SNS Mercury Target Issues and Development Program

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October 30, 2000

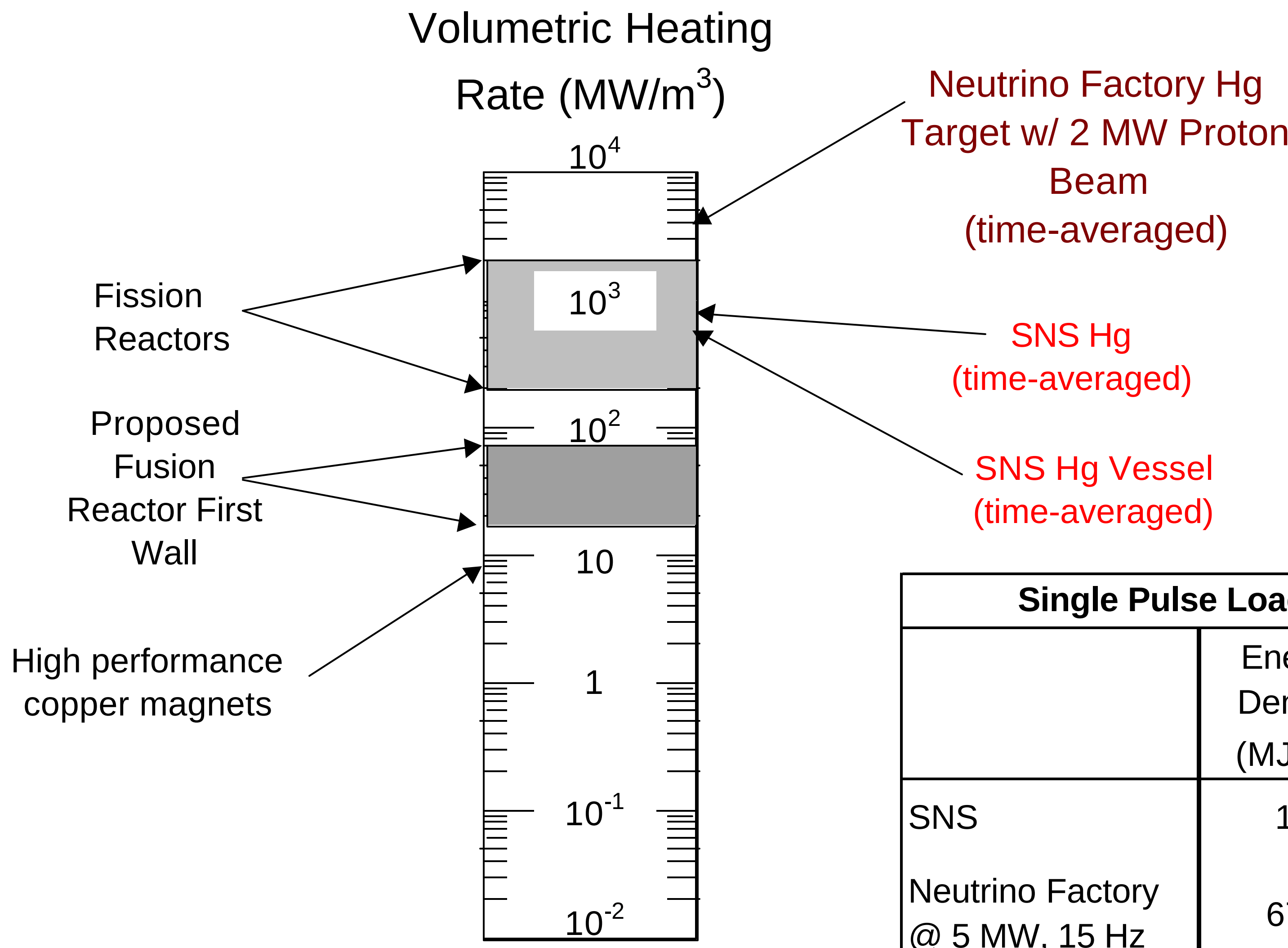
Outline

- SNS Target Requirements
- Why Hg?
- SNS Target Concept and Design Parameters
- Key Issues and R&D implemented to address them
  - Removal of time-averaged power
  - Handling pulsed beam loads
  - Materials compatibility and irradiation damage
- Hg processing and storage of radioactive byproducts
- Suggestions for Neutrino Factory R&D

Mercury Target Requirements

- 2 MW average proton beam power
- 1 GeV protons
- Pulse duration ~ 0.5 μs
- 60 Hz rep rate
- Resulting target loads
  - Energy deposition per pulse ~ 33 kJ
  - Peak time-averaged current on target 0.25 A/m^2
  - Peak time-averaged power flux on target vessel ~ 600 MW/m^3
  - Peak time-averaged power flux from vessel to Hg ~ 1 MW/m^2
  - Peak energy deposition in Hg ~ 800 MW/m^3

Comparison of Heat Loads



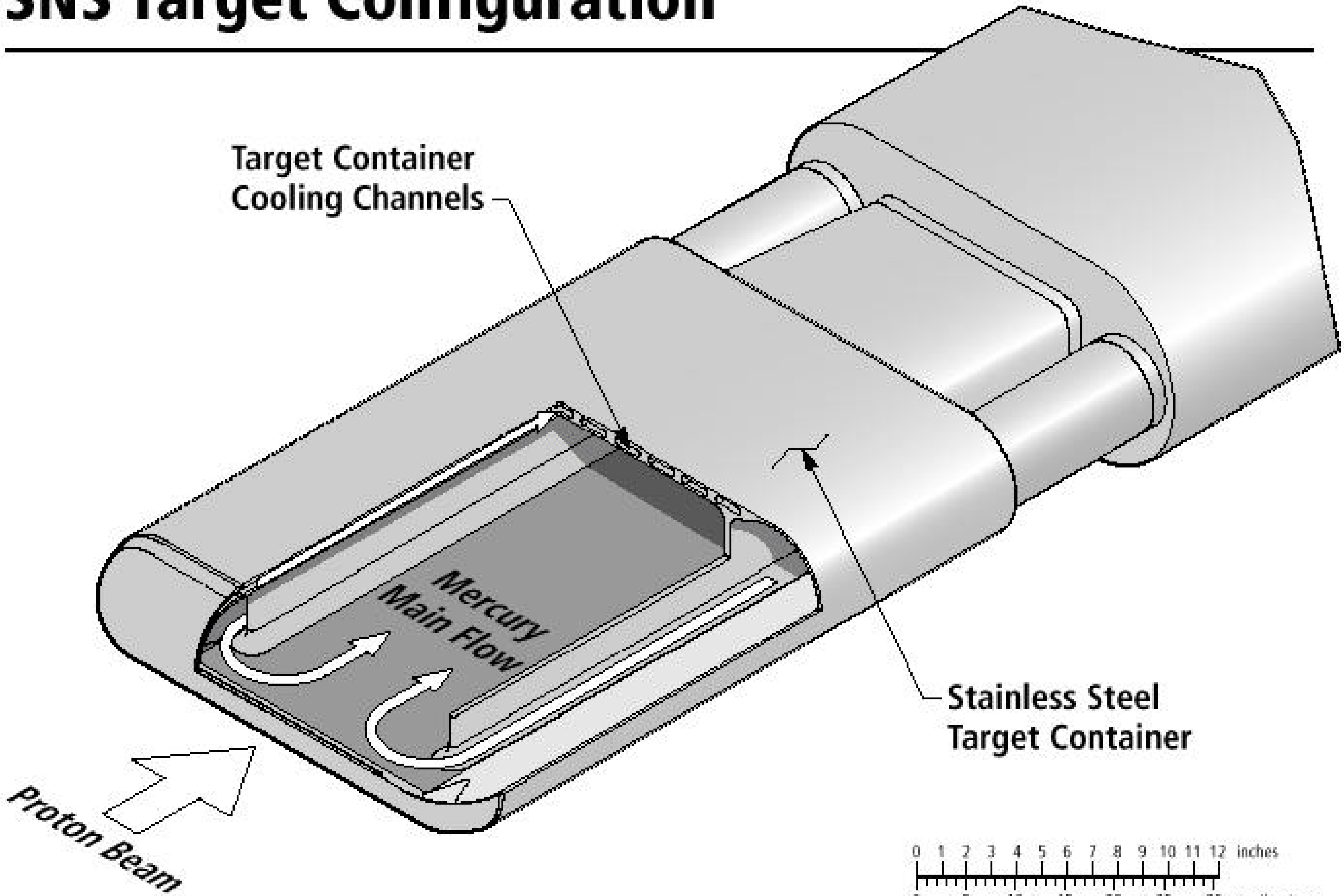
Single Pulse Loads in Hg

	Energy Density (MJ/m^3)	ΔT (K)
SNS	13	7
Neutrino Factory @ 5 MW, 15 Hz	670	350

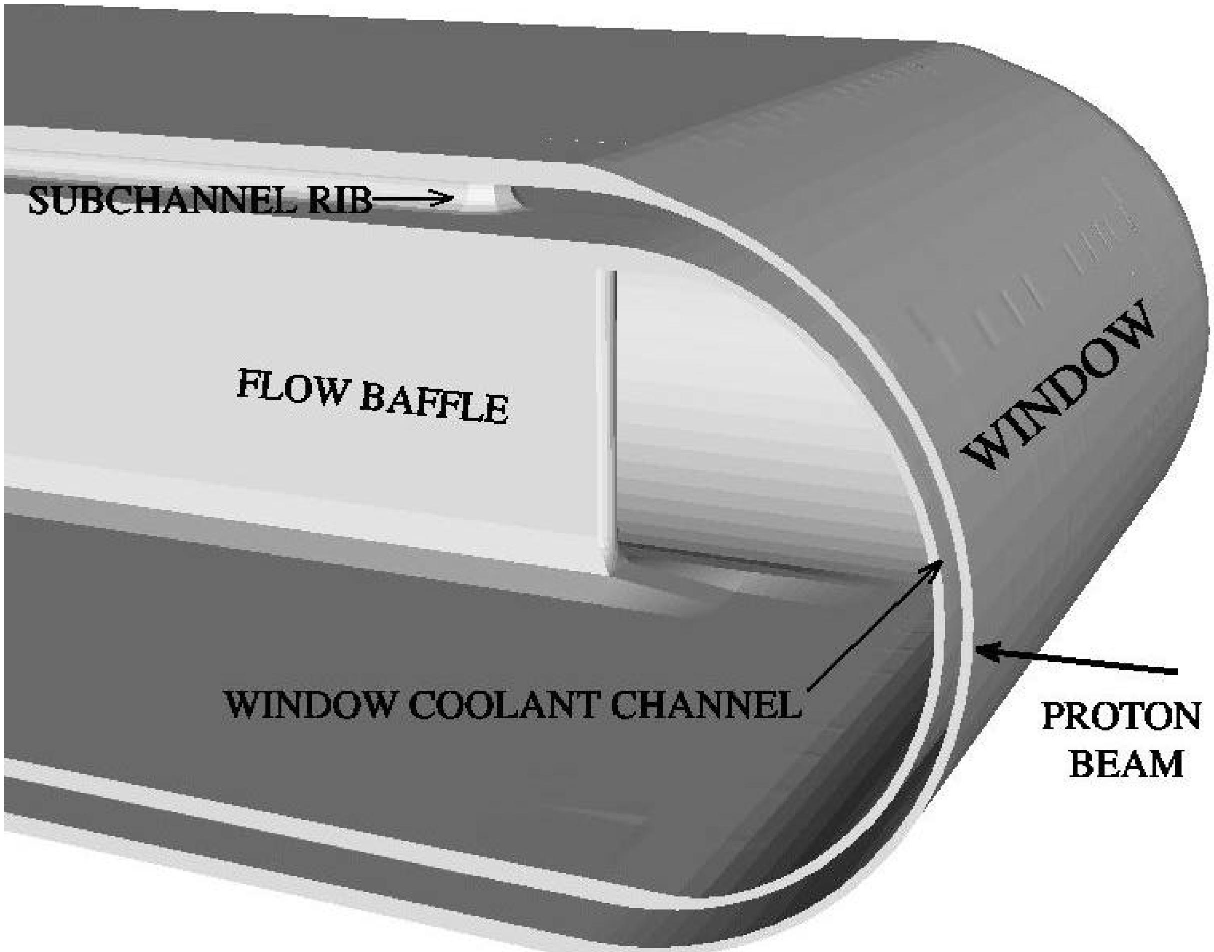
Why Mercury?

- High neutron yield (high-Z)
- High source brightness (high-density)
- Flowing liquid has excellent power handling capability
- Liquid at ambient temperatures
  - No liquid-to-solid phase change issues
- Minimal waste stream (compared to solid alternatives)
- Passive removal of decay heating
- No dominant extremely long-lived isotopes
- High thermal neutron absorption
  - Advantage for a pulsed-source

SNS Target Configuration



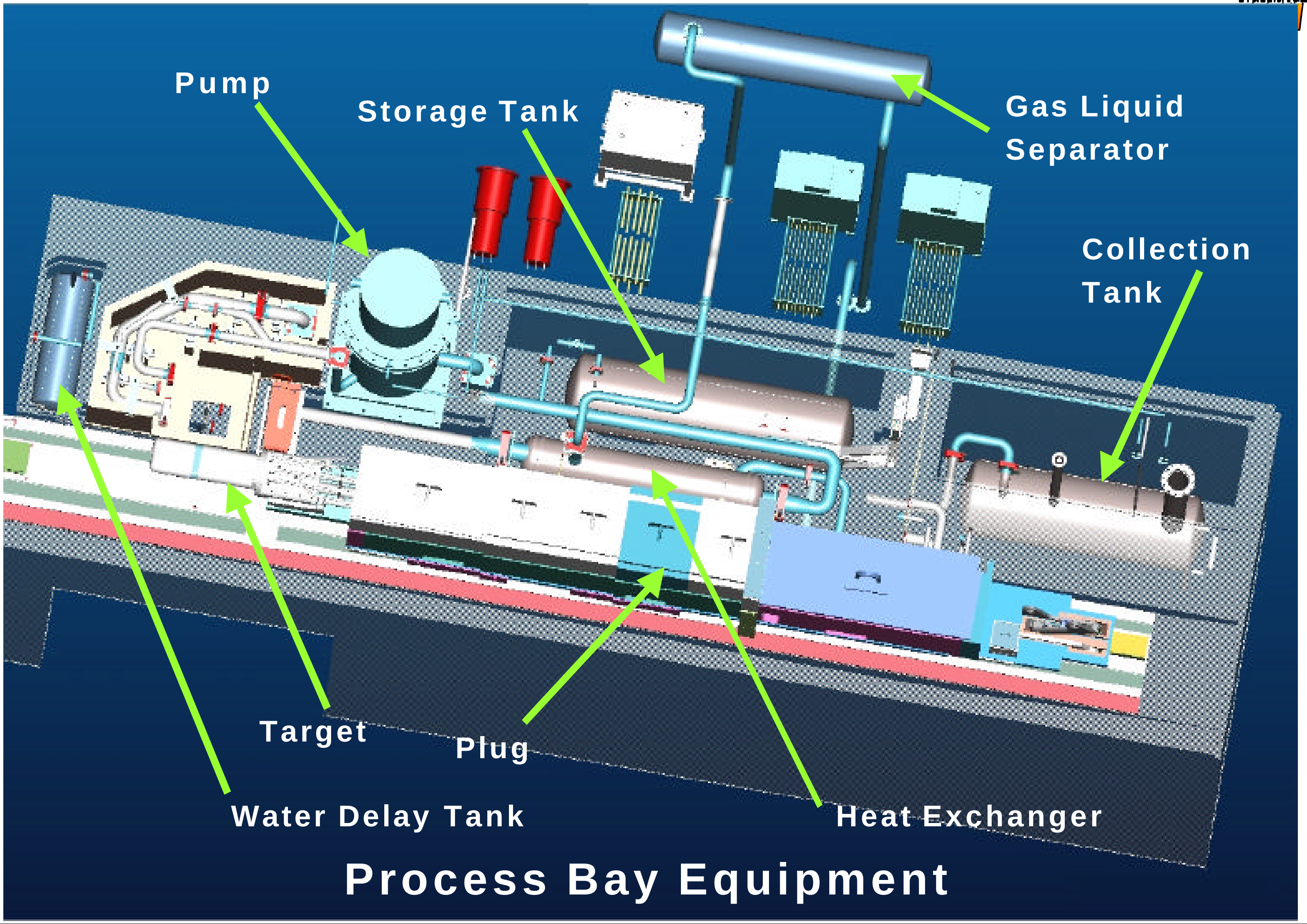
Target Vessel Is Internally Cooled With Separate Hg Stream



Mercury Loop Flow Parameters @ 2 MW

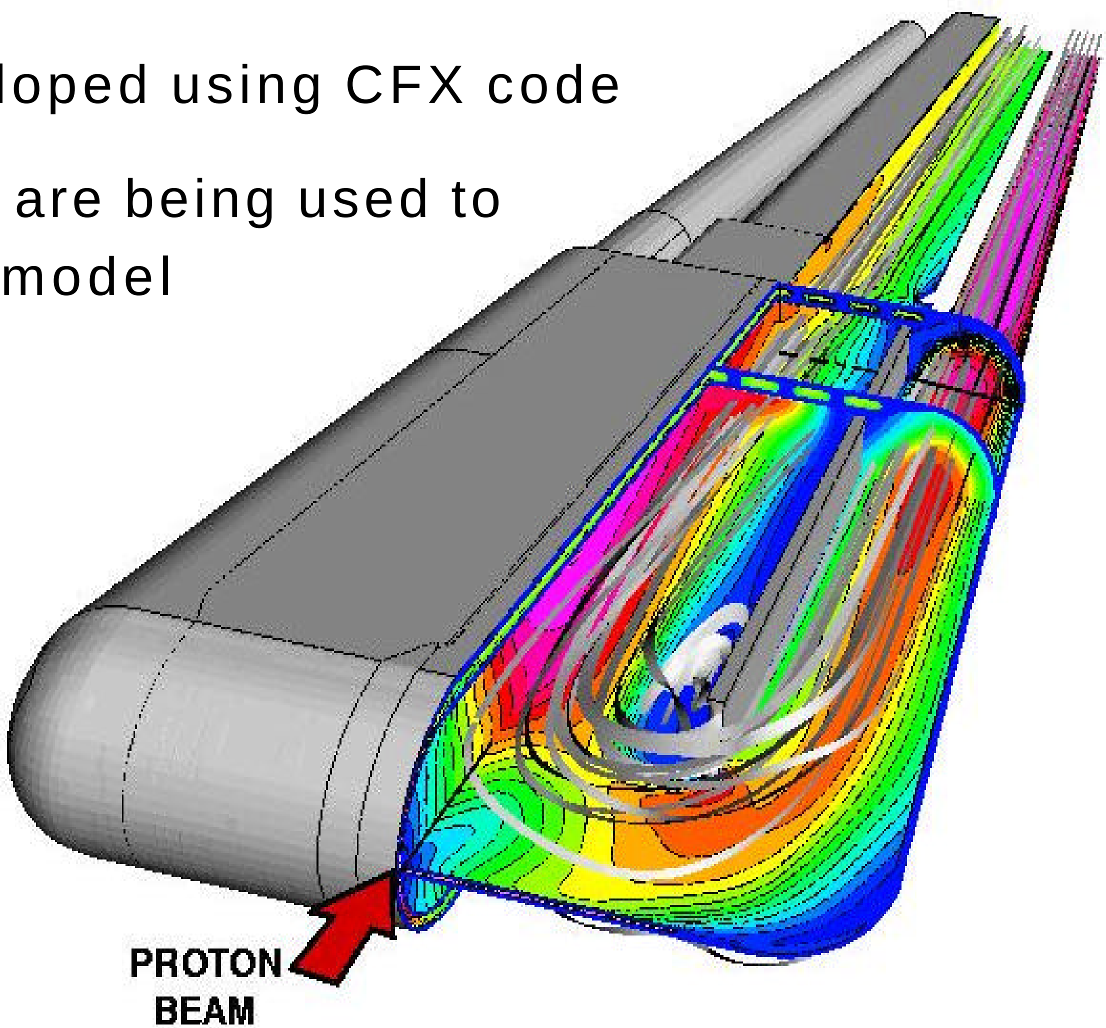
• Power absorbed in Hg	1.2 MW
• Nominal Operating Pressure	0.3 MPa (45 psi)
• Flow Rate	340 kg/s
• V_{max} (In Window)	3.5 m/s
• Temperature	
– Inlet to target	60ºC
– Exit from target	90ºC
• Total Hg Inventory	1.4 m^3 (20 tons)
• Pump Power	56 kW (75 HP)

Hg Process Loop



Three-Dimensional CFD Model

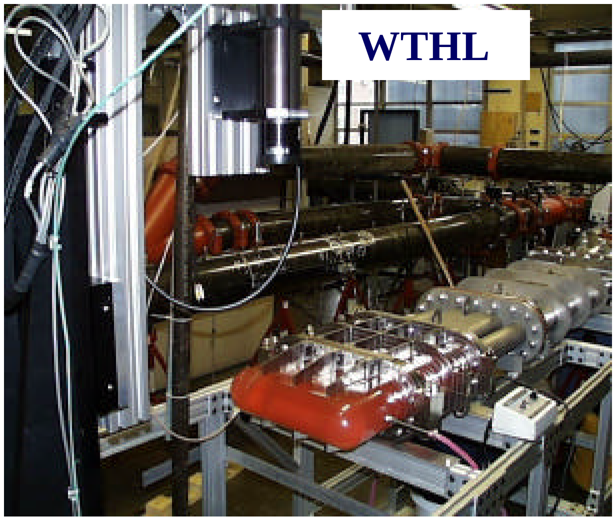
- Model developed using CFX code
- Test results are being used to benchmark model

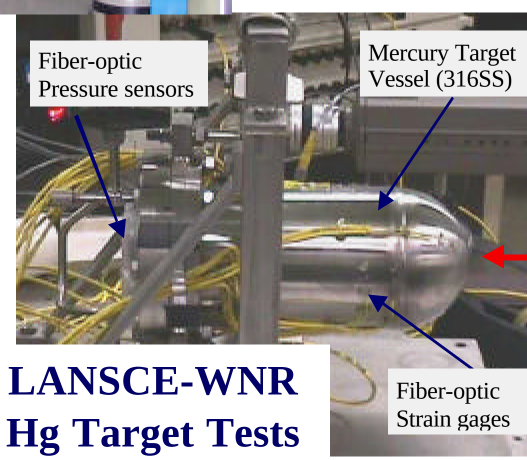


Key Issues for the SNS Mercury Target

- 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
  - Effects on bulk Hg flow
- Radiation damage to structural materials
- Compatibility between Hg and other target system materials
- Demonstration of key systems:
  - Mercury loop operation
  - Remote handling

Mercury Target Development

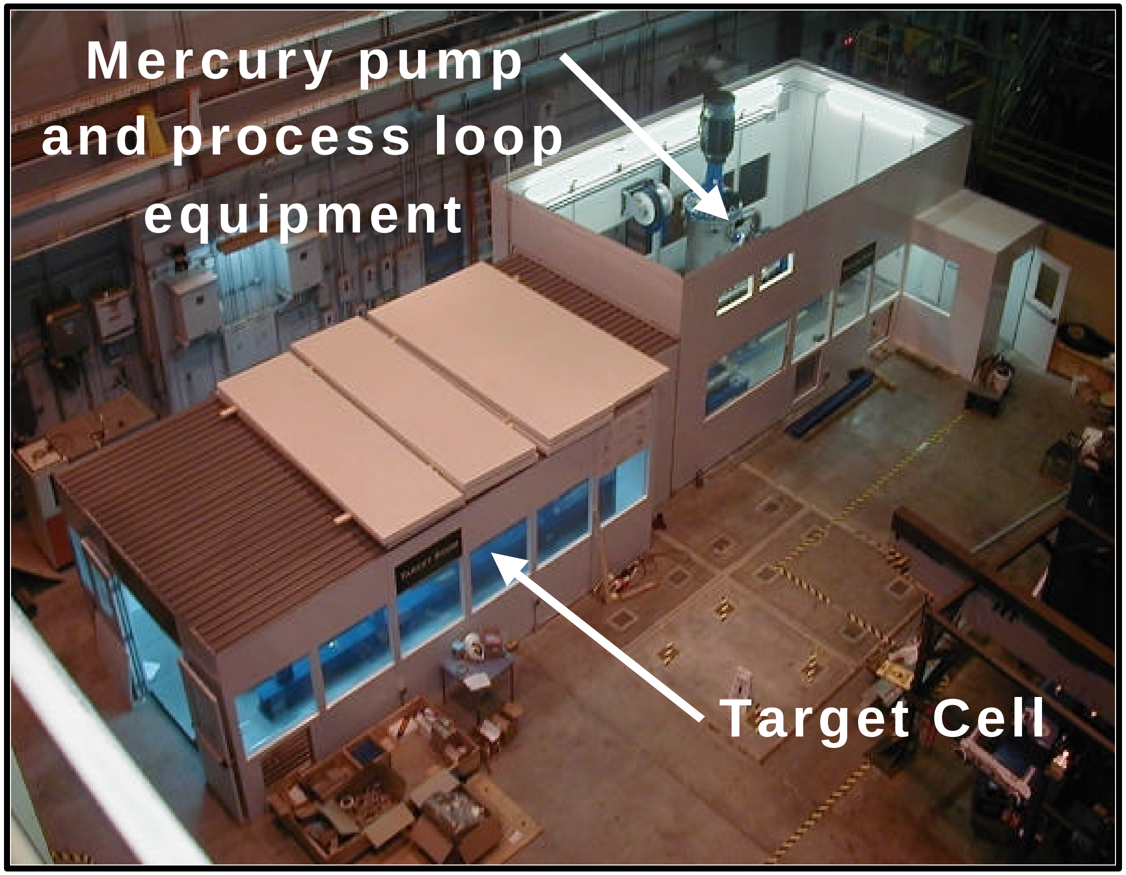




LANSCE-WNR Hg Target Tests

Target Test Facility Operations Began in October 1999

- Full-scale flow loop
- Centrifugal pump operated at 150% of nominal mercury flow rate
- Gaining operational experience
  - EPICS-based control system used to gain experience at ORNL on SNS control system
  - verifying some key design features
  - other features being changed to improve performance, reliability, or accessibility



Mercury Process Cell at TTF

Mercury Thermal Hydraulic Loop (MTHL) Became Operational in October 1999

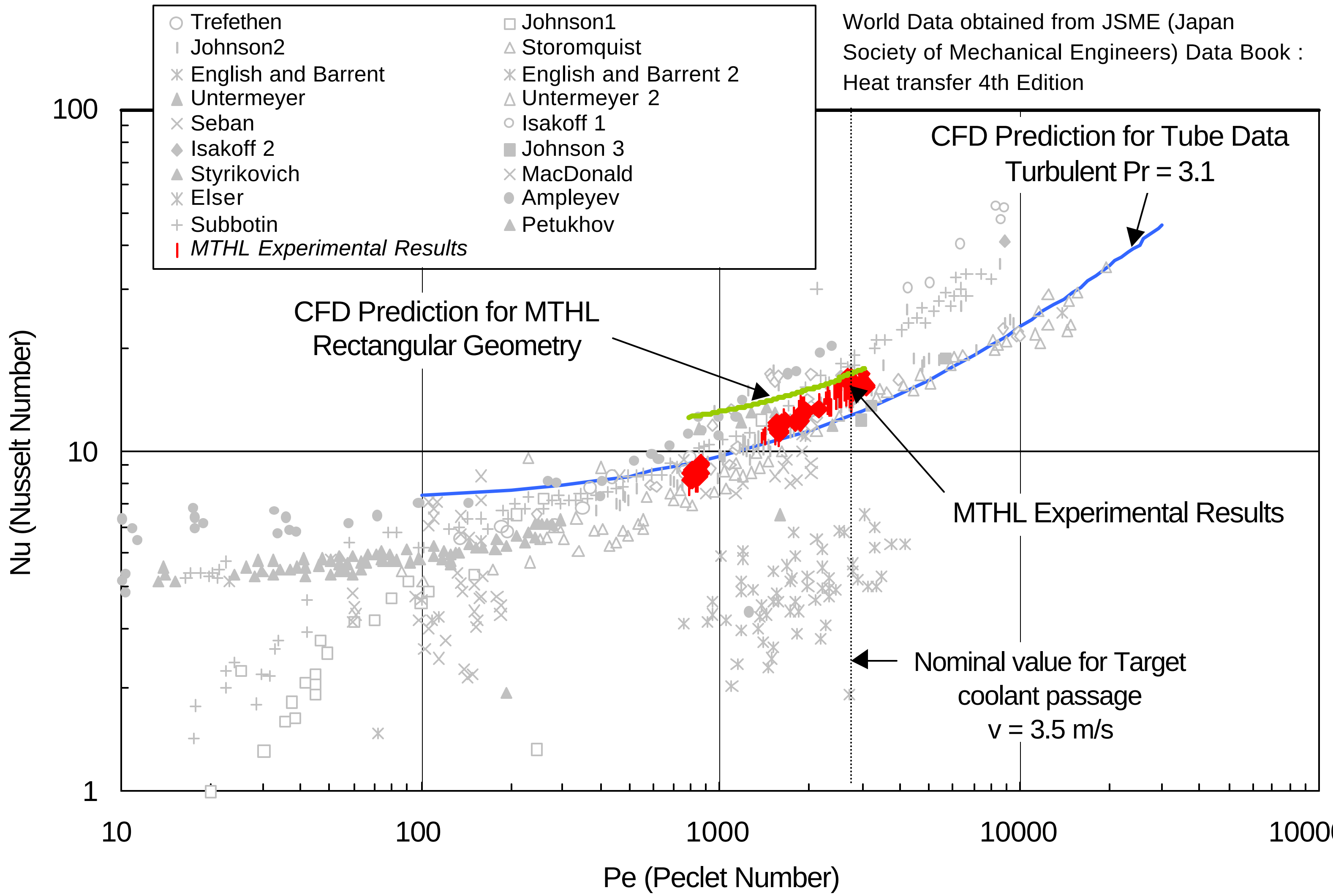
Hg-Water Heat Exchanger

EM Pump 27 L/min

Test Section

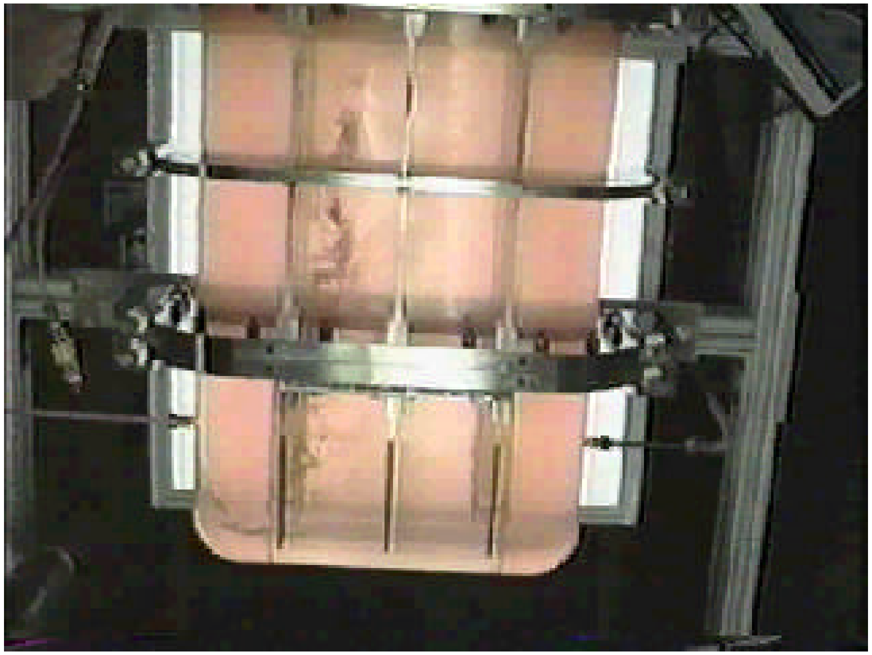
Mercury Can Be Used to Cool the 316 LN Target Container

World Data obtained from JSME (Japan Society of Mechanical Engineers) Data Book : Heat transfer 4th Edition



Flow Visualization Results on WTHL Compare Favorably with Predictions

WTHL Visualization



Predicted Flow Pattern

Laser-Doppler Velocimeter measurements start this month

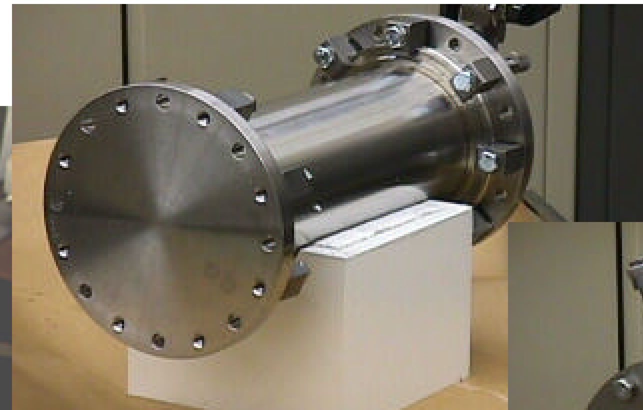
Thermal Shock Tests and Analyses

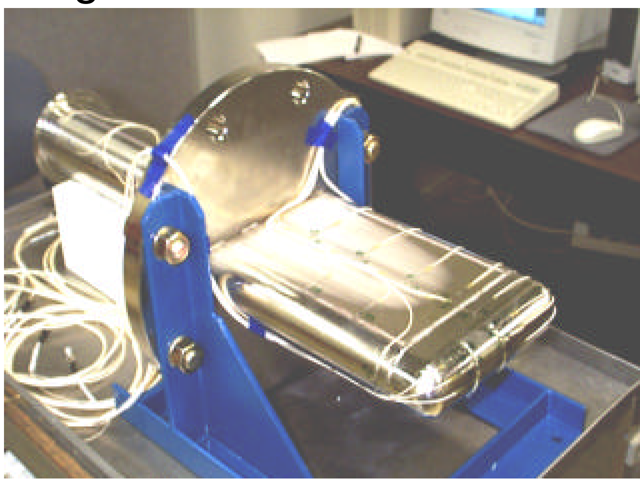
- Obtaining code benchmark and design data from thermal shock tests in accelerators is challenging
  - Intense radiation environment and fast response sensors required
  - Optical-fiber based strain and pressure sensors being developed
- Limited success in comparison of predictions with initial measurements
  - Magnitude of strain response about right, but poor match in time response after initial pressure wave/wall interaction
    - Complex geometry and penetrations at ASTE tests, simpler geometry and more controlled situation at WNR tests
    - Cavitation process difficult to model
  - Conventional finite-element and shock-physics “hydro codes” being used for predictions

Various Mercury Targets Were Used in WNR Tests in August 2000

- Data will help calibrate models for predicting target vessel stresses

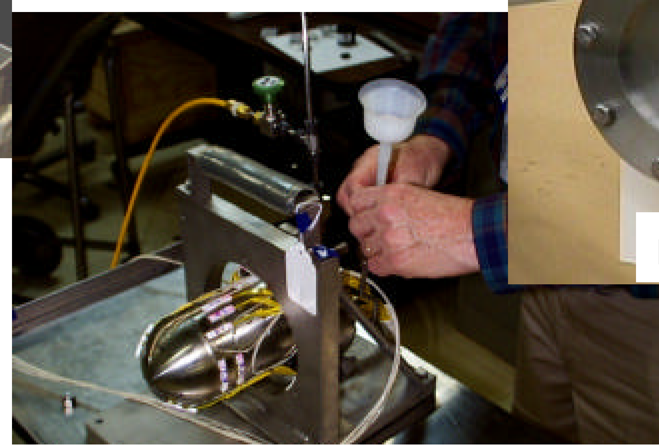
Large Effects Target





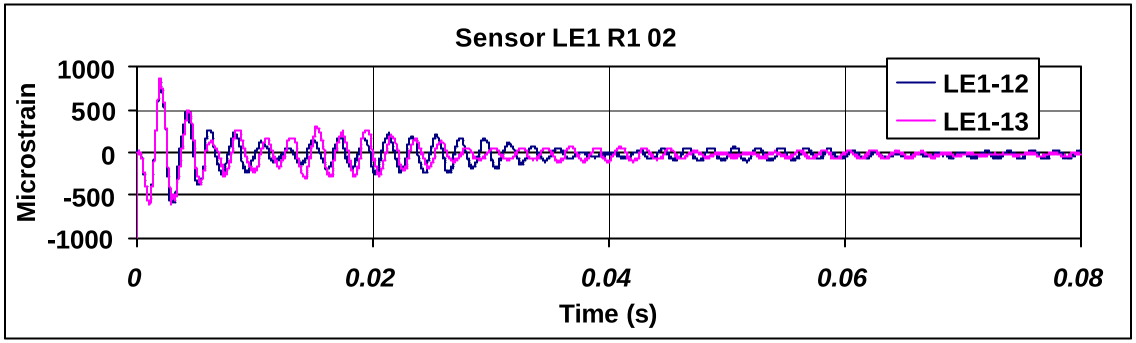
Prototypical Shape Target

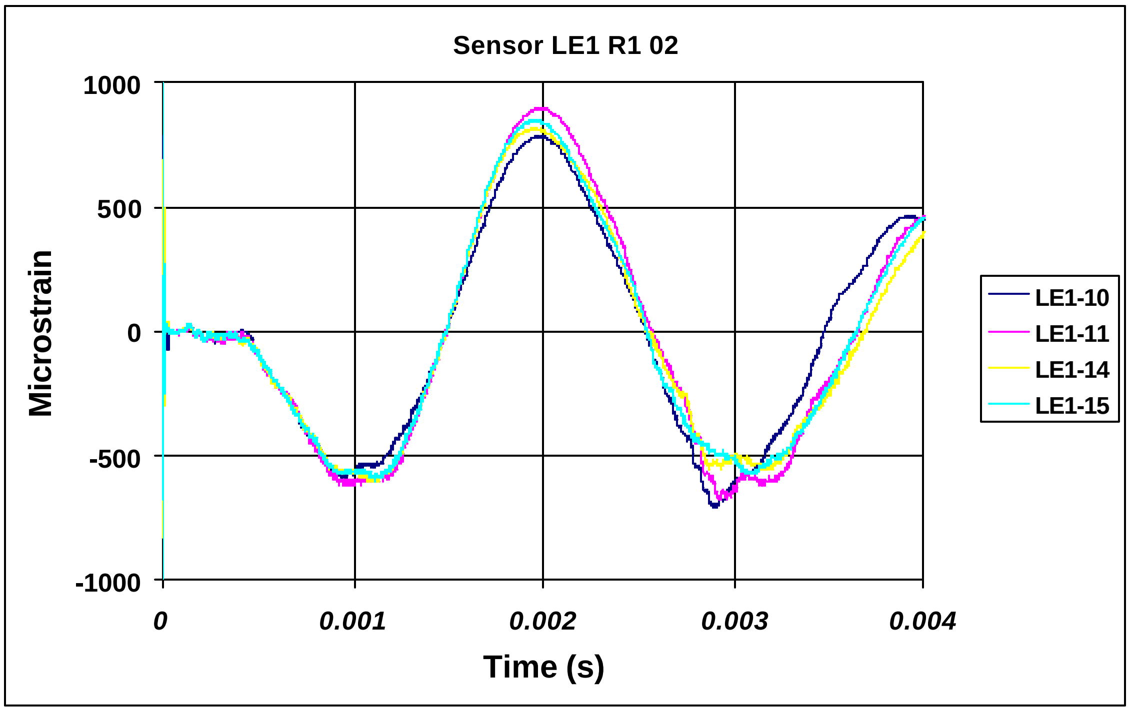
Energy Deposition Target



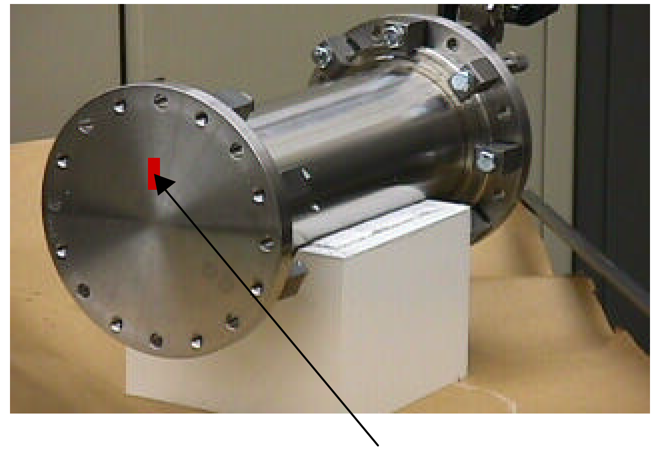
Axisymmetric Target

Measured Strains Respond at Much Lower Frequency Than Expected





Large Effects Target



Sensor LE1 R1 02
(Rear flange, 25 mm from center)

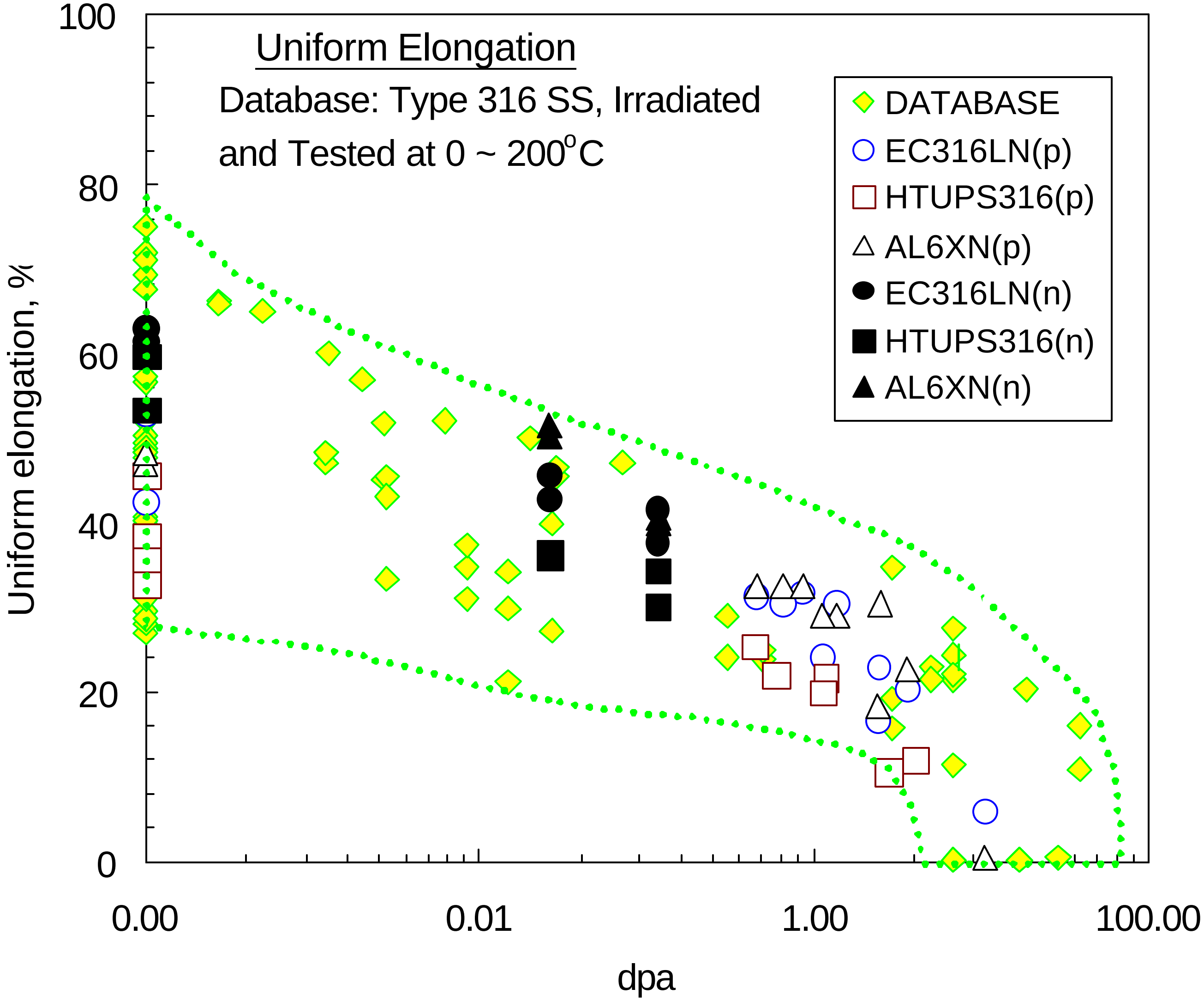
Measured Frequency ~ 500 Hz

Thin flanges (1.2 mm) used to ensure large strain was achieved.

Materials R&D

- An aggressive materials R&D program has been developed for Target Systems
  - Technical issues:
    - Radiation induced embrittlement by p and n fluxes
    - Effects of high He and H transmutation rates on properties
    - Thermal gradient mass transfer in Hg
    - Liquid metal embrittlement
    - Interactions of radiation effects and compatibility processes.
  - Facilities: LANSCE, SINQ, TIF, HFIR
  - Hg Loops and other test devices involving Hg have been built at ORNL.

Ductility of Irradiated Stainless Steels



Hg processing and handling of radioactive byproducts

- Mercury lasts the entire 40 year lifetime of SNS with no changeout required
  - "Burn-up" over 40 years is only ~ 0.1%
    - Most conversion is from one Hg isotope to another
    - Tritium production rate ~ 8 kCi/year
- No filtering required; tritium released from Hg to absorption system

Summary/Status of SNS Target R&D

- R&D program nearing completion
  - Hg target development - wettability confirmed, thermal hydraulic codes benchmarked to MTHL and WTHL data
  - Thermal shock data from recent tests being studied
  - Materials qualification - completing database on stainless steel irradiation, compatibility with Hg, fatigue limits
  - Neutronic code and database improvements completed
  - Remote handling technology demonstrated for selected operations
- Some multiple effect tests have been conducted, but interaction of all effects (combined radiation damage, erosion/corrosion, thermal shock effects) must await operation of SNS
  - Materials surveillance program will be part of operations
  - Will remove first target at relatively low fluence, for example < 1 MW-month

Suggestions for Hg Target R&D for Neutrino Factory

- Must carefully define requirements and a Hg target conceptual design that meets these requirements
  - Until this is done, efforts are likely to flounder and could be irrelevant in the end
  - Derive feasibility issues
  - Define R&D program that addresses critical feasibility issues
- Feasibility issues:
  - Hg jet formation and stability, especially in high B field, will be critical issue
  - How to re-establish jet before next beam pulse
  - Likely that others will result from conceptual design process