Analysis of the Causes and Consequences of Neutron Guide Tube Failures

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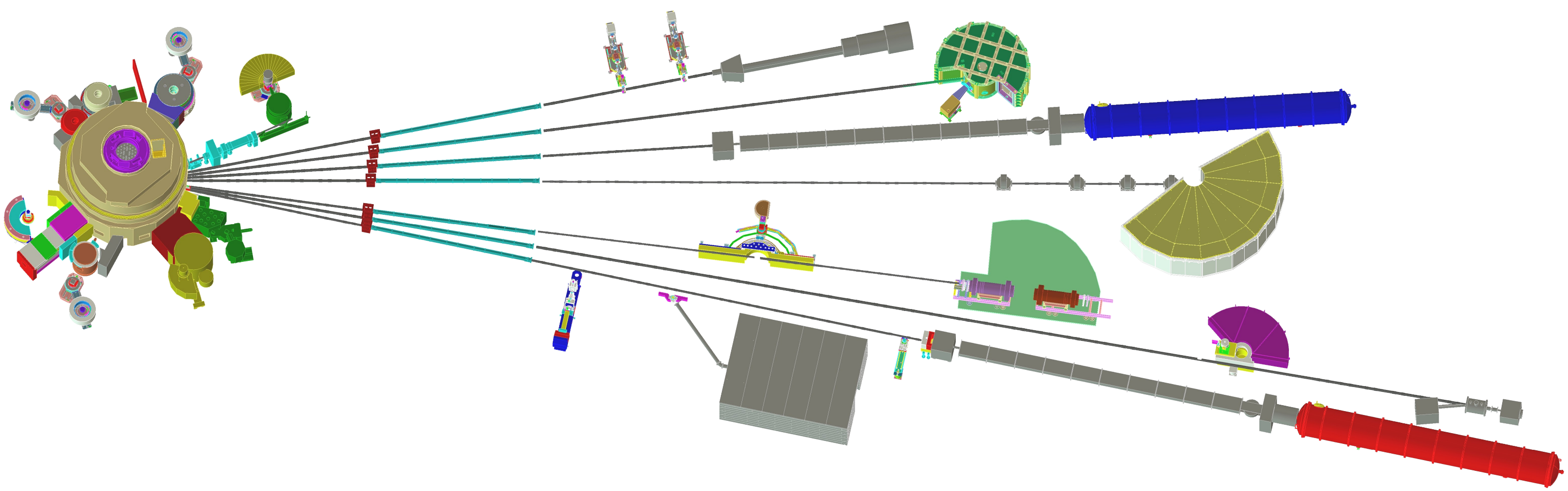
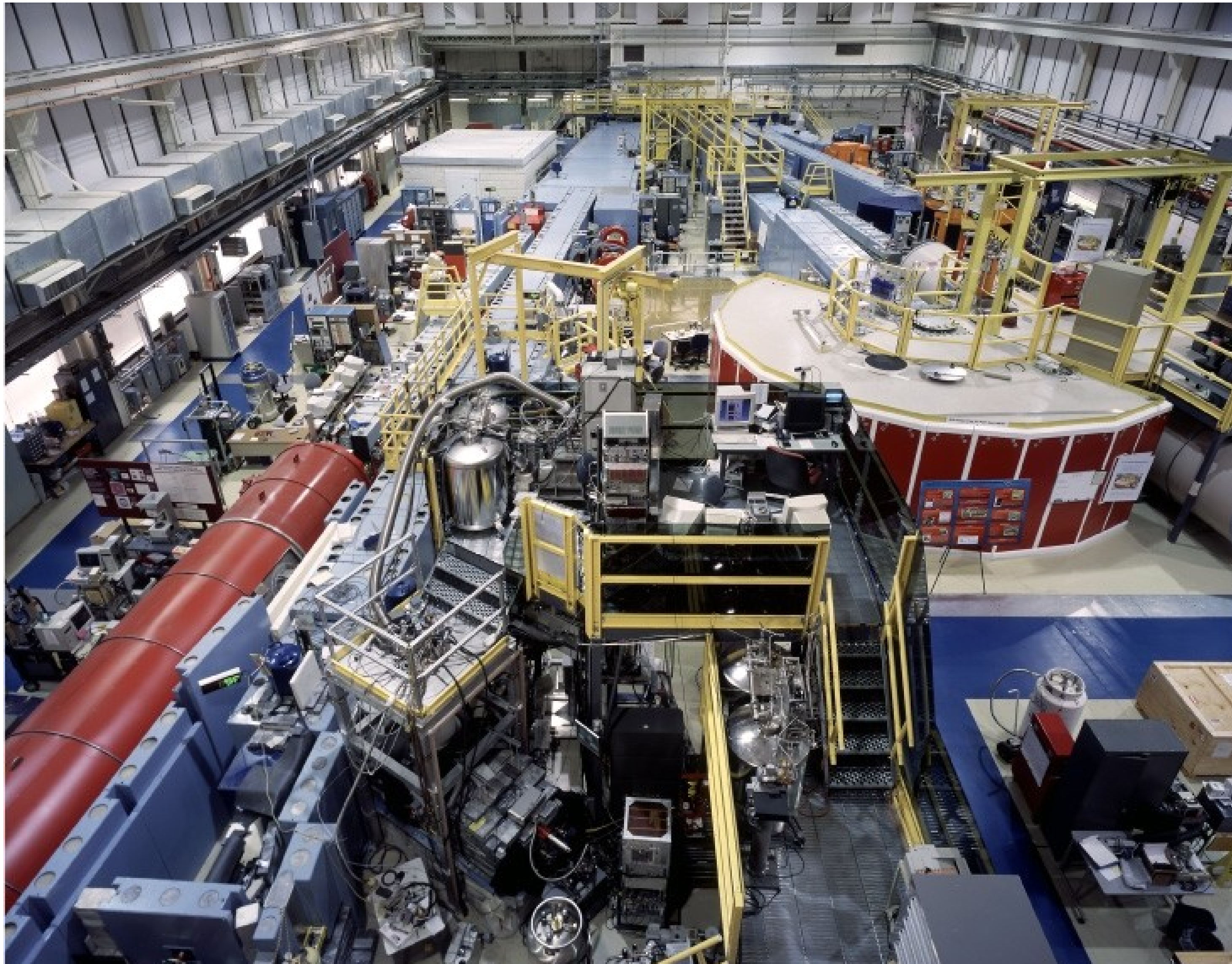
NCNR Guide Tube Layout



NIST Guide Hall 2003



The Problem

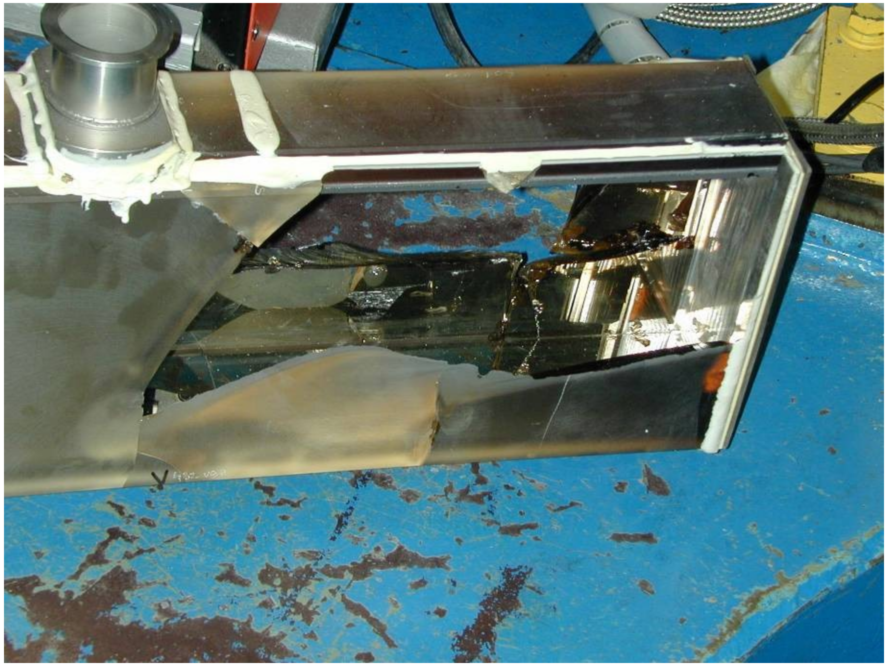
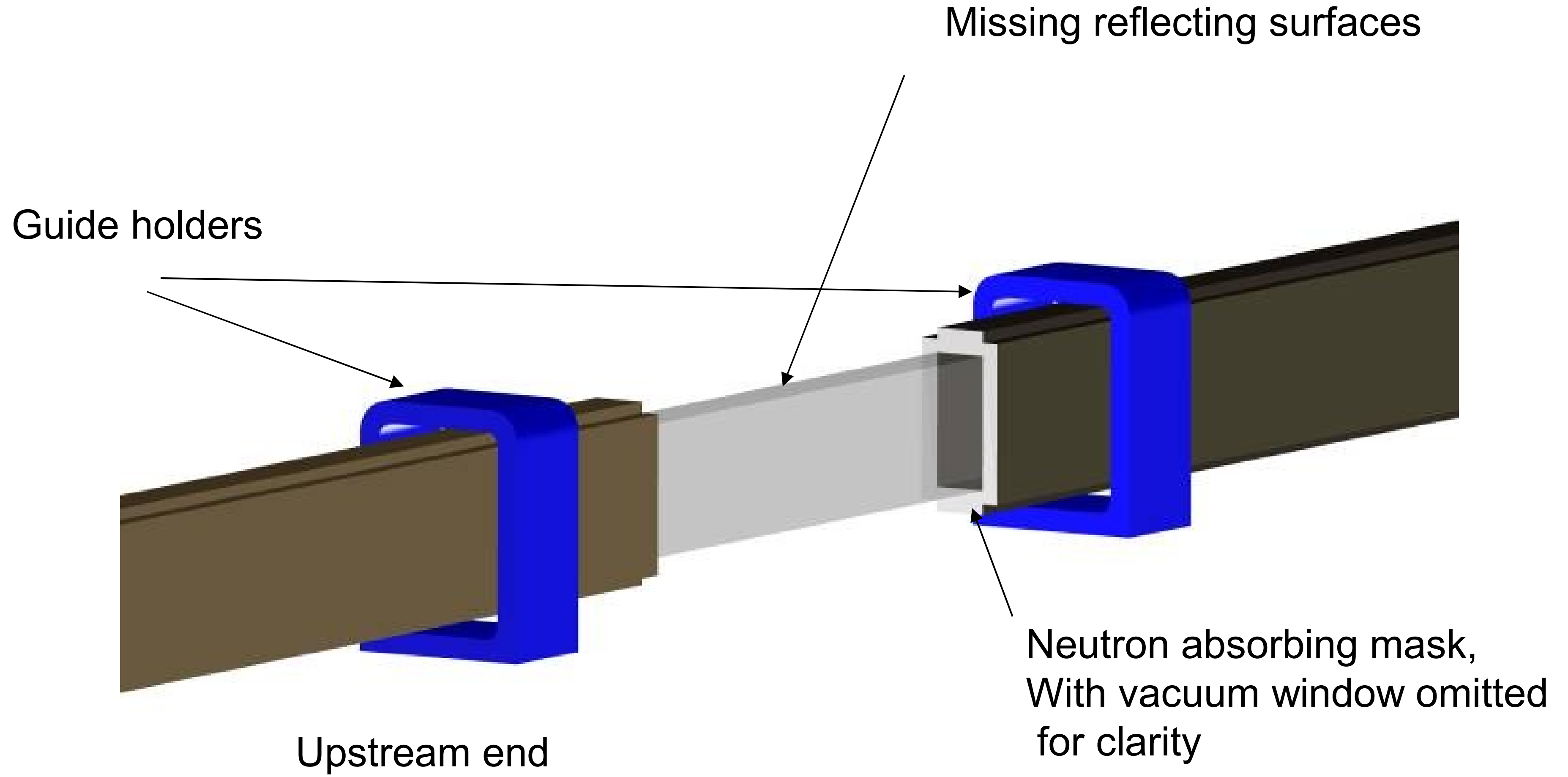
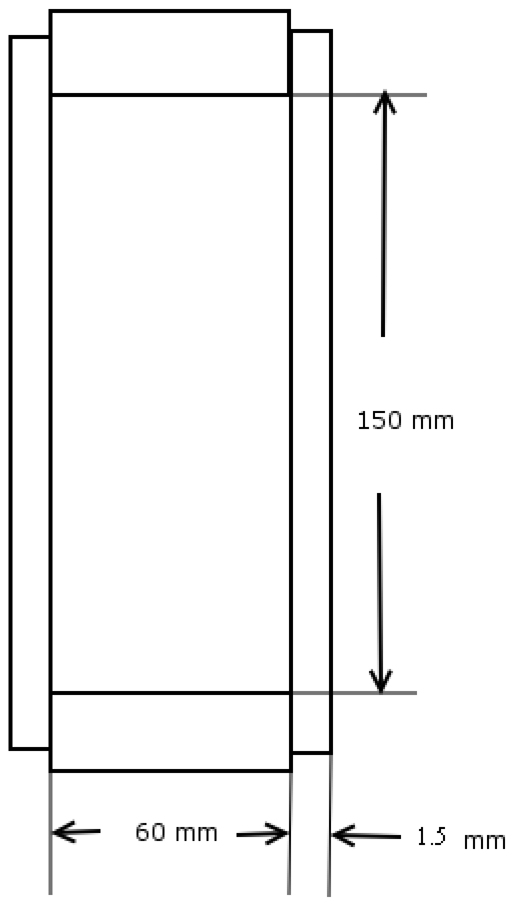


Diagram of Neutron Guide Cut



Cross-section View of guide



The Problem

- Neutron guide tubes are made of glass, polished flat and coated with Ni metal (or other materials)
- Most of the glass used is of the borosilicate type, in order to make use of the excellent mechanical properties
- When neutrons are captured in boron, α-particles are emitted, causing radiation damage
- While γ-radiation does cause damage, it is much less destructive than the α-particles (leads to color centers – dark brown)

The Problem Continued

- For regions of the guides away from the source, the guides are maintained under an internal vacuum, putting the walls under stress
- When the glass is sufficiently damaged, the guide can fail suddenly (implosion), causing a sudden loss of vacuum, and concomitant pressure wave and debris acceleration

The Solution

- The problem is directly attributable to radiation damage caused by neutron capture and α emission
- Therefore, prevent neutrons from hitting the glass
- Very well fabricated masks after any guide gap that cover the entire guide end, with very close tolerances (EDM of BAl)

Consequences

- Large pieces of glass can be accelerated along the guide in the direction away from the point of failure
- If a failure occurs such that this directs fragments towards the reactor and cold source, the vacuum windows can be breached, and one must analyze the possibility of cold source damage

Analysis

- There is a low energy shock wave generated, but it does no damage (high Mach Number, but low pressures)
- Glass fragments can be accelerated to high speeds, primarily by gas entering, *not* shock
- Calculation of speeds requires use of sonic flow equations for pressure waves
- Probability of penetration can then be calculated
- Windows can be sized to ensure safety

Some Salient Results

- Low energy shock
  - M = Macg Number = 6.1
  - P_{shock} = 500 Pa = mTorr
- High projectile velocities, up to 18 m/s for very large fragment
- Penetration criterion (50% probability) = 890h, h = window thickness in m
- DETAILS IN MANUSCRIPT

Further Observations

- Lifetime depends on many factors
  - Type of glass (Borkron, borfloat…)
  - Quality of masking (we EDM masks to high tolerance)
  - Neutron fluence rate at point of exposure
  - Length of guide cuts
- Other events can cause failure
  - Drop heavy object on guide
  - Cryogenic fluids

Summary

- Mask is essential
- Adequately sized window required
- Guides **must be protected when under vacuum**
  - Heavy shields during operation
  - Helium filled during maintenance
  - Protection from cryogens