# National Personal Protective Technology Laboratory

# Ultrasound in Respirators: Concept and Initial Results


Policy and Standards Development Branch

W. P. King and J. V. Szalajda


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# Overview

- Ultrasound and its uses
  - Leak detection
- Initial assessment in respirators
  - Preliminary results

# Objective

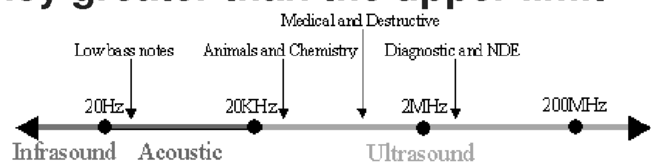
- Non-destructive method of monitoring fit or leakage *in situ*
  - Actual respirator
    - unprobed
  - Real time during use

# Specific Ultrasound Objectives

- Ultrasound characterization (frequency and power spectrum) of leaks in respirators
- Correlation of ultrasound characteristics and leak rate parameters (pressure and size)
- Correlation of ultrasound characteristics with respirator/wearer interface dimensions
- Characterization of non-leak ultrasound associated with individuals wearing various respirators (including respiration and environmental sources)
- The results will provide a basis for determination of the most effective strategies for monitoring respirator fit using ultrasound

# Ultrasound

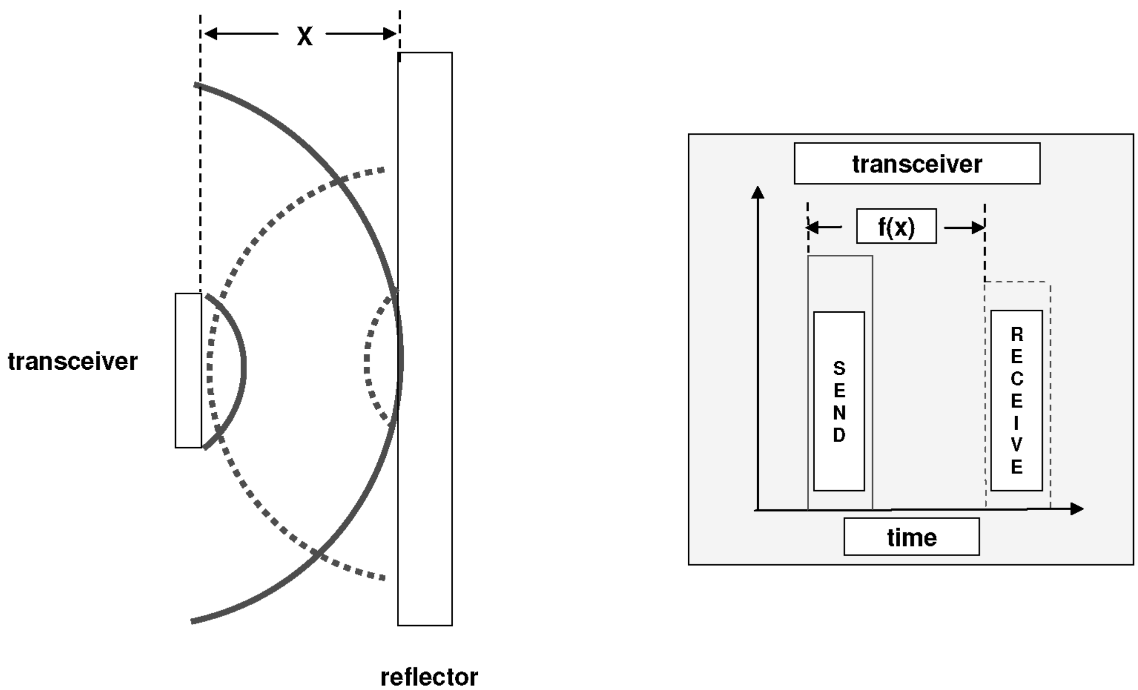
- **Cyclic sound pressure with a frequency greater than the upper limit of human hearing (≥ 20 kilohertz)**




- **Airborne ultrasound technology applications:**
  - SONAR, Tracking and positioning
  - Leak detection
- **Exposure to airborne ultrasound does not appear to pose a human health risk**
  - Inaudible

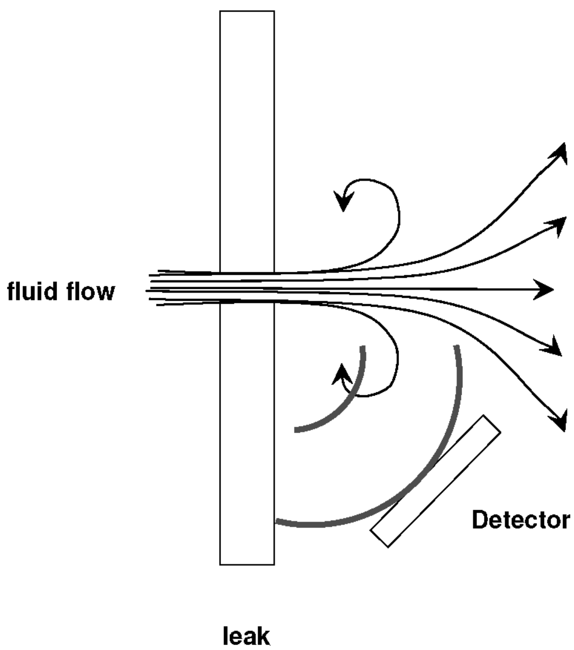
| TLVs for Ultrasound (2008) | | |
|---|---|---|
| Mid-Frequency of Third-Octave Band (kHz) | One-third Octave-Band Level In Air in dB | |
| | Ceiling Values | 8-Hour TWA |
| 12.5 | 105 | 89 |
| 16 | 105 | 92 |
| 20 | 105 | 94 |
| 25 | 110 | — |
| 31.5 | 110 | — |
| 40 | 110 | — |
| 50 | 110 | — |
| 80 | 110 | — |

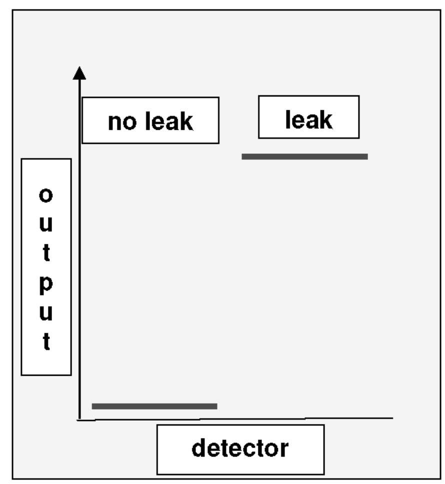
# Ultrasonic Ranging




**Transit** time of ultrasound **radiation** is directly related to distance, X

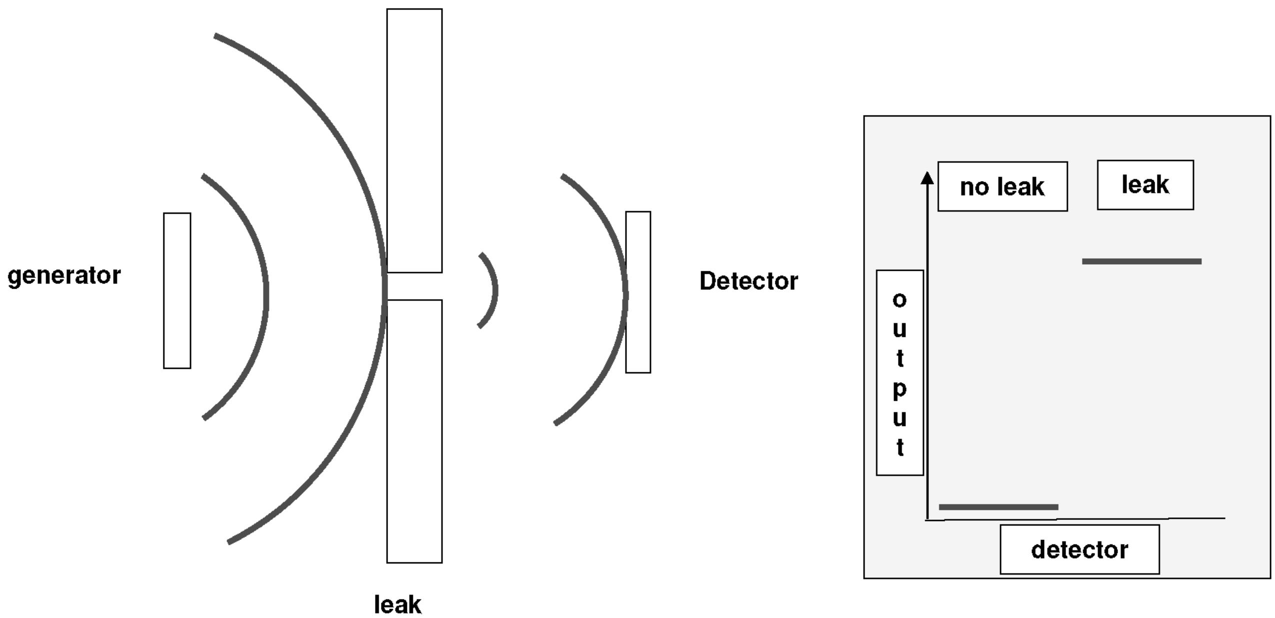
# Leak Detection




**Turbulent flow from leaks generates ultrasound radiation**

# Leak Detection with Generator



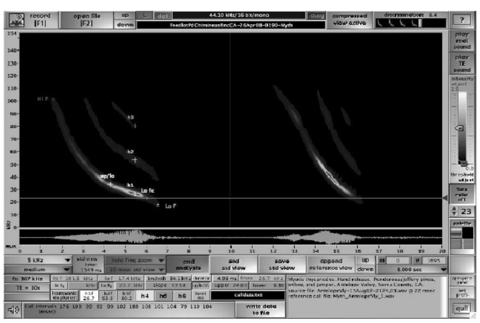

Leakage detection with generated ultrasound radiation

# Ultrasound Technology

- **Salient aspects**
  - Low power and size
  - Low cost
  - Sound techniques applicable


Ranging device

0.4” dia. x 0.1"



Spectral analysis


Leak detector with source

# Questions for use in respirators

- **Ultrasound sources?**
  - Leaks
  - Respiration
  - Others
- **Assessment of information available from ultrasound**
  - Amplitude (intensity): relationship with leak and fit factor?
  - Temporal: detect changes in real time?
  - Spatial: locate leaks?
  - Spectral: All of the above?

# Ultrasound Source Assessment

- **Reynolds numbers (Re):**

$$Re = \frac{\text{Dynamic pressure}}{\text{Shearing stress}} = \frac{\rho v_s^2 / D}{\mu v_s / D^2} = \frac{\rho v_s D}{\mu} = \frac{v_s D}{\nu}$$

Variables: *Vs* is the mean fluid velocity, *D* is the characteristic diameter, *v* (nu) is the kinematic fluid viscosity defined as $v = \mu/\rho$, $\mu$ is the (absolute) dynamic fluid viscosity, and ρ is the fluid density.

- **Critical Reynolds number $10^3$ - $10^4$**
  - Turbulent flow expected above critical Reynolds number

# Ultrasound Source Assessment

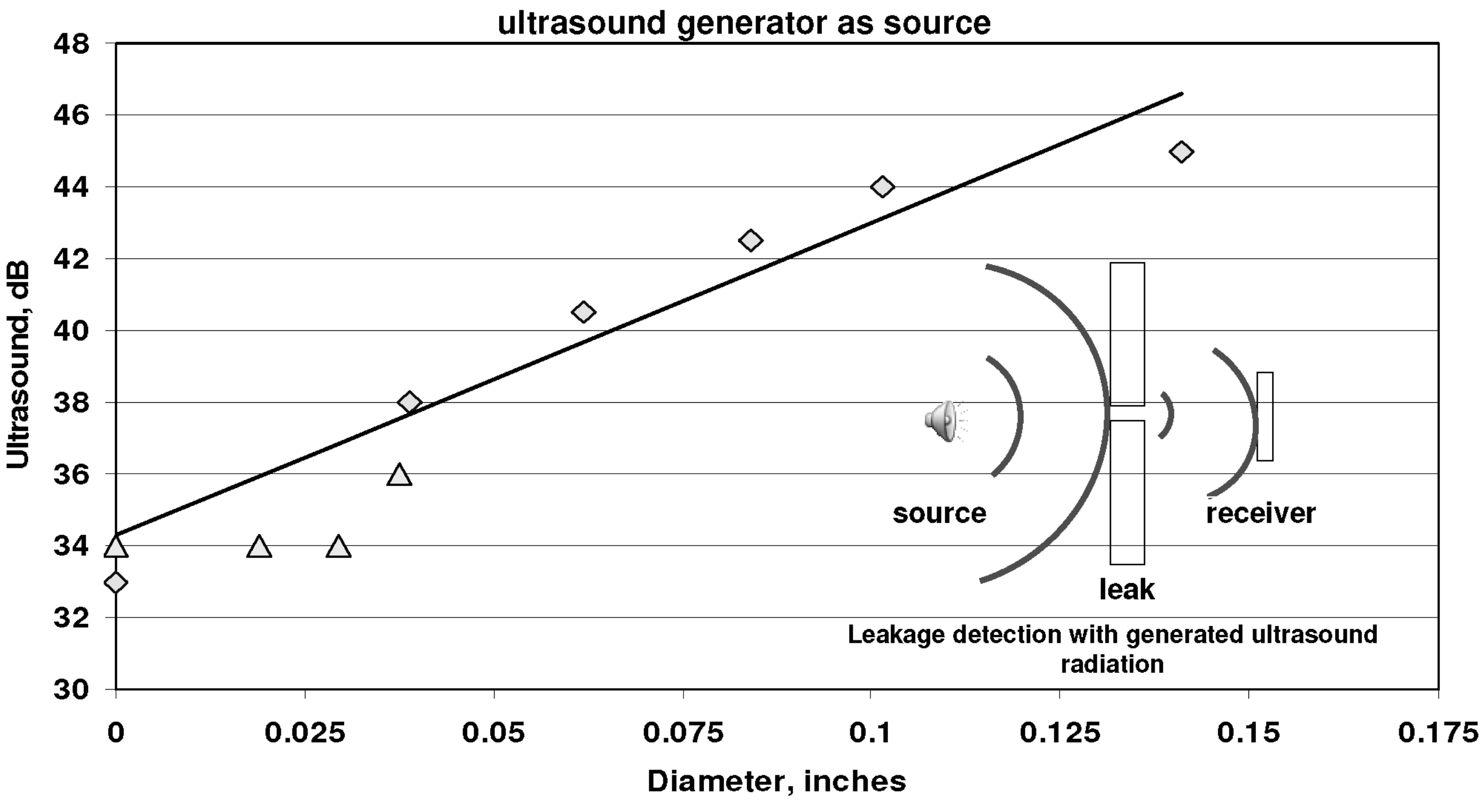
- Reynolds numbers (Re) calculated for some sources

| Source | Re | $V_s$ | *D* | v | µ | ρ | Ve | PF | W |
|---|---|---|---|---|---|---|---|---|---|
| | | $m\ s^{-1}$ | m | $m^2\ s^{-1}$ | $N \cdot s\ m^{-2}$ or $Pa \cdot s$ | $kg \cdot m^{-3}$ | $L \cdot min.^{-1}$ | | M |
| leak | 2.4E+01 | 3.3 | 0.0001 | 1.37E-05 | 0.0000178 | 1.294643 | 20 | 100 | 0.01 |
| nostril | 3.4E+09 | 259.8 | 0.007 | 1.37E-05 | 0.0000178 | 1.294643 | 10 | - | - |
| mouth | 8.2E+02 | 26.7 | 0.023 | 1.37E-05 | 0.0000178 | 1.294643 | 20 | - | - |

- Nasal breathing is the only expected source of ultrasound
  - Nasal
  - Mouth

Leak detector with source

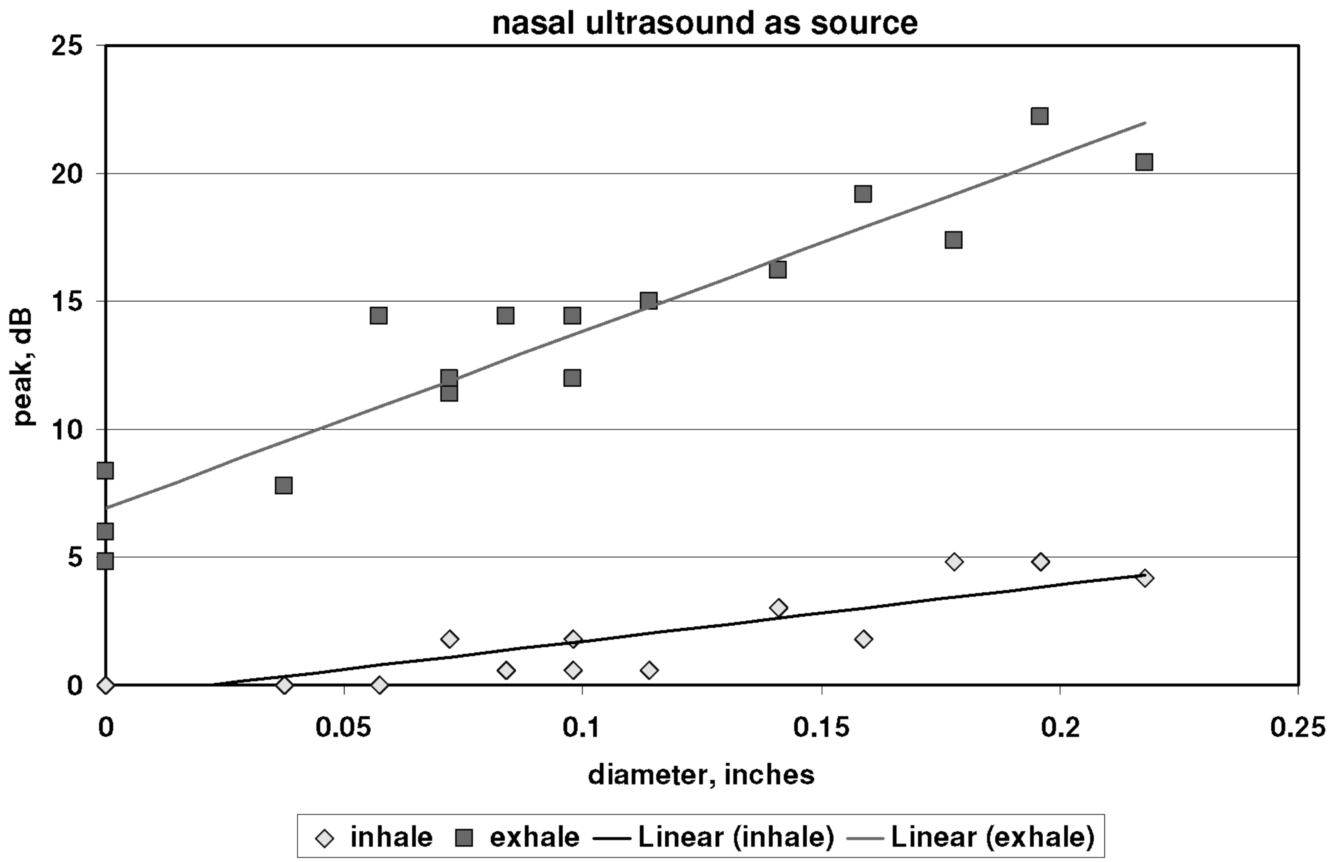
# Amplitude versus Leak Size




Adjusted $R^2 = 0.91$

Detected amplitude is proportional to leak diameter

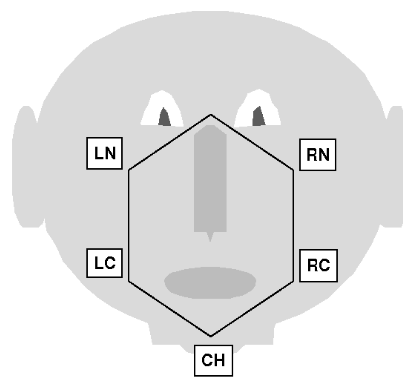
# Amplitude versus Leak Size




Adjusted $R^2$ = 0.90 exhale, 0.75 inhale

# Comparison of Ultrasound Leak Amplitude to Fit Factor for Half-masks

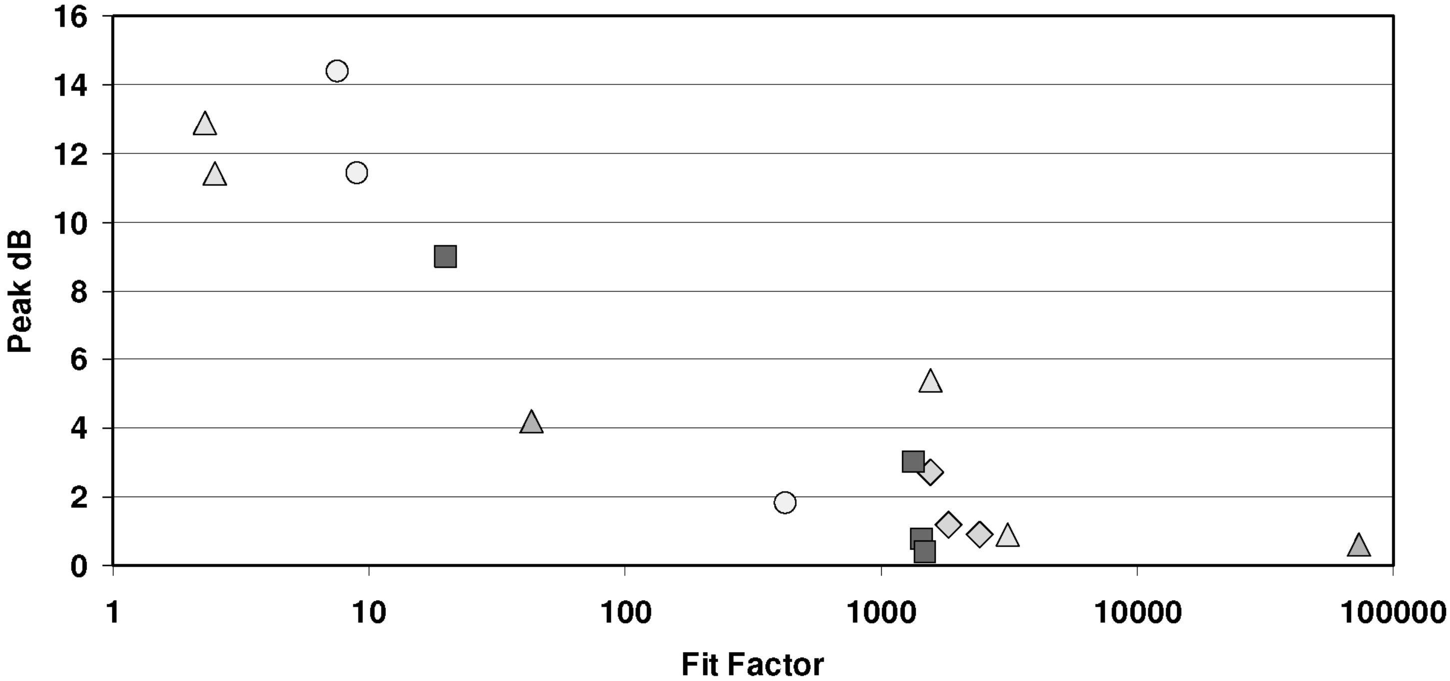
- **Used nasal breathing as ultrasound source on single subject**
- **Measured ultrasound level at five points around face seal**
- **Probed respirators to measure fit factor with PortaCount simultaneously**
  - Single exercise/sampling period
- **To modulate fit factor strap tension was varied on replicates**
  - Loose, (normal) tight, very tight



# Comparison of Ultrasound Leak Amplitude to Fit Factor for Half-masks

| Data Collected | | | | | | |
|---|---|---|---|---|---|---|
| Respirator | Condition | Peak ultrasound, dB | | | | Fit factor |
| | | point | inhale | exhale | back ground | |
| Slstrm SM 20107 | loose | left cheek | 1 | 2 | 0 | 20 |
| | | chin | 0 | 3 | 0 | |
| | | right cheek | 0 | 0 | 0 | |
| | | right nose | 5 | 7 | 0 | |
| | | left nose | 5 | 7 | 0 | |

## Average Ultrasound Leak Amplitude versus measured Fit Factor for Half-masks

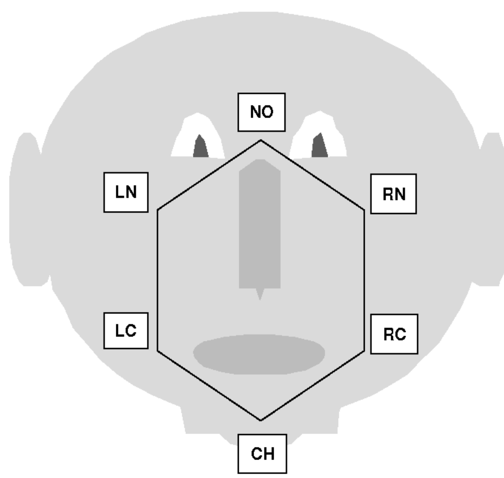



Adjusted $R^2$ = 0.79

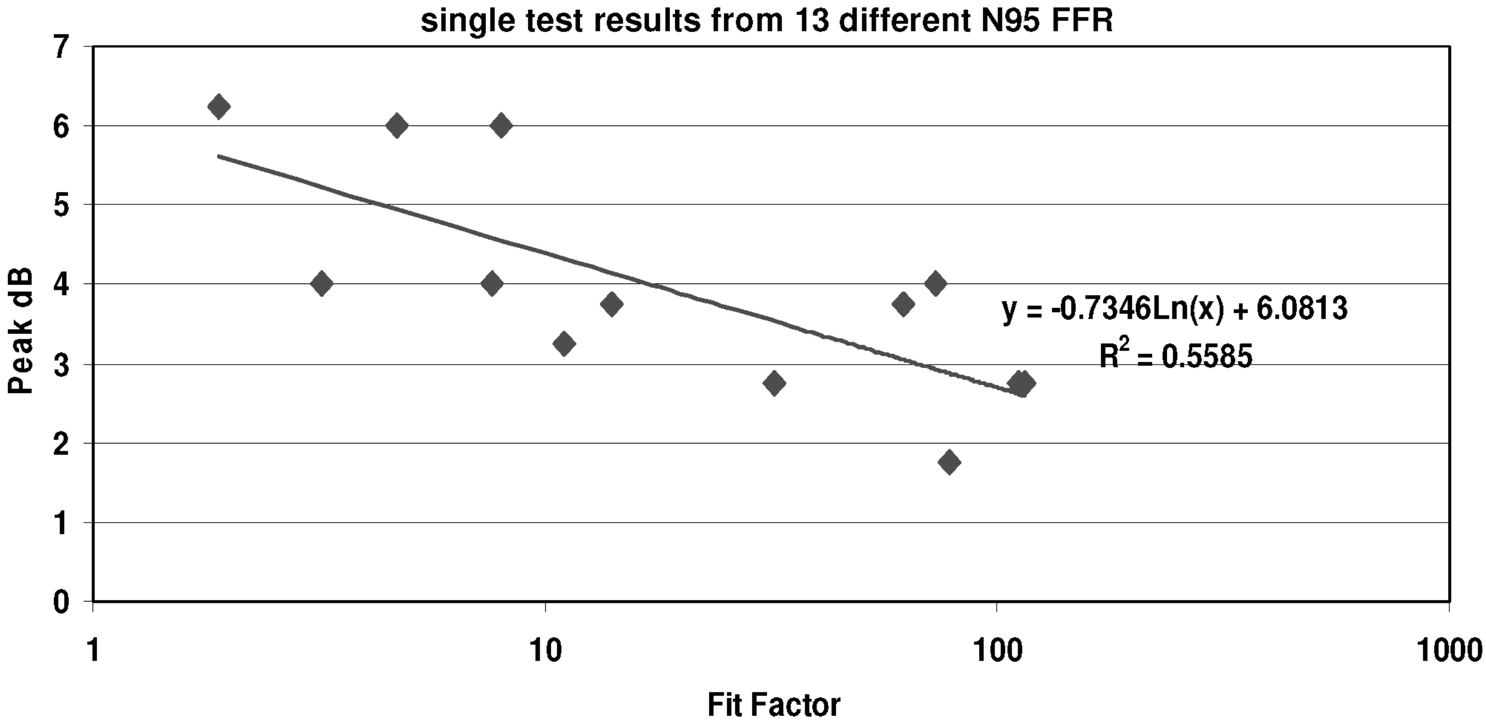
Ultrasound leakage has a discernable correlation with fit factor

# Comparison of Ultrasound Leak Amplitude to Fit Factor for N95 FFR

- Single test of each N95 FFR
- Readings from six points around face seal



# Average Ultrasound Leak Amplitude versus Measured Fit Factor for FFR




**Adjusted $R^2$ = 0.56**

**Ultrasound leakage has a discernable correlation with fit factor**

# Findings

- **Ultrasound sources**
  - Face seal leaks: no nascent ultrasound expected
  - Respiration: nasal is significant source
  - Others: friction, electrical
- **Assessment of information available**
  - Amplitude: Definite correlation with fit factor
  - Temporal: (at least seconds)
  - Spatial: (likely with the correct configuration)
  - Spectral: Not addressed

# Immediate Plans

- **Ultrasound sources and transceiver**
  - Prototypes for in and on mask
  - Data acquisition
- **Evaluate other strategies and configurations**