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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
 - CO₂ absorbed
 - Fresh oxygen added



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?



Computational Model

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

1st step: Need to define the complex geometry of a person wearing respirator

Head Geometry

3-D Scanner



3-D points



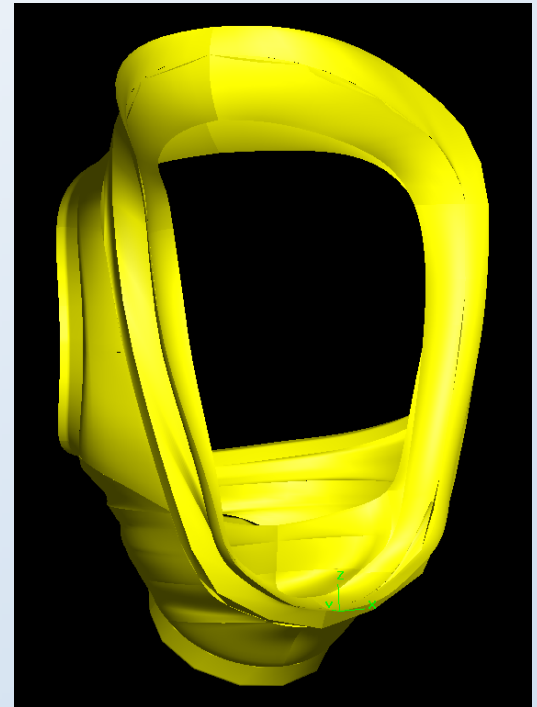
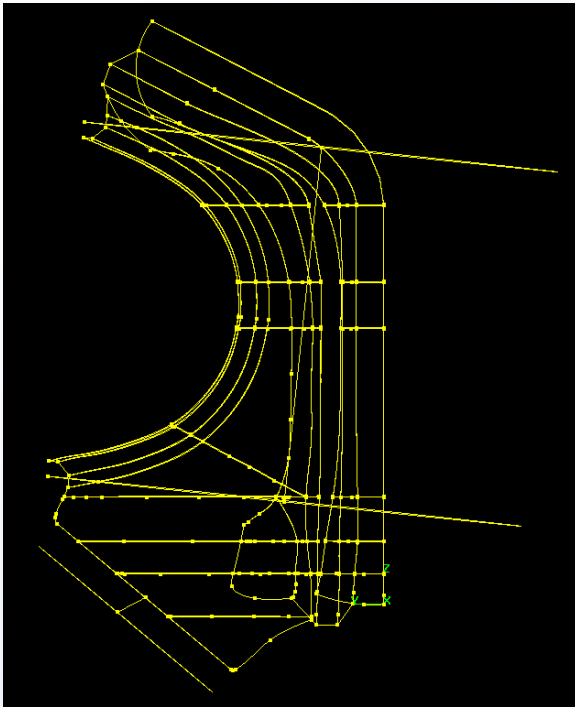
Smoothed, holes filled



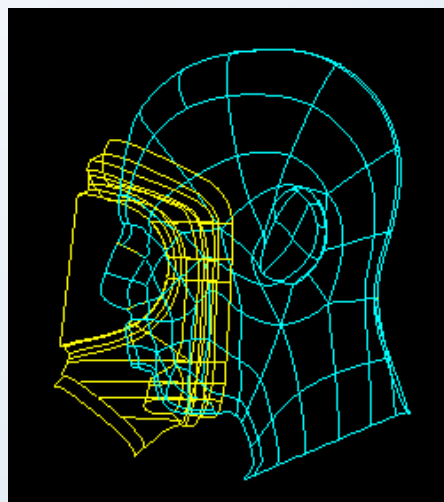
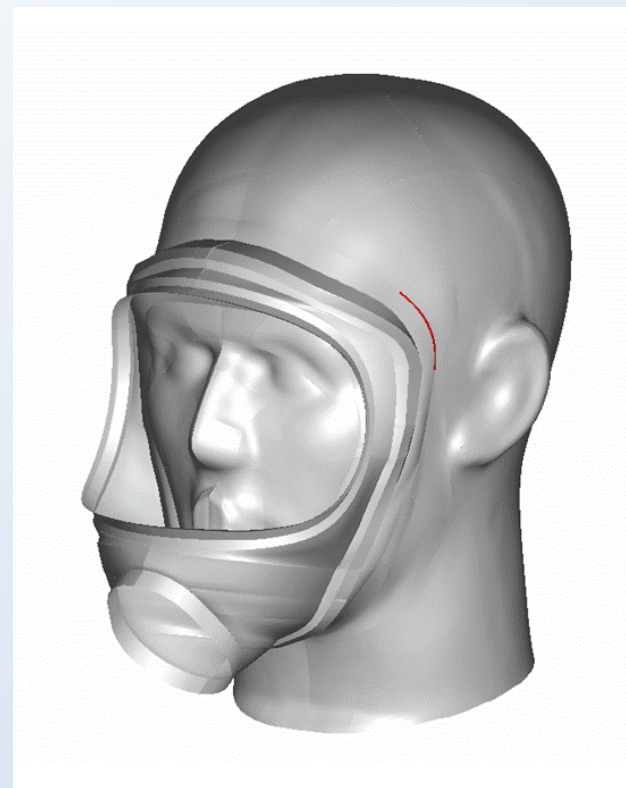
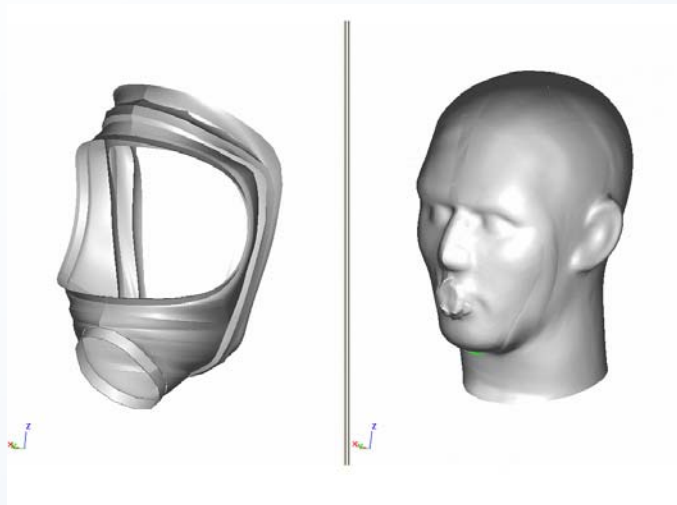
Clay removed

Mask geometry

Mechanical Drawings

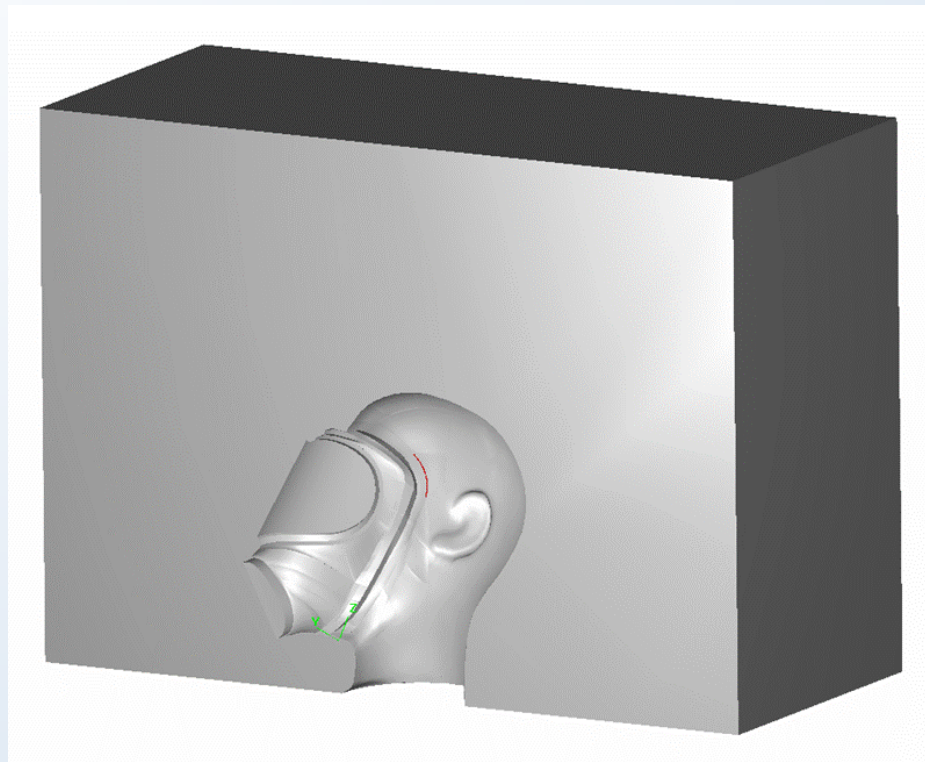


Head + Mask Combination

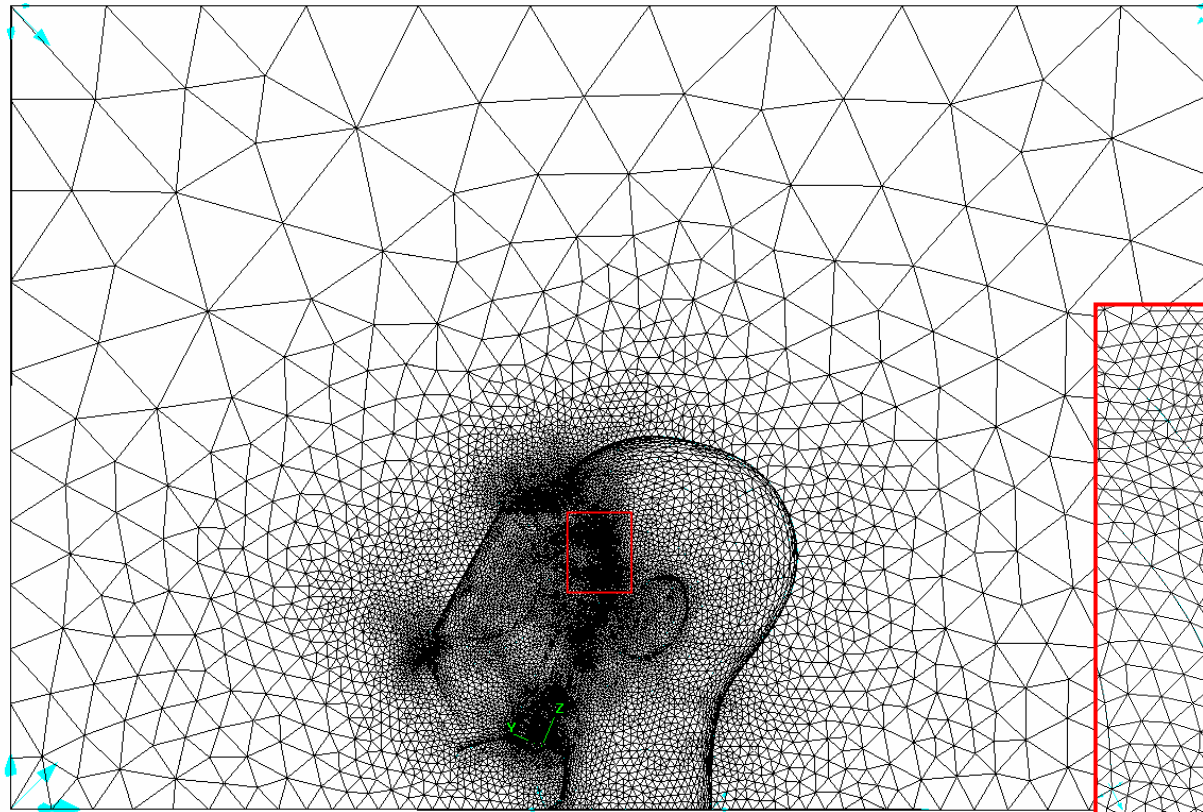


Problem Geometry

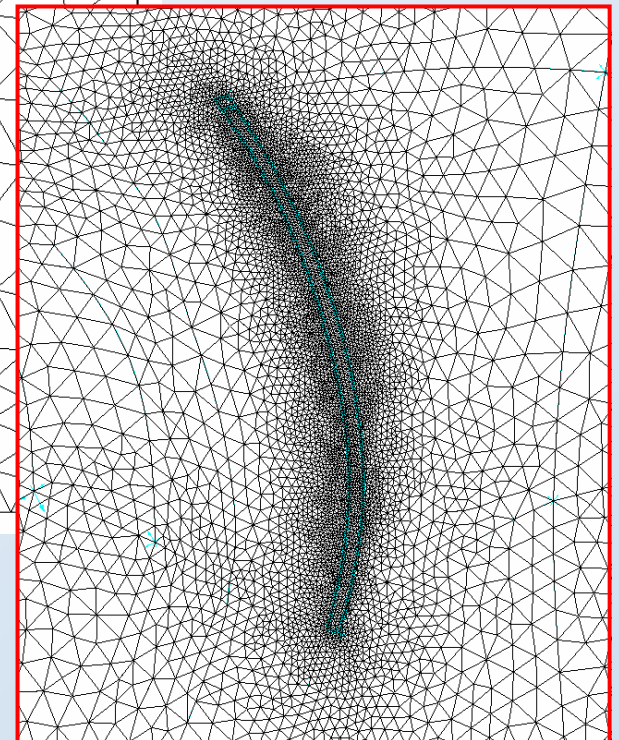
- Exterior to head + mask
- Symmetric – cut problem in half
- Define a leak region



Mesh – Refined where needed

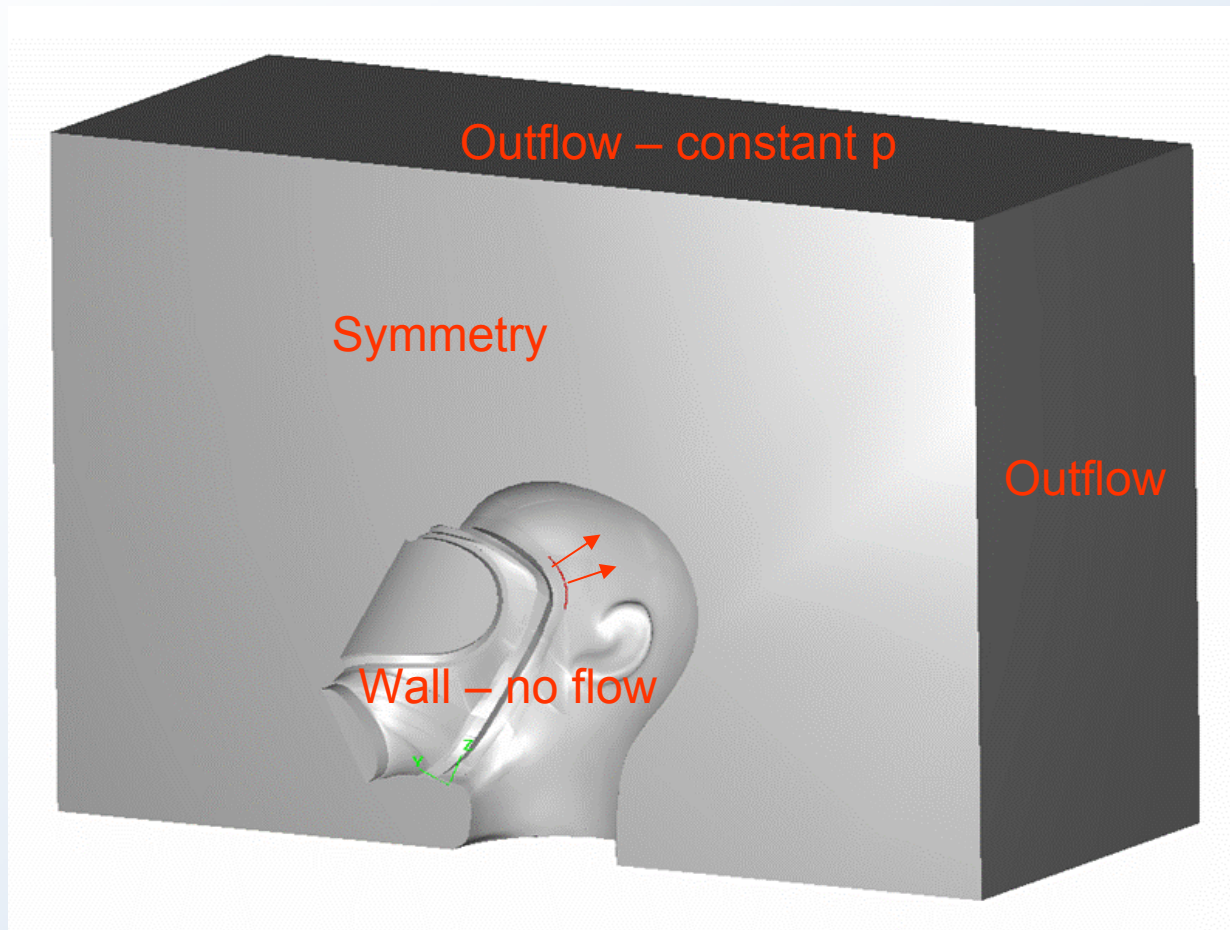


Leak

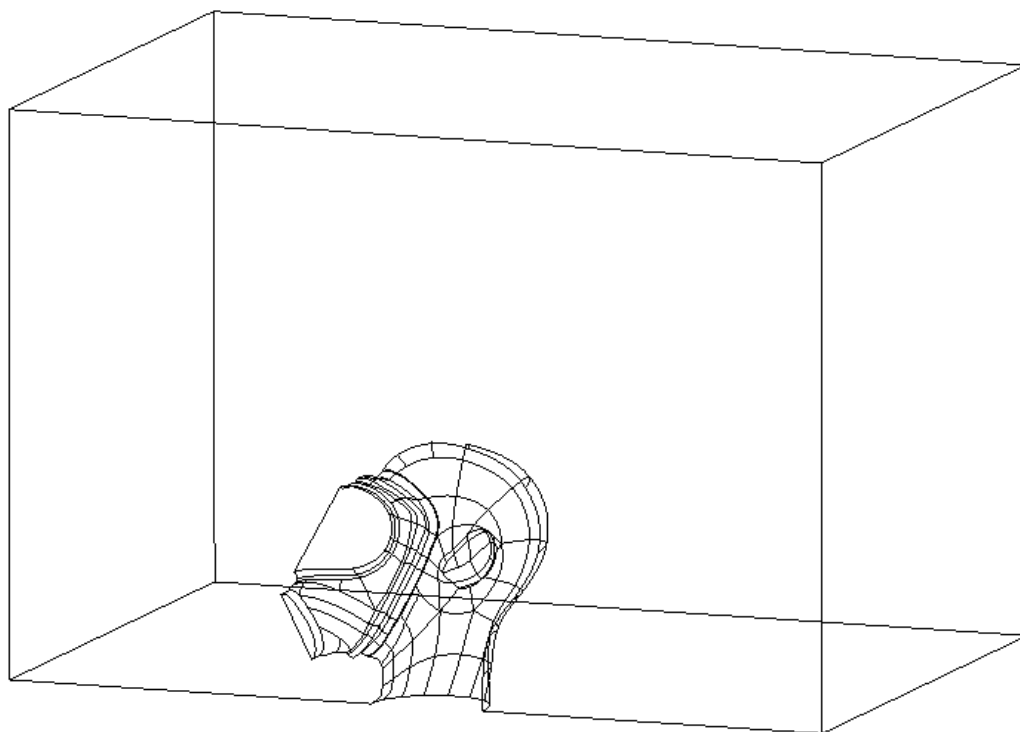


Mesh boundaries first, then interior
→ 465,000 cells

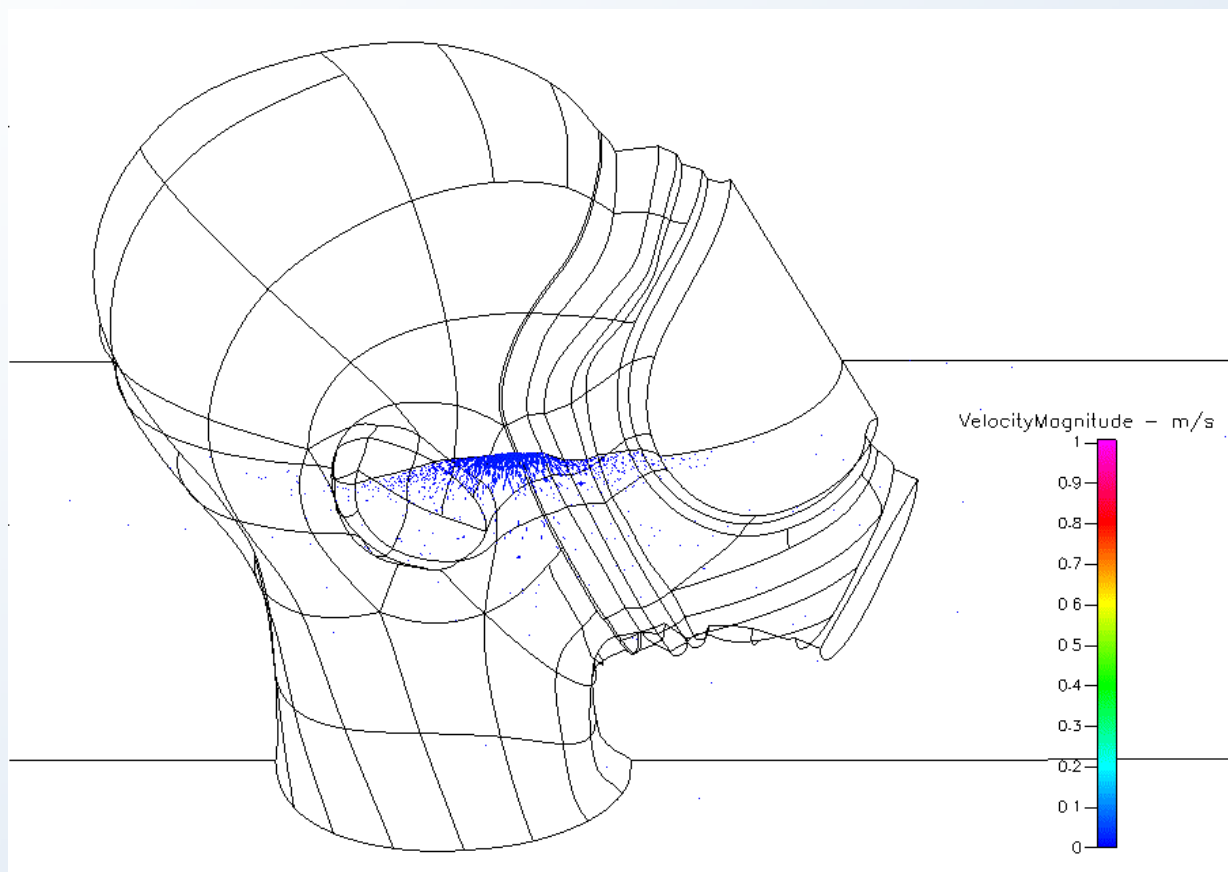
Boundary Conditions



3-D Geometry



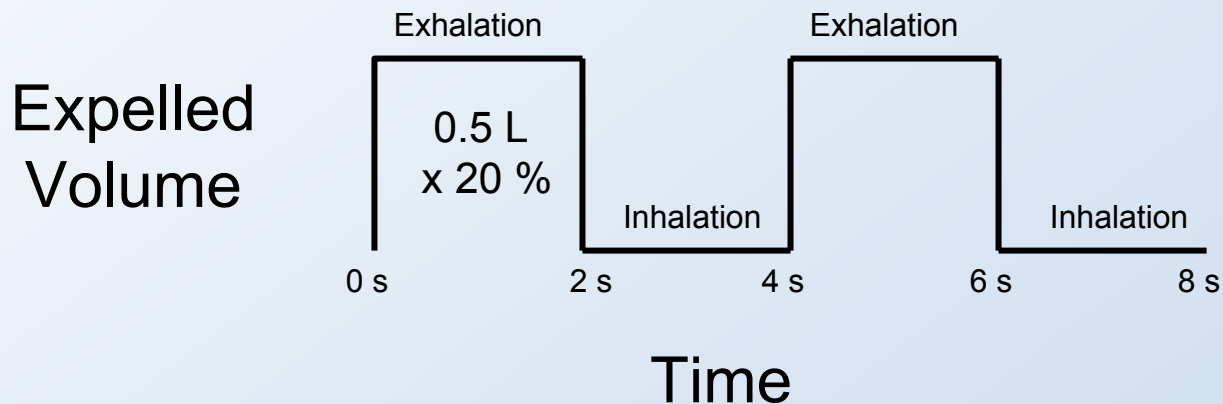
Velocities along Leak Length



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 ≈ 1 m/s at leak

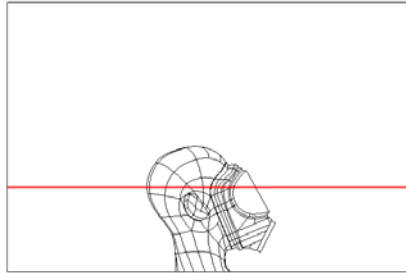


Model Conditions

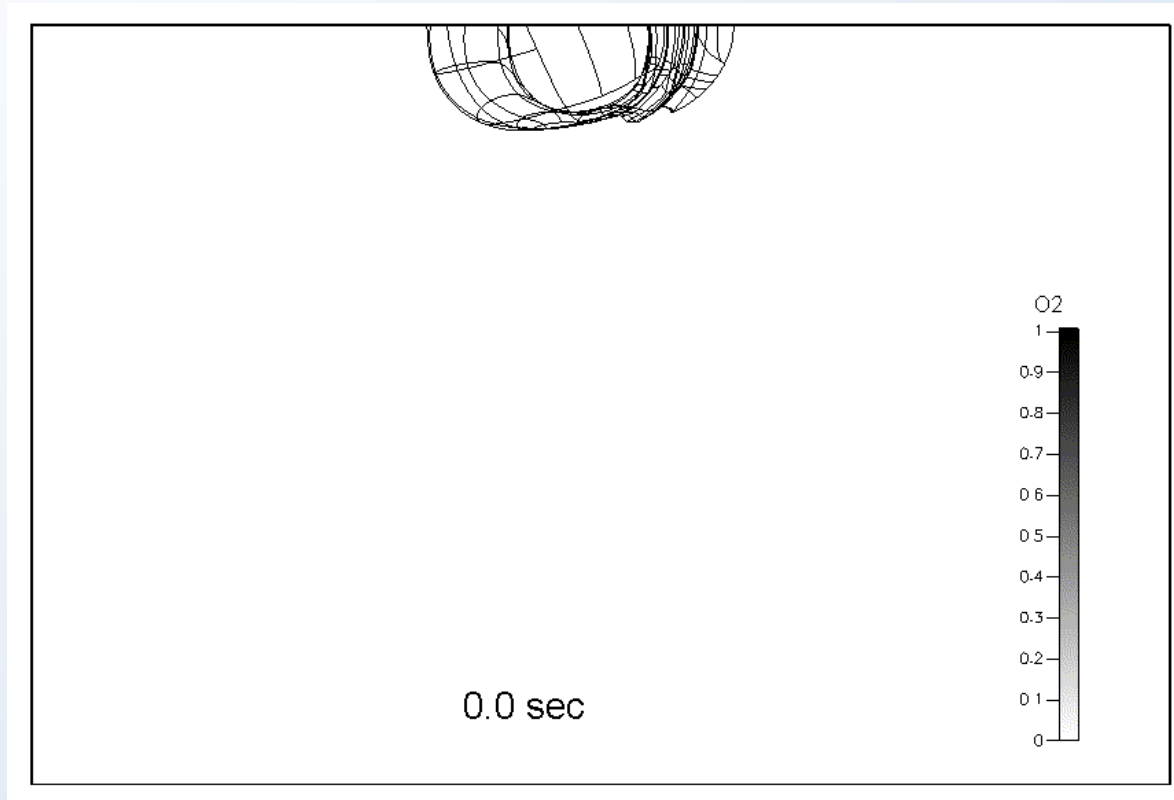
External Environment: 100 % Propane Gas

Exhaled from Leak: 100 % Oxygen

Oxygen / Propane Concentration



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



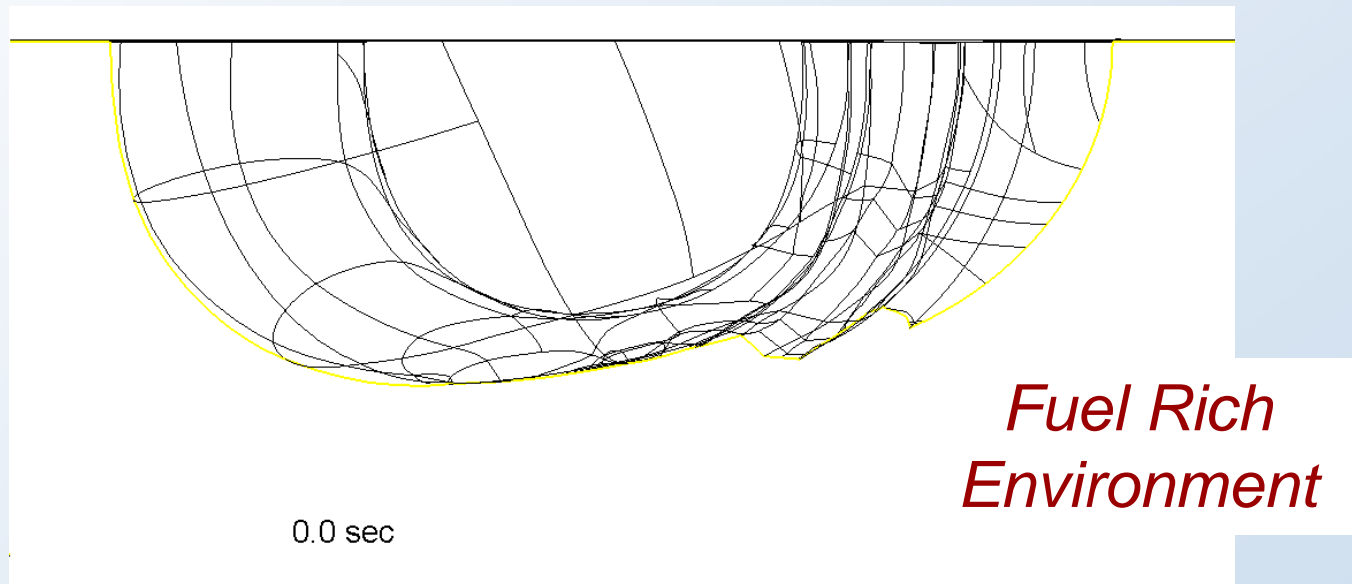
Flammability Concentration Limits

For propane,

Lower Flammable Limit (LFL) = 2.8 %

Upper Flammable Limit (UFL) = 9.5 %

Outside of these limits, will not burn

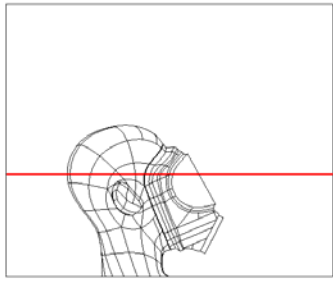


Model Conditions

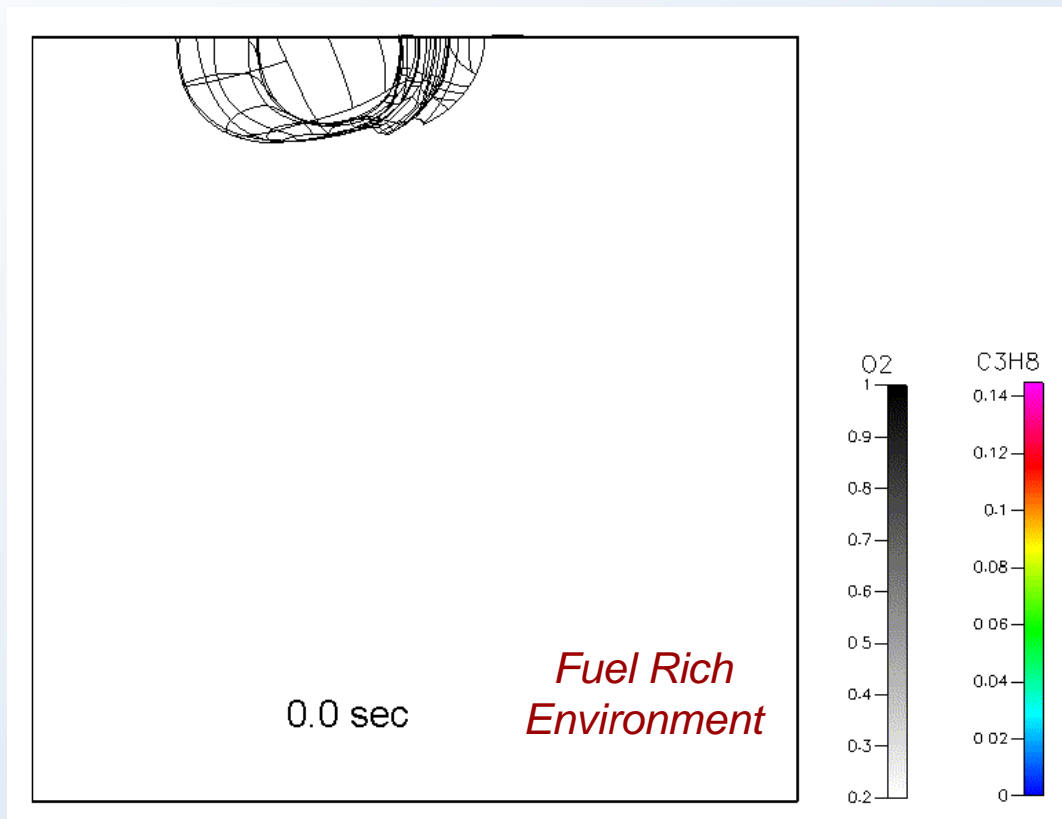
External Environment: 10 % Propane Gas
(just above UFL = 9.5 %)

Exhaled from Leak: 100 % Oxygen

Oxygen Concentration / Propane LFL and UFL



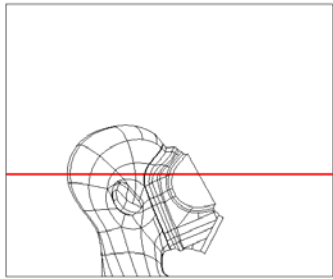
- 10% Propane Gas
- 100% Oxygen Leak (during exhalation only)
- Normal breathing



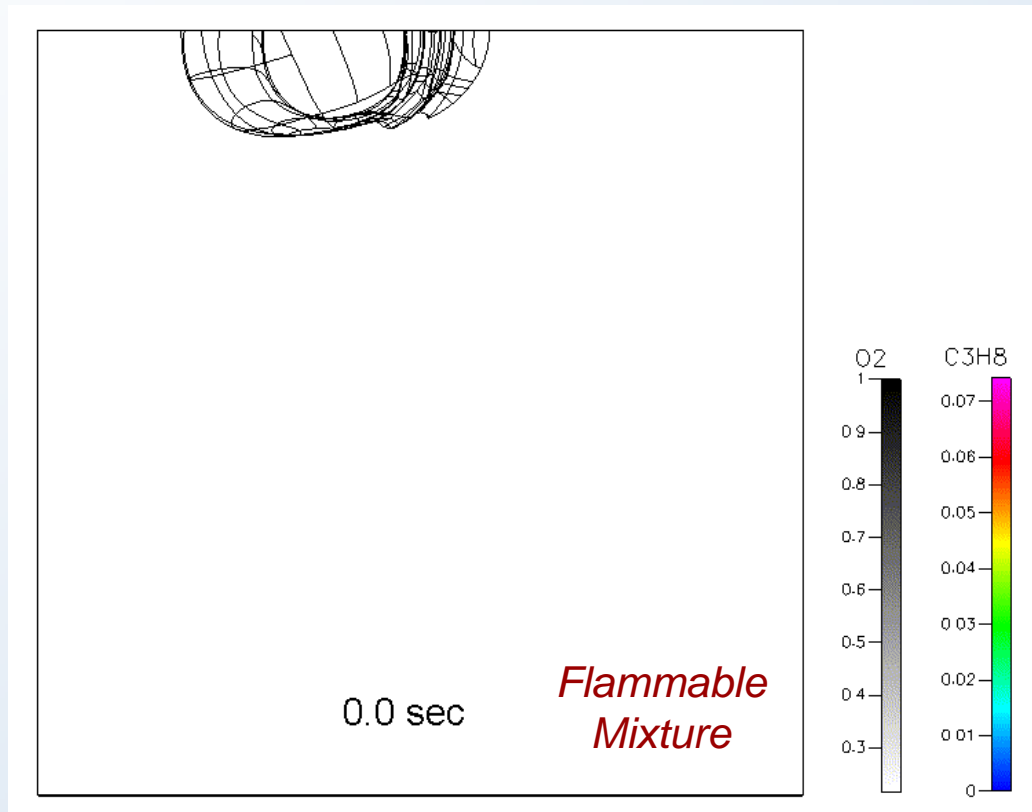
Model Conditions

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

Oxygen Concentration / Propane LFL Contour



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



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

Acknowledgments

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CC-SCBA

NIOSH Limitation of Use

- ❑ Cannot be used when there is direct exposure to open flame or high radiant heat

NFPA 1981

- ❑ Positive pressure at high work rates

CBRN

- ❑ Not hardened

