# Mercury Target Issues and Development Program

Neutrino Factory and Muon Collider Collaboration

Targetry R&D Meeting

Dec. 16, 2000

Brookhaven National Laboratory

Tandem Library, Bldg 901A

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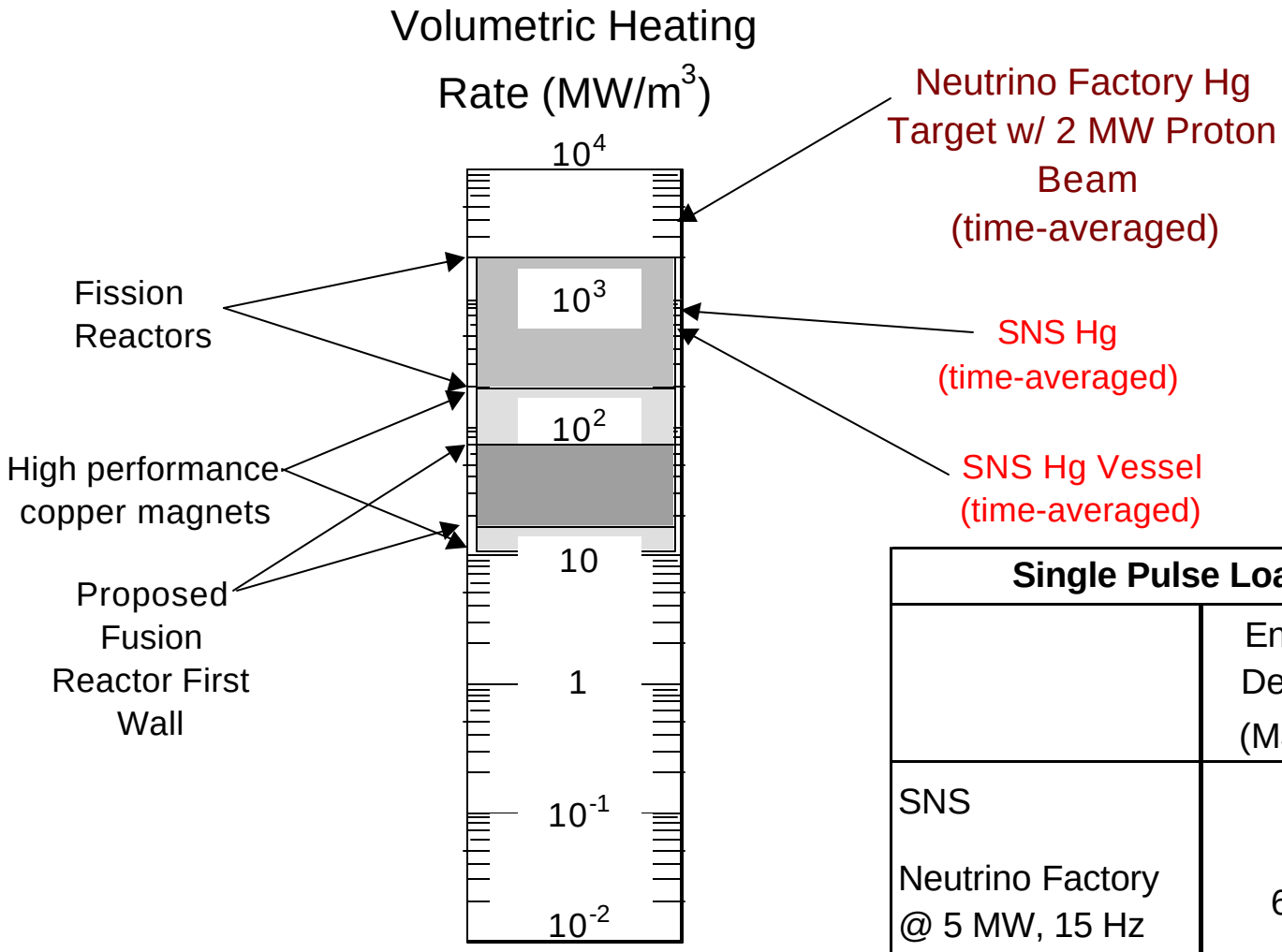
# Outline

- Comparison Between SNS and Neutrino Factory Target Requirements
- 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
- Comments on Safety Categorization and R&D for Neutrino Factory and Muon Collider

# SNS Mercury Target Requirements

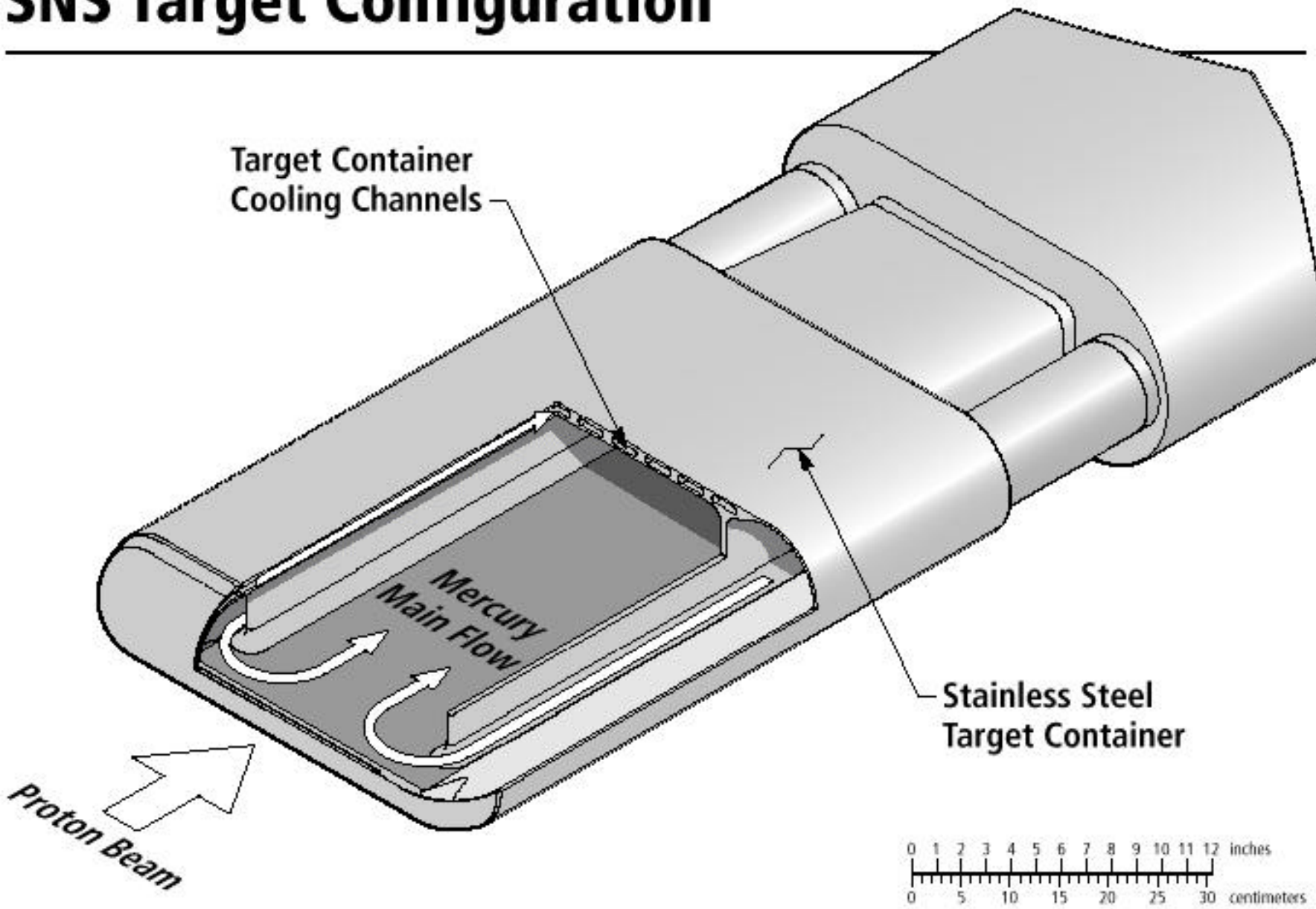
- 2 MW average proton beam power
- 1 GeV protons
- Pulse duration ~ 0.5 μs
- 60 Hz rep rate
- Resulting target loads
  - Energy deposition per pulse ~ 33 kJ
  - Peak time-averaged current on target 0.25 A/$m^2$
  - Peak time-averaged power flux on target vessel ~ 600 MW/$m^3$
  - Peak time-averaged power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

# Comparison of Heat Loads



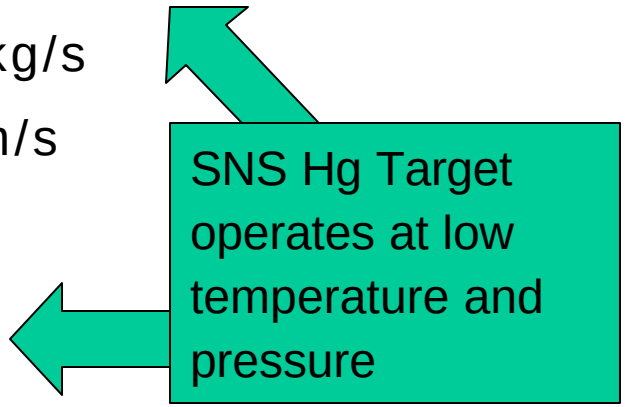

| Single Pulse Loads in Hg | | |
|---|---|---|
| | Energy Density ($MJ/m^3$) | $\Delta T$ (K) |
| SNS | 13 | 7 |
| Neutrino Factory @ 5 MW, 15 Hz | 670 | 350 |

# SNS Target Configuration

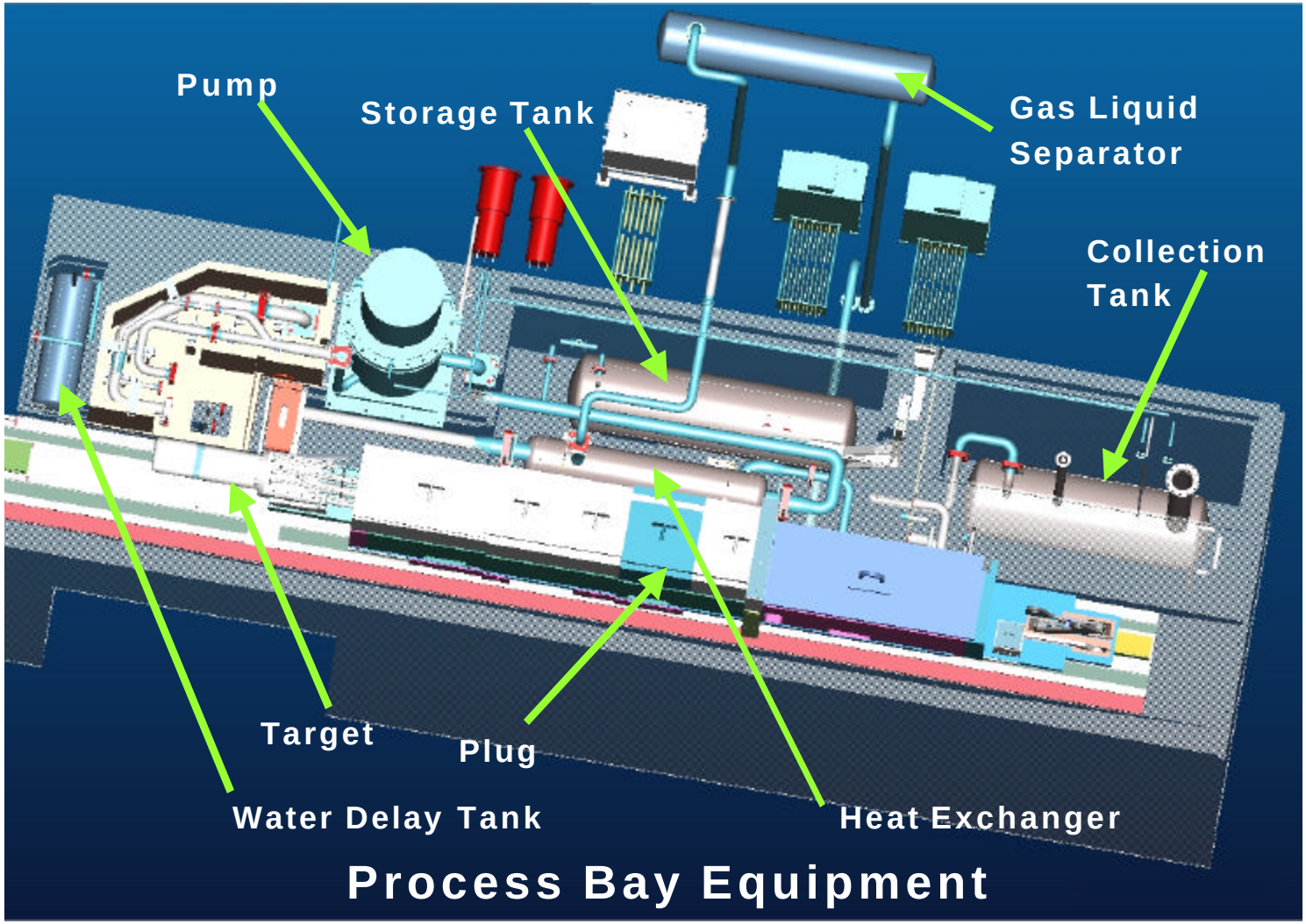


# Mercury Loop Flow Parameters @ 2 MW

| | |
|---|---|
| • 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

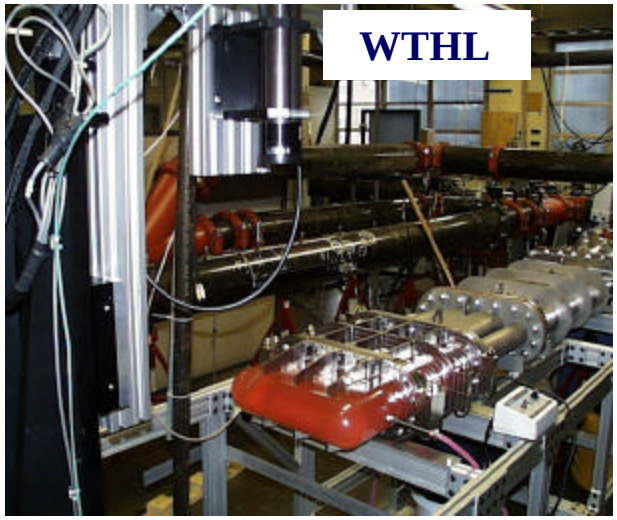


# Key Issues for the SNS Mercury Target

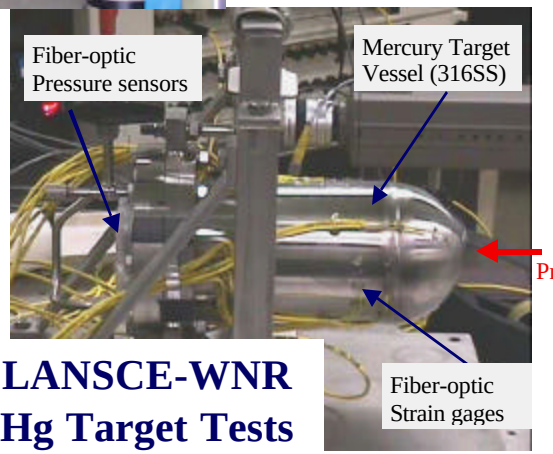
- Steady state power handling
  - Cooling of target/enclosure window - wettability
  - Hot spots in Hg caused by recirculation around flow baffles
- Thermal Shock
  - Pressure pulse loads on structural material
  - Effects on bulk Hg flow
- Radiation damage to structural materials
- Compatibility between Hg and other target system materials
- Demonstration of key systems:
  - Mercury loop operation
  - Remote handling

Some SNS Hg Target R&D Facilities, capabilities, and expertise might be directly applicable to neutrino factory

# Mercury Target Development






**LANSCE-WNR**
**Hg Target Tests**

# Mercury Process Cell at TTF

# 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.

# Materials Qualification Tests

| Test \ Item | Energy | Dose | He | H | Hg | Thick | Stress | Fatigue |
|---|---|---|---|---|---|---|---|---|
| **SNS** | high | high | high | high | flow | √ | √ | √ |
| **TIF 3- Beam** | low | high | high | high | | | | |
| **TIF p-Beam** | low | low | | | static* | | ? | |
| **LANSCE** | high | high | high | high | | √ | | |
| **SINQ** | high | high | high | high | | √ | | |
| **HFIR** | low | high | high | | | √ | | |
| **TC Loop** | | | | | flow | √ | | |
| **LME Tensile** | | | | | static | √ | √ | |
| **LME Fatigue** | | | | | static | √ | | √ |

***** **Low flow rate upgrade may be possible**

**Õ** **Typical for SNS**

**?** **Possible relevance to SNS**

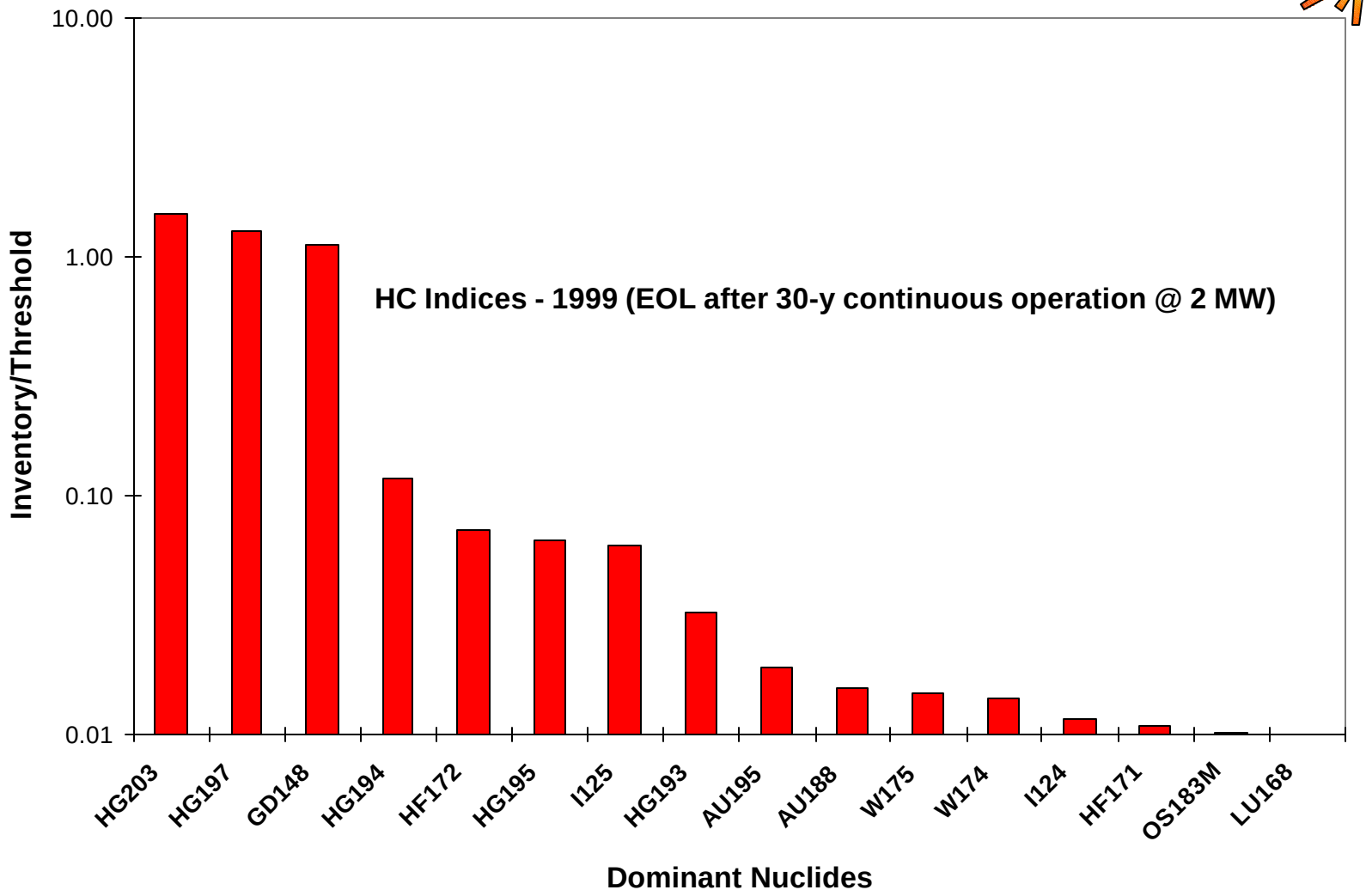
# Hg processing and handling of radioactive byproducts

- 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

# Safety Issues for SNS Hg Target

- SNS Target Region is a a Hazard Category 2 Nuclear Facility
  - Inventory of certain radionuclides (primarily mercury isotopes) exceed thresholds
- Mercury releases that exceed the site boundary limits are only possible if the mercury is at elevated temperature
- Safety Class Systems required to avoid elevated temperatures
  - Target Protection System used to trip the proton beam for abnormal loop conditions (high temperature or low flow)
  - Safety Class fire protection
    - Combustion Control program
    - 2 hour fire wall
    - fire suppression system
- Additional Safety Significant Equipment needed to protect workers

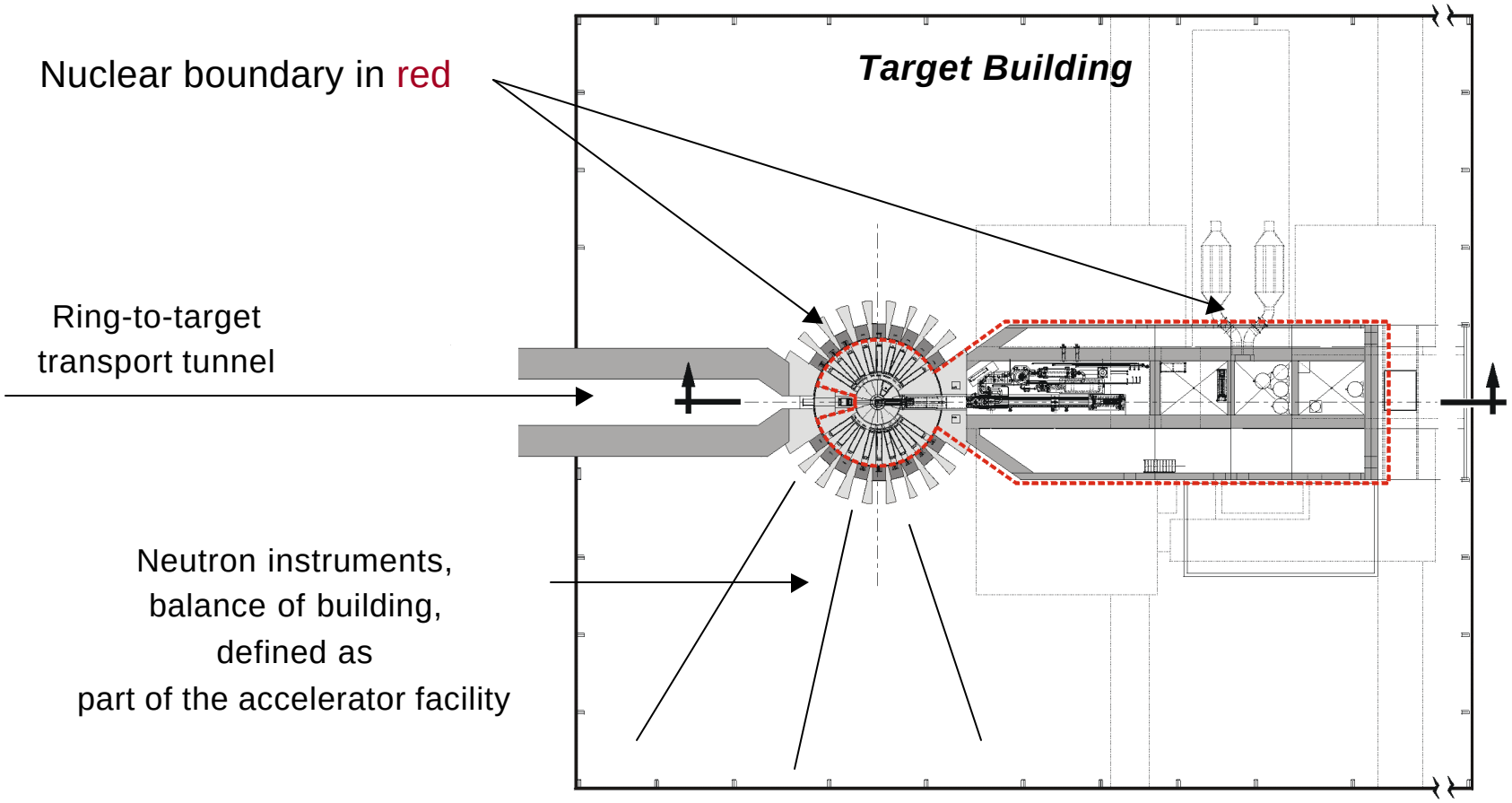
# Hazard Category 2 Indices for SNS Hg Target



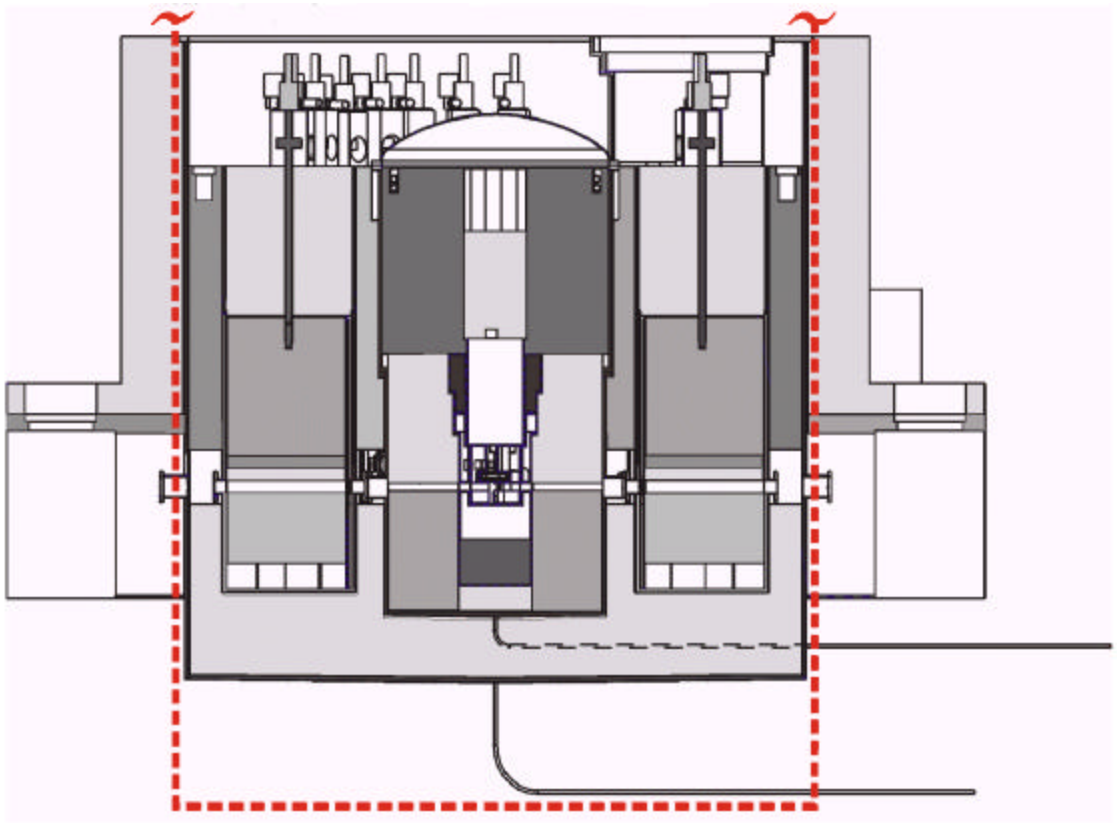
# DOE Safety Documentation Requirements Differ for Nuclear and Accelerator Facilities

- Accelerator Facilities: DOE Order 420.2 and related guidance
  - Preliminary Safety Assessment Document (PSAD) required for design stage
  - Independent review required
  - Approval authority with project management
  - Includes facilities integrally connected to accelerator
  - DOE approval of the Accelerator Safety Envelope required prior to commissioning and/or operations.
- Nuclear Facilities: DOE Order 420.1, 10 CFR 830, DOE Standards 3009, 1027, 1019-24, and others
  - Preliminary Safety Analysis Report (PSAR) required for nuclear facilities ... per DOE-STD-1027 this includes the SNS target and related facilities
  - Approval required before construction begins
  - DOE reviews and approves the PSAR
  - Approval of final SAR (FSAR) required for operation & commissioning

# The Nuclear Facility Includes a Portion of the Target Building (1)



# The Nuclear Facility Includes a Portion of the Target Building (4)



Section through target, monolith and neutron beam lines

## PSAR Process Takes Significant Time & Resources, and Must Be Completed Prior to Construction

| Activity | Time |
|---|---|
| Preparation by SNS and contractor | June – December 1999 |
| DOE Review | January/February 2000 |
| Approval (stipulated completion of chemical consequence analysis) | February 2000 |
| Chemical hazard and fire accident analysis | May – August 2000 |
| DOE Review of Chem/fire analysis | October 2000 (ongoing, approval expected soon) |

# Chemical Consequences Are More Limiting than Radiological

- WORKER, accident limit:
  - Toxicity limit for infrequent accidents is 10 mg/m$^3$ for 0.5-hours (IDLH -- “immediately dangerous to life and health”)
  - Rad dose due to 10 mg/m$^3$ for 0.5-hours (long lived Hg isotopes) = 4 rem (within 10 CFR 835 annual limit)
- PUBLIC: accident limit does not exist (SNS plans to propose 2 mg/m$^3$ for “ERPG-2” limit)
  - Toxicity “limit” is 2 mg/m$^3$ for 1-hour exposure (proposed ERPG-2)
  - Rad dose due to 2 mg/m$^3$ for 1-hour = 1.6 rem [DOE’s “evaluation guideline” (max limit) is 25-rem for public exposure to infrequent accidents]
- Bottom line: For accidents, the toxicity consideration is more limiting by factor of approximately 10.

# The Emergency Response Planning Guideline (ERPG) Values

- The Emergency Response Planning Guideline-2 (ERPG-2) value is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.

# Comments on Using a Hg Target 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
- Using mercury could significantly complicate the Environmental Impact Statement and Safety Analysis
  - Neutrino factory/muon collider will likely be a Nuclear Facility
- SNS facilities, capabilities, and expertise are available for the Neutrino Factory and Muon Collider Collaboration