REFUGE•ONE
AIR CENTRE

KEY FEATURES

- Removes Carbon Dioxide and replenishes Oxygen to maintain breathable air
- Does not require any compressed air or connection to surface
- Works independently of mine power for up to 36 hours
- Small size, easy to relocate
- Simple to operate under stressful emergency conditions
- Skid mounted for portability
- Modular design in 2 sizes can be combined for any sized refuge station needs
- Ten year underground life expectancy

DESCRIPTION

Experience dictates that accidents, mine fires or the sudden release of toxic or other gases can occur at any time and without warning. In a closed or sealed refuge station, CO_2 levels can rise and O_2 levels can deplete quickly to dangerous levels, putting lives at risk. Conventional sources of respirable air such as compressed high pressure cylinders or piped air from the surface can be dangerous or compromised in an emergency. Prepare for the unexpected with the **REFUGE ONE AIR CENTRE**. The **REFUGE ONE** has been designed as a source of respirable air during an emergency, providing safe, breathable air in a compact, moveable unit. Even if electrical power is cut off, the unit will operate for at least 36 hours on it's own battery supply. It constantly removes potentially harmful levels of Carbon Dioxide and replenishes Oxygen, maintaining safe breathing air within a sealed refuge station for up to 36 hours*.

***Actual capacity will depend on number of people in the refuge station. See minimum performance characteristics on opposite page.**

R&D Research & Development

Awarded the 1995 R&D award for Significant Technology

RANA-Medical
PATIENT FIRST
RESPIRATORY SERVICES

www.ranamedical.com

SPECIFICATIONS

Physical Dimensions:

Single Bed Unit:
Length: 57.25”
Width: 29.5”
Depth: 25.5” (15” with cover removed)
Weight: 720 lbs (500 lbs w/o O_2 cylinders)

Double Bed Unit:
Length: 55.5”
Width: 31”
Depth: 65.5”
Weight: 1,545 lbs (1,155 w/o O_2 cylinders)

Electrical:
115V, 60Hz standard (Other voltages/ frequencies available)

Oxygen connectors:
CGA540 standard, other connections available

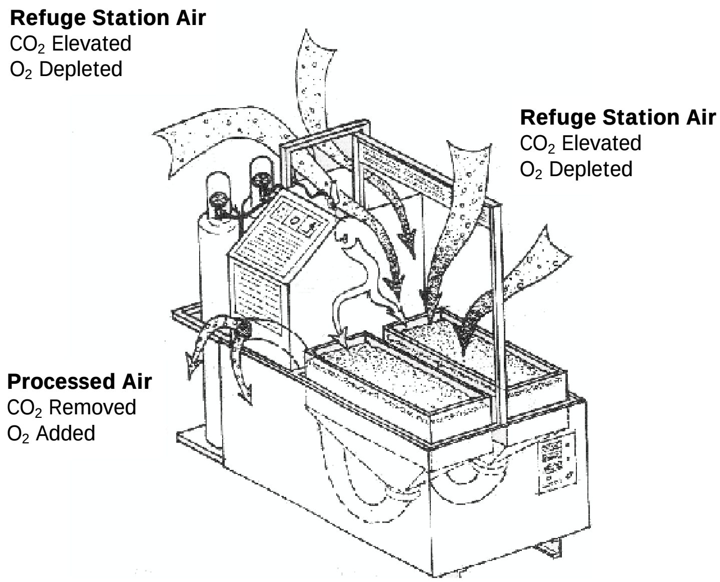
Mechanical:
Skid mounted for easy forklift transport.

OPERATING INSTRUCTIONS

The REFUGE ONE AIR CENTRE has been designed to operate under stressful conditions. The startup instructions are simple and easy to follow:

1) Break the security seals and remove the cover
2) Install the carbon dioxide absorbent chemical
3) Start the blower
4) Turn on the oxygen cylinders
5) Set the oxygen flow rate according to the number of people occupying the Refuge Station.

AIR/OXYGEN FLOW DIAGRAM



MINIMUM PERFORMANCE CHARACTERISTICS

Single Bed Unit: (with 15 people)
Oxygen: 30 hours
Carbon Dioxide Absorption: 31 hours
Battery Capacity: 36 hours

Double Bed Unit: (with 30 people)
Oxygen: 20 hours
Carbon Dioxide Absorption: 31 hours
Battery Capacity: 36 hours

TEST REPORT & MORE INFORMATION

The REFUGE ONE AIR CENTRE has been tested under realistic conditions. To obtain more information or the results of the CANMET Mining Research Laboratory test report, please contact us at the address below.

More information, including a comprehensive guide to providing respirable air in a refuge station entitled “Respirable Air Handbook” is available on our website or at the address below.

For More Information, Please Contact:

RANA-Medical
PATIENT FIRST RESPIRATORY SERVICES

205 Stephen Street
Morden, Manitoba, Canada
R6M 1V2
Phone: (204) 822-6595
Fax: (204)-822-3852

Distributed By:

OPERATION TOMMYKNOCKER

Test of Survival Equipment

for Underground Refuge Stations

at the

Underground Research Laboratory
Lac du Bonnet, Manitoba

March 04 & 05, 1993

by

E. J. Gardiner
M. B. Raber, P.Eng.
Rimer Alco North America Inc.
Morden, Manitoba, Canada

G. W. Kuzyk, P.Eng.
R. Hawkins, MD
AECL Research
Pinawa, Manitoba, Canada

B. D. Simoneau, CRSP
Mines Accident Prevention Association of Manitoba
Winnipeg, Manitoba, Canada

R. Glassford, P.Eng.
T. Redekop, MD
W. Schubert
Manitoba Department of Labour
Winnipeg, Manitoba, Canada

OPERATION TOMMYKNOCKER

CONTENTS

OPERATION TOMMYKNOCKER

Evaluation of the RANA-AIR Mine Refuge Air Centre for Life Support in an Underground Refuge Station

at the

AECL Research Underground Research Laboratory
Lac du Bonnet, Manitoba
March 04 & 05, 1993

EXECUTIVE SUMMARY

Operation Tommyknocker was a test to evaluate the Rimer Alco North America Inc. "RANA-AIR Mine Refuge Air Centre," a self-contained system to maintain safe oxygen and carbon dioxide levels for personnel in mine refuge stations under emergency situations.

The evaluation demonstrated that the RANA-AIR system successfully met the test criteria and satisfied the participants and the sponsors. It maintained oxygen at 19.5 to 20.9% (minimum TLV is 18%), and carbon dioxide at less than 2300 ppm (maximum TLV is 5000 ppm) for six volunteers sealed in the refuge station for 24 hours.

The test was conducted in a small station (22 m^3) so gas concentrations would change rapidly. During the first half hour, before the RANA-AIR system was activated, the volunteers were very busy organizing themselves. This activity produced a sharp increase in carbon dioxide concentration. However, shortly after the system was activated, the carbon dioxide was brought under control. The participants found the RANA-AIR system to be "simple and easy" to use. They turned it on, set the oxygen flow, and had no need to make further adjustments.

Carbon dioxide and oxygen gas measurement tubes were used by the volunteers for monitoring. The carbon dioxide tubes worked well, but readings from the oxygen tubes were variable in this application, possibly because of the high humidity. The volunteers also used a Comfocheck instrument developed by AECL Research to measure carbon dioxide, temperature and relative humidity.

The evaluation was performed under the leadership of the Mines Accident Prevention Association of Manitoba (MAPAM) and the Mines Inspection Branch of the Manitoba Department of Labour. They developed functional requirements for the equipment and the evaluation criteria. Rimer Alco developed the RANA-AIR Mine Refuge Air Centre for testing. AECL Research provided a simulated mine refuge station at the 240-metre level in the Underground Research Laboratory facility near Lac Du Bonnet, Manitoba. Six

volunteers from sponsoring MAPAM mining companies used the RANA-AIR system under actual underground conditions.

All the participants were extremely satisfied with the performance of the RANA-AIR Mine Refuge Air Centre. They agreed that it has the potential to enhance mine safety in an emergency situation, and that Rimer Alco should be encouraged to continue development of a production model.

OPERATION TOMMYKNOCKER

Evaluation of the RANA-AIR Mine Refuge Air Centre for Life Support in an Underground Refuge Station

1. INTRODUCTION

Changes in technology and mining methods prompted a review of the requirements for underground refuge stations by the Mines Inspection Branch of the Workplace Safety and Health Division, Manitoba Department of Labour (Mines Inspection Branch), and the Mines Accident Prevention Association of Manitoba (MAPAM). The demand for traditional mine services such as compressed air, water, electricity and communication systems have changed dramatically over the last decade. The introduction of equipment utilizing electric/hydraulic power is rapidly replacing pneumatic equipment, thereby reducing or eliminating the need for compressed-air lines in many workplaces underground. In the absence of compressed-air lines, alternate methods must be established to provide respirable air for refuge stations.

The directors of the MAPAM and representatives from the Mine Inspection Branch defined the operational requirements for an underground refuge station air supply system and developed an evaluation test for the proposed system. The test was to be called Operation Tommyknocker. The name "Tommyknocker" was derived from mining folklore. Tommyknockers are the spirits of trapped miners knocking for food and rescue.

Rimer Alco North America Inc. (Rimer Alco) developed the RANA-AIR Mine Refuge Air Centre according to the directors' requirements. The system was designed to add oxygen and remove carbon dioxide from the atmosphere in an underground refuge station containing trapped personnel. The system was also designed to be rugged, simple and totally self-contained.

Rimer Alco's involvement in Operation Tommyknocker was the result of their interest and awareness of the problem defined by the MAPAM directors and personnel from the Mines Inspection Branch as well as their interest in providing a solution to a potentially dangerous situation.

The directors arranged to have Operation Tommyknocker conducted in a simulated mine refuge station at AECL Research's Underground Research Laboratory (URL) near Lac du Bonnet, Manitoba. AECL developed the URL to carry out geotechnical research relating to the disposal of used nuclear fuel in the plutonic rock of the Canadian Shield. The URL is an important part of the Canadian Nuclear Fuel Waste Management Program and is ideally suited to carry out research projects and tests such as Operation Tommyknocker.

AECL Research's participation in providing a location, professional staff and the many services required for this type of test was done in the true spirit of cooperation. As a member of MAPAM, AECL Research also expressed a keen interest in participation to ensure "safe underground refuge stations."

The simulated refuge station was constructed in a dead-end tunnel in Room 207 on the 240-m level of the URL. The station was approximately 22 m^3 in volume (3.0 x 3.0 x 2.5 m). Six volunteers, representing the types of workers normally found in the mine environment, were isolated in the simulated refuge station and used the RANA-Air Mine Refuge Air Centre for a 24-h period. Technical and medical staff were present in the tunnel outside the refuge station during the test to observe the volunteers and gather environmental and physiological data.

The volunteers were mine personnel from participating MAPAM member companies. MAPAM is a nonprofit organization funded primarily through the Mining Association of Manitoba by the mining companies, mine contracting companies and diamond-drilling companies operating in the Province of Manitoba. Two participants were sent by INCO from Thompson, two were sent by Hudson Bay Mining and Smelting Limited (one from Flin Flon and one from Leaf Rapids), two were provided by The Tantalum Mining Corporation of Canada Limited (Tanco), Lac du Bonnet, and two were provided by AECL Research.

2. SYSTEM REQUIREMENTS

The requirements of the air supply system were defined by the Mines Inspection Branch and MAPAM with the objective of providing a safe respirable refuge environment for confined personnel. It was determined the equipment should:

1. Control oxygen and carbon dioxide concentrations as close to normal levels as possible or at least to nationally accepted safe levels.

   For the evaluation test, the carbon dioxide concentration should be less than the TLV-TWA value of 5000 ppm, and oxygen should be greater than 18%, so the volunteers would not be at risk.

2. Operate without reliance on electric power or compressed air from outside the refuge station for at least 24 h in an emergency situation.

3. Be simple and easy to operate with a minimal training.

4. Be durable and rugged, with a long stand-by life (i.e., years) without use and be able to stand up to the severe environmental conditions present underground, such as cool temperatures, high humidity and concussion from blasting

operations.

5. Affordable cost so the system would be feasible in any mine's safety program.

3. DESCRIPTION OF THE TEST

3.1 Purpose

The purpose of the test was to evaluate how well the RANA-AIR system would meet the requirements defined by the Mines Inspection Branch and the MAPAM directors, and to demonstrate its operation under realistic underground refuge station conditions.

Rimer Alco's objectives going into the test were to:

1. Determine how "simple and easy" the RANA-AIR system is to use.

2. Test the RANA-AIR system's ability to maintain oxygen and carbon dioxide levels as close to atmospheric as possible in underground refuge station conditions.

3. Determine if the monitoring equipment provided with the RANA-AIR system (to measure concentrations of oxygen and carbon dioxide) is effective and appropriate given the experience, training and anxiety of those required to operate it.

The unit had previously been tested by Rimer Alco staff on the surface in a small sealed room simulating a refuge station. To obtain baseline information and to verify the information obtained from the reference literature on rates of oxygen consumption and carbon dioxide production, nine men stayed in the room without adding oxygen or removing carbon dioxide. The results from this preliminary test generally agreed with data from the literature and confirmed the theoretical predictions.

3.2 Selection of Volunteers

Eight volunteers, who were experienced in Manitoba mine rescue procedures, were selected by MAPAM for the test. The volunteers were representative of the type of workers normally found in the underground environment. Prior to the start of the test, six of the eight volunteers were selected for enclosure in the simulated refuge station by the medical doctors during a pre-test medical examination. A briefing was carried out for the participants to explain the purpose of the test. Once they fully understood the operation, the volunteers signed consent forms. The volunteers were briefed on the operation of the monitoring equipment they were to use within the simulated refuge station and the operation of the RANA-AIR system immediately before the start of the test.

3.3 The RANA-AIR Mine Refuge Air Centre

The RANA-AIR system was a prototype unit built to evaluate the simplicity and the effectiveness of this type of equipment under emergency conditions. The system was intended to be rugged and easy to maintain. Measuring 160 mm high, 65 mm wide, and 90 mm deep, it had the capability of sustaining 10 people at rest for 36 h. Systems having a greater capacity can also be made available.

The six volunteer participants were sealed in the simulated refuge station at about 1300 on March 04. They organized themselves and started the RANA-AIR system about half an hour after entering the station.

The oxygen flow rate was set by the volunteers according to their demand. A nominal flow rate of 0.5 L/min per person was set for the test. The oxygen flow from the system was mixed with room air. The room air was circulated by a fan through a built-in carbon dioxide scrubber, which removed carbon dioxide from the atmosphere. Carbon dioxide is a product of breathing and would otherwise build up when the volunteers were confined within the sealed room.

The RANA-AIR system was totally self-contained. The volunteers only have to fill the carbon dioxide scrubber and turn on the oxygen and scrubber. Power was provided by a durable battery that is kept charged when the unit is on standby. The system was designed to be simple and easy to understand so that special skills were not required for its operation. Simple step-by-step instructions requiring a minimum level of training was all that was necessary to operate the system.

Draeger gas measurement tubes were provided as part of the system to monitoring the oxygen and carbon dioxide levels within the refuge station. The volunteer participants were instructed to make adjustments to the oxygen flow of the system based on the oxygen levels measured with the detection tubes. Carbon-dioxide-absorbing material would be changed if the absorber indicated saturation. The object was to maintain oxygen and carbon dioxide levels as close to normal atmospheric conditions as possible (i.e., 20.9% oxygen and less then 0.5% carbon dioxide).

This measurement method was selected because of the long shelf-life of the detection tubes, the ease of use, and measurement tubes are common in underground operations.

Components of the RANA-AIR system were selected for reliability and long standby life. The system was designed for easy maneuvering by personnel with the durability to withstand the ruggedness required for underground transport. It was intended the system would have a minimum 10-year life expectancy, with only periodic checks required.

3.4 Simulated Refuge Station

The simulated refuge station was constructed in a dead-end stub drift on the 240-m level of the URL. It consisted of a room with an excavated volume of 22 m^3 and dimensions of about 3.0 x 3.0 x 2.5 m. An air-tight wall was constructed of nominally 2 x 6 inch lumber, three-quarter inch plywood and plastic film. The room was large enough to accommodate two sets of bunks on either side, thereby providing four beds for sleeping. Two shelves were provided on either end of the room, one above the door. A small Plexiglas window, about 300 x 300 mm, was provided in the wall. A double-door air-lock was provided in the wall to provide an area of about 1 X 1 m.

The normal breathing of the participants resulted in quick changes of oxygen and carbon dioxide levels of the atmosphere within the confined space of the simulated refuge station.

Accessories within the simulated refuge station consisted of blankets, pillows, individually wrapped sandwiches, muffins, chocolate bars, juice, coffee, cards, magazines and TV and video player. A portable toilet was placed within the entrance air lock to provide privacy and control odour.

3.5 Safety

The purpose of the test was to evaluate the performance of the RANA-AIR system, not the reaction of the participants to confinement and isolation. The participants were volunteers who were healthy, free from any medical afflictions, and typical of individuals normally working underground. The following guidelines were used to select the participants:

1. normal vital signs,
2. normal heart and lung function,
3. normal mental psychological status (no phobias),
4. free from need to take medication, and
5. non-smokers.

Pre-test and post-test medical examinations of the volunteers were carried out by the two medical doctors involved in the test.

Technical representatives and a medical doctor were present during the entire test to ensure the necessary monitoring of the simulated refuge station atmosphere was carried out on a continuous basis and that the health of the participants was not jeopardized during the test. Before the test commenced, it was decided that the test would be aborted at any time if the participants felt threatened, wanted to leave the simulated refuge station, or the medical doctor felt the conditions were becoming a threat to their health or otherwise hazardous.

The atmosphere of the simulated refuge station was monitored during the test by the volunteer participants from within the station and independently by observers located outside the station. The atmosphere was maintained within the Threshold Limit Value (TLV) identified in the Manitoba Mining Regulations. Oxygen levels were not allowed to drop below 18.0% [1] and the carbon dioxide level was not allowed to rise above 0.5% [2] for more than one-half hour during the test. The short-term exposure limit is 5000 ppm [2].

It was intended that the test would not push the equipment to its limit or endanger the safety of the participants. The RANA-AIR system was designed with an oxygen supply for 360 person-hours. For six people, this would be 60 h in the anticipated mine refuge station conditions. The carbon dioxide absorber system had a capacity to operate for 144 person-hours. Enough absorber was placed within the simulated refuge station to fill the system twice, giving a total duration of 288 person-hours. For the purposed of Operation Tommyknocker, the system was set up to accommodate six people for a minimum of 48 h, or twice the maximum duration of the test.

The capacities are based on the selected values of 0.5 L/min oxygen and carbon dioxide per person. The nominal values cited in the literature for astronauts or submariners are 0.42 L/min oxygen and 0.35 L/min carbon dioxide [3]. These values are for people at rest or subject to little physical activity. Strenuous exercise will result in higher values. The selected values are greater than the nominal values to allow for any stress that may have arisen during Operation Tommyknocker because of the confined space.

Individual monitoring of all participants during confinement was carried out by one of the participants who was a Emergency Medical Assistant 1 (EMA-1). The following vital signs were recorded at regular intervals (i.e., about 1-h intervals):

1. blood pressure,
2. pulse, and
3. respiration rate.

A personal log was kept by each of the participants to record changing conditions within the simulated refuge station and his own physical and mental status (e.g., to note such things as drowsiness, odours, fumes, physical changes, mental attitude).

3.6 Atmospheric Monitoring

Continual monitoring of the atmosphere inside the simulated refuge station was provided for the following parameters:

1. oxygen level (%),
2. carbon dioxide level (%, ppm),
3. temperature (°C), and
4. relative humidity (%).

Measuring equipment used inside the refuge station by the volunteers consisted of a Comfocheck instrument for measuring carbon dioxide concentration, temperature and relative humidity, and a sling psychrometer for measuring relative humidity. The Comfocheck unit, which was located on top of the RANA-AIR system near the scrubber outlet, was set to record data every 16 s.

Manual monitoring of oxygen and carbon dioxide concentrations was carried out by the volunteer participants with gas tubes as well. Draeger gas measurement tubes were used to detect oxygen and Gastech tubes were used for carbon dioxide.

In addition, the volunteers provided other equipment from their respective mines, including an Industrial Scientific system (for oxygen concentration measurements) and a Kanomax system (for temperature and relative humidity).

A second Comfocheck instrument, located inside the simulated refuge station on a shelf beside the window, was connected via a cable that passed through a sealed hole to a computer located outside. This Comfocheck unit was set to record carbon dioxide concentration, temperature and relative humidity automatically every 5 min.

Two sampling tubes were passed through sealed bulkhead fittings in the Plexiglas window. The intake for one tube was located adjacent to the Comfocheck instrument on the shelf near the top of the door, while the other sampled from the output of the carbon dioxide scrubber. Valves located at the bulkhead were used to seal the tubes when not in use for measurement. The tubes delivered sample air to two Servomex model 571 oxygen analyzers used to measure oxygen concentrations. The oxygen analyzers were calibrated with tanks of nitrogen (0% oxygen) and 100% oxygen. A Gastech carbon dioxide analyzer (range 0 - 5000 ppm) was used to measure carbon dioxide. The carbon dioxide analyzer was calibrated against a Comfocheck analyzer before the test began.

A third Comfocheck instrument was set up outside the simulated refuge station to monitor the outside atmosphere at the 240-m level. This unit also recorded data every 5 min.

A mercury barometer was installed to record changes in atmospheric pressure outside the refuge station. A water manometer was installed through the window located in the wall of the station to monitor any difference in pressure inside and outside the refuge station. Pressure readings and humidity measurements made with the sling psychrometer were recorded every hour.

Dale thermistors (Model IC-3001-C3) coupled to a switch box and precision ohmeter were used to monitor temperatures at various locations within the simulated refuge station and outside the station. The thermistors were placed as follows:

1. Thermistor T1 was suspended from the back of the simulated refuge station about 150 mm from the rock surface.

2. Thermistor T2 was located 1.5 m above the floor about 150 mm from the back wall of the simulated refuge station.

3. Thermistor T3 was located 150 mm above the floor near the back wall of the simulated refuge station.

4. Thermistor T4 was located at the in-flow port of the RANA-AIR system.

5. Thermistor T5 was located at the out-flow port of the RANA-AIR system.

6. Thermistor T6 was located outside the simulated refuge station, under one of the tables, about 750 mm above the floor.

3.7 Comfocheck System

The Comfocheck Model I101-A system was developed by AECL Research. The system is designed to monitor the climate in an indoor working environment. The system measures the following parameters:

1. Temperature:	range accuracy resolution	-10 to 40°C, +\- 0.5°C, 0.2°C.
2. Relative Humidity:	range accuracy resolution	10% to 90% RH, +\- 3.5%, 1% RH
3. Carbon Dioxide:	range accuracy resolution	0 to 4500 ppm, +\- 100 ppm, +\- 50 ppm.

The Comfocheck system was designed for users who are not necessarily specialists in this field. The system weighs about 912 g and has dimensions of 215 x 140 x 60 mm. It consists of an instrument case, software for a desk or laptop PC and a cable to link the instruments to a personal computer. This system makes indoor climate monitoring practical and economical.

Temperature is sensed by a platinum resistance temperature device, relative humidity by a capacitance sensor and carbon dioxide concentration by a patented infrared absorption cell. Each sensor and its associated circuit are individually calibrated before the Comfocheck is shipped.

The Comfocheck instrument can be operated in either a "spot-check" or a "data-log" mode. The spot-check mode is used to quickly evaluate the current conditions. The data-logging mode is used to determine how the indoor climate varies over longer periods of time without the need for an operator to record the data.

All three Comfocheck instruments were calibrated on the afternoon of March 03, the day before the test, using standard calibrating procedures. Carbon dioxide response was calibrated using three standards, 0, 876 and 3950 ppm. Relative humidity readings were calibrated at two levels, 33% and 75% RH. A linear relationship between the output and the RH is specified by the manufacturer. The temperature response was calibrated against thermistors over the range of 5 to 35°C, and was rechecked against a high-precision glass thermometer at room temperature. Immediately prior to the start of the test, the carbon dioxide response was verified at 500 ppm and was varified again at the end of the test using 2000-ppm standards. Instruments inside the refuge station were within specifications both before and after the test. The instrument outside the station showed a slightly lower value (1875 ppm) than expected for the 2000-ppm standard. As these outside data are only of secondary importance, the data were not corrected for what appears to be a very slight drift in the results. The Gastech carbon dioxide analyzer was calibrated to the reading of a calibrated Comfocheck instrument to ensure measurement consistency.

3.8 Supporting Personnel

The following personnel were required to support the test over the 24-h period:

1. Two medical doctors.
2. Two surveyors to record data outside the simulated refuge station.
3. MAPAM representative/test supervisor.
4. Three Department of Labour representatives.
5. Two record keepers/inspectors.
6. Two Rimer Alco representatives.
7. One photographer/video operator.

4. TEST RESULTS

4.1 Oxygen Levels and Measurement

The RANA-AIR system was turned on about 26 min after the start of the test. The volunteer participants set the oxygen flow rate at the value recommended by Rimer Alco in the operating directions at this time (0.5 L/min per person), and after one small adjustment to the flow rate, did not make any further setting adjustments for the duration of the test. Figure 1 shows the oxygen levels over the 24-h duration of the test. The oxygen level remained quite stable, between 19.5% and 20.9%.

Some difficulty with the oxygen detection tubes was experienced during the test. The detection tubes provided reliable readings of oxygen levels at the beginning of the test. However, after about 6 h, the detection tubes indicated oxygen levels as high as 26%. This difficulty may have been related to the humidity inside the simulated refuge station, which reached a very high level

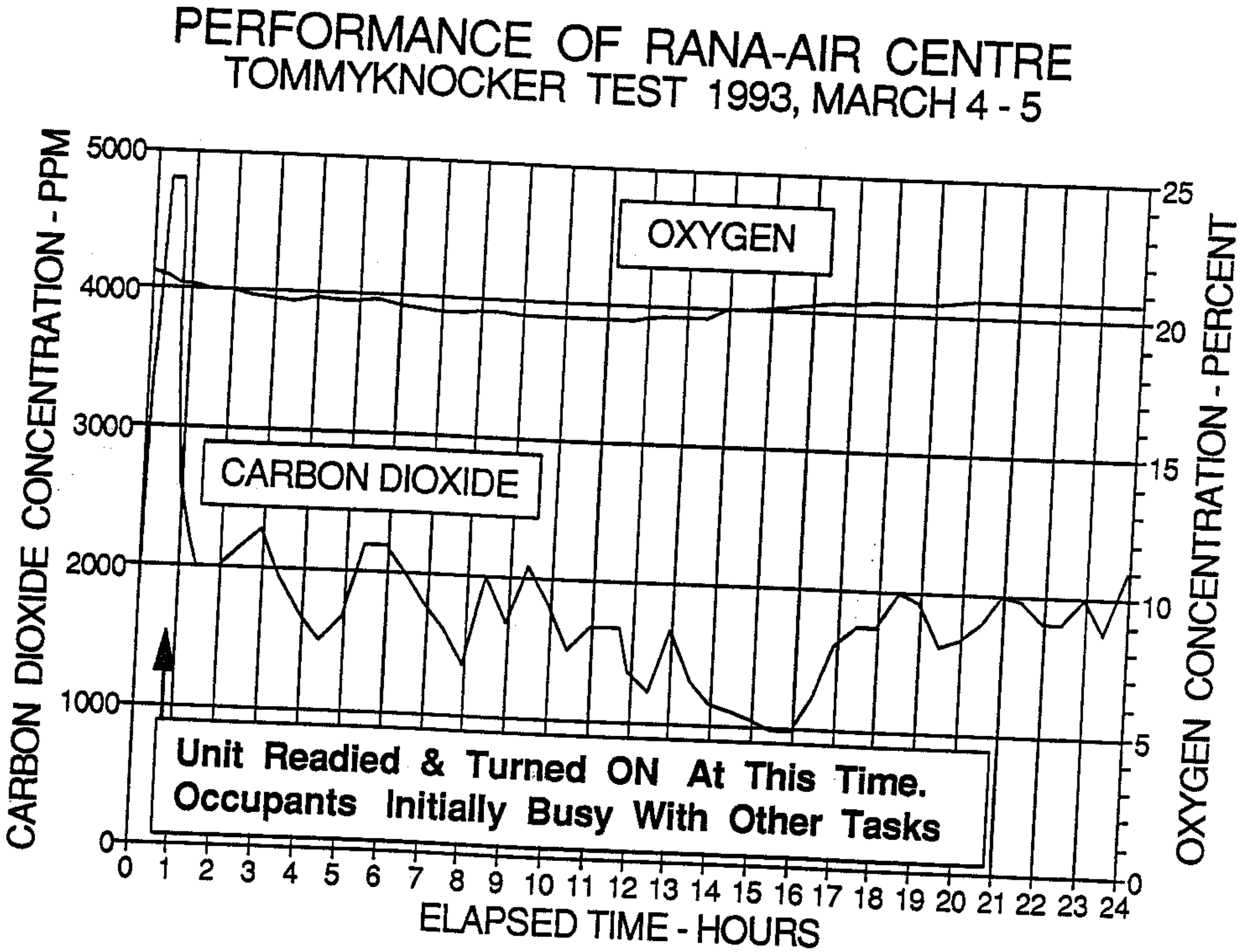

PERFORMANCE OF RANA-AIR CENTRE
TOMMYKNOCKER TEST 1993, MARCH 4 - 5
OXYGEN
CARBON DIOXIDE
Unit Readied & Turned ON At This Time.
Occupants Initially Busy With Other Tasks
CARBON DIOXIDE CONCENTRATION - PPM
OXYGEN CONCENTRATION - PERCENT
ELAPSED TIME - HOURS
0
1000
2000
3000
4000
5000
0
5
10
15
20
25
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Figure 1

(about 90%) after about 2 h. The oxygen measurement was made using a dryer tube connected before the measuring tube. It was intended that each dryer tube be used with four measuring tubes. Initially, the volunteer participants were able to use from one to three measurement tubes with each dryer tube before the oxygen level readings became erratic.

The volunteer participants felt very comfortable during the test and experienced no desire to change the oxygen flow rate on the RANA-AIR system after the initial setup.

4.2 Carbon Dioxide Levels

As shown in Figure 1, carbon dioxide levels increased rapidly upon commencement of the test. The analyzers saturated at about 4800 ppm, but the peak level was actually greater. This was because there was some delay, about 26 min, before the volunteer participants started the RANA-AIR system operating. During this time they were very active while organizing themselves and arranging everything inside the refuge station. Within 7 min after the RANA-AIR system was started, the carbon dioxide level was reduced to 5000 ppm.

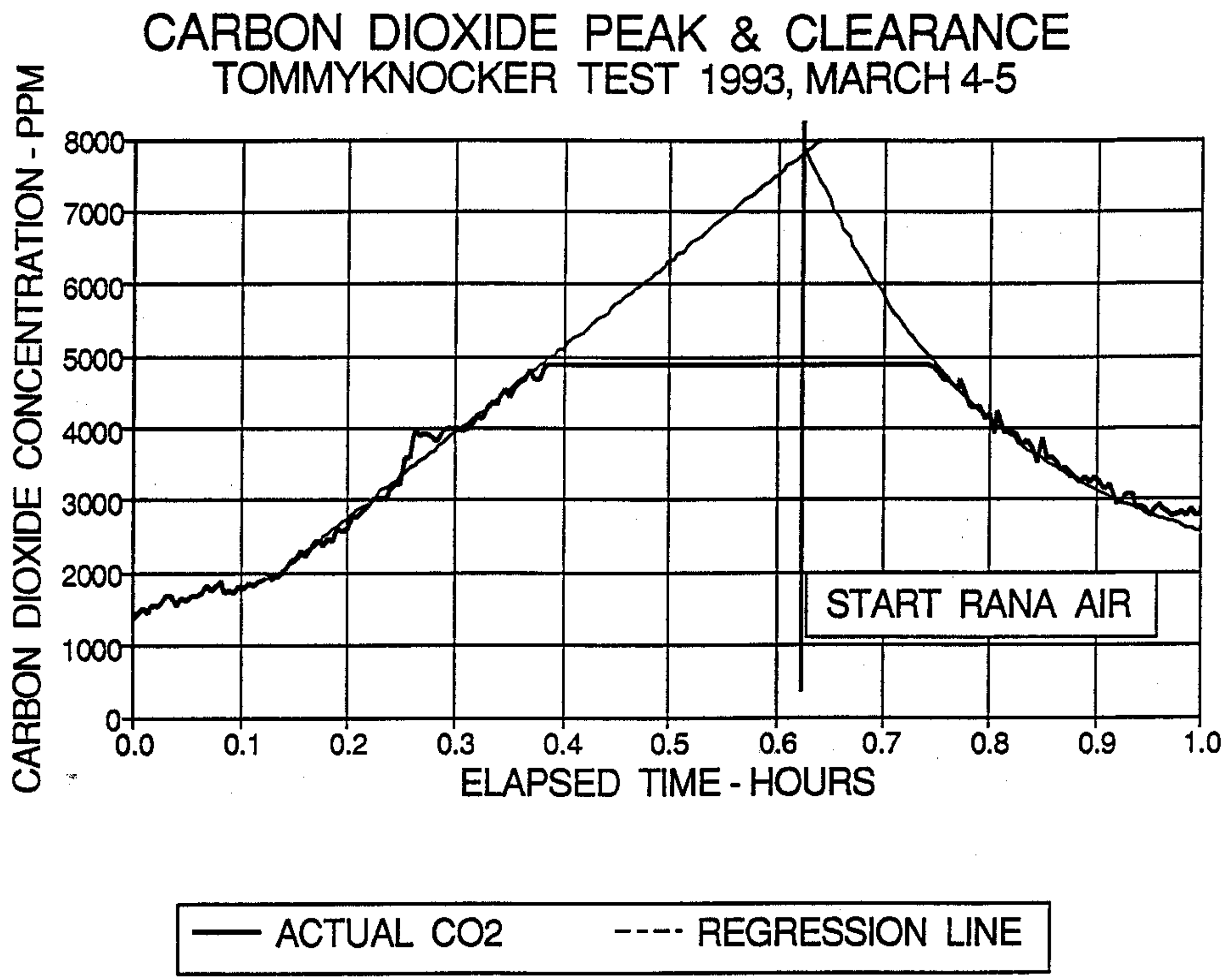
The initial high carbon dioxide spike was logged to off-scale readings at 16-s intervals, and these data are plotted in Figure 2. From this plot it is apparent that the carbon dioxide level reached 8000 ppm, which can be attributed to the delay in starting the RANA-AIR system. The value of 8000 ppm was within the short-term TLV of 30 000 ppm [2]. The volunteer participants all reported that they experienced a slight headache at this time. However, once the RANA-AIR system was operating, the carbon dioxide levels quickly reduced to a stable level of about 2000 to 2300 ppm. The volunteer participants reported that their headaches did not persist once the system was turned on.

After about 18 h of operation, about 1 cm of the carbon dioxide adsorbing material started to change its colour to a slightly pinkish tinge.

The carbon dioxide levels fluctuated between 1000 ppm and 2300 ppm during most of the test. It was noted that the levels were lowest 8 to 18 h after the test commenced, at times when some or all of the volunteer participants were sleeping.

The gas detection tubes used to measure carbon dioxide levels worked effectively during the test.

Figures 3 and 4 show the Comfocheck data for the units located beside the window and on top of the scrubber respectively. An absolute agreement between the two instruments inside the simulated refuge station should not be expected because the units were sampling different areas. Occupants exhaling in the vicinity of one instrument or the other would cause local maxima. However, as seen in the two figures, the two instruments do track each other very closely, rarely differing by more than 200 ppm.



CARBON DIOXIDE PEAK & CLEARANCE
TOMMYKNOCKER TEST 1993, MARCH 4-5
CARBON DIOXIDE CONCENTRATION - PPM
8000
7000
6000
5000
4000
3000
2000
1000
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
ELAPSED TIME - HOURS
START RANA AIR
ACTUAL CO2
REGRESSION LINE

Figure 2

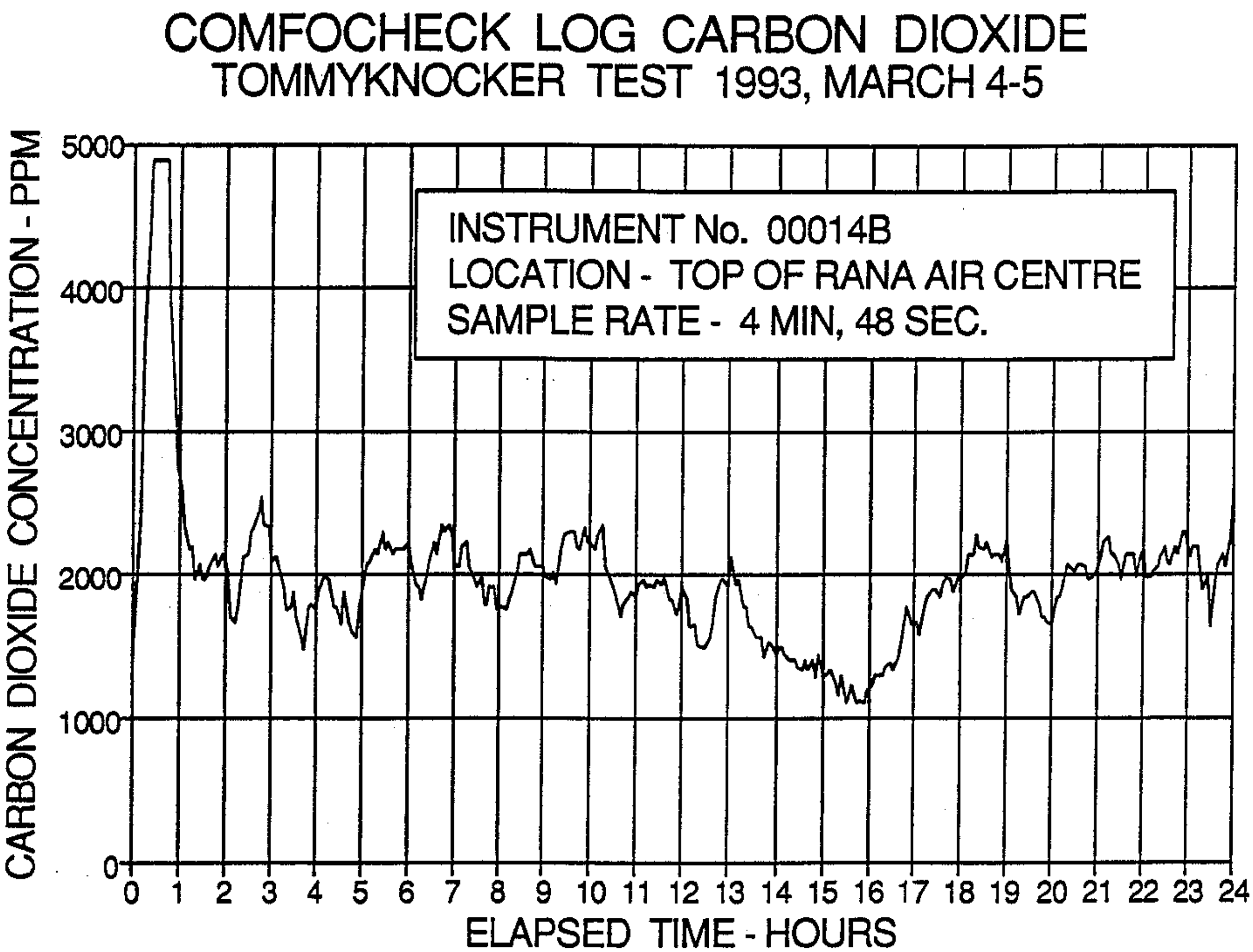

COMFOCHECK LOG CARBON DIOXIDE
TOMMYKNOCKER TEST 1993, MARCH 4-5
INSTRUMENT No. 00014B
LOCATION - TOP OF RANA AIR CENTRE
SAMPLE RATE - 4 MIN, 48 SEC.
CARBON DIOXIDE CONCENTRATION - PPM
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
ELAPSED TIME - HOURS

Figure 3

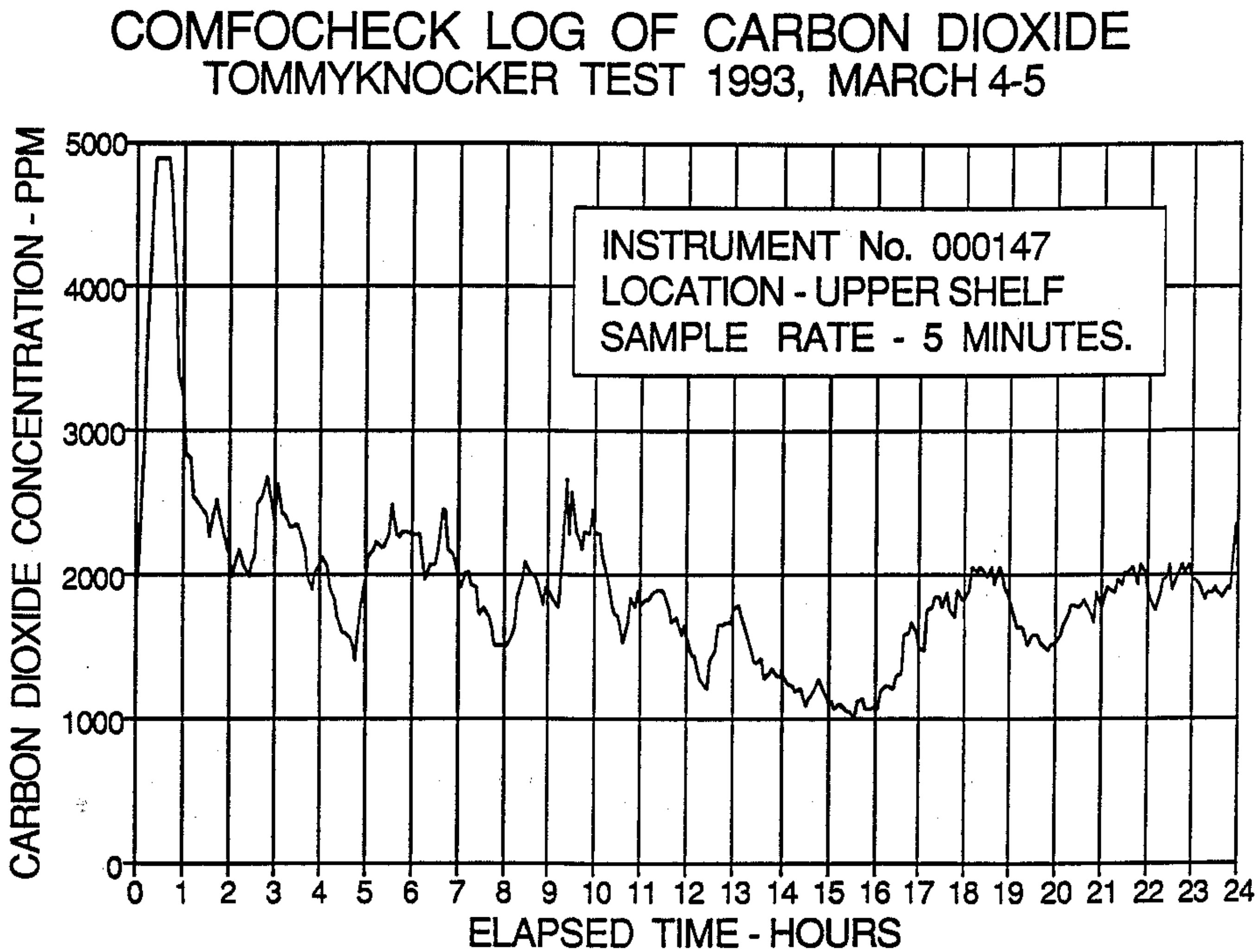

COMFOCHECK LOG OF CARBON DIOXIDE
TOMMYKNOCKER TEST 1993, MARCH 4-5
INSTRUMENT No. 000147
LOCATION - UPPER SHELF
SAMPLE RATE - 5 MINUTES.
CARBON DIOXIDE CONCENTRATION - PPM
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
ELAPSED TIME - HOURS

Figure 4

The carbon dioxide levels outside the simulated refuge station were about 800 ppm, as shown in Figure 5. This is somewhat higher than normal atmospheric air, which is less than 300 ppm. This higher than usual level occurred because the URL ventilation air is heated with "in-stream" propane heaters located in the fresh-air intake at the surface. The carbon dioxide combustion product is mixed with the incoming air.

The carbon dioxide concentration outside the station just before the volunteers entered the station was slightly higher, likely because there were many people active in the area to assist with the preparations for the test.

The carbon dioxide concentrations outside the refuge station showed a minimum around 1800 on March 04 at the start of the test, and a steady rise to a maximum near 0800 the next morning, corresponding inversely with surface daily maximum and minimum temperatures. This was because of the thermostat setup on the surface propane heaters, which will increase the heater output as the outside temperature decreases.

A sharp peak outside the station approximately 15.5 h into the test is attributed to someone leaning over the Comfocheck instrument at that moment to examine it.

4.3 Relative Humidity

Figure 6 show the relative humidity outside the station. The outside humidity varied between 70% and 80%. This is normal for the URL underground atmosphere during the winter months when the propane heaters are in use. The combustion products of propane are carbon dioxide and water vapour.

The relative humidity measured by the two Comfocheck units inside the simulated refuge station is shown in Figures 7 and 8. Both units indicated that the relative humidity increased rapidly within the first hour of the test to a maximum value. The Comfocheck was not calibrated to 100% humidity and in fact the RH sensor is only guaranteed to a 90% calibration level. Values above 90% can only be interpreted as tracking humidity changes in a qualitative way. Since the volunteers exhaled considerable amounts of water vapour, it may be expected that the actual relative humidity was approximately 100%.

The Comfocheck unit located on the shelf beside the window was positioned with its sensor within 30 to 50 mm of the rock surface, which was cooler than the air. As the scrubber also removes water from the air to a limited degree, one would expect the unit located on top of the RANA-AIR unit would show somewhat lower values, as it did.

The humidity, as described by the volunteer participants, became very apparent a few hours into the test. Clothing that was taken

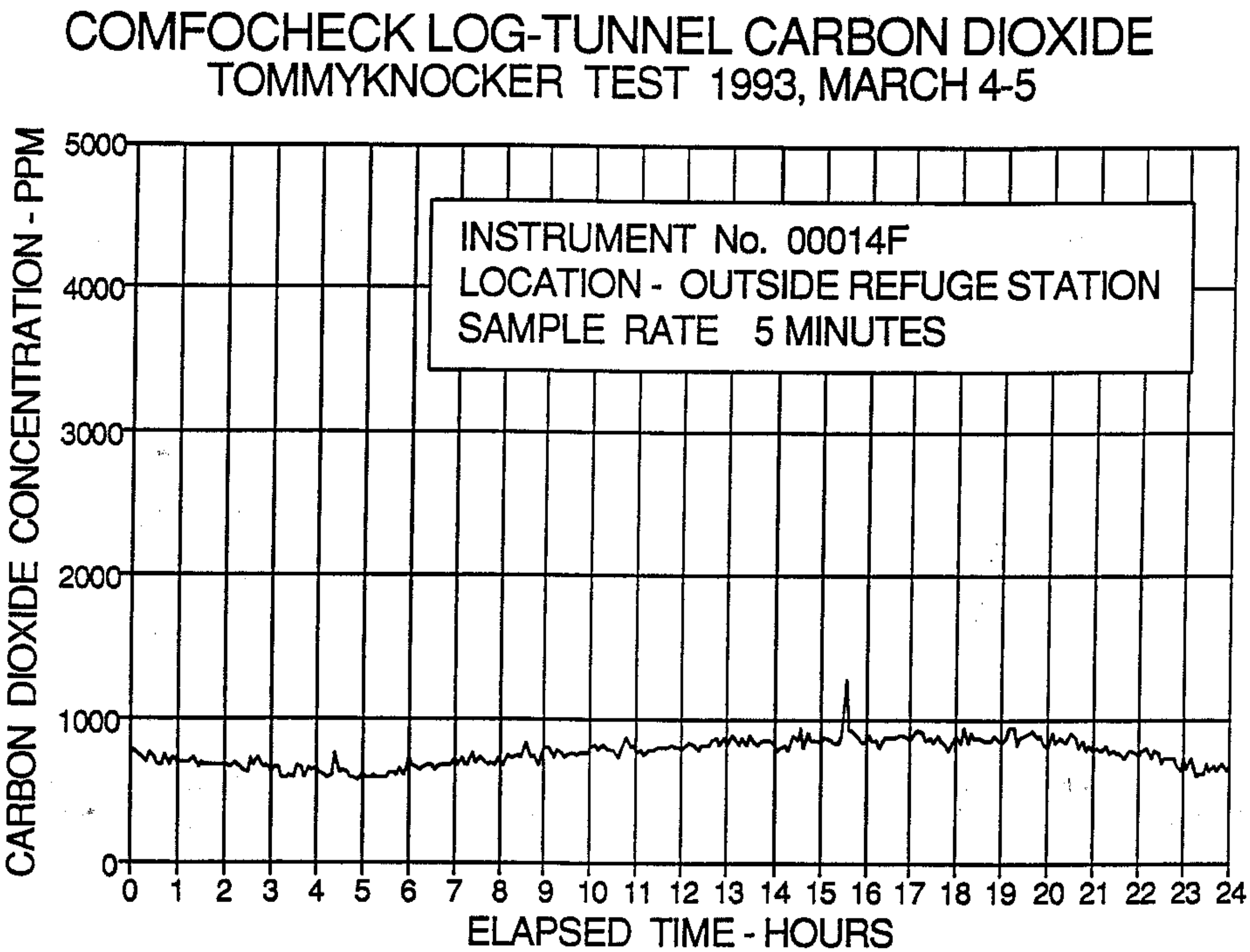

COMFOCHECK LOG-TUNNEL CARBON DIOXIDE
TOMMYKNOCKER TEST 1993, MARCH 4-5
INSTRUMENT No. 00014F
LOCATION - OUTSIDE REFUGE STATION
SAMPLE RATE 5 MINUTES
CARBON DIOXIDE CONCENTRATION - PPM
5000
4000
3000
2000
1000
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
ELAPSED TIME - HOURS

Figure 5

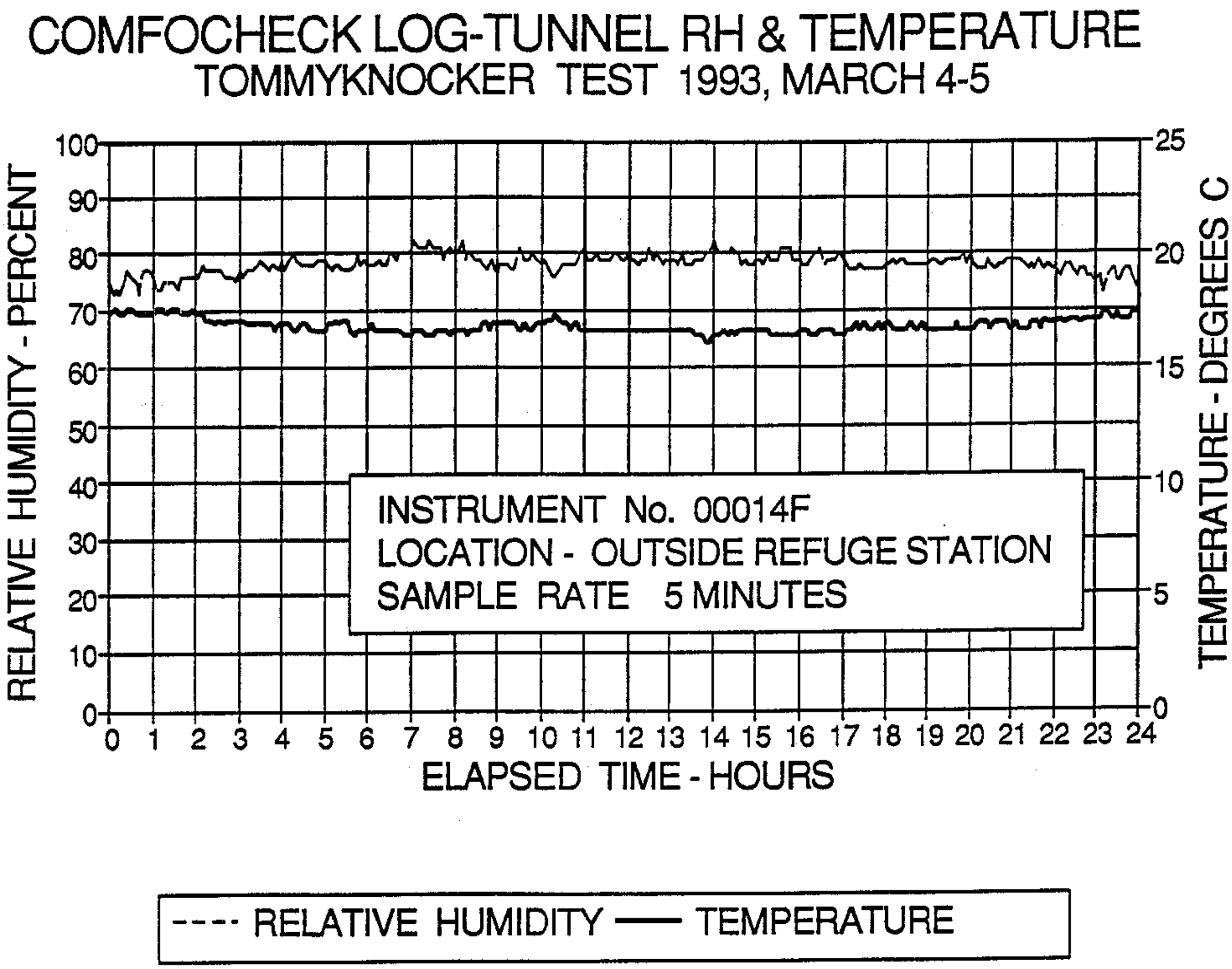

COMFOCHECK LOG-TUNNEL RH & TEMPERATURE
TOMMYKNOCKER TEST 1993, MARCH 4-5
RELATIVE HUMIDITY - PERCENT
TEMPERATURE - DEGREES C
100
90
80
70
60
50
40
30
20
10
0
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
ELAPSED TIME - HOURS
INSTRUMENT No. 00014F
LOCATION - OUTSIDE REFUGE STATION
SAMPLE RATE 5 MINUTES
---- RELATIVE HUMIDITY —— TEMPERATURE

Figure 6

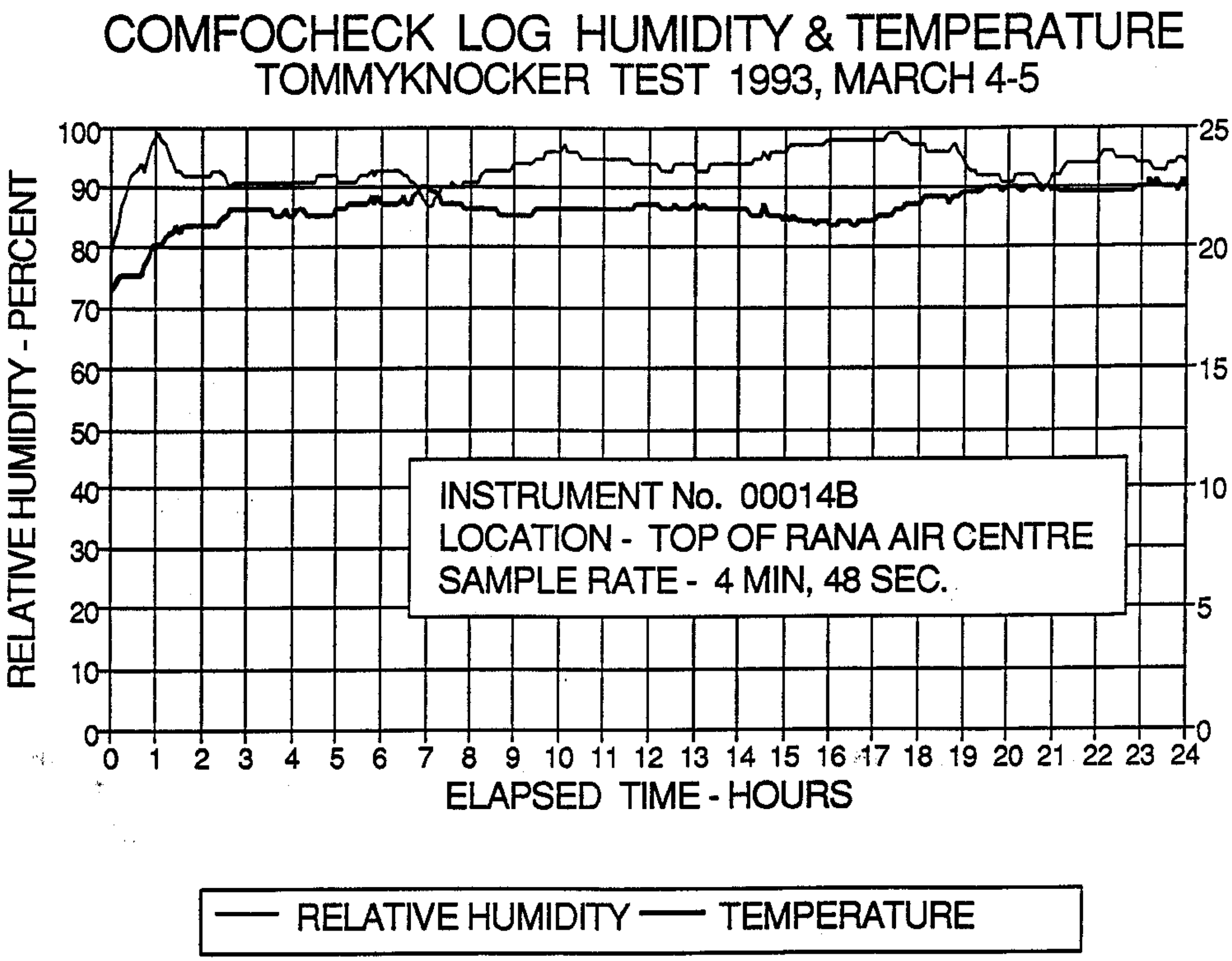

COMFOCHECK LOG HUMIDITY & TEMPERATURE
TOMMYKNOCKER TEST 1993, MARCH 4-5
RELATIVE HUMIDITY - PERCENT
100
90
80
70
60
50
40
30
20
10
0
TEMPERATURE - DEGREES C
25
20
15
10
5
0
INSTRUMENT No. 00014B
LOCATION - TOP OF RANA AIR CENTRE
SAMPLE RATE - 4 MIN, 48 SEC.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
ELAPSED TIME - HOURS
RELATIVE HUMIDITY
TEMPERATURE

Figure 7

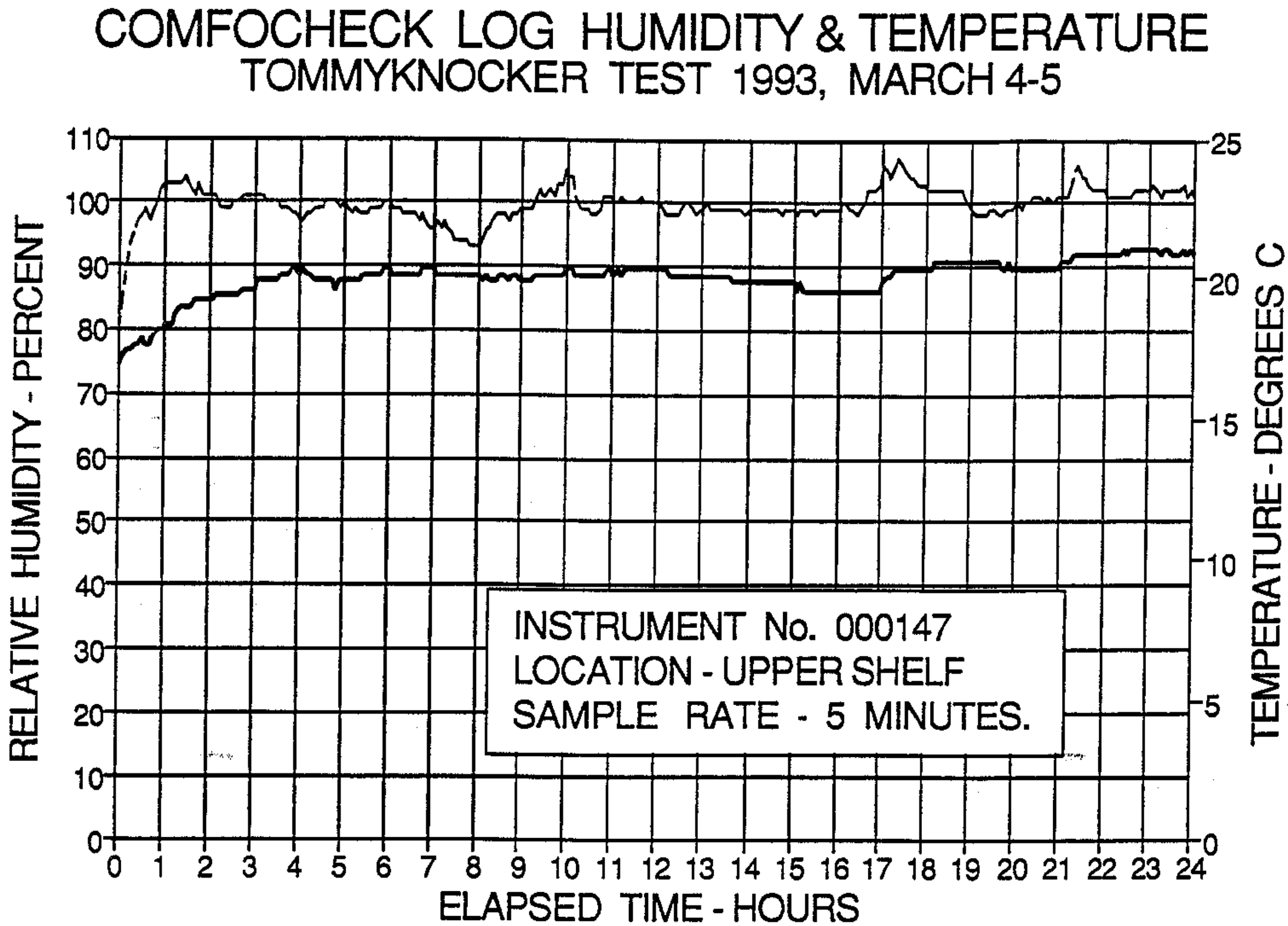

COMFOCHECK LOG HUMIDITY & TEMPERATURE
TOMMYKNOCKER TEST 1993, MARCH 4-5
RELATIVE HUMIDITY - PERCENT
TEMPERATURE - DEGREES C
0
10
20
30
40
50
60
70
80
90
100
110
0
5
10
15
20
25
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
ELAPSED TIME - HOURS
INSTRUMENT No. 000147
LOCATION - UPPER SHELF
SAMPLE RATE - 5 MINUTES.

Figure 8

off and placed on the benches became damp and felt very clammy when put back on. The sandwiches became "soggy" if not kept within closed containers. The back of the station became moist, but not enough water was present for droplets to form and fall.

The sling psychrometer used by the volunteers inside the refuge station produced totally variable readings because the humidity was so high. The sling psychrometer used outside the refuge station was quite reliable in the 70-80% RH range.

4.4 Temperature

The outside temperature is shown in Figure 6. It varied between 16.5 and 18.5°C. Temperatures were lower during the evening and night hours because of decrease in surface air temperature.

Temperatures measured by the two Comfocheck units located inside the simulated refuge station are shown in Figures 7 and 8. The temperatures recorded by both units are essentially identical, with no unusual features. Figure 9 shows that the temperature inside the room climbed from about 16°C at the beginning of the test to about 20°C after about 3 h, while the outside temperature remained fairly steady around 15°C.

Figure 10 shows the temperatures measured by the thermistors located at the back, wall and floor inside the simulated refuge station. The temperatures measured by the thermistors located above the floor level were similar to those determined by the two Comfocheck units. The temperature at the floor level was 2°C lower throughout the test.

Thermistors were placed on the air inlet and outlet of the RANA-AIR system. The data collected are shown in Figure 11. As would be expected, once the carbon dioxide absorber had stabilized, the air coming out of the system was at a somewhat higher temperature then the ambient air because of the chemical action of the carbon-dioxide-adsorbing material. The outlet air temperature stabilized at about 24°C, whereas the inlet air temperature was similar to that measured by the other thermistors inside the station, 20°C. The outlet temperature tracks the inlet temperature. This indicates that the carbon dioxide absorber did not have a significant effect on the temperature in the refuge station.

Figure 9 shows a plot of the air temperatures measured by the thermistors inside and outside the room. The thermistor located outside the room indicated a temperature of 15°C. This is about 1-2°C lower then the temperature indicated by the Comfocheck unit located outside the station (Figure 6). This difference is most likely attributable to the different measurement positions. The thermistor was located underneath a table, exposed to the cool floor, while the Comfockeck instrument was located on top of an adjoining table and was better exposed to the circulating air.

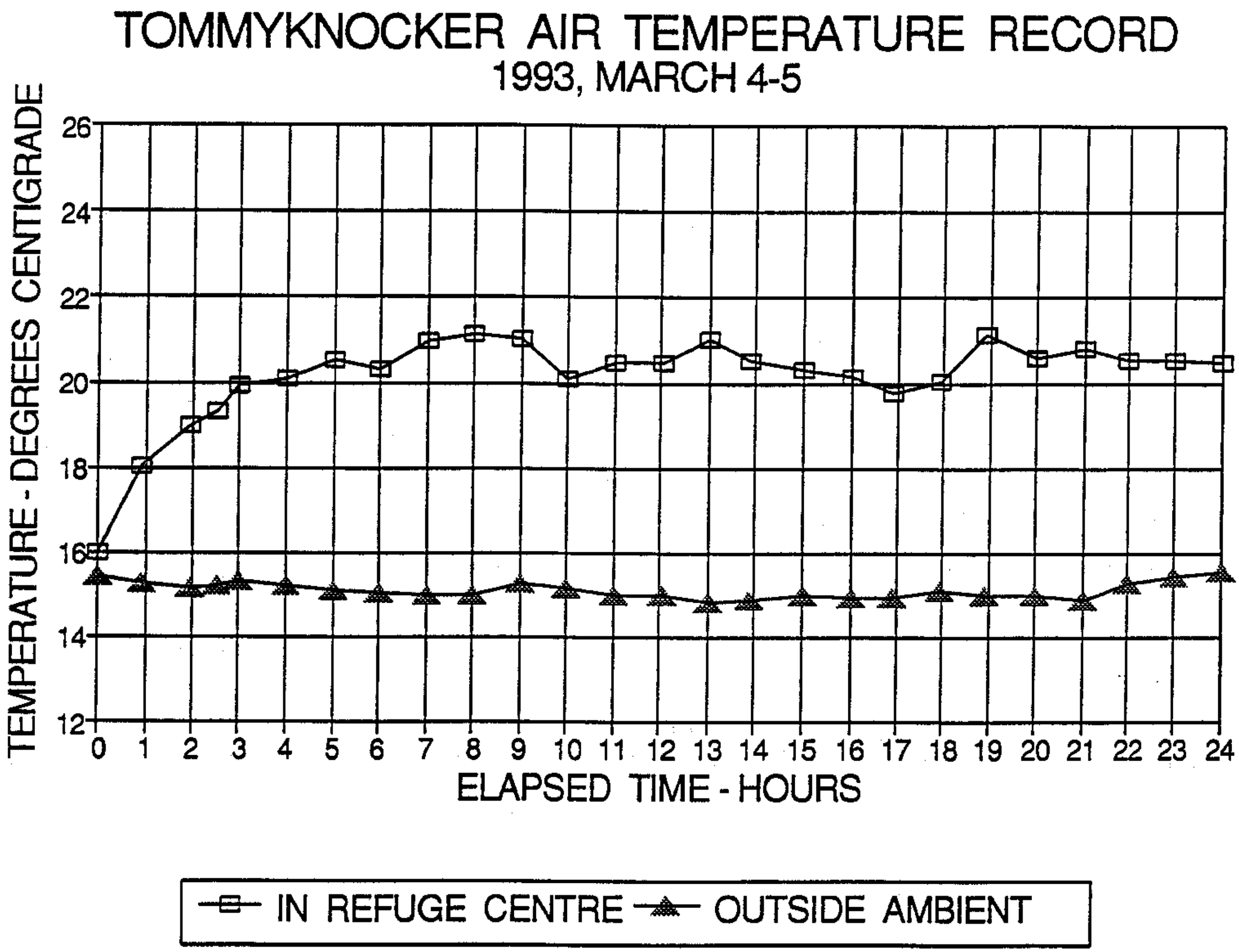

TOMMYKNOCKER AIR TEMPERATURE RECORD
1993, MARCH 4-5
TEMPERATURE - DEGREES CENTIGRADE
26
24
22
20
18
16
14
12
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
ELAPSED TIME - HOURS
IN REFUGE CENTRE
OUTSIDE AMBIENT

Figure 9

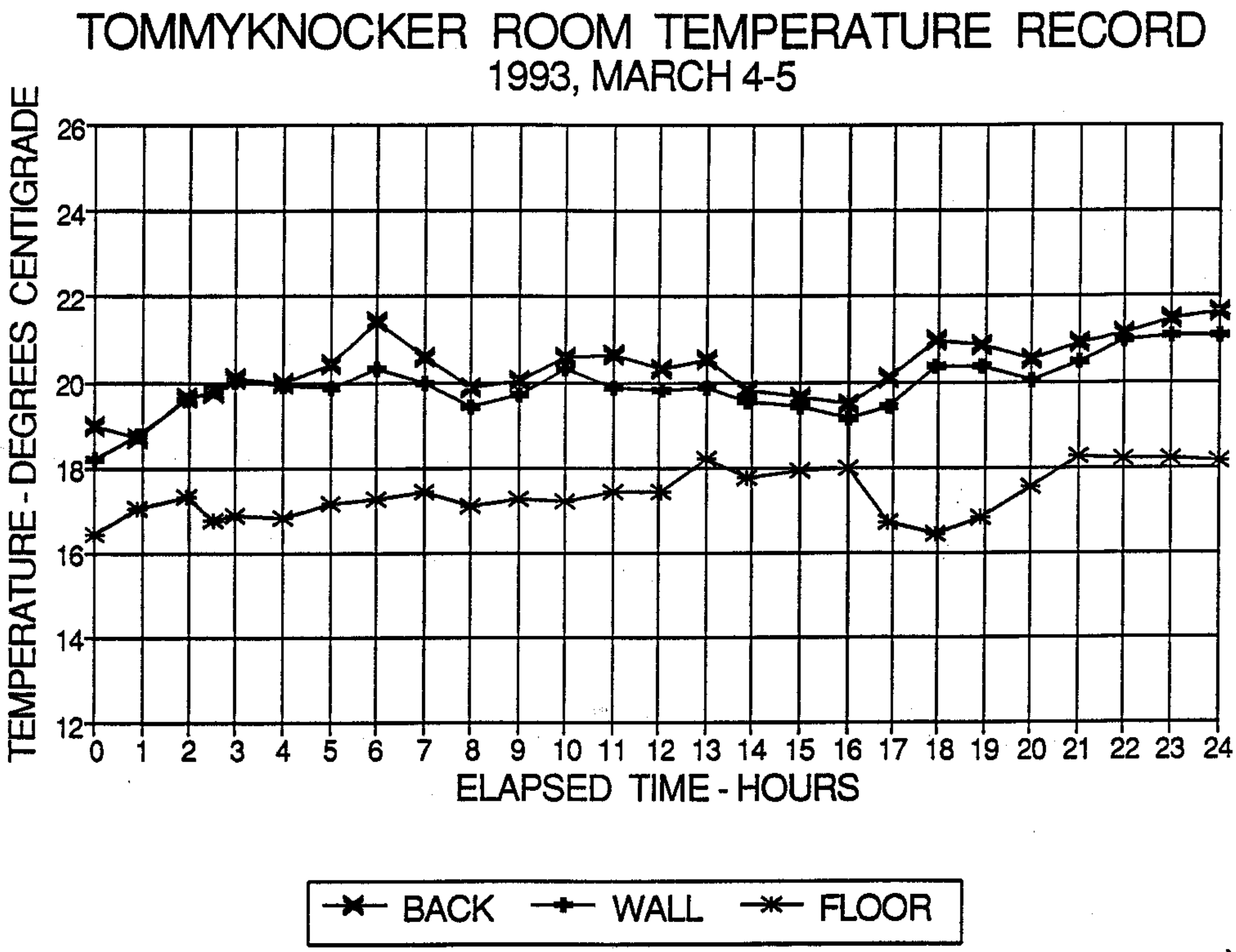
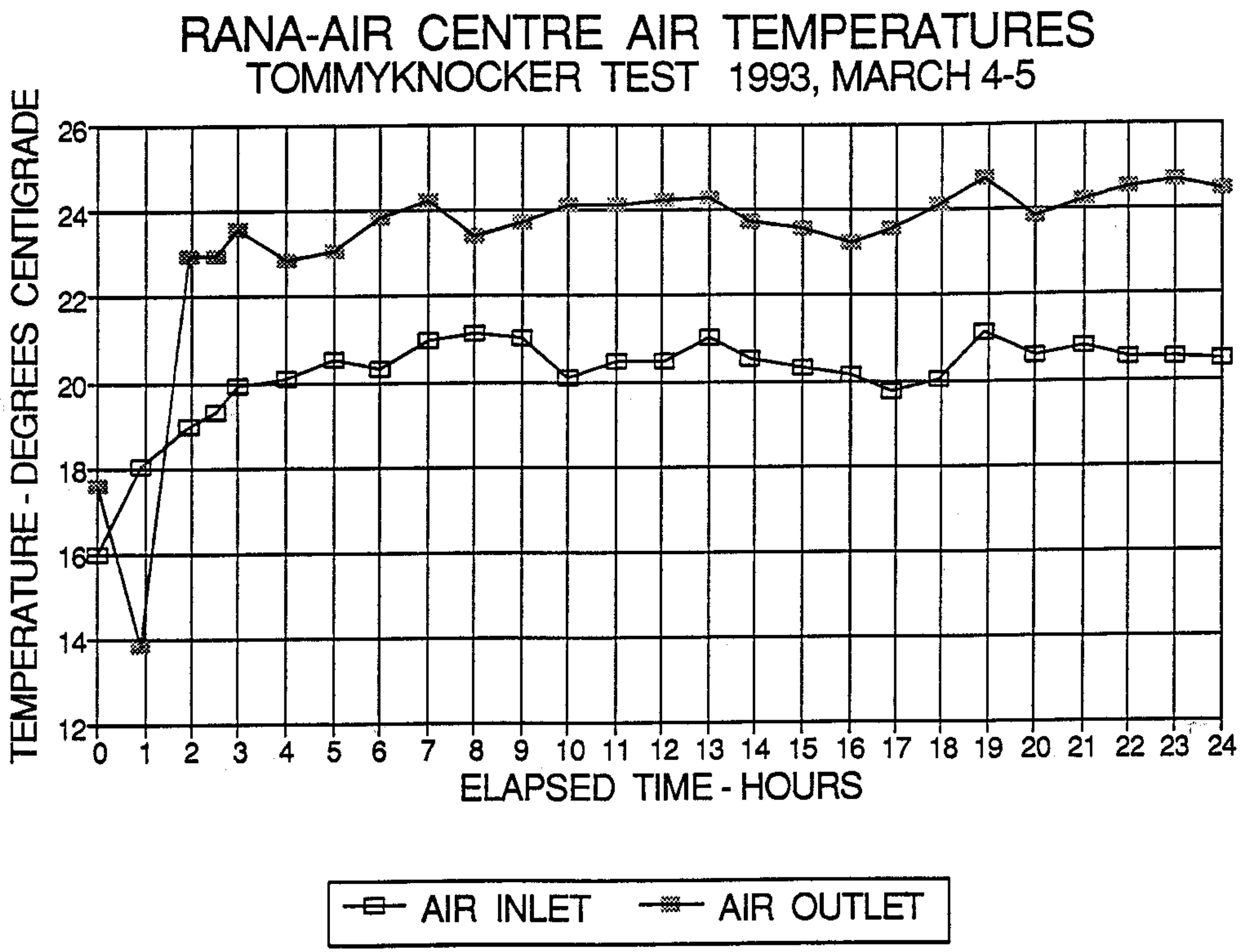

TOMMYKNOCKER ROOM TEMPERATURE RECORD
1993, MARCH 4-5
TEMPERATURE - DEGREES CENTIGRADE
26
24
22
20
18
16
14
12
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
ELAPSED TIME - HOURS
BACK
WALL
FLOOR

Figure 10



RANA-AIR CENTRE AIR TEMPERATURES
TOMMYKNOCKER TEST 1993, MARCH 4-5
TEMPERATURE - DEGREES CENTIGRADE
26
24
22
20
18
16
14
12
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
ELAPSED TIME - HOURS
AIR INLET
AIR OUTLET

Figure 11

4.5 Barometric Pressure

There was no significant change in the barometric pressure measured with a mercury barometer on the 240-m level during the test. The pressures recorded were in the 758 mm Hg range, +/- 4 mm. The manometer installed through the window of the station showed no relative difference in pressure inside and outside of the room, except for a brief period at the end of the test. During the last few minutes of the test, the volunteer participants were asked to increase the oxygen flow to produce a slight pressure increase. The manometer registered an increase of 24.6 mm of water inside the room, which took 36 s to equalize. This suggests that the simulated refuge station was effectively sealed during the test.

4.6 Performance of the RANA-AIR System

The volunteer participants recorded their opinions on performance and ease of use of the RANA-AIR system. These comments are presented in Appendix B, Participant Comments and Evaluation. Briefly, they thought the system was simple and easy to use. The measurements of carbon dioxide and oxygen levels indicate that the system maintained safe levels successfully.

4.7 Medical Surveillance

During the morning of March 04, Dr. R. Hawkins, Medical Director, AECL Research, examined eight volunteers and declared six men to be fit for 24-h confinement in the simulated refuge station.

At 1300 on March 05 the men were re-examined by Dr. T. D. Redekop, Chief Occupational Medical Officer, Manitoba Ministry of Labour, after completion the Operation Tommyknocker. All six men were asymptomatic and had no complaints about their reaction to the 24-h confinement, except that they had all experienced mild headaches early on before the oxygen-generating equipment was functioning and the carbon dioxide level in the room exceeded 5000 ppm for a brief duration. Their headaches subsided relatively quickly as the carbon dioxide level dropped to an acceptable level.

The men monitored their own blood pressure during this time period. The results did not indicate any level of concern.

Either Dr. Redekop or Dr. Hawkins was present to monitor the participants from outside the simulated refuge station during the 24-h test period.

The oxygen level in the refuge station was maintained at around 20.5% while the carbon dioxide level fluctuated around 2000 ppm. This level of carbon dioxide, well above the ambient air level, was quite acceptable for such circumstances, and in general one would not expect people to have any symptoms. The temperature in the room remained stable at about 20°C. The relative humidity rose to nearly 100%, which was not surprising considering six adults were confined in a small space. The volunteer participants did not complain about this to any extent. They did notice that they felt slightly chilly at night time when they were trying to sleep, even though the temperature remained at about 20°C.

A letter from Dr. T. D. Redekop, dated 1993 March 9, provided a medical opinion on the status of the volunteers participants and the levels of carbon dioxide and oxygen maintained during the test. To summarize, the gas concentrations were kept well within safe limits and the volunteers were healthy and unaffected by the test.

4.8 Feedback from the Participants

The volunteer participants generally felt comfortable during the test. There were no offensive odours from the RANA-AIR system or other conditions that threatened the disruption of the test. The participants were able to sleep during most of the late night hours. Appendix B contains a letter from R. Sullivan, volunteer participant from Hudson Bay Mining and Smelting, which is a summary of his views.

The volunteer participants indicated that the location of the toilet within the door lock area was in fact very important. It likely would not have been possible to continue the test if this provision had not been made. This fact is very relevant to the design of actual underground refuge stations. Provisions should be made for toilet facilities separated from the rest of the space.

4.9 Debriefing Notes

A debriefing was carried out after the test. The following points were noted during the debriefing.

1. It was suggested that the RANA-AIR system could be made smaller.

2. A Plexiglas cover could be placed over the gauges for better mechanical protection.

3. The battery charge alarm light came on shortly after the start of the test. The volunteer participants were somewhat confused by this until they read the manual. Some instruction concerning the light could be written on the panel.

4. The oxygen levels were less then normal, 20.9%. The volunteer participants said they had no great urge to increase the oxygen level delivery rate on the basis of this. There was a strong tendency to go along with the way they felt. Once their headaches went away after the RANA-AIR system was started, they felt happy to leave the oxygen settings alone.

5. There were some problems with the oxygen gas detection tubes. They were not working towards the end of the test. Oxygen readings over 26% were being obtained, which did not agree with the Kanomax unit within the station.

6. The Kanomax oxygen analyzer worked well during the test, however, the batteries went dead about 1930, and the unit was useless after this time. It was believed that this length of battery operation is typical for this type of self-contained unit.

7. It was suggested that the classical symptoms of carbon dioxide poisoning and oxygen deficiency be included in the manual. In the event of failure of gas detection tubes or gas analyzers, one could use these symptoms as a means of monitoring the carbon dioxide and possibly the oxygen levels within a refuge station.

8. A hand-operated blower could be considered as a standby unit for the electric fan.

9. The colour change of the carbon dioxide level was apparent after 18 h of operation. The colour change is intended to be a pre-warning only. It is reliable but not accurate. It was intended that the absorbing material would be changed on the basis of carbon dioxide levels determined by the gas detection tubes.

10. The noise made by the RANA-AIR system did not bother the volunteer participants.

11. The level of carbon dioxide in the simulated refuge station varied with the level of activity of the volunteer participants. The levels were lowest when the activity was low.

12. There were no unusual odours noticed. The unit blew cool air all the time.

13. The humidity was acceptable. It tended to get somewhat cool in the simulated refuge station. Water constantly dripped off the walls, but not the back of the unit.

14. The toilet would have been unbearable if kept in the same room. The toilet had an ammonia smell at the beginning, and a refuse smell later on.

15. The difference in temperature of up to 6°C between to top and bottom of the simulated refuge station was noticeable.

16. The participants felt that the design of the RANA-AIR system was simple enough and easy to use. The unit should be reliable and easy to repair.

17. It was generally felt that the Manitoba code for refuge stations could incorporate some of the information gathered by the test. Such things as considerations for separated toilet facilities and air locks could be considered.

18. It would be most beneficial if the RANA-AIR system incorporated a means of removing noxious gases and smoke from an underground refuge station as well. The station may be contaminated with gases such as carbon dioxide, nitrous oxides and smoke that may be present as a result of a fire.

19. A flame safety lamp could possibly be used to test for oxygen levels. This may not be a good idea when oxygen under pressure is used.

5. CONCLUSIONS

Operation Tommyknocker demonstrated that the RANA-AIR system was "simple and easy" to use. The volunteer participants operated the system for a full 24-h period with a minimum amount of instruction. The operating manual was acceptable and sufficient to operate the equipment.

It was clearly demonstrated that the RANA-AIR system maintained oxygen and carbon dioxide levels to safe values within the sealed, simulated refuge station for the duration of the test. Activity and delay in turning on the RANA-AIR system produced a high carbon dioxide level of 8000 ppm. Consequently, the carbon dioxide levels rose to levels above 0.5% for a short period. The volunteer participants experienced typical minor headaches as a result of this. This indicates that immediate control of the carbon dioxide levels is very important in underground refuge stations once they become isolated.

The monitoring system, which consisted of gas detection tubes for determining the levels of oxygen and carbon dioxide, was tested. The equipment was appropriate given the experience and anxiety level of those required to use it. The gas detection tubes for determining the carbon dioxide levels were effective. However, the gas detection tubes for measuring oxygen were unreliable, giving erroneous readings. Another method should be used to determine the oxygen levels if monitoring is required.

6. RECOMMENDATIONS

1. The RANA-AIR system should be developed for use in underground refuge stations.

2. A method other than gas detection tubes should be used to determine the levels of oxygen for monitoring the atmospheric conditions within the refuge station.

3. A system to remove noxious gases that may be present as a result of a fire underground should be incorporated within the design of the RANA-AIR system.

ACKNOWLEDGMENT

The authors wish to thank the Manitoba Department of Labour, the Mine Accident Prevention Association of Manitoba, AECL Research, INCO Thompson, Hudson Bay Mining and Smelting, Tantalum Mining Corporation of Canada, Croda Canada Ltd., Molecular Products Ltd., and the volunteer participants who kindly dedicated their time and effort to ensure Operation Tommyknocker was planned and carried out to achieve the objectives and goals. Through the efforts of these organizations, companies and individuals, we believe the RANA-AIR Mine Refuge Air Centre, being developed by Rimer Alco North America Limited to improve safety in underground mining and civil operations, is a great step closer to being a marketable commodity.

REFERENCES

1. Labour Canada Occupational Safety and Health Code.

2. Threshold Limit Values for Chemical Substances and Physical Agents, 1992-1993. American Conference of Governmental Industrial Hygienists, Cincinnati, OH.

3. U.C.Luft, Aerospace Environments, Chapter 10 of Environmental Physiology, N.B. Slonim, Editor, C.V. Mosby Co., 1974.

APPENDIX A

List of Participants

OPERATION TOMMYKNOCKER

List of Participants

Organizers

Greg Kuzyk	Engineer, AECL Research, Underground Research Laboratory
Earl Gardiner	President, Rimer Alco North America
Barrie Simoneau	Safety Coordinator, Mines Accident Prevention Association of Manitoba
Ray Lambert	AECL Research, Radiation and Industrial Safety
Ron Glassford	Director, Mines Inspection, Workplace Environment, Safety and Health, Manitoba Department of Labour
Bill Schubert	Mine Rescue Instructor, Workplace Environment, Safety and Health, Manitoba Department of Labour
Dr. Ray Hawkins	AECL Research, Medical Services Branch
Dr. Ted Redekop	Chief Occupational Medical Officer, Workplace Safety, Health and Support Services Division, Manitoba Department of Labour

Test Participants

Vern Steiner	AECL Research, Underground Research Laboratory
Ed Chuckrey	INCO Thompson
Ron Sullivan	Hudson Bay Mining and Smelting
Tim Haverlock	Tanco
Don Daymond	AECL Research, Underground Research Laboratory
Jamie Law	Tanco
Dennis Wilson	Hudson Bay Mining and Smelting
Wayne Mattson	INCO Thompson

Supporting Staff

Barney Kovacs	Manitoba Mining Association
Monte Raber	Rimer Alco North America
Gary Wallace	AECL Research
Paul Barnsdale	AECL Research
Don Hladki	AECL Research
Andy Gerwing	AECL Research
Jane Sargent	AECL Research
André Salloum	AECL Research
Larry Shewchuk	AECL Research
Rich Corman	AECL Research
Mitch Ohta	AECL Research, Underground Research Laboratory
Harry Backer	AECL Research, Underground Research Laboratory
Dwayne Onagi	AECL Research, Underground Research Laboratory
Glen Karklin	AECL Research, Underground Research Laboratory
Walter Schmidt	AECL Research, Underground Research Laboratory
Glen Snider	AECL Research
Richard Simcoe	J.S. Redpath Limited
Rolly Simard	Tanco
Ron Casson	Manitoba Department of Labour

Visitors

Darren Praznik	Minister of Labour and MLA Lac du Bonnet
Ben Sveinsen	MLA La Verendrye
Dave Marion	Reeve, RM of Lac du Bonnet
Robert Vachon	RCMP, Lac du Bonnet
Gille Lafreniere	RCMP, Lac du Bonnet
Nick Ostash	Bond Gold

APPENDIX B

Technical Information

Participant Comments and Evaluation

Letter from Dr. T.D. Redekop

Letter from R. Sullivan

RIMER ALCO NORTH AMERICA

MINE REFUGE AIR CENTRE TESTS

"PARTICIPANT COMMENTS AND EVALUATION"

Determine how "simple and easy" it is to use.

- Fairly straight forward.
- Very simple and easy. Directions on the system are very self–explanatory. It may be difficult for some non–mine rescue people to understand.
- Very simple and easy. RANA–AIR could be used by anyone without any prior knowledge of the system.
- Very simple. Instructions on the unit itself are clear and concise. I would venture to say, even an engineer could operate this equipment. (Maybe this is a rash statement.)
- The machine was easy to fill and simple to start according to the directions.
- Easy to start and easy to refill. Door should be removed, or replaced with a screen.

Prove it's ability to maintain Oxygen and Carbon Dioxide levels as close to atmospheric as possible.

- So far it has done a very good job.
- It has done its job, 20 minutes after it was turned on our headaches were gone.
- Our records will show unit works perfectly without any adjustments.
- CO_2 levels were increasing as we started the test. (There was a lot of pre–test action in the refuge station and a number of people in the room.) Within half an hour, the O_2 and CO_2 levels were within acceptable values.
- According to our records, the machine works very good. We had no problems with the levels once it was started.
- CO_2 levels were up. After starting up RANA–AIR, CO_2 dropped down.

Determine if the monitoring equipment provided with the system (to measure concentrations of O_2 and CO_2) are effective and appropriate, given the experience, training and anxiety of those required to operate it.

- Definite problems with O_2 tubes. Need to make sure expiry dates are current. Expiry 1992 tubes for CO_2 were not very good. 1992 CO_2 were N=1 while 1995 tubes were N=1+5. Need barometric pressure gauge and chart of O_2 barometric readings for quick and easy O_2 conversions.

- Bulb works well.

- We are familiar with Draeger tubes, but non–mine rescue people should have better instructions. Equipment supplied with the RANA–AIR would not be complete without a barometer. This should be built into the machine so the value can be seen.

- CO_2 tubes work effectively. O_2 tubes can only be sued once when the humidity gets high. Without a barometric pressure, the O_2 value cannot be calculated. A barometer on the RANA–AIR system would be a definite requirement. A graph of barometric pressure versus tube readings would eliminate calculations.

- The equipment supplied was sufficient and easy to use, but non–mine rescue personnel might need better instructions.

- Problems with O_2 tubes (3 tests to tube at beginning). Towards the end of the test, O_2 tubes were not reading accurately. Some readings as high as 23%

Size, Colour and Shape of System:

- Size seems bulky; appears to be a lot of wasted inside space. Possibility of having external O_2 bottles?

- Size seems a bit large, lots of wasted space where O_2 bottles are. By reducing size, the unit would be more portable.

- Bottom storage compartment door should be made to be removed. In our situation, it takes up floor space being open. We removed door. O_2 cylinders should be easier to put into the unit. Cylinders should go in from the side, not top.

- Colour OK. Shape OK. Size could be reduced by half if the O_2 bottles were external. Could then be cascaded with more O_2. A screen in the front door would negate having to open the front door.

- Size & Shape: The unit could be smaller. Colour: This has no bearing other than making instruction stand out more.

- Size could be reduced by half. Colour OK. Shape of system OK.

Noise Level:

- Not too bad, at least for me. Others find it irritating now especially after sleeping. Possibility of putting some type of muffler on to reduce the noise level some.

- The noise level is tolerable, even when sleeping.

- Low. Tolerate very easy.

- Tolerable. Can be aggravating in a small area when right next to system.

- There is no problem with the noise. If anything, it helps me sleep.

- OK if in a bigger Refuge Station.

Labelling and Manuals:

- Labelling is clear and easy to read. Should have "No Smoking" sign. O_2 instructions should be in RED.

- Small point: "Replace soda lime when colour change (purple) rises to arrows." There are no arrows. You should say "dashed line".

- O_2 warning should be in red. Manual is self explanatory. "No Smoking" signs should be on the system. Because of possible illiteracy on the part of someone who would use this system, a set of pictorial instructions in the manual might be useful.

- The labelling could stand out more. Example: Black letters on white. Manual should be simpler for non mine rescue users.

- O_2 warning should be in red.

Actual potential of Mining Companies to install these units in underground refuges:

- Good, especially if units could be made portable so that they could be used in temporary refuge locations (transported easily).

- I would say the potential for underground use is quite good, taking into consideration cost, portability and durability.

- My vote "YES".

- This system would be very adaptable in a permanent refuge station or portable refuge station if the size were reduced.

- I think personally, the system would work excellent in a refuge. Other than the size, it would be perfect for a mine refuge.

- Yes, this system would be good to have in a refuge station.

Other:

- – Should come with monitoring equipment (O_2, CO, RH).
  – Storage door should be of screen.
  – Should also have a side door for removing O_2 bottles, or make the unit smaller by having the bottles stand outside.
  – O_2 & Litre Flow Indicator should be protected by some sort of see–through cover.

- – Test start – Unit is producing cool air from exhaust.
  – Test middle – above.
  – Gloves could possibly be supplied in unit.

- – Difficult to see colour change in soda lime. 6 a.m. – 0.5 cm first time really visible.
  – Gauges should be protected.

Manitoba

Labour

Workplace Safety, Health
and Support Services Division

1000 — 330 St. Mary Avenue
Winnipeg, Manitoba, CANADA
R3C 3Z5

(204) 945-3446

March 9, 1993

Mr. Barrie D. Simoneau CRSP
Mines Accident Prevention
Association of Manitoba
700-305 Broadway Avenue
Winnipeg, Manitoba
R3C 3J7

Dear Mr. Simoneau:

RE: OPERATION TOMMYKNOCK MEDICAL REPORT

Number of Men Examined = 8

Number of Men Declared Fit for the 24 hour confinement in the mine refuge station = 6

Examiner Dr. R. Hawkins, AECL Medical Director (2 people were rejected for medical reasons - these 2 individuals supplied monitoring activity throughout this demonstration project).

Average age of participants was 37 years old; male - age ranged from 29 to 44.

All men were examined for fitness prior to entering the room. They were re-examined by me at 1:00 p.m. on March 5, 1993. All were asymptomatic and had no complaints about their reaction to the 24 hour confinement, except that they had all experienced mild headaches early on before the oxygenator was functioning and when the carbon dioxide level in the room reached at least 5000 ppm. Their headaches subsided relatively quickly as the carbon dioxide level dropped to an acceptable level.

The men monitored their own blood pressure during this time period, the results did not indicate any level of concern.

The oxygen level in the refuge station was maintained at around 20.5% while the carbon dioxide level fluctuated around 2000 ppm level. This level of carbon dioxide, well above the ambient air level, is quite acceptable for such circumstances and in general one would not expect people to have any symptoms. The temperature in the room remained stable at around 20°C. The relative humidity rose to near 100 % which is not surprising considering 6 adults in a small confined space but the participants did not complain about this to any extent. They did notice that they felt slightly chilly at night time when they were trying to sleep even though the temperature remained at about 20°C.

....2

MAR 15 1993

SUMMARY:

The six participants did not experience any adverse health effects except at start up when the carbon dioxide level rose to about 5000 ppm and prior to the oxygenator function.

Sincerely,

Dr. T. D. Redekop
Chief Occupational Medical Officer

PS: I think this was a very well run demonstration with optimum cooperation from the many participants. You are to be congratulated on organizing this so professionally.

Dr. Hawkins should be commended for steering the project through the ethics committee hurdle. This created some last minute "angst" but it did not impact on the timing nor the smooth running of this project.

cc: Dr. R. Hawkins, AECL
Ron Glassford

TDR/AR

COMON-Z:TOMMYKNOCKER

Hudson Bay Mining & Smelting Co., Ltd.
Ruttan Operations

OPERATION TOMMYKNOCKER

Submitted by Ron Sullivan

Six men entered the Refuge Station at 1:00 pm, March 04, 1993.

After being in the station for approximately one half hour, the CO_2 went up to over 5000 ppm. All individuals started to get a headache.

At this time we started up the Rana-air unit, filling it with approximately 60 lbs. of soda lime. We then turned on the two oxygen bottles and set the oxygen flow to three litres per hour.

After the Rana-air unit was started, the CO_2 went back to normal.

All individuals in the station helped with the testing. We had to test for O_2, CO_2, temperature and "R" humidity. We also had our vital signs taken every hour for the first eight to ten hours, and during the last two hours we were in the Refuge Station.

The oxygen stayed at approximately 20.5% and the temperature was constant at 20.5° to 22.9° at the end of the twenty-four hour period. The "R" humidity levels were 80° to 90°, towards the end of the twenty-four hour period, it went up to over 100°.

There were photographs and videos taken during our confinement in the Refuge Station.

In conclusion, the Rana-air unit will provide the oxygen needed for breathing, and will remove the carbon dioxide produced by the miners during a period of entrapment.

Ron Sullivan
Advanced Mine Rescue
Ruttan Mine
March 16, 1993
/cs

Operation Tommyknocker, Phase II - Evaluation of the Rimer Alco, RANA-AIR Mine Refuge System at Falconbridge Ltd., Kidd Creek Division.

Michel Grenier*, John Vergunst+, Malcolm Smith**, Kevin Butler++, Stephen Hardcastle* and Barrie Simoneau"

Division Report MRL 94-051 (TR) OCTOBER 1994

*** Research Scientist, Natural Resources Canada, CANMET, Mining Research Laboratories, Sudbury, Ontario, P3E 5P5, Tel : (705) 677-7815**

+ Provincial Mining Specialist - Environment, Ontario Ministry of Labour, Sudbury, Ontario, P3E 6B5

**** Senior Mine Rescue Officer, Ontario Ministry of Labour, Sudbury, Ontario, P3E 6B5**

++ Mining Environment Technologist, Natural Resources Canada, CANMET, Mining Research Laboratories, Sudbury, Ontario, P3E 5P5

" Safety Director, Mines Accident Prevention Association of Manitoba (MAPAM), Winnipeg, Manitoba, R3C 3J7

FALCONBRIDGE LIMITED

Royal Oak Mines Inc.

PLACER DOME INC.

Ontario Ministry of Labour

ONTARIO MINE RESCUE

CANMET

MAPAM

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The Rimer Alco RANA-AIR prototype Mine Refuge System was tested in an underground refuge station to verify its ability to keep oxygen and carbon dioxide levels at normal or close to normal concentrations. In this test, 25 volunteers were assembled in a functional refuge station for a period of 24 hours, without the benefit of standard compressed air being supplied inside the sealed chamber. The prototype system was designed to operate on a self-contained power supply for a period of at least 27 hours. The system supplied oxygen at a metered rate and removed carbon dioxide by re-circulating the refuge station air through soda lime scrubbing units or drawers. Throughout the 24 hour period, carbon dioxide concentrations were maintained at an average of 2500 ppm and oxygen concentration remained in a narrow range between 20.2% and 20.6%. The volunteers inside the refuge station found the prototype easy to use and expressed confidence in its ability to provide a safe atmosphere. The test showed that this technology has the potential of becoming part of a refuge station's emergency equipment.

EXECUTIVE SUMMARY

In underground mines, standard emergency procedures require miners to take refuge in a safe area in the event of a mine fire. In these refuge stations, workers are required to seal themselves in and to turn on a compressed air line to supply air for breathing. There have been instances where the compressed air line has failed. Therefore, alternative means of supplying breathable air are being investigated.

In April of 1994, 25 Ontario Mine Rescue team members volunteered to spend 24 hours in a sealed underground refuge station on the 5200 Level at the Kidd Creek Mine (Falconbridge Ltd.). This project required the direct involvement of several mining companies and agencies, namely, Falconbridge Ltd., Kidd Creek Division, Placer Dome Inc., Dome Mine, 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 test, which had previously undergone a medical ethics review, was conducted under strict medical guidelines. Volunteers were under the supervision of a physician throughout the test period via telephone and video camera contact.

The purpose of this 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. The unit is a stand alone system which supplies oxygen from cylinders and removes CO_2 by passing the refuge station air through chemical CO_2 scrubbing drawers.

One of the objectives of this 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. This included deciding when the CO_2 chemical scrubbing drawers needed to be changed. The CO_2 chemical absorbent contains an indicator which turns blue or purple when the chemical is no longer effective. Oxygen and carbon dioxide concentrations inside the room were monitored remotely by CANMET staff with instrumentation located in the main drift.

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 2500 ppm. The time-weighted average exposure value (allowable limit of exposure) for an eight hour shift is 5000 ppm. In theory, this value of 5000 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 initial concentration of oxygen in the refuge station was 20.6%. Normal atmospheric concentrations of oxygen are usually around 20.9%.

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 includes filling the two scrubbing drawers with chemical took less than 10 minutes.

This study showed that one of two approaches can be used to determine when the CO_2 absorption chemical needs to be changed. First, the participants can decide to change the chemical when the color change indicator shows that half of the scrubbing chemical has been spent. Alternatively, a

theoretical approach can be used which assumes worst case conditions, and where a fixed amount of time is allowed to elapse after which the chemical is changed regardless of the state of the color indicator. Using the first approach, the volunteers would have changed the chemical scrubber ten hours into the study. The second approach would have required the participants to change the chemical every 6 to 7 hours with a significant safety margin. Data collected during the study showed that after 10 hours, both chemical drawers were still operating efficiently.

In summary, the field test conclusively showed that the life support system maintained oxygen and carbon dioxide concentrations well within safe levels. It also met and exceeded the original objectives of the test as well as the participants expectations.

BACKGROUND

Refuge stations became an integral part of the emergency procedures of Ontario mines, after 39 miners died in a mine fire in 1928. Typically, refuge stations are chambers which are excavated out of the rock close to where miners are working. These areas must be provided with drinking water, compressed air and a communication system. Refuge stations must also be separated from other workings by one or more fire walls.

The primary function of these refuge stations is to sustain life in the event of a major underground fire by preventing fire gases from entering and by providing a source of breathable air. The air is usually provided by a compressed air line which is opened from inside the refuge station. The air also serves to pressurize the refuge station, thereby preventing noxious gases from entering.

In the event of a mine fire, the workers enter the nearest refuge station, activate the compressed air line, close and seal the door with fire clay and remain calm and at rest. Periodically, someone is asked to walk around the chamber to mix the air. It is important that the miners rest and remain calm in order to conserve oxygen and to keep the carbon dioxide levels as low as possible as shown in Table 1.

Level of Physical Activity	Breathing Rate (L/min.)	Oxygen Consumed (L/min.)	Carbon Dioxide Production (L/min.)
Exhausting Effort	69	3.2	2.7
Strenuous Work/Sports	46	2.1	1.8
Moderate Exercise	30	1.4	1.2
Mild Exercise	19	0.9	0.7
Standing/Light Work	11	0.5	0.4
Sedentary/At Ease	7.5	0.4	0.3
Reclining/At Rest	6.0	0.3	0.2

Table 1. Average oxygen consumption and carbon dioxide production for humans (1).

Recently, emergencies have occurred in hard rock mines where compressed air lines supplying refuge stations have been damaged or destroyed. In one instance, smoke was transported through a ruptured air line, into a refuge station (Ontario, 1990). Some soft rock mines do not have compressed air underground and as more and more of the mine production is performed without compressed air, the need for self-contained life support systems for refuge stations becomes an important issue.

The Mines Accident Prevention Association of Manitoba (MAPAM) and the Manitoba Department of Labour in cooperation with the Ontario Ministry of Labour (Mine Rescue) decided that an initiative was necessary to determine what other types of protection could be made available in the event of a fire emergency. Through a collaborative effort involving the above parties and Rimer Alco North America, work began to develop a life support system for refuge stations. Rimer Alco is a Canadian Company (Morden, Manitoba) which manufactures on-site hospital oxygen production plants.

In March of 1993, six volunteers entered a simulated refuge station at the 240 m level of the Atomic Energy of Canada Ltd.'s Underground Research Laboratory at Lac Du Bonnet, Manitoba. The $22m^3$ chamber (777 ft^3) was sealed and for the next 24 hours, the participants depended solely on the Rimer Alco North America Inc. RANA-AIR Mine Refuge Station System to maintain safe levels of oxygen and carbon dioxide. This first field trial was appropriately designated as Project Tommyknocker (legendary spirits of trapped coal miners).

This first evaluation demonstrated that under these simulated conditions, the RANA-AIR system successfully maintained oxygen concentrations between 19.5% and 20.9%, while keeping carbon dioxide levels at less than 2300 ppm. The report of investigation for this first phase (2) concluded that the RANA-AIR system was easy to use and could over an extended period of time maintain safe environmental conditions within the room. The report also stated that under actual emergency situations, trapped personnel would need a method other than CO_2 gas detection tubes for deciding whether or not the CO_2 scrubbing material used by the system needed to be changed.

In April of 1994, a second study was undertaken which is described in the present report. The objectives of Tommyknocker II were :

1. to evaluate the RANA-AIR system in a real underground refuge station containing a large number of mine rescue personnel,

2. to test an improved prototype of the system for ease of operation as per the first study recommendations and to verify the system's ability to maintain safe levels of CO_2 and O_2

3. to use external monitoring of gases in the refuge station in order to duplicate realistic conditions where personnel inside have to take the decision as to whether or not to change the CO_2 scrubbing drawers using only the scrubbing material indicator (color change).

4. and, finally, to determine the potential applications of this equipment in underground emergency situations.

In order to achieve these goals, twenty five mine rescue volunteers were selected and were asked to spend 24 hours in an operating Ontario mine refuge station. These volunteers were asked to follow normal fire emergency procedures upon entering the refuge station. This included choosing a leader and proceeding to sealing the outside door with fire clay. In addition a team was selected to prepare and start the RANA-AIR system. Throughout the test, the volunteers took turns at monitoring the life support system to insure proper operation. The volunteers' vital signs were monitored on an on-going basis as well as levels of CO_2 and O_2 in several locations inside the refuge station.

RANA-AIR UNIT DESCRIPTION

The RANA-AIR unit consists of two integrated processes; an oxygen supply and a carbon dioxide scrubbing system. The prototype tested was designed to accommodate 25 miners over a period of at least 24 hours. To supply oxygen, three cylinders were linked to a manifold and their pressure was regulated down to accurately set the required flow of 0.5 L/min. per person. This was achieved with a single stage regulator and a rotameter. Based on available research on human oxygen consumption, the system was designed to supply the 25 volunteers for a period of at least 27 hours.

Carbon dioxide is removed by circulating refuge station air through two separate scrubbing drawers using battery operated fans, each operating at 2260 L/min. (80 cfm). The scrubbing chemical (Sofnolime), is a soda lime manufactured by Molecular Products UK. The principles of CO_2 scrubbing using soda lime involves a series of chemical reactions whereby the gas diffuses into the water layer surrounding the soda lime granules. The scrubbed air is then discharged on opposite sides of the console in order to enhance air circulation in the refuge station (See Figure 1). As the chemical becomes saturated with CO_2, it changes color from white to blue or purple. When the color change reaches a line near the top of an observation window, it is an indication that the chemical in the drawers should be replaced with fresh material.

The dimensions of the prototype system tested were 169 cm in height, 91 cm in depth and 65 cm in width (66 in. x 36 in. x 26 in.) and it weighed approximately 410 kg (900 lbs). Chemical scrubber capacities were 52 L and 41 L, respectively, for the side and front drawer. At 25°C and 80% relative humidity the front drawer should in theory last 6 to 7 hours while the side unit could last as long as 9 hours. Under the actual test conditions of 26°C and 95% relative humidity the drawers should last about 40% longer. To accommodate these conditions, enough chemical was stored in the refuge station to allow up to 5 complete drawer changes.

The long-life battery used to power the system, when fully charged, will provide for a minimum of 36 hours of operation. Built into the system is a charging circuit which automatically maintains full charge. This circuit also includes an alarm which will warn personnel if the power supply capacity falls below what is required to supply 24 hours of service. This is a useful feature in the event that the unit becomes unplugged or if the AC power supply is interrupted. During the test, the unit was unplugged to simulate a power disruption.

The system controls were designed to be simple to insure that untrained people could easily start and operate the system if required to. There are two main operating controls on the system, these are the oxygen flow regulator and the fan On/Off switch. Five basic instructions are clearly listed on the RANA-AIR unit's front panel. These are :

1. Remove CO_2 drawers and fill with soda lime. Re-insert drawers and tighten into place.
2. Slowly open oxygen tank valves in rear compartment.
3. Set O_2 flow control to the recommended setting for the number of people in the room.
4. Turn "ON" CO_2 blowers and open the lower storage compartment hatch.
5. Change soda lime as per directions on CO_2 absorber drawer.

IMPORTANT : refer to manual for detailed operating instructions.

The numbers 1 to 5 on the list above are also found clearly identified on the surface of the system casing near the part of the unit where the task needs to be performed.

Included with the system is an Operator's Manual, which describes the operation of the system as well as details on maintenance and service requirements. Also included with the unit are supplies such as dust masks, garbage bags, ear plugs and pens.

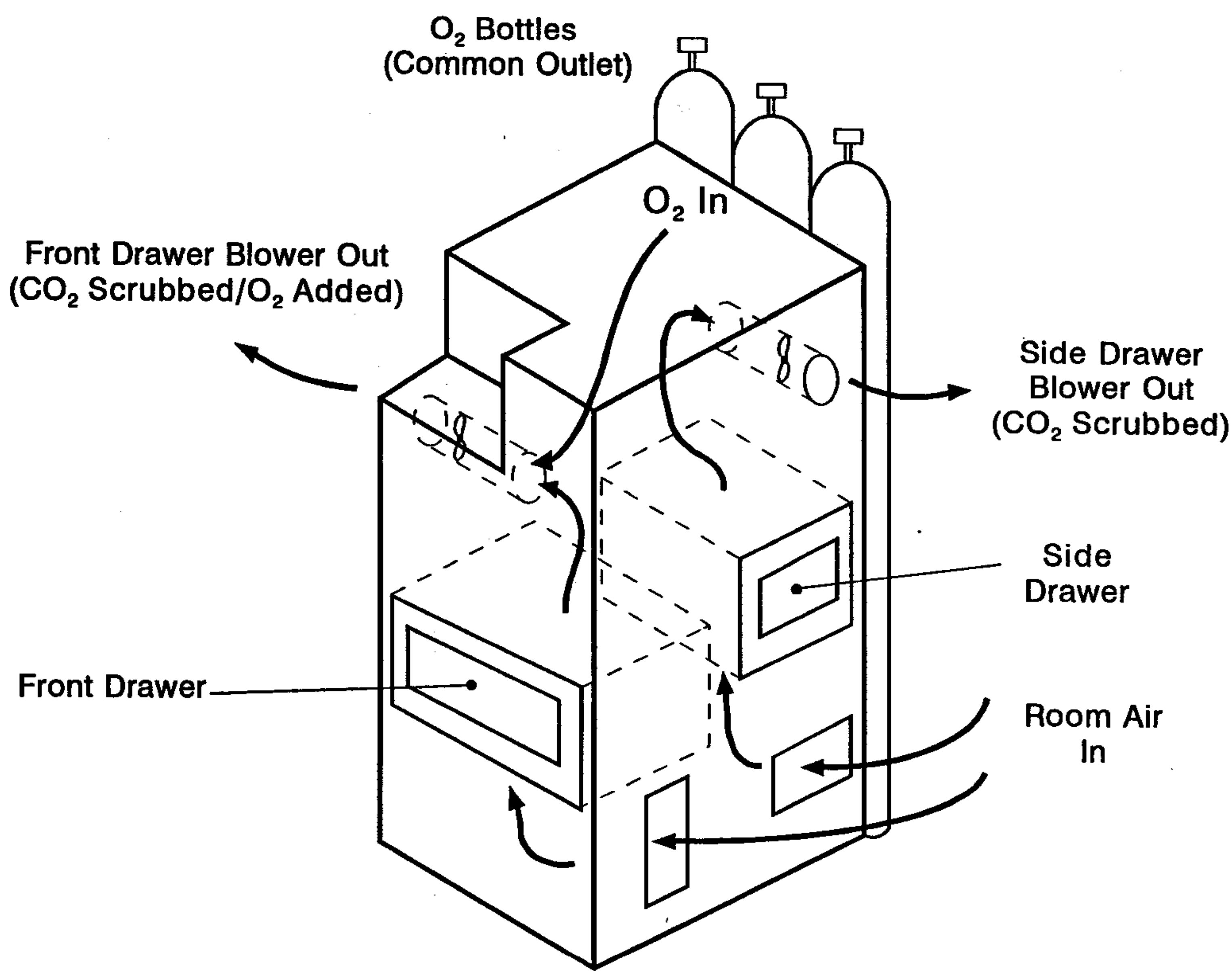


Figure 1. RANA-AIR system.

SITE DESCRIPTION

The mine refuge station chosen for the test was located on the 5200 level of Falconbridge Ltd., Kidd Creek mine. It was typical in size and design and could easily accommodate the 25 volunteers. It was constructed with an airlock and a two door entry system on both bulkheads (see Figure 2). The station dimensions were on average 12.4 m in length, 5.3 m in width and 3.6 m in height (40.7 ft. x 17.4 ft. x 11.8 ft.) for a total approximate volume of 240 m^3 (8475 ft^3). With 25 volunteers this meant an average of 9.6 m^3 (339 ft^3) volume of air per person as compared to 3.7 m^3 (131 ft^3) for the phase I test in Manitoba.

The refuge station was serviced with air and water. The air line was closed off in the main drift for the duration of the test. Both bulkheads were constructed of 25 cm (10 in.) thick poured concrete and these were sealed wherever the walls met the rock. Both walls have openings to allow services into the refuge station. These were covered with steel plates and sealed with foam insulation and fire resistant caulking (see Figure 3).

The airlock area was used to accommodate the chemical toilet. In the main chamber, an area close to the entrance and immediately to the left was used to store food and was also chosen to accommodate the vital signs monitoring area. The RANA-AIR system was installed on the left wall close to the center of the chamber. Five collapsible cots were placed at the end of the refuge station with the rest of the surface left available for tables and walking space.

An area immediately outside the refuge station was selected to accommodate the station for monitoring chamber conditions inside the chamber. The CO_2 and O_2 monitoring and calibration instruments were placed on a table in a well lit area on a level concrete pad. Electrical outlets supplied 120 VAC and a 3000 watt diesel generator was available for back-up electrical power. Flexible plastic tubing was run from internal sampling sites through the chamber bulkheads to the gas analysis instruments.

Telephones were installed inside and outside the refuge station. These allowed the user to call off-site if necessary. Two-way radios were also installed for quick communication between the outside and the inside of the refuge station if necessary. The entire test was recorded on VHS using a video recorder with a camera installed inside the room. The camera was mounted high on the inner bulkhead. It had excellent remote control panning and zooming capabilities which allowed all the details of the test to be recorded for later analysis. The video system was also used by the on-site physician to observe the participants throughout the test period.

INSTRUMENTATION

Sampling Strategy

Remote sampling of CO_2 and O_2 in the refuge station and at the RANA-AIR outlet ports was accomplished by using a sampling manifold designed and built for the study (see Figure 4). It consisted of 8 sets of plastic tubing lines which converged into one line. The lines were equipped with a valve which permitted each to be sampled in sequence. Each sampling line was used to sample a different area of the refuge station. The lines went through the bulkheads and into the manifold. The sampled air was directed through a water trap, a desiccator, a self-regulated

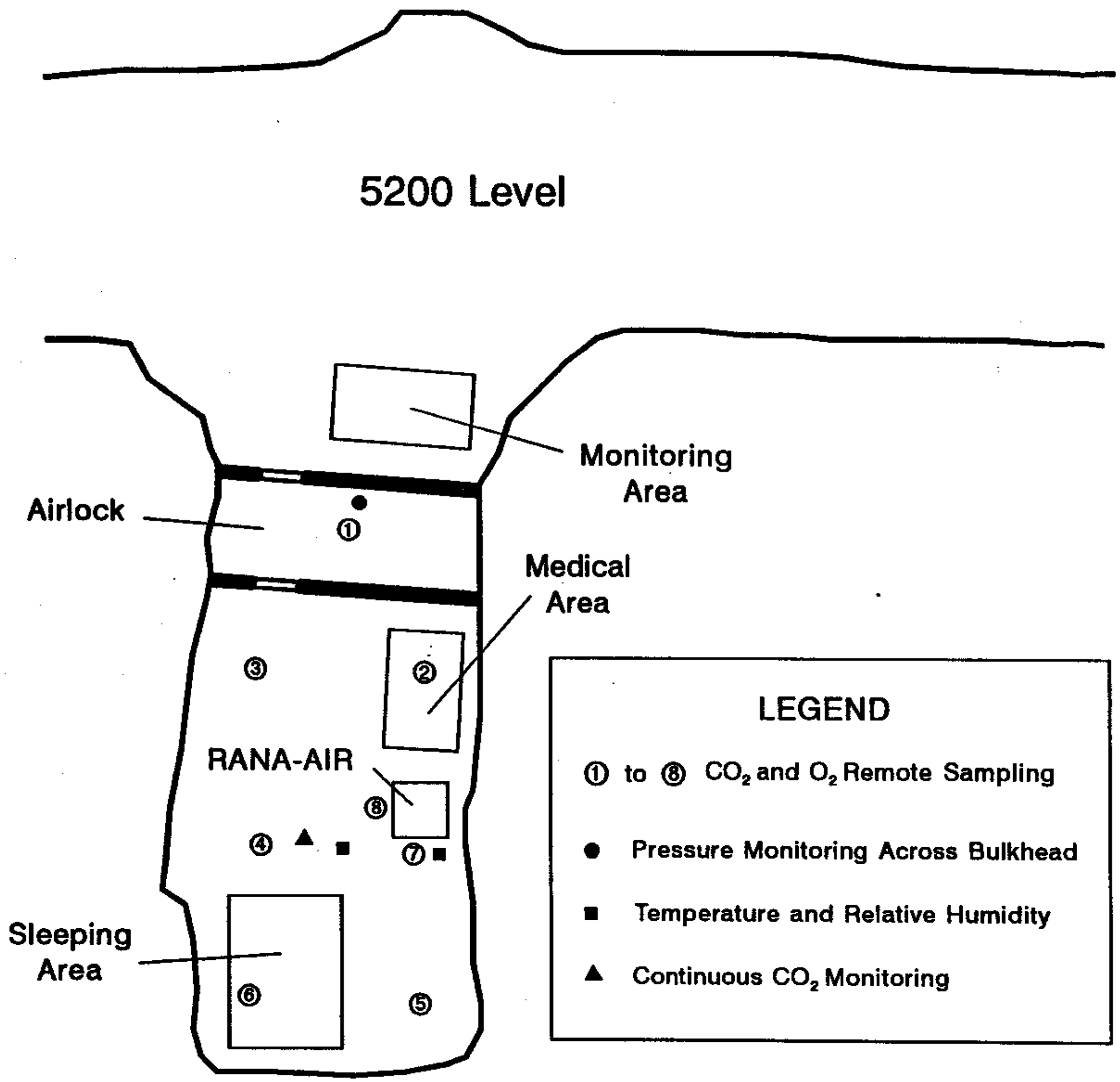


Figure 2. Refuge station schematic plan (not to scale).

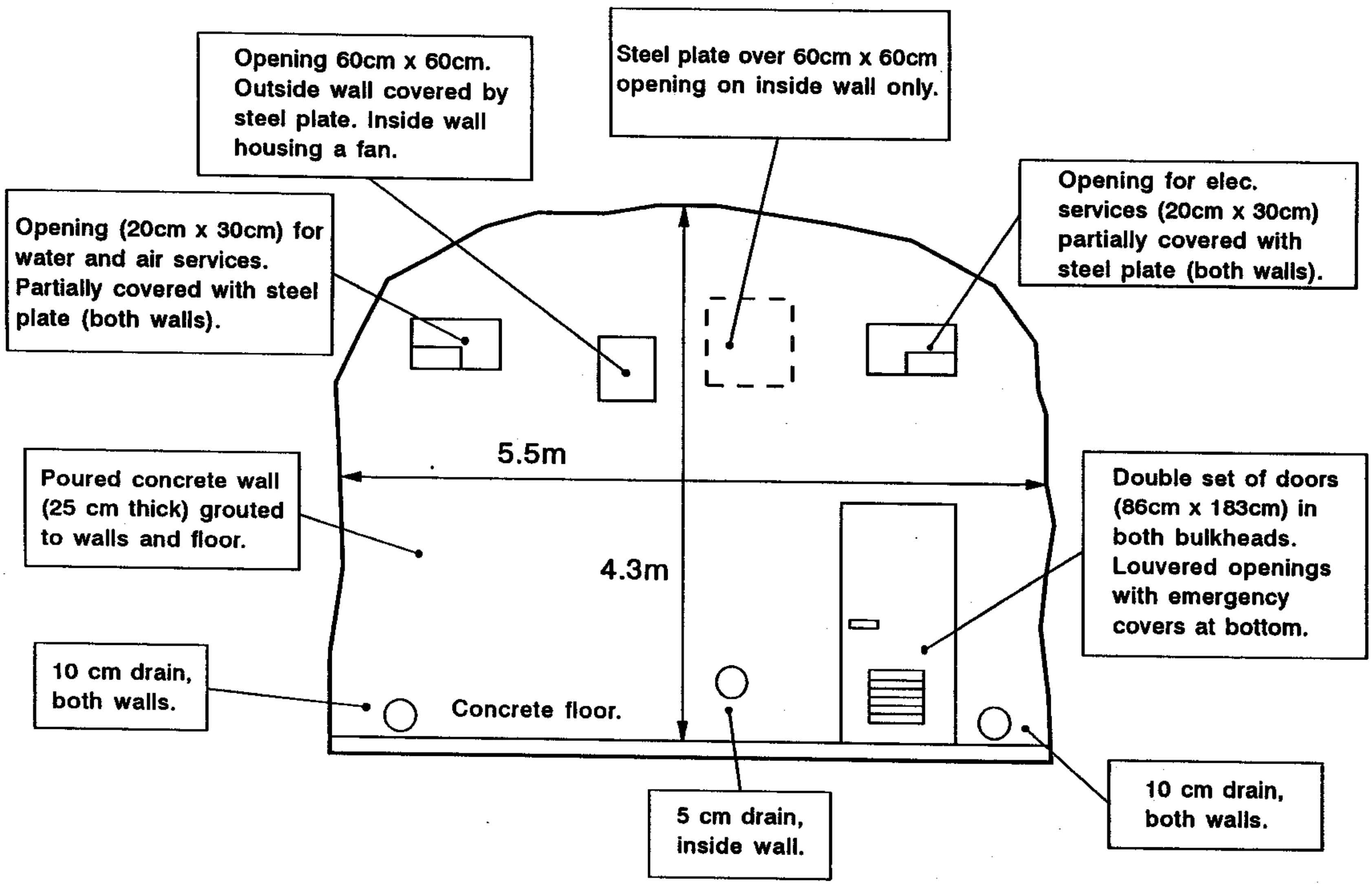
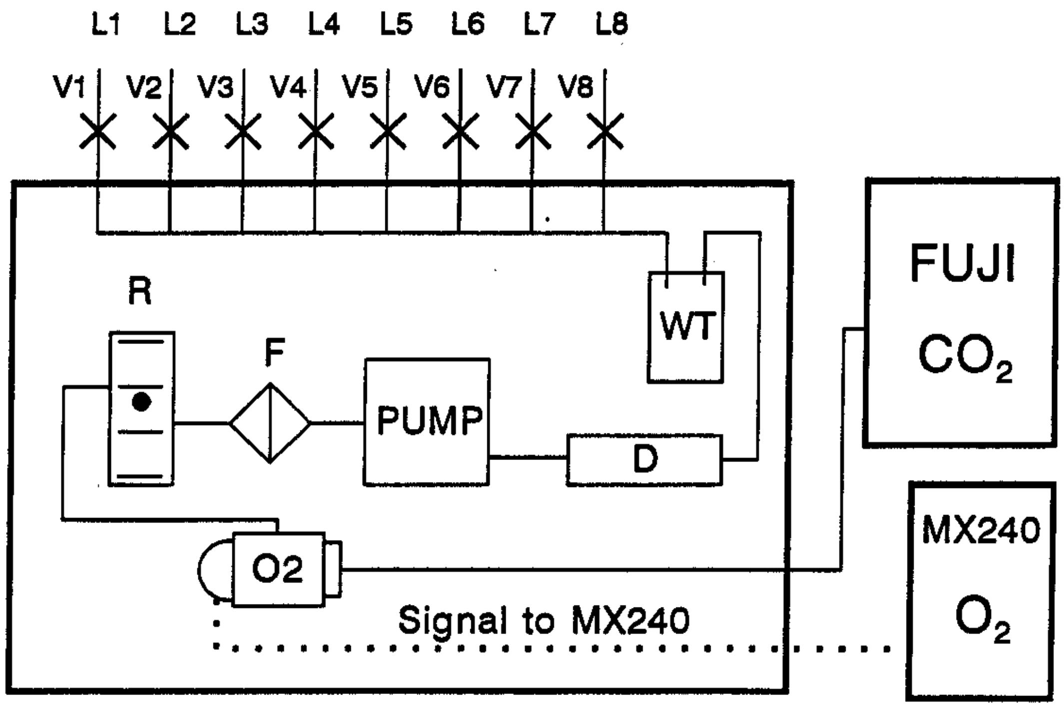


Figure 3. Schematic diagram of the refuge station bulkheads(not to scale).



L1 ... L8 : Sampling Lines
V1 ... V8 : Line Valves
WT : Water Trap
D : Desiccator
F : Filter
R : Rotameter
O2 : MX240 Oxygen Cell

Figure 4. Schematic diagram of manifold assembly.

sampling pump, a rotameter, an in-line O_2 sensor and finally a Fuji ZFP-5 CO_2 monitor. The areas sampled are listed in Table 2. In addition, the pressure across the outside bulkhead was measured using a micro-manometer. The relative humidity and temperature were measured in the refuge station and at the RANA-AIR outlet.

Sampling Port #	Area Sampled
1	Air Lock Area
2	Left at Refuge Station Entrance
3	Right at Refuge Station Entrance
4	Refuge Station Center
5	Left at Back of Refuge Station
6	Right at Back of Refuge Station
7	RANA-AIR Side Drawer CO_2 Scrubber Outlet
8	RANA-AIR Front Drawer CO_2 Scrubber Outlet

Table 2. Description of sampling locations inside the refuge station.

Carbon Dioxide Monitoring

Two types of instruments were used to measure concentrations of carbon dioxide. One was a Brüel and Kjaer (B&K) type 1302 Multi-Gas Monitor and the other was a Fuji ZFP-5 analyzer.

The B&K monitor is a very accurate and stable quantitative gas analyzer which operates on a photo-acoustic infra-red detection method. The instrument which has internal data logging capabilities, has a detection threshold of 1 ppm and a repeatability of 1% of the measured value (approximately 30 ppm). The monitor was calibrated in the laboratory prior to the study by using zero and span gases. It is quoted by the manufacturer to require re-calibration every three months. The instrument was operated in the one to 15000 ppm CO_2 range during the study and it was used to continuously sample the carbon dioxide concentration at the center of the chamber.

The Fuji ZFP-5 analyzer operates on a non-dispersive infra-red principle. The ZFP-5 was operated in the high range (0 to 5000 ppm CO_2) where it has an accuracy of 10% of the reading (about 300 ppm CO_2). The instrument was calibrated in-situ at the beginning, the end and half-way through the 24 hour test. Calibration was performed using Matheson nitrogen as zero gas and 3930/44.2 ppm CO_2/CO Matheson certified Standard 2 as span gas. This instrument measured the refuge station's carbon dioxide concentration as sampled through the manifold.

Oxygen Monitoring

Oxygen levels were monitored using an Industrial Scientific Model MX240 gas sampler. This instruments is designed to be used as portable hand-held device and had to be extensively modified to accommodate data logging, in-line sampling as well as the extended sampling period involved with the test.

In order to be able to sample remotely and in an in-line fashion, the O_2 sensor (electro-chemical cell) was removed from the MX240 and the sensor was fixed and sealed at the end of a small sampling chamber (20 cc). This cell/chamber combination was then wired back to the MX240 component board. The MX240's battery pack was disconnected and DC power was supplied directly to the instrument by an external power supply. Data logging was made possible by connecting a data logger to a 0 to 300 mV signal on the component board which is directly proportional to the 0% to 30% O_2 range of the instrument. The MX240 has an accuracy of ± 0.75% in the 0% to 30% O_2 range and it was also calibrated on site using the same zero gas as for the CO_2 instruments and a 20.9% oxygen standard span gas supplied by Industrial Scientific.

Temperature, Relative Humidity and Pressure Monitoring

Temperature and relative humidity inside the refuge station were measured using VH-L probes manufactured by Vaisala. These were connected directly to the data loggers. These probes had been calibrated prior to the study.

Pressure across the refuge station bulkhead during the test and during the bulkhead integrity test were measured by Air Ltd. MP series electronic micro-manometers. Two of these were available, the MP6KD (0 ± 1999 Pa range) and the MP3KD (0 ± 199.9 Pa range). Both instruments are accurate to better than 1% of the reading.

Atmospheric pressure was measured using an Airdata ADM-870 multi-meter. This instrument is factory calibrated annually using standards and techniques traceable to the U.S. National Bureau of Standards. The accuracy of the instrument is 2% of reading plus or minus one digit. All data were collected and logged using Grant, 1200 series 12-bit Squirrel meters.

Vital Signs Monitoring

Throughout the test period, blood oxygen content or oxygen saturation percentage was measured using a Nonin model 8500 hand held pulse oxymeter. This instrument also recorded the volunteer's pulse rate. The CO_2 partial pressure in arterial blood was measured with a Johnson & Johnson Critikon Fastrac combination CO_2 and pulse oxymeter. The blood pressure was measured using a standard blood pressure cuff/manometer along with a stethoscope. The breathing rate of the volunteers was measured by performing a 15 second manual count.

TEST PREPARATION

Medical Ethics Considerations

Since human volunteers were asked to be part of the study, a comprehensive description of the test was submitted for medical ethics review, for recommendations and ultimate approval. Two physicians (Department Heads) from St. Michael's Hospital in Toronto, reviewed the test proposal from an ethical and scientific perspective. The proposal included a description of the monitoring instrumentation, action levels with respect to allowable concentrations of CO_2 and O_2 and acceptable ranges in volunteers' vital signs. The submitted proposal was accepted without changes.

As a result of this process, it was agreed that any significant deviation in a volunteer's vital signs as compared to the pre-test medical could result in immediate removal of the person in question.

Furthermore, a sustained pulse rate greater than 110, respiratory rate greater than 20, a systolic blood pressure greater than 140, a diastolic pressure greater than 90 may be deemed as sufficient cause for removal of an individual. In any event, a decision to remove a participant on medical grounds was the sole responsibility of the on-site physician.

In addition to the above parameters, chamber air concentrations of O_2 were not to go below 18%. Sustained CO_2 levels in excess of 5000 ppm would trigger enhanced medical surveillance which would lead to immediate test suspension if the physician had reason to believe that participants were at risk.

Volunteer Selection

Twenty five mine rescue volunteers, in addition to a few spares, were selected several weeks ahead of the test. All participants were chosen from the Timmins area and had to meet the following criteria :

- have been certified fit for mine rescue in the previous six months
- be a non-smoker or be willing to abstain for the duration of the test
- must not be on prescribed medications
- be healthy 24 hours prior to and on the day of the test
- agree to undergo a pre- and post-test medical
- keep a personal log of physical and mental status during the test
- be available for vital signs monitoring during the test

The participants were also asked to follow some dietary rules during the 24 hours preceding the test, such as refraining from drinking alcohol or consuming certain food types which may cause discomfort to the volunteer or his companions. The participants were made aware of the test procedure and were invited to ask questions at a briefing session. Finally, each participant was asked to sign a consent form prior to the test.

Site Preparation

The test site was made ready by ensuring that proper and private sanitary facilities were provided. Communication in the form of telephones and two-way radios was available. An ample food supply and beverages were available to the volunteers. Collapsible cots were provided for the volunteers to sleep in shifts.

Leakage Testing of the Refuge Station Bulkhead

During the week preceding the test, the outside refuge station wall was tested for leaks. This was considered important as the refuge station could not be pressurized with compressed air. The bulkhead is a 25 cm (10 in.) thick poured concrete wall. Both the inside and the outside wall have openings to allow the entry of electrical services as well as the air and water lines (see Figure 3). These openings were covered with steel plates and sealed with fire stop foam and caulking.

After all the openings were sealed, the tightness of the seal was evaluated by slightly pressurizing the refuge station using the compressed air line. The following procedure was used :

- Seal the outside wall,
- Mount a set of critical orifices on the compressed air line in order to measure the air flow into the refuge station,
- Mount a micro-manometer across the outside wall to measure the pressure differential between the refuge station and the main drift,
- Seal the inside door of the outside wall with fire clay,
- Turn on the compressed air and wait for the pressure to come to equilibrium,
- Measure the atmospheric pressure as well as the wet and dry bulb temperature in order to determine the air density,
- Measure and record the pressure across the outside wall,
- Repeat the test at different compressed air flow rates,
- Evaluate the wall leakage against known standards.

From this pressure test, the following information was obtained :

Variable	Test #1	Test #2	Test #3
Atm. Pressure (kPa)	117.2	117.2	117.2
Wet Bulb Temp. (°C)	18.9	18.9	18.9
Dry Bulb Temp. (°C)	22.2	22.2	22.2
Orifice Pressure (Pa)	1543	912	1878
Press. Across Wall (Pa)	366.0	250.3	459.8
Press. Across Wall (in. w.g.)	1.47	1.01	1.85
Air Flow into Chamber (m^3/s)	0.022	0.017	0.024
Air Flow into Chamber (cfm)	46.98	36.2	51.74
Leakage Rate (L/min./m^2 @ 50 Pa)	22.43	20.96	21.83
Leakage Rate (cfm/ft^2 @ 0.2 in. w.g.	0.074	0.069	0.073

Table 3. Results of the refuge station wall leakage/pressure test.

As noted above, the outside refuge station wall is solid poured concrete, but it has several potential leakage points, including the doors and frame, the service openings and the drift wall/concrete bulkhead point of contact.

The average leakage rate across the refuge station wall was 21.74 L/min./m^2 @ 50 Pa (0.072 cfm/ft^2 @ 0.2 in. w.g.). This falls within the published values for leakage through cast concrete elevator shaft walls (73 - 136 L/min./m^2 @ 50 Pa) and fire escape stair wells (3 L/min./m^2 @ 50 Pa) (3). These leakage rates consider all leaks through walls, closed doors and openings at the top of the shaft and in walls.

Comparing the measured leakage rates with those cited above, the refuge station wall can be considered to be well sealed. When using the compressed air during an emergency, leakage is not normally considered an issue as smoke and gases are kept out through pressurization of the refuge station. However, leakage can be an important consideration when using a life support system such as the one tested in this study. The unit does not generate any appreciable pressure within the refuge station which means that the implementation of this technology will have an influence on the design and sealing of refuge station walls.

Equipment Testing

On the day preceding the actual test, a dry run was performed in order to evaluate all of the equipment which would be used during the study. The air monitoring instruments and the RANA-AIR unit performed well. The sampling and monitoring instruments were left running until the following morning when the actual test began.

TEST DESCRIPTION AND SCHEDULE

The evaluation took place over a weekend. The participants started to arrive around 5:00 on Saturday morning. While CANMET and Rimer-Alco staff went directly underground to perform a last check of the site, volunteers were undergoing the pre-test medical and briefing. Food was brought inside the refuge station. By 6:20 all of the instruments had been checked and re-calibrated.

The 25 volunteers arrived on site at 7:29. By 7:36 all had entered the refuge station. Six minutes later both the RANA-AIR system drawers had been filled with CO_2 scrubbing granules and the prototype was operational. By 7:46 the outside door on the outer bulkhead was sealed with fire clay and the volunteers settled in for the 24 hour test.

At 14:50 the fire clay seal on the outside door on the outer bulkhead was checked and re-sealed to ensure the integrity of the seal. At 15:05 the other door (inside door) on the outside bulkhead was also sealed. Between 5:04 and 5:10 on Sunday morning, the RANA-AIR system was stopped and the scrubbing material in both drawers was changed. At 5:22 the participants started to get ready to leave the refuge station and so activity increased markedly. At 6:45 the volunteers were asked to perform an agreed upon exercise routine to try to raise the CO_2 concentration and to note the effect on levels of CO_2 and O_2. This was done in order to simulate an increased activity level which could, for example, occur if a mine rescue team entered the refuge station during a real emergency. This exercise period lasted 5 minutes.

At 7:15 on Sunday, the volunteers were ready to leave the refuge station. At 7:36 the door seals were broken, the participants left the refuge station at 7:40 and went back to surface for the post-test medicals. The monitoring instruments were then re-calibrated to verify that none had drifted during the latter part of the test.

RESULTS

Chamber Conditions

This section summarizes the results of refuge station monitoring during the 24 hour test. CO_2 and O_2 concentrations, relative humidity and temperature, and other data are listed.

Figure 5 shows the pressure measured in Pascals across the bulkhead during the actual test while volunteers were in the refuge station. The only conclusion which can be drawn from these data is that the pressure varied around zero during the entire test. Some larger negative and positive swings can be observed which were caused by events linked to production (operation of ventilation doors, fans and cage movement).

Figure 6 shows the CO_2 concentration as measured by the B&K monitor at the center of the refuge station. Noted on the graph are some of the events which may have affected the gas concentrations. The concentration increased from a background of about 700 ppm to stabilize at an average of 2500 ppm after the volunteers had entered and started the RANA-AIR system.

CO_2 concentration was fairly stable, until about 21:00 on Saturday evening. At that time, the volunteers' activity went down noticeably, which is reflected in a stable and slightly lower value of CO_2 concentration between 22:00 and 5:00 the following morning. There is a small peak at 5:00 when the scrubber drawers were changed. The entire process took 6 minutes to complete and it had no significant or long term impact on the air quality. The exercise program which lasted 5 minutes caused the concentration of CO_2 to increase to a maximum of about 3300 ppm. This was performed at the end of the test and data are not available to verify that concentrations would eventually return to the previous average level of 2500 ppm.

Figure 7 shows the CO_2 concentration measured at sampling points 1 to 6, respectively. One overall observation is that there is no evidence of significant differences in CO_2 conditions as a function of location in the refuge station. All curves show that concentration levels increased from baseline to around 2500 ppm.

The only notable difference can be seen in the graph which shows the CO_2 concentration in the airlock. First, the concentration is slightly lower overall (2200 - 2300 ppm) due to the absence of volunteers and limited air circulation in this area for most of the study. Shortly after 15:00 on Saturday, there is a significant increase in CO_2 concentration when the volunteers entered the airlock area to verify the outside door seal and also to apply a clay seal to the inner door. Concentrations slowly returned to 2300 ppm after the volunteers left the airlock area.

Figure 8 shows similar graphs for the O_2 concentration at sampling points 1 to 6. The concentration profiles are also near identical, regardless of the area being sampled. The O_2 concentration varies in a very narrow range between 20.2% and 20.6%. The variation pattern in O_2 concentration goes from high at the beginning of the test, to low towards the middle and back up to high towards the end of the test. The initial decrease in concentration is probably caused by the amount of activity in the first half of the study. Then, as the participants rested on Saturday evening, the O_2 levels start going back to the initial test values.

Figure 9 shows the temperature and relative humidity profile in the refuge station. These measurements were taken close to the RANA-AIR air intake and may not be totally representative of the average conditions in the room. Because of technical limitations with the temperature probe hardware, the sample had to be taken closer to the floor and it is likely that refuge station temperatures were slightly higher on average than the values shown on the graph.

The temperature increased quickly between 7:30 and 9:30. This increase resembles the initial CO_2 increase and is probably caused by the combined influence of the presence of the 25 volunteers

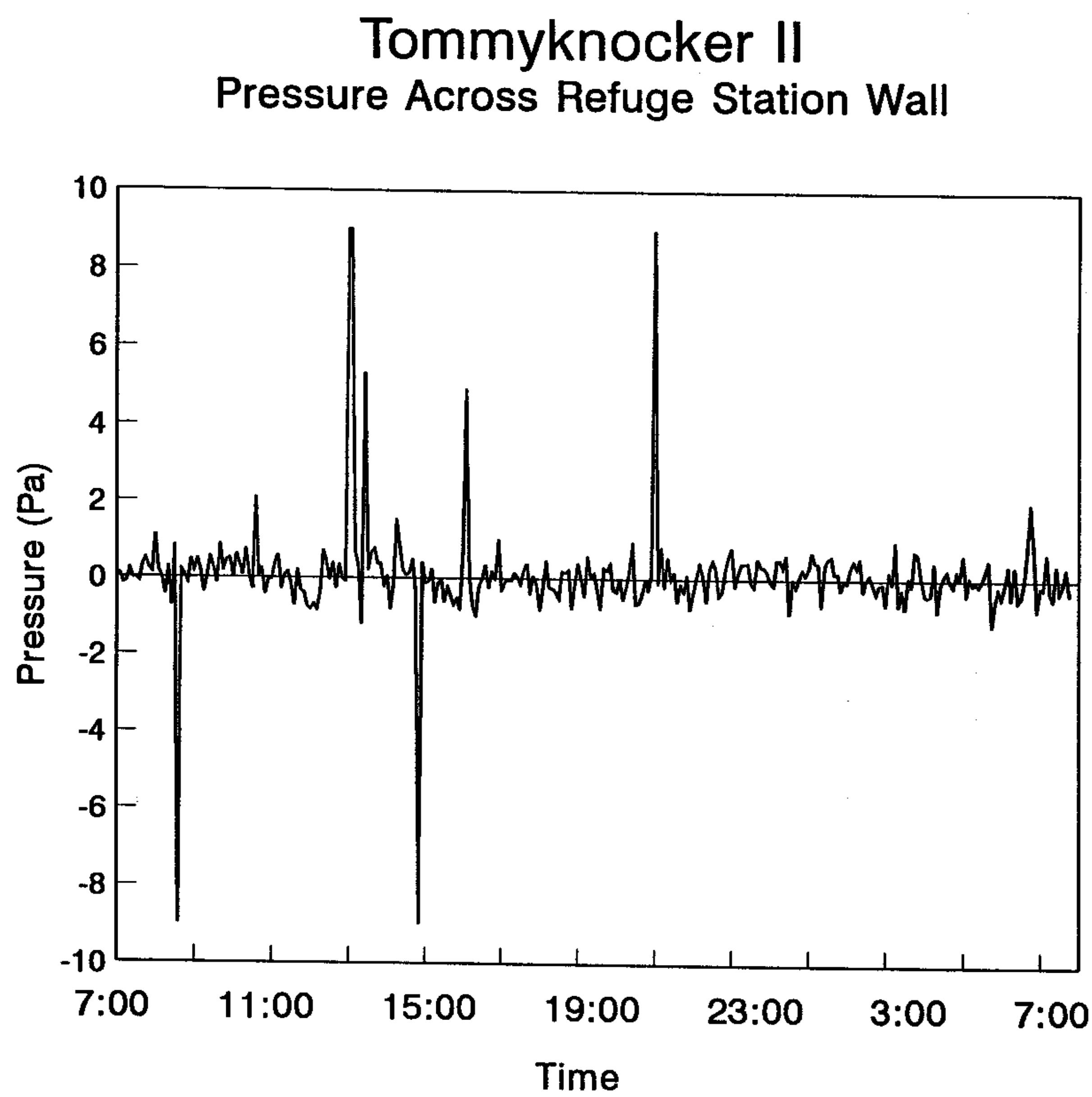


Figure 5. Differential pressure across refuge station bulkhead.

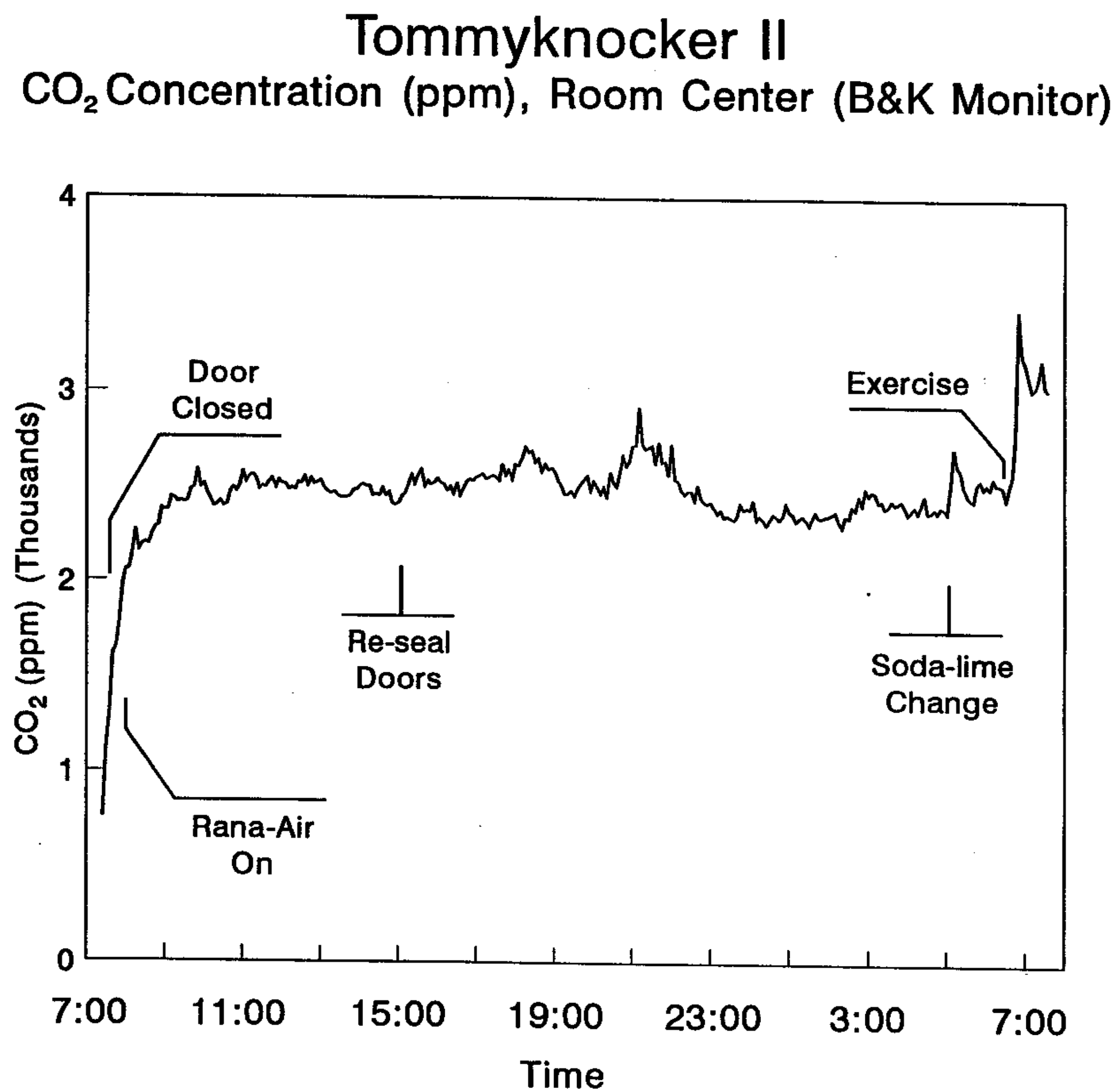


Figure 6. Carbon dioxide concentration in the center of the refuge station.

Ambient Carbon Dioxide Concentration Profiles

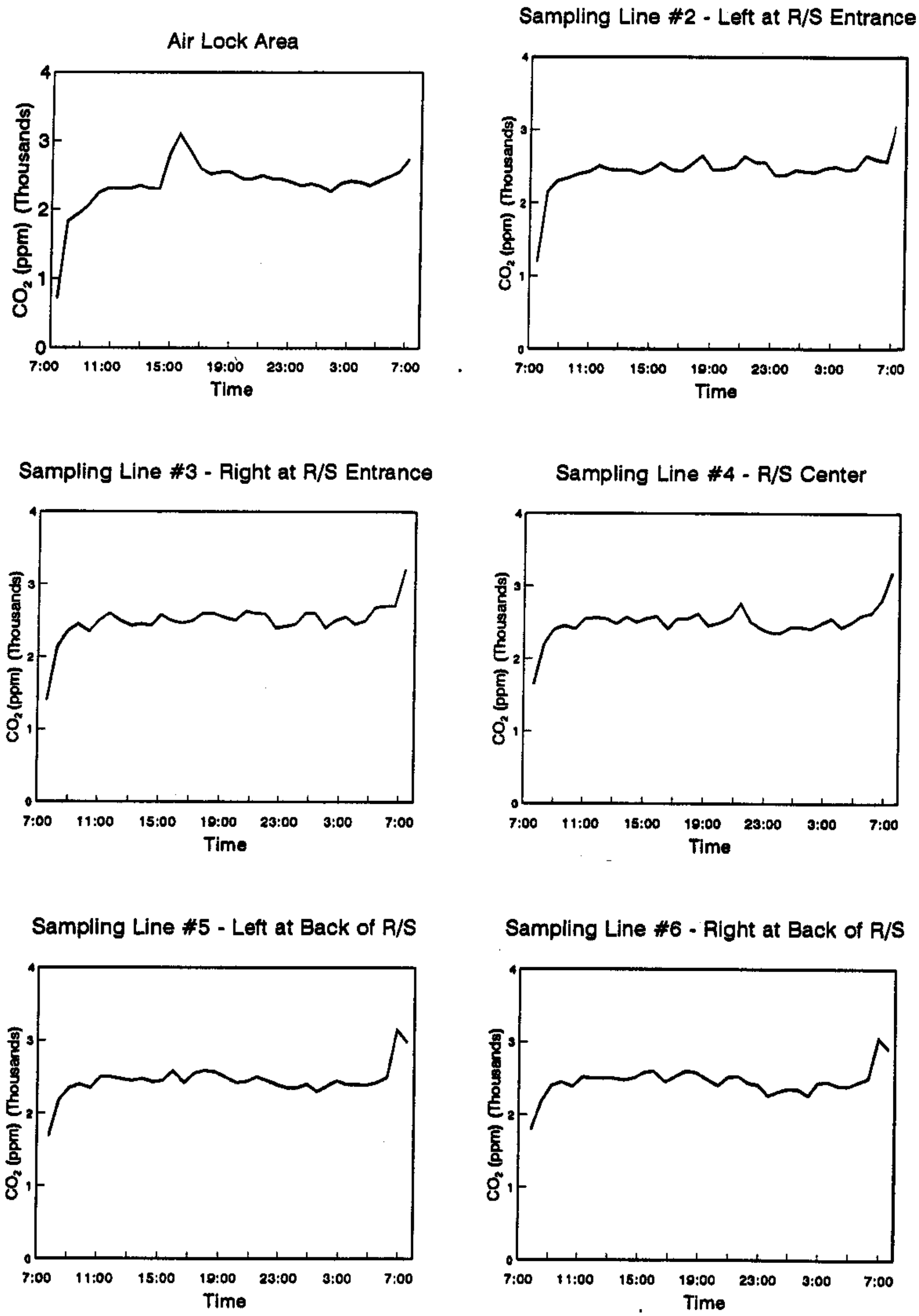


Figure 7. Carbon dioxide concentration in the refuge station.

Ambient Oxygen Concentration Profiles (%)

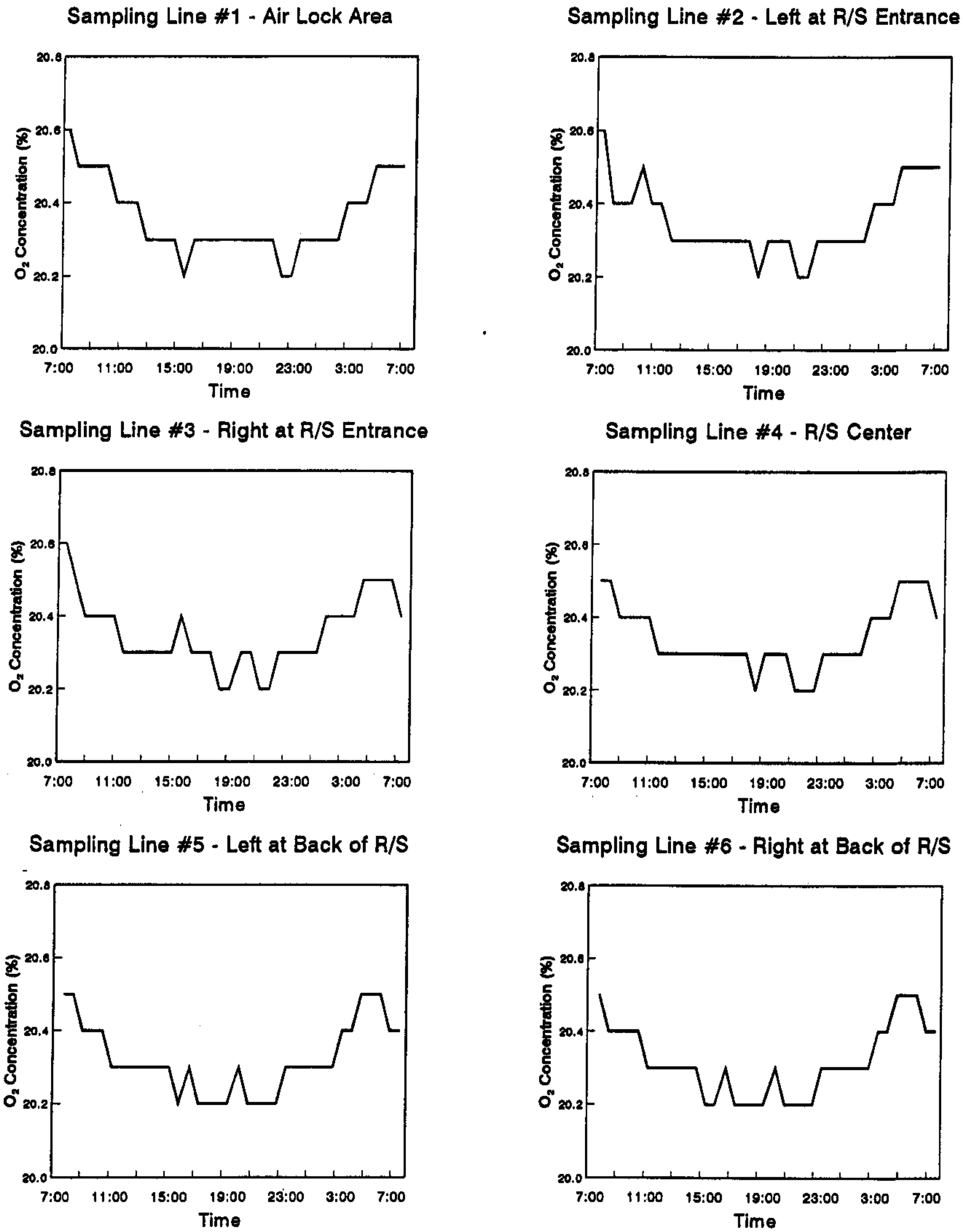


Figure 8. Oxygen concentration in the refuge station.

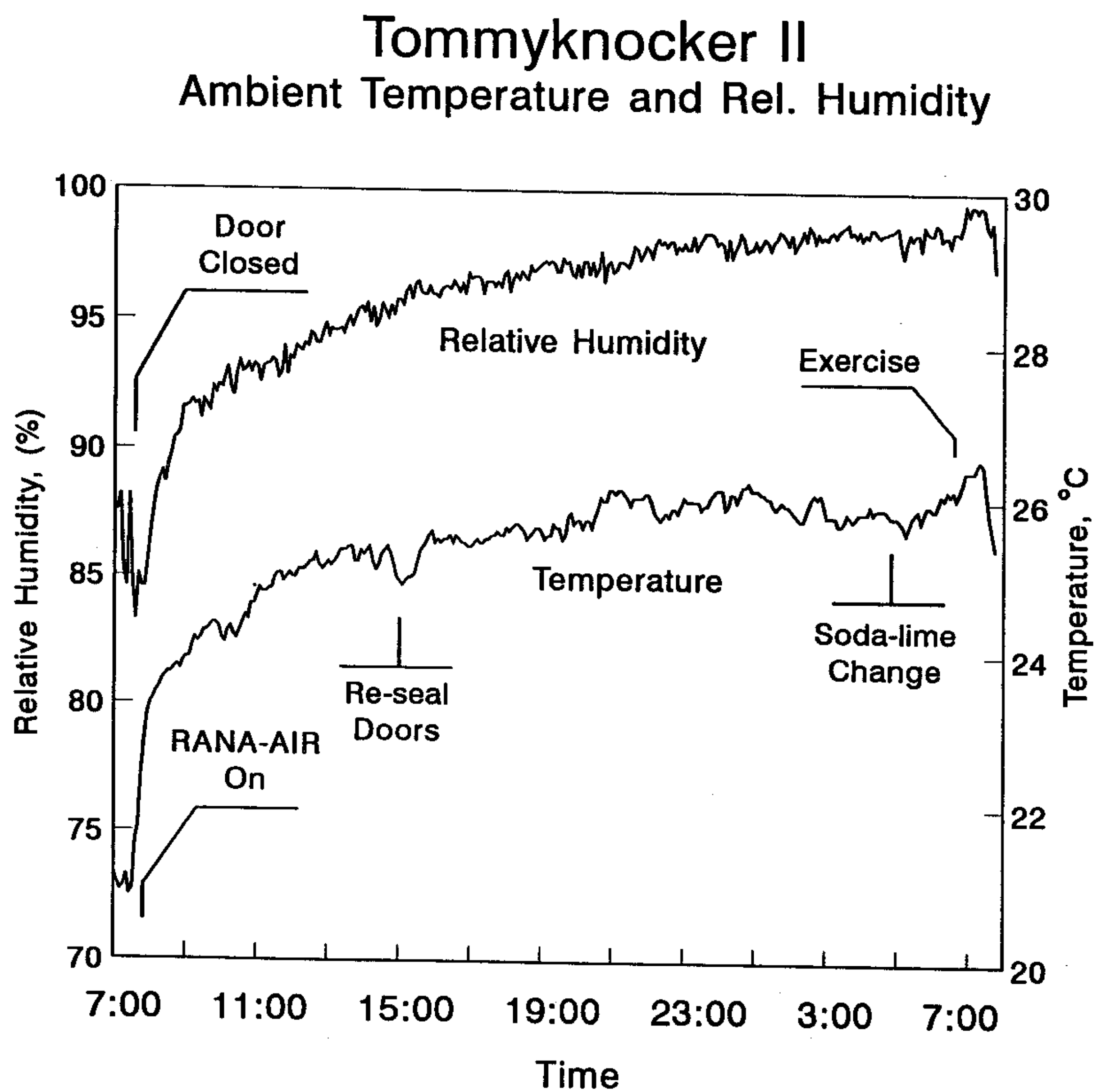


Figure 9. Ambient temperature and relative humidity.

and the heat being produced by the RANA-AIR system. The temperature goes from about 22.0°C, initially, to 25.5°C towards the end of the test. The relative humidity was quite high throughout the test, starting at around 80% and rising gradually to about 98% in a profile which is very similar to the temperature graph.

Carbon Dioxide, Oxygen, Relative Humidity and Temperature at the RANA-AIR Outlets

The above parameters were measured directly at the air outlet of the RANA-AIR system. CO_2 and O_2 were measured on both the front and side drawer outlets while humidity and temperature were only measured on one of the two outlets.

The CO_2 concentration profiles are shown in Figure 10 for the side and front drawer outlet air. The results show some definite differences between both drawers. Whereas the side drawer outlet CO_2 concentration remained unchanged until the scrubbing chemical was changed, the front drawer started showing signs of loss of effectiveness at around 23:00. The side drawer outlet concentration remained constant at around 700 ppm throughout the study. The front drawer outlet was initially much lower at 350 ppm and remained fairly constant until about 20:00. From then, until the drawers were changed at around 5:04 on the following morning, the CO_2 concentration out of the front drawer quadrupled to around 1500 ppm. After the drawers were replaced, the CO_2 concentration returned to 600 ppm for the front drawer 700 ppm for the side drawer.

The O_2 concentration profiles measured from the side and the front drawers are shown in Figure 11. The two curves are very similar, as they both follow the same trend as the O_2 profiles discussed earlier. This is to be expected since the pure oxygen supplied by the RANA-AIR at a constant rate of flow is mixed with room air which is passed through the scrubbing drawers.

Figure 12 shows the temperature and humidity measured at the RANA-AIR output. These curves are very similar to the ones measured in the chamber air. The outlet temperature is, however, 4°C warmer than the chamber air, indicating that the unit is a source of heat in the refuge station. Also, the relative humidity is sensibly lower in the outlet. Both graphs clearly show the point in time when the scrubbing drawers were changed (approximately 5:00 Sunday morning).

RANA-AIR Oxygen Flow Rate/Pressure and Color Change Indicator Observations

The rotameter indicating the oxygen flow rate from the compressed O_2 cylinders was set at 13.0 L/min. from the start of the test. This is approximately equivalent to 0.5 L/min. per participant, which is the O_2 flow required according to the operating instructions. This rate was verified throughout the test and did not change according to the volunteers' observations.

The oxygen cylinder pressure as recorded from the pressure gauge preceding the one stage regulator decreased in a linear fashion going from 2200 psig at the start of the test to 500 psig the following morning when the test ended. The O_2 pressure values are plotted as a function of time in Figure 13. Extrapolation of this line back to zero pressure indicates that the O_2 supply would, at best have lasted another 6 hours or until around 13:00 on Sunday.

Color indicator observations are shown in Table 4. It is important to study this parameter in a little more depth, since in an emergency situation, users would depend on this parameter to

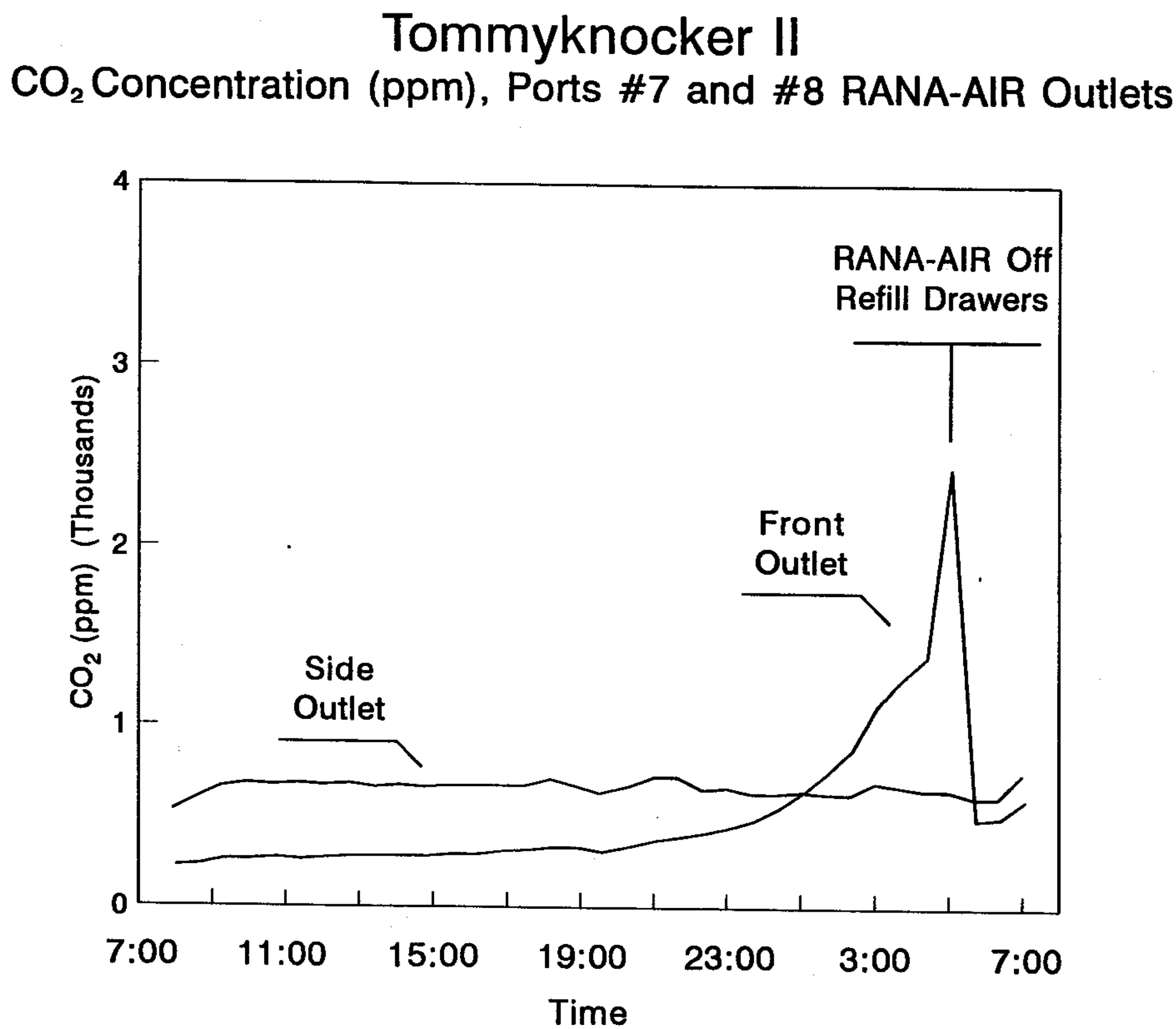


Figure 10. Carbon dioxide concentration at the RANA-AIR outlets.

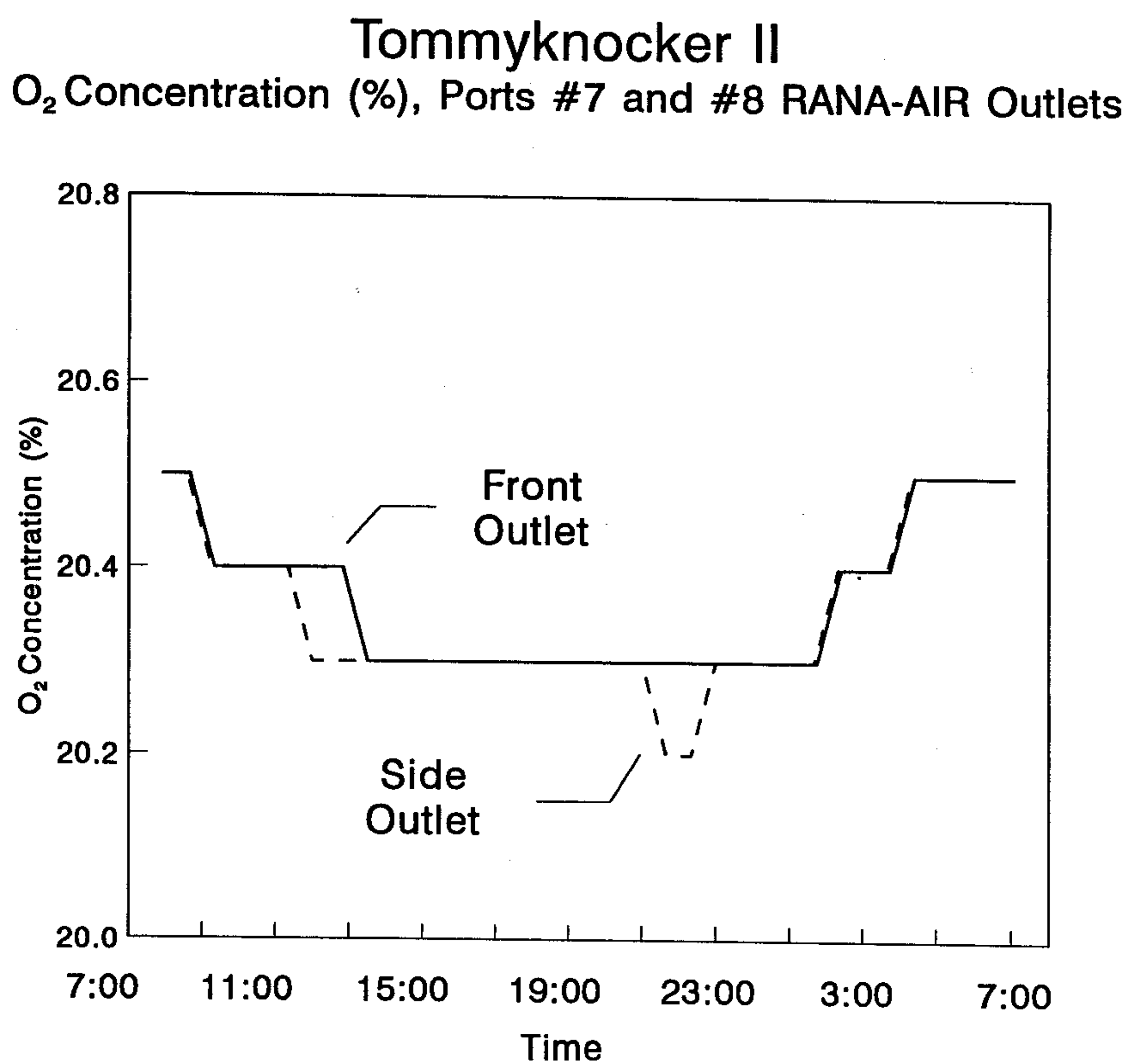


Figure 11. Oxygen concentration at the RANA-AIR outlets.

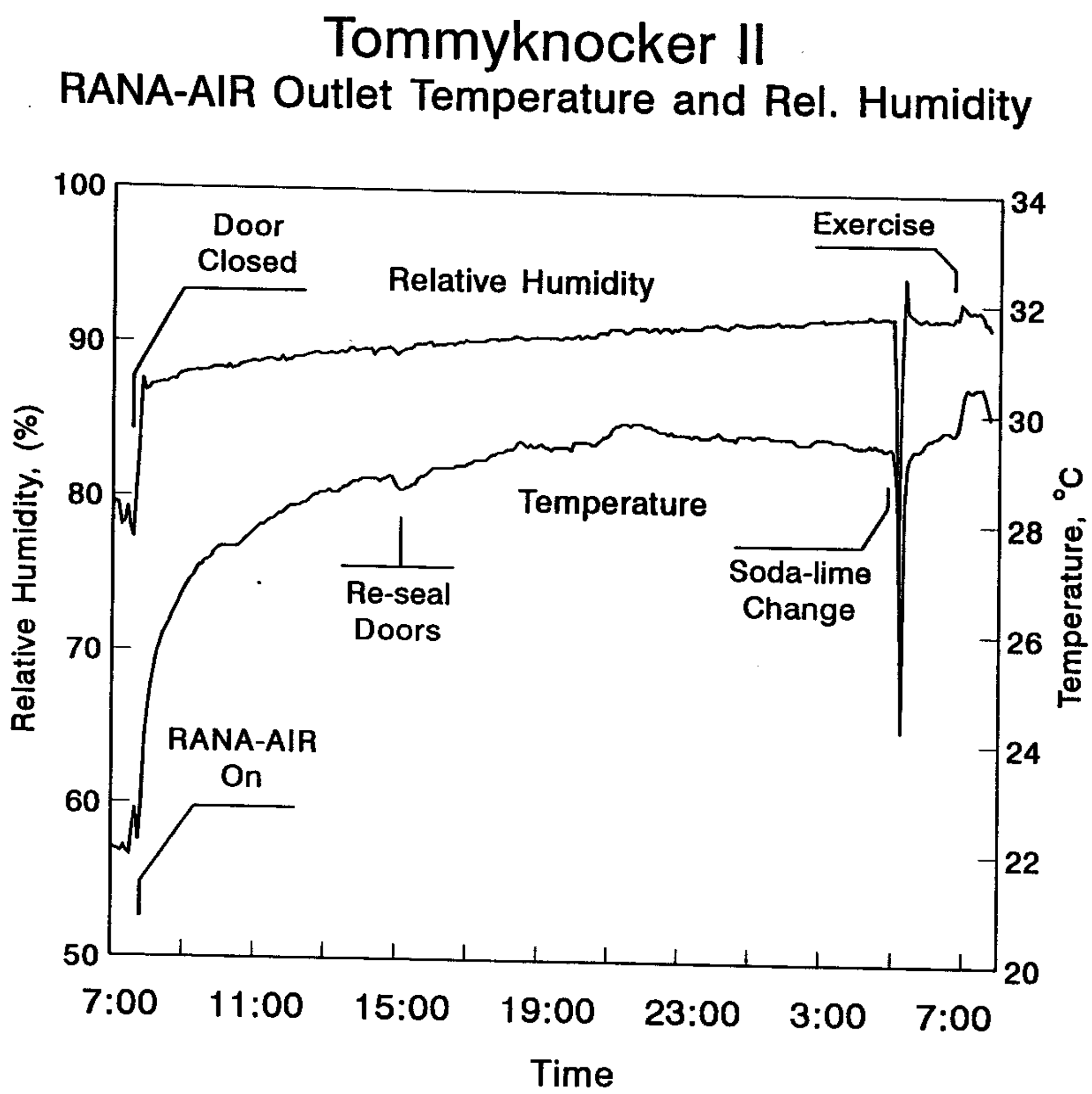


Figure 12. Relative humidity and temperature at the RANA-AIR outlet.

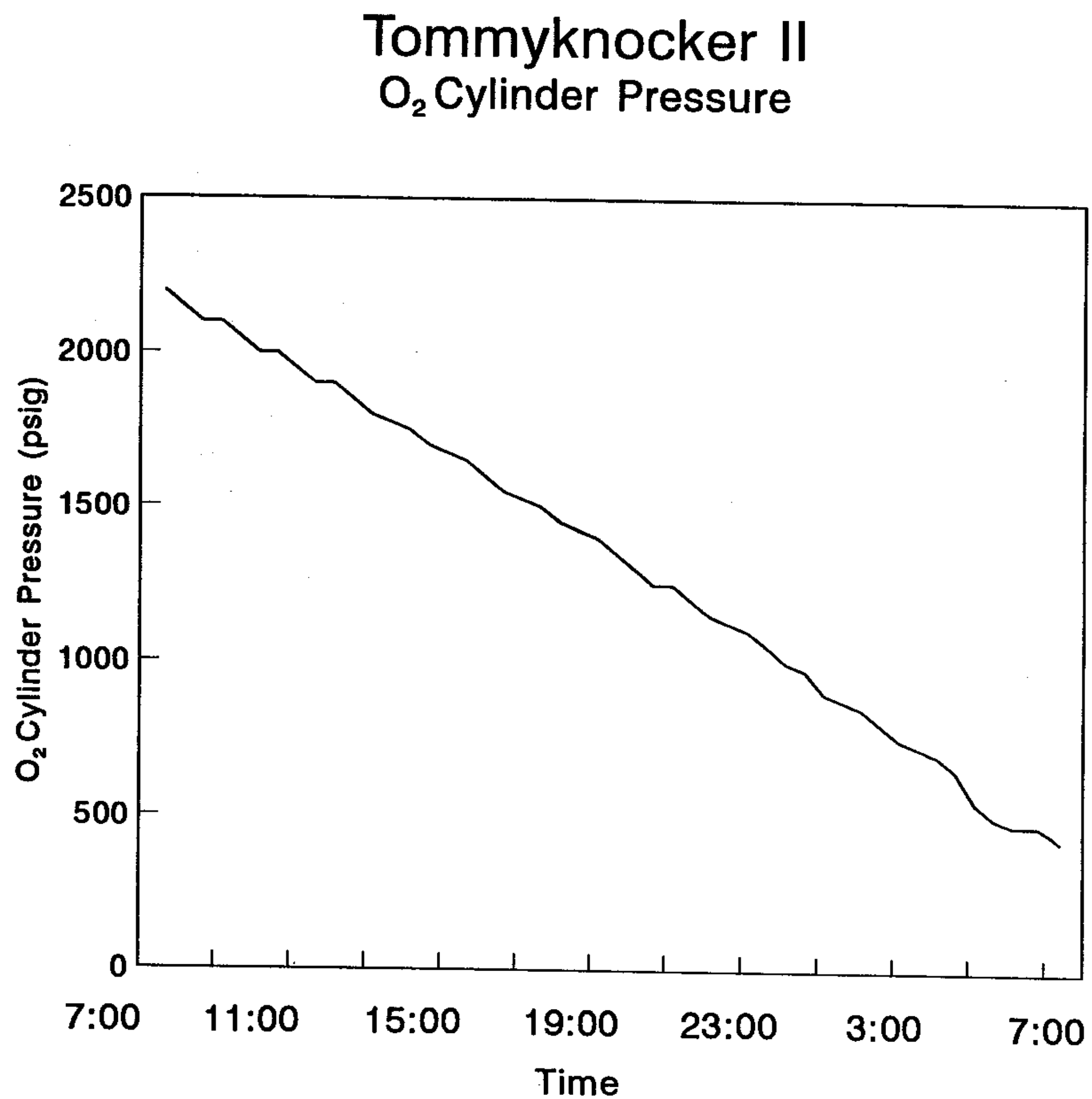


Figure 13. Oxygen cylinder pressure.

estimate the scrubbing chemical efficiency. This information should be compared with the CO_2 concentration graphs obtained from the RANA-AIR outlets and the dimensions and capacities of each scrubbing drawer.

The color indicator observations were obtained by estimating the extent of the scrubbing material color change using a ruler on the window on the front of the drawer. As the scrubbing granules loose their effectiveness, they will gradually turn purple starting from the bottom of the drawer where air enters. In theory, in a perfectly packed chemical drawer and with an even flow distribution across the surface of the drawer, one would expect a straight line formed by the advancing front of the color indicator. In practice, however, this line is unlikely to progress in such a fashion across the observation window.

Time Span	Observations	
	Front Drawer	Side Drawer
7:40 - 11:40	No change	No change
11:40 - 14:10	Few granules changed	No change
14:10 - 15:40	Indicator line @ 6.4 cm	No change
15:40 - 16:40	Indicator line @ 7.6 cm	No change
16:40 - 17:10	Indicator line @ 7.6 cm	Few granules changed
17:10 - 18:40	Indicator line @ 7.6 cm	Indicator line @ 5 cm
18:40 - 19:10	Indicator line @ 10.2 cm	Indicator line @ 6.4 cm
19:10 - 19:40	Indicator line @ 12.7 cm	Indicator line @ 7.6 cm
19:40 - 22:40	Indicator line @ 12.7 cm	Indicator line @ 8.9 cm
22:40 - 23:40	Indicator line @ 12.7 cm	Indicator line @ 11.4 cm

Table 4. Scrubber material color indicator observations.

No color change took place in the first 4 hours of the study. After that time, the front drawer started showing some indicator change in the form of a few granules having turned purple. By 15:40 or almost 8 hours into the test, the front drawer had developed an indicator line at around 6.4 cm from the bottom of the window, while the side drawer showed no indicator change. The observations at 16:40 revealed a line at 7.6 cm for the front drawer and a few purple granules for the side drawer. By 23:40, the front drawer line was up to 12.7 cm while the side drawer had a distinct line at 11.4 cm. After that time, there seemed to be little change in the state of the indicator and records were no longer kept. One thing to mention is that the indicator lines were not clear cut horizontal lines. These lines were a bit diffuse, high at the sides and low in the middle for the front drawer and slanting from right to left for the side drawer.

From the graph showing the CO_2 concentration at the outlet of the front drawer (Figure 10) it appears that the participants should have changed the front drawer granules by 23:00 as the CO_2 concentration from that point on goes up rather rapidly. This is an indication that the scrubbing material in the front drawer is reaching the end of its useful life. At that point in time, the participants did not feel compelled to change the scrubbing material, based on the color indicator observations.

Vital Signs

Table 5. lists the average vital signs values for the 25 participants. On average, around 20 readings of pulse, respiratory rate and O_2 blood saturation were taken on each participant. Blood pressure was measured eight times and trans-cutaneous CO_2 partial pressure in arterial blood was measured once on 11 volunteers.

Vital Sign	Average Measured Value
Pulse Rate (per minute)	76
Respiratory Rate (per minute)	16
Blood Pressure (mm Hg)	119/78
Oxygen Saturation (%)	97.6
Carbon Dioxide Pressure (mm Hg)	47

Table 5. Average of vital signs monitored on the 25 volunteers.

Vital signs results for individual volunteers are listed in Appendix I. From this table it is evident vital signs were within normal ranges for all participants. The results of pre- and post medical examination also failed to reveal any abnormal conditions or any acute medical problems.

Volunteers' Comments

The comments gathered as part of the survey of volunteers are listed in Appendix II. These have been re-organized and listed for all participants under the particular question headings. Otherwise, the comments have been transcribed directly as given by the participants. The questions in the survey may be separated into two main categories. First, comments regarding the actual RANA-AIR unit performance; and, finally, comments on the general level of comfort both physical and psychological.

Concerning the system performance as perceived by the inside volunteers, the comments were very positive. The consensus amongst the volunteers was that the unit was easy to use and that the operating instructions were clear and concise. The system's dimensions, color and shape was acceptable to most, while some mentioned that it should be smaller in size and made of lighter material. Perhaps a cast plastic housing could be used to achieve this and remove sharp edges and corners. Drawers were found by some to be heavy which made them hard to handle. The noise produced by the system's blowers was not a problem, a few mentioned that the noise was comforting.

Some comments were made with respect to the ability to gauge the level of performance of the scrubbing granules using the color indicator as viewed through the drawer window. The indicator's color pattern and the rate of progression up the window was not as obvious and predictable as what had been anticipated. This could lead to difficulties in assessing the efficiency of the scrubbing drawers in actual emergency situations especially if the users have had little or no experience with the RANA-AIR system. One participant mentioned that the unit should have built-in CO_2 and O_2 monitoring capabilities.

The level of comfort in the refuge station seemed to be acceptable. The level of humidity and the lack of space were the major sources of discomfort. Volunteers as a rule were enthusiastic and very much enjoyed their contribution to the test.

DISCUSSION

One of the objectives of this test was to evaluate the RANA-AIR's performance from the point of view of its ability to perform in a real refuge station with a large number of miners inside. This included verifying the user friendliness of the system, its ability to maintain safe levels of CO_2 and O_2 and finally, ensuring that the color indicator method of checking the scrubbing material performance was adequate.

From the test results and the volunteers' comments, the prototype performed very well overall. CO_2 concentrations in the room were on average 2500 ppm and very stable even after the front scrubbing drawer started to decline in efficiency. The exercise program which lasted about 5 minutes caused the concentration of CO_2 to rise to 3500 ppm and stabilize momentarily, before starting on a downward trend.

It is important to compare the average concentration of 2500 ppm, measured during the test, to exposure limits set by existing regulations and to conditions which could arise as a result of present refuge station procedures in Ontario. First, it can be calculated that the CO_2 concentration during this test would have reached in excess of 60,000 ppm if compressed air was not used and the life support system had not been scrubbing CO_2. Under these conditions, unconsciousness would have occurred within a few minutes.

Secondly, the Ontario Regulation 833/90 states that the exposure of workers to carbon dioxide is to be less than 5000 ppm over an 8 hour shift and a 40 hour work week and that this exposure value must be prorated for extended work schedules. In effect this would have resulted in a prorated TWAEV of 1666 ppm for this test. Although it was not possible to achieve this lower value during the present test, there is no evidence in the literature that extended exposure to levels below 5000 ppm carry any increased health risk.

Theoretical concentrations of carbon dioxide assuming compressed air had been used in the refuge station have also been calculated. Using an oxygen consumption rate of 0.5 L/min., approximately 0.43 L/min. of carbon dioxide would be produced by each volunteer (Table 1). Assuming good mixing of air in the refuge station (Figure 7) and compressed air flow rates of 0.024 and 0.047 m^3/sec (50 and 100 cfm) it can be calculated that carbon dioxide concentrations would have reached 7700 and 4030 ppm, respectively.

Figure 14 shows the actual CO_2 concentration in the refuge station along with the theoretical concentrations assuming 50 and 100 cfm of compressed air had been used. The RANA-AIR system maintained concentrations below the theoretically calculated values, but above the required 1666 ppm level required for a 24 hour extended work shift.

Remote sampling of several areas of the refuge station also showed that except for the airlock area, concentrations of CO_2 and O_2 were consistent regardless of the sampling location. This is due to a combination of human movement and the air outlet design of the RANA-AIR system

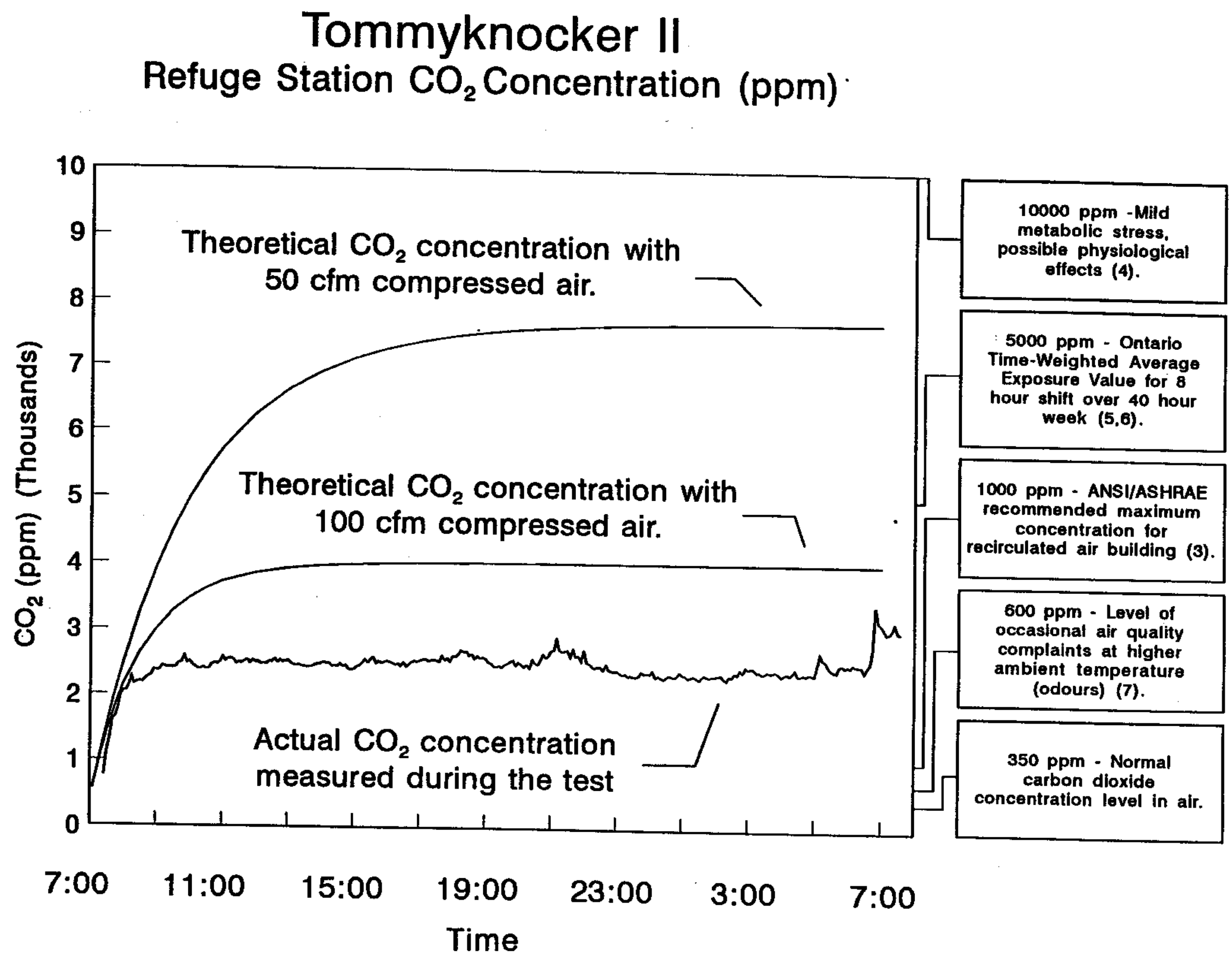


Figure 14. Theoretical and actual carbon dioxide concentrations in refuge station.

which has blowers coming out of either sides of the console. The airlock area displayed slightly lower CO_2 levels and very similar O_2 concentrations as compared with the rest of the refuge station. The access door of the airlock chamber was left closed for most of the study.

This study also demonstrated that immediate start-up of the system causes CO_2 concentrations to come to quick equilibrium from the initial low values. Whereas the priority of starting the system within the existing refuge station emergency procedure (sealing doors, communication, etc.) has to be determined, it is important to ensure that initial CO_2 levels are not allowed to reach high values. In a real emergency, background CO_2 concentrations in the main drift and inside the refuge station could be high to start with. Reaching safe conditions as quickly as possible should be a key part of the procedure.

The air supplied by the RANA-AIR unit contained on average between 300 and 700 ppm of CO_2, when the scrubbing beds were in place. Considering that the incoming air had on average 2500 ppm of CO_2, the unit had an average scrubbing efficiency of around 80%. It is possible that some of the air bypassed the scrubbing drawers thereby causing the outlet concentration to be higher than it could have been. One indication that this may have occurred is the fact that the scrubbing drawers had significantly different CO_2 output concentrations. Both drawers should in theory have produced low, similar CO_2 output concentrations.

The CO_2 concentrations measured at the outlet of the system also showed that the side drawer far outlasted the front drawer. This can be explained by the difference in geometry of the drawers, the amount of scrubbing material in each drawer and to some extent, the fact that the front drawer seemed to be more efficient at scrubbing CO_2. First, the front drawer contains about 20% less scrubbing granules as compared to the side drawer. Also, the same amount of air flows through both drawers, but the front drawer air throughput area is only 87% of the side drawer area. This would increase the velocity of air through the scrubbing drawer which may in turn increase the incidence of breakthrough of the scrubbing chemical.

The part of the system which supplies oxygen is fairly simple and it performed very well. The levels of O_2 in the refuge station were stable between 20.2% and 20.6%. The temperature traces show a 4°C difference between the intake and outlet air temperature, indicating that the unit is a source of heat in the refuge station. The reverse was observed with relative humidity, with the air intake being at 98% and the outlet at 90%.

From an operational standpoint, the volunteers concurred the system was easy to operate and that the instructions were clear. One participant mentioned that the drawers were heavy and a bit awkward to handle. These, however, fitted well into their respective tracks. The process of removing spent chemical, re-filling and re-starting the unit was performed very quickly and had a minimal impact on the conditions inside the chamber. The entire process which was performed about 22 hours into the test took 6 minutes to complete.

One point which needs to be addressed, with the prototype tested, is the ability of volunteers to determine the proper time at which to change the scrubbing chemical based on the state of the color change indicator. Under normal conditions, (room temperature and low to medium relative humidity) the user could decide to change the scrubbing material when the color change indicator reached any part of the top of the observation window. According to the manufacturer, however, high humidity conditions can affect the pH reaction which controls the color indicator status. This could lead to errors when trying to estimate the scrubbing drawer efficiency.

As an alternative, the scrubbing material manufacturer recommended doubling the safety margin, and changing the scrubbing material when the average indicator line reaches half way up the observation window. According to the color indicator observations, this situation occurred at around 19:00. Verifying the CO_2 concentration measured at the outlet of the front drawer suggests that this would have been the ideal time to change the scrubbing material. The time coincides with the start of the rapid increase in CO_2 concentration as measured at the outlet of the front drawer.

CONCLUSION

The RANA-AIR unit 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 (2),

2. the prototype was easy to operate, the participants agreed that the instructions were clear. The system can be started in less than 10 minutes, which includes filling the drawers with chemical. The system provided safe CO_2 levels (average of 2500 ppm) and maintained O_2 levels within an acceptable range (20.2% and 20.6%).

3. external monitoring of CO_2 and O_2 levels was used to verify the fact that the scrubbing chemical color indicator can be used by inside participants in order to make the decision to change the chemical scrubber,

4. the study provided data and information which will be useful in formulating the requirements needed in order to be able to apply this new technology in U/G emergency situations.

At the onset, it was calculated that the scrubbing material should last between 5 and 9 hour. As it turned out, data shows that in the worst case, the front drawer was still very efficient up until 14 hours into the study. The oxygen supply which was designed to provide 27 hours of service at a rate of 0.5 L/min. per participant performed reliably. Data shows that the cylinders would have lasted close to 30 hours.

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 (see Appendix II).

The results suggest that two factors should be addressed. First, data showed that the outlet of the front and side drawers differed by a factor of two from the start of the study. Presumably, the side drawer should be as efficient as the front one. It would be interesting to find out what caused the difference. Once the reason is established, the knowledge gained would ensure better CO_2 control and higher overall scrubbing efficiency.

The second factor deals with the volunteers' interpretation of the color change indicator. Knowing that the indicator is affected by high humidity and temperature conditions, the test results show clearly that changing the scrubbing material when the indicator is half way up the observation window would have been acceptable. This would have provided over 10 hours of continuous service before the beds needed to be changed. Alternatively, it is possible to use a fixed time approach in which participants change the chemical after a period of time regardless of the state of the color indicator.

As it applies to the RANA-AIR system, therefore, the scrubbing drawers design should be finalized with respect to depth, overall volume and the requirements for chemical change. There is a possibility to use pre-packaged absorbent cartridges as an alternative to re-fillable drawers. The specification with respect to absorption capacity, color change indicator or replacement frequency should be determined, tested and specified by the soda lime manufacturer in conjunction with Rimer Alco.

The final design of the RANA-AIR 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 to protect the controls from possible tampering.

In the course of this study, it became apparent that some thought needs to be given to refuge station design. Within the emergency refuge station program, some work is needed in order to assess the impact of low or negative pressure conditions occurring inside the refuge station whether or not compressed air is used. More information is needed on the processes which are at play when the refuge station undergoes the mild pressure swings which were recorded during this study. Knowing that gases will migrate through the concrete bulkhead, we need to know to what extent conditions outside the refuge station can affect the inside atmosphere.

A similar test, although not necessarily requiring the participation of volunteers, could be conducted in which several variables are considered. The refuge station bulkhead could be treated with impermeable substances and tracer gas (SF_6) released in the main drift could be sampled for, inside the refuge station, to quantify the impact of the environment outside the refuge station on inside conditions.

RECOMMENDATION

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, pending some minor modifications could be used underground as part of a comprehensive mine emergency response program.

ACKNOWLEDGMENTS

The authors would like to thank everyone who helped make this project a success; in particular, from Falconbridge Ltd., Kidd Creek Division, Gerry Bilodeau, on-site Project Coordinator, John Chenier, Safety and Security Supervisor and Dr. Gordon Hall and Susan Cahoon, Medical Supervision. Kim Barney, Dr. Albert Cecutti, Norm Dallaire, Walter Fischer, Peter Fleming, Tony Fontana, Allen Hayward, Dennis O'Hare, John Pappone, Vince Patitucci, Len Secord and Leonard Vincent also from Kidd Creek and Don Lenihan of Royal Oak Mines Inc. should be commended for their efforts and a job well done.

Next our appreciation also goes to the twenty eight mine rescue volunteers who gave up their weekend in order to help advance the cause of workplace safety and health. These people were :

Team #1	Team #2	Team #3	Team #4	Team #5
Dean Rigg (C)	Ernie Sapinski (C)	George Rodda (C)	James Fleurie (C)	Darryl Vickers (C)
Camille Bois	Mike Butler	Frank Monfils	Trevor Eagles	Robert Ladouceur
J.C. Cayen	Rick Byrnes	Pat Vaillancourt	Dennis Tomini	Paul Magny
Randy Robitaille	Don Cayen		David Lee	Scotty Robertson
Ron Séguin	Mike Charette		Peter Diprofio	Terry Sprowl
Al Truax	Alex Soucy			

Spares : Jamie Mortson, Kostic Tschop and Nelson Girard.

Our thanks also to Earl Gardiner, Russ Hildebrand and Monty Raber of Rimer Alco North America and Joe MacInnis, Mine Rescue Officer, Timmins. We acknowledge the contribution of Falconbridge Ltd., Kidd Creek Division for hosting this study as well as Placer Dome Inc., Dome Mine and Royal Oak Mines Inc., Timmins Division for their keen interest and help throughout the project. Finally, we would like to thank Northern Voice and Video Inc., Sudbury, Ontario for loaning the high quality video equipment used during this study.

REFERENCES

1. American Society of Heating, Refrigeration and Air Conditioning Engineers, "ASHRAE Handbook, Systems", Published by ASHRAE, Atlanta, Georgia, 1980.

2. "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. American Society of Heating, Refrigeration and Air Conditioning Engineers, "ASHRAE Handbook, Fundamentals", Published by ASHRAE, Atlanta, Georgia, 1981.

4. American Conference of Governmental Industrial Hygienists, "Documentation of the Threshold Limit Values", Fourth Edition, ACGIH Inc., Cincinnati, Ohio, 1985.

5. American Conference of Governmental Industrial Hygienists, "1993 - 1994 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices", ACGIH Inc., Cincinnati, Ohio, 1993.

6. Government of Ontario, "Regulation Respecting Control of Exposure to Biological or Chemical Agents", RRO 1990, O. Reg. 833.

7. Rajhans, G.S., "Indoor Air Quality and Carbon Dioxide Levels", Occupational Health in Ontario, Vol. 4, pp. 160 - 167, Ontario Government Publications, 1983.

APPENDIX I

VOLUNTEERS VITAL SIGNS

Vital Signs

Table A1. lists the average of vital signs monitoring for each one of the 25 volunteers. Also shown in the table are the standard deviations associated with each average.

Volunteer #	Pulse (per min.)	Respiration (per min.)	Blood Pres. (mm Hg)	O_2 Sat. (%)	CO_2 Pres. (mm Hg)
1	72 ± 8	16 ± 2	122 / 81	98.0 ± 0.6	--
2	75 ± 5	17 ± 2	104 / 67	97.4 ± 0.7	--
3	74 ± 7	16 ± 2	112 / 70	97.4 ± 1.0	--
4	82 ± 9	16 ± 3	112 / 78	98.1 ± 0.6	--
5	81 ± 6	15 ± 2	117 / 80	97.7 ± 0.8	48
6	80 ± 7	18 ± 3	122 / 83	98.0 ± 0.6	41
7	83 ± 8	16 ± 2	123 / 85	98.0 ± 0.7	49
8	68 ± 8	16 ± 2	118 / 76	97.8 ± 0.6	--
9	83 ± 8	16 ± 2	118 / 81	97.5 ± 0.7	--
10	53 ± 5	13 ± 2	130 / 78	98.0 ± 0.4	--
11	68 ± 5	18 ± 3	103 / 67	97.4 ± 1.0	--
12	74 ± 6	16 ± 3	130 / 83	98.6 ± 0.5	--
13	74 ± 7	18 ± 2	118 / 77	97.8 ± 0.6	49
14	72 ± 8	15 ± 2	113 / 74	97.2 ± 0.8	44
15	87 ± 6	16 ± 3	125 / 79	97.5 ± 0.6	--
16	72 ± 10	17 ± 3	117 / 77	96.1 ± 2.0	--
17	72 ± 9	14 ± 2	120 / 76	97.0 ± 0.6	--
18	74 ± 6	16 ± 2	122 / 82	97.6 ± 0.7	49
19	76 ± 7	16 ± 2	122 / 83	97.5 ± 0.6	37
20	82 ± 4	16 ± 2	124 / 82	98.1 ± 0.5	57
21	80 ± 8	15 ± 2	115 / 79	97.4 ± 0.8	41
22	80 ± 8	15 ± 2	120 / 78	97.7 ± 0.7	54
23	87 ± 8	17 ± 2	113 / 78	97.2 ± 1.0	--
24	80 ± 8	16 ± 2	128 / 84	97.5 ±0 .8	--
25	70 ± 6	16 ± 2	126 / 81	97.8 ±0 .6	49

Table A1. Average vital signs for the 25 volunteers.

APPENDIX II

VOLUNTEERS COMMENTS AND SUGGESTIONS

RIMER ALCO

"OPERATION TOMMYKNOCKER-PHASE II"

RANA-AIR MINE REFUGE AIR CENTRE

"PARTICIPANT COMMENTS AND EVALUATION"

Developing the right piece of equipment for the application we feel can best be achieved by listening to the input of those trained, active, and concerned in the field the equipment will be used and applied. We believe this to be particularly true with safety/life support equipment.

Rimer Alco needs and welcomes your comments and suggestions to properly progress the development of the Mine Refuge Air Centre. Going into the tests at Kidd Creek there were a number of objectives which were to be evaluated and which your feed back on would be valuable to have. In the space provided below please provide your comments on each of the areas, and any other points which you feel would provide benefit to the final design.

1. Did you find the system simple to use and was it easy to operate? What improvements and/or changes would you suggest to improve it in this area?

1 *I find the system simple to use.*

2 *Yes, it was simple to use and was easy to operate.*

3 *Very simple and easy to operate.*

4 *It was easy to use.*

5 *Yes.*

6 *None.*

7 *Yes, O.K. to operate.*

8 *Yes, very easy to use.*

9 *Very easy to understand, even with little underground experience. Perhaps a colour chart for the soda lime might be of value.*

10 *Yes, I found the system to be easy to operate. I see no need to improve it.*

11 *The system was very nice to use. There were no problems with the instructions at all.*

12 *Very simple to start up.*

13 *Very easy to use.*

14 *Yes, it was easy to use and operate. Make colour change more noticeable.*

15 *The system is simple and easy to use.*

16 *Yes, it is simple to understand the system. I think there should be no changes to the system.*

17 *Yes. None.*

18 *Yes.*

19 *Yes, the system is simple to use. I don't think it needs any improvements.*

20 *Yes, the system was very self-explanatory when setting it up for use. No changes or improvements at this time could or should be made.*

21 *Yes.*

22 *Yes, simple to use. No improvements suggested. Good instructions on machine.*

2. Based on how you felt and with the information on the Oxygen and CO_2 levels do you feel the RANA-Air system proved its ability to maintain Oxygen and Carbon Dioxide to safe levels?

1 *The RANA-AIR System has the ability to maintain oxygen and carbon dioxide to safe levels.*

2 *I feel that it is very safe.*

3 *Yes, because you could notice when your carbon dioxide levels are getting higher by the discolouring of the soda lime.*

4 *Yes.*

5 *Yes.*

6 *Yes.*

7 *Yes,*

8 *Very much so.*

9 *The machine performed perfectly. No problem to breathing at all.*

10 *The system has proven to me that its main purpose has well exceeded its expectations.*

11 *The RANA-AIR System surpassed all of my expectations. Its performance was flawless.*

12 *Very much so.*

13 *Yes.*

14 *Yes, it does maintain oxygen and carbon dioxide in safe levels.*

15 *Good system. Oxygen and carbon dioxide levels O.K.*

16 *Yes.*

17 *Yes.*

18 *Yes.*

19 *Yes it did.*

20 *Yes, equipment was found by men inside to work above what we told would happen!*

21 *Yes.*

22 *Yes.*

3. What other factors existed in the refuge station that were a result of many people trapped in a small area for a prolonged period of time that effected how you felt and how comfortable you were (odour, humidity, noise, stress, temperature, etc.)?

1 *I felt the humidity for a prolonged period to become uncomfortable.*

2 *It was warm and humid, but if the RANA-AIR System would save your life, why not.*

3 *Humidity was the only uncomfortable thing during our duration in the refuge station. The noise was very acceptable, but could have been a little more quiet.*

4 *Humidity and temperature.*

5 *Humidity and temperature.*

6 *ODOUR - Slowly as time goes on, you get used to it. HUMIDITY - is very high. O.K. to sleep for short periods of time. NOISE - O.K. STRESS - not bad. TEMPERATURE - O.K.*

7 *Lack of moving air. Ceiling fan would be appropriate.*

8 *The humidity and a rise in temperature was acceptable. When the drawers were changed at 5:00 a.m., I noticed a small decrease in temperature.*

9 *Humidity was high, and there was a need for more space. Odour was not a problem.*

10 *Although there were obstacles encountered in this test, I found that there was very low levels in stress, except for the stress caused by lack of sleep.*

11 *It was very humid, and sleeping arrangements came into play. All people in the room became very sleepy after about sixteen hours.*

12 *Humidity was the only really uncomfortable factor.*

13 *Odour and humidity.*

14 *There was a lot of humidity and body odour.*

15 *Everything was bearable.*

16 *Temperature and too much light.*

17 *Humidity should be lower.*

18 *Very little odour. Humidity was O.K. Noise was very little. I felt no stress. Temperature was comfortable.*

20 *Humidity is very noticeable after eight hours, but bearable over the twenty-four hour period. Temperature (29.4°C) was easy to handle. No problem here!*

21 *Shortage of room. You could reduce the noise of the blowers.*

22 *Humidity the number-one concern. Temperature the number-two concern.*

4. General Comments/Suggestions Regarding the RANA-AIR Mine Refuge Air Centre:

Is the size, colour and shape of the system appropriate?

1 *Yes, size colour and shape are appropriate.*

2 *You don't really need storage compartments. Just use the soda lime box when it is not in use. It would decrease the size of the machine.*

3 *Size is very compact for the size of this lunch-room (refuge station).*

4 *It is a good sized unit.*

5 *The size should be smaller.*

6 *Yes.*

7 *Yes.*

8 *I guess it is O.K. What can you say, to me the system did its job.*

9 *Perhaps a colour chart for the soda lime might be of value.*

10 *Yes.*

11 *I would like to see a smaller unit, and the shell could be made of fibreglass, plastic or kevlar. Take all sharp edges away, and maybe have it on wheels. Blue is a calming colour. Maybe this should be considered.*

12 *Yes.*

13 *Yes.*

14 *Size, colour and shape are O.K.*

15 *Yes, except smaller soda lime drawers.*

16 *Yes.*

17 *Size should go with size of refuge station. Colour and shape O.K.*

18 *I think it was appropriate for the amount of men we were (twenty-five).*

19 *Yes.*

20 *This unit is well made. The drawers containing soda lime fitted well into the cabinet!*

22 *Could be smaller. Colour is O.K.! Shape is O.K.!*

Did the noise level of the system cause you concern? In a real emergency situation, given the purpose of the blower system, would the noise have added to your anxiety and stress?

1 *No, the noise level of the system is worth its purpose.*

2 *It would depend on how long the RANA-AIR System is on.*

3 *No, not for twenty-four hours, but it could have added anxiety for a longer period of time.*

4 *Noise is very low and does not cause any stress.*

5 *No.*

6 *No.*

7 *Noise levels were O.K. Hearing the blower system would, in my opinion, relieve people in an emergency situation, knowing the system is working.*

8 *No noise concern to me. But maybe, under different conditions, the noise could add to the level of stress and anxiety.*

9 *Not at all. When we changed the soda lime, the absence of the blower was missed.*

10 *In a real emergency situation, the little noise caused by this unit would be very welcome.*

11 *No, the noise was hardly noticeable with the activity of twenty-five men.*

12 *Not at all!*

13 *I did not feel the system was noisy.*

14 *Noise level was all right. No, it would not have bothered me.*

15 *Noise level O.K. No added anxiety or stress. Easier to take than a compressed airline blowing.*

16 *No, the noise did not bother me.*

17 *Noise is O.K.*

18 *I do not think so.*

19 *No, I did not find it to be noisy.*

20 *No, I personally do not think so because it would give the persons inside the refuge station a feeling of protection by hearing the fan blowing.*

21 *The noise level could be reduced.*

22 *No. No, because if you can hear it you know it is working.*

Was the labelling on the unit and the description of operation in the manual sufficient to use and operate the system effectively?

1 *Yes, labelling and description in manual is sufficient to operate the system effectively.*

2 *It is well labelled for anyone to operate the system.*

3 *Very effective and sufficient.*

4 *Yes.*

5 *Yes.*

6 *Yes.*

7 *Yes, O.K. to understand.*

8 *I think the information was very clear and straight-forward.*

9 *No problem.*

10 *Yes.*

11 *Everything was very clear and precise.*

12 *Yes, it was.*

13 *Yes.*

14 *Yes, it was good enough.*

15 *Yes, easy instructions.*

16 *Yes.*

17 *Yes.*

18 *Yes.*

19 *Yes.*

20 *Yes.*

21 *Yes.*

22 *Yes, very good instructions!*

Referring to the memo posted on the RANA-AIR system as "IMPORTANT INFORMATION" do you like the changes that are proposed in the materials of construction and in the way in which the Soda Lime is proposed to be packaged? What other suggestions could you offer?

1 *No, I would not want changes in any way.*

3 *Yes.*

4 *I like the changes.*

6 *I think the sealed packaging is a good idea because it will make it a lot easier to start it up.*

7 *Fibreglass construction, smaller unit.*

8 *I think so. The proposed changes would make it more convenient to start and handle.*

9 *Good idea.*

10 *I see no reason to change anything.*

11 *Yes, everything is good, but there is always room for improvements.*

12 *Good!*

13 *Yes.*

14 *Yes, the changes will be O.K.*

15 *The changes are good.*

17 *All O.K.*

19 *Yes.*

20 *Yes. Soda lime installation is no problem for handling. Put Unit on casters for moving around in refuge station.*

21 *Yes.*

22 *Good ideas. But put system on wheels.*

Other Comments and/or Suggestions:

2 *During your next Tommyknocker operation, they should not have any table. They should have a cot for every person.*

3 *Very simple to operate.*

5 - *For the amount of people that were inside the refuge station, I feel very confident with the RANA-AIR System. The soda lime and oxygen lasted longer than they predicted.*
- *The shell should be made of a hard plastic.*

7 *Could this unit be designed so that exhaust air would exit the RANA-AIR unit in such a way that the air in the refuge station would be circulating around the room? This may help relieve some of the stickiness in the air! Would it be possible to recommend to companies using this unit that circulation fans be in place or ceiling fans?*

8 *I am impressed with this unit and feel comfortable that I might have to depend on it some day. Thanks.*

11 *I was glad to participate in your tests of this unit. Thank you.*

12 *The blower's exits could have tubes to be fed to the extremes of the refuge station. This might create a better circulation within.*

17 *Carbon dioxide and oxygen monitors should be put onto the machine.*

18 - *This unit, in my opinion, works very well.*
- *I would like to know if we can down-size the size of the unit.*
- *Regarding the out-take of air, can you make the blower point up and out, so that we can have better circulation?*

20 *This test showed me that anything is possible today within the mining industry, and with equipment such as this. I know that I would feel safer working down greater depths.*

22 - *Very simple to operate.*
- *Maybe ceiling fans to circulate air?*

23 - *Participants should be shown the inside of the machine so as they can suggest if the unit could be smaller.*
- *Second drawer for the side was very tight.*
- *When soda lime was changed, air leaving the exhaust felt cooler.*

Thanks again.