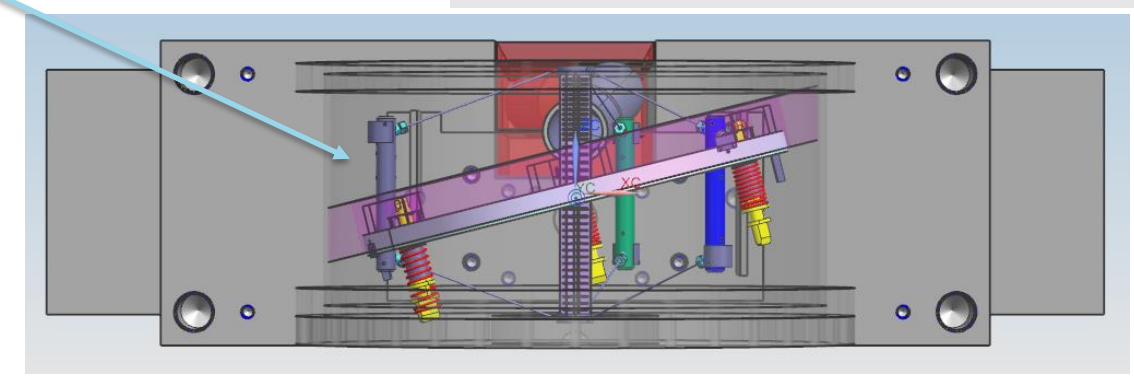
Mu2e Target Test Vessel and Target Assembly:

Identical target and bicycle ring and spoke supports to the one planned for use in Mu2e.

Bicycle ring mounted 14 degrees to square to align target with the beam:







Resulting Hand Calculated Stresses for Acceptable Creep:

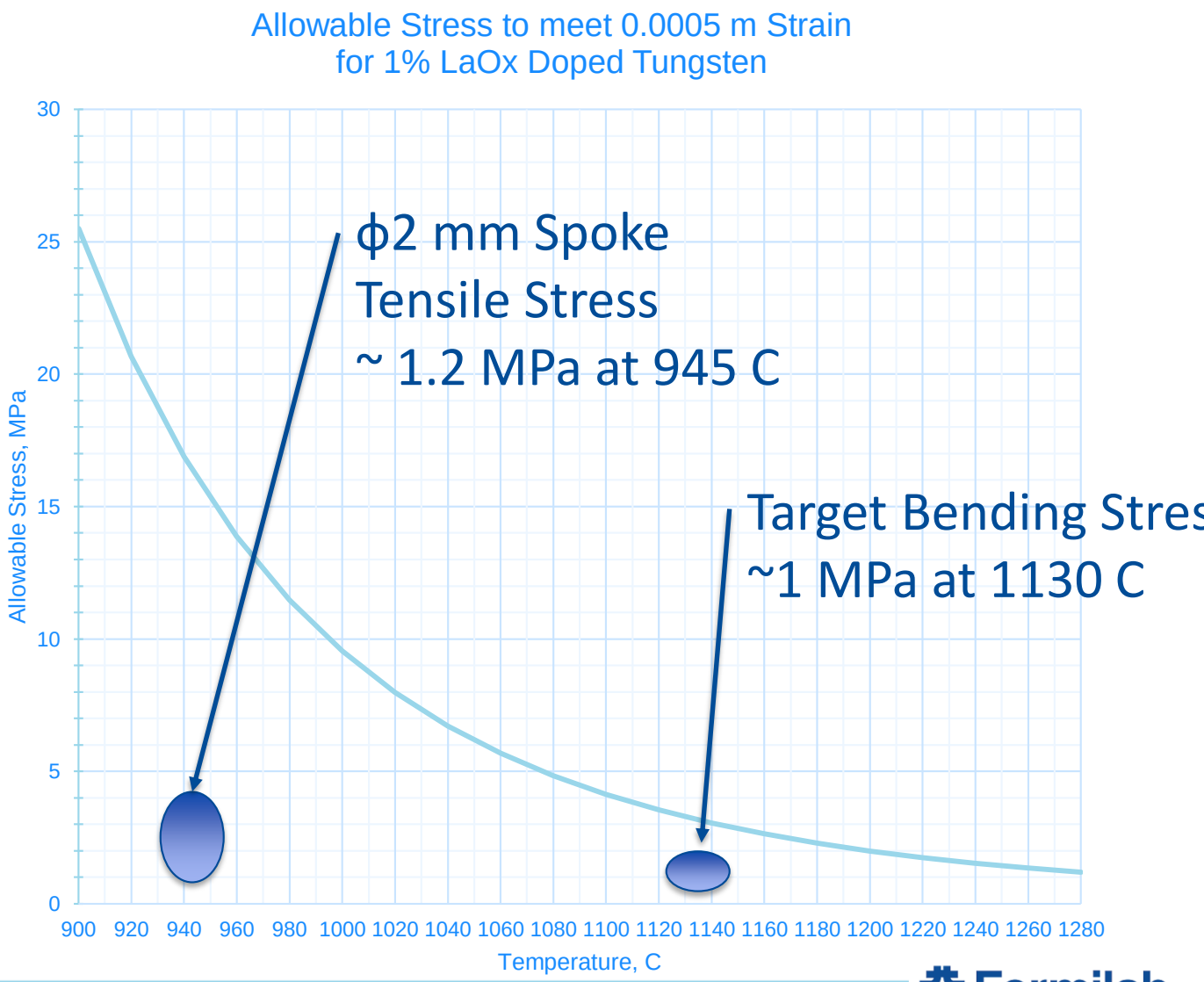
Creep depends on:

Stress,
Temperature
and Time.

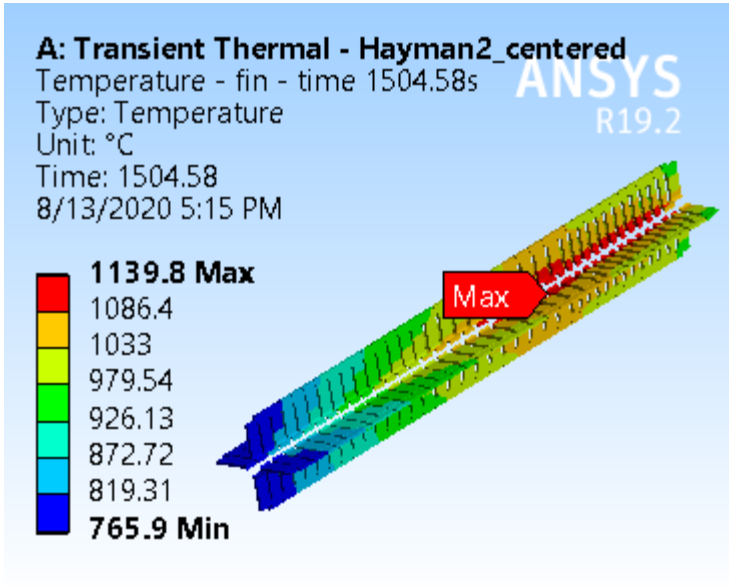
Test Duration likely

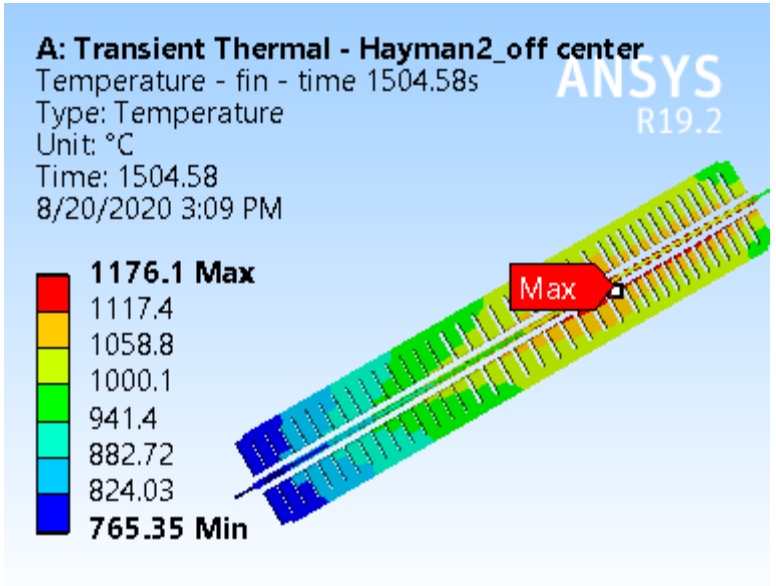
Unable to match 1 year operation to fully compare creep.

An oven test would be a more economical method to probe creep



FEA Predicted Target Fin Temperatures for centered and off axis beam





Above are excerpts for an analysis report by Ingrid Fang (PPD) using Edep date from Kevin Lynch (CUNY, York College)

Comparing centered beam and 2 mm off-set beam

(1504.58 seconds is where the transient analysis has reached a steady state condition)

Target Failure Modes Continued, Oxidation:

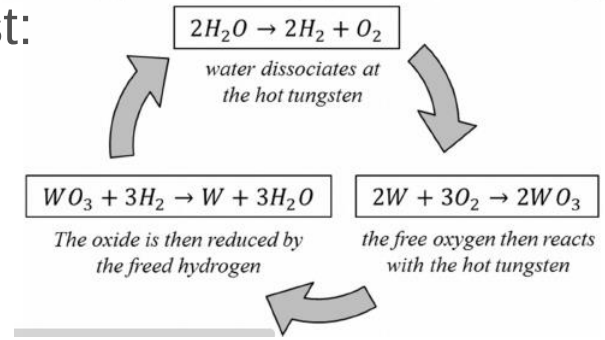
Oxidation driven by residual Oxygen and Water Vapor in the vacuum.

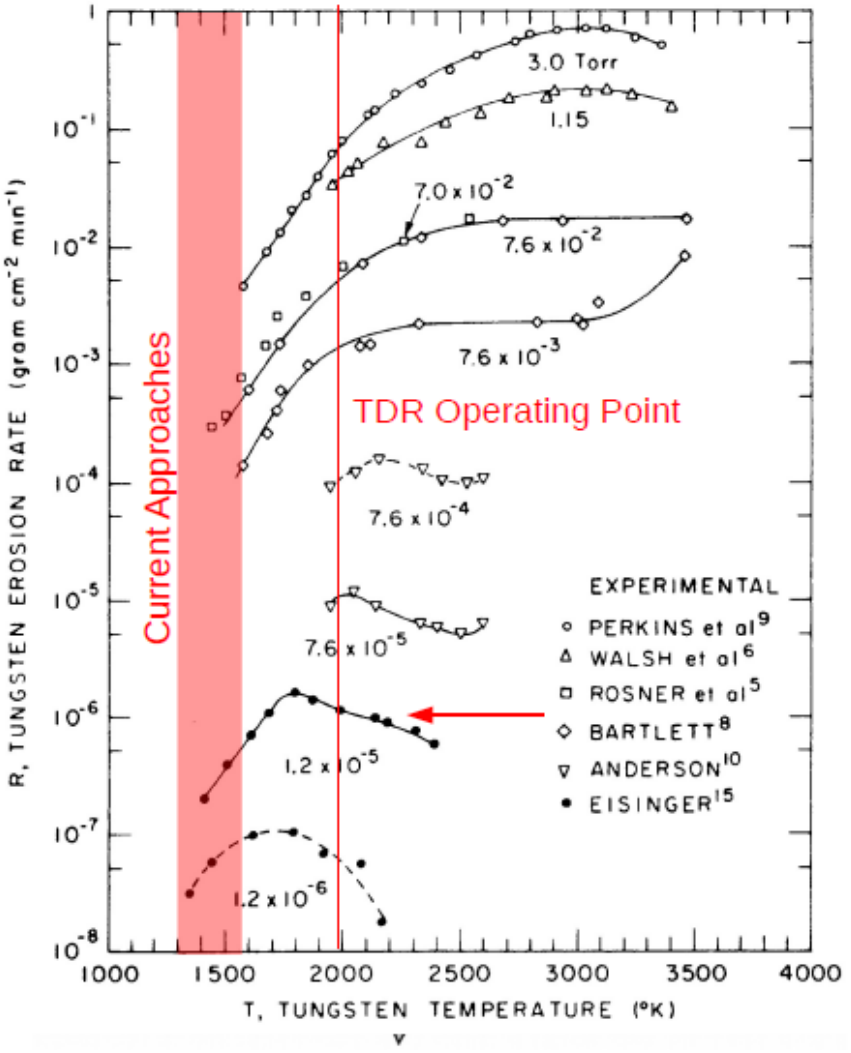
- Depends on the concentrations of O2 and H2O and on the temperature. Negligible if the temperature is sufficiently low.
- Oxygen Cycle:

$$W_{(s)} + O_{2\,(g)} \rightarrow WO_{2\,(g)}$$

$$2W_{(s)} + 3O_{2\,(g)} \rightarrow 2WO_{3\,(g)}$$

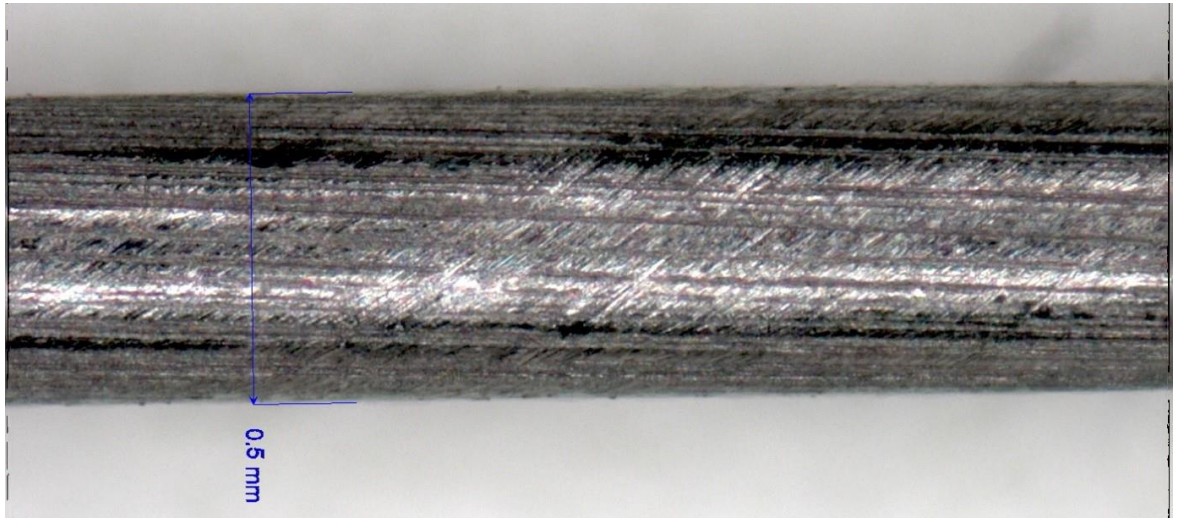
- Water Catalyst:



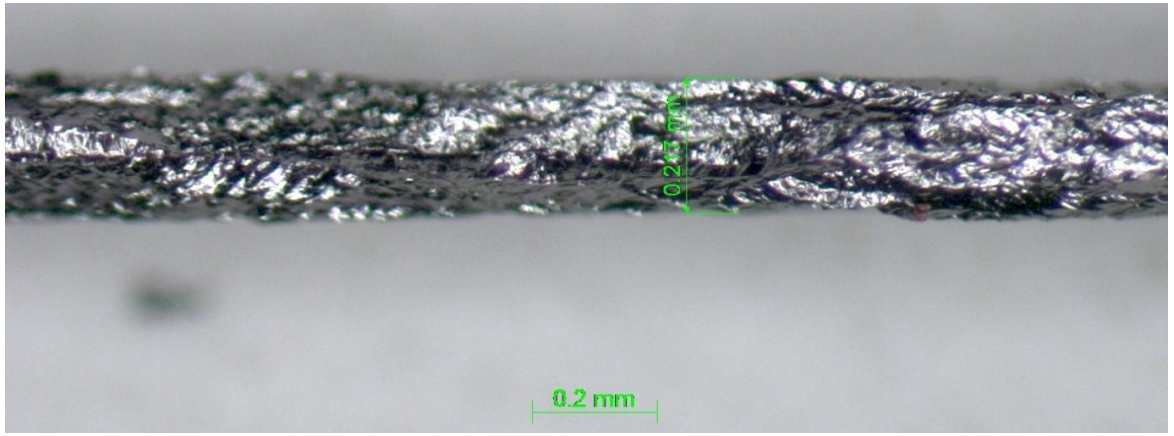


Target Failure Modes Continued, Oxidation:

The two photographs show before and after oxidation tests performed by RAL with an air leak to a vacuum.



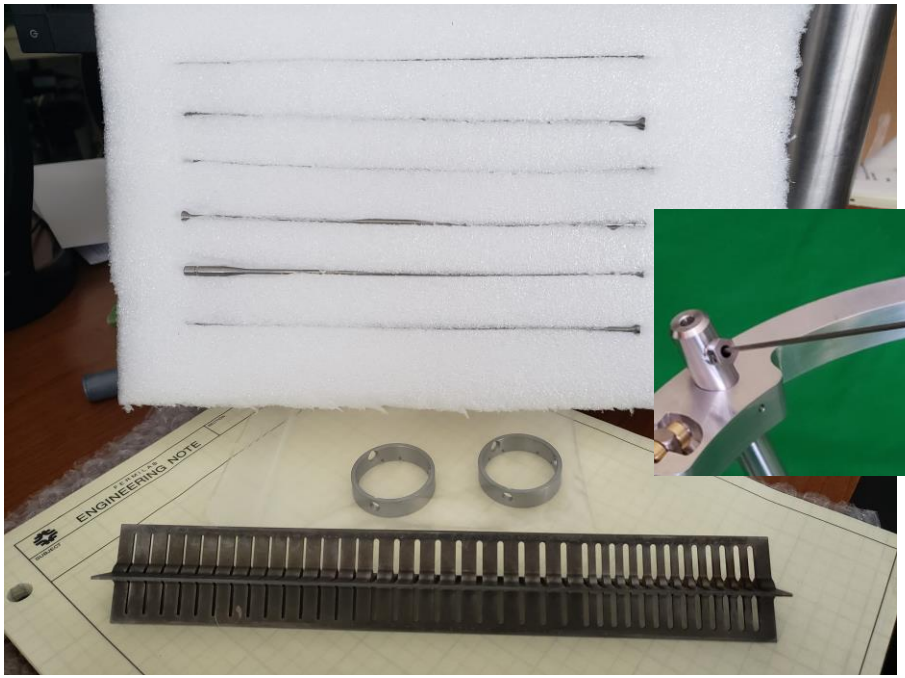
Better Vacuum lowers residual Oxygen and water vapor, reducing the material loss.

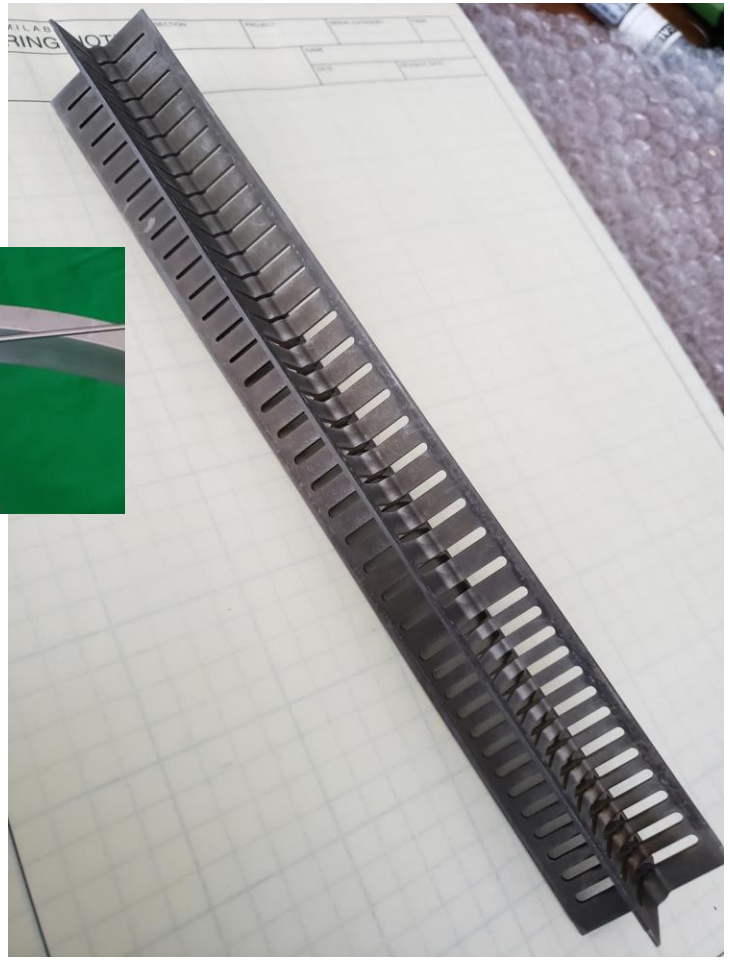


Vacuum Calculations indicate $1x10^{-5}$ torr around target.

Better vacuum limited by conductance of high vacuum line.

Un-mounted target images showing thin sections:





Spokes are 2 mm diameter

Fins are 1 mm thick

Core is 6.3 mm diameter

Tungsten loss due to Oxidation can severely affect target.

Testing Plan:

- Expose to beam, Measure Target Temperature & Stress:
  - Operate at a full, steady state temperature (min ~ 30 minutes)
  - Compare measured temperature to FEA temperature predictions:
    - Informs us on our emissivity validity
    - Heats target from the inside out (puts extremities in tension)
      - An oven test is the opposite
    - Accounts for actual beam center spot variation.
  - Measure stress in surfaces on target fin, spokes, ring, & core
    - Compare measured stress to FEA Stress prediction

- Rinse and repeat as necessary. (Take target thru multiple thermal cycles).

Testing Plan:

- During beam tests
  - Record vacuum levels in the target chamber
  - Ideally measure residual gas composition
- Post beam exposure, inspect for tungsten surfaces deterioration due to oxidation & examine for evidence of Creep distortion.
  - Perform in a hot cell at C0
  - Requires the development of tooling to expose target
  - Mostly visual examination, with some measurements.

- Extrapolate damage to target in Mu2e from test target data

Target Testing Challenges & Status:

- Build a target to test: DONE
- Build a bicycle ring to mount the target in: DONE
- Find a place to test a target with a Mu2e like beam: AP0
- Build a vacuum vessel to house the test target: In Progress
- Find a AP0 module to support the test vessel: DONE
  - Thank-you Jim Morgan and the AD / Muon Department folks!
- Identify appropriate instrumentation to measure target temperature, stress: Not currently filled
  - James Popp (CUNY, York College) providing some input
  - FNAL / AD / TSD asked for help, help TBD
- Post exposure examination plans not developed.
  - Some preliminary discussion in FNAL / AD / TSD held.
  - No Firm Plan(s) developed.

Team of Participants:

- CUNY, York College:
  - James Popp: Instrumentation
  - Kevin Lynch: G4 beamline Modeling
- Fermilab:
  - Jerry Annala (Muon): Mgmt
  - Peggy Crayton (MSD, Drafting): Vessel & Window drawings.
  - Yun He (TSD): Mgmt
  - Tom Kobilarcik (External Beams): Mgmt
  - Alyssa Miller (External Beams): Minutes, coordination
  - James Morgan (Muon): AP0 Expert & Beam Expert
  - Dave Pushka (TSD): Design, vessel, windows, target
  - Steve Werkema (Muon): Mu2e Project Mgmt

Potential Schedule:

- May take several more months to procure vessel, perhaps complete Fall 2021
- Several months to procure window. Fall 2021
- Post 2021 shut down (assuming technician availability), mount vessel to module, add shielding.
- Mount target and ring to vessel
- Install instrumentation & instrumentation feed thru (s)
- Install windows on vessel
- Helium Leak check target and vessel assembly in AP0
- Await for next g-2 hiatus for opportunity to put target module in AP0 target chase.