The SNS Mercury Target

B. W. Riemer
Engineering Specialist, Target Systems

CARE Annual Meeting / BENE Workshop

DESY Hamburg, Germany

November 3, 2004

The Spallation Neutron Source

- **World's most powerful neutron science facility for studying the structure and functionality of materials.**
- **$1.4B DOE Project.**
- **October 1999–June 2006.**
- **Short pulsed proton beam from Linac/Ring creates neutrons by spallation reaction with mercury target.**

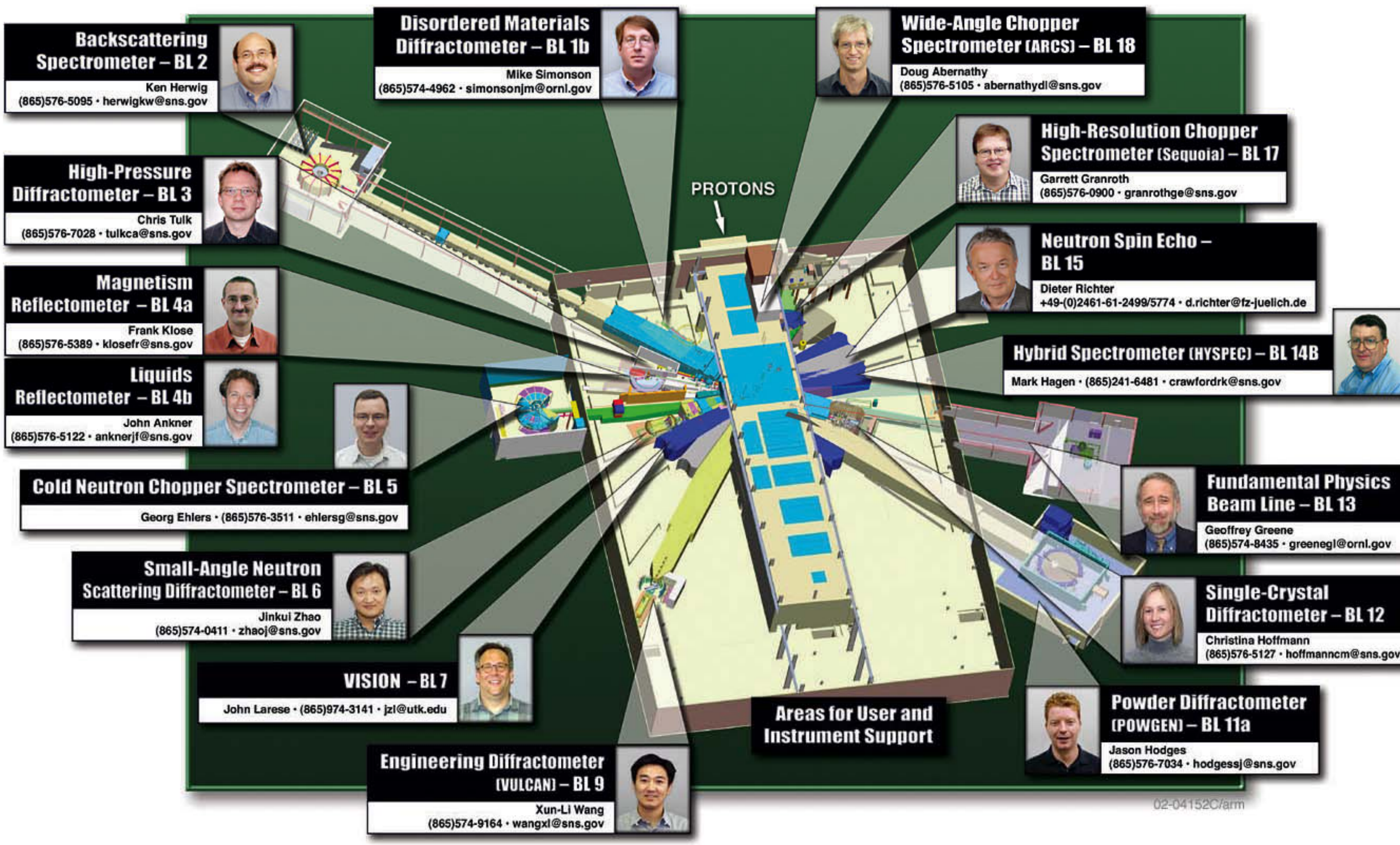
- **Partnership of six laboratories under direction of the ORNL SNS Project Office (LBL, LANL, JLAB, BNL, ORNL, and ANL).**

SNS Basic Parameters List

• Beam power	>1 MW
• Beam energy	~1 GeV
• Pulse rate	60 hertz
• Pulse length	<1 μs
• Energy per pulse	>17 kJ
• Target/Instrument building	1
• Max. number of neutron scattering instruments	24

16 Instruments Now Formally Approved

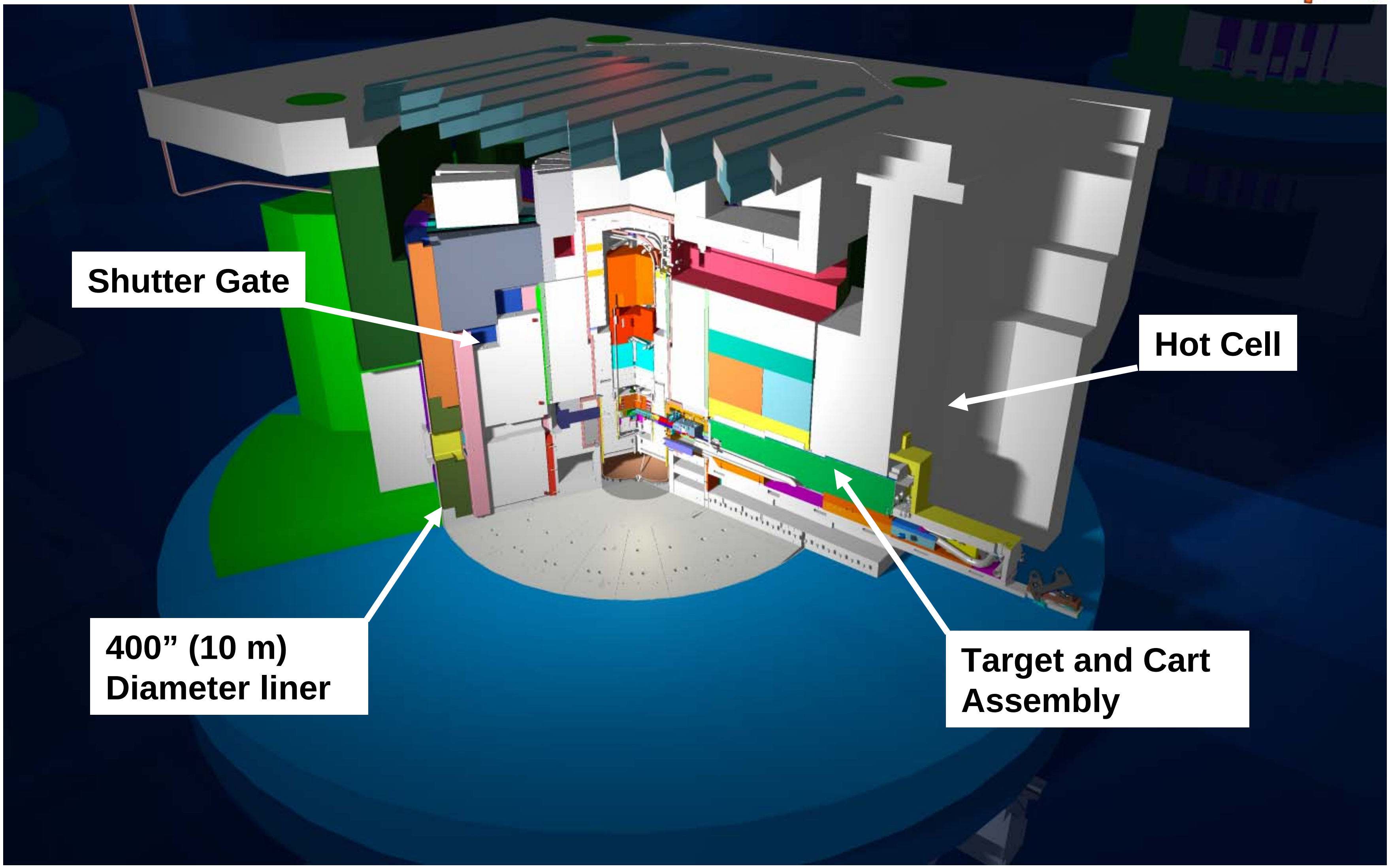
SNS
SPALLATION NEUTRON SOURCE



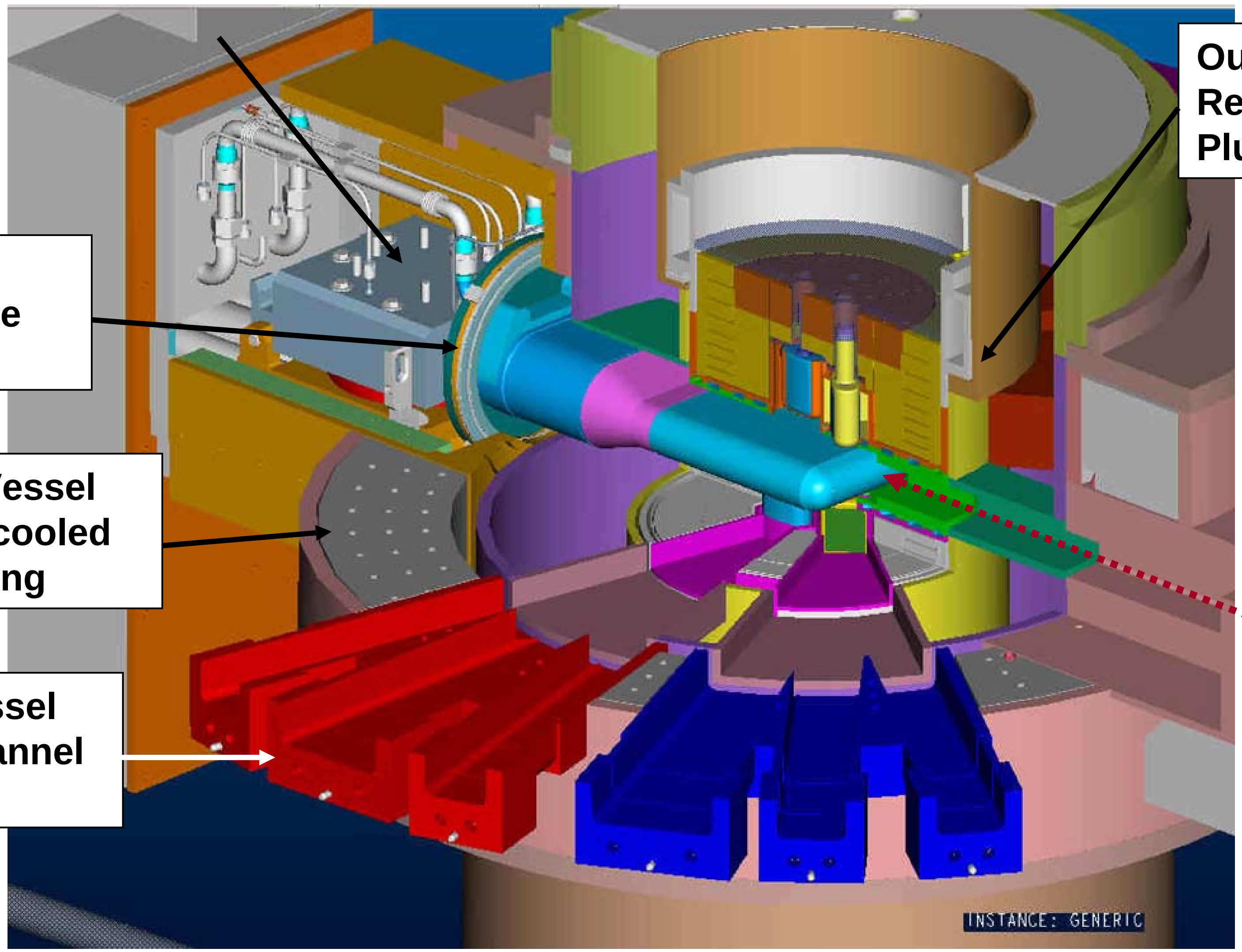
Central Lab Office & Target Building

November 3, 2004

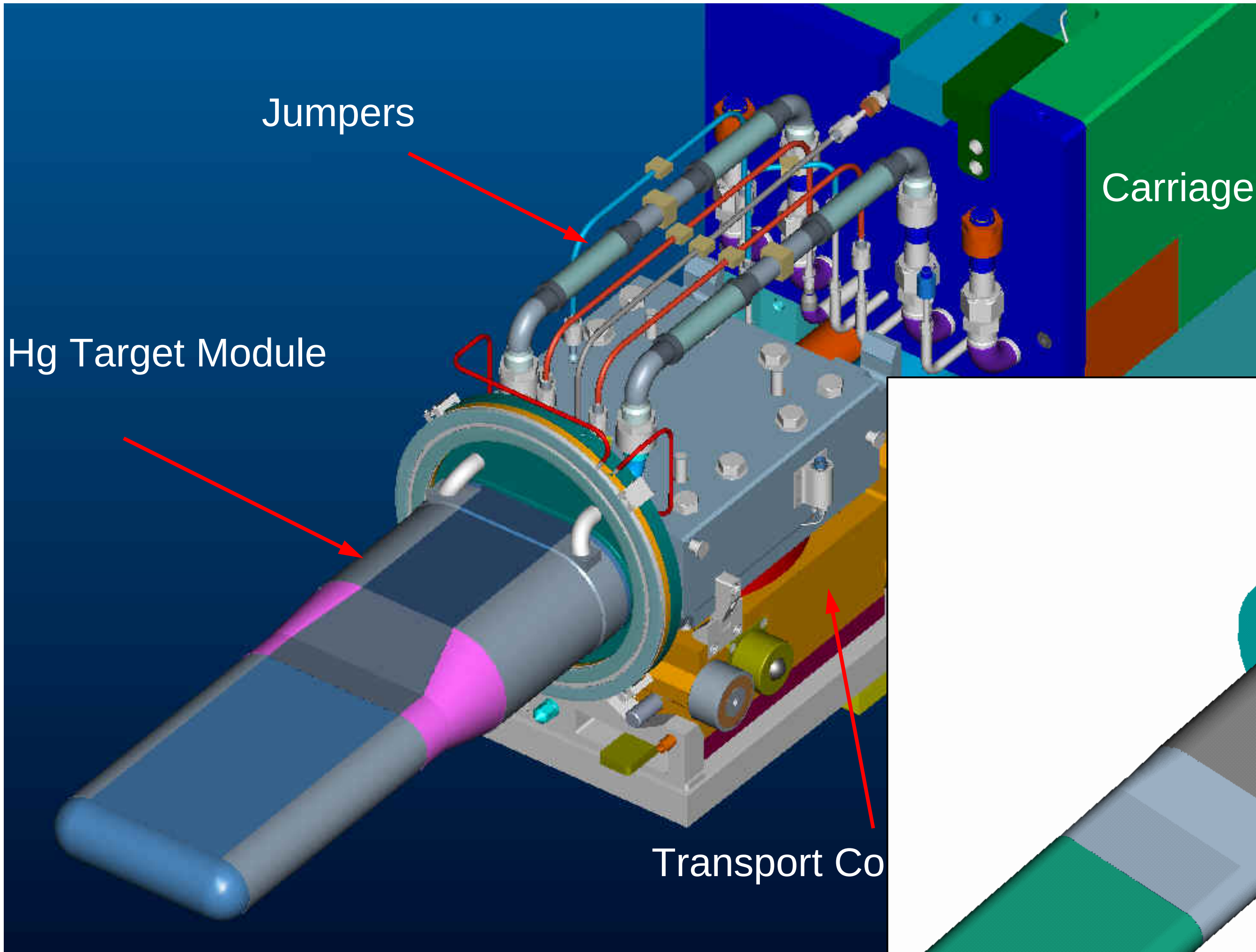
Target Monolith 3-D Model

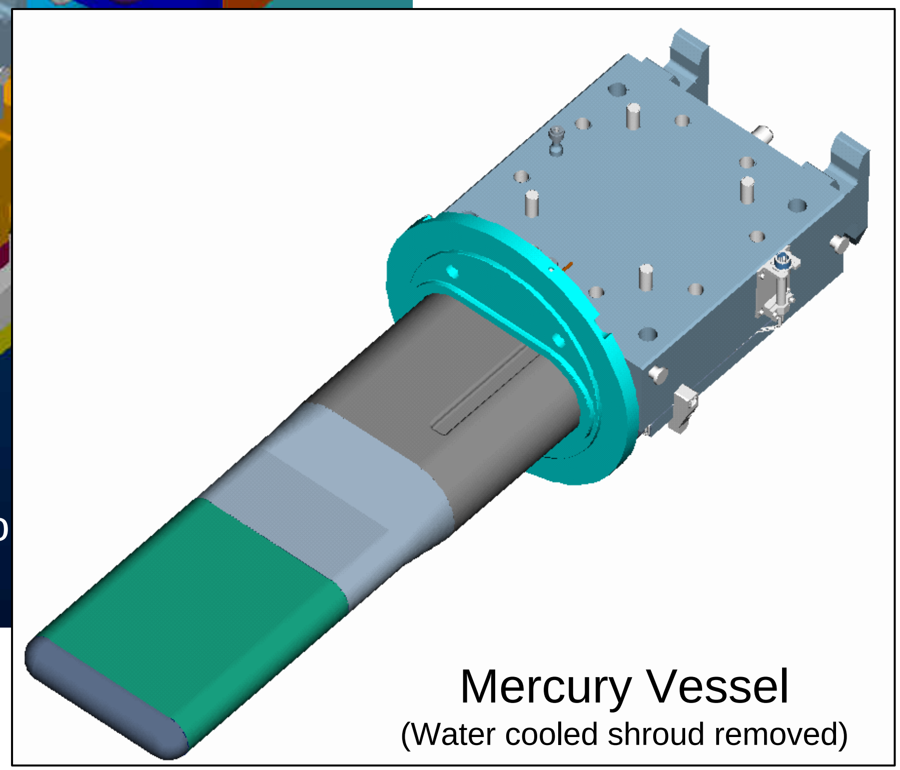


Target Region Within Core Vessel

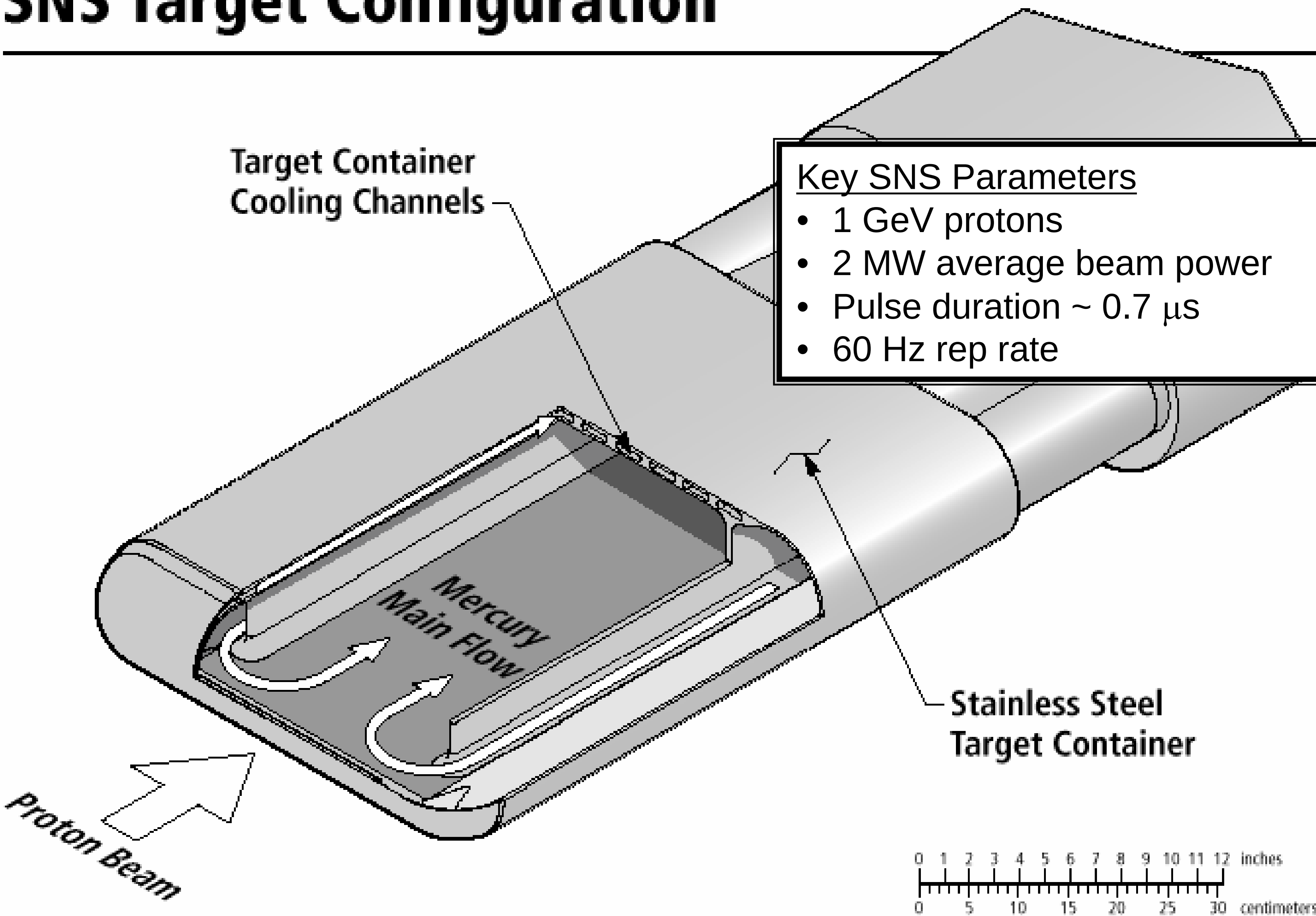


Mercury Target Module





SNS Target Configuration



<u>Key SNS Parameters</u>

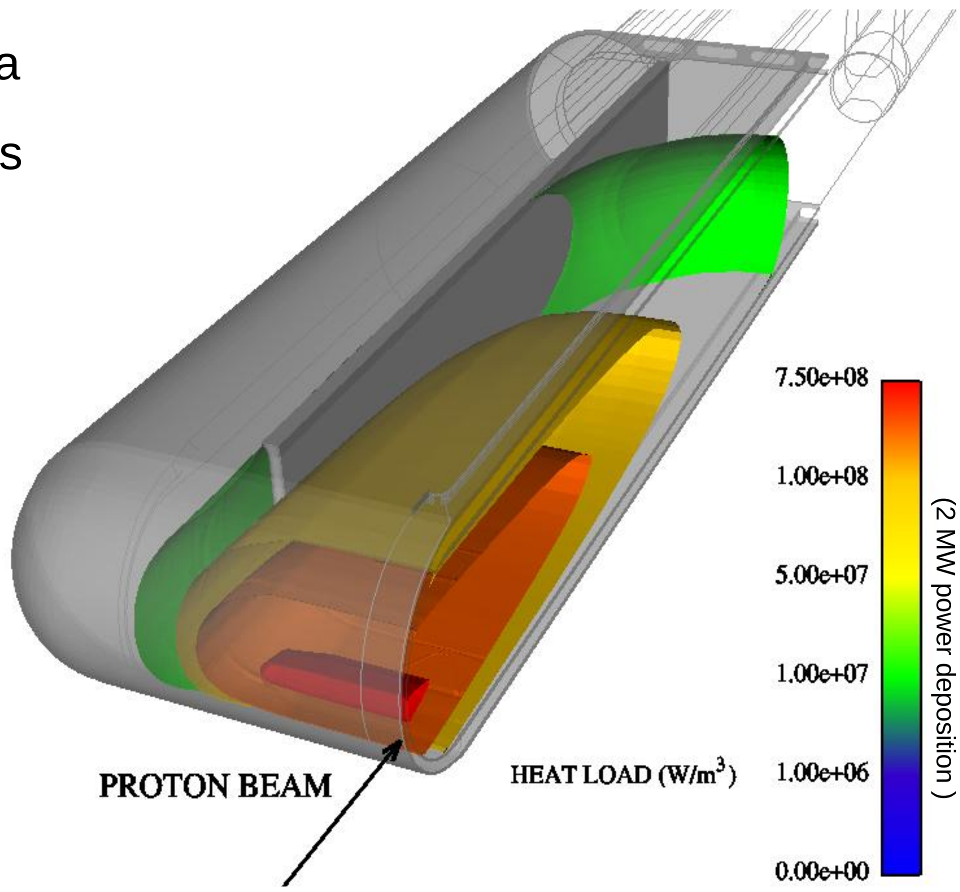
- 1 GeV protons
- 2 MW average beam power
- Pulse duration ~ 0.7 μs
- 60 Hz rep rate

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.

Mercury Loop Parameters @ 2 MW

- Power absorbed in Hg 1.1 MW
- Nom Op Pressure 0.3 MPa
- Flow Rate 340 kg/s
- V_{max} (In Window) 3.5 m/s
- Temperature
  - Inlet to target 60ºC
  - Exit from target 90ºC
- Total Hg Inventory 1.4 m^3
- Pump Power 30 kW

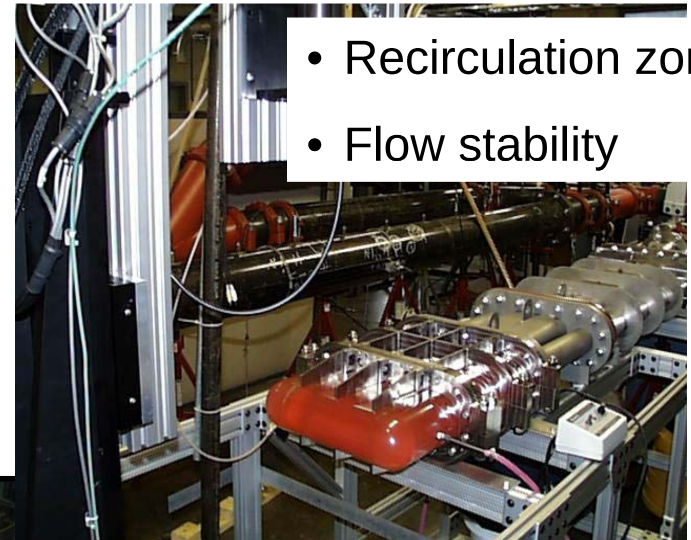


Three Thermal-Hydraulic Loops Were Constructed to Develop the Mercury Target

Mercury Thermal Hydraulic Loop (MTHL)

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

Water Thermal Hydraulic Loop (WTHL)

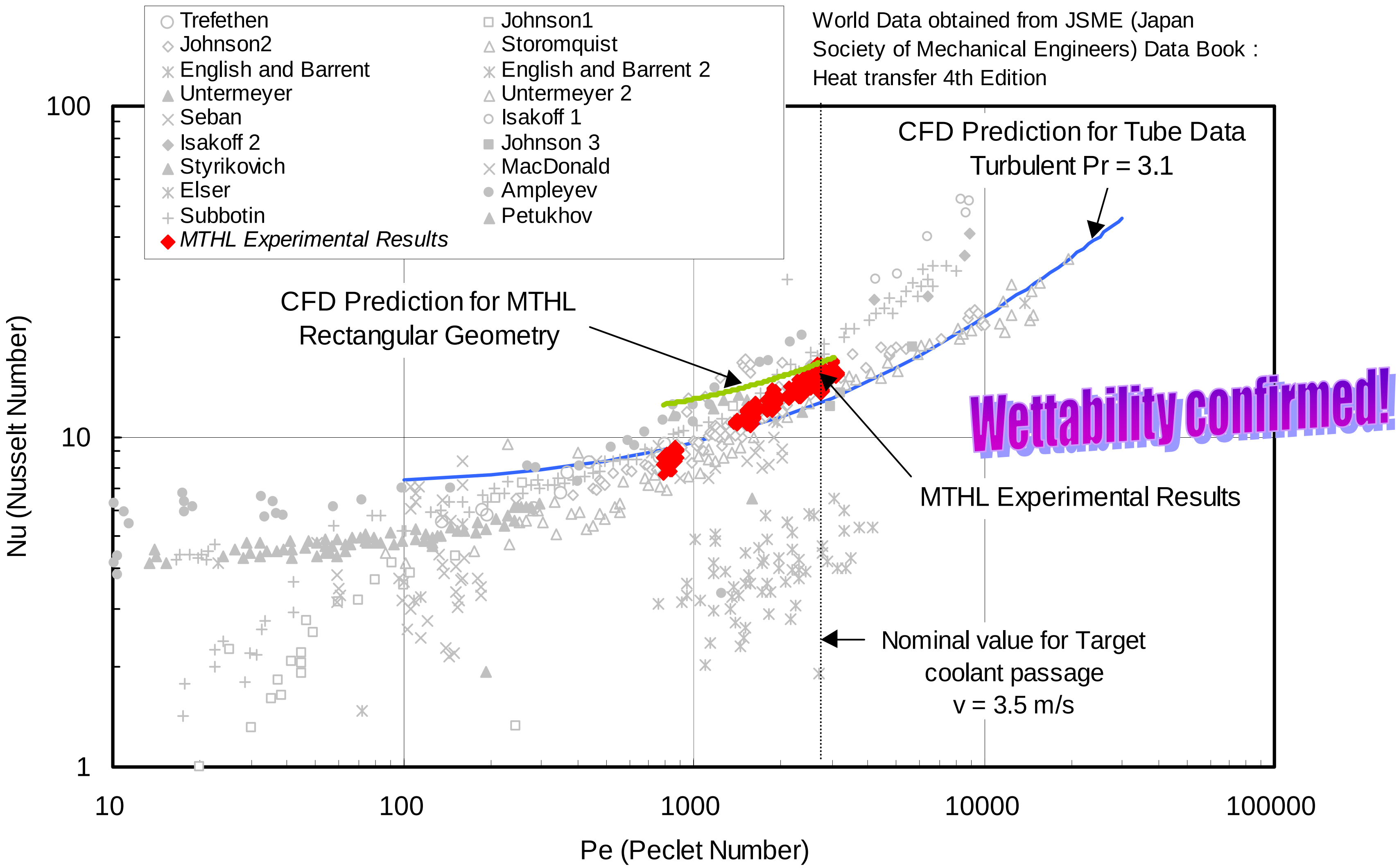


- Recirculation zone
- Flow stability

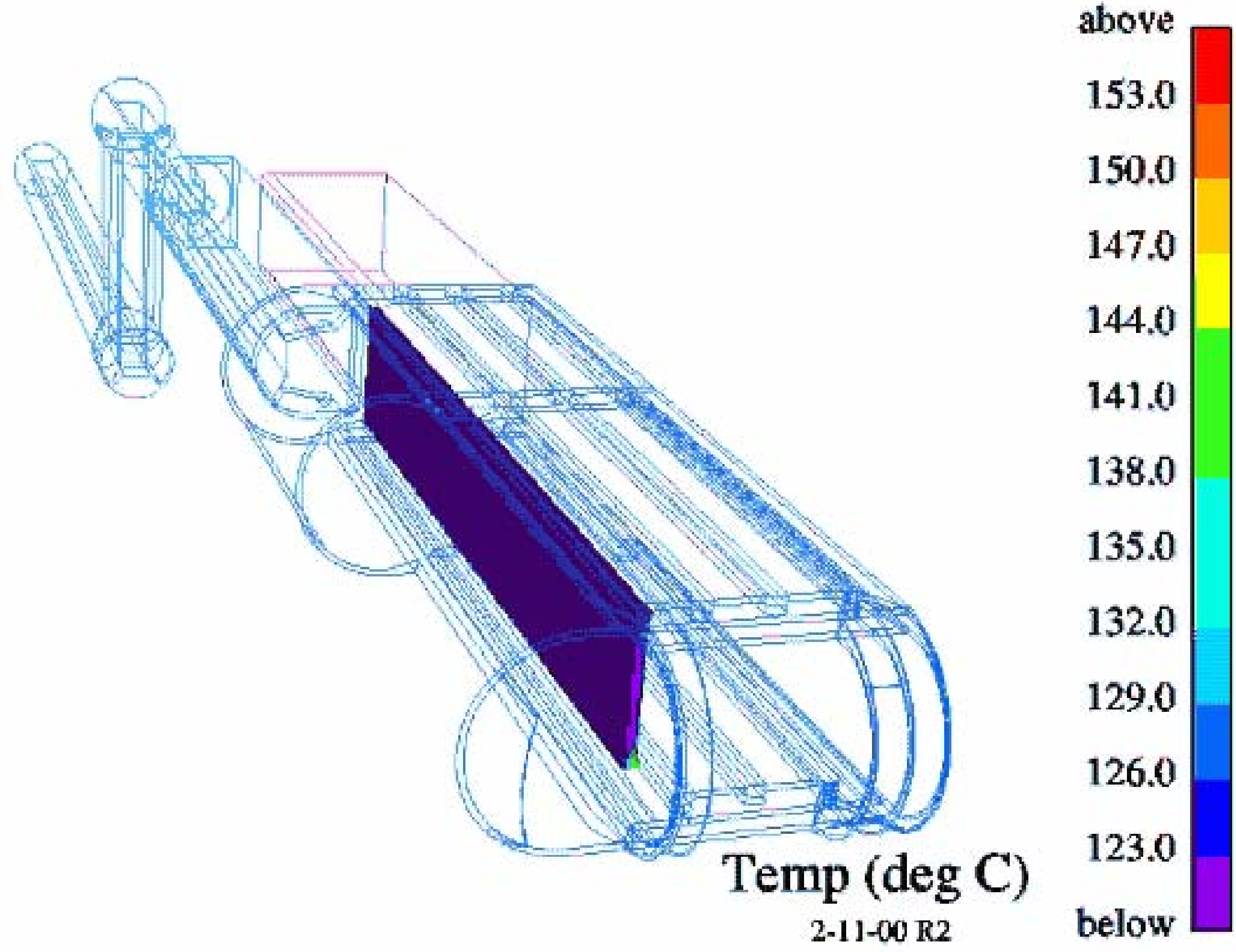
Target Test Facility (TTF)

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

Mercury Can Be Used to Cool the 316 LN Target Container

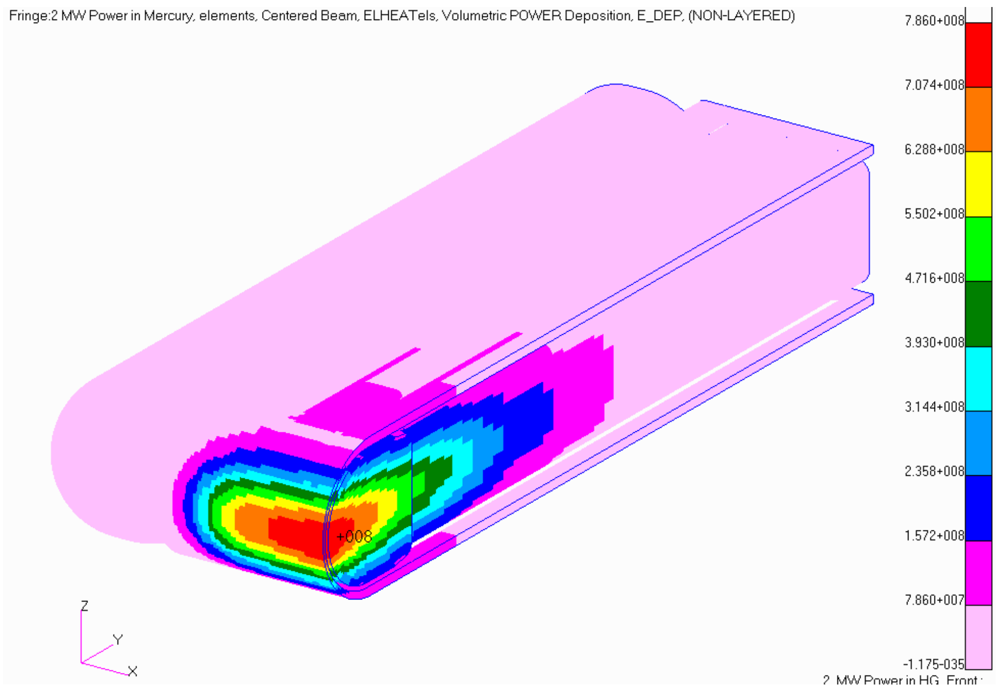


CFD Results Predict Recirculation Zone Near Flow Baffles



Constant Volume Heating Process Leads To Large Pressure Pulse In Mercury

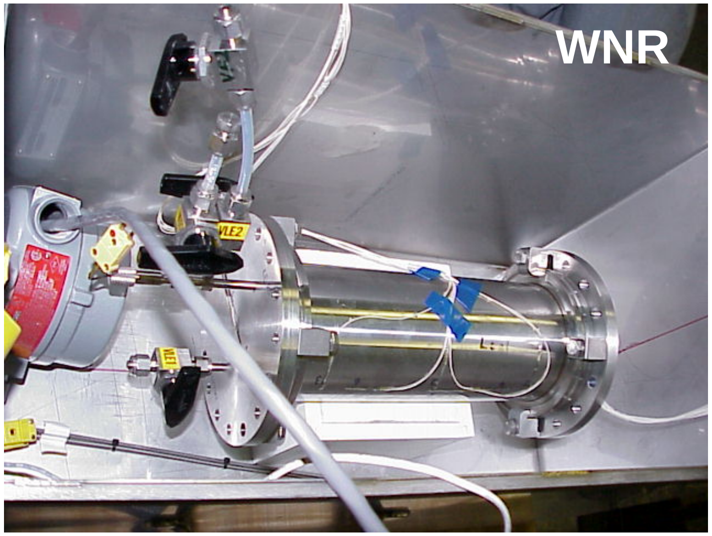
- **Peak energy deposition in Hg for a single 2 MW pulse = 13 MJ/m^3**
  - Peak temperature rise is only ~ 10 K, but rate is 14 x 10^6 K/s!
- **This is an isochoric (constant volume) process because beam deposition time (0.7 μs) << time required for mercury to expand.**
  - Beam size/sound speed ~ 33 μs.
- **Local pressure rise is 40 MPa (static pressure is only 0.3 MPa!).**



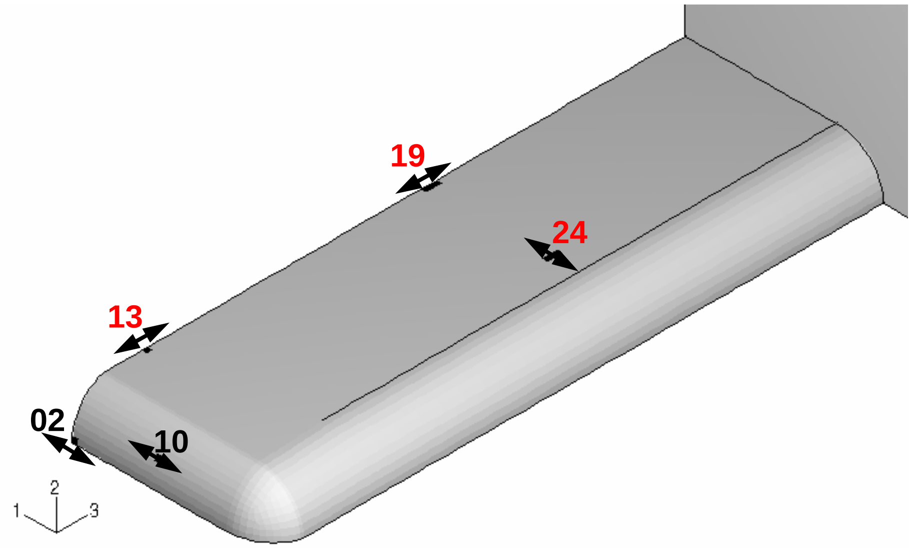
November 3, 2004

Pressure Pulse leads to mercury vessel stress that is difficult to simulate

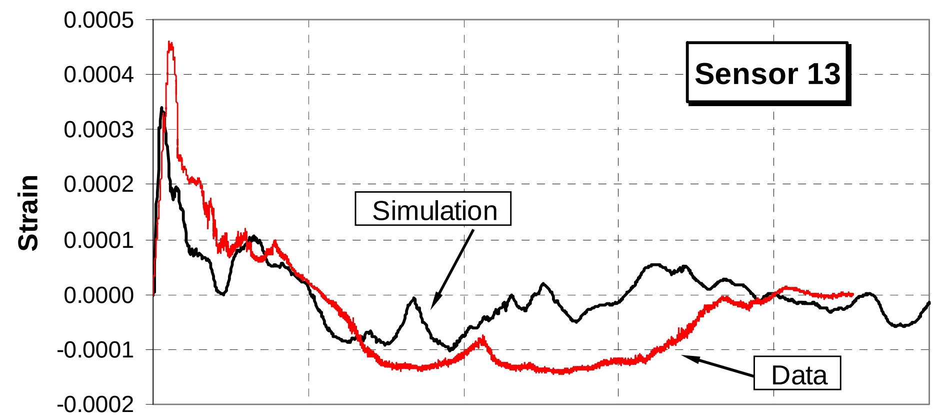
- Development of simulation technique for estimating dynamic response required experimental strain data.
- Fiber optic strain system works well in radiation environment.
- R&D programs have produced a body of strain data from mercury filled vessels responding to short pulse proton beams.

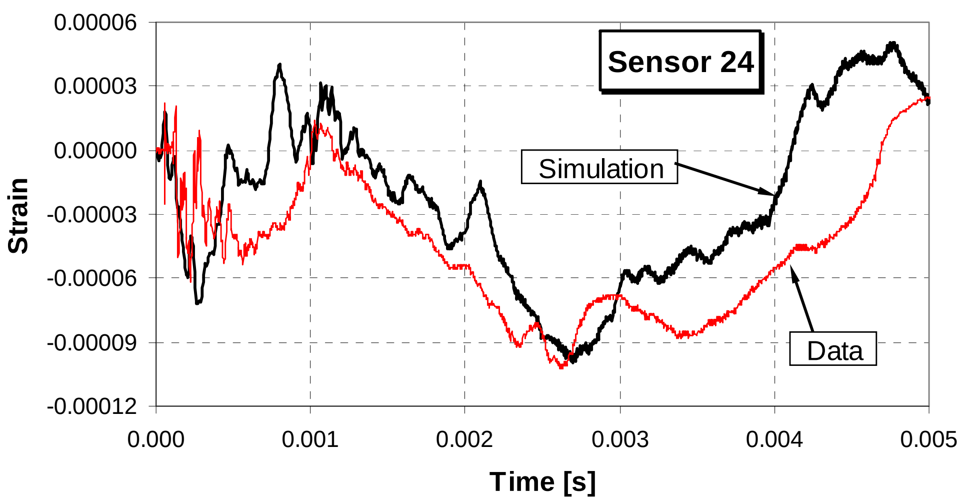


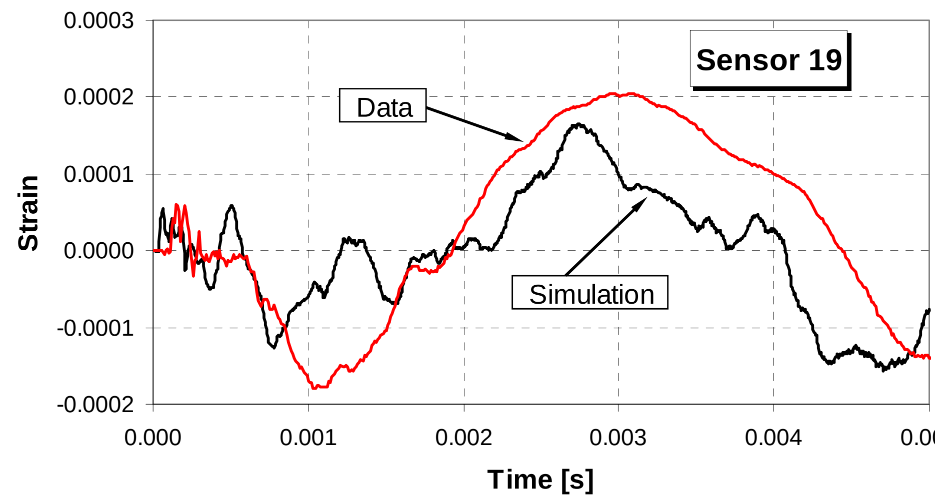
Successful benchmarking of simulation with experiment data



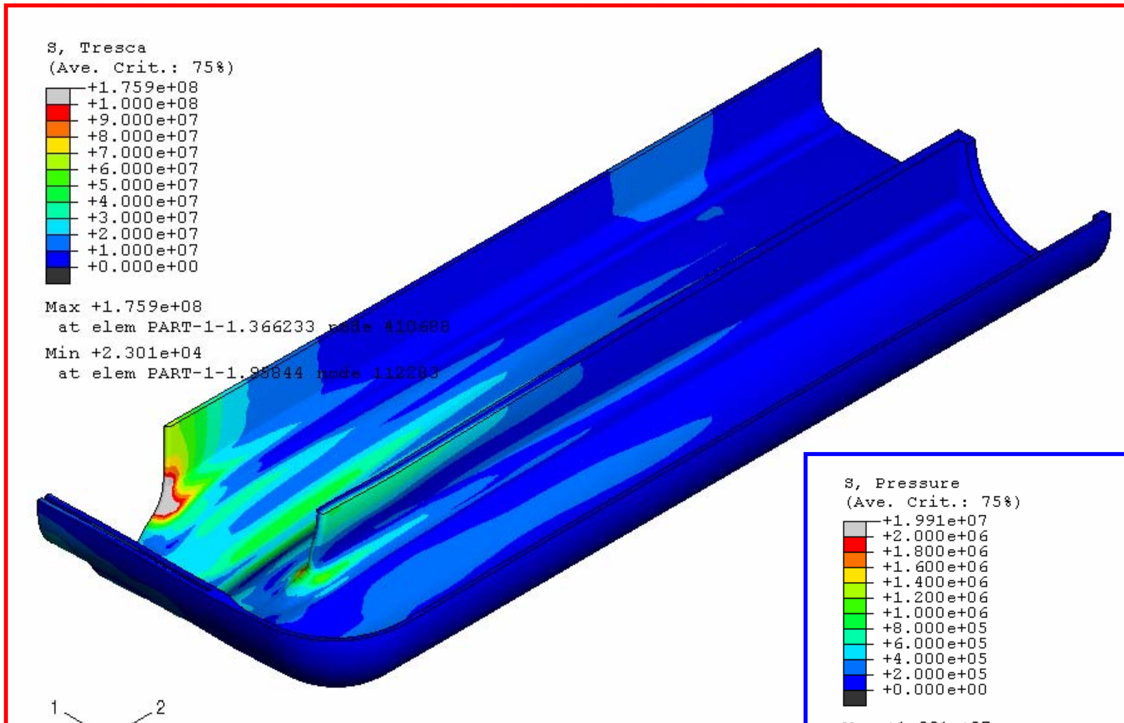
Body location sensors



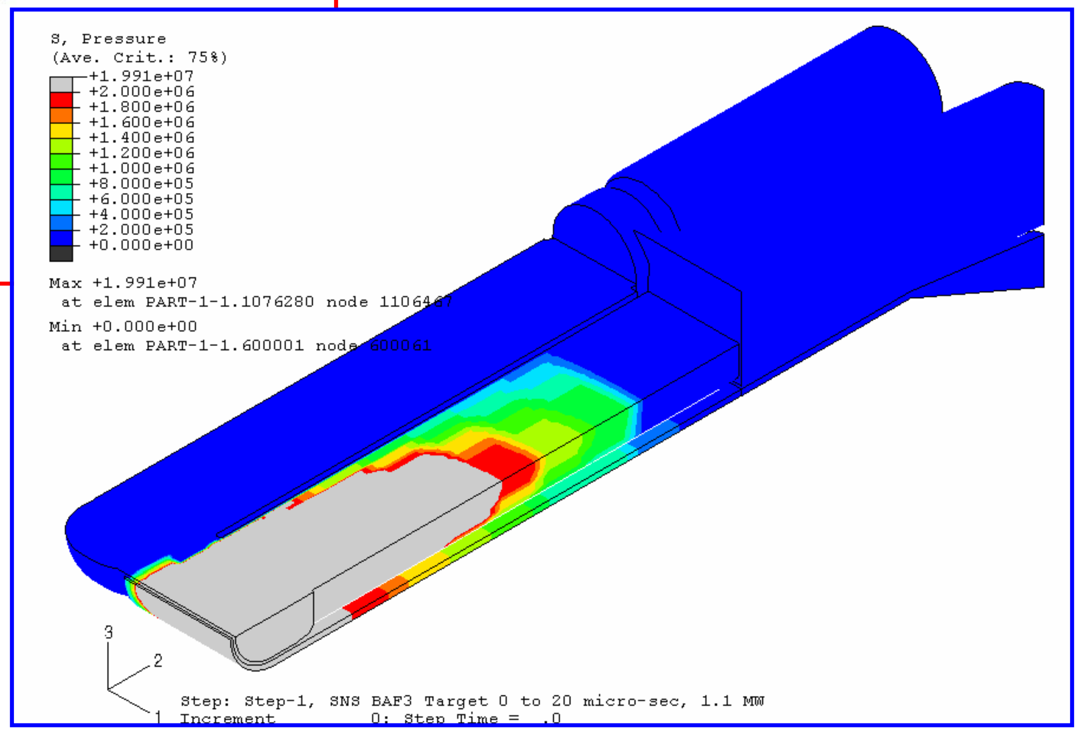




Response of SNS Target to 1 MW pulse



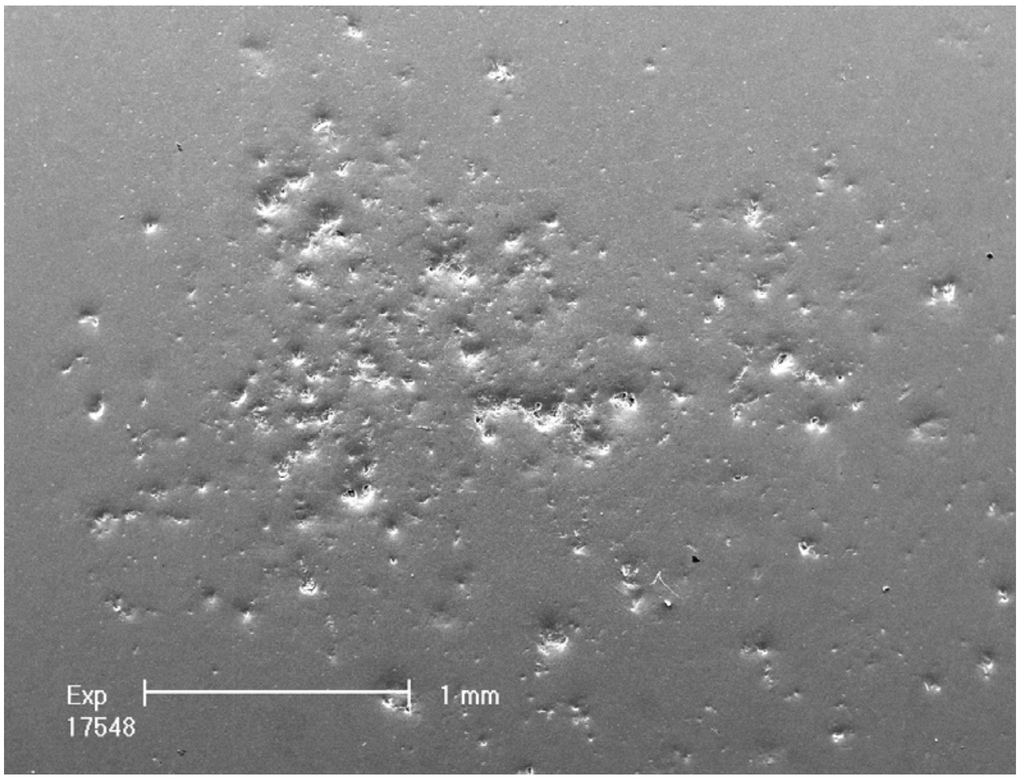
Vessel stress – ¼ section



Mercury pressure evolution includes cavitation

Cavitation Bubble Collapse Leads to Pitting Damage

- **Large tensile pressures occur due to reflections of 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.

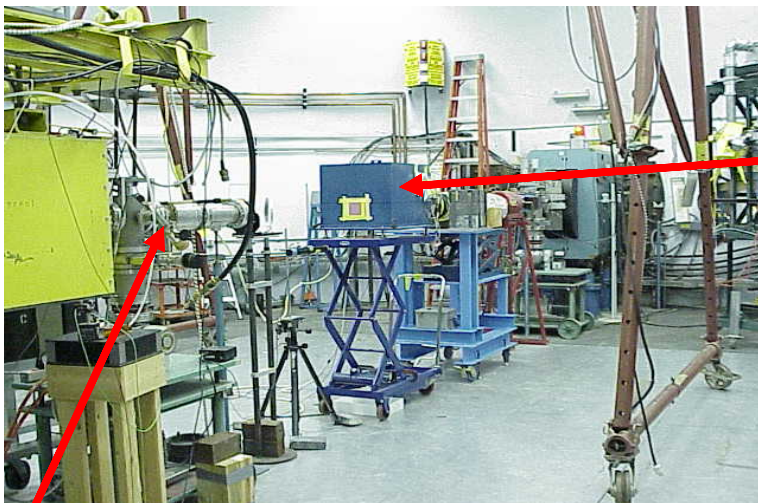


Damage in region with large pits for bare 316SS-LN diaphragm after July 2001 WNR tests.

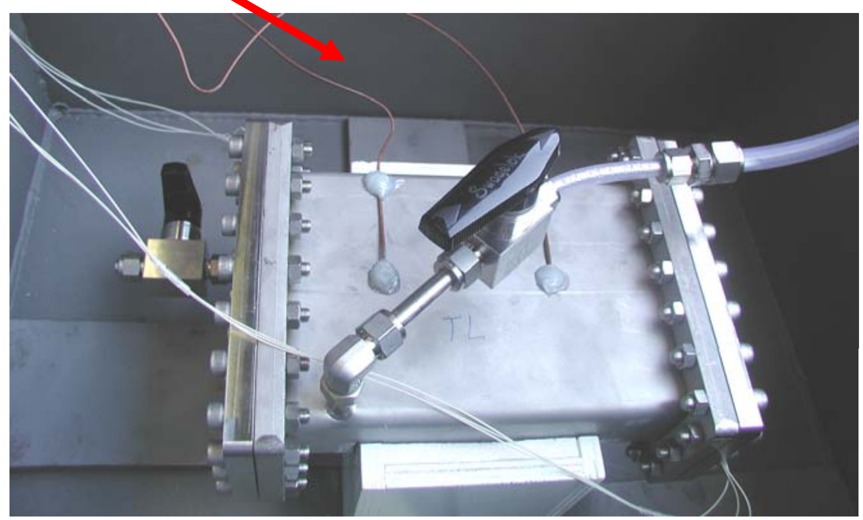
21 Targets Were Tested in the June-July 2002 Campaign at the WNR Facility

- **Most targets have rectangular cross-section.**
- **Many have plates at top or bottom to simulate slot in duplex structure.**
- **Base case uses CW 316SS test surfaces and 100 pulses.**

- Power dependence
- Bubble/gas layer mitigation tests
- Geometry effects
- Material variations
- Effect of number of cycles (1,000)



Secondary container

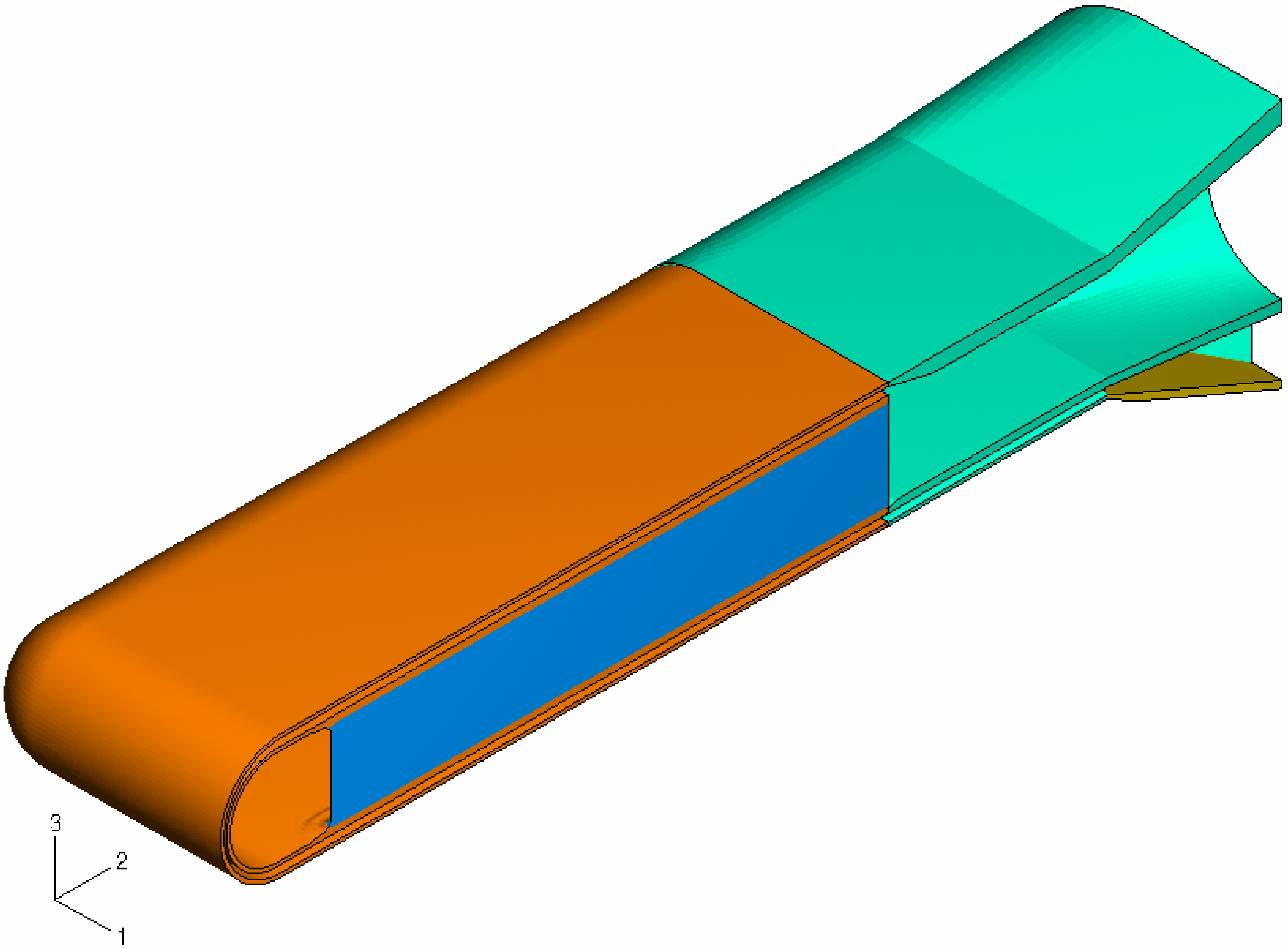


800 MeV proton beam duct

Remote Handling Demonstration Tests Are Driving Design Improvements

- **Target module handling procedure successfully demonstrated.**
  - Target module hold-down bolts remotely operated with hydraulic torque wrench.
  - Target module remote handling performed with lift fixture and crane.
  - Secondary feedlines removed and installed using manipulators and tools.
- **Target module Hg-seal tested with prototypic target blocks.**
  - Tests using double-Helicoflex® seals were unsuccessful.
  - New design using double knife-edge on iron seal has tested well.

- **Data obtained from irradiation tests at LANSCE and PSI.**
  - Confirm selection as 316LN for target vessel.
- **Fatigue tests show no difference between Hg and air environment in high-cycle regime.**
  - Negligible frequency effect from 0.1 to 700 Hz.
- **MTHL used for long-term high-velocity erosion tests.**
  - 3.5 m/s, 200/250 ˚C.
  - Completed 1000+ h of testing.
- **Hg compatibility tests were carried out for many materials.**
  - Type 316LN stainless steel.
  - AL-6061.


3
2
1