In Situ Determination of Molecular Oxygen Concentrations in Full-Scale Fire Suppression Tests Using TDLAS

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IDEAL Fire Extinguishing Agent

Efficient at fire suppression
(Halon 1301 as the yardstick)

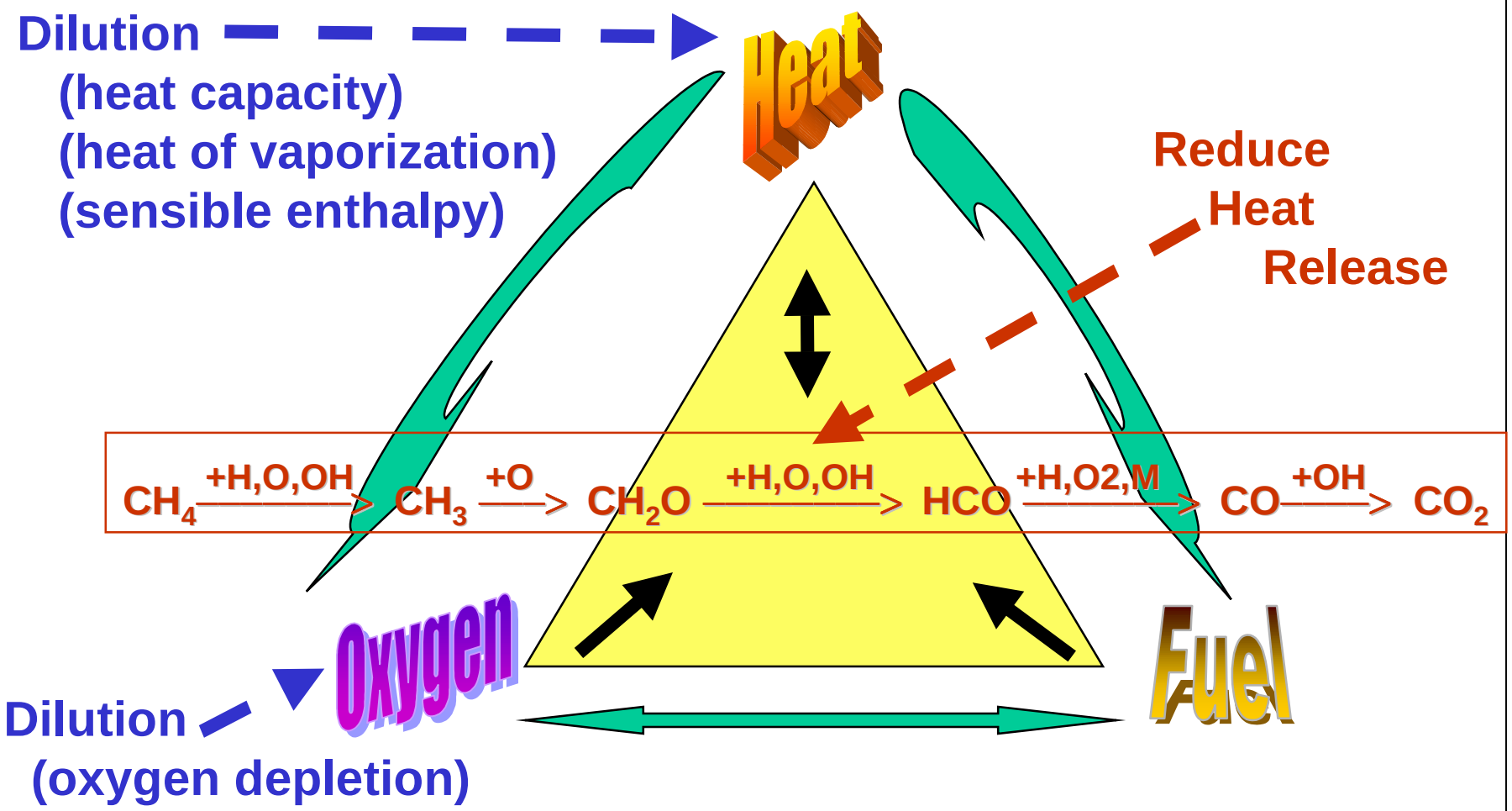
Non-conducting, Non-corrosive, No residues

- No (low) toxicity

- Minimum environmental impact
  - Zero ozone depleting potential
  - Zero global warming

- Cost effective

Physical versus Chemical Suppression



Fire Suppression by Water Mist

Sprinkler spray: drop diameter >1000µm

"Fine" water mist: drop diameter < 200µm

Molecular Oxygen Detection Methods

Paramagnetic	extractive	dry value
Electrochemical ZrO_2	*in-situ*	"dry" value
Gas chromatography	extractive	dry value
Optical	***in situ***	**absolute** (humid) value
TDLAS 759-770 nm	linestrength	< 8.8·10E-24cm^{-1}/molec·cm^{-2}
FT-IR 5.8µm-7.4µm	linestrength	< 1.5·10E-28cm^{-1}/molec·cm^{-2}

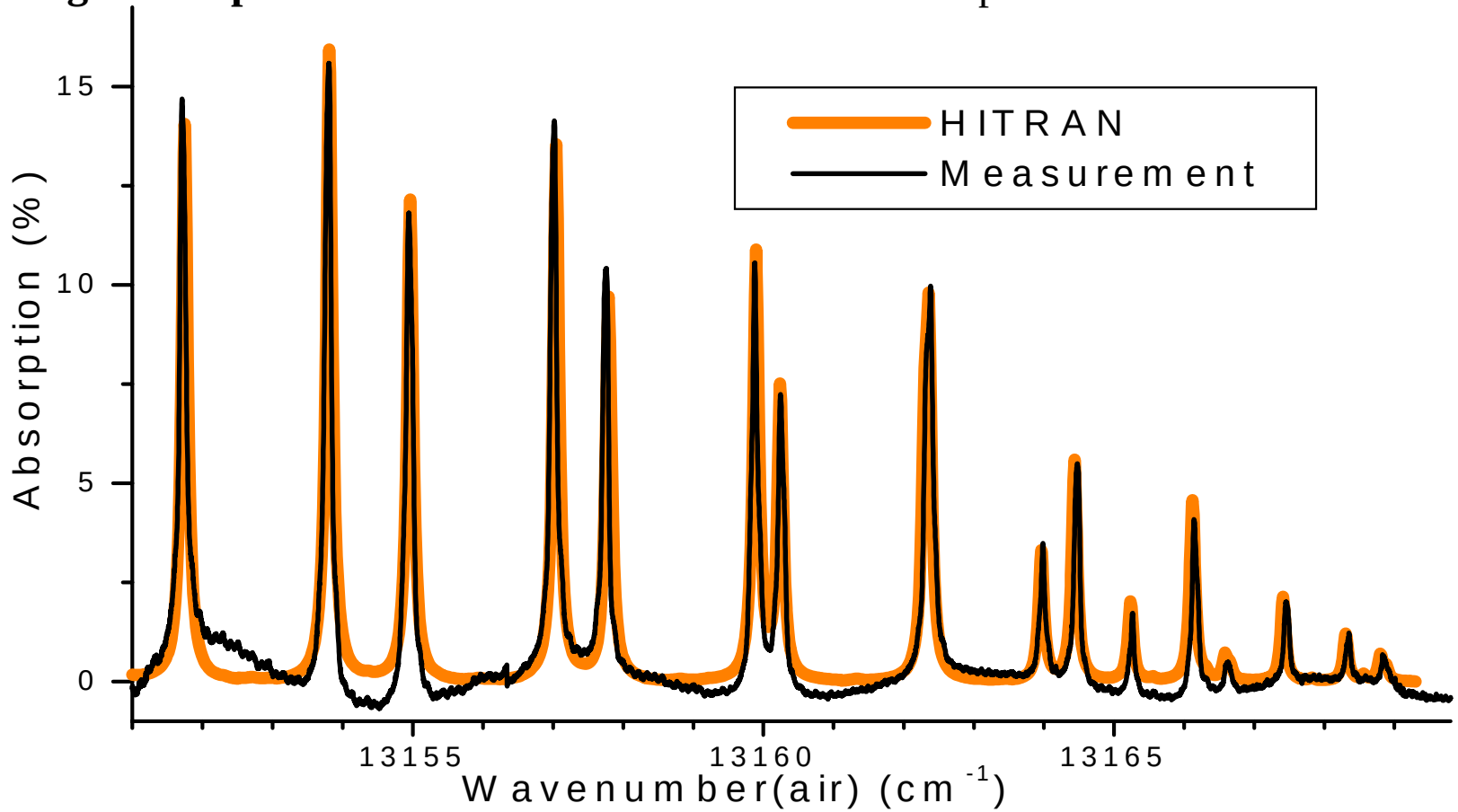
The Spectrum of Molecular Oxygen

A-Band (0← 0), 759 nm -770 nm

Magnetic Dipole Transition

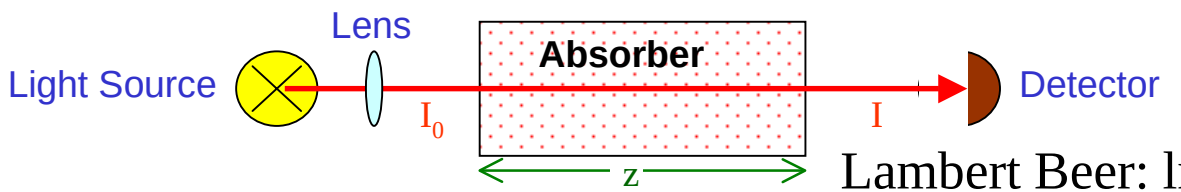
Lorentz Profile (Pressure broadening)

Width at room temperature: FWHM = 4.3 GHz

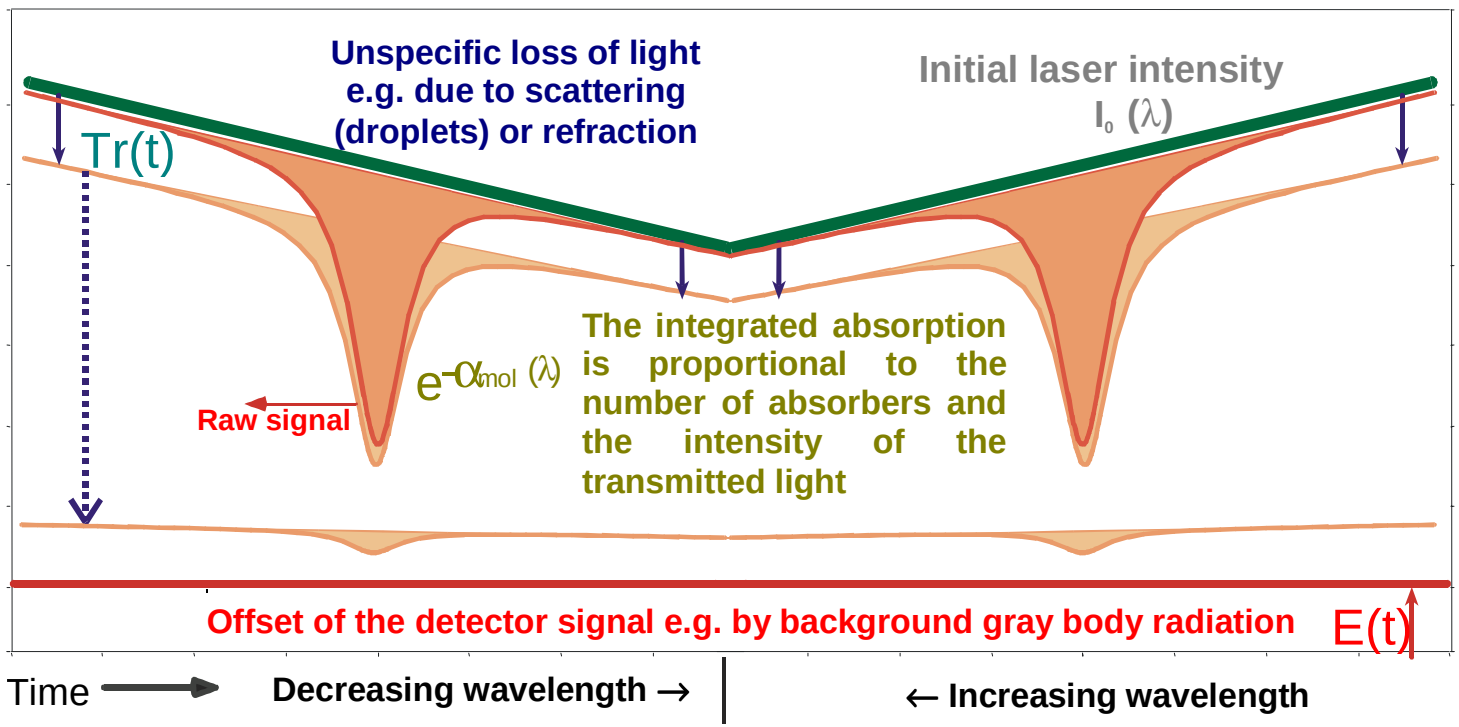


Method

Tunable Diode Laser Absorption Spectroscopy (TDLAS)



Lambert Beer: $\ln(I/I_0)=-\alpha Nz$



REQUIREMENTS for O_2 TDLAS SPECTROMETER

- Capability of *in situ* measurement of O_2
- Accuracy better than 1 vol.% O_2 absolute
- Time resolution < 1 sec
- Probe volume length $\leq$ 50 cm (current FT- IR is 30 cm)
- Reasonably Small Footprint
- Hardened to function in water drop, water vapor, and fire (up to 500 kW) environment
- Mobile (including cables, purges, cooling, etc.)

TYPICAL FIRE TEST CONDITIONS

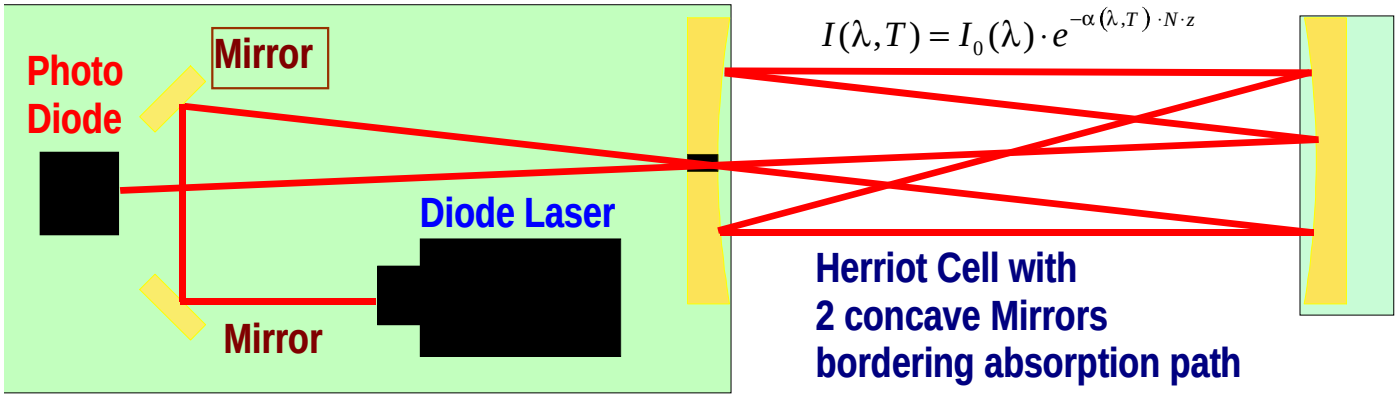
- O_2 variations of 5 to 21%
- Temperature variations from ambient to 150°C
- Need > 4 % absorption for all operating conditions - pathlength > 1 m
- Large and rapid obscuration gradients - 0 to 99.99%

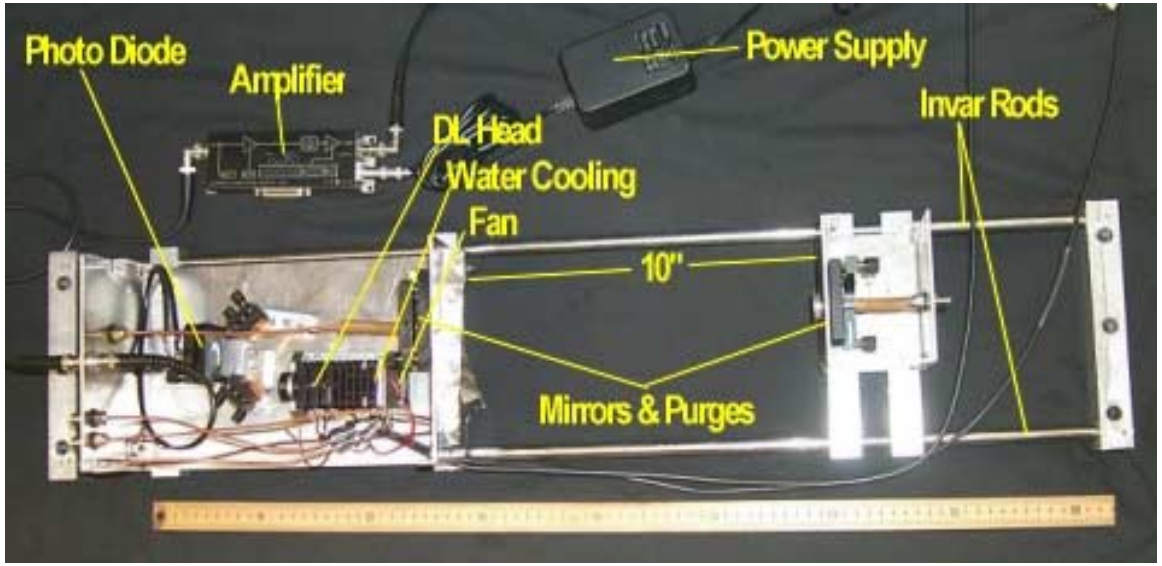
COMPROMISES

- Pathlength (molecular absorption versus scattering)
- Temporal resolution (signal acquisition time versus sensitivity)
- Hardware (ruggedness versus mobility)

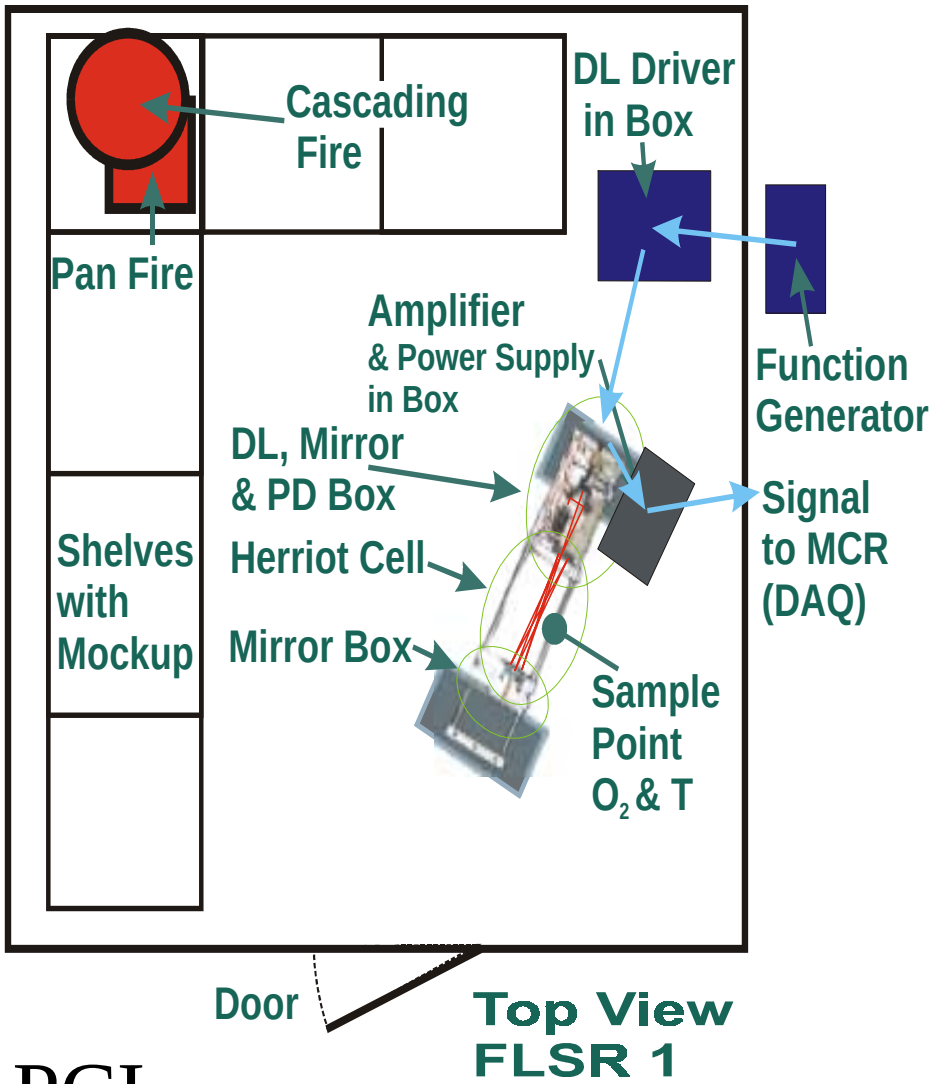
Setup

Instrumentation and Herriot Multipass Cell





Setup in the Flammable Liquid Store Room (FLSR 1)

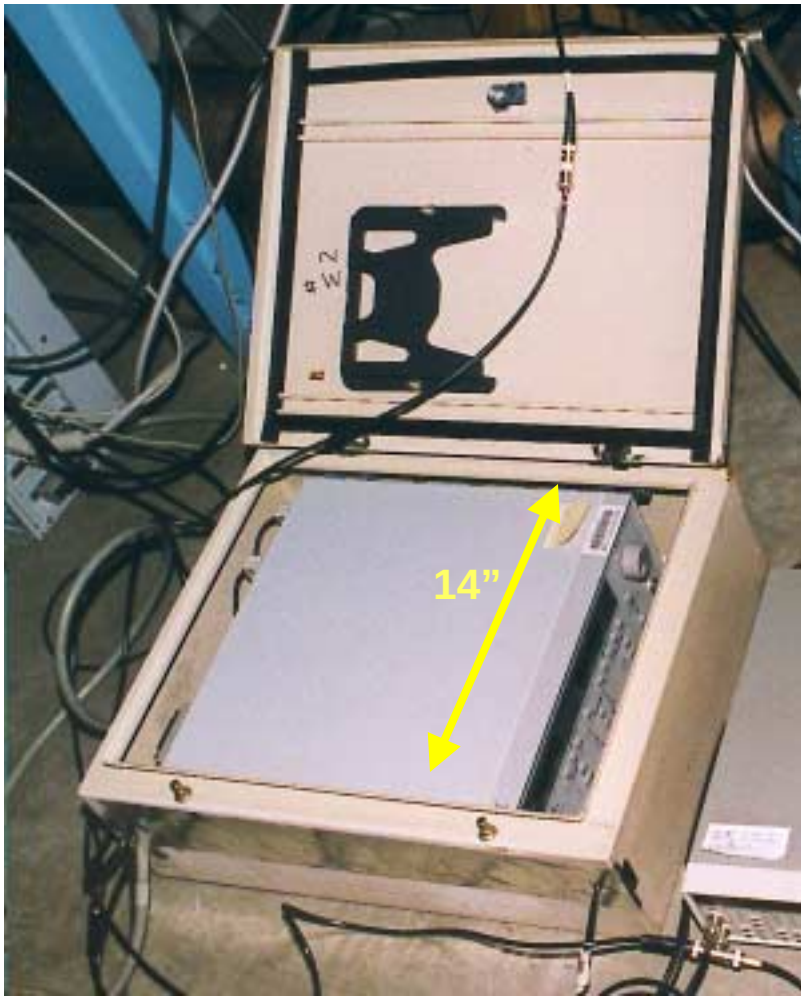


Cascading Fire

Setup of the Spectrometer and Adaptations to the Environment

↑Diode Laser and Detector Box

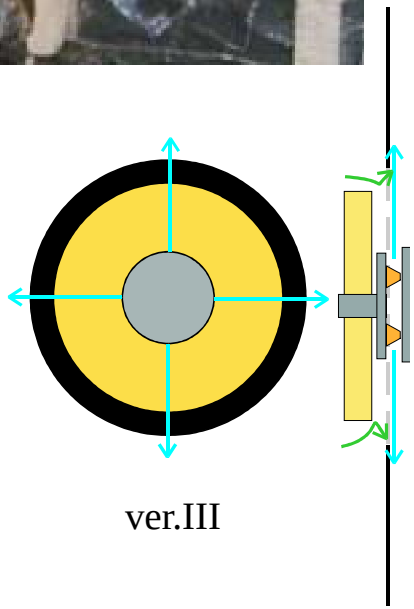
↓Diode Laser Control Unit



Adaptations to the Environment: Purges

Fire:
200kW
Heptane
cascading
& pan

Water Spray
Discharge:
WSCS
(TF8FC)



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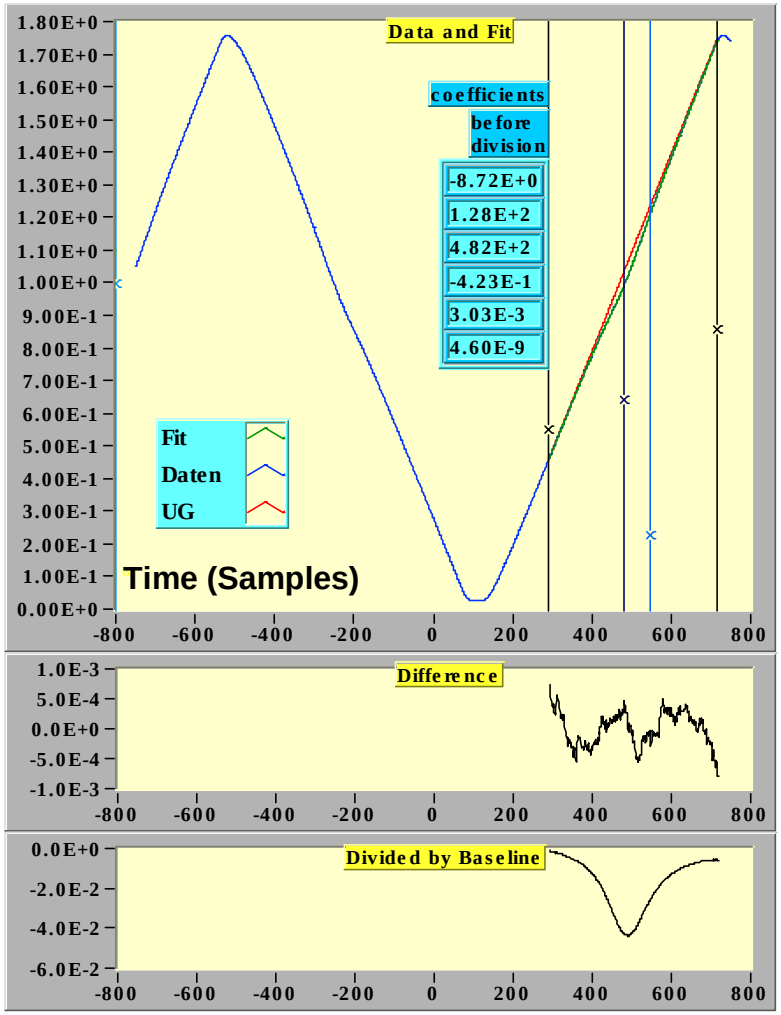
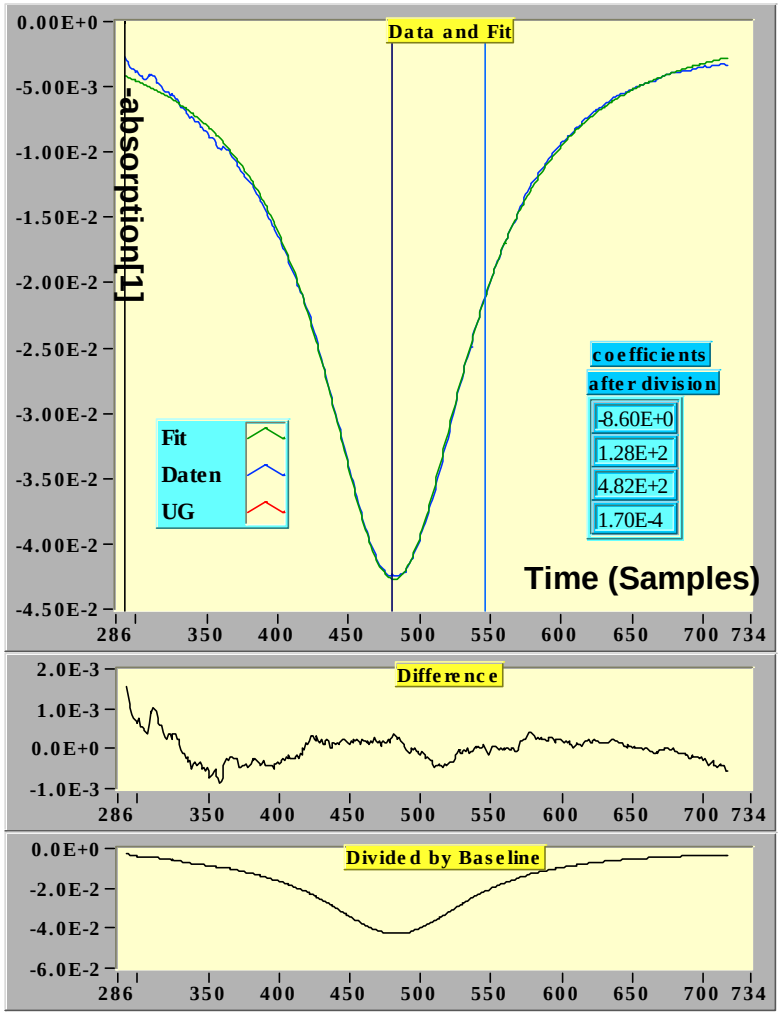
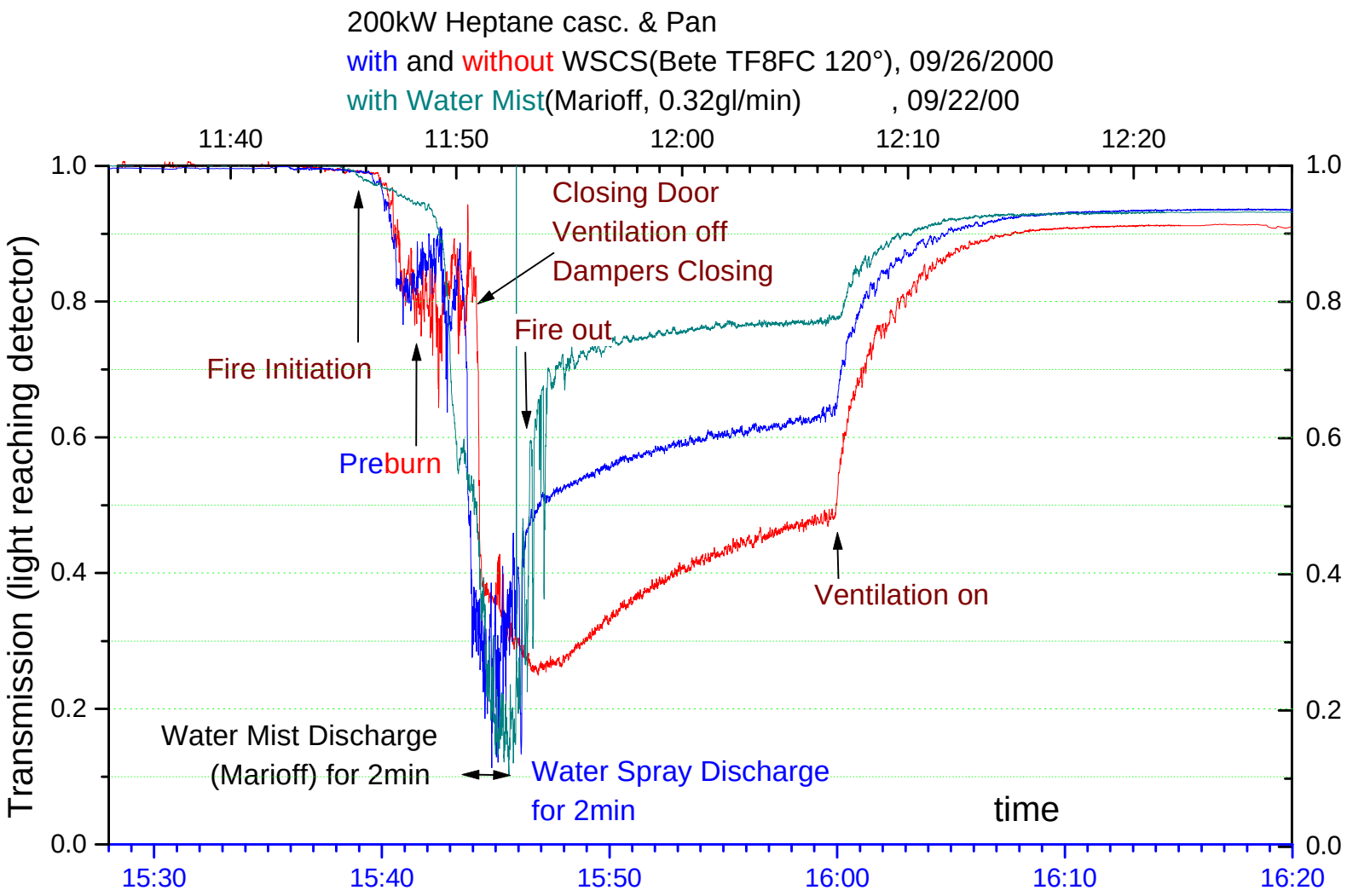
Data Evaluation

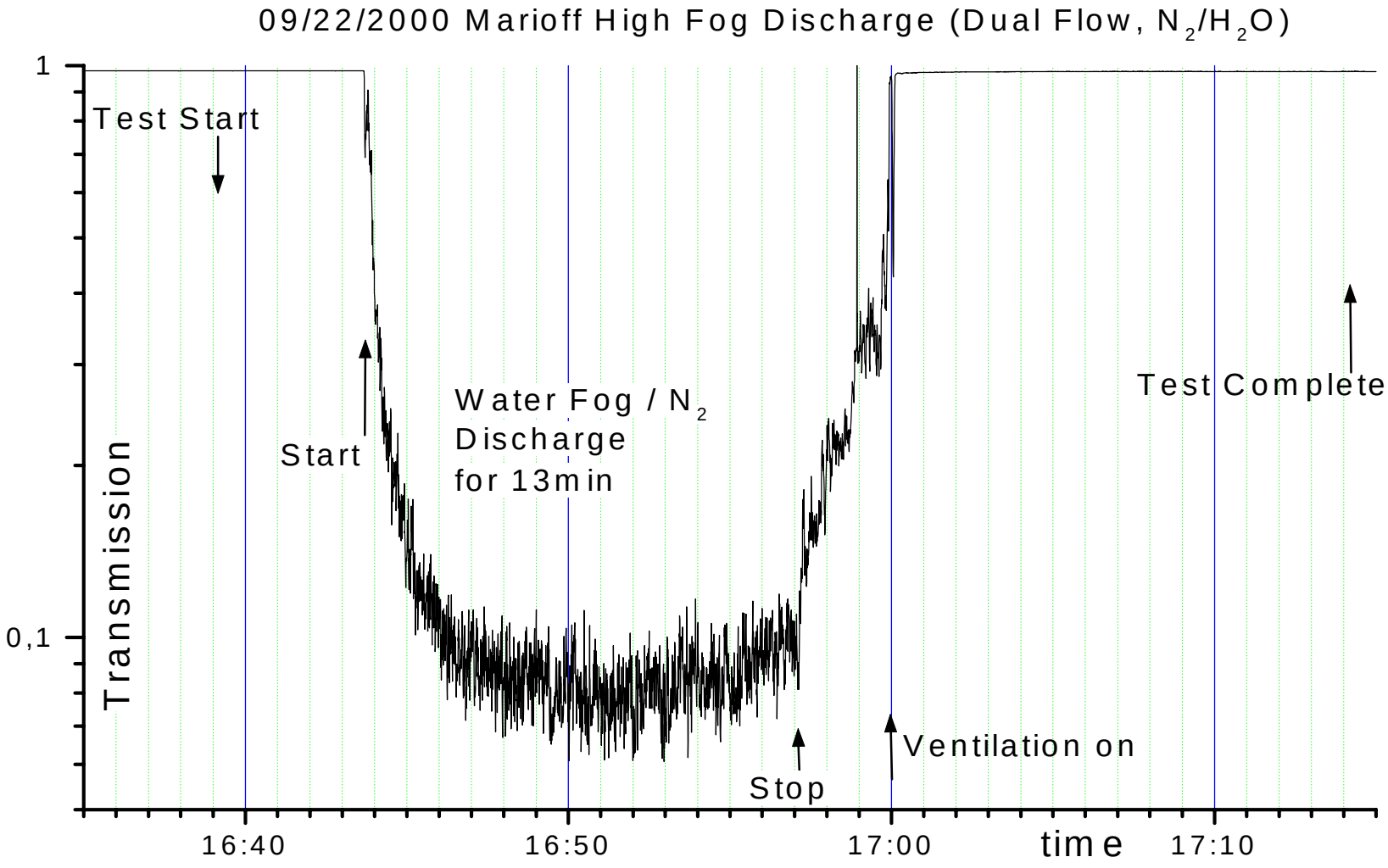




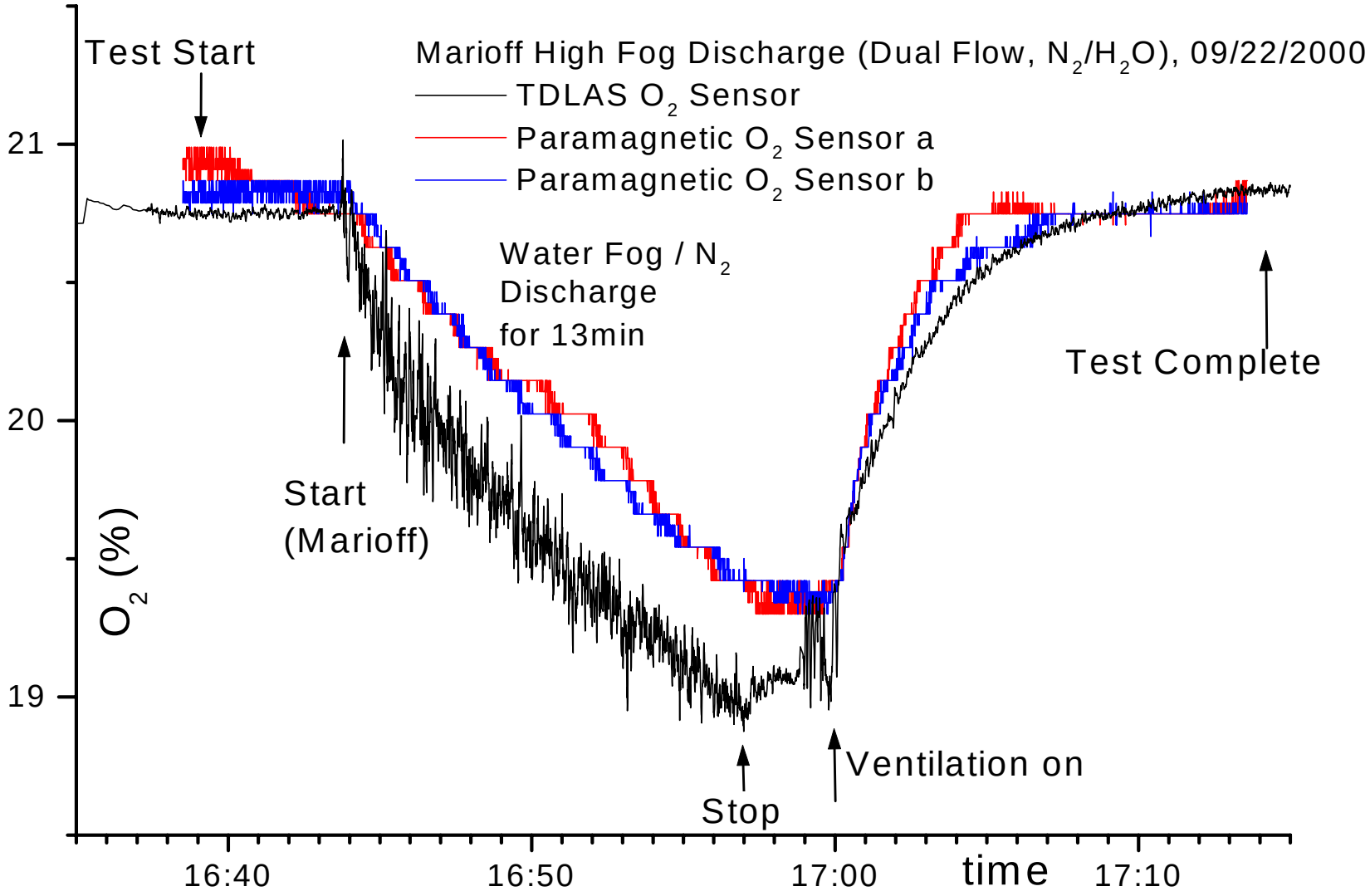
Unsuppressed / WSCS Suppressed Heptane Fire - Transmission



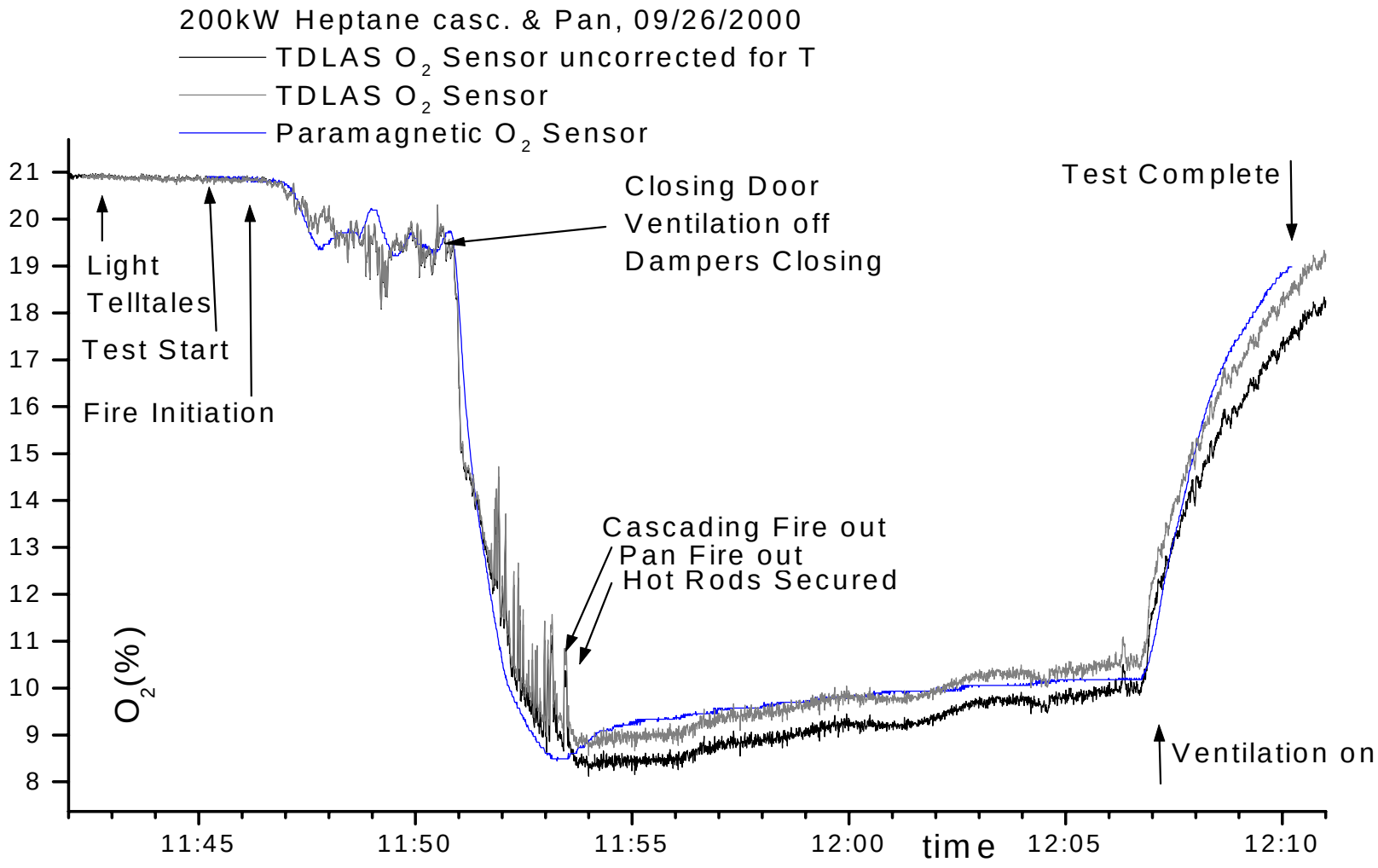
Water Mist Discharge (no Fire) - Transmission



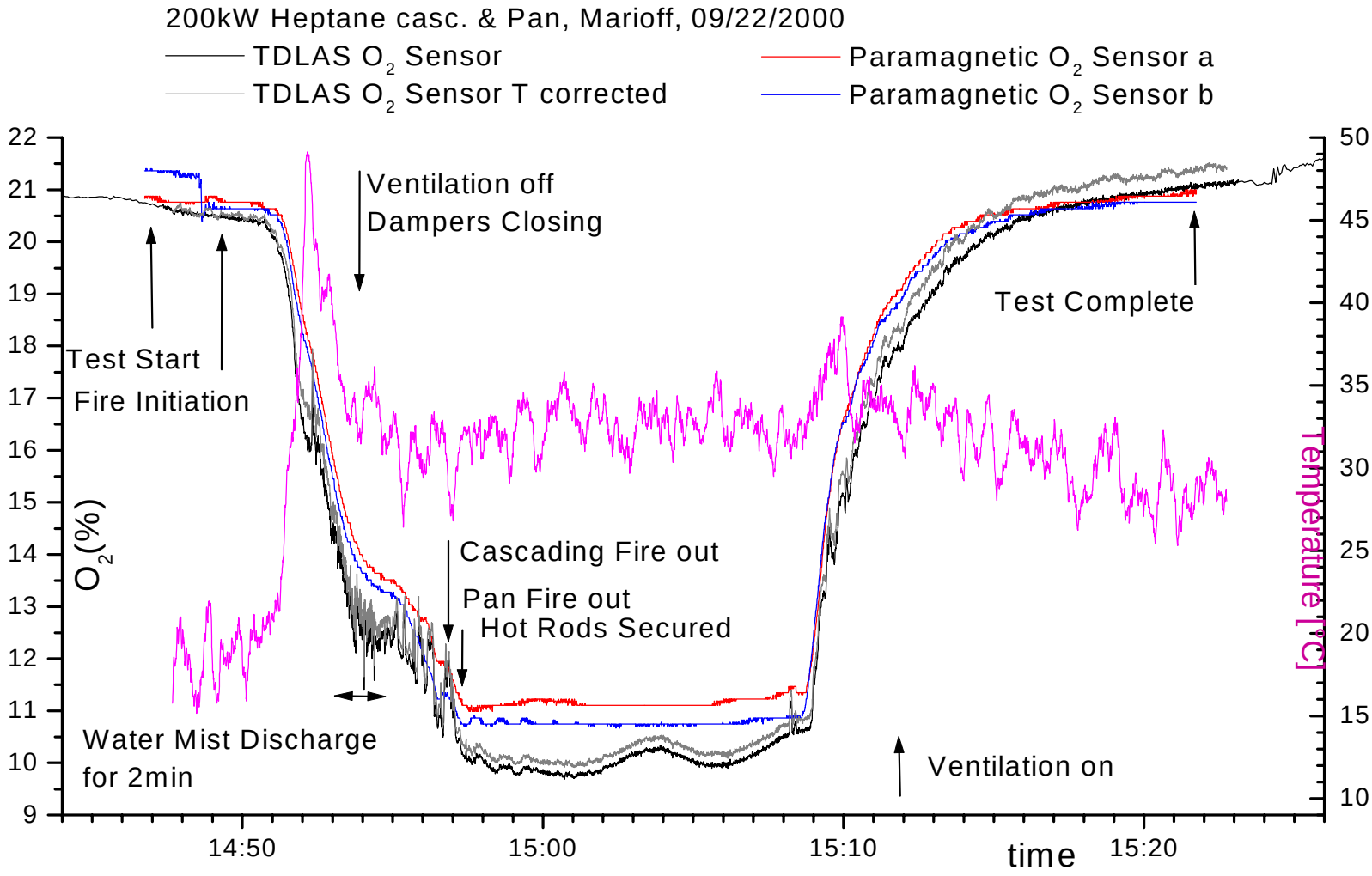
Water Mist Discharge (no Fire) – O_2 Concentration



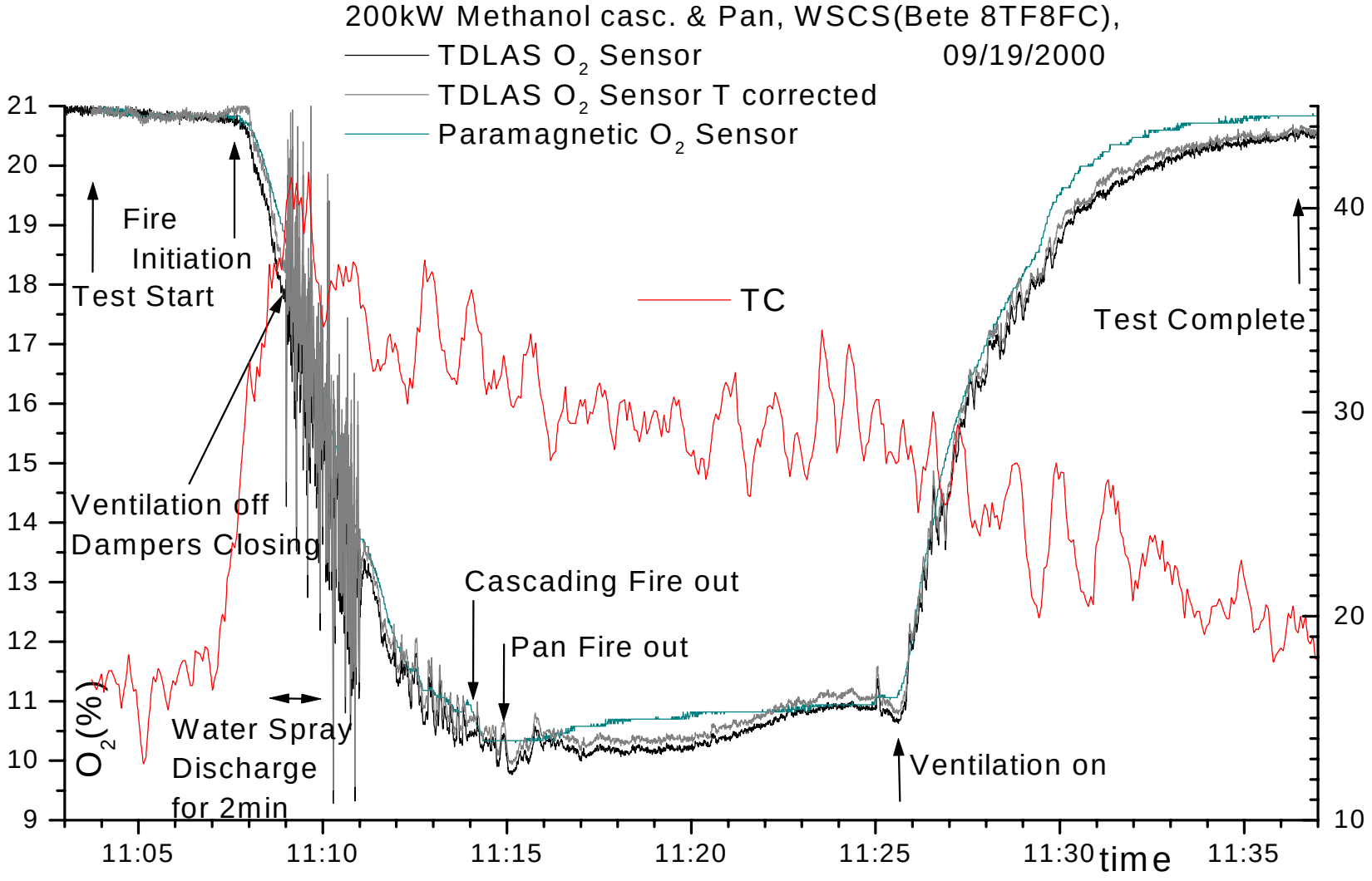
N-Heptane Fire (no Suppression) – O_2 Concentration



Water Mist Suppressed n-Heptane Fire - O_2 Concentration



Water Spray Suppressed MeOH Fire - O_2 Concentration



Summary - Test Results

- Minimum transmission normalized to a one meter pathlength:

  100 % (background)

  47 % (200 kW n-heptane)

  51 % (WSCS, BETE TF8FC, 4.9gal/min)

  24.6% (WSCS, BETE TF12FC, 11.7gal/min)

  25% (Marioff, 0.32gal/min)

  77% (resting interval).
- O_2 concentration range : 8 to 21vol% (O_2)
- Sensitivity (noise) :
  - 0.01 vol% (no fire, no mist)
  - 0.5 vol% (fire and water spray)
  - 1 vol% (water mist)
- Referenced to paramagnetic O_2 sensors and GC-grab samples
- Accuracy currently 1vol% O_2, limited by T measurement (±10K)

Conclusions

- Demonstrated *in situ* TDLAS measurement of absolute O_2 concentration profiles in real-scale fire test.
- Test conditions included rapidly changing obscuration levels due to soot, water mist and water spray.

TDLAS Spectrometer

- NIR-TDLAS at 760nm (R9R9, R7Q8)
- Herriot-multipass cell with purged mirrors

  Measurment length: 0.3 m

  Pathlength : 1.84m (6 reflections)
- Ruggedized for *in situ* testing
- Time resolution was 2.5Hz (0.4s)

Outlook

- Refinement and use of the sensor for ongoing tests, incl. HFCs.
- Other species with higher sensitivity, e.g. H_2O, HF, HCl, HBr, CO_2, CO

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