

“Minibake” discussion

- Advisory to PI/PM; no decision
- Baseline schedule assumed:
 - ›› Fab begins 8/96, install begins 10/96
 - ›› Fab/install proceeds on two modules in parallel
 - ›› Fab/install proceeds immediately to next arm
 - ›› Module bakeouts proceed immediately after acceptance test

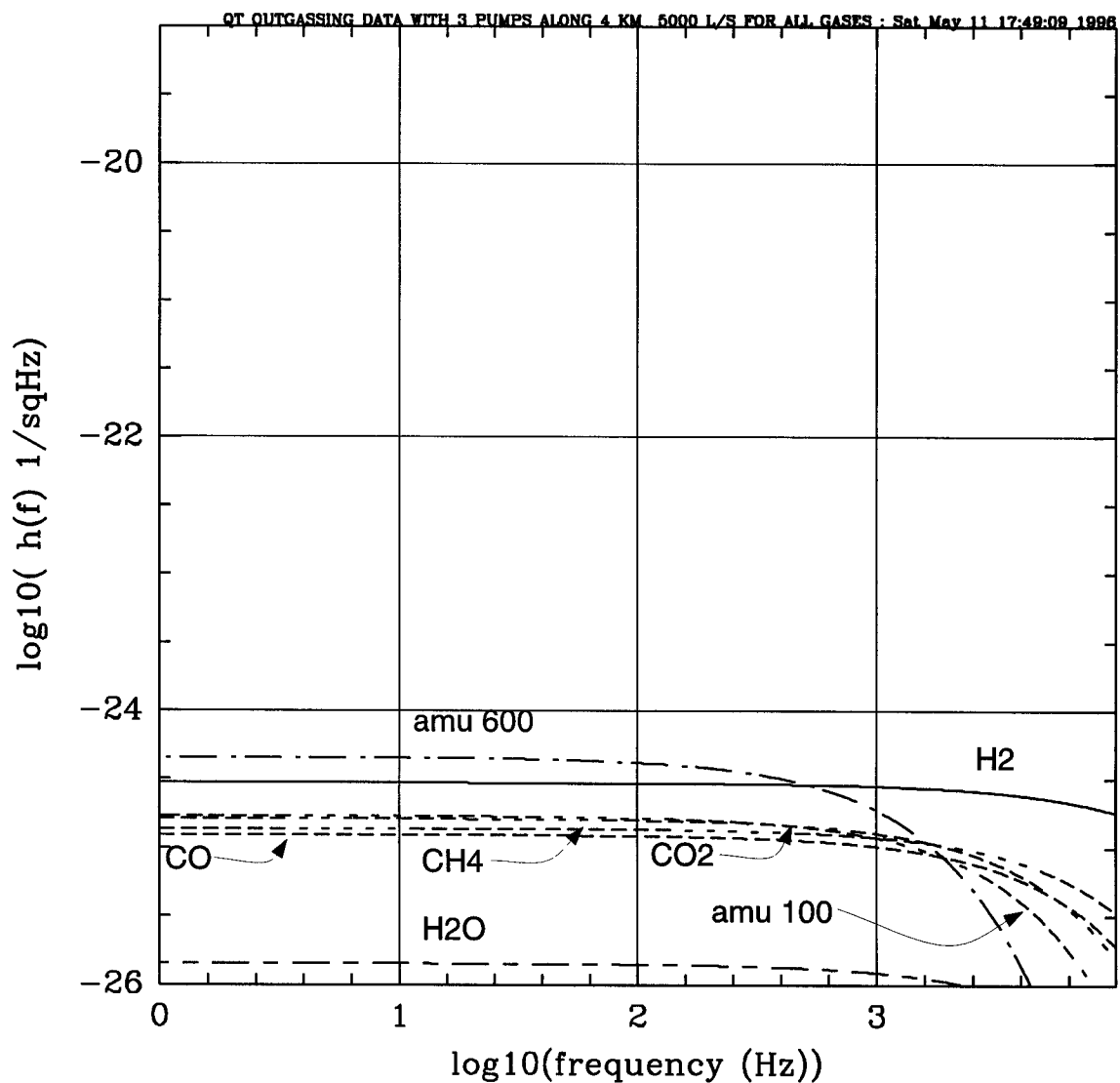
Beam Tube Performance Requirements

- Clear aperture
 - ›› CBI is responsible for delivering 1.19 m clear aperture at supports; we estimate 1.05m clear aperture w/baffles
- Leak-free
 - ›› CBI is responsible for all detectable leaks before bake: $>10^{-5}$ t-L/s guaranteed by CBI; $>2 \times 10^{-8}$ t-L/s (our estimate)
- Vacuum performance level
 - ›› CBI is responsible for following approved low H₂ steel, cleaning and handling procedures

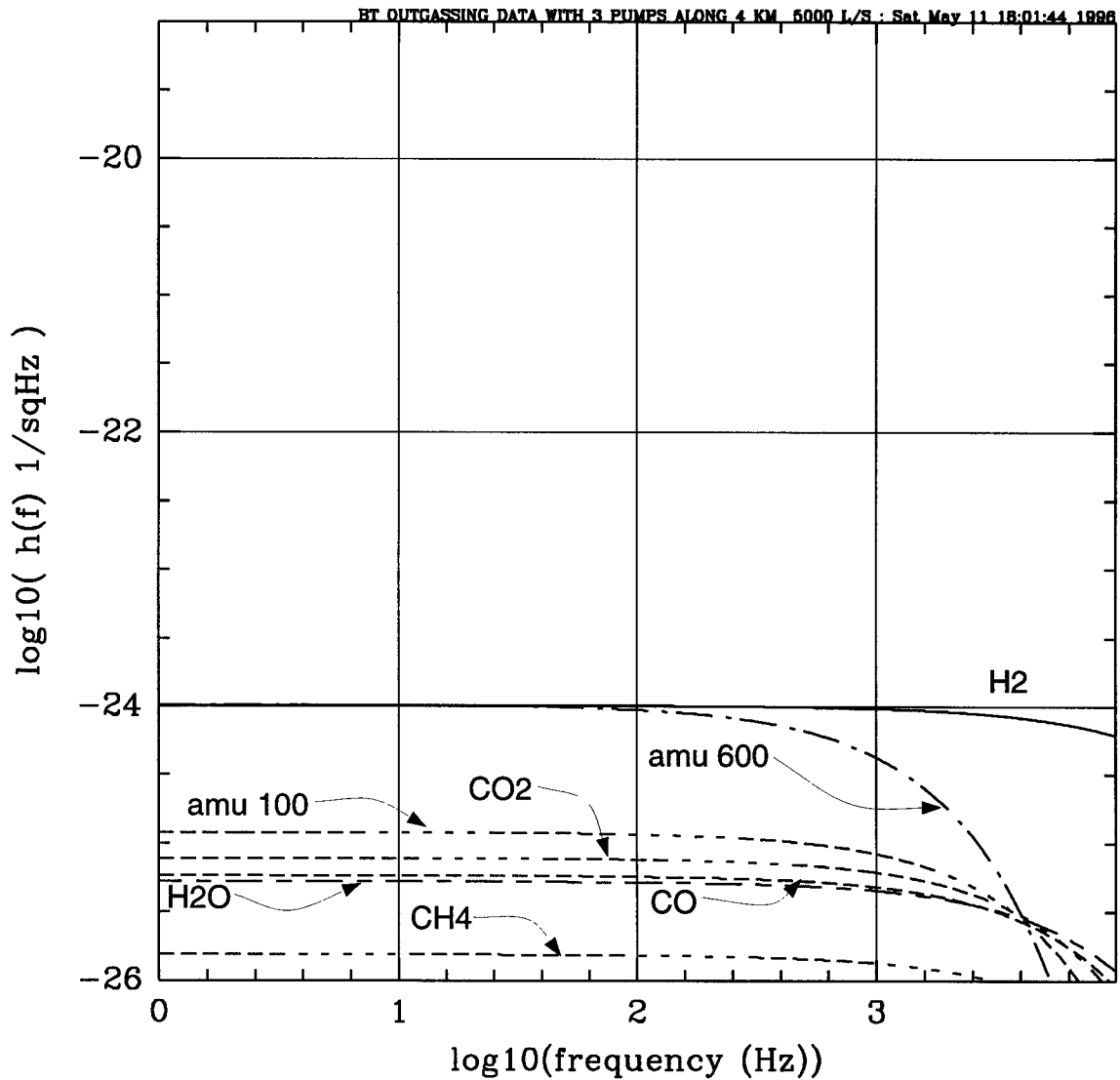
What did the Qualification Test (QT) do?

- Demo'd vacuum performance (comparison with LIGO sensitivities)
- Demo'd air signature leak detection procedure
- Demo'd coupon H₂ outgassing test apparatus
- Demo'd basic mechanical design, fit
- Demo'd baffle installation procedure (design since changed)
- Demo'd girth weld procedure, equipment
- Revealed a problem with spiral weld procedure/equipment
- Demo'd thermal performance of expansion joint, bakeout insulation/heating
- Many lessons learned

QT OUTGASSING 3 PUMPS

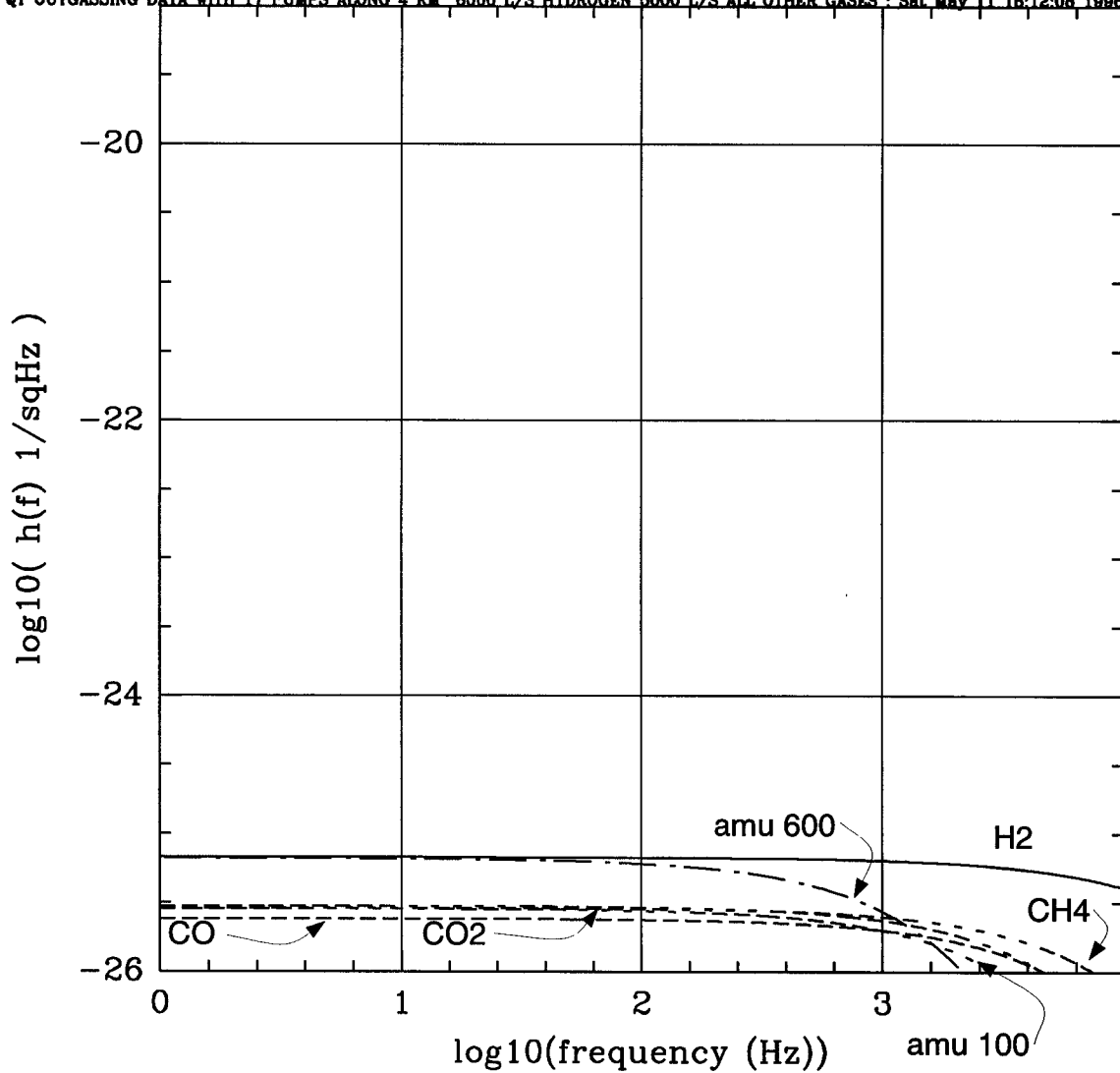


BTD OUTGASSING 3 PUMPS

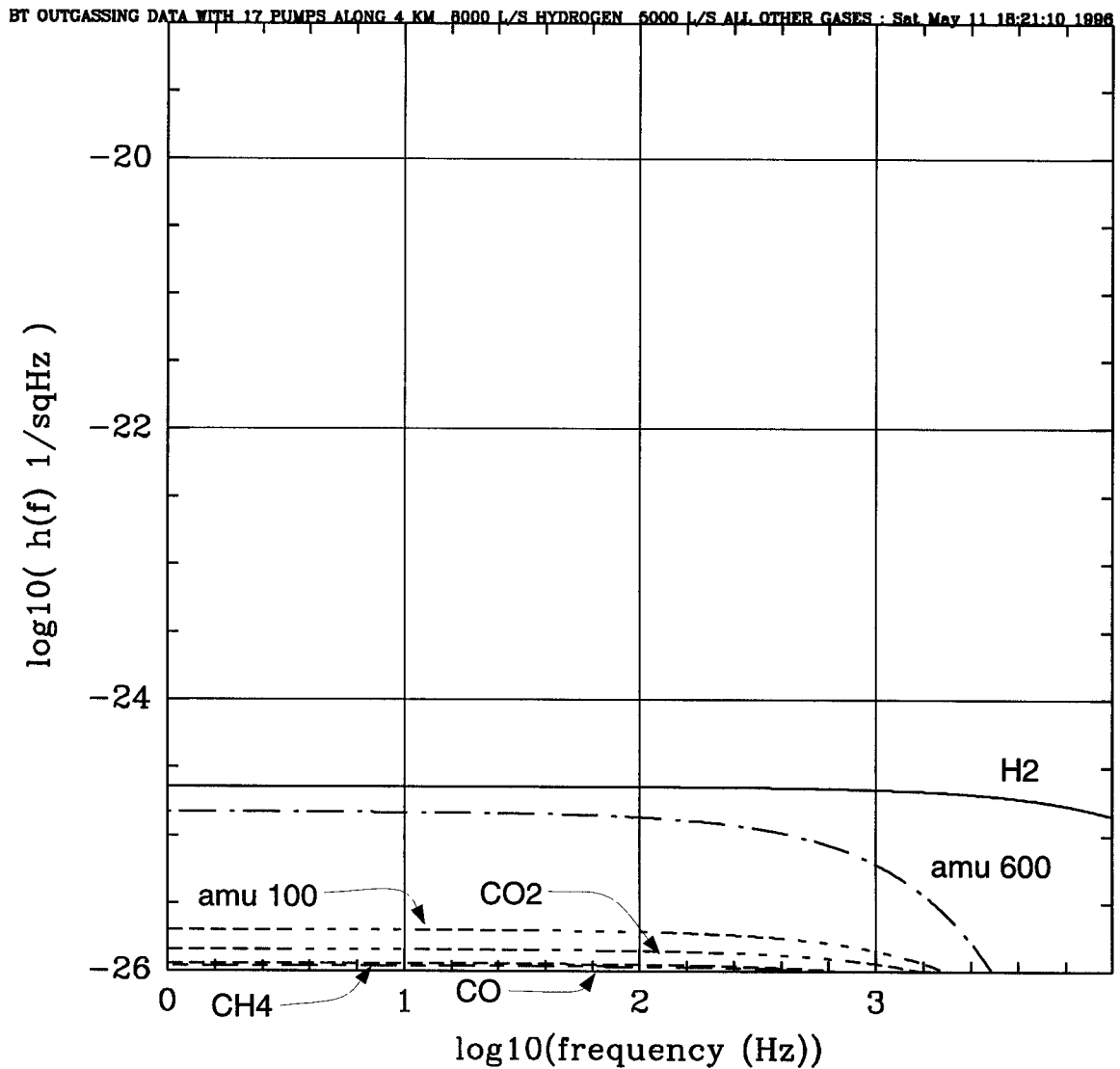


QT OUTGASSING 17 PUMPS

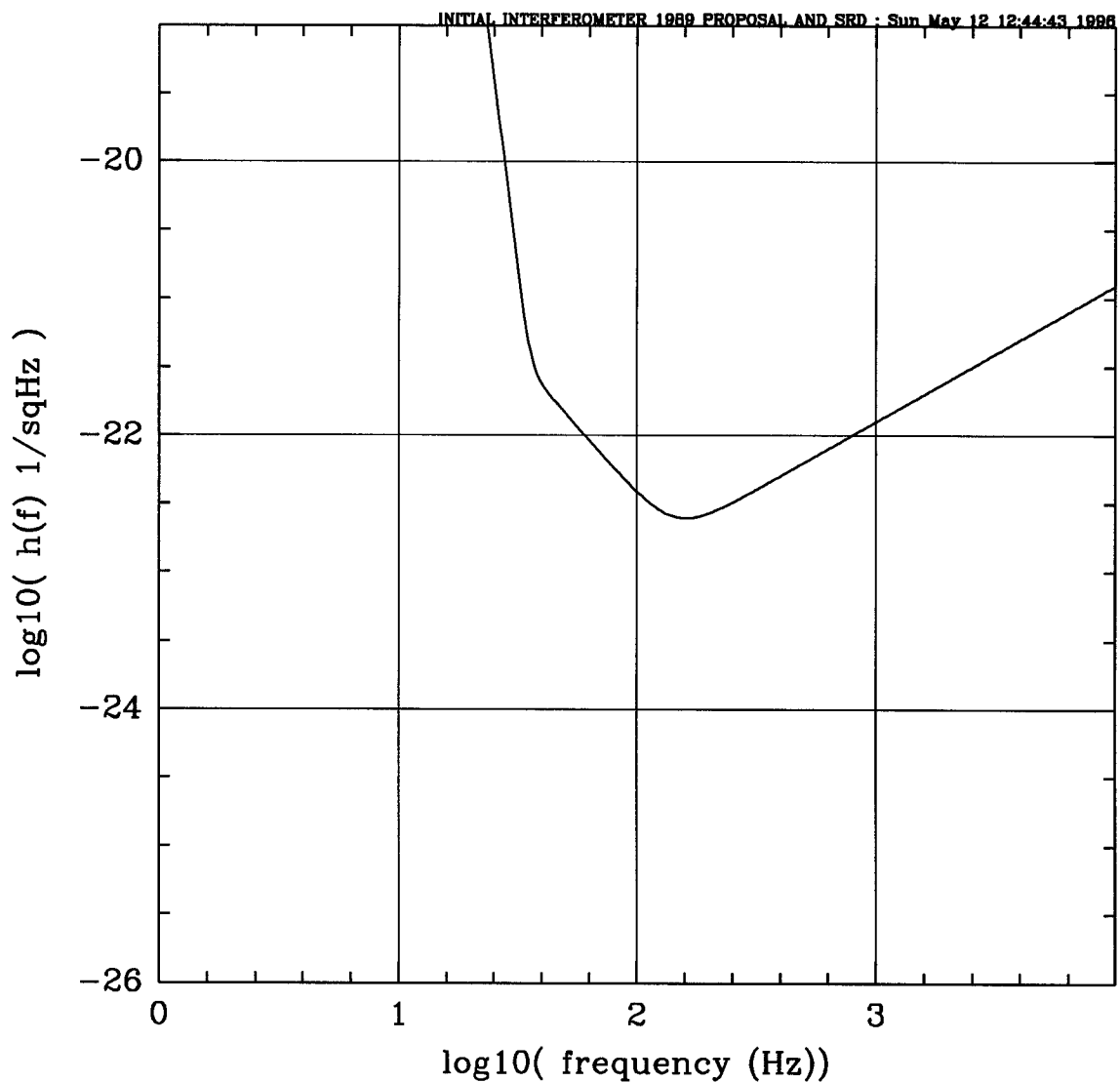
QT OUTGASSING DATA WITH 17 PUMPS ALONG 4 KM 8000 L/S HYDROGEN 5000 L/S ALL OTHER GASES : Sat May 11 18:12:08 1996



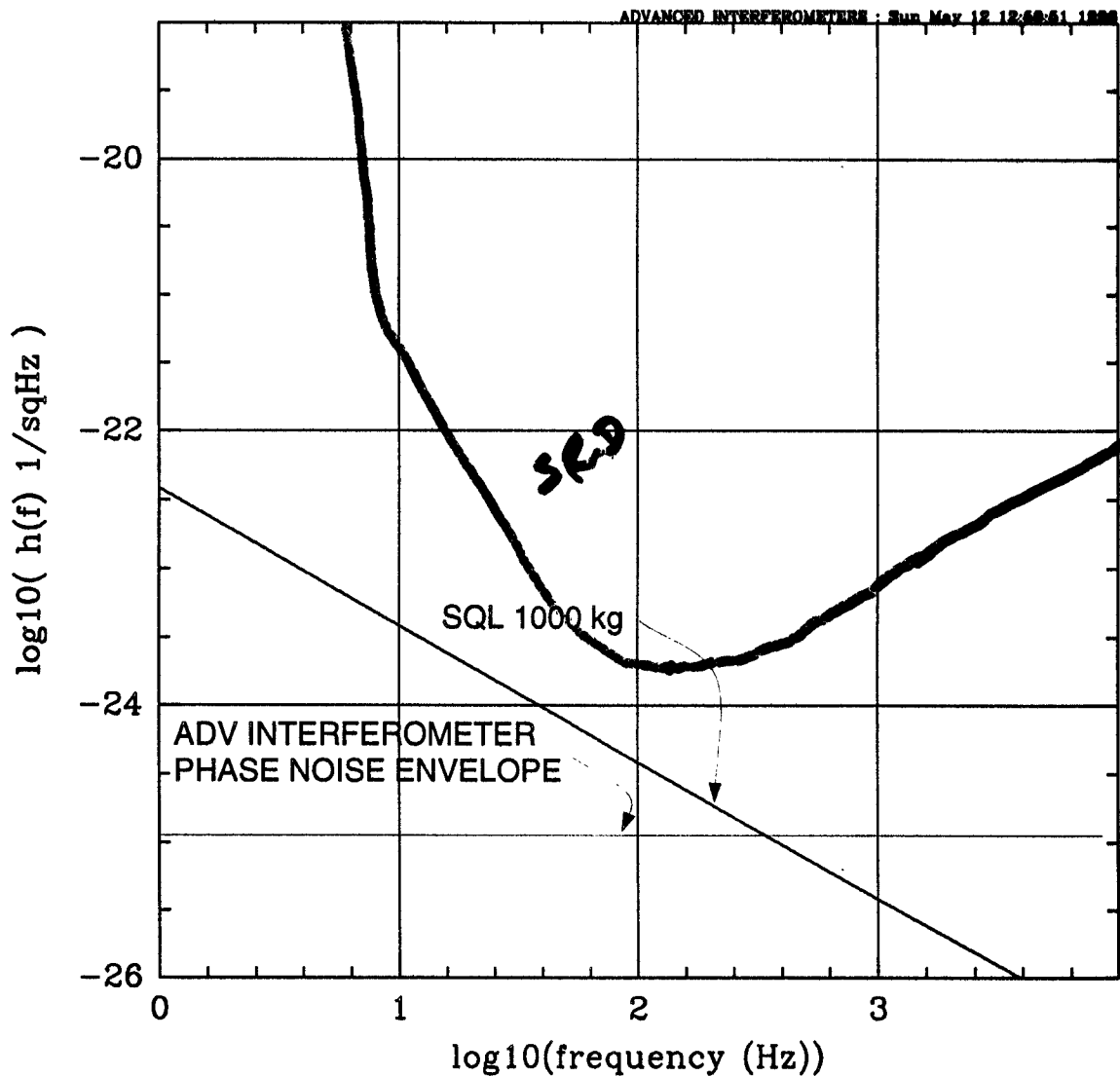
BTD OUTGASSING 17 PUMPS



INITIAL INTERFEROMETER



ADVANCED INTERFEROMETER



POST BAKE OUTGASSING

| gas | BTD outgassing rate torr liters/sec cm ² | QT outgassing rate torr liters/sec cm ² |
|------------------|--|---|
| H ₂ | 1×10^{-12} | 8×10^{-14} |
| CO | 6×10^{-17} | 2×10^{-16} |
| CO ₂ | 4×10^{-17} | 2×10^{-16} |
| CH ₄ | 4×10^{-18} | 3×10^{-16} |
| amu 100 | $< 2 \times 10^{-18}$ | $< 4 \times 10^{-18}$ |
| amu 600 | $< 2 \times 10^{-18}$ | $< 2 \times 10^{-19}$ |
| H ₂ O | $< 2 \times 10^{-16}$ | $< 8 \times 10^{-18}$ |

What was *NOT* tested by the QT?

- Field installation equipment
 - ›› Portable clean rooms: seals against environmental intrusion
 - ›› Portable clean rooms: confined working space
- Outdoor conditions
- Beam tube structural supports, termination anchors
- Outgassing of gate valves
- Leak localization techniques
- Pump port hardware
- Section leak test coffins
- Expanded tube section ends

What has changed since the QT?

-
- Spiral weld: tube mill, skelp width, welding equipment, weld procedures, personnel (now CBI)
 - Cleaning procedure
 - Baffle design, coating
 - Baffle installation procedure

Cleaning procedures

| QT | LIGO BT Modules |
|--------------------------------------|------------------------------------|
| Detergent bath (Mirachem, undiluted) | Steam spray wash w/Mirachem (1:30) |
| Spray rinse with DI water | |
| Steam spray rinse with DI water | Steam spray rinse with DI water |
| Isopropyl wash bath | |
| Isopropyl rinse bath | |

- Changes:
 - ›› Hot spray of diluted Mirachem rather than room temp undiluted bath
 - ›› Delete alcohol steps

Current Planned QA Checks Production Tests

- Steel mill metallurgical/chemical/physical properties (1/heat)
- Steel coupon H₂ outgassing (1/bake lot)
- Tube section dimensional tests (100%)
- Expansion joint tests (100%)
- Tube section assembly leak test (100%)
- Spiral weld X-section inspections (each 65')
- Tube section post-cleaning FTIR test (first 10 sections, each 10th section thereafter)
- Girth seam leak test (100%)
- Post-installation visual inspection (each section)
- Alignment checks

Current Planned QA Checks

One-time Tests

- Spiral weld coupon H₂ outgassing measurement
- 65' tube section prototype
- Individual certification of each piece of fabrication shop and field installation equipment/set up

Risk Assessment - Problems Detected at Beam Tube Module level

| Problem | Reaction | Impact |
|--------------------|---|--|
| Leak (before bake) | a) Locate and repair | --- |
| | b) Revise weld procedures, modify equipment | Schedule delay |
| Leak (after bake) | a) Repair (no air release) and retest | 1-3 mo delay, <\$0.2M |
| | b) Repair (air release), rebake and retest | 2-6 mo delay, <\$0.5M |
| | c) Procedure/tooling changes | 3 mo delay, CBI standby = \$1M to \$2M |

Risk Assessment - Problems Detected at Beam Tube Module level

| Problem | Reaction | Impact |
|---------------------------------------|---|---|
| Outgassing problem | a) Bake longer/hotter | schedule delay, add'l bake power cost <\$0.5M |
| | b) Locate and fix process contamination problem | 3 mo delay, CBI standby = \$1M to \$2M |
| Unanticipated problem: | | |
| Insulation failure | Rework insulation and restart bakeout | \$0.1M to \$0.2M |
| Problem with bake procedure/equipment | a) Repair, rebake | \$0.25M |
| | b) Catastrophic: replace module | \$4M |

What have we missed?

Nightmare Scenarios

- Ultimate vacuum performance limits LIGO sensitivity prematurely due to inadequate cleaning procedure ...
- H₂ outgassing starts increasing after 3 years ...
- Field worker leaves a tuna sandwich in the tube ...
(variant: field mice discover fine living conditions - until ...)
- Screw around with beam tube planning and process qualification too long, NSF discovers our insecurity and panics ...

Additional special qualification or in-process tests

- Periodic weld coupon outgassing
- Coupon surface tests (Auger, SIMS analysis of cleaning)
- Laser backscatter inspection after installation of each section
- Increased FTIR test frequency
- Increased H₂ outgassing coupon test frequency

“Minibake” scenarios (vacuum performance tests of baked vessels)

- Ship first 65' section to CBI or Caltech or MIT, cap, bake/test
- Join two capped sections on-site, cover with BTE, bake/test
- Install isolation valve 250m downstream in first production module, insulate and bake/test in-situ
- [violates schedule assumption] Bake/test first module (of 2 initial) before proceeding with other 6
- [baseline plan] Bake/test first module in parallel with fab/install of remainder (results to late too affect Hanford installation)

Discriminants between “Minibake” scenarios

- Impact on CBI’s plans
- Impact on LIGO staff
- Number of “real” variables tested
- Timing of availability of results
- \$ costs