RIMER ALCO NORTH AMERICA

RESPIRABLE AIR HANDBOOK

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PREFACE

In the past, very little attention has been given as to how, why, and if respirable air could really be assured if miners had to use a refuge station. Up until recently, it was "accepted" that if a chamber was "large enough" or if there was a compressed air pipeline, sufficient oxygen would be available to keep people alive during an emergency. It assumed that if oxygen was taken care of, the buildup of carbon dioxide was automatically controlled. Now it has been clearly shown that control of carbon dioxide takes much more air than is needed to just ensure sufficient oxygen. It is also now recognized that common methods of providing compressed air to a refuge station are at risk when needed, and when kept intact are insufficient for occupancy times greater that just a few hours.

Rimer Alco North America offers this handbook to assist you in understanding the requirements for respirable air, and in planning for the most practical strategy for your particular mine refuge station conditions. The information will assist you in meeting regulations for respirable air by making rational operational decisions for risk management.

We believe that when the rationalization provided within this handbook is applied to your mine's particular situation, that your decisions will ensure that occupants of your refuge stations will be safe until Mine Rescue teams can get to them.

SAFETY FIRST, LAST AND ALWAYS!

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1.0 INTRODUCTION AND HISTORY

1.1 INTRODUCTION

Refuge Stations play a very important role, both in the immediate safety of an underground worker in the event of a fire or gas release (ie. SO_2), and in the overall planning of Mine Rescue. Having the ability to thoroughly plan a well thought out rescue, with adequate time for implementation and then execution, greatly ensures the safety of both the Rescue Team and the trapped miners.

Breathing within a closed space results in Carbon Dioxide being dispersed into the air, and Oxygen being removed. Factors which effect the significance of the resulting risks are; the number of people, the length of time they may have to remain within the closed space, and the physical size of the space.

One of the most significant benefits of a Refuge Station, and it's resources, therefore is to provide the worker with Respirable Air. In order to assure this, the process of determining risk and need can be broken down into two (2) categories:

A. WHAT ARE THE FUNDAMENTALS REQUIRED TO ADDRESS THE RISK?
This can be covered by addressing:

- Where are Refuge Stations located?
- How many people may occupy the Refuge Station?
- How long will it take Mine Rescue to execute a successful rescue operation?
- What are the acceptable levels of increased CO_2 and decreased O_2 in an emergency?

These issues are covered in detail in Section 2.

B. HOW CAN RESPIRABLE AIR BE PROVIDED WHEN NEEDED?
The "real" options are:

- The Use of "Dead Air"
- The Use of a Mine's "Compressed Air"
- The Use of a "REFUGE ONE" Air Centre

These issues are covered in more detail in Section 3.

Ensuring that the Refuge Station's first role can be met, "quick access to protection from dangerous gases, when exit from the mine is not an option", has been well established. Refuge Stations, by and large, have been strategically located, based on their various uses (safety, lunch, meetings, etc).

Providing adequate protection from the consequences of having a long wait in a Refuge Station, which primarily results from the simple task of "breathing" in a confined space, is still really in the developmental stages. Understanding the factors that make for well engineered systems may be all that is required to make existing compressed air systems safe. In other circumstances it may require a different approach to achieve the level of safety that the process of "due diligence" would derive.

Well engineered and supported information is being developed to help Safety Engineers with risk assessment and needs evaluation, in order to ensure that when an underground accident occurs, and Mine Rescue will be required, that trapped miners will be safe for a sufficient period of time to execute a successful rescue operation.

1.2 HISTORY OF EVENTS THAT HAVE LEAD TO THE ESTABLISHMENT AND IMPROVEMENT OF UNDERGROUND REFUGE STATIONS

On February 10, 1928, 39 miners died in an underground fire at Hollinger Consolidated Gold Mine. The subsequent Report of the Commissioner, T.E. Godson, made 15 recommendations; the most important being the establishment of mine rescue stations in Ontario. In 1930 the Mining Act was amended to include provisions for refuge stations where the Chief Inspector deemed necessary. Refuge stations were to "have water, air and telephone connections to surface and be separated from the adjoining workings by closeable openings so arranged and equipped that gases can be prevented from entering the refuge station."

On May 2, 1972 a major underground fire occurred in the Sunshine Mine in Kellogg, Idaho. Of the 173 men working underground at the time, 80 escaped before the hoistman died, 2 more were rescued and the remaining 91 died of carbon monoxide poisoning. Eighteen men were working on the bottom three levels with the only access being the shaft. The final report on the disaster stated, "If a refuge was available, it is conceivable that some of the men could have been rescued."

On October 6th, 1990 at Ruttan Mine in Northern Manitoba, a fire broke out in an underground conveyor gallery. At the time of the fire thirty-eight (38) workers were underground. The fire quickly destroyed air, water, electricity and communication lines which serviced the mine by way of the conveyor gallery. The mine emergency warning system was activated but since the main air lines were severed and the intake ventilation fans were without power the stench gas never entered the mine workings. Two quick thinking underground supervisors (both trained in Mine Rescue) who by coincidence were talking on the mine phones realized what was happening, gathered their crews and at personal risk, guided them to refuge stations.

When the men sealed themselves into the refuge station they cracked a compressed air header to provide a supply of breathable air. However, when this was done, instead of air coming into the chamber, it was drawn out through the airline at the location where the fire had severed the line. Fortunately, within 4 1/2 hours the Mine Rescue teams had accounted for all 38 men and they were secured on surface.

This fire raged for 19 hours, and if rescue had been delayed due to the fire, the likelihood of all **38 men dying** from very high levels of Carbon Dioxide build-up and extremely low levels of Oxygen, would have been very real!

In Ontario, also in 1990, a vehicle being refuelled in a fuelling bay caught fire and burned vigorously. Workers underground, following procedure, rushed to the Refuge Station and opened the compressed air line, only to have smoke begin to fill the room. It is believed that the fire vaporized the rubber seals in the vitaulic couplings and smoke from the fire was drawn into the compressed air. Again well trained Mine Rescue teams came through in time, and no deaths resulted.

In December 1995, the Government of the Northwest Territories, implemented legislation that requires underground Refuge Stations to have "an air supply independent of the mine air system and designed to provide a minimum of 12 hours supply of air for as many persons as the Refuge Station is designed to shelter", as well as "suitable equipment for monitoring the air quality each hour or at a lesser interval if required".

All too often, changes in approach to unsafe situations occur after an accident where FATALITIES have resulted. Fatalities, such as those described in the first incidents have caused positive changes in a mine's approach, as Refuge Stations are now commonplace. This is not unusual in the development of safety procedures and equipment, **but it is avoidable**. Changes where required, can be planned for, and made affordable, within the scope of a mine's underground safety plan.

In some cases this change is lead by the Province or State, through "regulations and/or guidelines" (ie. new regulations in the N.W.T) and in others, industry and technology lead the way.

With the information that is now available, a "fatal" incident should not be required to be the impetus for the implementation of a process of "**assessing the risk**", "**evaluating the need**" and "**taking the required action**" that will move Refuge Station safety to a new level.

2.0 WHAT ARE THE FUNDAMENTALS REQUIRED TO ADDRESS THE RISK and ESTABLISH THE NEED (To ensure respirable air)

Four fundamental activities are required prior to being able to determine how respirable air will be provided to a Refuge Station. They are; 1) where will the Refuge Station be located, 2) how many persons are to be accommodated in an emergency, 3) how long may they have to be there until rescue can occur, and 4) what are the acceptable levels for Carbon Dioxide accumulations and Oxygen depletion?

2.1 LOCATION

Location considerations must take into account the following:

2.1.1 Timeliness of Installation

Most refuge stations are established once the initial development is well under way. The use of portable refuge stations or the provision of oxygen self rescuers are alternatives to establishing a permanent refuge station. Until refuge stations are established underground, interim procedures must be in place before an emergency occurs. Once an emergency occurs, it is too late.

Refuge stations should always be considered when:

a. An escapeway or secondary means of egress from the mine is not available.

b. Mining in an area remote from the normal access route into the mine.

c. Developing new levels.

d. Developing a new mine or re-entering an old mine.

2.1.2 Access and Route of Travel

a. Located on main or normal routes of travel.

b. Refuge stations should be located a safe distance away from any hazardous areas or conditions including:

- explosives magazine or storage container (60 m or 200 ft.)
- electrical transformers greater than 5 KVA (15 m or 50 ft.)
- garages or fuelling bays (placed so that in the event of a fire or explosion,there will be a minimal effect)
- blasting operations and concussion
- inadvertent entry of uncontrolled vehicles

c. In a location that provides ready access to mine rescue teams.

d. In areas where the ground is safe or well supported.

2.1.3 Length of Time to Get to Refuge

a. As close as possible to the majority of the working places in the area.

b. The maximum length of time to walk to a refuge station should be no more than 15 to 30 minutes.

c. If the length of time to get to a refuge station is excessive (greater than 30 minutes), then the use of self rescuers should be considered for those workers.

2.2 NUMBER OF OCCUPANTS

Design should be based on the maximum number of workers that are normally expected to use that refuge station at any one time, and then further consideration should be given to additional numbers that may frequent the location at various times (eg. geologists, visitors, inspectors, trainees, mine management, etc.).

NOTE: At no time should the refuge station be posted to limit the number of people within. For example, if a group of people were touring the level when an emergency occurred they are not to be turned away because of initial design considerations.

2.3 OCCUPANCY TIME

Occupancy time is a major factor in the engineering of a refuge station and it's equipment, as it relates to it's second role, "a safe place to wait for rescue". The determination of occupancy time therefore becomes a matter of "worst case scenarios" for Mine Rescue to get to the refuge station. A minimum 12 hours occupancy time is suggested. In other cases, this may be longer, up to 24 hours, depending on the location; for example, in the case of single access to a refuge station. **Mine Rescue should be very involved in determining occupancy times**, as it will greatly benefit them knowing sufficient time is available to; a) organize and plan an effective rescue operation, with variables accommodated in the plan, and b) execute the plan.

Some factors to be considered by Mine Rescue in calculating "Occupancy/Rescue Time" are:

<u>**FACTORS/CONDITIONS EN-ROUTE TO/FROM REFUGE STATION**</u>

Distance to surface exit (ie. exit via: skip, ramp, manway, etc.)

Potential Hazards Enroute	-	Explosive Storage
	-	Fuelling Bays
	-	Electrical Transformers
	-	Mining and Transportation Equipment
	-	Ventilation
	-	Ground Fall Potential
	-	Other
Air Line Integrity	-	Are vitaulic couplings used on the compressed air line?

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2.4 ACCEPTABLE CONCENTRATIONS OF INCREASED CARBON DIOXIDE AND DECREASED OXYGEN LEVELS

In a sealed Refuge Station without ventilation the falling Oxygen Concentrations and the rising Carbon Dioxide levels, produced through the breathing process, will pose varying degrees of discomfort and at some point a life threatening circumstance to the persons in the Refuge Station. Individually these dramatic changes in concentrations can be dangerous, combined the effects are even more severe.

Left untreated by a means of adequate ventilation and/or replenishment/treatment of the room air will result in the following Physiological Effects from:

Carbon Dioxide Accumulations:

Concentration - PPM	Physiological Effects*
350	Normal Concentration - no effect
5,000	Time-Weighted Threshold Limit Value (TLV-TWA). Slight increase in breathing rate.
10,000	Headache, Increased rate of breathing.
30,000	Short-Term Exposure Limit (TLV-STEL).
50,000	Panting, Discomfort, Intoxication in 30 minutes.
100,000	Unconsciousness
>100,000	Unconsciousness in one minute, Death.

* With normal oxygen concentrations.

Oxygen Depletion:

Concentration - %	Physiological Effects*
20.9%	Normal Concentration - no effect.
19.5%	Minimum Acceptable Value.
18.0%	Slight increase in breathing effort.
16.0%	Flame lamp goes out. Minimum Limit Value. Slight increase in pulse and breathing rate.
14.0%	Abnormal fatigue upon exertion, emotional upset, impaired judgement, and faulty coordination.
12.0%	Impaired respiration can cause cardiac damage, poor judgement, discomfort, vomiting, nausea.
< 10.0%	Unconsciousness, Death.

* With normal carbon dioxide concentrations.

The available data on the physiological effects varies somewhat depending on the source of information, however all sources clearly indicate the adverse effects of the deterioration of the breathing air. Although it is the authority having jurisdiction that inevitably establishes the allowable limits to maintain a safe "working" environment, under emergency situations, higher exposure levels may be acceptable.

It should be noted that it is the increasing levels of the Carbon Dioxide that plays the more significant role in the physical and emotional well being of the individuals in the Refuge Station. It is to be remembered that the charts above describe the physiological effects of CO_2, given that other concentrations are normal (ie. O_2). Likewise with O_2 depletion, it assumes the CO_2 concentrations are normal. Also, when determining acceptable limits to exposure, one has to account for the rapid increase in breathing that results as the CO_2 level rises (thus using more O_2 and producing CO_2 at a greater rate).

Although it is "generally" accepted that if oxygen levels can be prevented from dropping to 18%, and Carbon Dioxide accumulation does not rise above 20,000 ppm (2%), that a person of good health would survive with only minor discomfort, these values need to be evaluated and decided by the mine. Refer to Appendix "1" for reference to the changes that result in CO_2 and 0_2 concentrations given varying sizes of Refuge Stations, and varying numbers of occupants.

The determination of the levels that are acceptable to the Mine (and the authority having jurisdiction) is not an easy one, but is required if "dead air" is going to be considered as a safe means to ensure respirable air. It must be recognized that the length of time for the room environment to change is directly related to the size of the Refuge Station and the number of individuals in it. However, as stated above, accepting higher levels than the published TLV's and STEL's is only an issue where "dead air" space is being used as the primary or secondary source of respirable air. Although it could be argued that it should also be a factor in the engineering requirements for compressed air and the "REFUGE ONE" Air Centre, properly engineered and installed, they both can maintain CO_2 within the 5,000 TLV and O_2 above 20%.

The mine's Industrial Hygienist would be a good resource to assist with setting the parameters for Carbon Dioxide and Oxygen levels. It is important for analysis purposes to ensure that the acceptable levels are stated, as these become part of the equation for calculating the supply options.

By knowing the location, the number of occupants, the time of occupancy, and the acceptable levels of CO_2 and O_2, a determination of how to provide a safe supply of "respirable air" can now be engineered.

3.0 HOW CAN RESPIRABLE AIR BE PROVIDED WHEN NEEDED?

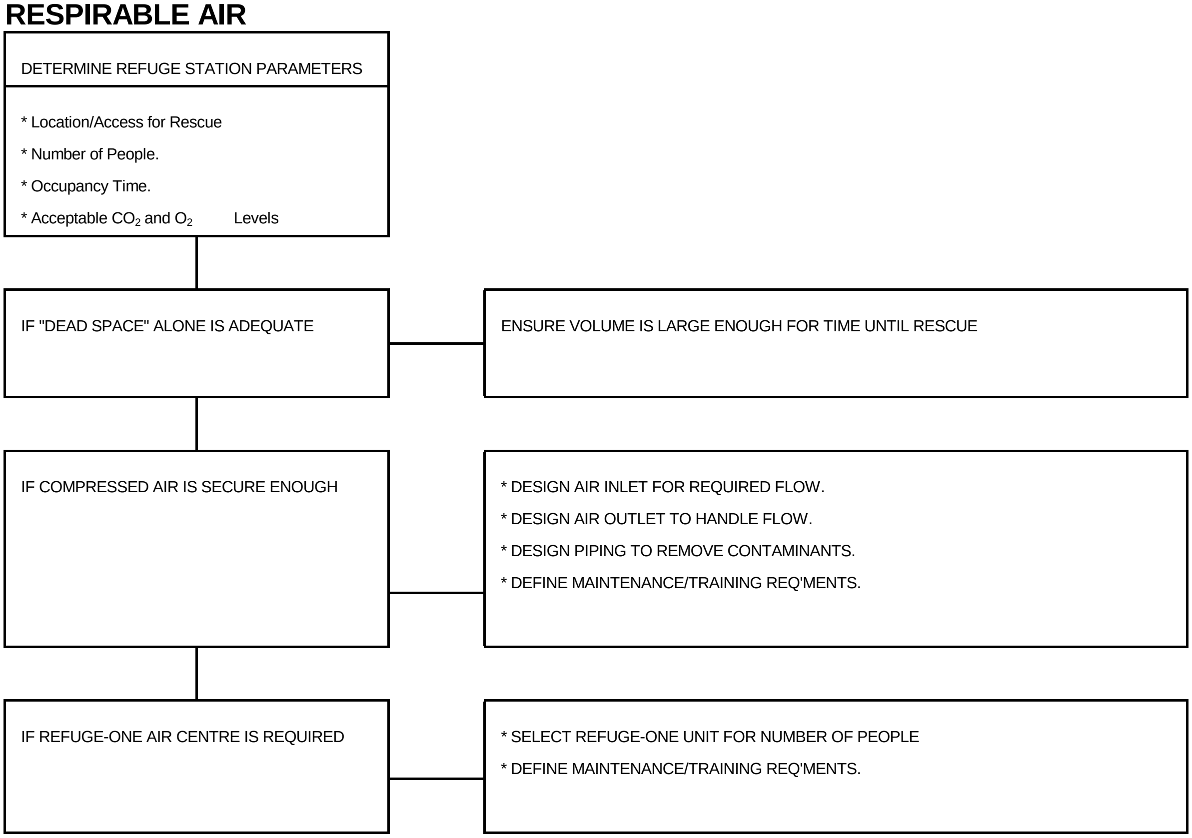
With the information on; location of the Refuge Station, the number of occupants, the maximum duration of occupancy time to be planned for, and the safe levels which CO_2 can elevate to and O_2 drop to, the safest and most economical method of ensuring the level of safety, can be determined.

At the present time there are three (3) methods that are deemed to have the required reference, under the correct circumstances, to provide a safe supply of respirable air. These include; 1) "dead air space", 2) a mine's "compressed air supply", and 3) the "REFUGE ONE" Air Centre.

The physical design (sizing) of the refuge station is of minimal consequence relative to other important factors (such as the number of people to be accommodated), unless "dead air volume" is being used as a means to ensure respirable air for the occupancy time required. Design engineers should not jump to the conclusion of having to provide "dead air volume" until other options to provide respirable air are evaluated, first from a safety perspective, and then based on cost.

Each of the methods/options to provide respirable air are different, and thus have unique factors. These include design considerations and the risk related to ensuring reliability, economic circumstances, etc.. They do not impact on why and where a refuge station should be located, and therefore each of the methods are addressed in detail separately.

REFUGE STATION PLANNING - DETERMINING THE OPTIMAL SOURCE OF RESPIRABLE AIR



3.1 THE USE OF "DEAD AIR" SPACE

3.1.1 How to determine the volume of air space required:

Once the threshold levels have been identified (refer to Section 2.4), a simple process using a NASA-NRC graph (specifically developed for this purpose) can be used to determine whether the air space in the Refuge Station alone will afford the miners the available time for rescue before the levels are reached, or if an alternative means of respirable air is required. The determining factors include; the size of the Refuge Station, the maximum number of occupants anticipated in the given Refuge Station, and the maximum amount of time to rescue (this information can be gathered on the "Refuge Station Information Sheet").

Calculation of the "dead air space" required per person is not an easy calculation to understand. In the past "rules of thumb" have suggested that a person requires 1 cubic meter of air per hour. This then is generally multiplied by 8 hours to determine the volume of space required within the refuge Station.

This "rule of thumb" assumes 8 hours is long enough. This however can be misleading, depending on what a mine considers to be acceptable time frames relative to achieving "rescue". For example, experiments have been conducted where a man is confined to a space of approximately one cubic meter of air. At the end of an hour this cubic meter of air will contain about 14% of Oxygen and 5% of Carbon Dioxide. By referring to the charts in Section 2.4, these levels of exposure could be very dangerous.

By utilizing the graph developed by NASA-NRC (refer to Appendix "3"), specifically for this purpose, and the "Refuge Station Information Sheet" (refer to Appendix "2"), a calculation can determine what the respective Gas Concentration Levels will be in the air (as a per cent by volume).

An assumption is made, for the purpose of developing the following examples, that the threshold levels have been set at a maximum of 2% (20,000ppm) Carbon Dioxide and 18% Oxygen. These levels permit a small margin of safety to the point where the physiological effects will begin having a significant physical and emotional effect on the miners.

Using these threshold levels, three scenarios are given on the following pages as examples as to how different circumstances will dictate your respirable air options:

Example #1 (also refer to attached "REFUGE STATION INFORMATION):

Using the "Refuge Station Information Sheet" the following data has been identified and evaluated:

Refuge Station is located on the **600 Level** and is identified as **RS-1**.

Item # 1 The physical dimensions of the Refuge Station is 10 ft. x 16 ft. x 30 ft, or **4,800 ft^3**.

Item # 2.1 The activity level around this refuge station has been identified as minimal, as the level is not currently being mined.

Item # 2.2 The anticipated occupancy under extreme conditions will be **5** people.

Item # 2.3 The "Worst Case Scenario" indicates an occupancy time of **8** hours.

The concentration levels that would be reached can be determined as follows:

1. The unit volume per person in the refuge station is 960 ft^3.

2. They are required to remain in the refuge station unassisted for 8 hours.

3. The ratio for time to unit volume per person would be as follows:

$$\text{Ratio } \frac{T}{V} = \frac{\text{time in refuge station (hours)}}{\text{unit volume per person}} = \frac{8}{960} = 0.008$$

Locate the ratio of 0.008 on either side of the graph (Appendix "3") and draw a horizontal line across the graph. Where the line intersects the respective diagonal lines labelled "No Ventilation" is where you then draw a perpendicular line upward, to indicate the concentration levels of the Carbon Dioxide and Oxygen.

In this instance the levels would be .75% (750ppm) Carbon Dioxide and 19.5% Oxygen. Both of these levels would be within acceptable breathing air limits.

Based on this data, and again using the graph indicating "Gas Concentration in Air", it is possible to determine that the available air space would be sufficient to support the five miners for up to 24 hours before the threshold levels were reached.

CONCLUSION: Dead air space can provide the respirable air required.

Example #2 (also refer to attached "REFUGE STATION INFORMATION):

Using the "Refuge Station Information Sheet" the following data has been identified and evaluated:

Refuge Station is located on the **2200 Level** and is identified as **RS-2**.

Item # 1 The physical dimensions of the Refuge Station is 10 ft. x 16 ft. x 30 ft, or **4,800 ft^3**.

Item # 2.1 The activity level around this refuge station has been identified as ongoing, with a constant number of miners due to an active work face.

Item # 2.2 The anticipated occupancy under extreme conditions will be **15** people.

Item # 2.3 The "Worst Case Scenario" indicates an occupancy time of **12** hours.

The concentration levels that would be reached can be determined as follows:

1. The unit volume per person in the refuge station is 320 ft^3.

2. They are required to remain in the refuge station unassisted for 12 hours.

3. The ratio for time to unit volume per person would be as follows:

$$\text{Ratio } \frac{T}{V} = \frac{\text{time in refuge station (hours)}}{\text{unit volume per person}} = \frac{12}{320} = 0.0375$$

Locate the ratio of 0.0375 on either side of the graph (Appendix "3") and draw a horizontal line across the graph. Where the line intersects the respective diagonal lines labelled "No Ventilation" is where you then draw a perpendicular line upward, to indicate the concentration levels of the Carbon Dioxide and Oxygen.

In this instance the levels would be 3.1% (31,000ppm) Carbon Dioxide and 16.75% Oxygen. Both of these levels have exceeded the established threshold levels, but arguably maintain an adequate environment to support the life of the miners. The concern under these conditions would be whether the trapped miners would be in an acceptable physical condition to exit the mine under their own power when the Rescue Team arrived. The likely answer is that consideration would have to be given to assisting some or all of the miners in some fashion.

Based on this data, and again using the graph indicating "Gas Concentration in Air", it is possible to determine that the available air space would be sufficient to support the fifteen miners for up to 8 hours before the threshold levels were reached. That would indicate that the miners would be exposed to levels greater than the limits set for a period of 4 hours.

CONCLUSION: **Dead air space WILL NOT provide the level of protection required.** Either compressed air or the "REFUGE ONE" Air Centre should be considered.

Example #3 (also refer to attached "REFUGE STATION INFORMATION):

Using the "Refuge Station Information Sheet" the following data has been identified and evaluated:

Refuge Station is located on the **5500 Level** and is identified as **RS-3**.

Item # 1 The physical dimensions of the Refuge Station is 10 ft. x 16 ft. x 30 ft, or **4,800 ft^3**.

Item # 2.1 The activity level around this refuge station has been identified as ongoing and developmental, with a varying degree of miners and support personnel.

Item # 2.2 The anticipated occupancy under extreme conditions will be **25** people.

Item # 2.3 The "Worst Case Scenario" indicates an occupancy time of **18** hours.

The concentration levels that would be reached can be determined as follows:

1. The unit volume per person in the refuge station is 192 ft^3.

2. They are required to remain in the refuge station unassisted for 18 hours.

3. The ratio for time to unit volume per person would be as follows:

$$\text{Ratio } \frac{T}{V} = \frac{\text{time in refuge station (hours)}}{\text{unit volume per person}} = \frac{18}{192} = 0.078$$

Locate the ratio of 0.078 on either side of the graph (Appendix "3") and draw a horizontal line across the graph. Where the line intersects the respective diagonal lines labelled "No Ventilation" is where you then draw a perpendicular line upward, to indicate the concentration levels of the Carbon Dioxide and Oxygen.

In this instance the levels would be 6.3% (63,000ppm) Carbon Dioxide and 12.8% Oxygen. Both of these levels have exceeded the established threshold levels, and have placed the life of the miners in danger. The trapped miners would not be in an acceptable physical condition to exit the mine under their own power when the Rescue Team arrived. This would therefore require that provision was made to resuscitate/revive the miners condition prior to their removal from the Refuge Station, or that some provision would have to be made to assist in the miners evacuation upon arrival at the Refuge Station. Both of these circumstances would undoubtedly add time to the rescue operation, as well as potential risk.

Based on this data, and again using the graph indicating "Gas Concentration in Air", it is possible to determine that the available air space would be sufficient to support the twenty-five miners for 4 to 5 hours before the threshold levels were reached. That would indicate that the miners would be exposed to levels greater than the limits set for a period of 13 to 14 hours.

CONCLUSION: **Dead air space WILL NOT provide the level of protection required.** Either compressed air or the "REFUGE ONE" Air Centre should be considered.

3.1.2 Cost of Providing "Dead Air Space":

For existing Refuge Stations, where based on the number of people and the length of stay, the volume of dead air space is sufficient to ensure levels don't exceed the pre-determined acceptable levels, there is no extra cost.

Should existing Refuge Stations have to be enlarged or if a new one is being considered, the cost is based on the mine's current drilling cost per volume to be excavated. Where Refuge Stations also double as lunch and meeting rooms the size may be determined by the space convenient for these purposes. If this size is sufficient to meet the dead air space requirements, then it could be rationalized that there is no cost to provide dead air space.

3.1.3 Risks and benefits of using "Dead Air Space":

Risks: The major risk associated with the engineering of a system that depends on dead air space, to provide respirable air, is that concentrations of Carbon Dioxide and Oxygen are continuously changing. If the number of people that was planned for increases, and/or the length of time to achieve rescue is greater than planned, then the miner's risk increases proportionally.

If there is any concern that the protection that is able to be achieved is marginal, then it would be advisable to avoid using dead air space as the primary source of respirable air. It may be more appropriate as a secondary source.

Dead air space cannot create any positive pressure from within the Refuge Station. Therefore, provision to ensure the wall and it's openings can be sealed, becomes important.

Benefits: Depending on the cost of excavation, it may be an economical alternative to both compressed air or the "REFUGE ONE" Air Centre. Another benefit is that it is a "non-mechanical", thus not subject to risks such as mechanical failure or the consequence of fire.

**** When training personnel on Refuge Station safety, ensure that it is well understood that remaining calm, and restful will significantly reduce the CO_2 output and O_2 consumption. When dead air space is the source of respirable air this becomes a very important aspect to understand.

3.2 THE USE OF A MINE'S "COMPRESSED AIR"

3.2.1 Fundamentals to the achieve the benefits of using Compressed Air:

Using air from a mine's compressed air pipeline appears so simple. Compressed air from the pipeline generates a positive pressure inside the Refuge Station and so keeps hazardous gases from migrating into the Refuge Station, while supplying fresh air.

Only recently however has there been an appreciation that when using compressed air the focus has to be on "purging" the room with air to dilute, and prevent carbon dioxide accumulations. In the past it appears that the focus was on replenishing oxygen, rather than purging out carbon dioxide. It is easy to calculate the amount of oxygen consumed through breathing, and then relatively easy to provide a source to replace it. Given the small quantity required, even compressed air in cylinders, or oxygen in cylinders could all provide it, for extended periods. Based on this past logic, it is therefore understandable how the guideline "crack the air line until you hear it" became the standard.

In order to deal with the more serious problem, the removal of Carbon Dioxide, FIVE (5) times as much air is required than to replace Oxygen. Therefore, when designing a system using compressed air, **focusing on "Carbon Dioxide" removal is the key**. This can only be controlled by a continuous process of "changing the air" in the Refuge Station (commonly referred to as "Air Changes"). With the large volumes of air required to achieve the number of air changes, the oxygen is replaced and automatically kept at normal concentrations.

3.2.2 Factors to review when considering the security/integrity of the compressor and the pipeline:

The most important factor to effectively using compressed air is achieving the re-assurance that the incident that has caused the emergency and forced miners to go to the Refuge Stations, will not also damage or disrupt the compressed air source and/or the pipeline delivering it.

In a fire, hazardous gases will be produced. The compressor air intake should be located so that it will not be contaminated by hazardous gases from a fire, or the air should be filtered to remove poisonous gases. The compressor should be guarded against mechanical failure and loss of power.

The compressed air pipeline delivering air from compressors at the surface or underground is vulnerable to interruption along its length. Air lines have been destroyed by fires or accidents. There may not be a practical way to protect the air line to a Refuge Station, however evaluation of some of the risks to the line is necessary to determine if a secondary source of providing respirable air is needed.

Consideration should be given to the following factors/conditions as they could damage the line and thus severe the supply to the Refuge Station:

Potential Hazards to the Compressed Air Line:

- Storage of Explosives
- Fuelling Bays
- Electrical Transformers
- Large Equipment
- Ground Fall
- Vaporization of Vitaulic Couplings

If there is concern over any of the above effecting the reliability of the air to the Refuge Station, then consideration should be given to ensuring that a secondary method of providing respirable air can be supplied (ie. Dead Air Space or the "REFUGE ONE" Air Centre).

3.2.3 Factors to consider to properly engineer a compressed air system:

3.2.3.1 Flow Rate:

When proceeding with the design of compressed air as either the primary or secondary source of respirable air, the assumption made is the supply is secure. Based on this, the capacity of the supply is essentially unlimited. Therefore, whereas with calculating the use of dead air space the maximum exposure limits of CO_2 and O_2 had to be determined, when designing a system using compressed air, it is just as easy to maintain a concentration of CO_2 that is within the acceptable TLV (eg. 5,000 ppm).

In calculating the volume of compressed air required to purge the Refuge Station of CO_2, the **Number of People** is the key piece of information required. The following rates of flow will ensure the CO^2 will not rise above 5,000 ppm at any time during the course of confinement.

Number of People	Flow Rate Required
1 - 10	25 cfm
10 - 20	50 cfm
20 - 30	75 cfm
30 - 50	100 cfm

3.2.3.2 Piping Layout:

When running the compressed air line into the Refuge Station it is important to appreciate that water, oil and rust will accumulate in the line due to it's limited use. Also, in an emergency stench gas is put into the line. Therefore the piping schematic should include a valved bypass/return back into the drift. Prior to opening the supply valve, the miner would open the bypass/return valve for a sufficient period of time to get rid of the oil, water, rust and stench gas into the drift.

3.2.3.2 Piping Layout (continued):

The air outlet should be located at the opposite end of the Refuge Station from the compressed air inlet so as to obtain mixing of the fresh air with the Refuge Station air throughout the space. If zones of unmixed air exist, the oxygen and carbon dioxide levels in those zones may be poorly controlled.

The diagram included as Appendix "5" shows an example of a recommended piping schematic for a Refuge Station.

3.2.3.3 Flow control, noise prevention and oil removal.

FLOW CONTROL. As described in 3.2.3.1 above, the flow rate through the Refuge Station must be high enough to ensure an adequate number of air changes per hour in order to avoid CO_2 build up. Therefore, the setting of the flow cannot be left to the miner's impression - judging by noise level, or how it feels against the hand. These methods can establish too low a flow rate.

It is recommended that downstream of the shut off valve, an orifice, with the diameter large enough to provide the flow, given the operating pressure of the line, be installed. Refer to Appendix "4" for a table on "Discharge of Air Through An Orifice". This approach then allows the instruction to be "FULLY OPEN THE VALVE", and takes away any decision or judgement.

An alternative method to using a fixed orifice would be to install a flow metering device downstream of the shut off valve. A sign could be posted above it that advises on what flow rate to set, based on the number in the Refuge Station. This is not as economical and straight forward an approach as using a fixed orifice. However, should a situation result where the pressure in the line dropped (vitaulic couplings begin to vaporize), which in turn would cause the flow to drop off, the trapped miners have ability to read the flow meter and thus open the valve more to maintain an adequate flow.

Given the large volume of air that will be entering the Refuge Station, it is very important to have vents or louvres installed in the wall. The vents must be large enough to keep the pressure in the Refuge Station at a low value under the maximum air flow from the pipeline. The force on the broad area of a wall from even moderate pressures can cause serious damage if the outflow is restricted (e.g. "blow the wall out") and leave the miners at extreme risk,. The vents should be capable of automatic or manual sealing in case the inlet air flow is interrupted.

NOISE PREVENTION. When a high flow of air jets out of a pressurized air pipeline the noise level will be very high. The continuous high noise level can affect the personnel - by affecting hearing or causing emotional distress. A muffler on the air outlet can be installed, at a minimal cost, to bring the noise level down to tolerable limits.

3.2.3.3 Flow control, noise prevention and oil removal (continued)

OIL REMOVAL. At a high rate of flow, the air in the Refuge Station will very quickly be filled with contaminants from the pipeline. Whether this is a serious concern, or not, will depend on the contaminants that are either generated by the compressors themselves (e.g. oil vapour), or what has been added either intentionally or otherwise (e.g. anti freeze, rust, corrosion, stench gas, smoke, etc.). This may be a greater concern in older contaminated air systems. Compressed air filters to remove contamination are readily available, and are not cost prohibitive.

3.2.4 Cost of using Compressed Air:

Whether it is currently recognized or not, there is a capital cost to equipping a Refuge Station with a compressed air pipeline system. This cost can vary depending on the distance that the existing "mine air" must be piped to the Refuge Station, and the design of the system. New information has illustrated that existing designs may need to be revised and/or upgraded to meet the standards of a properly engineered system (consisting of the appropriate piping, valving, filtration, ventilation, etc.). This presents a real capital cost to equipping a new Refuge Station appropriately, and may result in an additional cost where existing "Compressed Air Equipped" Refuge Stations fail to meet current standards.

In modern mining development, where electric over hydraulic equipment is replacing air driven systems, compressed air is not required. Where this is the case, it will be very expense to supply an air line to the Refuge Station. In these situations a self-contained system, such as the "REFUGE ONE" Air Centre, should be given consideration in lieu of running air lines for the sole purpose of equipping the Refuge Station.

3.2.5 Risks and benefits to using "Compressed Air":

Risks: It is critical that the routing of the compressed air line is evaluated to determine the potential risk factors that could disrupt it, as this is the only real risk to a system using compressed air. This of course is assuming the system is properly engineered, and the reliability of the compressor providing the air is accounted for.

Benefits: The obvious benefit **(assuming the integrity of the supply)**, when compared to the use of dead air space, is that compressed air properly engineered and used, can maintain Carbon Dioxide and Oxygen at near normal levels for an indefinite period of time.

A second benefit is the ability to create positive pressure within the Refuge Station. Although the openings (ie. doorways) are designed to be sealed with fire clay, the positive pressure acts as a backup to the sealing.

A third benefit is that the size of the Refuge Station only needs to accommodate the physical requirements of the occupants, versus providing space to ensure adequate "dead air" space is available. When using compressed air, the smaller the Refuge Station, the quicker air can be changed. Smaller Refuge Stations cost less to excavate.

3.3 THE USE OF A "REFUGE ONE" AIR CENTRE

3.3.1 How it operates:

The "REFUGE ONE" Air Centre is a self-contained system that is designed to provide oxygen at controlled rates, and to remove carbon dioxide from the air in an enclosed space. The unit does not depend on the compressed air pipeline, and in an emergency does not require an external electrical source.

The air within the Refuge Station is "processed" by the "REFUGE ONE" Air Centre, as opposed to purging the CO_2 laden room air with "new air" from the compressed air. To effectively accomplish this, the air flow through the carbon dioxide scrubbers has to be at the same rate as required by the compressed air system.

To replenish the oxygen consumed by the occupants, oxygen from high pressure cylinders is injected at a metered rate (dependant on the number of occupants) into the blower circuit.

The "REFUGE ONE" Air Centre's principle of operation is very similar to the Drager BG 174 self contained breathing apparatus. Whereas the "REFUGE ONE" Air Centre sits in the middle of a sealed chamber (the Refuge Station), processing the air to remove CO_2 and replenishing the 0_2, the BG 174 also operates in a sealed chamber, albeit closed circuit tubing.

At present the "REFUGE ONE" Air Centre comes in two sizes. One which will process the air at a rate of 80 scfm (single bed unit) and the other which processes air at a rate of 160 scfm (double bed unit).

When 120 volt AC power is not available, the unit operates on internal long-life batteries to operate blowers. The batteries will operate the blower (s) continuously for a minimum of 36 hours. Under normal conditions, when the electricity is servicing the Refuge Station, the batteries are maintained under full charge.

Refer to Appendix "6A & 6B" for air flow diagrams (single bed and double bed), and Appendix "7" for the capacity of the two units (oxygen supply, carbon dioxide absorption capacity, and power reserves).

Selection of the correct model size is directly dependant with the number of people the Refuge Station is being designed for. Each model has a standard built-in, stored supply of soda lime and oxygen. However, the capacity in hours can be extended by providing additional kegs of soda lime and cylinders of oxygen in the Refuge Station.

3.3.2 Performance Testing:

The development of the "REFUGE ONE" was as a result of a serious fire in Northern Manitoba in 1990, in which the compressed air lines were severed. There were five specific performance criteria outlined by the mining industry. They were:

1. The system had to maintain Carbon Dioxide and Oxygen at near normal atmospheric levels, for a minimum of 20 people for 24 hours.

2. Operate during an emergency without requiring any external compressed air or electricity.

3. Be simple and easy to use under emergency conditions.

4. Be durable and rugged enough to withstand harsh underground conditions (including concussion).

5. Be affordable so as to allow the implementation of the technology to fit into a Mine's safety program and budget.

In addition to setting the performance criteria, the "REFUGE ONE" also under went two stringent underground tests.

Tommyknocker #1:

The first, conducted by the Mines Accident Prevention Association (MAPAM) and the Manitoba Department of Labour, took place at Atomic Energy Canada Limited (AECL) Underground Research Laboratory in Lac Du Bonnet. This test involved 6 miners being sealed into an underground Refuge Station for a 24 hour period, with CO_2 and 0_2 being controlled by a "REFUGE ONE" prototype (prototype name "RANA-AIR").

Although there were a number of aspects being monitored and evaluated, the most significant were:

a. CO_2 and O_2 levels throughout the 24 period,

b. Simplicity of operation, and

c. What was the simplest and most effective method for the occupants to determine the air quality within the Refuge Station.

Tommyknocker #1 Conclusions:

The results of the test indicated that the average CO_2 level throughout the 24 hour period was 2,300 ppm, with the oxygen level varying between 19.5% and 20.9%.

The volunteers within the Refuge Station collectively reported that the system was very simple and easy to use, almost intuitive.

Drager gas detection tubes were used at regular intervals to monitor the oxygen and carbon dioxide levels within the Refuge Station. It was concluded that they served no purpose with respect to making judgements as to if the flow of oxygen was accurately set (injection of O_2 was equal to consumption), or if the Soda Lime was effective throughout the test.

Complete details of this test are published in Atomic Energy Canada Ltd.'s report, "Operation Tommyknocker - Test of Survival Equipment for Underground Refuge Stations at the Underground Research Laboratory", Lac Du Bonnet, Manitoba, March 4th and 5th, 1993.

3.3.2 **Performance Testing** (continued):

Tommyknocker #2:

A second, and more severe test was undertaken by the Kidd Creek Mine in Timmins, Ontario in conjunction with the Ontario Department of Labour - Mine Rescue Division.

In April of 1994, 25 Ontario Mine Rescue team members volunteered to spend 24 hours in a sealed underground Refuge Station on the 5,200 Level at the Kidd Creek Mine (Falconbridge Ltd.). The project included the direct involvement of several mining companies and agencies, namely, Falconbridge Ltd., Kidd Creek Division, Placer Dome Inc., Royal Oak Mines Inc., Timmins Division, Rimer Alco North America Inc., the Ontario Ministry of Labour - Ontario Mine Rescue, the Mines Accident Prevention Association of Manitoba and CANMET's Mining Research Laboratories.

The purpose of the study was to test the ability of the Rimer Alco North America RANA-AIR Mine Refuge System to provide the volunteers with breathable air during a 24 hour period and in the absence of compressed air.

One of the objectives of the study was to test the unit under realistic conditions. The unit was also evaluated from the point of view of ease of operation and user friendliness. The tests were designed to determine the unit's ability to provide a safe atmosphere and to verify that participants could, without outside help, effectively operate the system.

The test results showed that the unit performed very well by successfully maintaining stable conditions. CO_2 increased from a baseline of about 700 ppm to stabilize at 2,500 ppm. The time weighted average exposure value (allowable limit of exposure) for an eight hour shift is 5,000 ppm. In theory, this value of 5,000 ppm would have been exceeded 1.5 hours into the test if neither compressed air or the RANA-AIR system had been available in the Refuge Station. Oxygen levels varied slightly between 20.2% and 20.6%.

The participants also completed an extensive survey questionnaire, the results of which demonstrated a high level of acceptance for the system. Starting the unit, which included filling two scrubbing drawers with soda lime took less than 10 minutes.

Tommyknocker #2 Conclusions:

It was determined that the RANA-AIR unit ("REFUGE ONE") met and in some respects surpassed the expectations of the test participants. As far as meeting the objectives of the project, it can be said that:

1. the RANA-AIR unit performed well in a realistic Refuge Station emergency situation and results were consistent with data collected in the first phase study (Tommyknocker #1).

2. the prototype was easy to operate, the participants agreed that the instructions were clear. The system provided safe CO_2 levels (average of 2,500 ppm) and maintained O_2 levels within an acceptable range (20.2% and 20.6%).

3.3.2 **Performance Testing** (continued):

The volunteers who will be the ultimate end users, were comfortable and receptive to the technology. The comments dealing with the unit's performance were positive and the volunteers seemed confident in the system's ability to maintain a safe atmosphere.

Recommendations:

- The temperature and humidity in the Refuge Station is not predictable, and these factors can effect the reaction of the colour change process within the soda lime. Therefore if possible, a fixed time approach in which occupants change the chemical after a period of time, that is relative to the number of people in the Refuge Station, regardless of the state of the colour indicator.

- The final design of the system should include a heavy duty casing which will encapsulate the unit in order to protect it from physical damage, the harsh underground environment and also protect the controls from possible damage.

  (the above two recommendations have been incorporated into the production units manufactured by Rimer Alco)

* Upon completion of the field test and after reviewing the study data, the Tommyknocker II Planning and Coordinating Committee collectively recognized that the life support centre concept has the potential to greatly improve the safety of underground workers and that the RANA-AIR prototype (REFUGE ONE), pending some minor modifications could be used underground as part of a comprehensive mine emergency response program.

Acknowledgements:

With the exception of the Tommyknocker tests in 1993 (I) and 1994 (II), which were designed specifically to prove the effectiveness of the "REFUGE ONE" Air Centre, **NO** real life underground testing has been done in Canada to prove the effectiveness of compressed air or dead air space.

The "REFUGE ONE" Air Centre has been recognized at a national and international level for it's achievements. In September 1995 the technology received the **"R & D 100"** award for 1995 - a top honour in the international field of applied research.

In October 1996 the "REFUGE ONE" Air Centre received the **OSH '96 "Innovative Product" Award of Excellence in Occupational Health and Safety**. In order to qualify for this Canadian Award the product must have:

- been on the Canadian market as of January 1, 1995,
- have been tested and approved by a government-approved agency or institution,
- pay particular attention to health and/or safety features,
- be easy to use, adaptable and reliable,
- have significant potential impact on occupational health and safety, and
- have received testimonials and/or endorsements from outside groups.

3.3.3 Cost of using the "REFUGE ONE":

The obvious cost associated with the use of a "REFUGE ONE" Air Centre is the capital purchase of the system. This factor may be overcome if a lease alternative was to be considered during the active usage period of the Refuge Station.

Additionally, there is a cost associated with the oxygen cylinders stored within the system. This would include the original purchase of the oxygen in the cylinder, and where the cylinders were provided by a compressed gas company, a lease or rental charge.

The ongoing maintenance/operating costs would include a minimal amount of time/labour to carry out preventative maintenance checks, and the occasional replacement of soda lime and oxygen cylinders (every 5 years). To help defer this cost the soda lime could be utilized for training purposes, and the cylinder oxygen for normal welding activities.

3.3.4 Risks and benefits to using the "REFUGE ONE" Air Centre:

Risks: The blower(s) within the unit is/are the only moving part(s), and it's reliability could be perceived as a risk. The assurance of their performance can be covered off with a simple routine maintenance check. Additional assurances could be achieved by storing a new blower(s) with the system (although this likely is an unnecessary cost).

The batteries available power is directly related to the charging system, and as such is constantly monitored by an indicator light and alarm. Should their performance deteriorate and go unchecked, and the power to the Refuge Station be lost, the capacity of the system would be effected. This could be overcome by a simple daily visual check.

The "REFUGE ONE" does not create significant "positive pressure", and therefore it is important that the openings to the Refuge Station be tightly sealed to prevent the inward migration of air.

Benefits: The "REFUGE ONE" Air Centre is an easy to use, self-contained system, which is a proven method of maintaining the desired environment within the Refuge Station. Therefore, it is not exposed to the variables which may threaten the integrity of the compressed air line (and the respirable air).

The "REFUGE ONE" has a heavy duty steel base which accommodates a fork lift, and can be easily moved. This will permit the system to move with the development of the mine, providing the Refuge Station it was previously in can meet the requirements without it.

Like the use of compressed air, the "REFUGE ONE" does not need the added volume of space designed into "dead air space" Refuge Stations. The size of the Refuge Station only needs to accommodate the physical requirements of the occupants and the system. This could result in a significant reduction in the cost of excavating the Refuge Stations.

4.0 OTHER SOURCES OF SUPPLY THAT HAVE BEEN CONSIDERED

Other sources of supply have been presented to and/or considered by mining companies as a method of providing a sustainable environment in a Refuge Station.

Some of these methods include:

- Compressed Air in Cylinders;
- Oxygen Candles; and
- High Pressure Oxygen Cylinders.

Each of these methods only deal with a portion of the equation when all the factors are considered in ensuring the respirable air is supplied.

The ability to supply oxygen that is consumed is a relatively simple process which was described earlier in Section 3.2.1. What is significantly more difficult is the ability to remove the Carbon Dioxide. With each exhaled breath, the CO_2 dissipates to every corner of the Refuge Station. Any system that does not address the proper control of carbon dioxide levels, **should not be considered**. Therefore the use of just oxygen candles or cylinders of high pressure oxygen is not appropriate.

A system using an oxygen candle, with the ability to remove Carbon Dioxide, should be closely evaluated to ensure that some reliable method of determining the volume of oxygen being supplied is available. With most oxygen candle varieties, irrespective of how many occupants are in the Refuge Station, once the candle is ignited the rate of O_2 flow is not controllable (thus creating a potential for an oxygen enriched environment). The chemical reaction within the candle also produces significant heat, and minimal amounts of C0 and CO_2.

In principle, compressed air in jumbo cylinders has the potential to be safer than a mine's compressed air pipeline, because when the cylinders are stored in the Refuge Station their ability to deliver air is not dependant on any external conditions (ie. a fire or rock shift severing the pipeline). In order for cylinder compressed air to be effective, the rates of flow are identical to those required with air supplied from the pipeline.

In practise however, compressed air in cylinders is very "impractical" due to the large number of cylinders that would be needed to provide the volume of air required. Using an example where 20 people would require air for 12 hours to keep the TLV below 5,000 ppm, 180 large jumbo cylinders would be required (50 cfm). Not only does this create a problem with respect to floor space and manifold cost, most regulations covering breathing air requires that these cylinders be changed every three (3) months.

5.0 REVIEW and TRAINING

Given that the activity in mines is continuously moving, the number of people in areas also changes. Therefore annual reviews should be done on each Refuge Station within the mine to determine if the need has changed, and if so, does the current method (s) of providing respirable air still fill this need. The exercise of reviewing the "risk and need" should include the completion of a new REFUGE STATION INFORMATION SHEET (refer to Appendix 2") each time.

Irrespective of the method used to provide respirable air, all personnel working underground should be trained on the effective use of the respirable air source (s) being supplied. Initial training, and regular on-going in-servicing is critical.

6.0 SUMMARY

Ensuring that the Refuge Station can meet it's role, as a "safe haven" until rescue can be achieved is now easier than it has ever been. By following the two step process of "determining risk and assessing the need" that has been outlined in this Handbook, you will have applied the "due diligence" to assure that your Mine Refuge Stations can meet or exceed the requirements for respirable air that you wish to provide for your people.

The steps again are as follows:

Identifying the fundamentals required to address the risk, including:

* The Location of the Refuge Station;
* The Maximum Number of Occupants;
* The Maximum Time to Execute Rescue; and
* The Acceptable Levels of CO_2 and O_2 in an Emergency.

and

Identifying the most appropriate alternative of providing the respirable air, from the following options:

* The Dead Air Space in the Refuge Station
* The Mine's Compressed Air Lines
* The REFUGE ONE Air Centre

Don't wait for a FATALITY to be the reason to take action. With the information that is now available, a **fatal** incident should not be required to be the impetus for the implementation of a process of assessing the risk, evaluating the need, and taking the action required, that will move Refuge Station Safety to a new level.

7.0 REFERENCE AND ACKNOWLEDGEMENTS:

There have been numerous resources used to gather and compile the information which has been presented in this Handbook. Most notably they are as follows:

* Unpublished, "Operation Tommyknocker - Test of survival Equipment for Underground Refuge Stations at the Underground Research Laboratory", Lac Du Bonnet, Manitoba, March 4th and 5th, 1993.

* Grenier, M., Vergunst, J., Smith, M., et. al., "Operation Tommyknocker, Phase II - Evaluation of the Rimer Alco, RANA-AIR Mine Refuge System at Falconbridge Ltd., Kidd Creek Division" CANMET, Division Report MRL 94-051 (TR) October 1994.

* Ontario Mine Rescue Handbook, 1984

* Raber, M., "Keeping People Alive in an Underground Refuge Station - A Comparison of Life-Support Methods", unpublished, November, 1995

* Raber, M., "Using the Compressed Air Pipeline for Breathing in an Underground Refuge Station During an Emergency", unpublished, November, 1995

* Mines Accident Prevention Association of Ontario, "Sub-Committee Report on Refuge Station Guidelines", Ontario Natural Resources Safety Association, North Bay, Ontario, September 12, 1990.

All of the reference documents are available in detail by contacting Rimer Alco at:

15 Jefferson St.
Morden, Manitoba
Canada R6M 1Y4
Ph. (204) 822-6595
Fax (204) 822-3852

In addition to these written documents, additional written information and input was provided by the following people, to whom we are very grateful:

* Mr. John Vergunst, Provincial Mining Specialist - Environment, Ontario Ministry of Labour, Occupational Health & Safety Branch - Sudbury, ON

* Mr. Barrie Simoneau, Safety Director, Mines Accident Prevention Association of Manitoba (MAPAM), Winnipeg, MB

* Mr. William (Bill) M. Schubert, Mines Inspector/Mine Rescue Instructor, Manitoba Department of Labour, Workplace Safety and Support Services Division, Mines Inspection Branch

APPENDICES

1) Quality of Air in Refuge Stations

2) Refuge Station Information Sheet

3) NASA-NRC Graph

4) Discharge of Air Through an Orifice

5) Refuge Station Piping Schematic

6A) "REFUGE ONE" Air Centre – Air Flow Chart – Single Bed

6B) "REFUGE ONE" Air Centre – Air Flow Chart – Double Bed

7) "REFUGE ONE" Air Centre – Performance Chart

APPENDIX “1”

QUALITY OF AIR – REFUGE STATIONS

REFUGE STATION SIZE				Number of People in Refuge Station	CO2 & O2 Levels Without Refuge One Operating			
					CO2		O2	
					Hours to Reach		Hours to Reach	
Length (ft)	Width (ft)	Height (ft)	Volume (cu ft)		5,000 ppm	20,000 ppm	18%	16%
15	8	10	1,200	10	0.7	2.8	3.3	5.6
15	8	10	1,200	20	0.4	1.4	1.6	2.8
30	16	10	4,800	30	0.9	3.8	4.4	7.4
30	16	10	4,800	40	0.7	2.8	3.3	5.6
45	16	10	7,200	50	0.8	3.4	3.9	6.7
45	16	10	7,200	60	0.7	2.8	3.3	5.6
60	20	10	12,000	70	1.0	4.0	4.7	7.9
60	20	10	12,000	80	0.9	3.5	4.1	6.9
75	20	10	15,000	90	1.0	3.9	4.8	7.7

APPENDIX "2"

REFUGE STATION INFORMATION SHEET	REFUGE STATION LOCATION:
	LEVEL: I.D.#:

1. SIZE:

LENGTH:__________________ ft. x WIDTH:_______________ ft. x HEIGHT:_______________ ft. = CU.FT.:

2. OCCUPANCY:

2.1 What activity is currently occurring:

BEFORE THE REFUGE STATION: ______________________________

AT THE REFUGE STATION: ______________________________

PAST THE REFUGE STATION: ______________________________

2.2 Anticipated Occupancy - Normal Conditions: ________# OF PEOPLE
- Extreme Conditions: ________# OF PEOPLE

2.3 Occupancy Time (**Mine Rescue Time - Worst Case Scenario**) [see below] ________# OF HOURS

....

MINE RESCUE WORK SHEET
"FACTORS THAT COULD EFFECT RESCUE OPERATIONS"

Based on the factors listed below, and others significant to delaying a safe and effective rescue operation, determine the **maximum** time that the Refuge Station should be designed to keep workers safe.

Factors/Conditions En-route To/From Refuge Station	Egress Routes		Compressed
	Main	Secondary	
Distance to surface exit (ie. exit via: skip,ramp,manway,etc.)			
Identify hazards (Y/N):- Explosive Storage			
- Fuelling Bays			
- Electrical Transformers			
- Mining & Other Equipment			
- Poor Ventilation Control			
- Ground Fall Potential			
Other -			
Are Vitaulic Couplings Used on Compressed Air Line?			

Notes to support rescue time stated above:

____

____

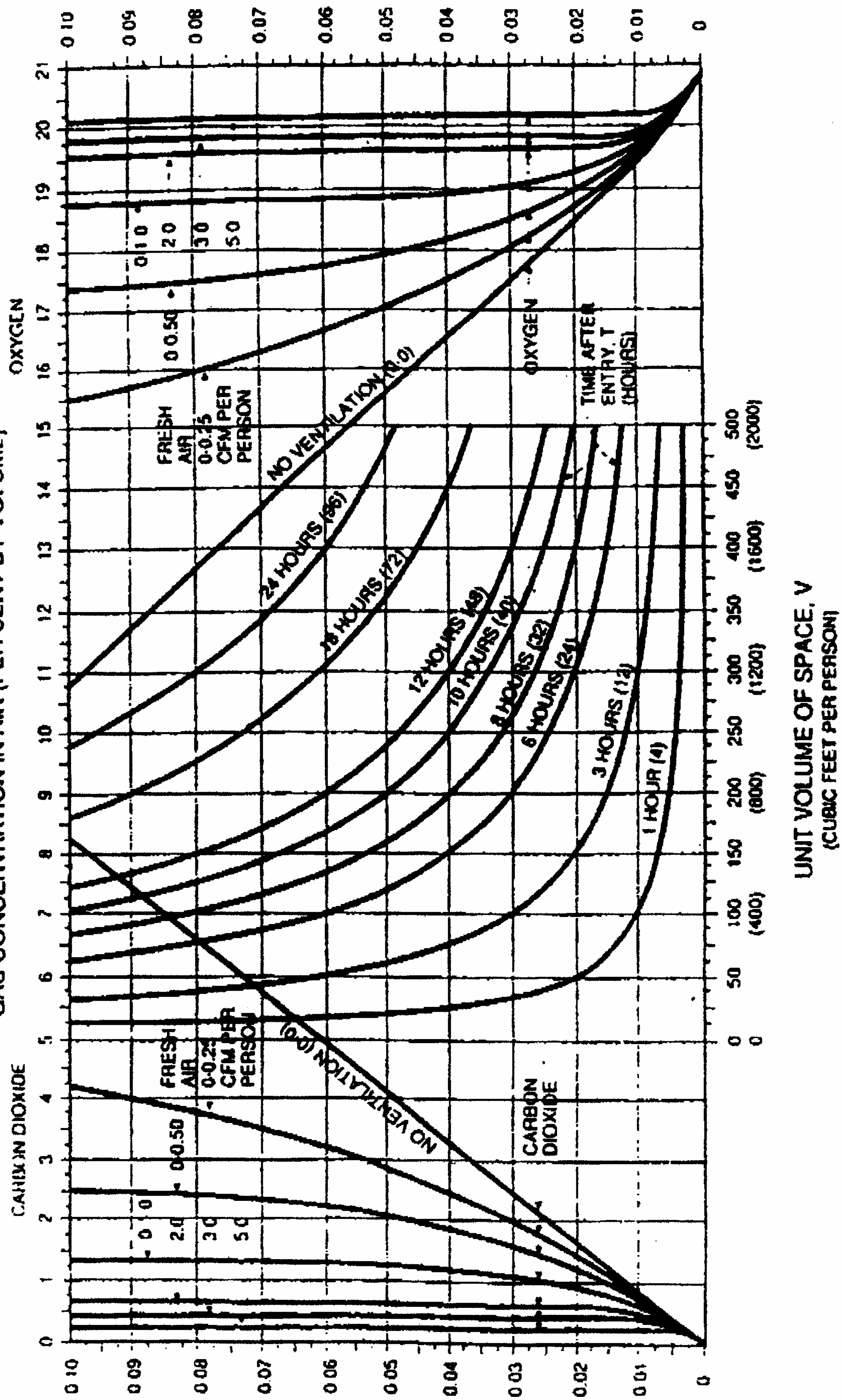
____

____

COMPLETED BY DATE

APPENDIX "3"

NASA-NRC GRAPH



APPENDIX "4"

DISCHARGE OF AIR THROUGH AN ORIFICE

In cubic feet of free air per minute at standard atmospheric pressure of 14.7 lb per sq. in. absolute and 70°F.

Gauge Pressure before Orifice in Pounds per sq. in.	DIAMETER OF ORIFICE										
	1/64"	1/32"	1/16"	1/8"	1/4"	3/8"	1/2"	5/8"	3/4"	7/8"	1"
	Discharge in cubic feet of free air per minute										
1	.028	.112	.450	1.80	7.18	16.2	28.7	45.0	64.7	88.1	115
2	.040	.158	.633	2.53	10.1	22.8	40.5	63.3	91.2	124	162
3	.048	.194	.775	3.10	12.4	27.8	49.5	77.5	111	152	198
4	.056	.223	.892	3.56	14.3	32.1	57.0	89.2	128	175	228
5	.062	.248	.993	3.97	15.9	35.7	63.5	99.3	143	195	254
6	.068	.272	1.09	4.34	17.4	39.1	69.5	109	156	213	278
7	.073	.293	1.17	4.68	18.7	42.2	75.0	117	168	230	300
9	.083	.331	1.32	5.30	21.2	47.7	84.7	132	191	260	339
12	.095	.379	1.52	6.07	24.3	54.6	97.0	152	218	297	388
15	.105	.420	1.68	6.72	26.9	60.5	108	168	242	329	430
20	.123	.491	1.96	7.86	31.4	70.7	126	196	283	385	503
25	.140	.562	2.25	8.98	35.9	80.9	144	225	323	440	575
30	.158	.633	2.53	10.1	40.5	91.1	162	253	365	496	648
35	.176	.703	2.81	11.3	45.0	101	180	281	405	551	720
40	.194	.774	3.10	12.4	49.6	112	198	310	446	607	793
45	.211	.845	3.38	13.5	54.1	122	216	338	487	662	865
50	.229	.916	3.66	14.7	58.6	132	235	366	528	718	938
60	.264	1.06	4.23	16.9	67.6	152	271	423	609	828	1082
70	.300	1.20	4.79	19.2	76.7	173	307	479	690	939	1227
80	.335	1.34	5.36	21.4	85.7	193	343	536	771	1050	1371
90	.370	1.48	5.92	23.7	94.8	213	379	592	853	1161	1516
100	.406	1.62	6.49	26.0	104	234	415	649	934	1272	1661
110	.441	1.76	7.05	28.2	113	254	452	705	1016	1383	1806
120	.476	1.91	7.62	30.5	122	274	488	762	1097	1494	1951
125	.494	1.98	7.90	31.6	126	284	506	790	1138	1549	2023
150	.582	2.37	9.45	37.5	150	338	600	910	1315	1789	2338
200	.761	3.10	12.35	49.0	196	441	784	1225	1764	2401	3136
250	.935	3.80	15.18	60.3	241	542	964	1508	2169	2952	3856
300	.995	4.88	18.08	71.8	287	646	1148	1795	2583	3515	4592
400	1.220	5.98	23.81	94,5	378	851	1512	2360	3402	4630	6048
500	1.519	7.41	29.55	117.3	469	1055	1876	2930	4221	5745	7504
750	2.240	10.98	43.85	174.0	696	1566	2784	4350	6264	8525	11136
1000	2.985	14.60	58.21	231.0	924	2079	3696	5790	8316	11318	14784

Table is based on 100% coefficient of flow. For well rounded entrance multiply values by 0.97. For sharp edged orifices a multiplier of 0.61 may be used for approximate results.

Values for pressures from 1 to 15 lbs gauge calculated by standard adiabatic formula.

Values for pressures above 15 lb gauge calculated by approximate formula proposed by S. A. Moss.

$$W = 0.5303 \frac{ACp_1}{\sqrt{T_1}}$$

Where:

W = discharge in lbs. per sec

A = area of orifice in sq in.

C = Coefficient of flow

p_1 = Upstream total pressure in lbs. per sq. in. absolute

T_1 = Upstream temperature in °F. abs.

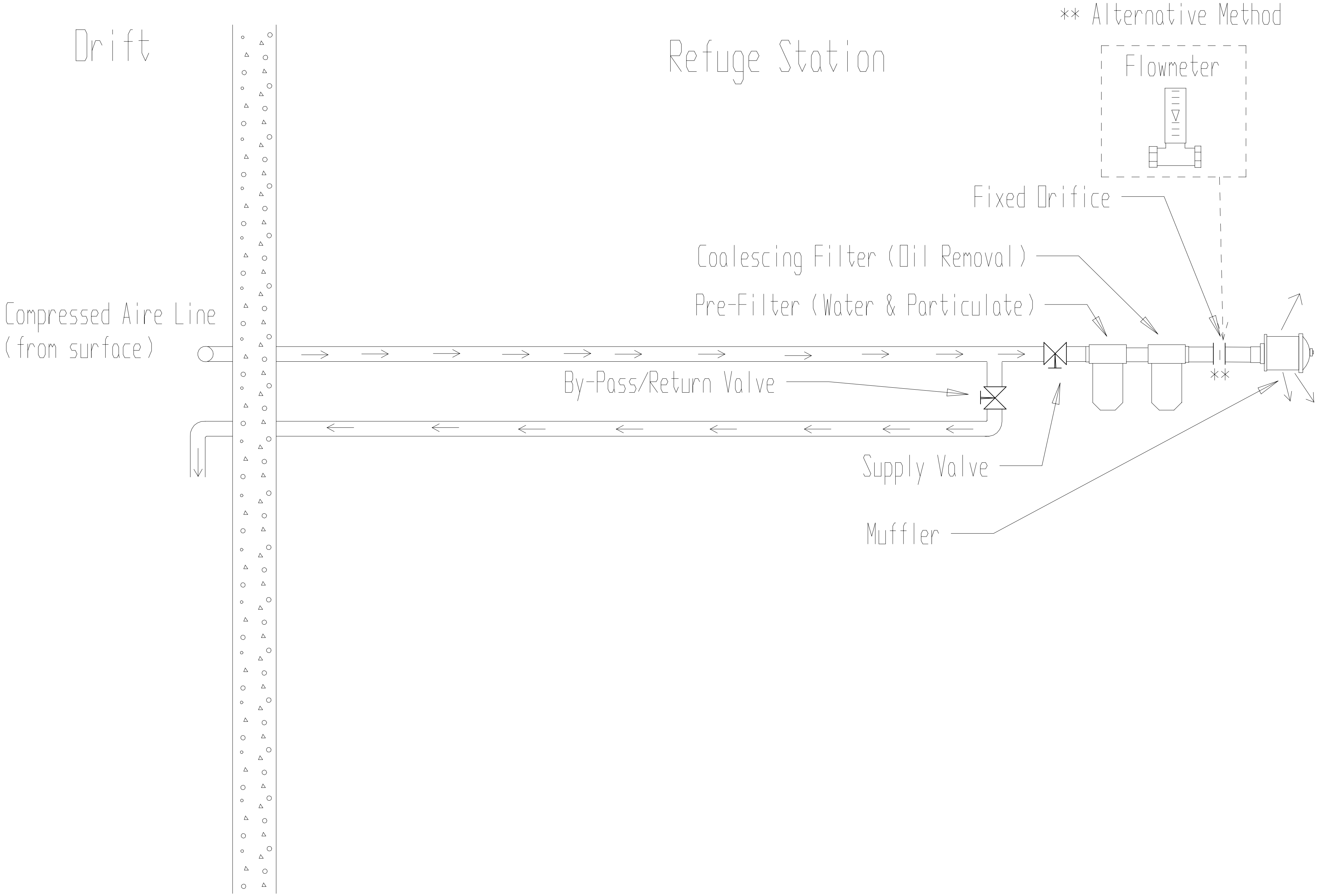
Values used in calculating above table were; $C = 1.0$, p_1 = gauge pressure + 14.7 lbs./sq. in T_1 = 530°F. abs.

Weights (W) were converted to volumes using density factor of 0.07494 lbs./cu. ft. This is correct for dry air at 14.7 lbs. per sq. in. absolute pressure and 70°F.

Formula cannot be used where p_1 is less than two times the downstream pressure.

in. x 25.4 = mm; psi x 6.895 = kPa; cfm x 0.02832 = m³/min; 70°F = 21.1°C

See page 33-114 for orifice formula in metric units.



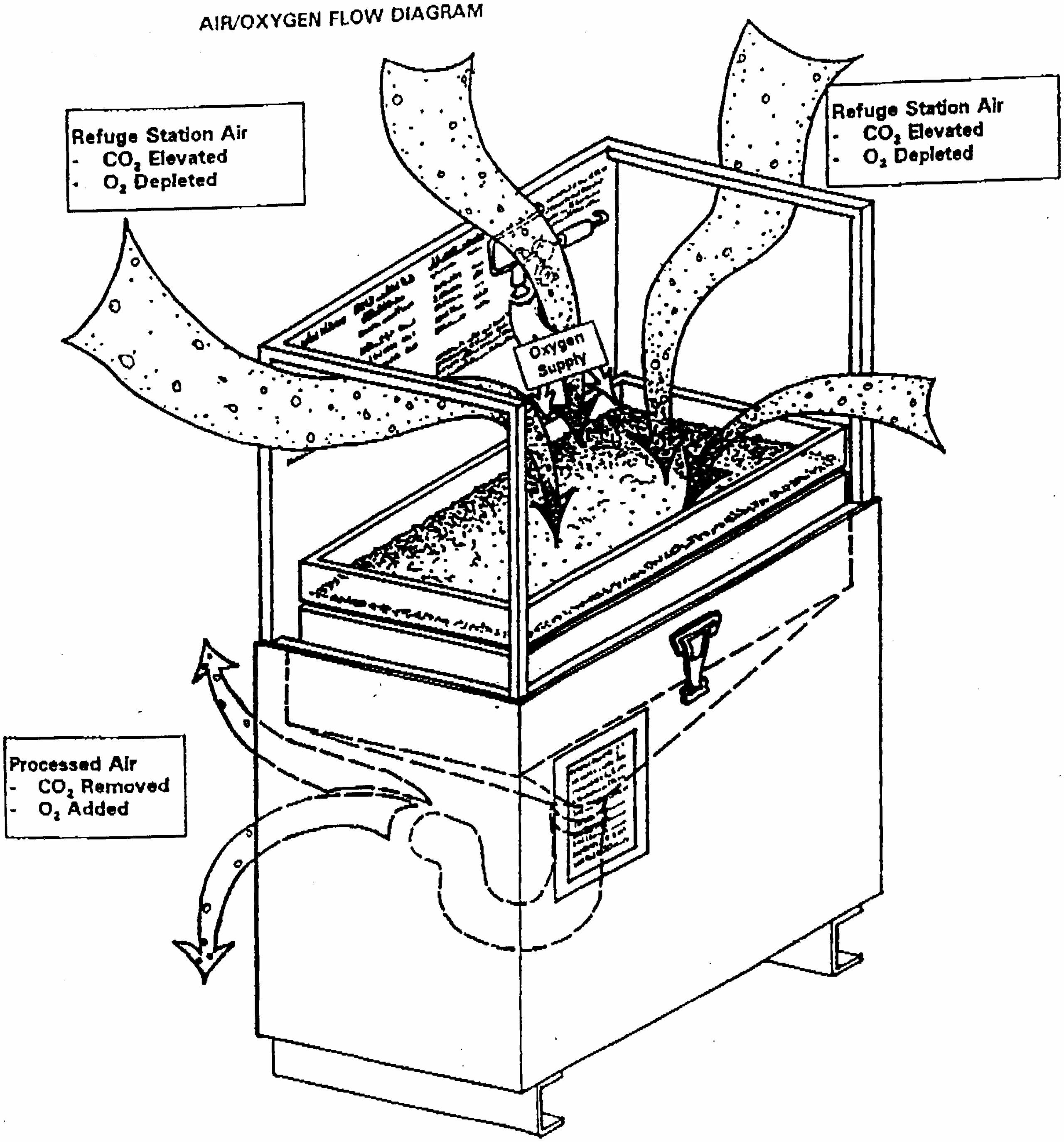
NO.	DATE	REVISION	BY:	CHCK:	DRAWN BY: KKA DATE: OCT 24/96	DRWG #. 96-A-0480 DRAWING TITLE: SCHEMATIC FOR REFUGE STATION COMPRESSED AIR PIPE	REPLACES DRWG No.	RIMER ALCO

RIMER ALCO NORTH AMERICA
15 JEFFERSON ST.
MORDEN, MB. CAN. R6M 1Y4
Phone: (204) 822-6595
Fax: (204) 822-3852

APPENDIX "6A"

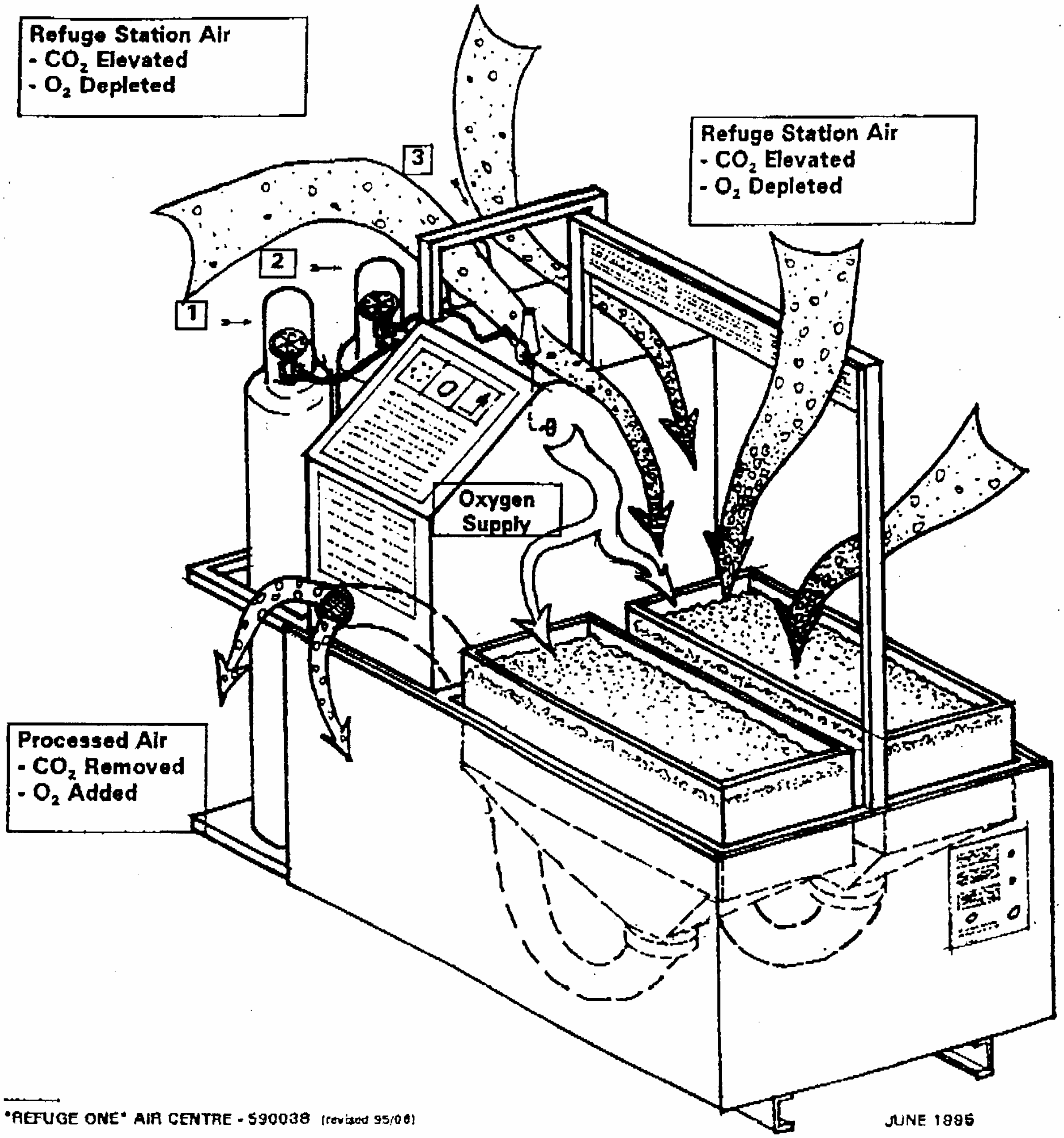
"REFUGE ONE" AIR CENTRE

AIR/OXYGEN FLOW DIAGRAM



"REFUGE ONE" AIR CENTRE

AIR/OXYGEN FLOW DIAGRAM



APPENDIX "7"

"REFUGE ONE" AIR CENTRE

Performance of "REFUGE ONE" Air Centre (Based on the Number of People in a Refuge Station)

Number of People in Refuge Station	With Single Bed "REFUGE ONE" Operating				With Double Bed "REFUGE ONE" Operating			
	CO_2		O_2		CO_2		O_2	
	MAX. CO_2 PPM (Note #1)	Capacity of **R - 1** In Hours (Note #2)	%	Capacity of **R - 1** In Hours (Note #3)	MAX. CO_2 PPM (Note #1)	Capacity of **R - 1** In Hours (Note #2)	%	Capacity of **R - 1** In Hours (Note #3)
5	883	93	20.9	89	441	187	20.9	133
10	1,766	47	20.9	45	883	93	20.9	67
15	2,649	31	20.9	30	1,324	62	20.9	45
20	3,531	23	20.9	22	1,766	47	20.9	33
25	4,414	19	20.9	18	2,207	37	20.9	28
30	5,297	16	20.9	15	2,649	31	20.9	22

NOTES:

PERFORMANCE AND CAPACITIES STATED ABOVE ARE BASED ON THE FOLLOWING:	SINGLE "REFUGE ONE" AIR CENTRE OPERATING	DOUBLE "REFUGE ONE" AIR CENTRE OPERATING
#1 AIR FLOW RATES	80 SCFM	160 SCFM
#2 KILOGRAMS OF SODA LIME (# of Kegs)	80 Kgs/4 Kegs	160 Kgs/8 Kegs
#3 CYLINDERS OF OXYGEN (6.77 m^3/cylinder)	2 Cylinders	3 Cylinders

OTHER INFORMATION:

PHYSICAL DATA - HEIGHT	57.25"	65.50"
- DEPTH	25.50" (15"with cover off)	55.00"
- WIDTH	29.50"	31.00"
- WEIGHT (without chemical or O_2)	400 lbs	1,155 lbs
ELECTRICAL CAPACITY - WITH MINE POWER	Unlimited	Unlimited
- WITHOUT MINE POWER (Battery Capacity)	36 Hours	36 Hours