

## Modeling the Dissipation of Oxygen from an Outward Leak of a Closed-Circuit Breathing Device

NIOSH/NPPTL  
CBRN Closed-Circuit SCBA, and PAPR  
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## Closed Circuit, Self-Contained Breathing Apparatus

- Compressed air tanks contain a maximum 1 hour supply
- Longer durations may be necessary for emergency responders
  - Contaminated environments, including CBRN
  - Tunnels, mines, ships, high-rise buildings
- CC-SCBA (rebreather) enables up to 4 hour use
  - Recirculates exhaled gas
  - CO<sub>2</sub> absorbed
  - Fresh oxygen added



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## NIOSH CC-SCBA Standard

- NIOSH/NPPTL is developing a CC-SCBA standard to address use in environments containing CBRN materials identified as inhalation hazards
- Firefighter concern: Since the supply tank contains pure oxygen, what happens if there is a respirator leak in a fire environment?



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## Computational Model

- Can test variety of situations
  - Breathing pattern
  - Leak geometries
  - External environments
- Visualization of results
  - Oxygen / fuel gas concentrations
  - Velocity

1<sup>st</sup> step: Need to define the complex geometry of a person wearing respirator

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## Head Geometry

### 3-D Scanner



3-D points



Smoothed, holes filled

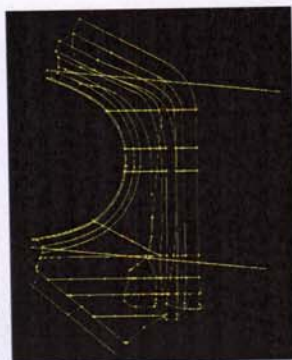


Clay removed

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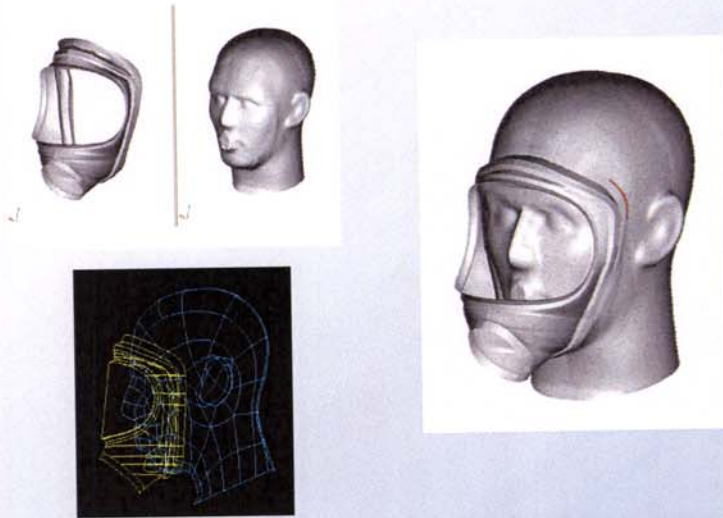
## Mask geometry

### Mechanical Drawings



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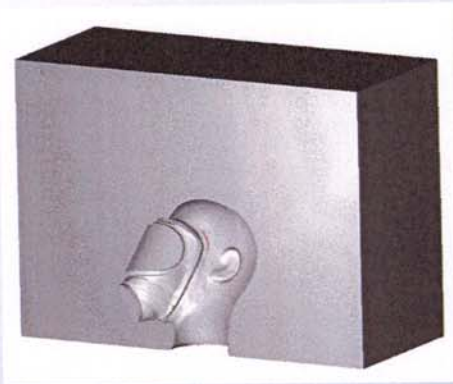
## Head + Mask Combination



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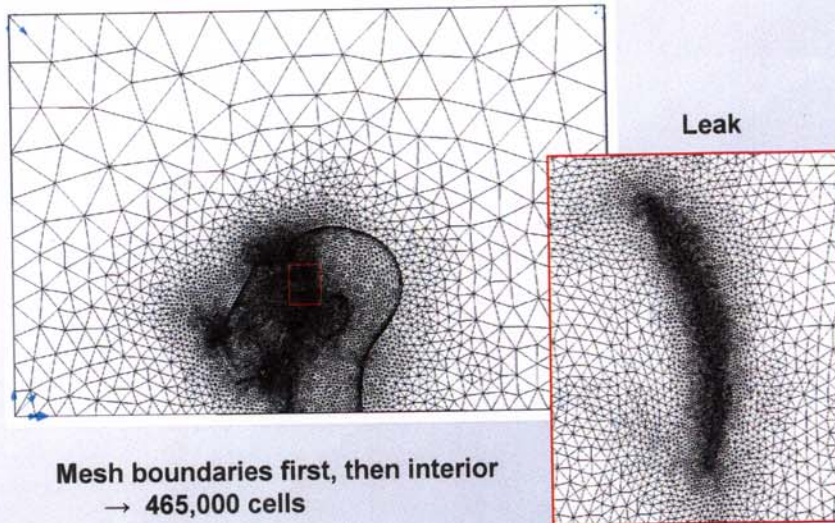
## Problem Geometry

- Exterior to head + mask
- Symmetric – cut problem in half
- Define a leak region



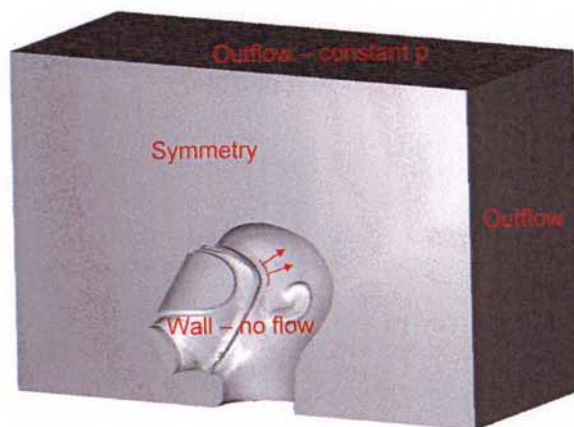
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## Mesh – Refined where needed



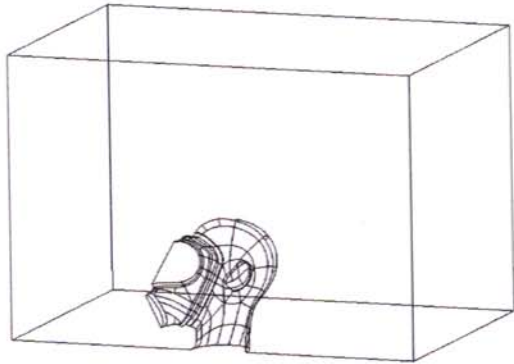
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## Boundary Conditions



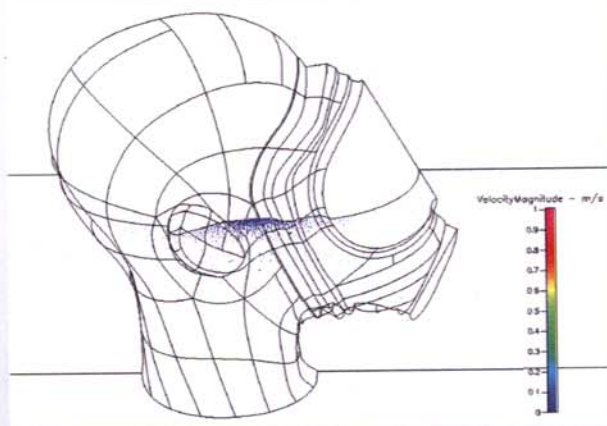
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### 3-D Geometry



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### Velocities along Leak Length

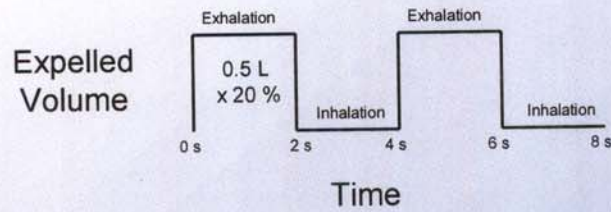


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## Normal Breathing Pattern

Assume

- 15 breaths per minute
- 0.5 L tidal volume
- 20 % lost through leak during exhalation
- Leak closes during inhalation
- Leak 1 mm wide x 44 mm long
- Velocity  $\approx$  1 m/s at leak



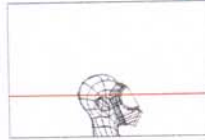
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## Model Conditions

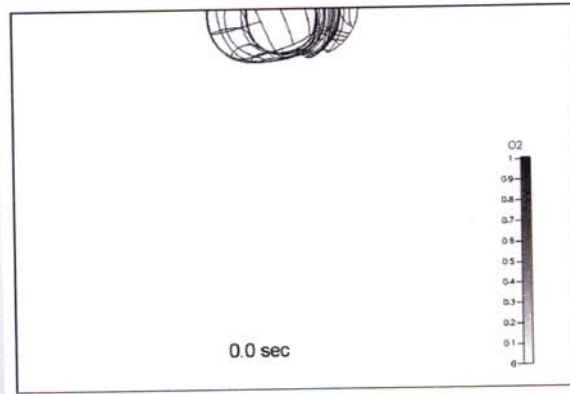
External Environment:	100 % Propane Gas
Exhaled from Leak:	100 % Oxygen

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## Oxygen / Propane Concentration



- 100% Propane Gas
- 100% Oxygen Leak (during exhalation only)
- Normal breathing



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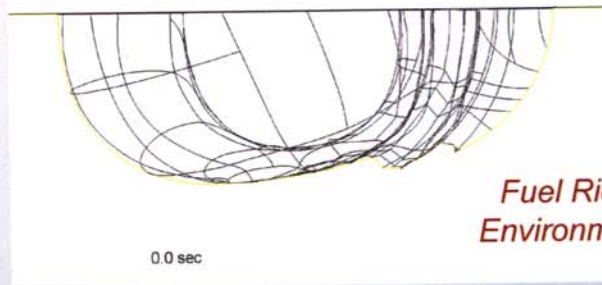
## Flammability Concentration Limits

For propane,

Lower Flammable Limit (LFL) = 2.8 %

Upper Flammable Limit (UFL) = 9.5 %

Outside of these limits, will not burn



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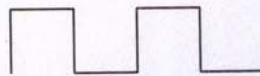
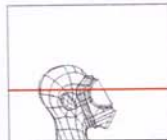
## Model Conditions

External Environment: 10 % Propane Gas  
(just above UFL = 9.5 %)

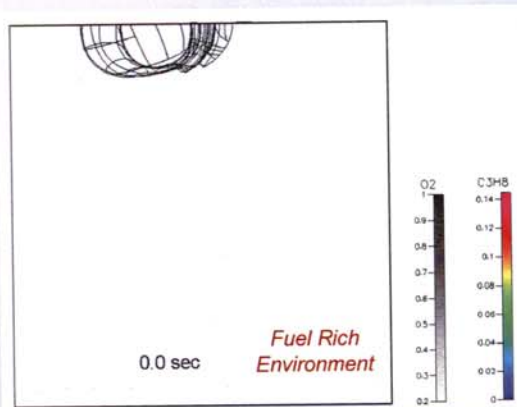
Exhaled from Leak: 100 % Oxygen

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## Oxygen Concentration / Propane LFL and UFL



- 10% Propane Gas
- 100% Oxygen Leak (during exhalation only)
- Normal breathing



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## Model Conditions

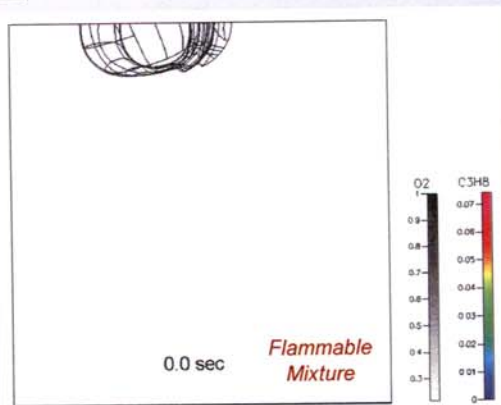
External Environment:	5 % Propane Gas (Between LFL = 2.8 % and UFL = 9.5 %) Flammable Mixture
Exhaled from Leak:	100 % Oxygen

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## Oxygen Concentration / Propane LFL Contour



- 5% Propane Gas
- 100% Oxygen Leak (during exhalation only)
- Normal breathing



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## Conclusions

- Oxygen expelled through leak in respirator is propelled away from head region through advection and dissipates through diffusion
- Risk of flammable mixture near head is observed in 10 % propane environment
  - This is an extreme environment (fuel-rich, near flammable mixture)
- In case of flammable environment, oxygen leak results in small fuel-lean region near head
- In fuel-lean environment, oxygen further decreases fuel concentration

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