Methods for Providing Breathable Air

Survival considerations, assumptions, and calculations:

Some mines produce high amounts of methane, hydrogen sulfide, and hydrocarbons. This document provides some guidance on various methods which can be used to provide breathable air to miners awaiting rescue in a safe haven. Not all mines will be able to successfully adopt all of these recommendations due to their inherent mining conditions.

Safe Haven Assumptions

- No Methane (CH_4) liberation into safe haven atmosphere
- CO_2 scrubbing does not account for strata oxidation rates
- Miners die from the effects of CO_2 rather than O_2 deficiency
- Carbon monoxide (CO) purging utilizing compressed air cylinders anticipated as necessary to reduce safe haven concentration to less than 25 parts per million (PPM) for safe havens with a captive volume (not utilizing positive pressure forced air from either a compressed air line or borehole from the surface)
- Body heat and moisture generation is assumed to be dissipated by contact with the safe haven mine roof, ribs, and floor.
- The maximum acceptable temperature in the safe haven is 95^0 F.
- Miners shall monitor air quality through approved multiple gas detector which includes oxygen, carbon monoxide, carbon dioxide, and methane.
- Compressed air and oxygen cylinders are controlled through the usage of a regulator.
- Pressure relief valves are required when supplying fresh air (ie, 750 cubic feet per hour per person).

Breathing Rates & Calculations

- Respiratory Quotient, which is the ratio of CO_2 expelled to O_2 consumed = 0.8 (Technical resources cite respiratory quotients range from 0.7 – 1.0)
- Breathable air is the quantity, quality and methods to supply air necessary to sustain trapped miners
- Assumed Breathing Rate consists of activity levels of 4/5 at rest and 1/5 moderate activity
- Breathing rate at rest = 0.010 cubic feet per minute (CFM) O_2 per person = 0.60 cubic feet per hour (CFH) O_2 per person
- Breathing rate at moderate activity = 0.070 CFM O_2 per person = 4.2 CFH O_2 per person
- Oxygen (O_2) consumption (at Assumed Breathing Rate) = 4/5 x 0.010 +1/5 x 0.070 = 0.022 CFM per person = 1.32 CFH per person
- Carbon Dioxide (CO_2) generation (at Assumed Breathing Rate) = O_2 consumption x Respiratory Quotient = .022 x 0.8 = 0.018 CFM per person = 1.08 CFH per person

Supplied Air Specifications

- Lithium hydroxide (for CO_2 scrubbing) is provided in woven curtains

- Lithium hydroxide required in woven curtain form = .244 lbs. per person per hour; shelf life for LiOH is 5 years
- "K" size compressed air cylinders (9.25 inches diameter x 60 inches height) ref. U.S.DOT specification gas cylinders used for specialty gases spec. 3AA2400 (Grade D) each containing 282 ft^3 @ 2200 psi and weigh 170 lbs each

note: "K" size air cylinders gas volume can vary according to fill pressure. At 2400 psi, the volume would increase to 310 ft^3. This fill pressure range can affect the number of cylinders mine operators need to provide for the maintenance of miners.

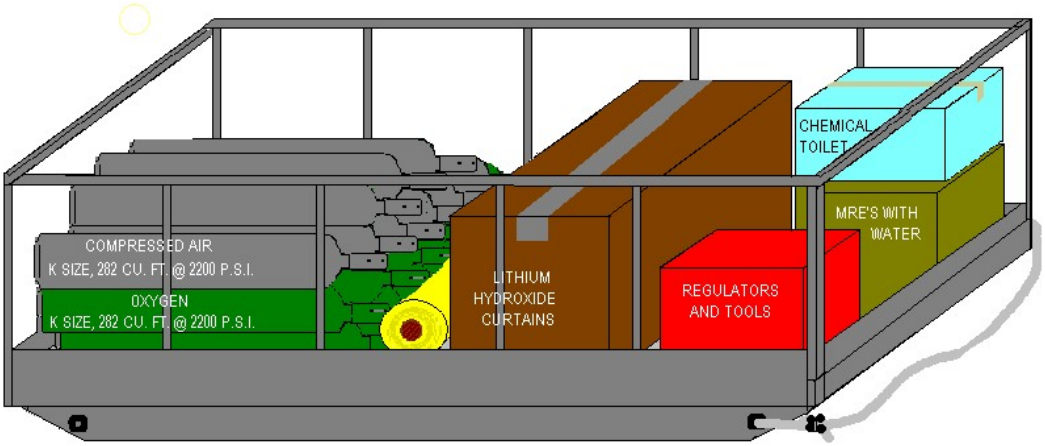
- Grade D air specifications:
  - O_2 = 19.5 to 23.5 %
  - CO = 10 PPM max
  - CO_2 = 1000 PPM max
  - Oil = 5 mg/m^3 max
  - Odor = lack of noticeable odor
- "K" size standard O_2 cylinders (non-USP with greater than 99% O_2) (9.25 inches diameter x 60 inches height) each containing 282 ft^3 @ 2200 psi and weigh 170 lbs each. Welding oxygen cylinders which are greater than 99% oxygen will suffice.

note: "K" size O_2 cylinders gas volume can vary according to fill pressure. At 2400 psi, the volume would increase to 310 ft^3. This fill pressure range can affect the number of cylinders mine operators need to provide for the maintenance of miners.

- Chemically generated oxygen provided by thermal decomposition of chlorate compounds (self-contained oxygen generators SCOGs). Other methods of chemically generated oxygen can be inorganic super oxides or per chlorates
- Safe haven purging "efficiency" estimated to require compressed air cylinders providing at least 3 times the amount of safe haven volume. Miners are to be inside of safe haven volume wearing an SCSR while purging is accomplished.
- Air source and quality provided for compressors and blowing fans is considered to be uncontaminated ambient air

<u>Emergency Supplies</u>

Compressed air and or compressed oxygen cylinders, lithium hydroxide curtains, chemical toilet, brattice cloth, tools, ready to eat meals, and valve regulators can be stored on a portable skid as seen in the example below.



CO_2 Exposure Example with Calculations

The following example demonstrates the rate at which a person would over expose from CO_2 if CO_2 were not removed from the environment (this example does not contain safe haven construction or population density requirements): A hypothetical sealed mine barricade has a volume of 1800 cubic feet (20 feet long, 18 feet wide and 5 feet high) and contains one person. Assuming the initial air quality was 19.5% O_2, and 0 .03% CO_2, below is shown the method used to calculate the period of time per cubic feet of barricade space per person before carbon dioxide reaches unacceptable levels. (Note: unacceptable level would be 3% based on Peele Mining Engineers' Handbook and current MSHA Short Term Exposure Limits for CO_2)

Breathing rate (4/5 at rest and 1/5 moderate activity) for oxygen inhaled is 0.022 cubic feet per minute per person. With respiratory quotient (ratio of CO_2 expelled to O_2 consumed) of 0.8 for persons at rest the rate of CO_2 produced would be 0.018 CFM per person.

0.03% X 1800 ft^3 = 0.54 Cubic Feet (Ambient air containing 0.03% CO_2)

3.0% X 1800 ft^3 = 54 Cubic Feet (Limit - unacceptable air containing 3% CO_2)

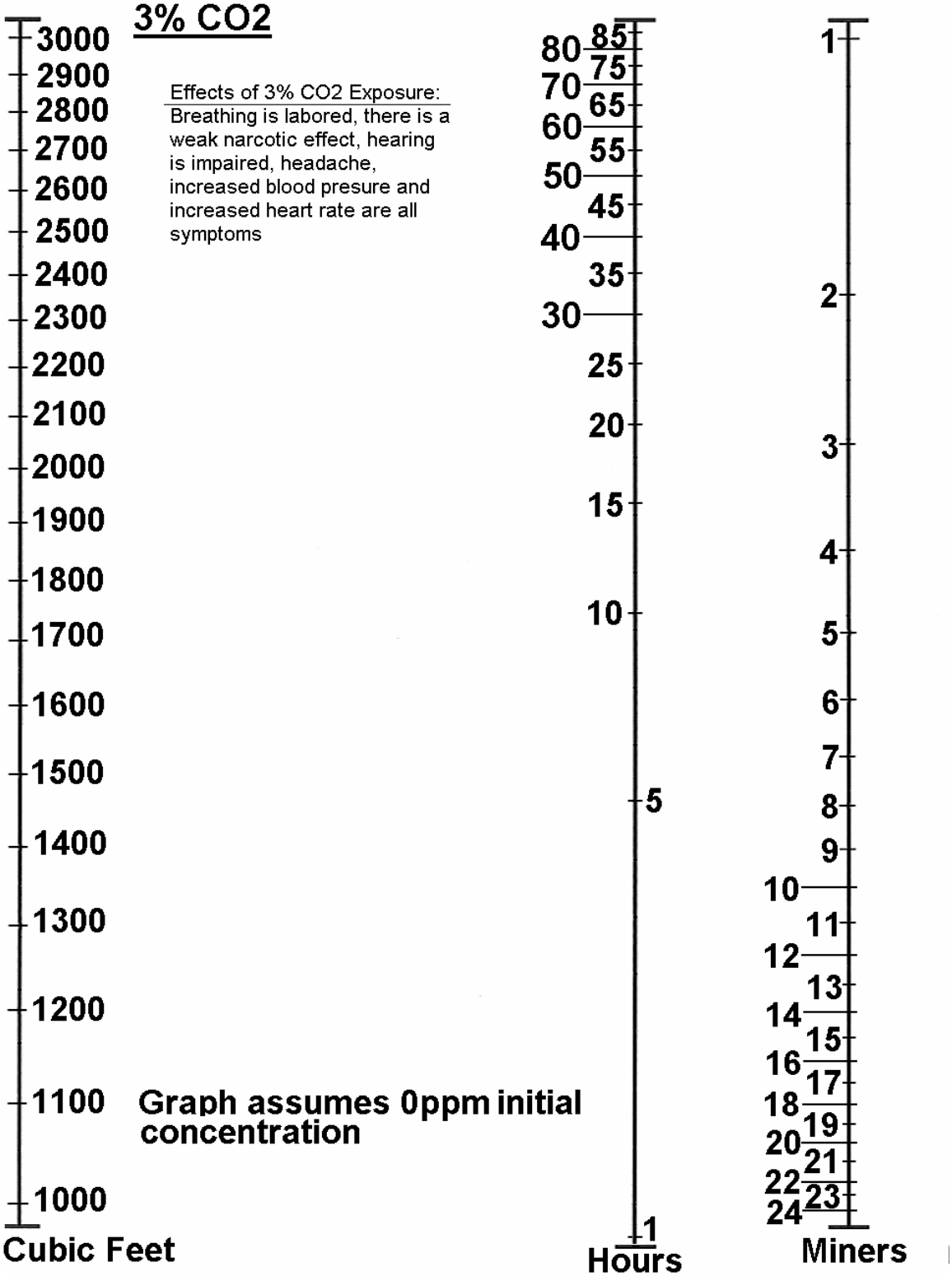
54 ft^3 - 0.54 ft^3 = 53.46 Cubic Feet of Air available before reaching unacceptable level

53.46 ft^3 / 0.018 (CFM exhalation rate per person of CO_2) = 2970 minutes or 49.5 hours

Therefore one miner could be maintained 49.5 hours in a barricade with the aforementioned dimensions and initial air quality or 1.65 minutes per cubic foot of barricade space (volume). Correspondingly, 10 miners could be maintained in an 1800 cubic foot space for 4.95 hours before the CO_2 concentration reached the defined unacceptable level.

Additionally, 10 miners in the above defined 1800 ft^3 volume would reach 10 % CO_2 and resulting unconsciousness in approximately 16.6 hours.
The maintenance time for multiple miners in the 1800 cubic feet space is inversely proportional to the number of miners in the barricaded area.

Carbon Dioxide Nomograph
Shown below are two nomographs, one for 3% exposure and one for 10% CO_2 exposure. To use these charts: Connect cubic feet volume behind barricade to the number of miners in barricade with a straight edge and read the result on the center line. The result is the amount of time it takes for the atmosphere to reach 3% or 10% CO_2 in the safe haven volume with the corresponding number of miners. Safe haven volume is the volume behind the barricade.


3% CO2
Effects of 3% CO2 Exposure:
Breathing is labored, there is a weak narcotic effect, hearing is impaired, headache, increased blood presure and increased heart rate are all symptoms
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
Cubic Feet
Graph assumes 0ppm initial concentration
80
85
70
75
65
60
55
50
45
40
35
30
25
20
15
10
5
1
Hours
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
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19
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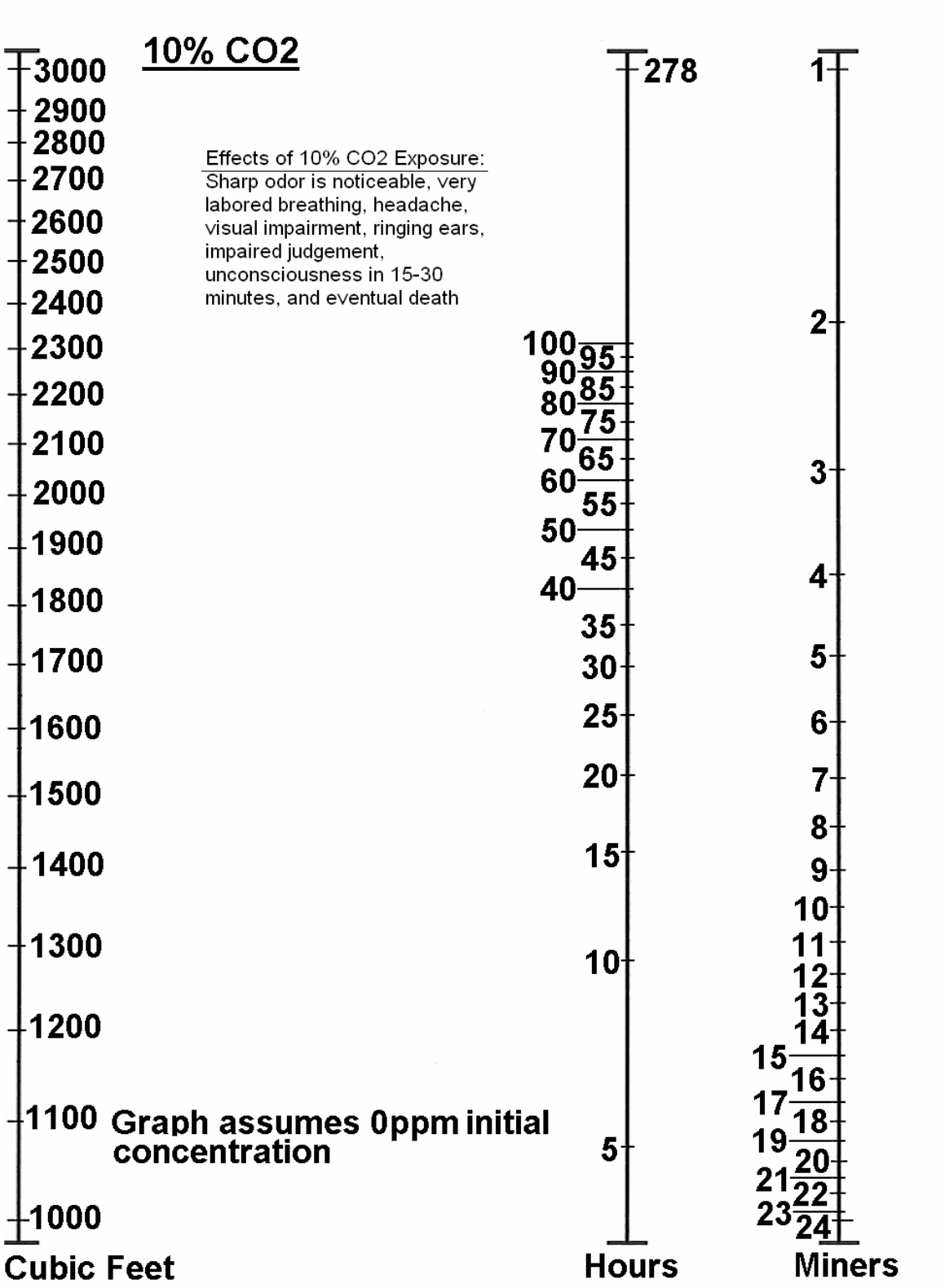
21
22
23
24
Miners


10% CO2
Effects of 10% CO2 Exposure:
Sharp odor is noticeable, very labored breathing, headache, visual impairment, ringing ears, impaired judgement, unconsciousness in 15-30 minutes, and eventual death
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
Graph assumes 0ppm initial concentration
Cubic Feet
278
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
Hours
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Miners

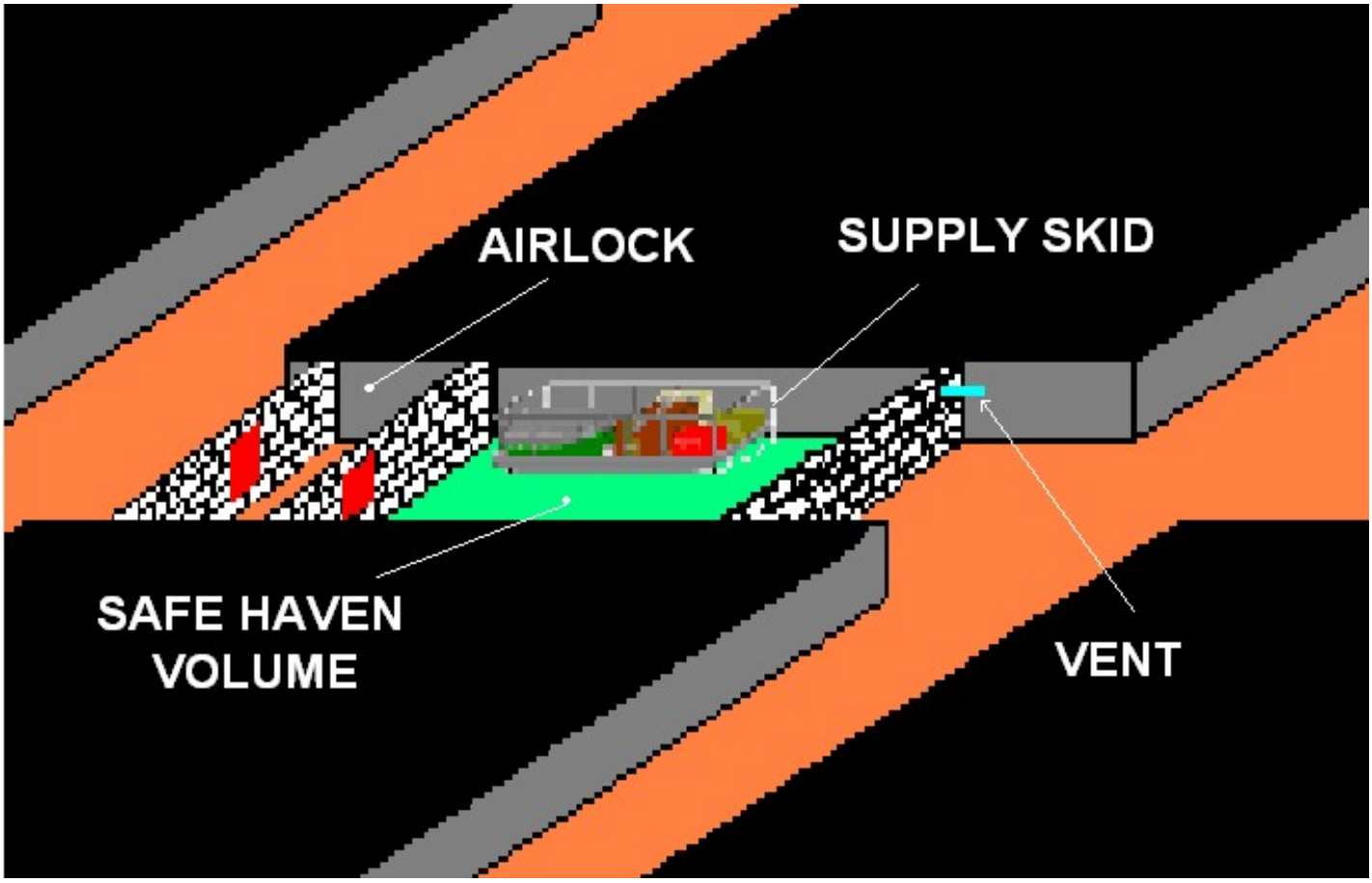
Examples of Methods/Systems for Providing Breathable Air

There are concerns with using the supplied air from compressed cylinders and outside positive pressure blowing systems. For more information on these concerns, please see MSHA's Safety Awareness Information discussing Hazard Awareness for Compressed Air and Compressed Oxygen systems (***See Document***).

O_2 Cylinders

- 1.32 cubic feet per hour (CFH) per person = .022 CFM
- CO_2 scrubbing required for miners in the safe haven
- Lithium hydroxide required in woven curtain form = .244 lbs. per person per hour (or equivalent CO_2 scrubbing agent)

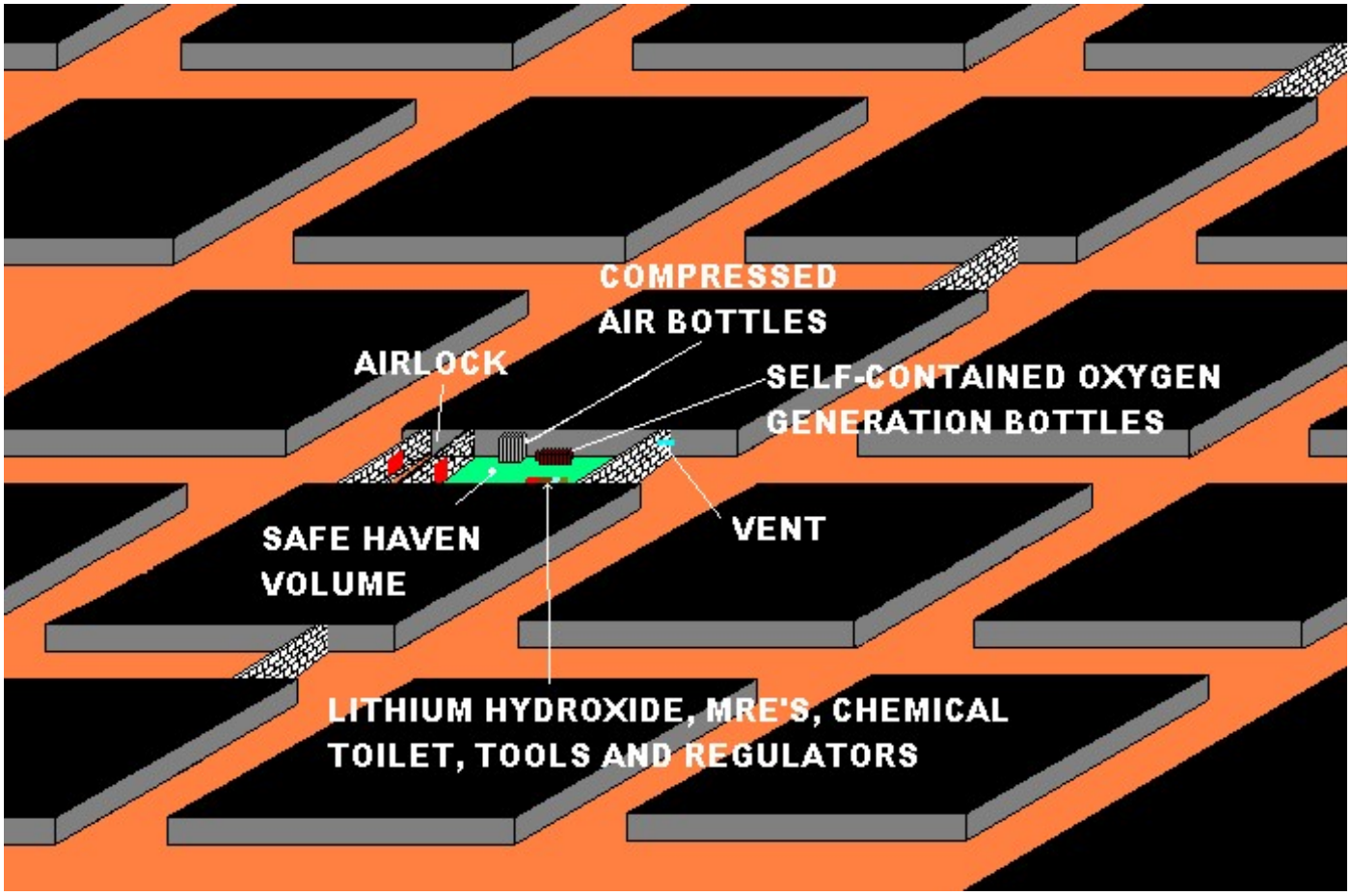
Visual depiction of safe haven scenario using compressed oxygen and compressed air cylinders.



Chemically Generated O_2

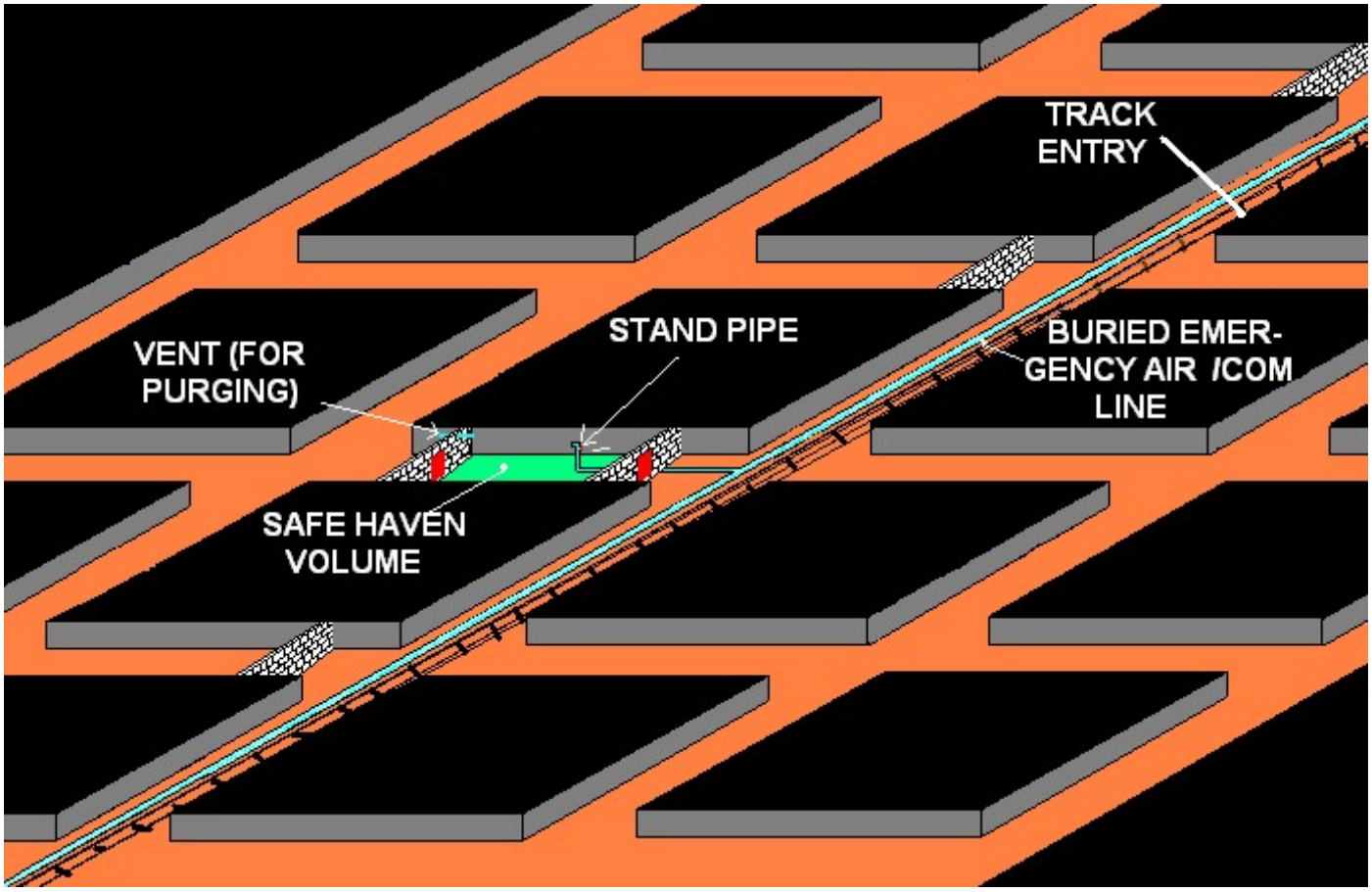
- Chemically generated oxygen provided by thermal decomposition of chlorate compounds (self-contained oxygen generators SCOGs). Other methods of chemically generated oxygen can be inorganic super oxides or per chlorates
- 1.32 CFH per person = .022 CFM per person
- CO_2 scrubbing required for miners in the safe haven
- Lithium hydroxide required in woven curtain form = .244 lbs. per person per hour (or equivalent CO_2 scrubbing agent)

Visual depiction of safe haven scenario using chemically generated oxygen and compressed air cylinders (used for purging initial air environment)



Compressed Air Lines (buried from portal or from vertical borehole to safe haven)

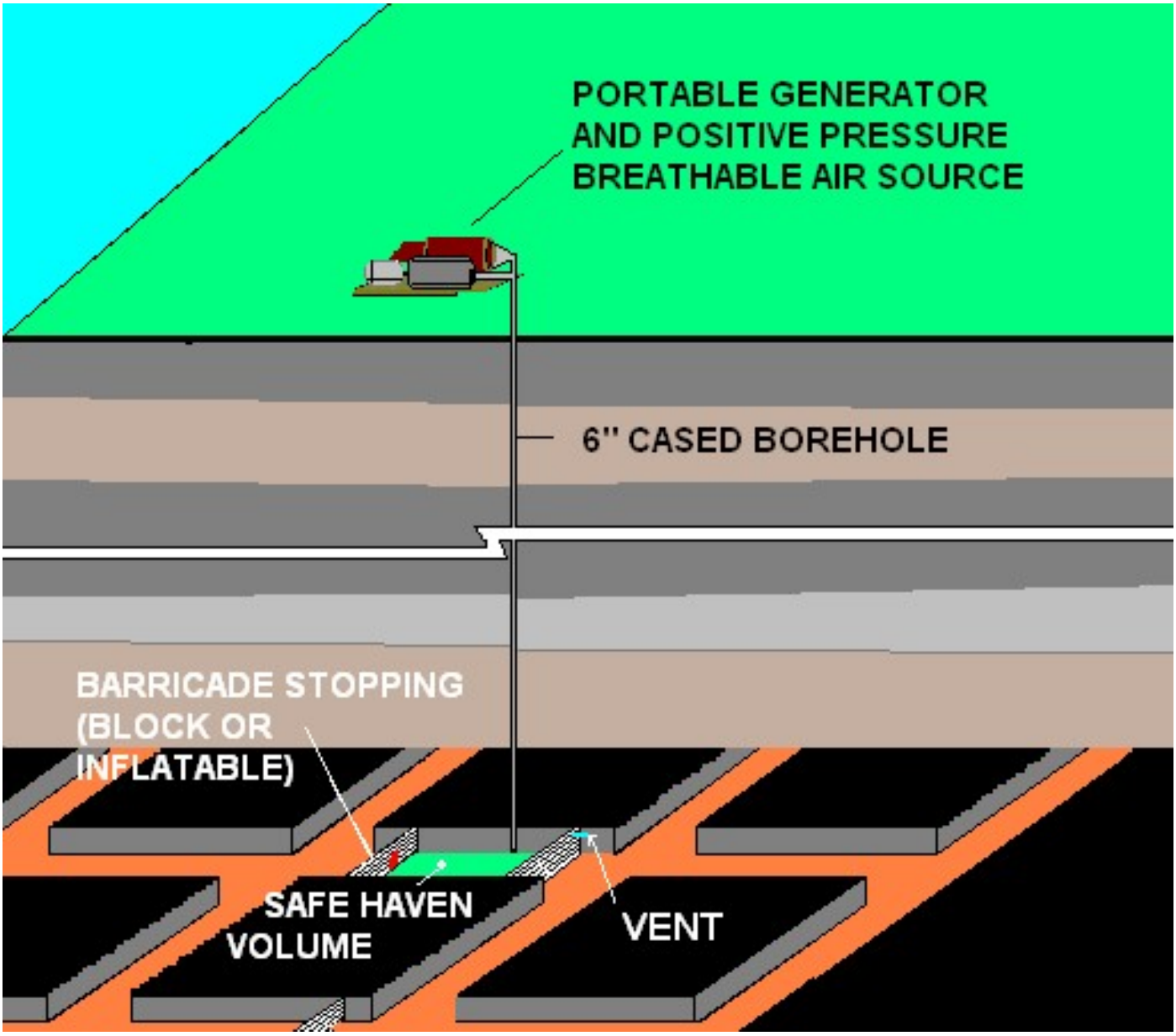
- 750 CFH per person = 12.5 CFM per person
- Breathable air provided by oil compressor with CO filtering capability, or oilless compressor
- No CO_2 scrubbing required
- An option for mines using track haulage in order to secure compressed air lines against explosive forces could be to lay out a properly sized and rated air line and ballast over it.



Vertical Boreholes

- 750 CFH per person =12.5 CFM per person
- Breathable air provided by positive pressure blowing fan
- No CO_2 scrubbing required (CO_2 exits through the vent)

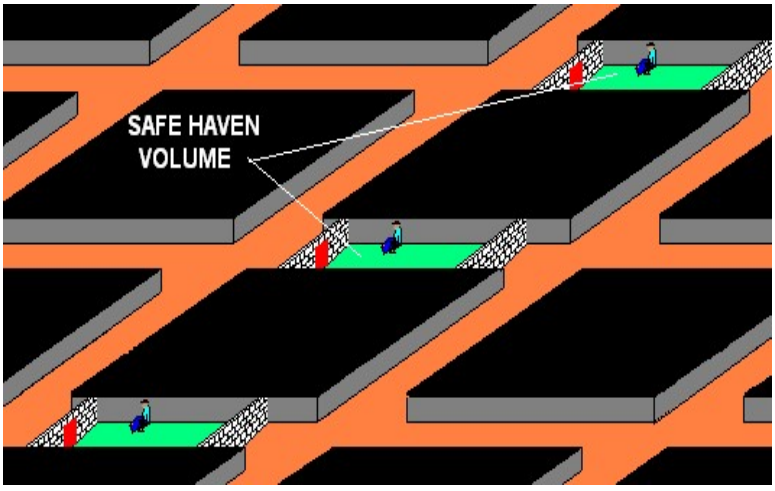
Visual depiction of safe haven scenario using supplied air via a vertical borehole from the surface.



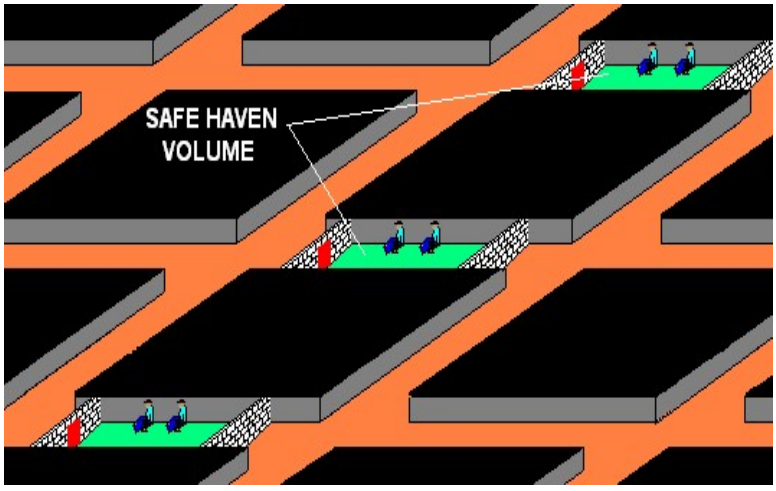
Multiple Safe Havens with Purge Air Provided

- This option is essentially placing miners in small groups within multiple safe havens.
- The theory is that the smaller number of people over a larger volume of safe haven space are less likely to perish from exhaled Carbon Dioxide (CO_2).
- Purge air using Grade D, K sized compressed air cylinders
- No additional compressed air or oxygen cylinders needed
- No CO_2 scrubbing agents needed

Assuming 1800 ft^3 volume per safe haven, each purged with compressed air cylinders.
1 miner will take 49.5 hours to reach 3% CO_2 and 166 hours to reach 10% CO_2
2 miners will take 25 hours to reach 3% CO_2 and 83 hours to reach 10% CO_2
3 miners will take 16.5 hours to reach 3% CO_2 and 55 hours to reach 10% CO_2
4 miners will take 12 hours to reach 3% CO_2 and 41 hours to reach 10% CO_2

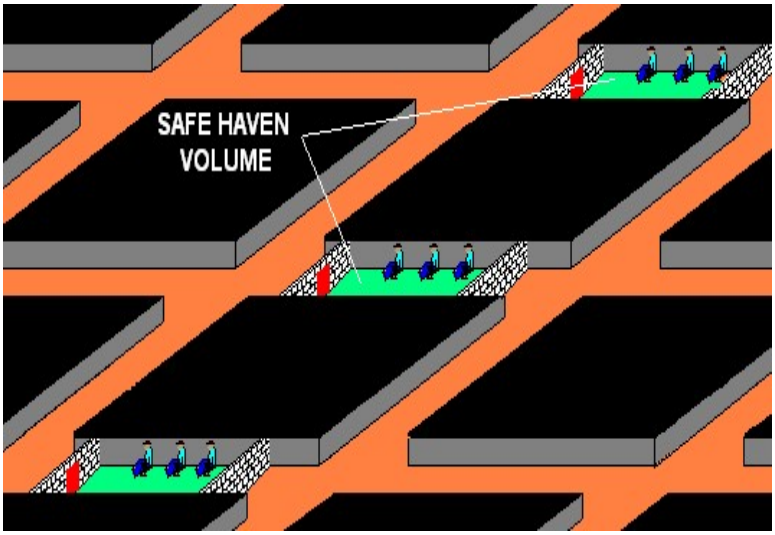


One miner in each safe haven

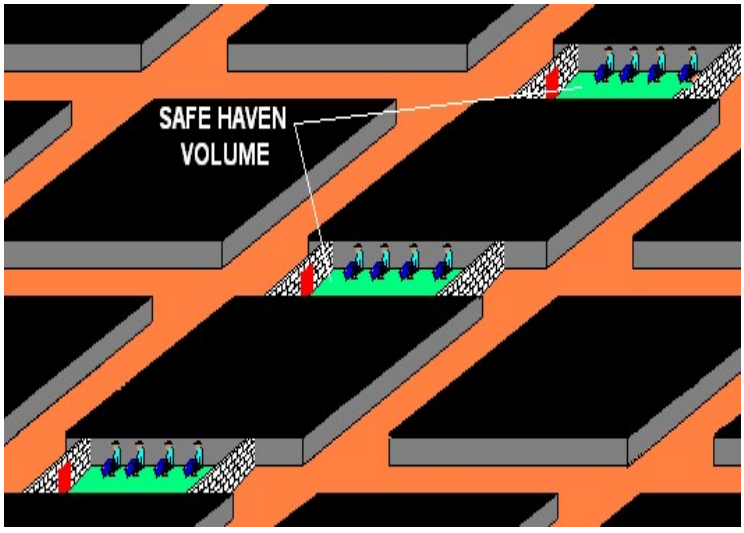


Two Miners in each safe haven

Three miners in each safe haven



Four miners in each safe haven



Compressed Air Cylinders

- MSHA considers the use of compressed air cylinders as the sole means of providing breathable air to be an impractical solution and encourages mine operators to consider other options.
- The number of K size Grade D compressed air cylinders required to sustain 24 miners for 48 hours is 3,142. Each Grade D breathable compressed air cylinder can provide 22.5 minutes of breathing air per person.
- 750 CFH per person = 12.5 CFM per person if used for providing breathable air

  Note: 750 CFH was derived from the amount of air needed for respiration and dilution of CO_2. By adding excess volume of compressed air (12.5 CFM) to the safe haven beyond what is needed to breathe eliminates the need for lithium hydroxide as a means for removing CO_2. A pressure is created as contaminated air is moved out of the haven through a pressure relief vent. CO_2 scrubbing not required if breathable air is provided solely by compressed air cylinders at the volume specified above. The number of compressed air cylinders should provide air volume at least 3 times the safe haven volume when used for purging.