# Dynamic Strain and Pressure Measurements of a Mercury Target Under Thermal Shock Tests

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ANS 1999 Annual Meeting, Boston Massachusetts
June 6-10, 1999

# Acknowledgement


- The SNS project is funded by the U. S. Department of Energy.
- We would like to thank S. A. Wender and his colleagues at Los Alamos National Laboratory (LANL) for their excellent support in providing reliable 800-MeV proton beams for the mercury target thermal shock tests.
- This work has benefited from the use of LANL/LANCE beam facility, funded by the U.S. Department of Energy.

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# Introduction

- Spallation Neutron Source (SNS) has been proposed for producing neutron beams
  - Neutrons are produced via spallation reactions in a target material following high-energy proton bombardment.
- Solid targets are being used in neutron sources with proton beam power << 1 MW.
- Mercury targets capable of high neutron production efficiency are designed for high beam powers of ~5 MW.

# Merits & Concerns

- Mercury has been chosen as SNS neutron production target material, because it is:
  - a liquid metal with high density, high atomic number, and low melting point
  - expected to withstand thermal shock loads caused by pulsed proton beams of 33,000 Joules in ~0.5 μs
- A key design issue is the mercury vessel that will be made of thin-wall stainless steel.
  - Cyclic stresses in the target vessel
  - limiting of the vessel lifetime

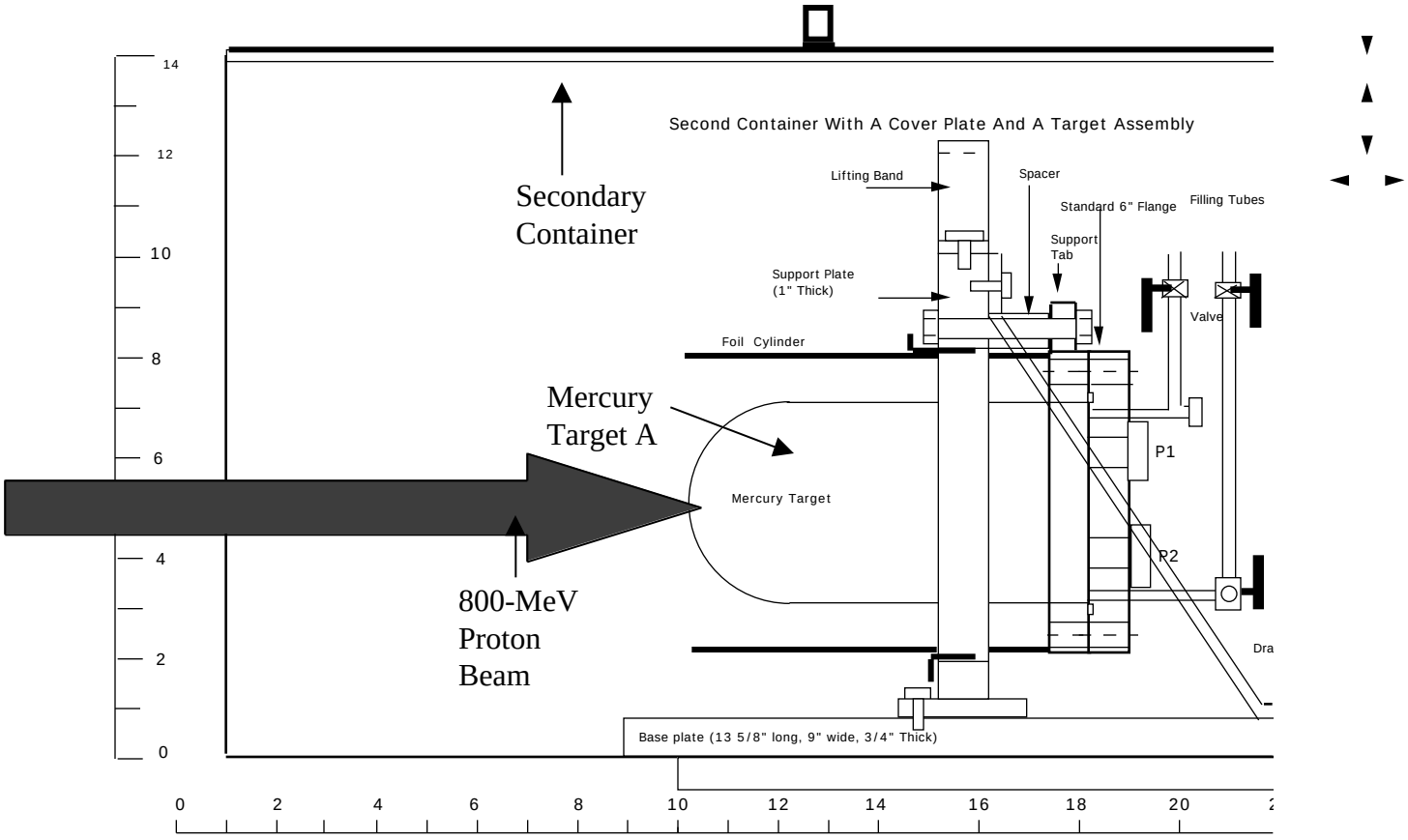
# SNS Mercury Target Development

- A liquid mercury target is being designed and developed for the proposed Spallation Neutron Source (SNS).
- The target will be bombarded by short-pulse (~0.5 μs), high-energy (1-GeV) proton beams (~2 x $10^{14}$ protons / pulse) at 60 Hz.
- Thermal shock loads (33 kJ) cause an enormous rate of temperature rise, ~$10^7$ K/s in mercury (on the order of 2 degree temperature rise per pulse in the target vessel).
- The thermal shock induced pressure wave could lead to excessive stresses in the target vessel.
- To benchmark the computer code for the target design, dynamic sensors are used for measuring transient strains and pressures of mercury targets in development tests at existing accelerator facilities.

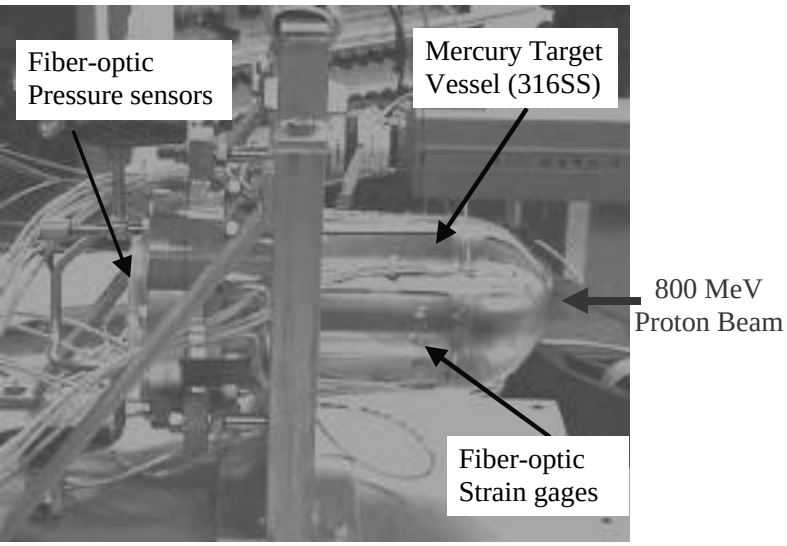
# Tests at the LANSCE-WNR Facility

- Thermal Shock Tests
  - Target A with 20 strain sensors, 3 pressure probes and 2 temperature sensors
  - Target B with 4 strain sensors on its thin diaphragms
  - Phosphor screens for beam profiles
- Neutronic Tests
  - Metal foils for monitoring spallation produced neutrons
  - Gamma radiation monitor for beam intensity
  - Metal foils for beam profiles

# Target A

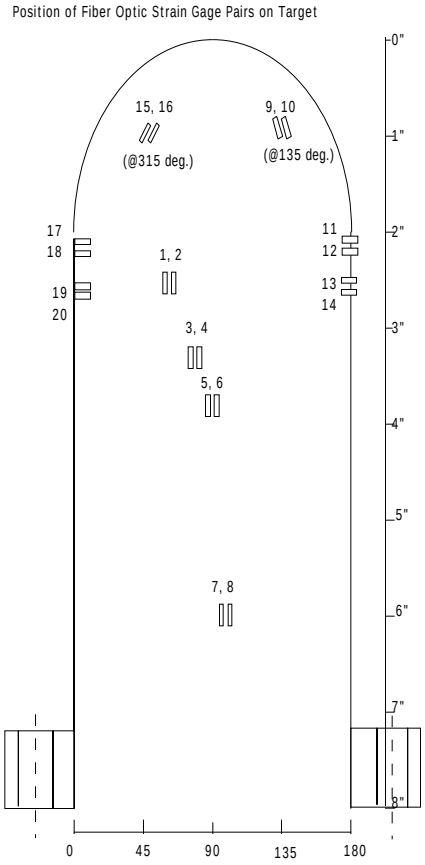

Secondary Container
Second Container With A Cover Plate And A Target Assembly
Lifting Band
Spacer
Standard 6" Flange
Filling Tubes
Support Tab
Support Plate (1" Thick)
Valve
Foil Cylinder
Mercury Target A
P1
Mercury Target
P2
800-MeV Proton Beam
Base plate (13 5/8" long, 9" wide, 3/4" Thick)
0
2
4
6
8
10
12
14
16
18
20

# Mercury Target A

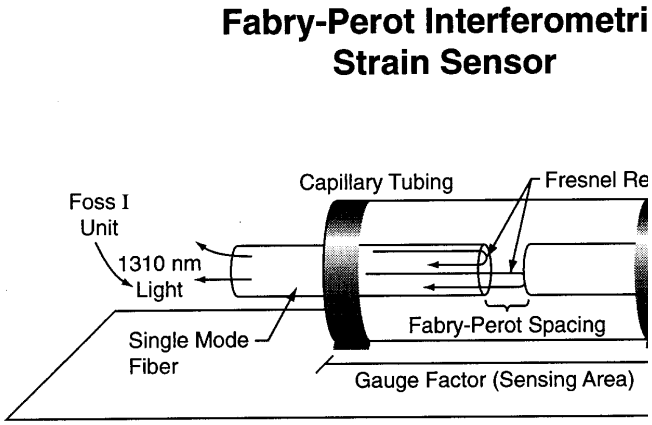



- Bullet-shaped target vessel (hemispherical front dome attached to a cylinder)
  - 2 mm thick SS walls
  - Front dome - 5 cm in radius
  - Cylinder 10 cm in diameter and 15 cm long
  - End flange- 15.24 cm in diameter
- Target instrumented with:
  - 20 fiber optic strain gages on vessel walls
  - 3 fiber optic pressure probes on flange
  - One thermocouple
- Multiple single-pulse thermal shock tests
  - ~2.4 x $10^{13}$ protons per pulse
  - 800-MeV proton energy
  - ~0.3 μs beam pulse width
  - 3 to 4 cm beam diameter

# Fiber Optic Strain Gages on Target A



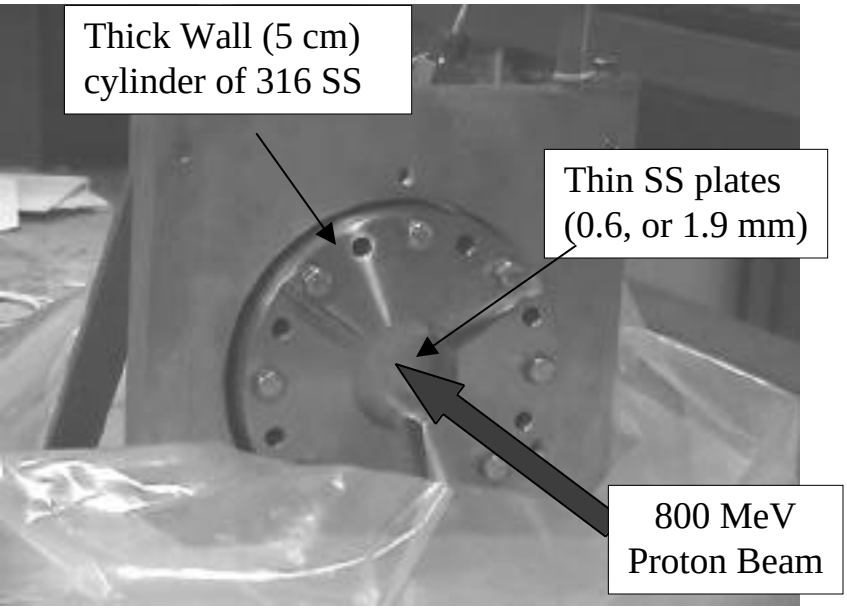

- Positions of 20 fiber optic strain gages that were installed on Target A.
- Sketch of a fiber optic strain gage.



# Pressure probes of Mercury Target A

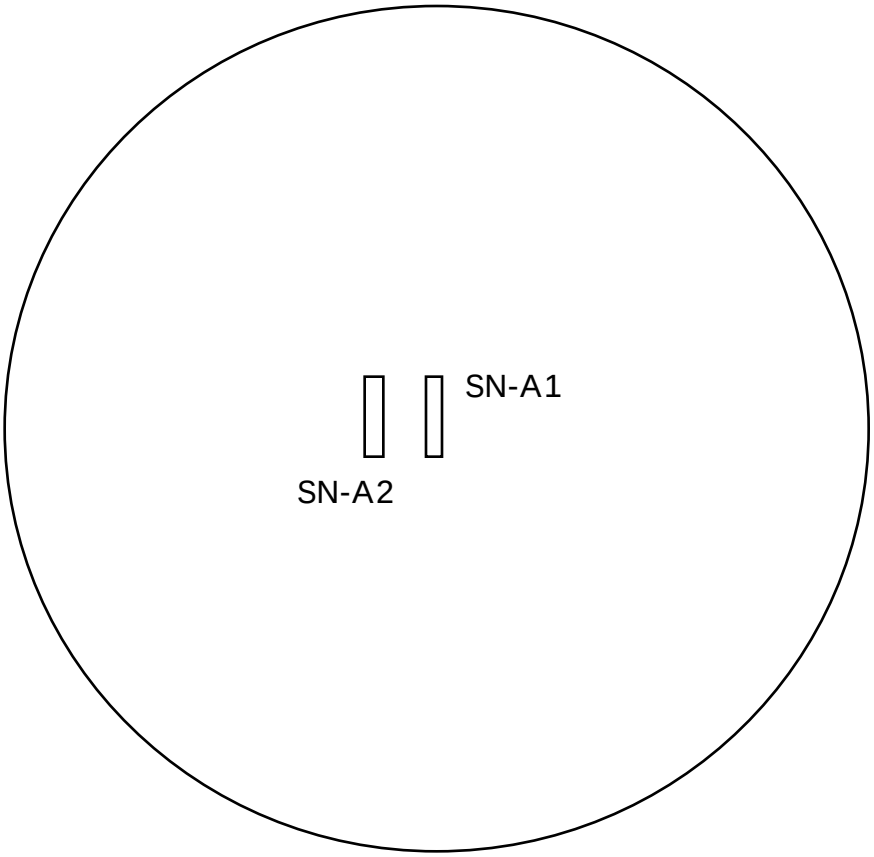
- Low-Sensitivity Pressure Probe
  - 2500 psi
  - 0.254 mm thick, 7.9 mm diam., and 0.261 mm gap.
- High-Sensitivity Pressure Probe
  - 100 psi
  - 0.05 mm thick, 7.9 mm diam., and 0.161 mm gap
- Phosphor-Fluorescence Pressure Probe

# Mercury Target B




- A small cylindrical target volume
  - 5 cm diameter
  - 8 cm long
  - 5 cm thick walls
- Very thin end plates
  - 0.6 mm thin 316 SS plates
  - 1.9 mm thin 316 SS plates
- Thermal shock tests
  - Each shot ~ 2.4 x $10^{13}$ protons at 800 MeV
  - Single shot for 0.6-mm plates
  - Multiple shots for 1.9-mm plates
  - 2 fiber optic strain sensors at near center of each plate

# Fiber Optic Strain Gages on Mercury Target B

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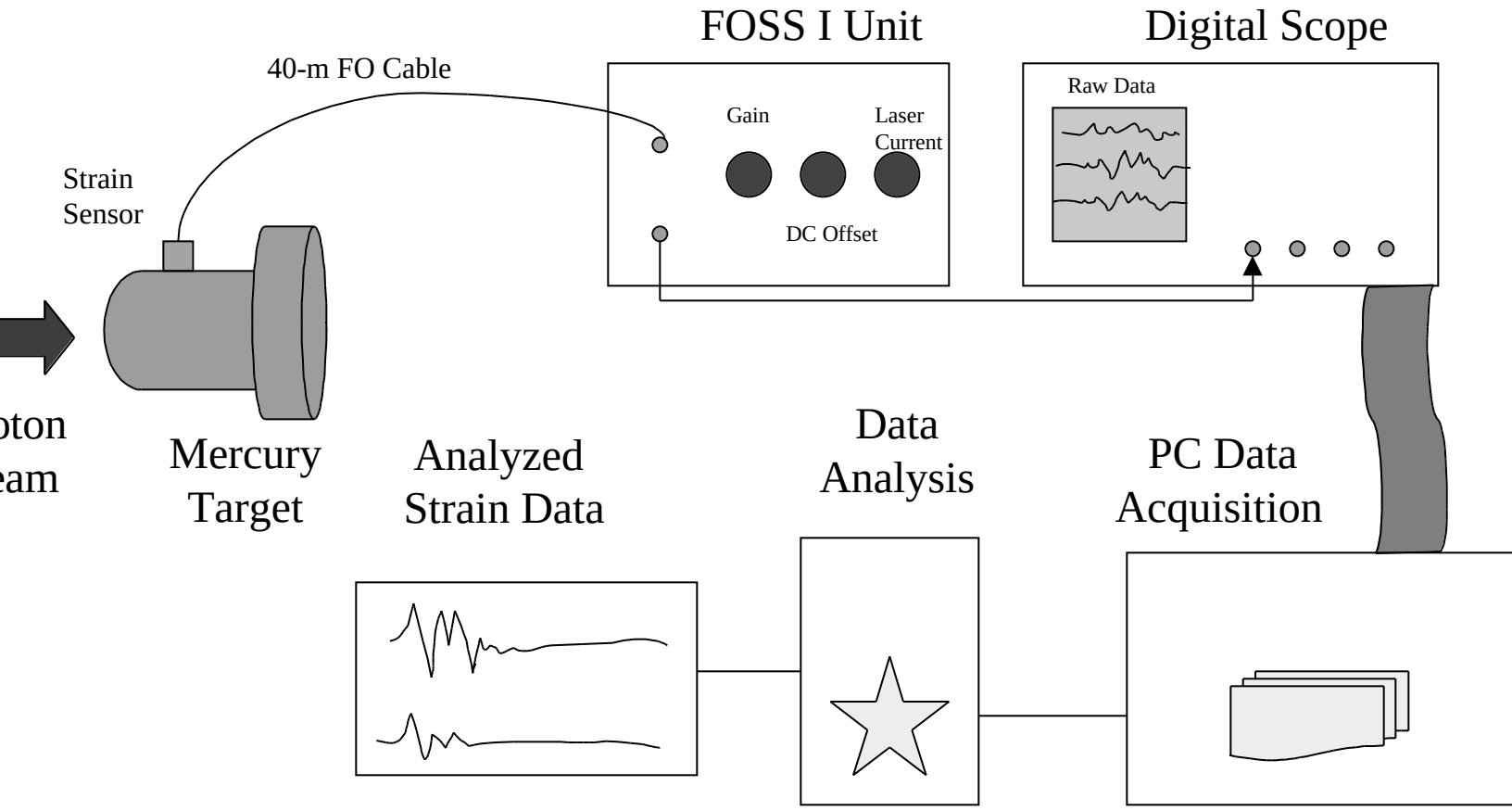
# Strain Measurement System

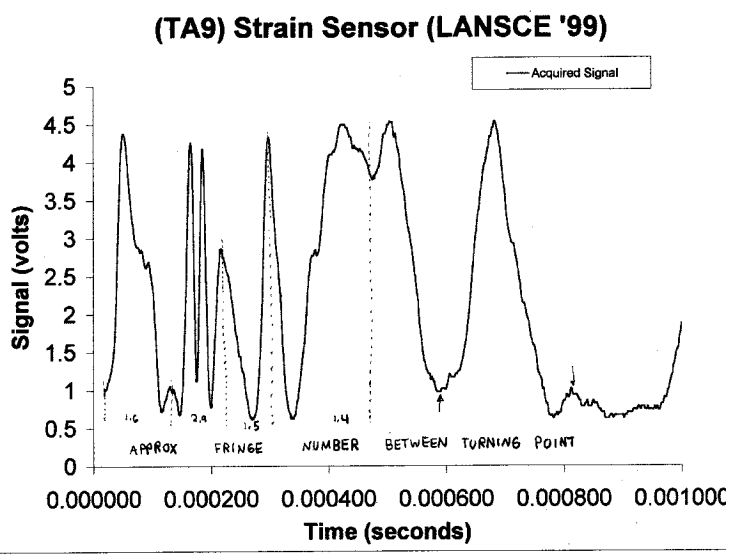


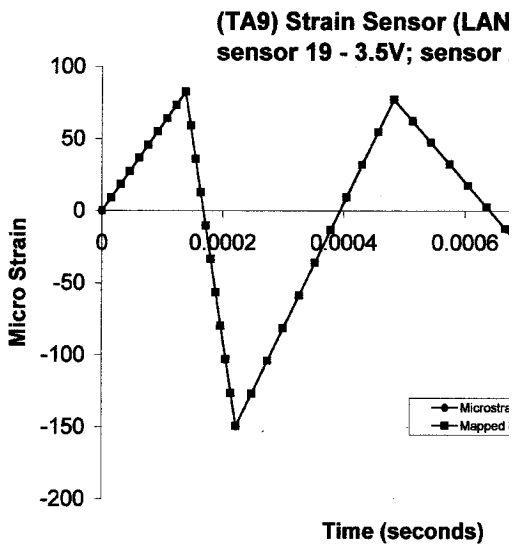
# Key Factors Affecting Strain Measurement

- Proton beam: intensity, profile, centering on target
- Fiber optic instrument
  - Sensor: gage factor, gap, fiber alignment
  - FOSS I unit: laser current, gain, DC offset, frequency response
- Data acquisition system
  - Digital scope: sampling rates, record length
  - PC data acquisition: record length, transfer rates
- Data analysis code: program logic

# Strain Data Analysis

- Strain (in microstrain) = 655 * (No. of Fringes) / Gage Factors (in mm)
- Strain (in microstrain) = 655 * [Signal (in mV) / Peak-to-Peak Voltage (in mV)] / Gage Factor (in mm)

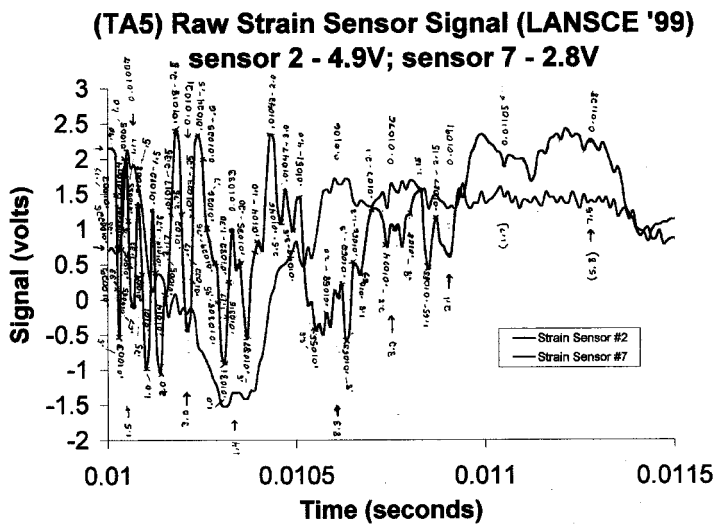


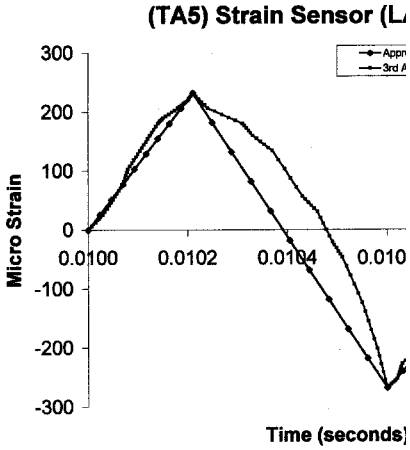



# Strain Analysis Using Spreadsheet Modeling Codes and Iteration Processes

- Determine the times of turning points from raw signals of fiber optic sensor pairs
- Determine the numbers of fringes between turning points
- Assign time-fringe ordered pairs between turning points
- Enter appropriate values of phase angle, DC offset, and peak to peak value

# Measured Strains of Mercury Target A



# Preliminary results

- Measured peak strains:
  - Average about 50 microstrains on Target A
  - Some strain excursions above 100 microstrains on Target A
  - About 300 to 400 microstrains on Target B
- Measured mercury temperature rise (at back flange)
  - ~0.5 degree using thermocouple
  - ~0.5 degree using phosphor sensors
- Measured pressures in mercury
  - Range of >100 psi to <2500 psi based on raw data that are not yet analyzed.

# Summary

- Fiber optic sensors work well for measuring strains, pressures, and temperatures under intense radiation.
- Fiber optic strain sensors pair reproduced similar analog voltage output signals shot to shot.
- Raw data are being analyzed. The preliminary results are:
  - Measured strains of ~50 microstrains for 2 mm thick vessel of Target A and of ~400 microstrains on 0.6 mm thick diaphragm of Target B
  - Pressure range of 100 psi to 2500 psi based on raw data that are not yet analyzed
  - Measured temperature rises of ~0.5 degree K in mercury
- Improvements of instrumentation system will be implemented to enhance technical support to engineering design of SNS targets.
  - Data acquisition system for capturing of raw data from analog output waveforms
  - Optical instrumentation for analyzing raw data of strains and pressures.