Tunable Diode Laser (TDL)

NH_3, HCl, H_2S, HF, HCN

Cemtek Environmental
Emissions Seminar & Training Session
Santa Ana, CA

A technical solution to meet every need

CEMTEK Environmental Inc.
3041 S. Orange Ave.
Santa Ana, CA 92707
800-400-0200
www.cemteks.com

Why NH_3 Monitoring is Useful

Purpose for monitoring Ammonia (NH_3) Slip

- **Overall verification of efficiency for NOx control**
- **Check of errors in over NH_3 injection**
- **Prevention of air preheater blocking specifically in minimization of ABS formation especially if using high sulfur coal**
- **Corrosion and maintenance of equipment**
- **Regulatory emissions limits for both NO_X and NH_3 slip**
- **Can be related to a measure of reduction of catalyst activity**
- **Economic Considerations:**
  - **NO_X emission trading credit maximization**
  - **Contamination of fly ash**
  - **Cost of consumable ammonia/urea**

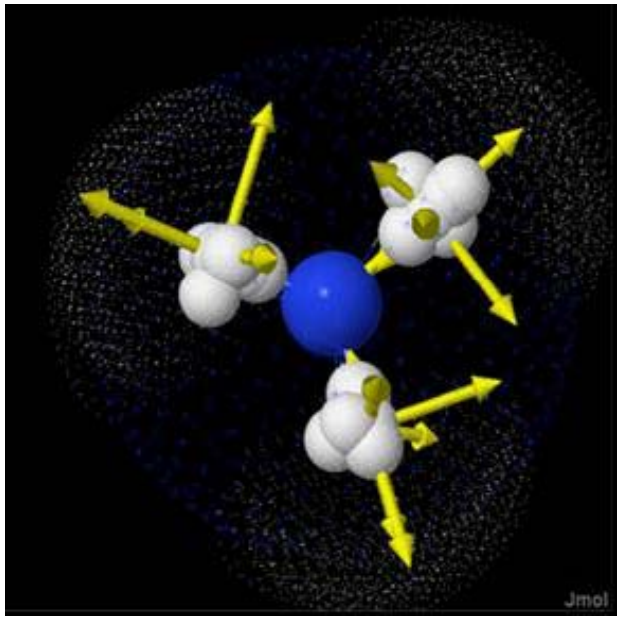
Basic Concepts of Optical Detection

- **Most molecules absorb infrared (IR) light**
  - **The patterns of IR wavelengths (colors) they absorb are unique to each molecule**
  - **The amount of light they absorb is proportional to their concentration**

- **As a result:**
  - **The presence of specific compounds can be unequivocally determined by the absorption patterns**
  - **The concentration of the compounds can be measured by the strength of the absorption patterns**

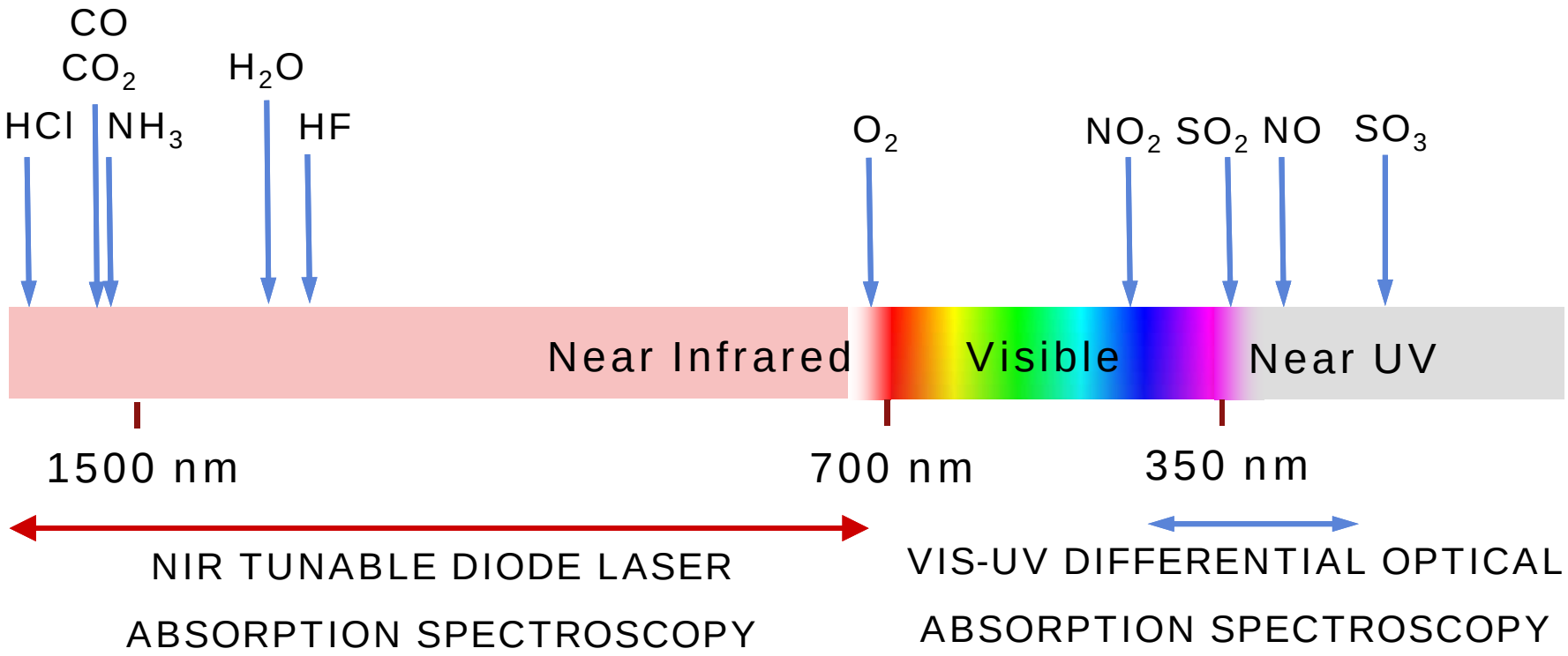
Measuring NH_3

- **Diode lasers are ideally suited for overtone spectroscopy of molecules with chemical bonds such as C-H, O-H, and N-H in the near-IR region ~0.78–2.5 µm.**



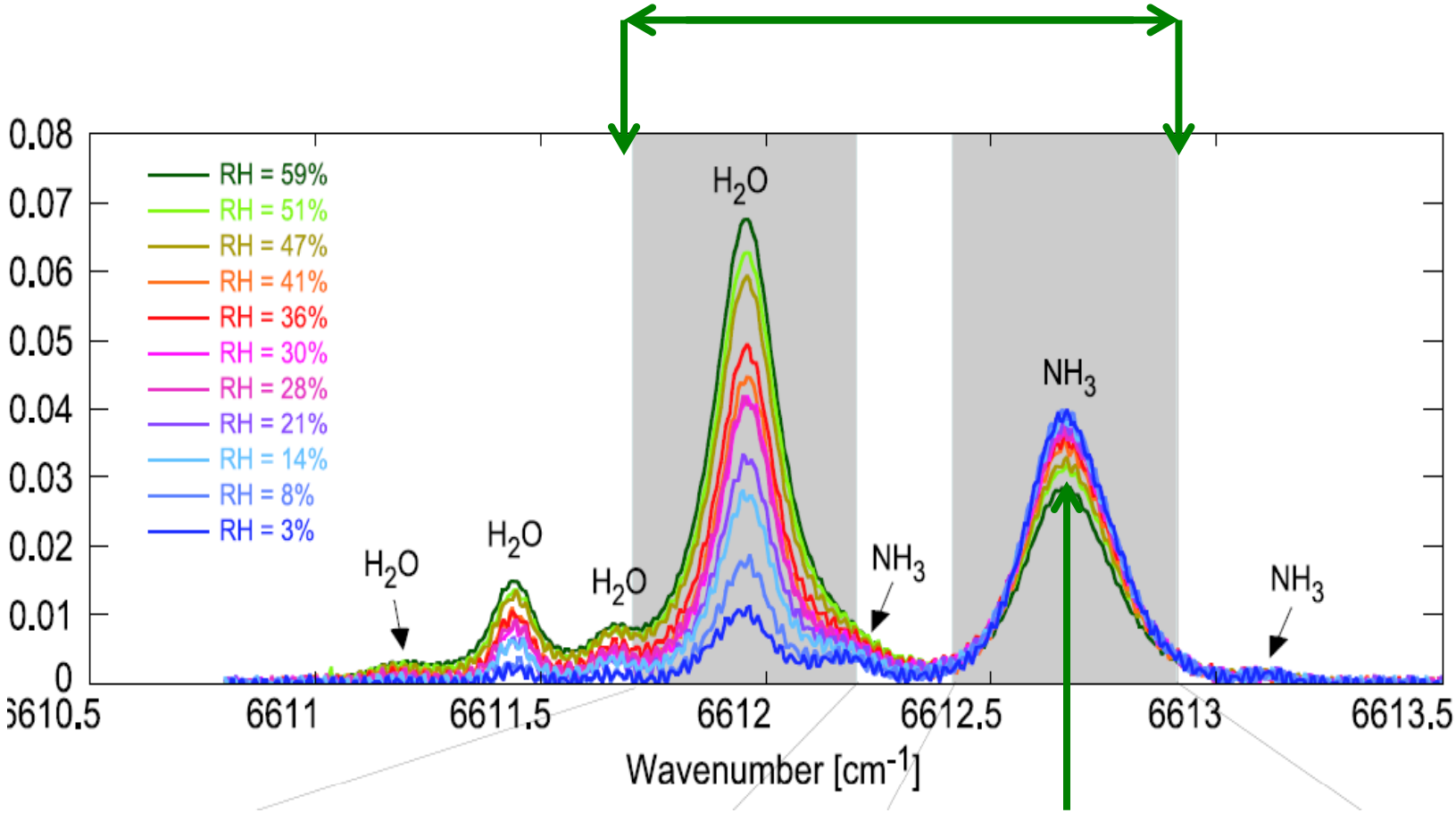
- **Figure shows the dynamics of a NH_3 molecule which has a rich spectrum in the near-IR region.**
- **These spectral absorption features are from the vibrational and rotational characteristics of this molecule as it absorbs energy of a specific wavelength.**
- **In just the spectral range from 1450 to 1560 nm ~;6400–6900 cm^{-1}, 381 lines due to rotational–vibrational transitions in the combination band n1 to n3 and the overtone band at 2n3 have been characterized.**
- **Characterization has examined these lines for interferences, specifically moisture, and currently the best lines for monitoring purposes with near IR ammonia measurements are the lines at 1512.3 and 1514.1 nm.**

Tunable Diode Laser Measurement Technique



NH_3 Spectrum of Interest

Laser scanning range measures NH_3 and H_2O concurrently



Laser currently used by Unisearch

Spectroscopy: Beer-Lambert Law

- **Concentration of the desired molecule done via the Beer-Lambert Law**

$$\frac{I}{I_0} = \exp\left[-\varphi(\phi) \times N \times L\right]$$

- **where**
  - **I = transmitted power**
  - **I_0 = incident power**
  - **L = path length [cm]**
  - **N = concentration [# molecules / cm^3]**
  - **φ(Φ) = absorption cross-section of molecule [cm^2 / molecule]**

- **Which provides a simple mathematical solution as:**
  - **I and I_0 are measured by the analyzer**
  - **Path length, L, and absorption coefficient, φ(Φ), are constants that are input into the analyzer**
  - **All parameters are known except for concentration, N (in ppmV) which what is solved and reported**

Fast Scan Direct Absorption Technique

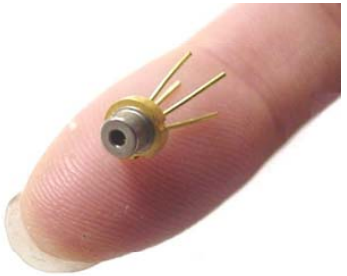
- Advantages
  - **Very fast response time**
  - **Excellent sensitivity**
  - **Independent of extraneous radiation emissions from other sources as IR emission from hot boiler flue gas**
  - **Optical effects as etalons, which may perturb the background structure are easily compensated by taking background measurements when NH_3 levels are below detection limits**
  - **System does not require calibration as it is a pure, direct absorption measurement but can be easily audited with an internal reference cell or an external audit cell**
  - **Relatively inexpensive as it does not require shielded RF modulation electronics**
  - **Wide dynamic range; typically 5 orders of magnitude**
  - **Can easily correct in real time for wide power swings typical in heavily laden dust environments as found in coal-fired power plant flue gasses prior to the air heater via continuous measurement of laser power (I_0)**

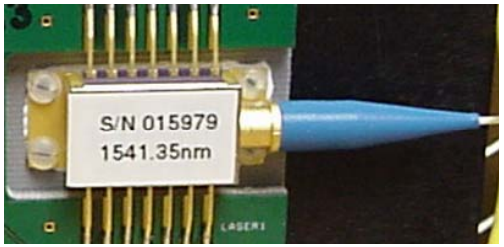
TDL Detection Limits

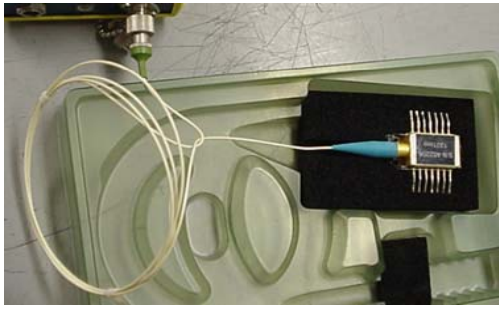
- Factor of both path length, path measurement time, measurement temperature, pressure and species being measured
  - Normally longer path length = lower detection limit as long as the optical return power is above threshold (60 microwatts), laser initially are 10 milliwatts in power)
  - Longer path yields greater absorption and sensitivity of measured species but in heavily laden dust environments must yield enough return power
  - Scales by factor of square root of measurement time
    - E.g. 1 s → 1 min integration time = 7-fold enhancement of detection limit
- Typically 0.1 –0. 5 ppmV-m for NH_3 depending on pathlength and integration time
- For most coal-fired power plant applications, measurements at one-minute over 5 meters, yield better than 0.2 ppmV MDL's at 700 °F

TDLs: How they work

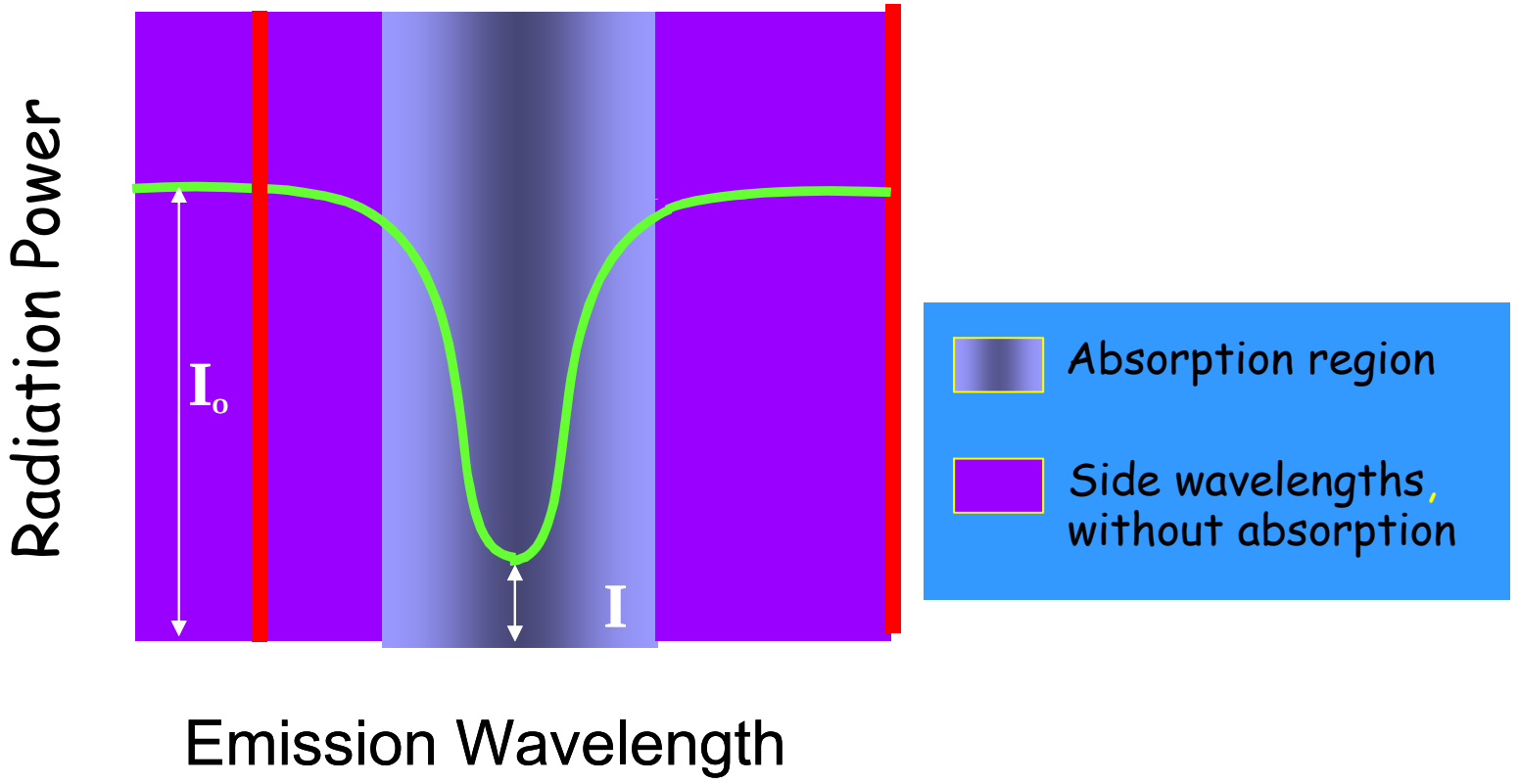
- **Tunable diode lasers**
  - **Made of small crystals of Ga, As, Sb, P**
  - **Similar to lasers used in telecommunications applications**
    - **Rugged**
    - **Long life**
  - **Commercially available at a low cost**
  - **Emits light emissions in the near-infrared region when an electric current is applied**
  - **Laser center wavelength depends on composition of crystal**
  - **Laser wavelength can be tuned over narrow range by changing current (fine) or by adjusting laser operating temperature (coarse)**
  - **Output can be fiber coupled allowing easier installation and multi-channel capability**





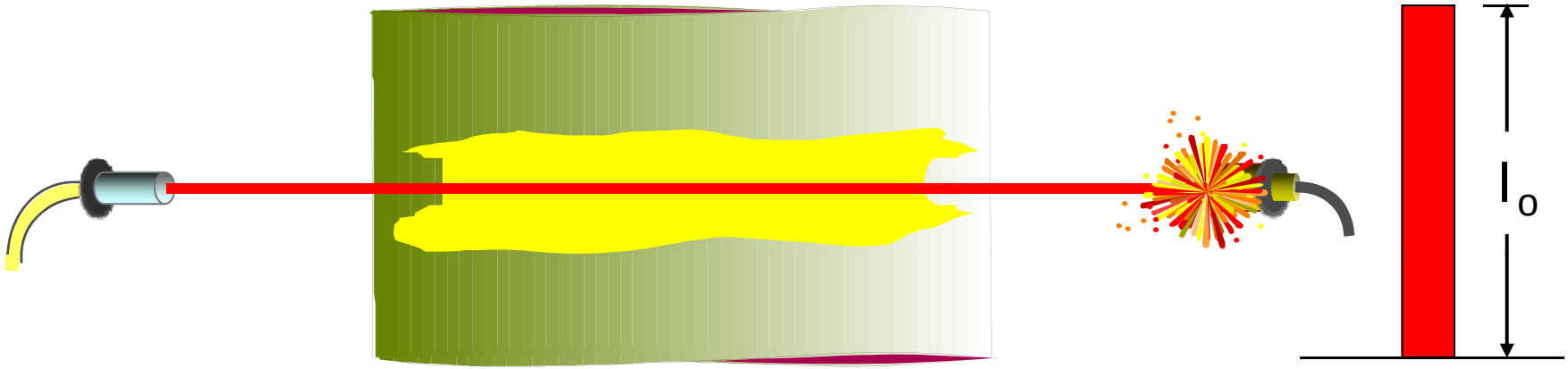


TDL: What's happening at wavelength scale

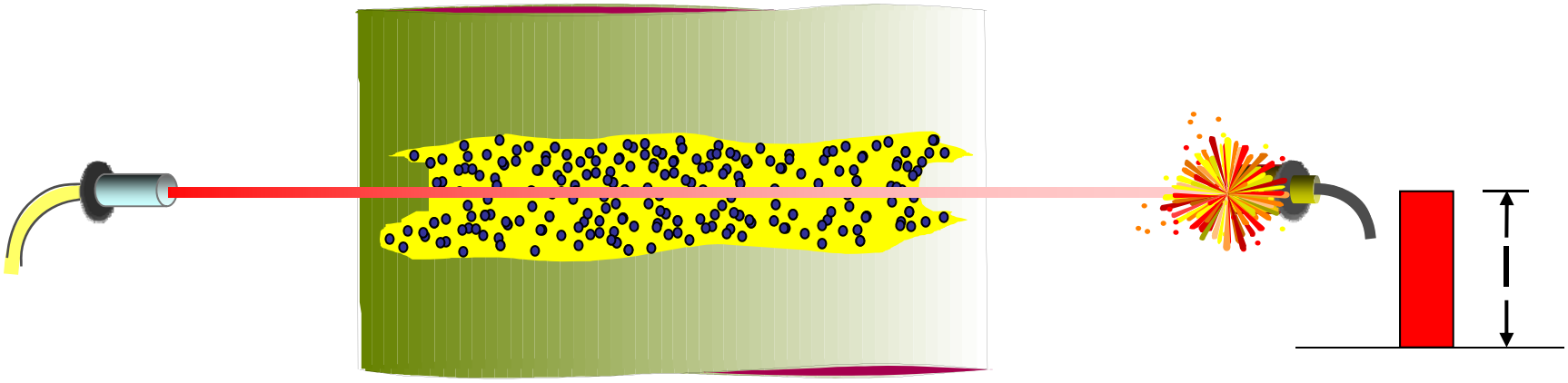


Intensity (I) and (Io) Measurement

When no gas present...

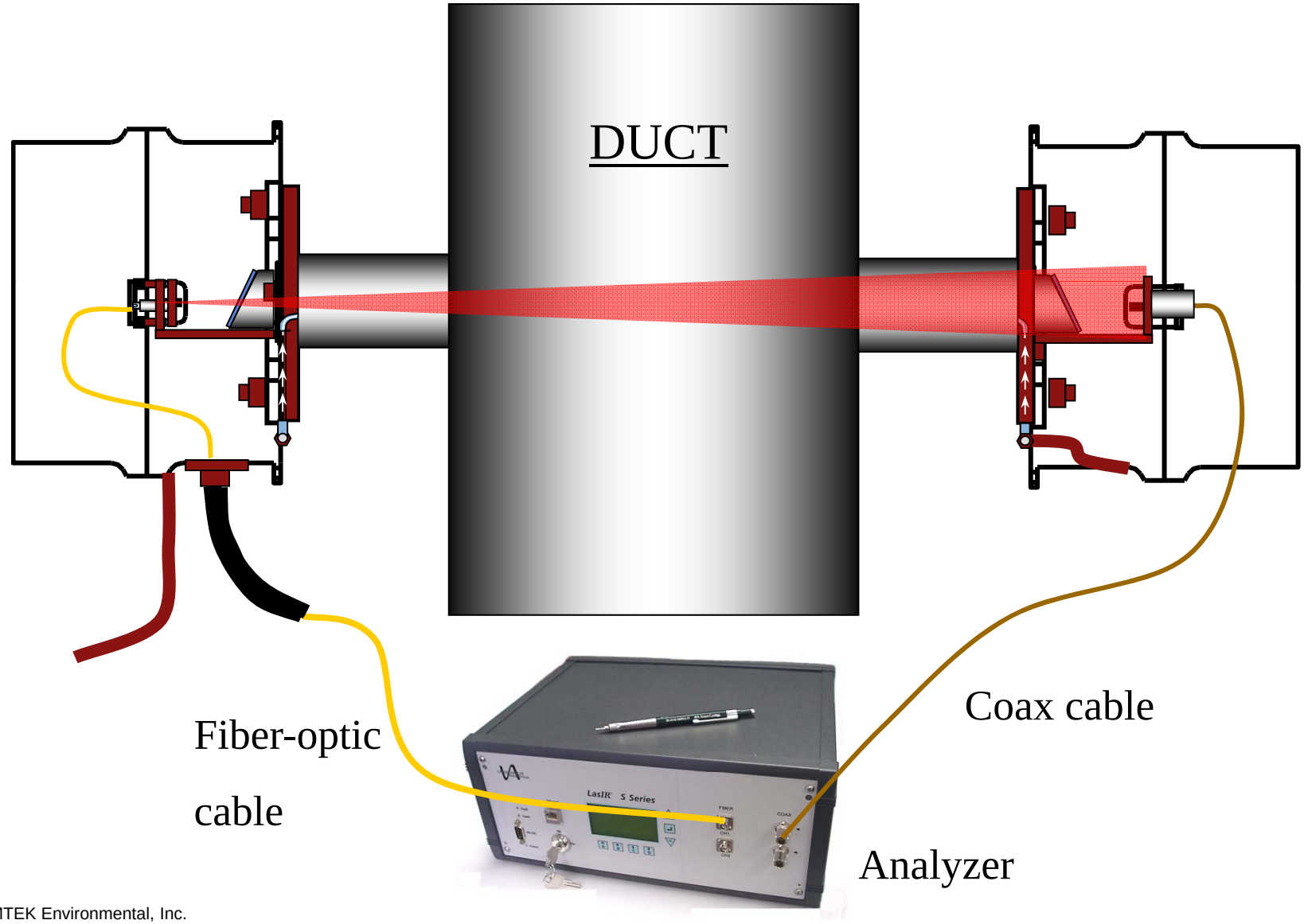


When gas present...

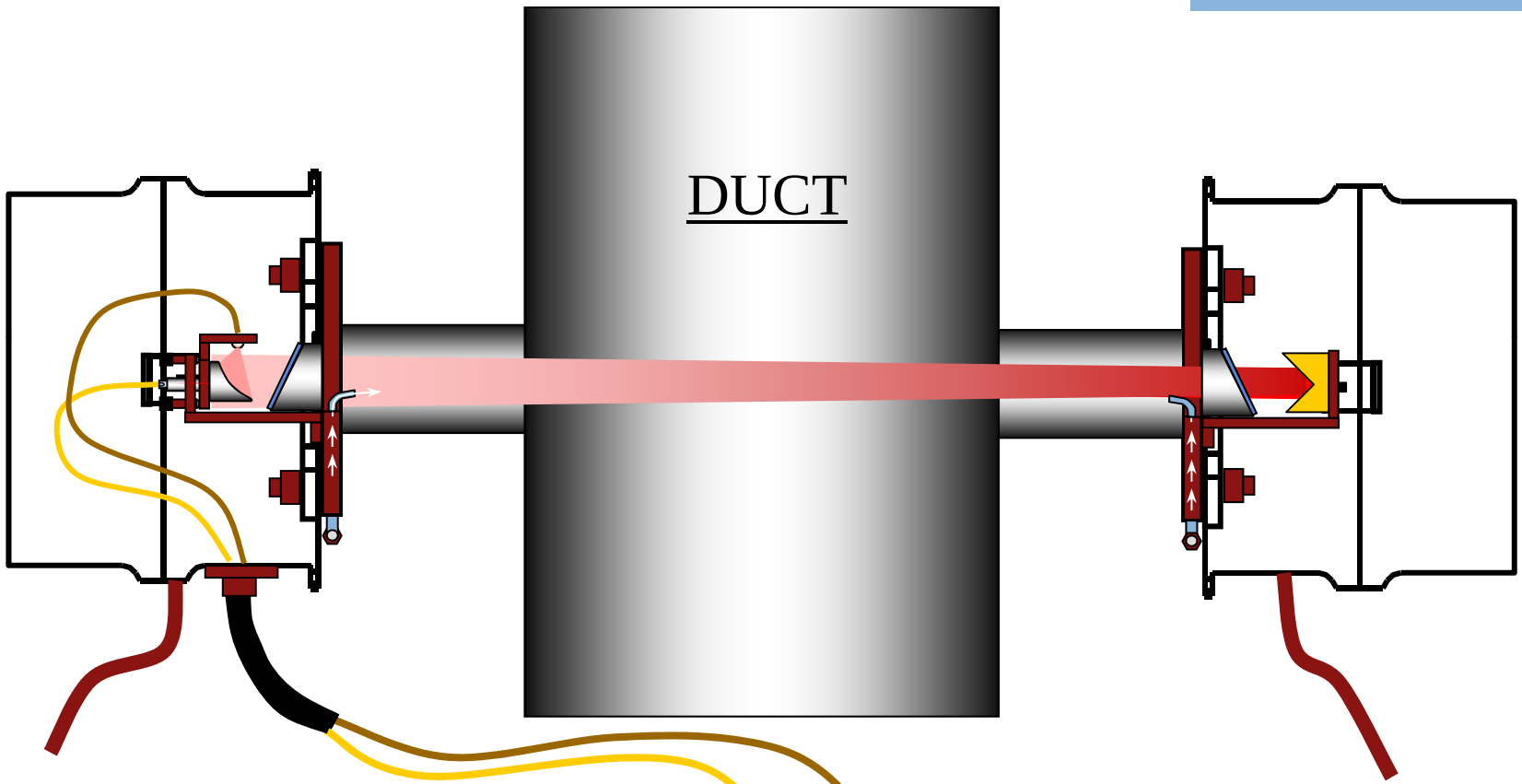


Absorbed intensity, $\delta I = I_o - I$

Single Pass (Bi-static) Duct Configuration



Dual Pass (Mono-static) Duct Configuration

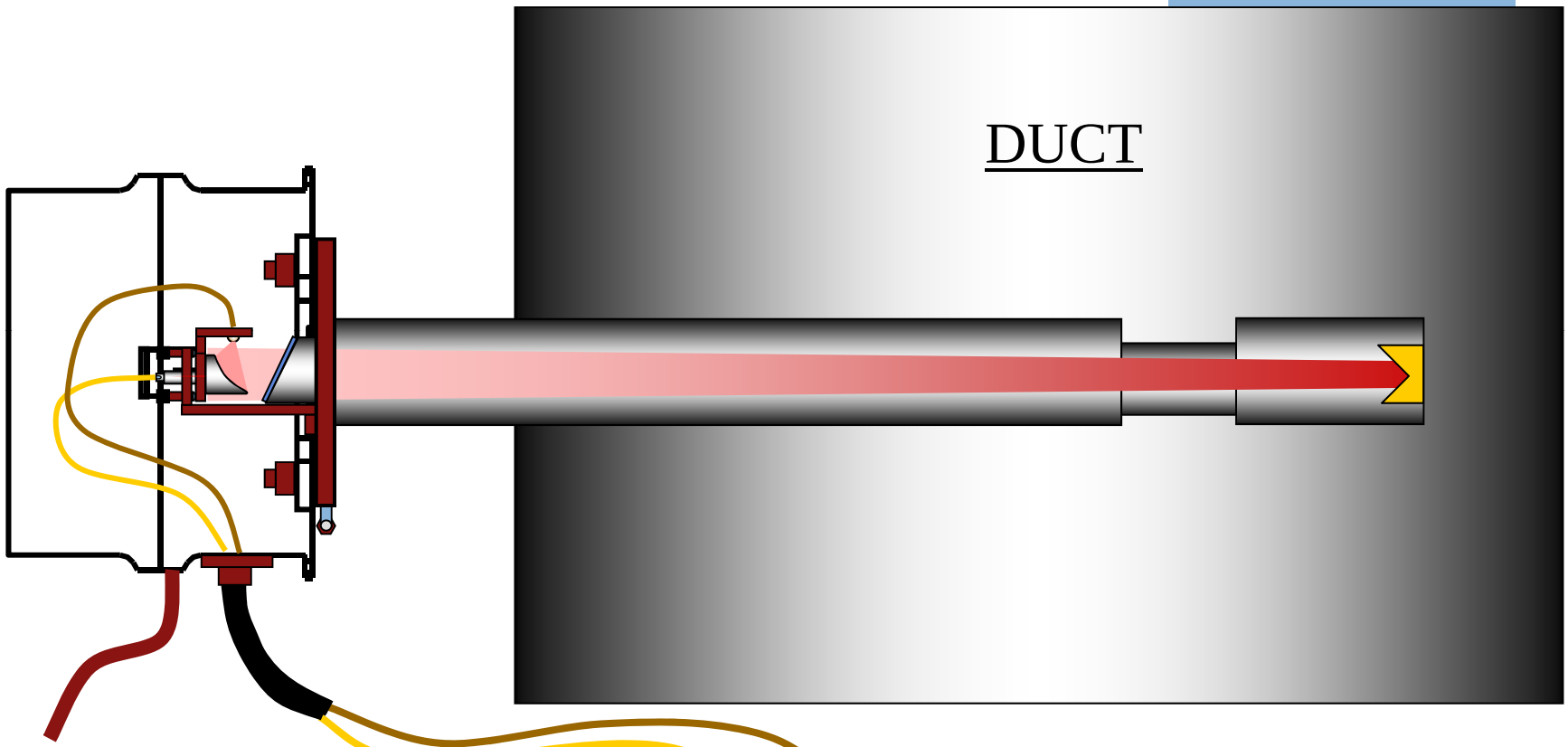


Fiber-optic

& coax cables

Analyzer

Dual Pass (Mono-static) In-Duct Configuration

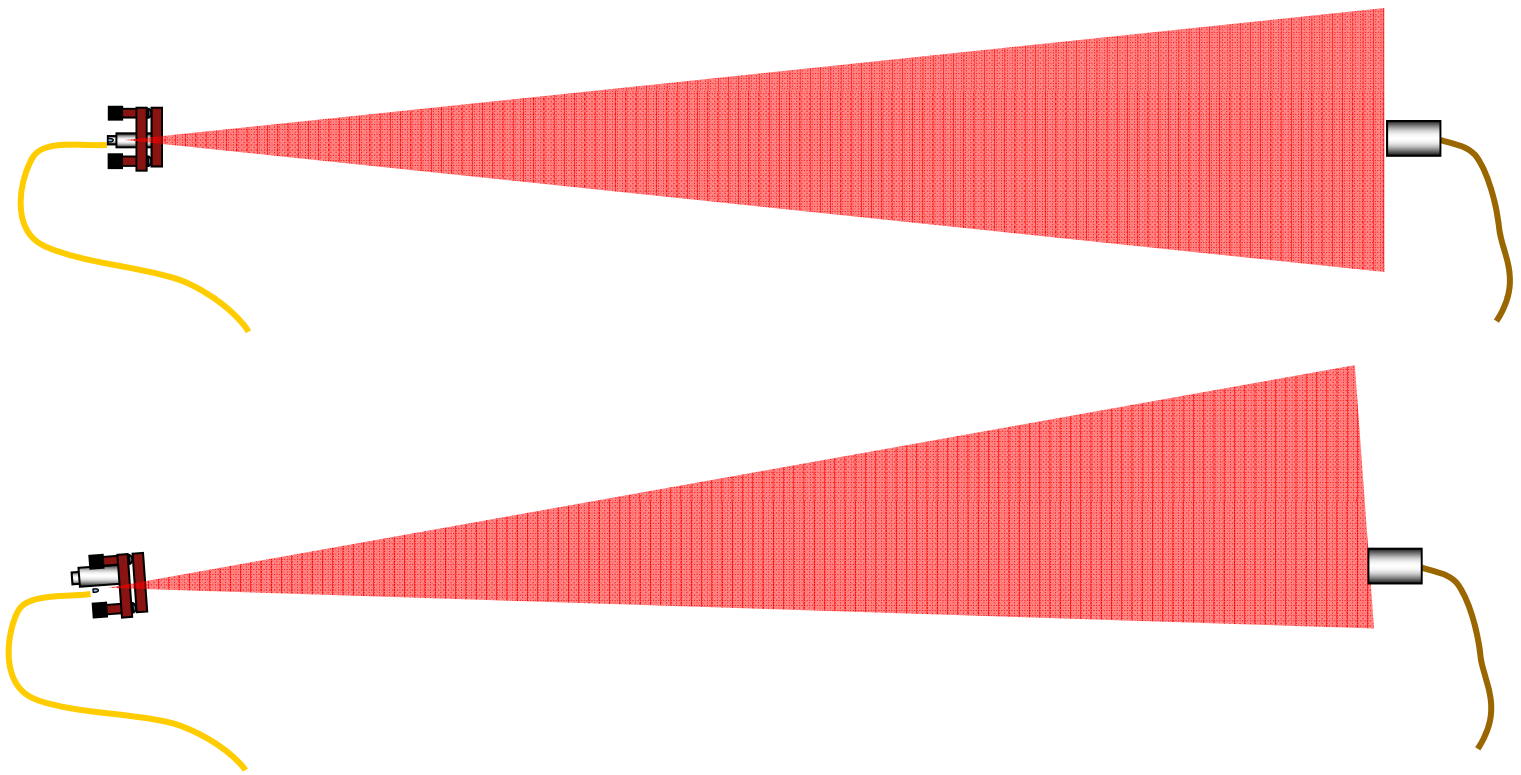


Fiber-optic

& coax cables

Analyzer

Beam Expansion for Alignment Stability

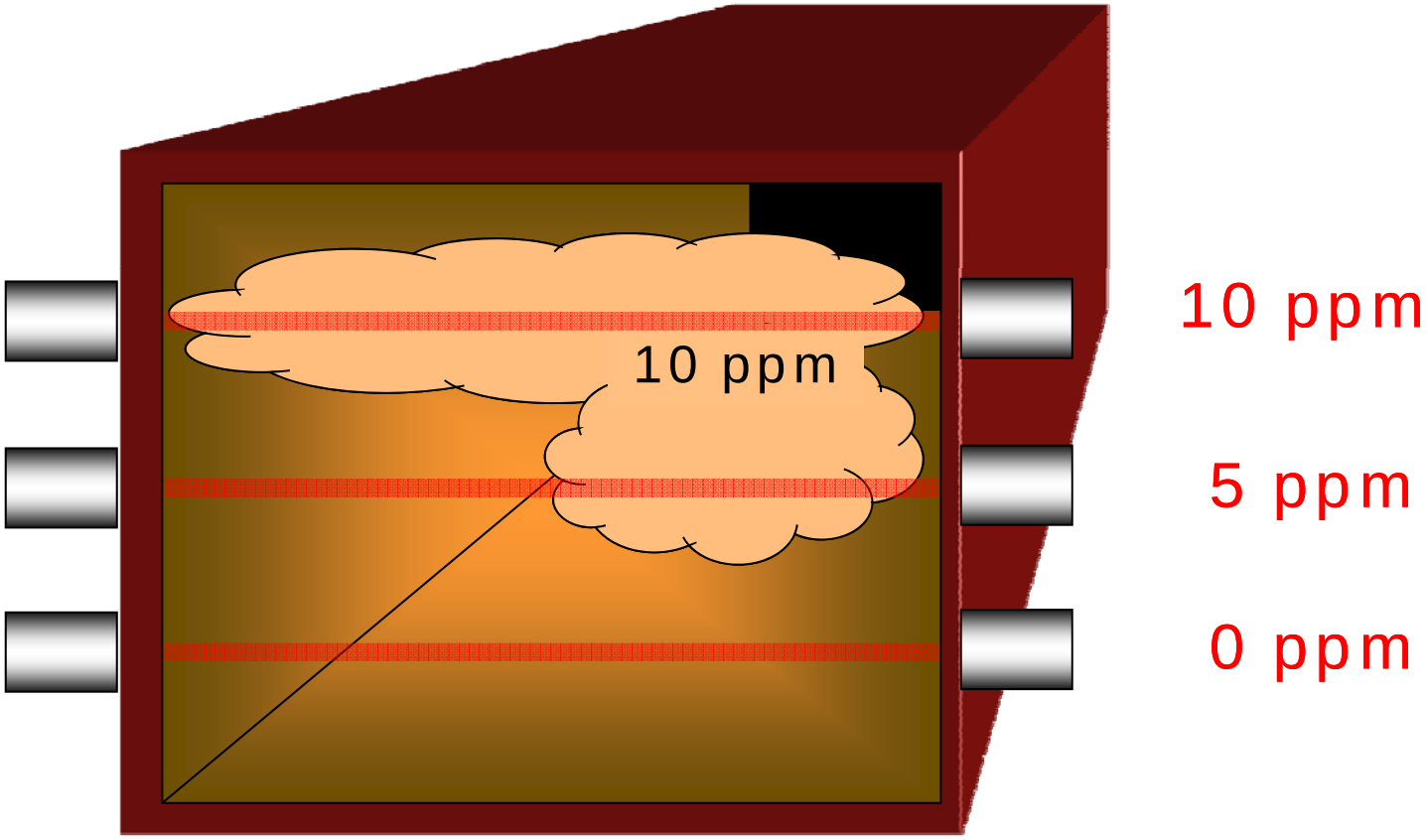


- **Higher laser powers allow beam expansion to attain alignment stability**
- **By de-focusing the beam, overfill of the detector optics allows for alignment changes**

Multiplexed Optical Signal

- The near IR TDL used by Unisearch has its emission fiber coupled
- This has the very advantageous feature of being able to incorporate optical elements as beam splitters and multiplexers to direct the beam over multiple paths.
- A multiplexer can direct the optical signal for a multi-path array configuration with up to eight lines of sight
- Multiplexing splits the signal by time instead of power
  - Multiplexing sends approximately 95% of signal power to each measurement path, with 5% being used as a reference
  - Beam splitting sends approximately 25% of signal power to each measurement path (4 path array) which limits optical path lengths to short distances in coal-fired power plant applications
- Multiplexed optical signal allows for not only use in heavy dust laden applications with longer path lengths but is very cost effective as one instrument needs to have only optical elements mounted on the boiler duct with the instrument fiber coupled to the elements but in a thermally controlled environment.

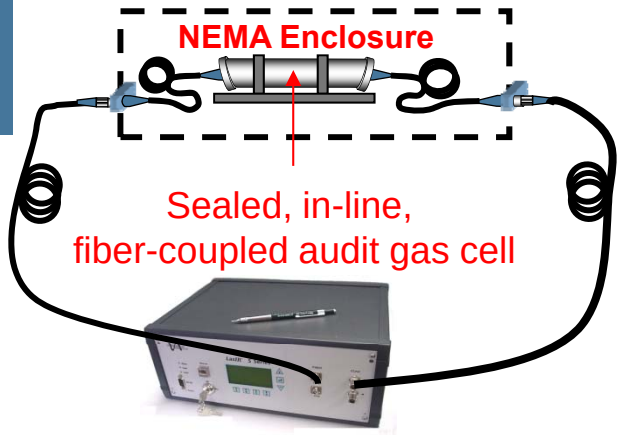
Multi-Path Array Configuration



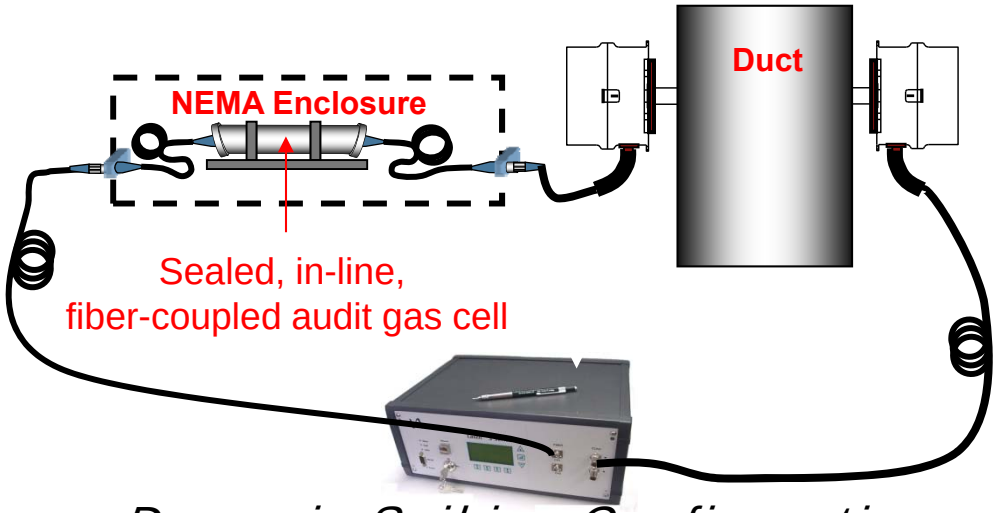
Measurements over multiple paths can spatially help isolate problem areas within the SCR reactor.

Tunable Diode Laser External Audit Method

- **Diagnostic Tool**
- **Dynamic Spiking**
- **Analyzer Isolation**



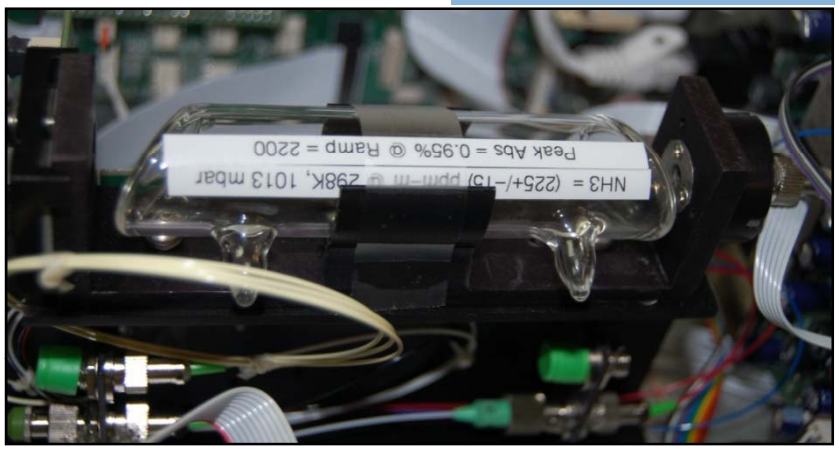
Analyzer Isolation Configuration



Dynamic Spiking Configuration

Tunable Diode Laser Internal Audit Method

- **Module spiked with known amount of target gas**
- **Isolated cell measurement**

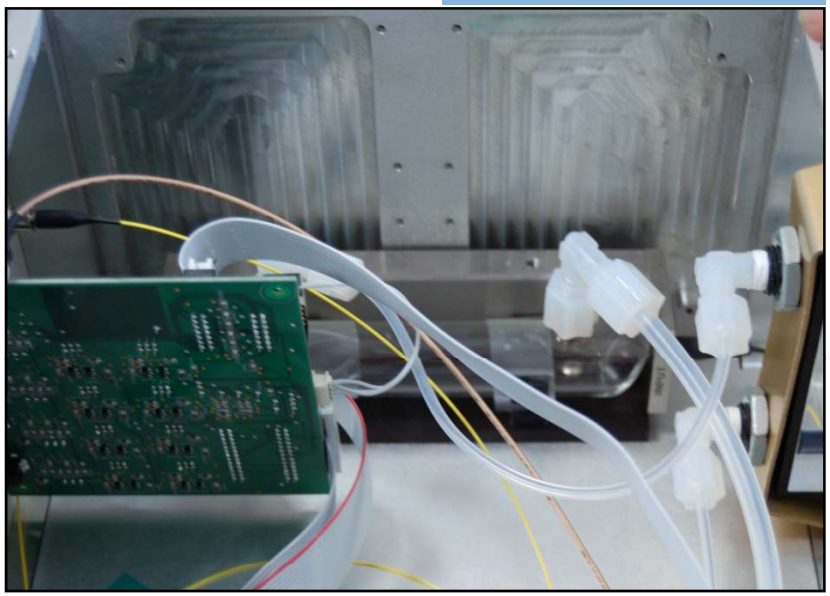


Internal Audit Module

Tunable Diode Laser Flow-Through Audit Method

Flow-Through Audit Cell

- **Dynamic spiking audit**
- **Short recovery time**
- **Temperature correction factor used to account to difference between flow through cell and flue gas temperatures**



Tunable Diode Laser Purge Options

Instrument Air

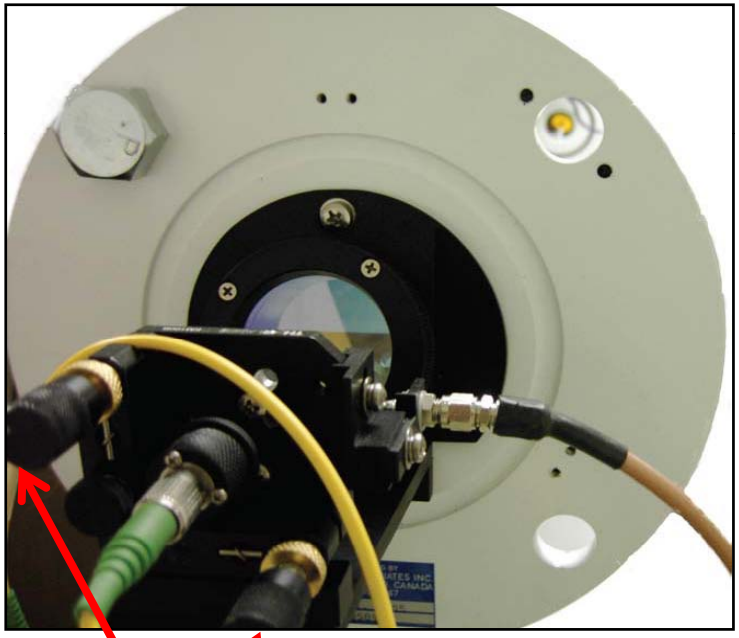
Opacity Type Blower

Tunable Diode Laser Maintenance & Adjustment

Maintenance

Lens Removal for Cleaning

Alignment



Micro Adjustment Screws

Questions?

Cemtek Environmental, Inc.

714-437-7100