Target Systems for the Spallation Neutron Source

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at the
High-Power Targetry for Future Accelerators
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The Spallation Neutron Source

- Partnership of 6 labs (LBL, LANL, JLAB, BNL, ORNL, and ANL) under direction of ORNL
- World's most powerful neutron science facility
- $1.4B project, with completion in 2006
- Pulsed proton beam creates neutrons by spallation reaction with Hg target

SNS Project

Technical Parameters

• Beam power	> 1 MW
• Beam energy	1 GeV
• Pulse repetition rate	60 Hz
• Pulse length	700 ns
• Neutron beam ports	24

Status

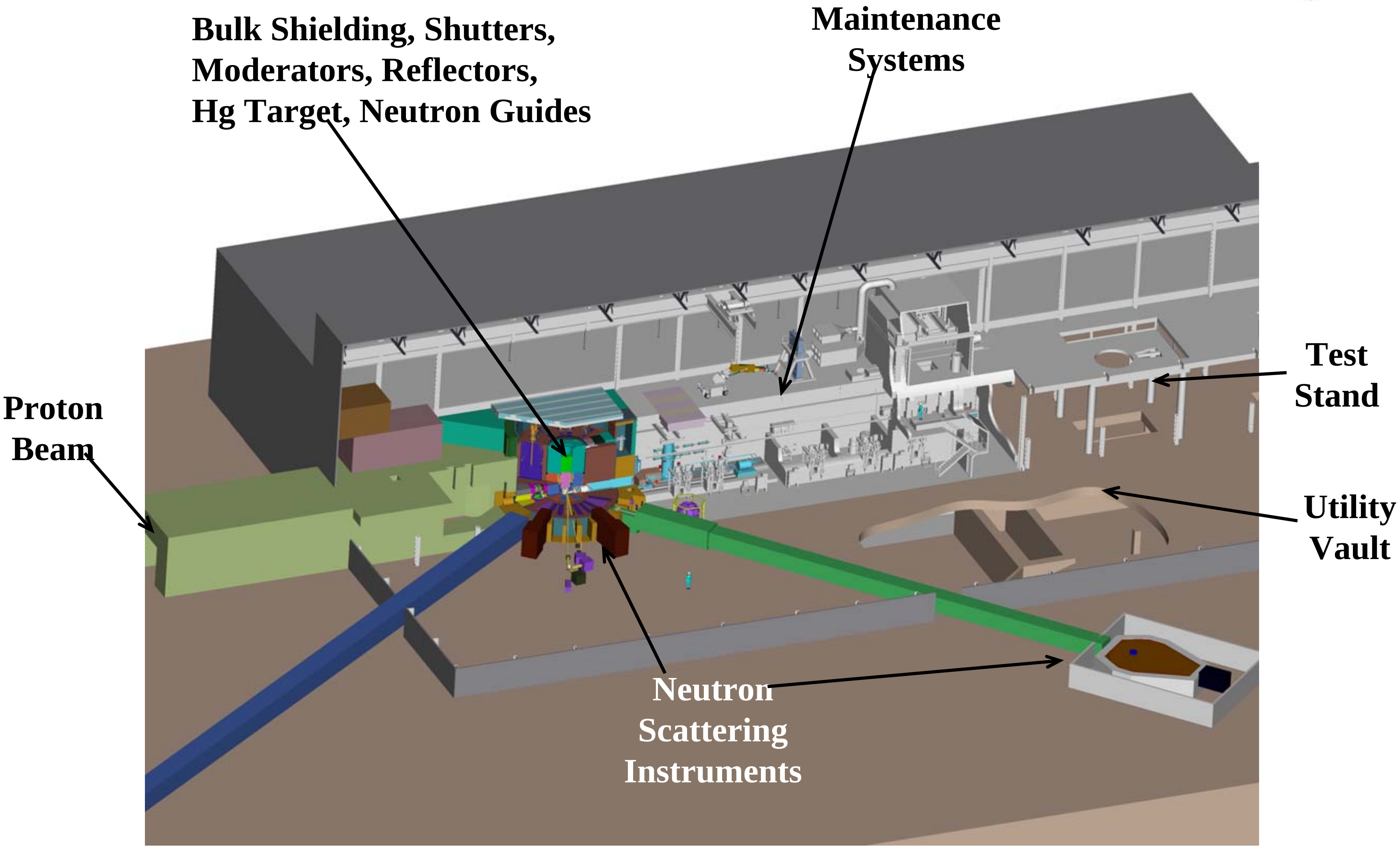
- Overall project is 68% complete and within budget and schedule constraints
  - $1.4B and June 2006 completion
  - Target Systems is 60% complete
- Overall project design is 92% complete
  - Target Systems design is 100% complete

Technical Scope of Target Systems

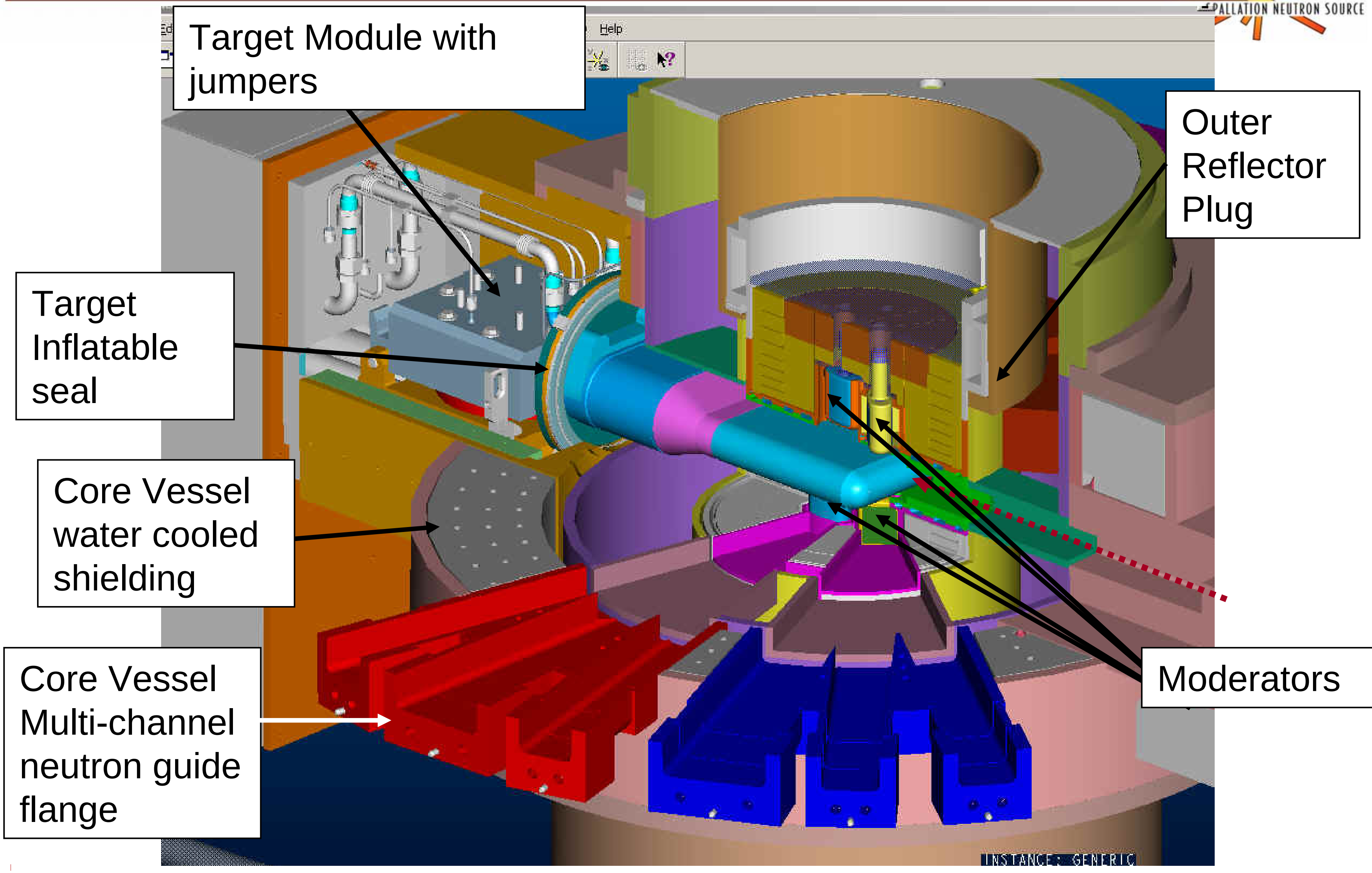
- Target
  - Mercury
  - Replaceable Vessel
- Moderator
  - Wing configuration
  - One ambient water
  - Three cryogenic supercritical H_2
- Reflector
  - Be
- Vessel Systems
  - Encloses components that need to be replaced routinely
- Target Systems Shielding
  - Steel
  - Vertical Shutters
- Target Systems Utilities
  - Heavy & light water
  - He and vacuum
- Remote Handling Systems
  - Target module
  - Mercury process equipment
  - Reflector/moderator plugs
  - Proton beam window
  - Shutters/Inserts
- Local I&C
- Beam Dumps
  - LINAC dump
  - Ring injection dump
  - Ring extraction dump
- Neutronics and shielding analysis for entire SNS complex

The Hg target, shielding, and maintenance systems will be a Nuclear Facility that must be designed in accordance with appropriate safety requirements

Global View Of The SNS Target and Scientific Instrument Station



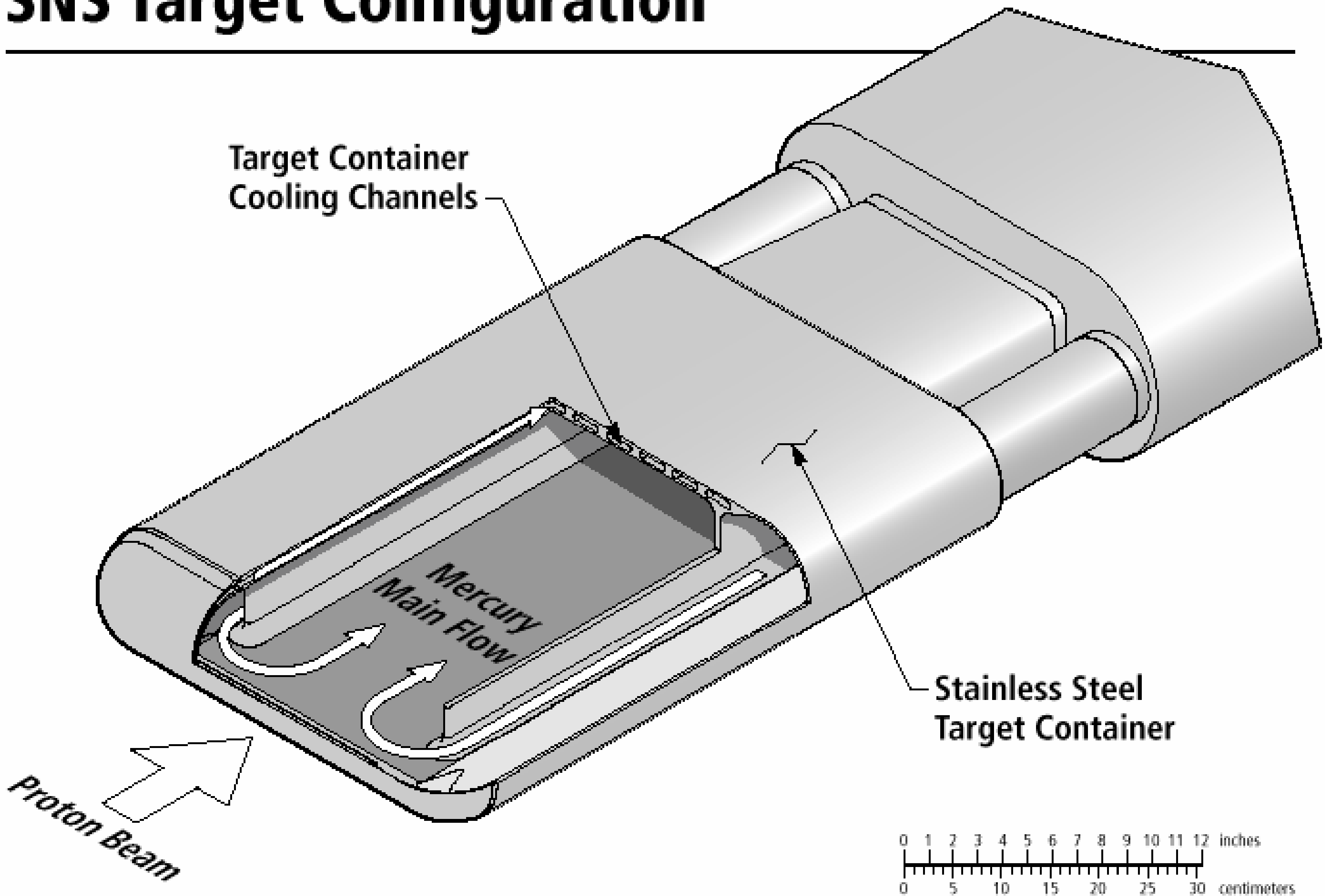
Target Region Within Core Vessel



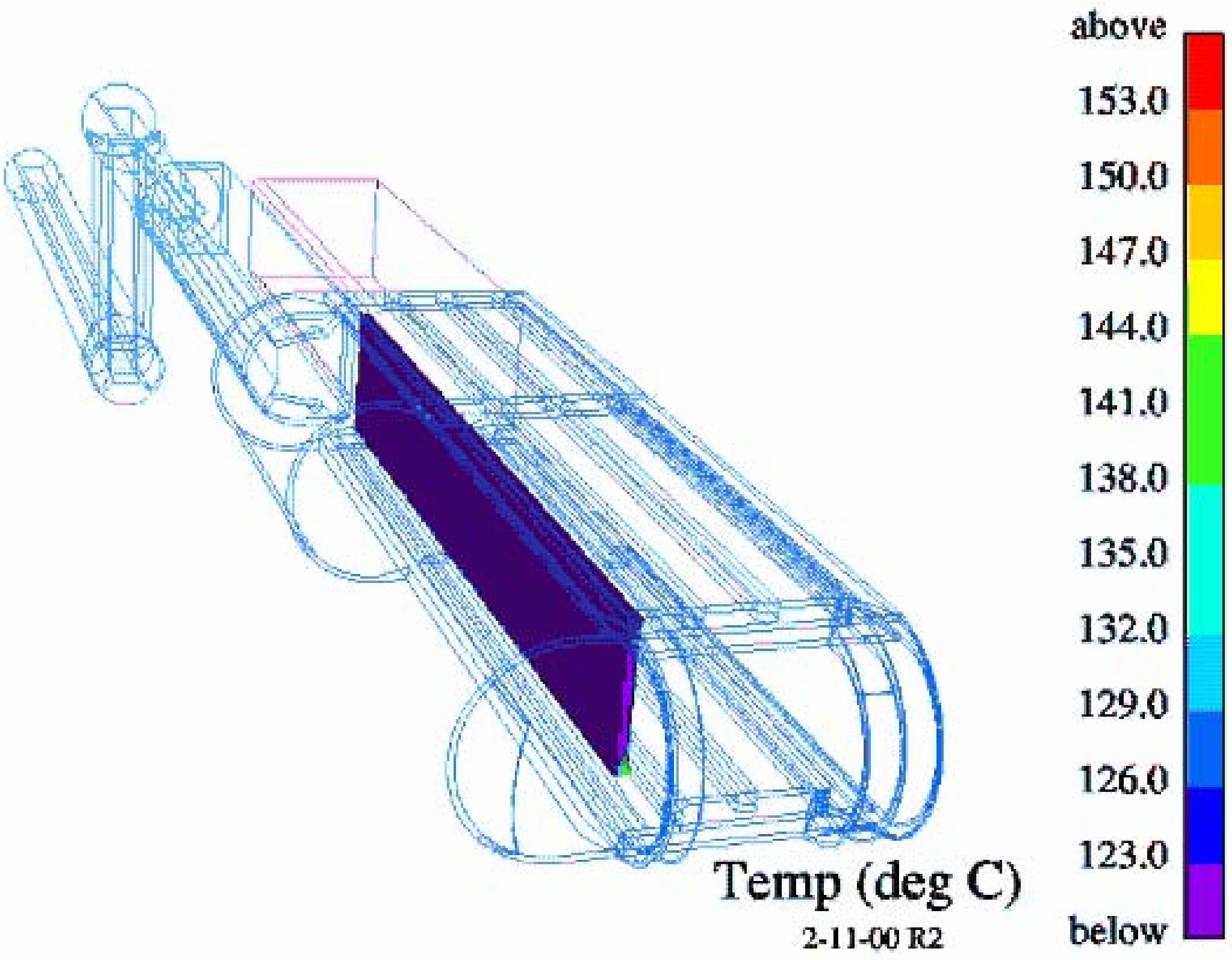
Target Systems Installation Has Started

- Equipment installation occurs while the building is being constructed
- Major components have been installed
  - Base plate
  - Outer liner
  - Inner and outer support cylinders
  - Drain tanks and Bulk shield liner drain line
  - Shield blocks

SNS Target Configuration



CFD Results Predict Recirculation Zone Near Flow Baffles



Mercury Loop Parameters @ 2 MW

• Power absorbed in Hg	1.2 MW
• Nominal Operating Pressure	0.3 MPa (45 psi)
• Flow Rate	340 kg/s
• Vmax (In Window)	3.5 m/s
• Temperature	
– Inlet to target	60ºC
– Exit from target	90ºC
• Total Hg Inventory	1.4 m^3 (20 tons)
• Pump Power	30 kW
• Reynolds Number	1.4×10^6 bulk flow
• Pr	0.014

SNS Hg Target operates at low temperature and pressure

Target R&D Program Has Addressed Key Design and Operational Issues

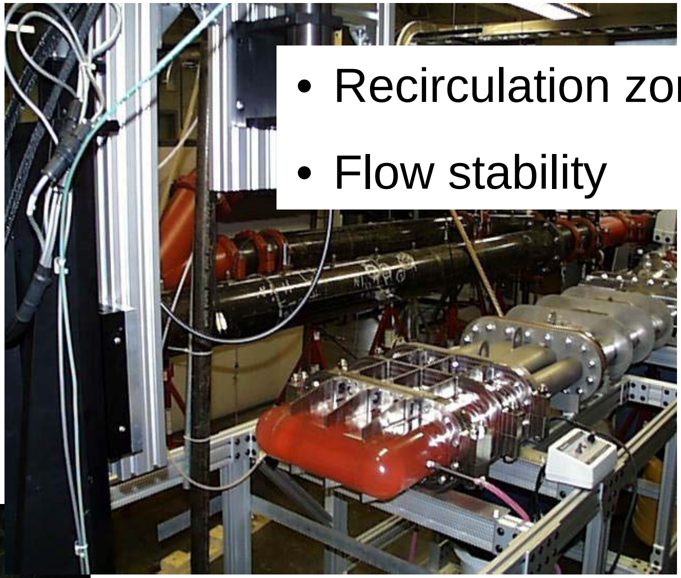
- Steady state power handling
  - Cooling of target/enclosure window - wettability
  - Hot spots in Hg caused by recirculation around flow baffles
- Thermal Shock
  - Pressure pulse loads on structural material
  - Cavitation induced erosion (so-called pitting issue)
- Materials issues
  - Radiation damage to structural materials
  - Compatibility between Hg and other target system materials
- Demonstration of key systems:
  - Mercury loop operation
  - Remote handling

Three Thermal-Hydraulic Loops Were Constructed to Develop the Mercury Target

Mercury Thermal Hydraulic Loop (MTHL)

- Wettability
- Design data for target window
- Corrosion/erosion test

Water Thermal Hydraulic Loop (WTHL)



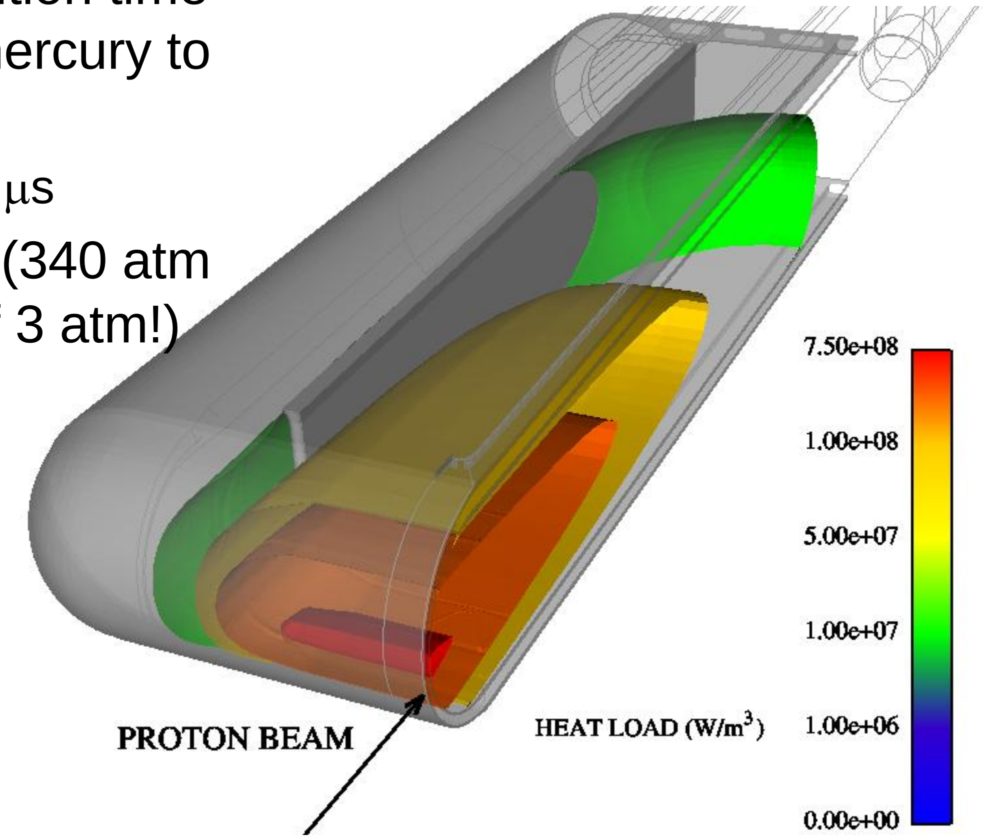
- Recirculation zone
- Flow stability

Target Test Facility (TTF)

- Full-scale loop
- Final CFD benchmark
- Verify Hg process equipment
- Operational experience

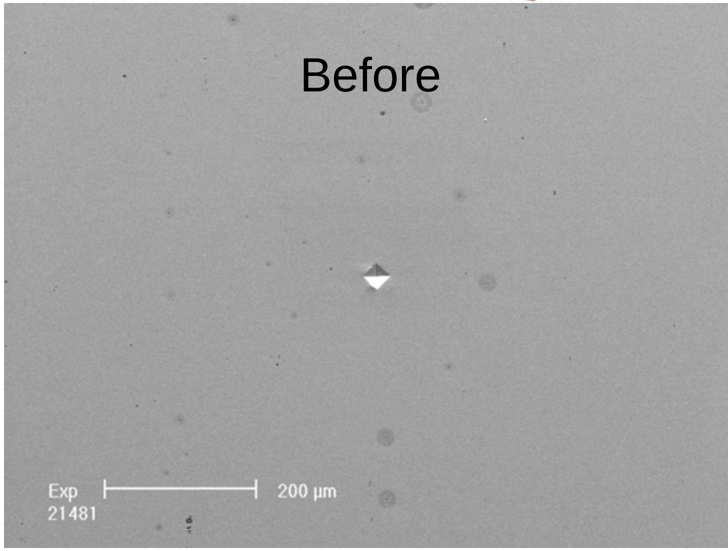
Rapid heating process leads to large pressure pulse in mercury

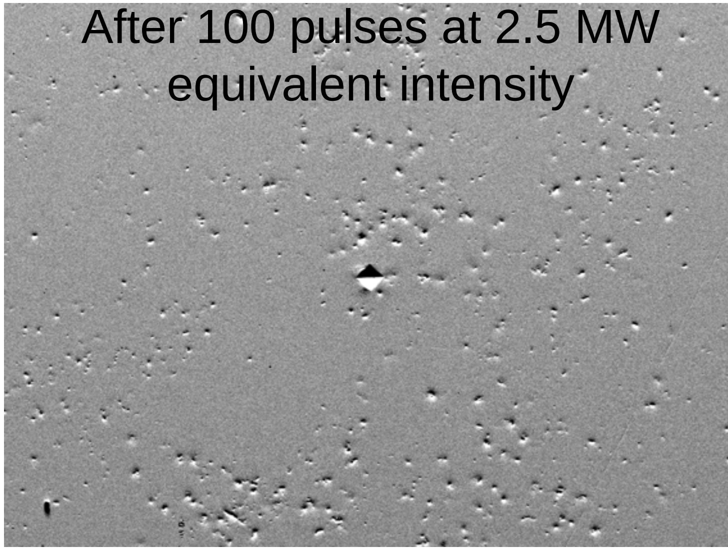
- Peak energy deposition in Hg for a single pulse = 13 MJ/m^3
  - Peak temperature rise is only ~ 10 K for a single pulse, but rate of rise is 14 x 10^6 K/s!
- This is an isochoric (constant volume) process because beam deposition time (0.7 μs) << time required for mercury to expand
  - Beam size/sound speed ~ 33 μs
- Local pressure rise is 34 MPa (340 atm compared to static pressure of 3 atm!)



Cavitation Bubble Collapse Leads to Pitting Damage

- Large tensile pressures occur due to reflections of initial compression waves from steel/air interface.
  - These tensile pressures break (cavitate) the mercury.
  - Damage is caused by violent collapse of cavitation bubbles under subsequent interaction with large compression waves.
- A series of tests were conducted at LANLs WNR facility to examine sensitivity of pitting damage to various parameters, materials, and mitigation schemes
  - 100 - 1,000 pulses
  - Stagnant Hg inside closed targets
  - Examined highly polished surfaces before and after irradiation to quantify damage
- Extrapolation to > 10^8 pulses performed using off-line pressure pulse tests





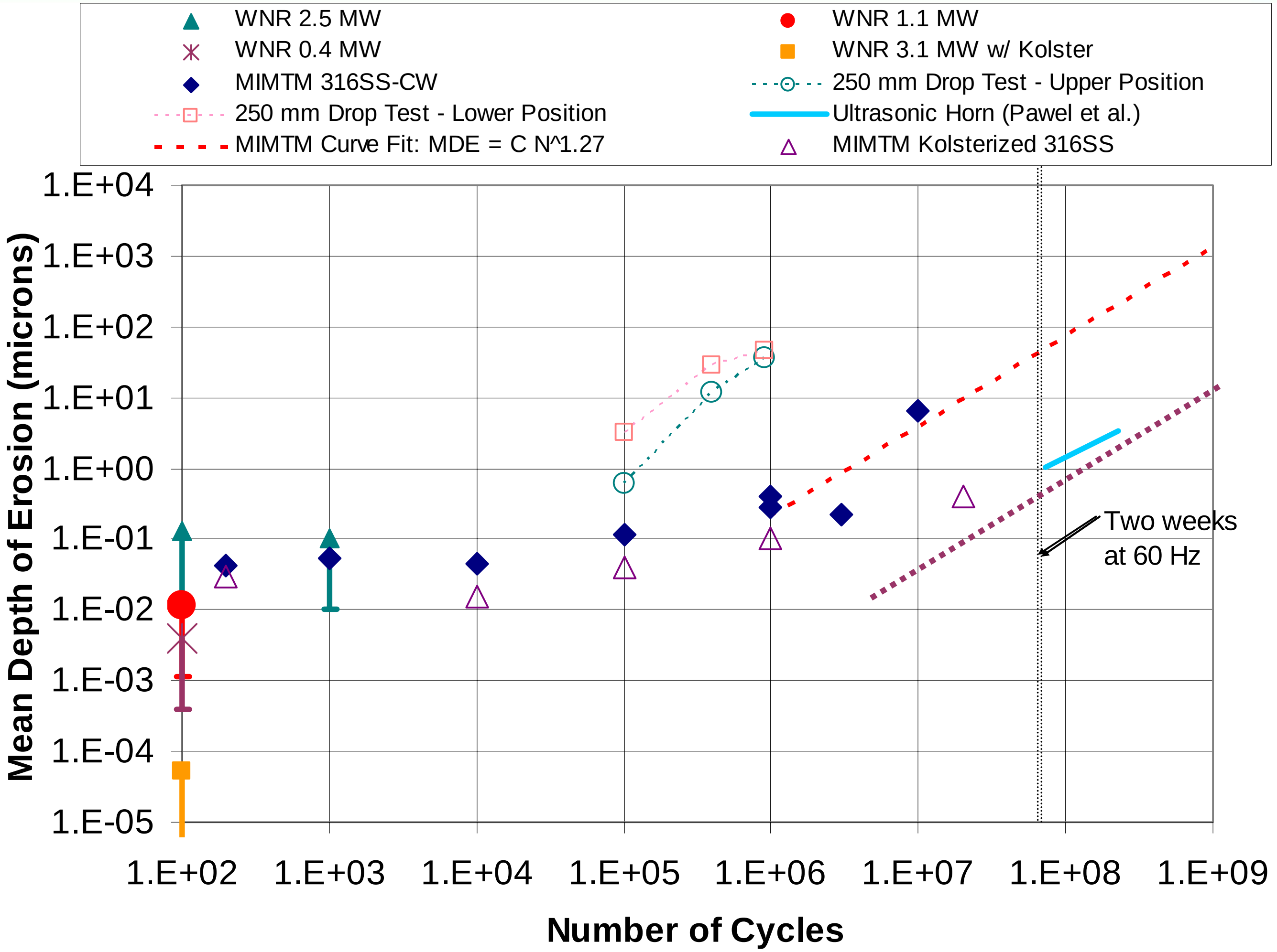
Summary of WNR Pitting Tests

- Several test cases showed significantly reduced erosion on the front wall specimen.

Feature	Normalized Erosion*
Gas layer near surface	0.06
Bubble Injection	0.25
Kolsterized surface	0.0008
1/2 Reference Power	0.09

* Erosion relative to reference (2.5 MW) case

Summary of Pitting Erosion Tests



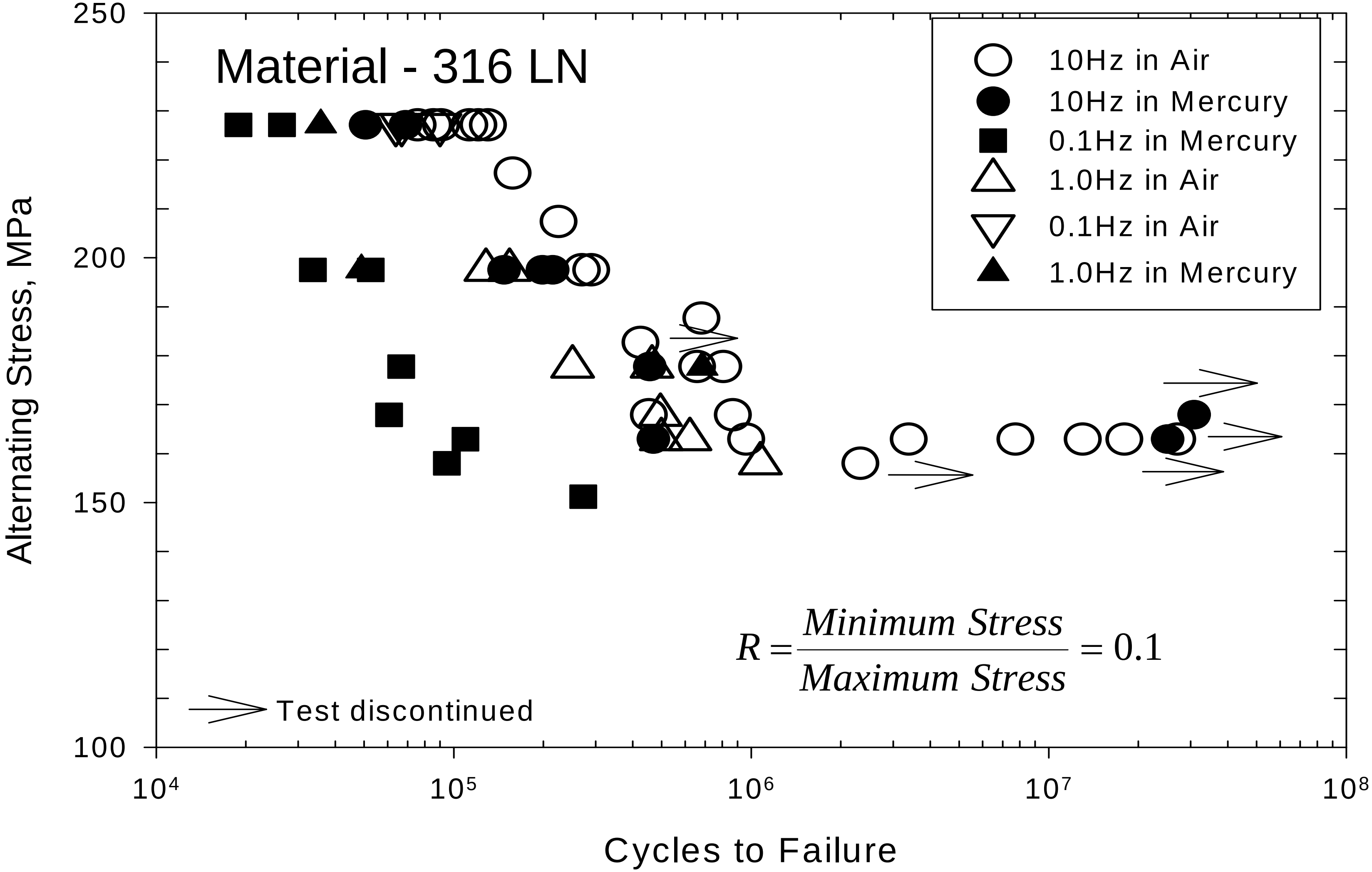
Using this data, the estimated Mean Depth of Erosion at 1 MW for 2 weeks < 50 μm.

This is judged to be acceptable, but improvements must be pursued.

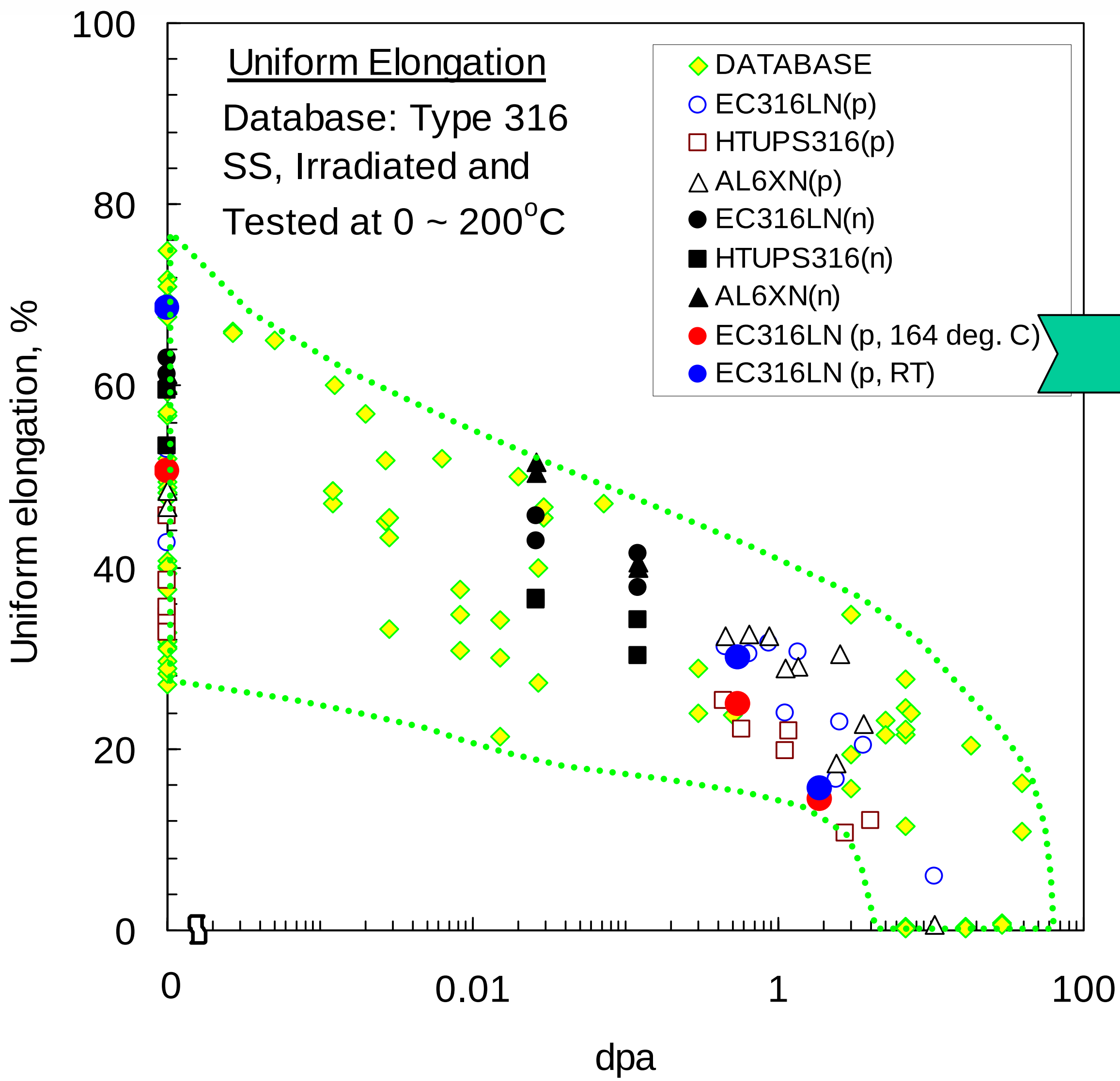
High Power Target Development Plans

- Plans are integrated with Japanese and European collaborators
- Examine irradiation damage resistance of Kolsterised layer
  - Measure hardness of specimens irradiated to ~ 1 dpa on HFIR
- Perform bubble injection tests on TTF in collaboration with ESS team and Univ of Tennessee (Fall 2003)
  - Measure bubble lifetime, saturation level, and pressure pulse attenuation
  - Examine performance of Hg loop with bubbles
- Perform in-beam tests with flowing Hg and bubble injection
  - Fabricate and test Hg loop in FY2004; perform in-beam tests in FY2005
    - Measure strain and pitting attenuation

Load Frequency and Mercury Contact Do Not Affect Fatigue Endurance Limits



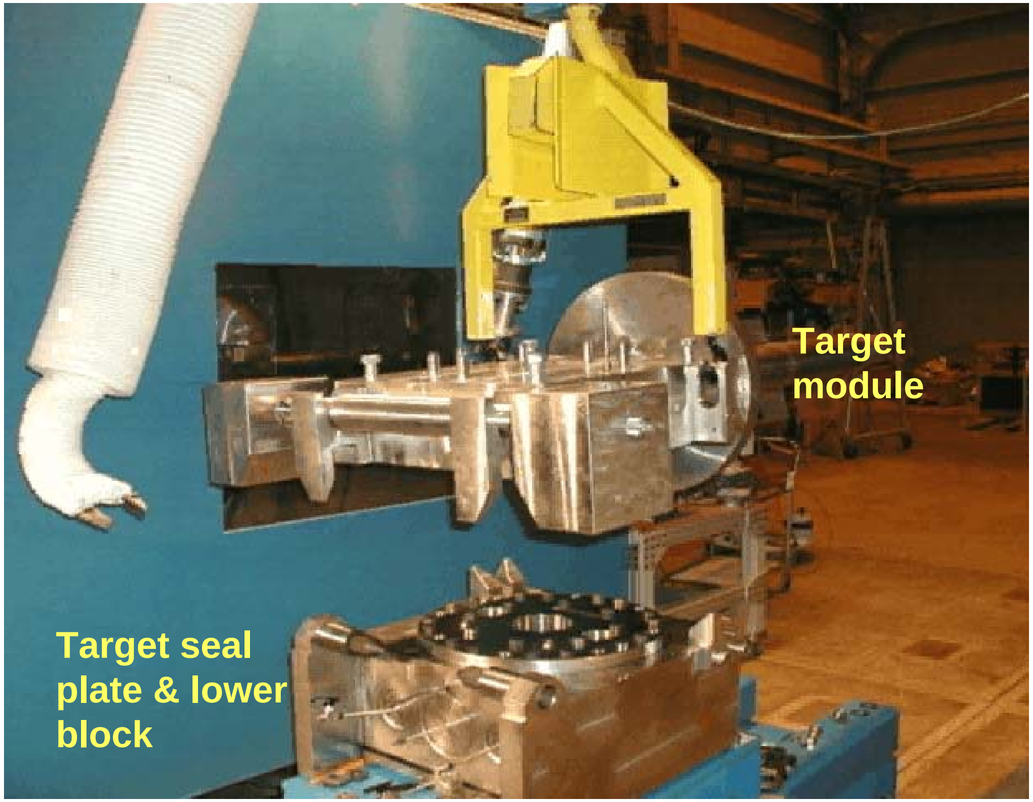
Tensile Data for Spallation Conditions Fall within the Range of Reactor Database



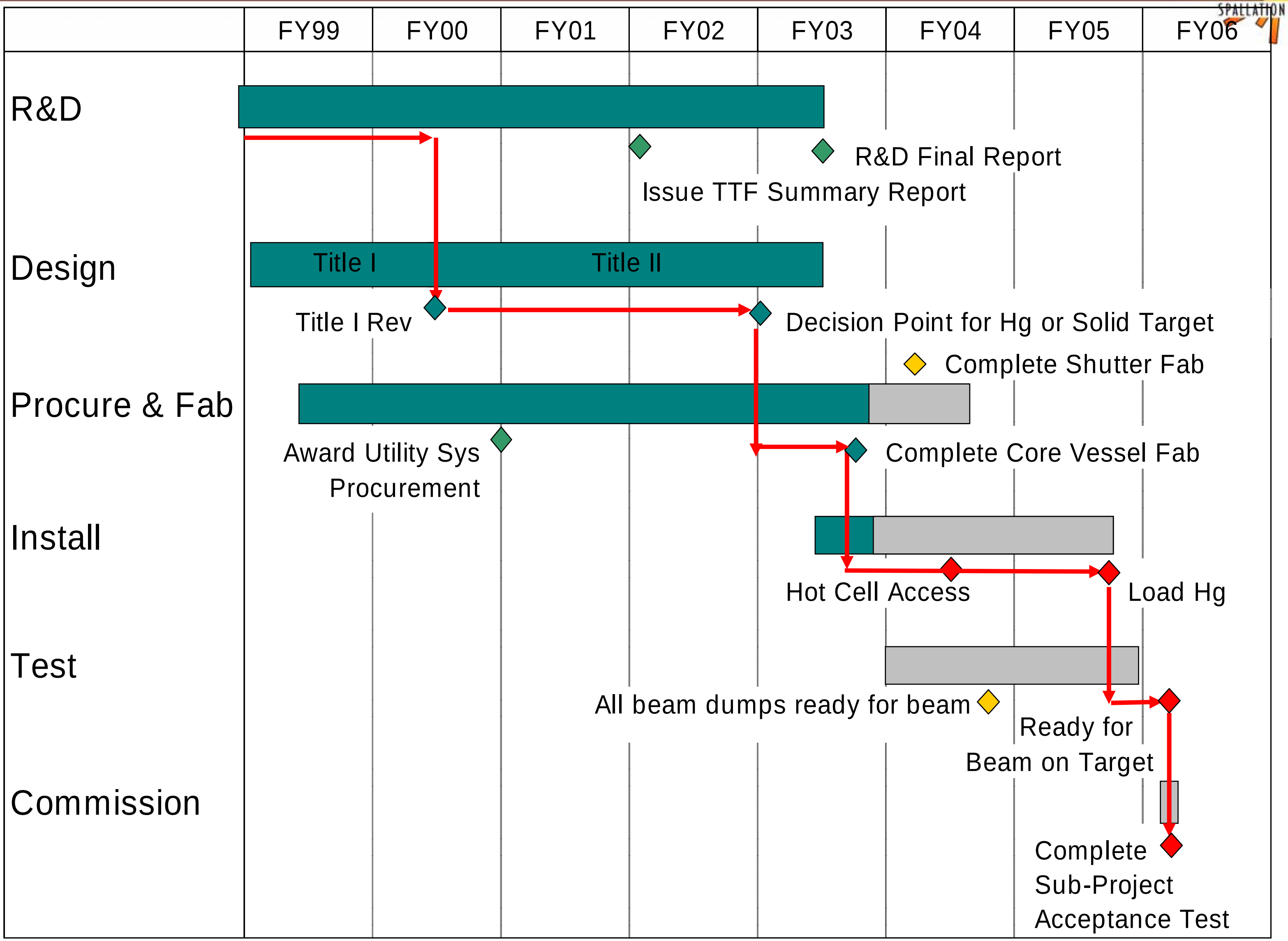
Data from LANSCE-irradiated specimens

Remote Handling Demonstration Tests Drove Design Improvements

- Target module handling procedure successfully demonstrated.
  - Used to check-out remote handling tools, handling fixtures, hot cell crane, and manipulators
  - Many design revisions to enable or simplify remote handling implemented based on results of mock-up tests



Target Systems' Schedule



Concluding Remarks

- SNS Target Systems Design and R&D efforts are complete
  - Verified Hg “wettability” and flow stability
  - Gained operational experience with prototypical loop and equipment; avoided mistakes on SNS (leaky valves, cavitation, …)
  - Most critical remote handling issues addressed by constructing mockups and performing tests
  - Materials irradiation and compatibility issues addressed in separate tests
    - Combined effects of irradiation with mercury and stress remain uncertain
  - Considerable progress has been made on the pitting issue, however significant uncertainties and associated risks remain
    - Further R&D and target design efforts are underway within the framework of an international collaboration
- SNS Target Systems installation has commenced