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

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Ontario Ministry of Labour

ONTARIO MINE RESCUE

CANMET

MAPAM

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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.

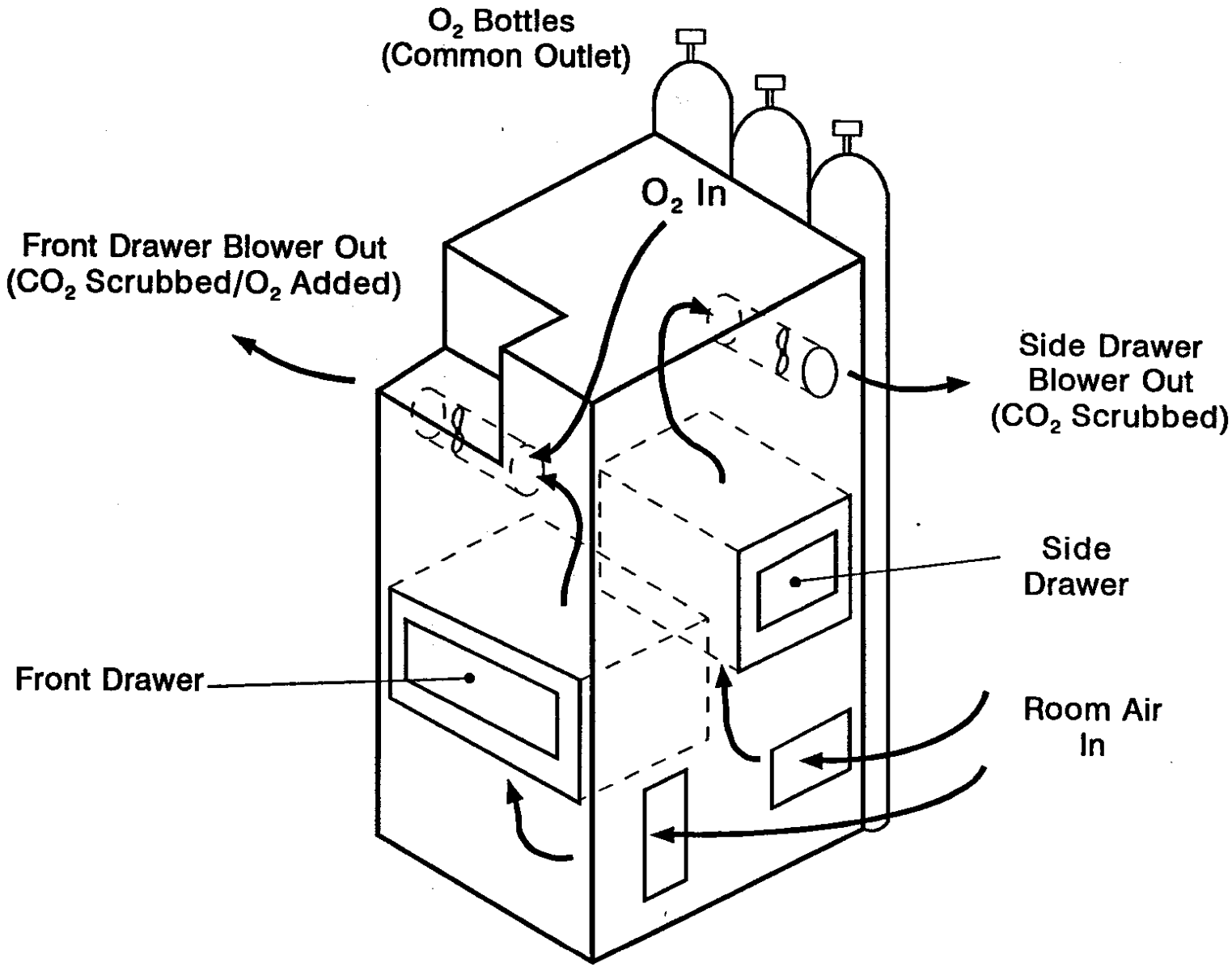


Figure 1. RANA-AIR system.

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

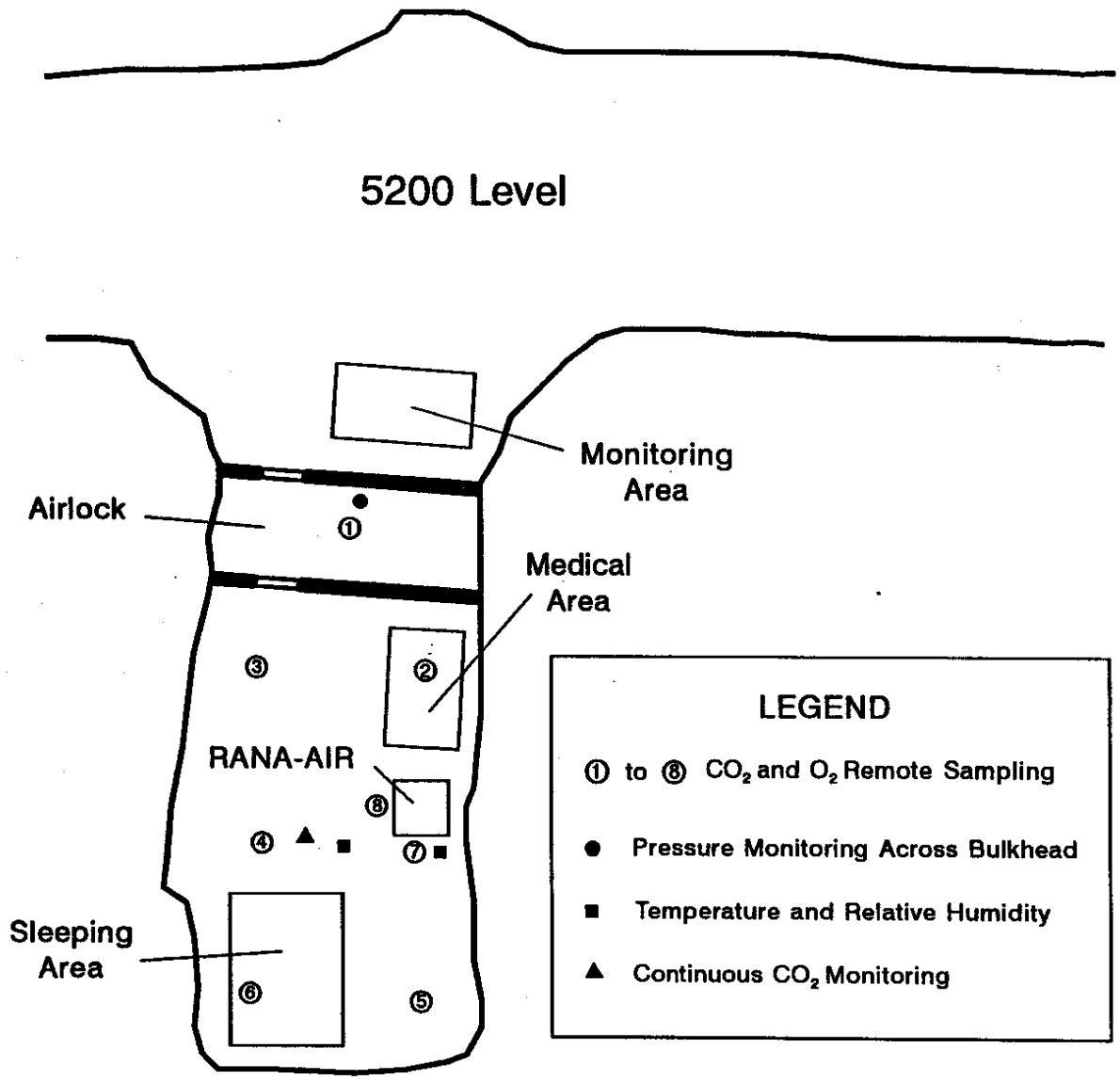


Figure 2. Refuge station schematic plan (not to scale).

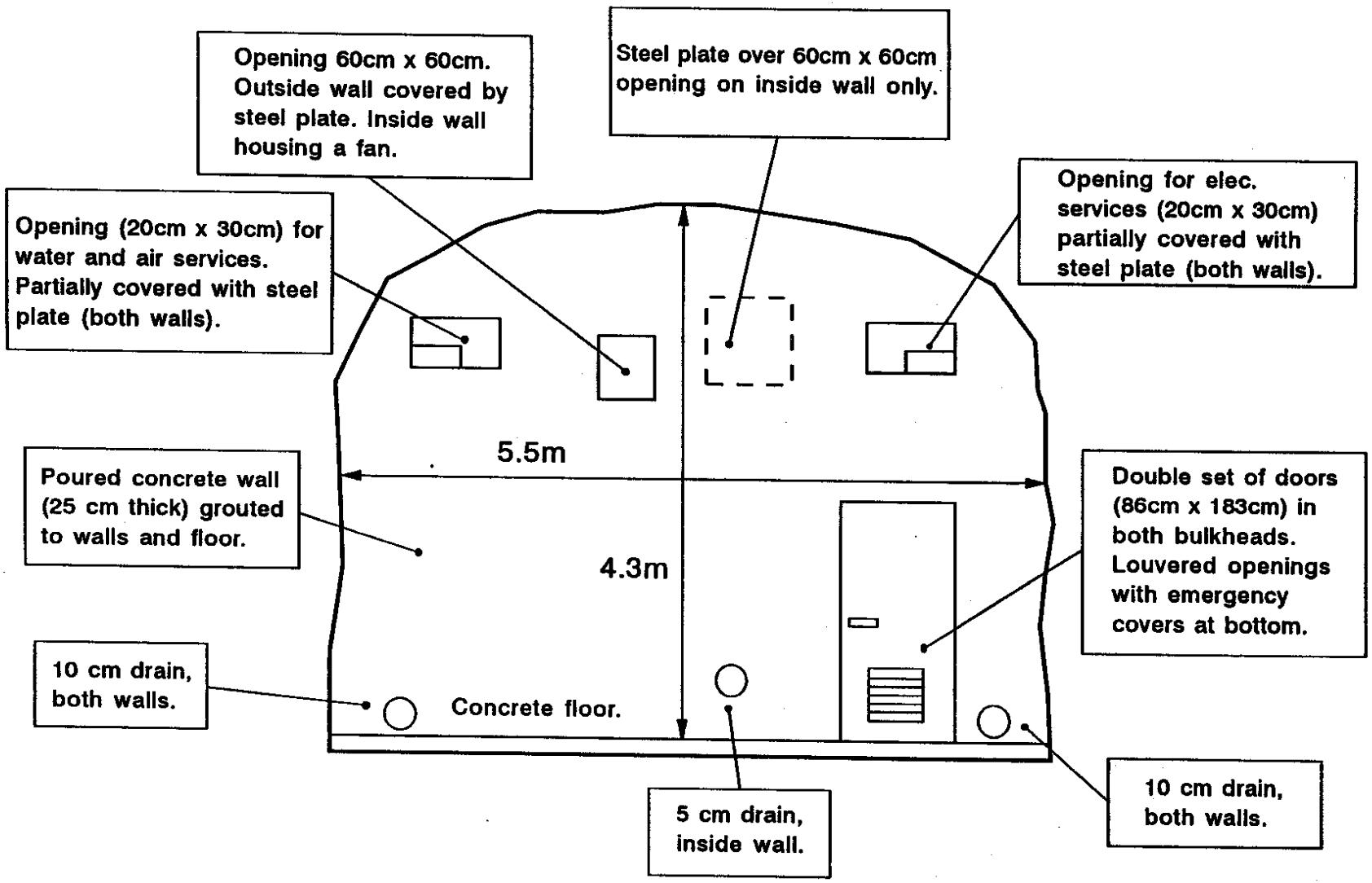
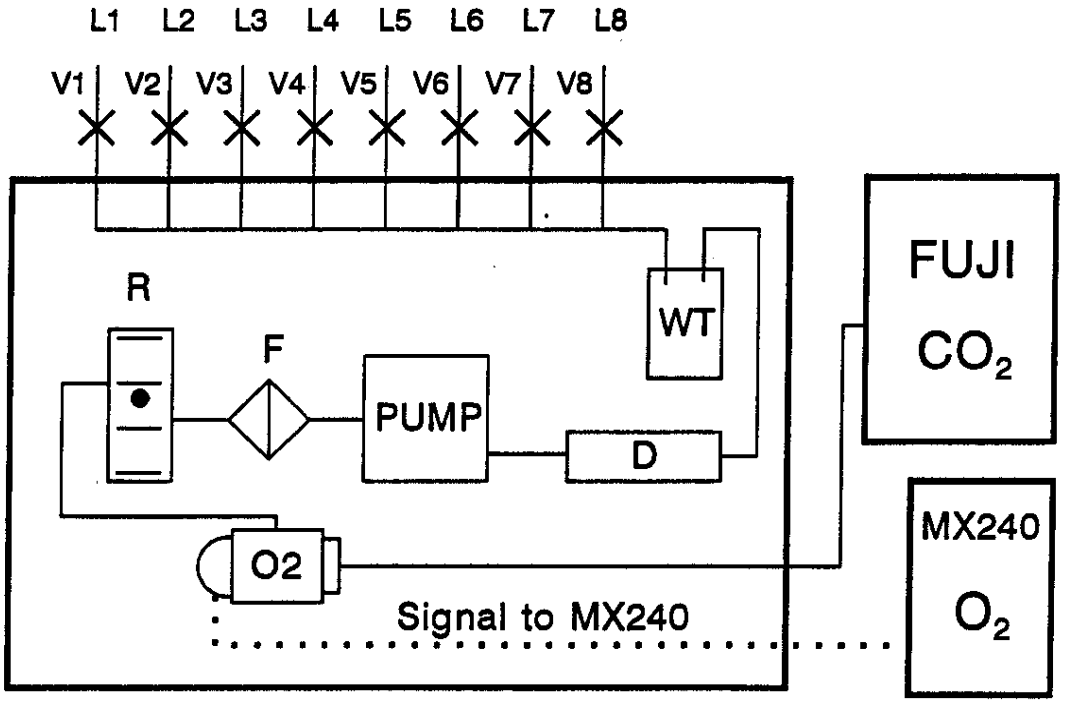


Figure 3. Schematic diagram of the refuge station bulkheads(not to scale).



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

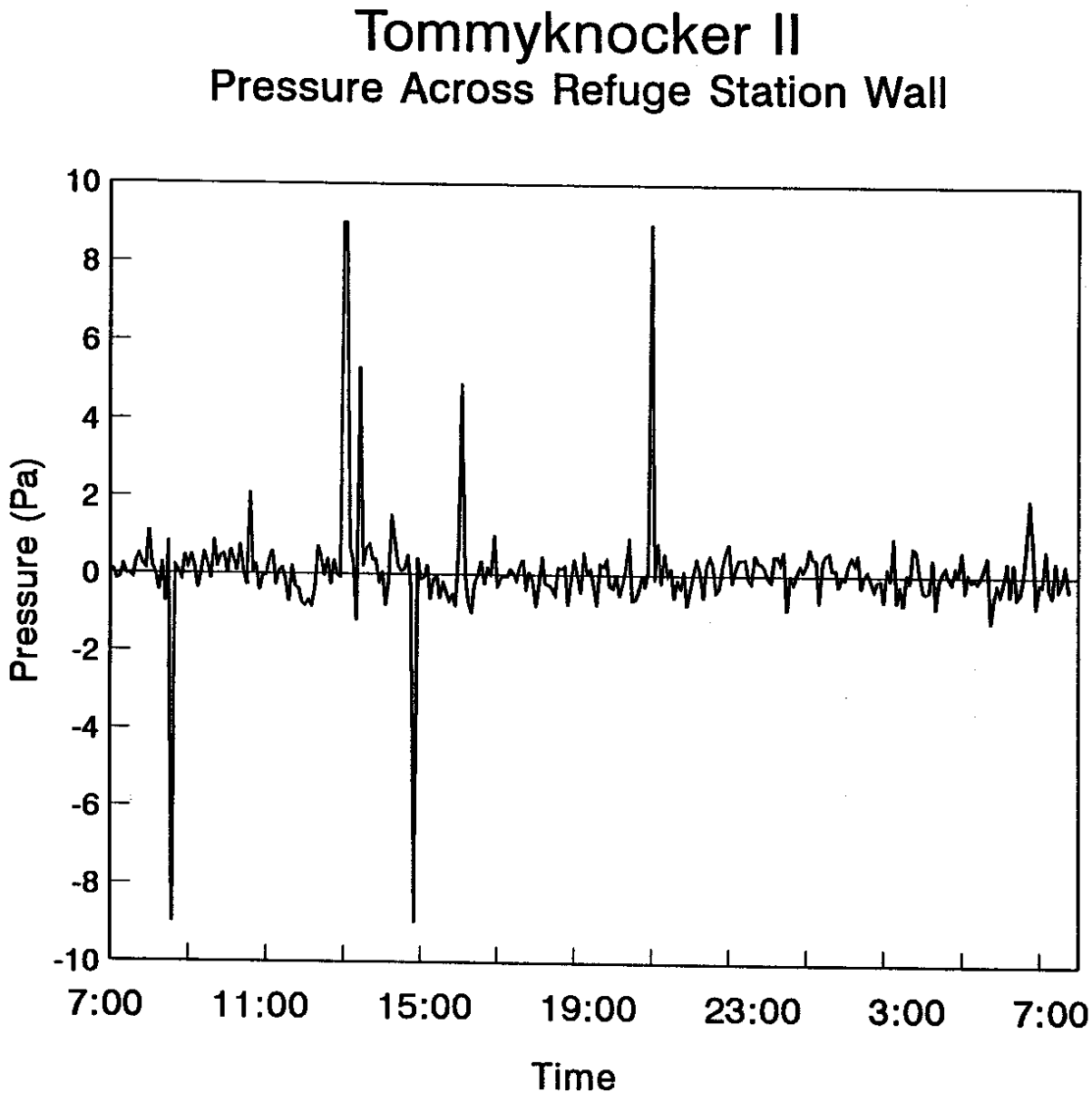


Figure 5. Differential pressure across refuge station bulkhead.

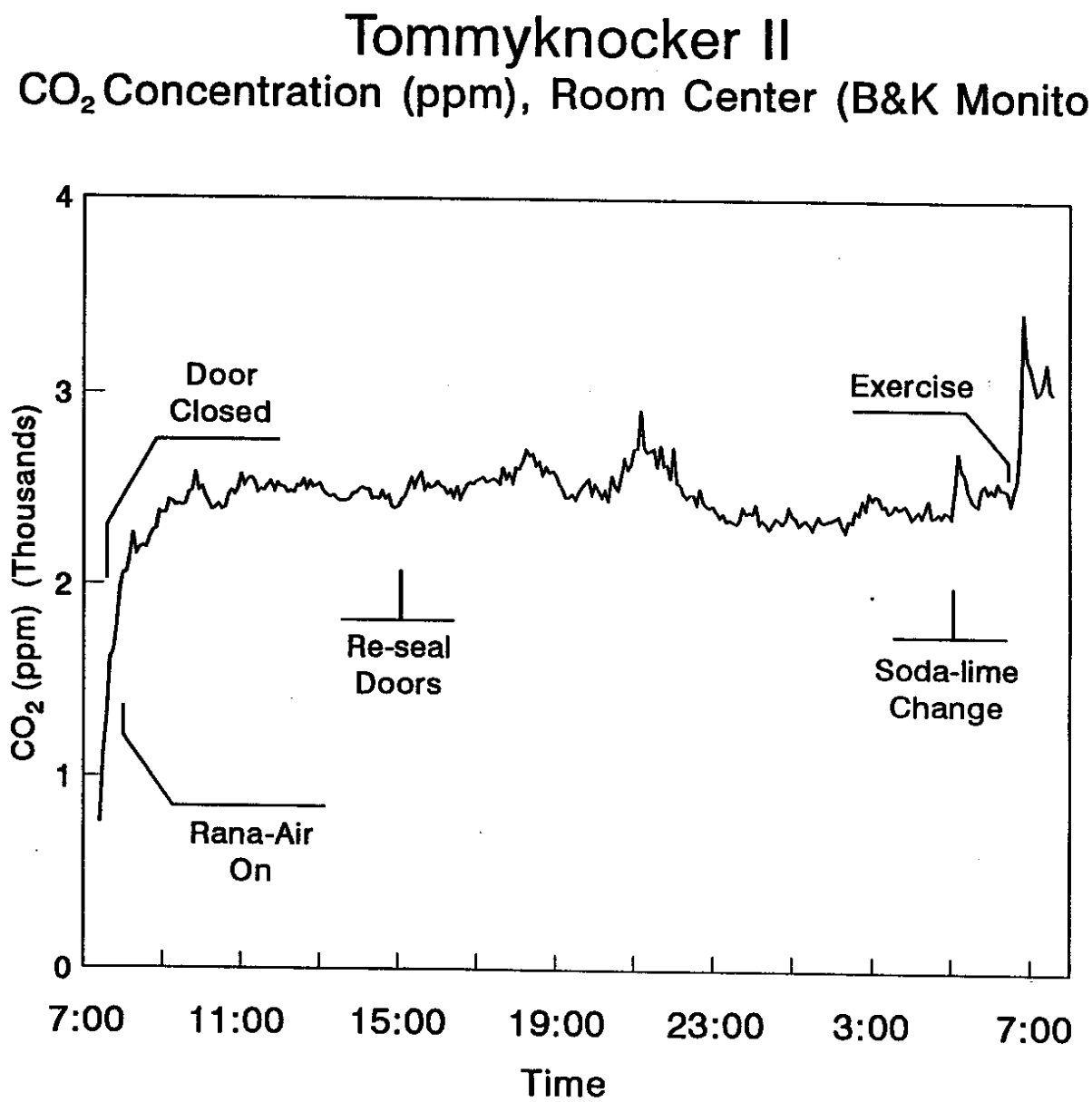


Figure 6. Carbon dioxide concentration in the center of the refuge station.

Ambient Carbon Dioxide Concentration Profiles

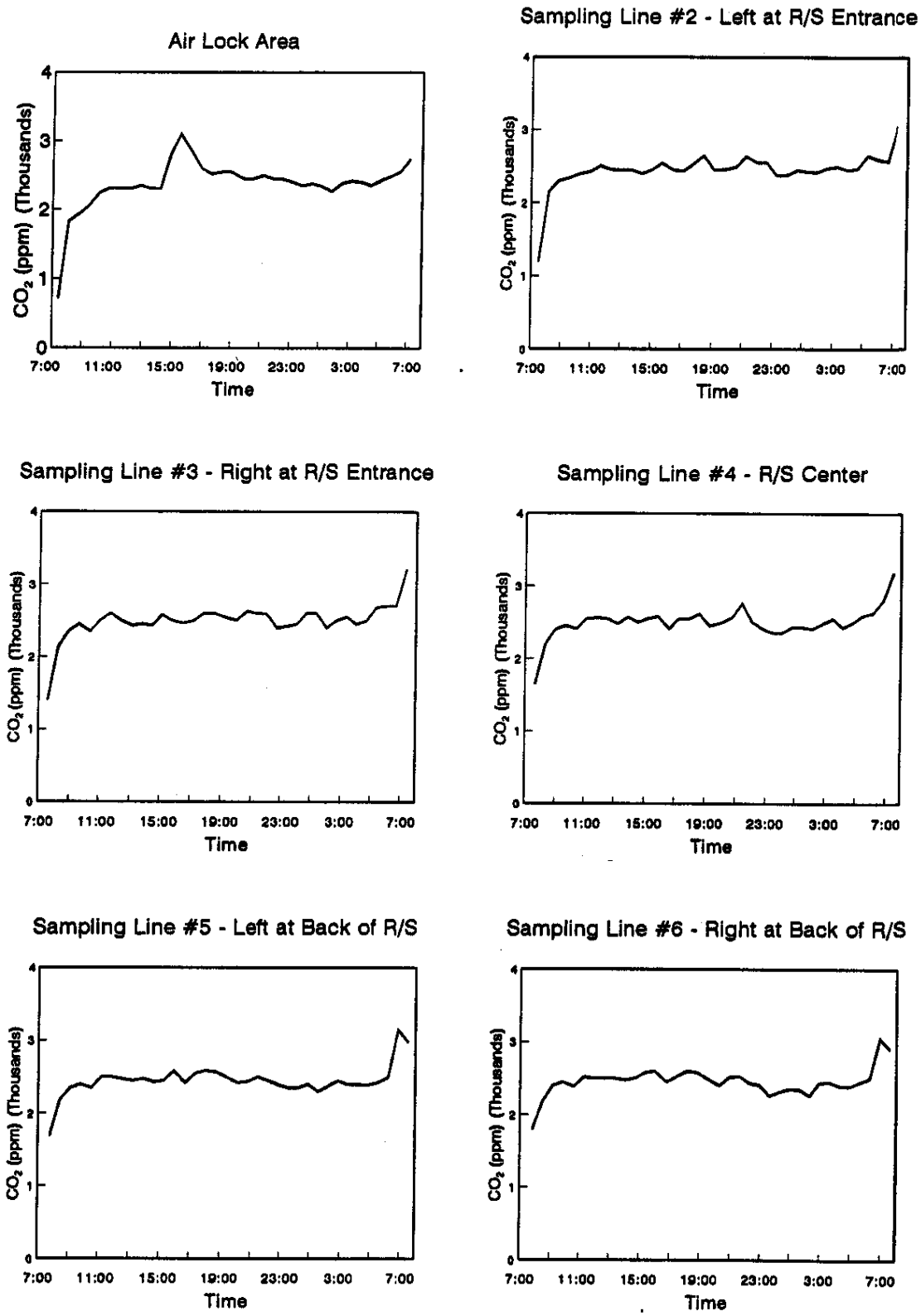


Figure 7. Carbon dioxide concentration in the refuge station.

Ambient Oxygen Concentration Profiles (%)

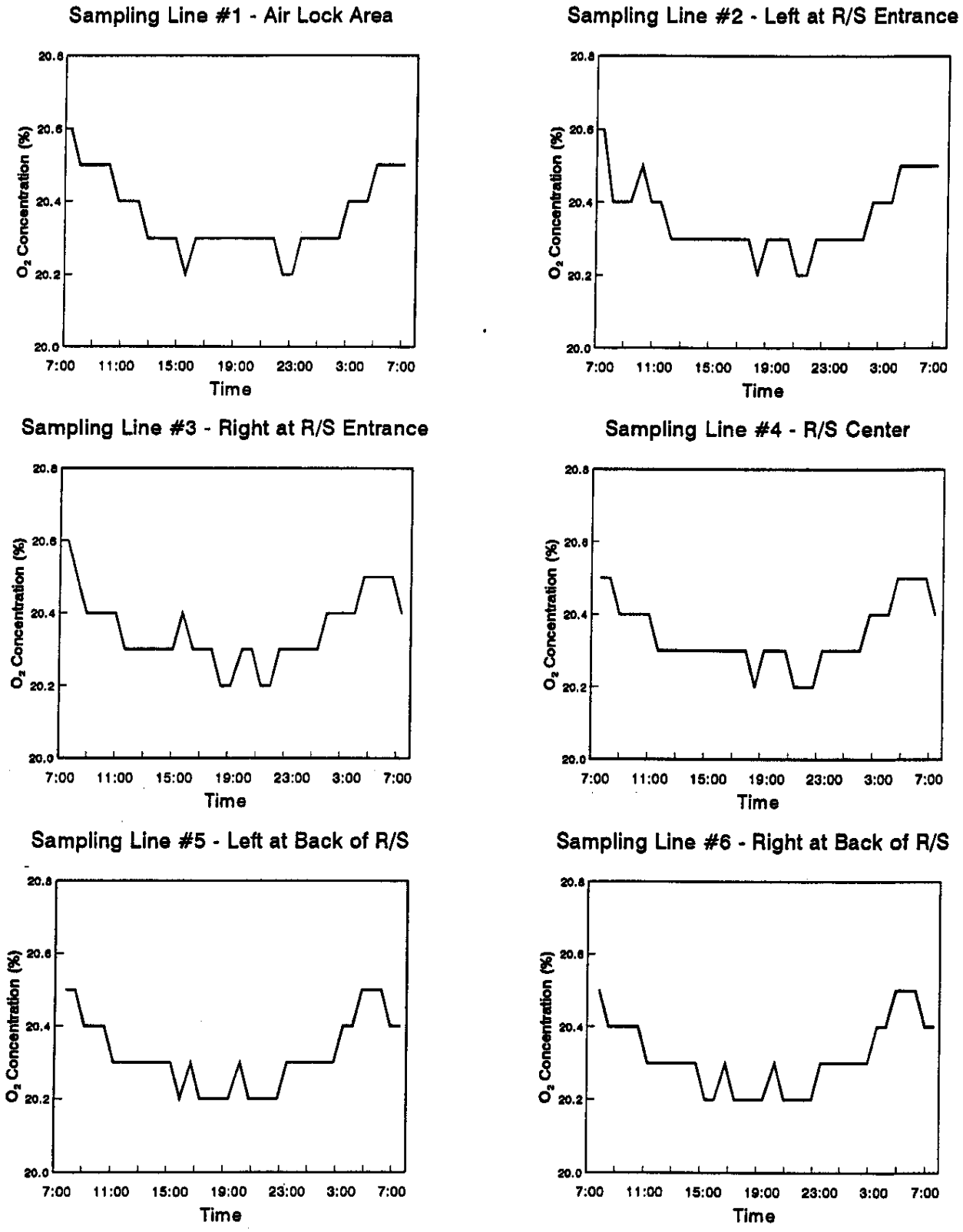


Figure 8. Oxygen concentration in the refuge station.

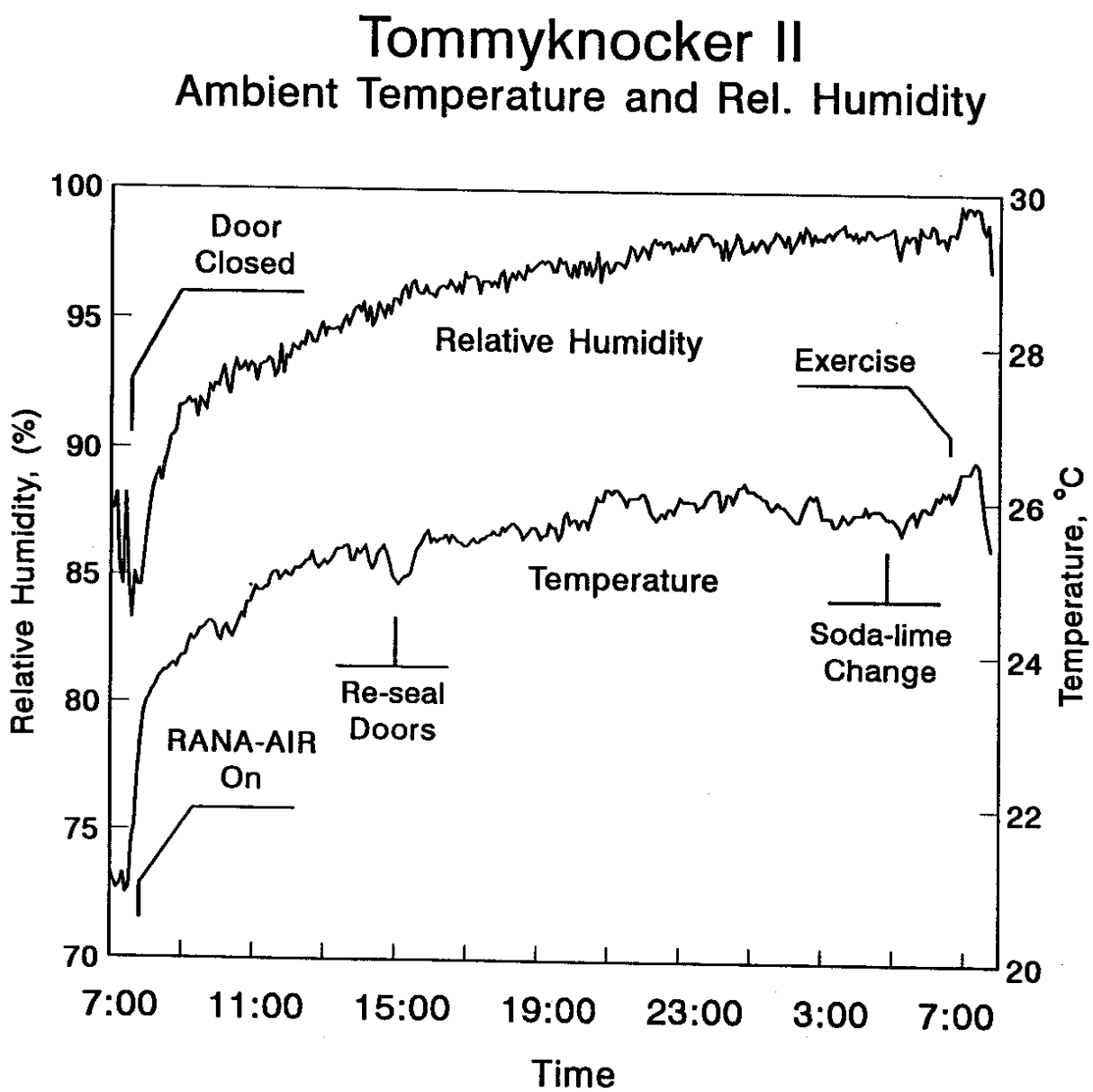


Figure 9. Ambient temperature and relative humidity.

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

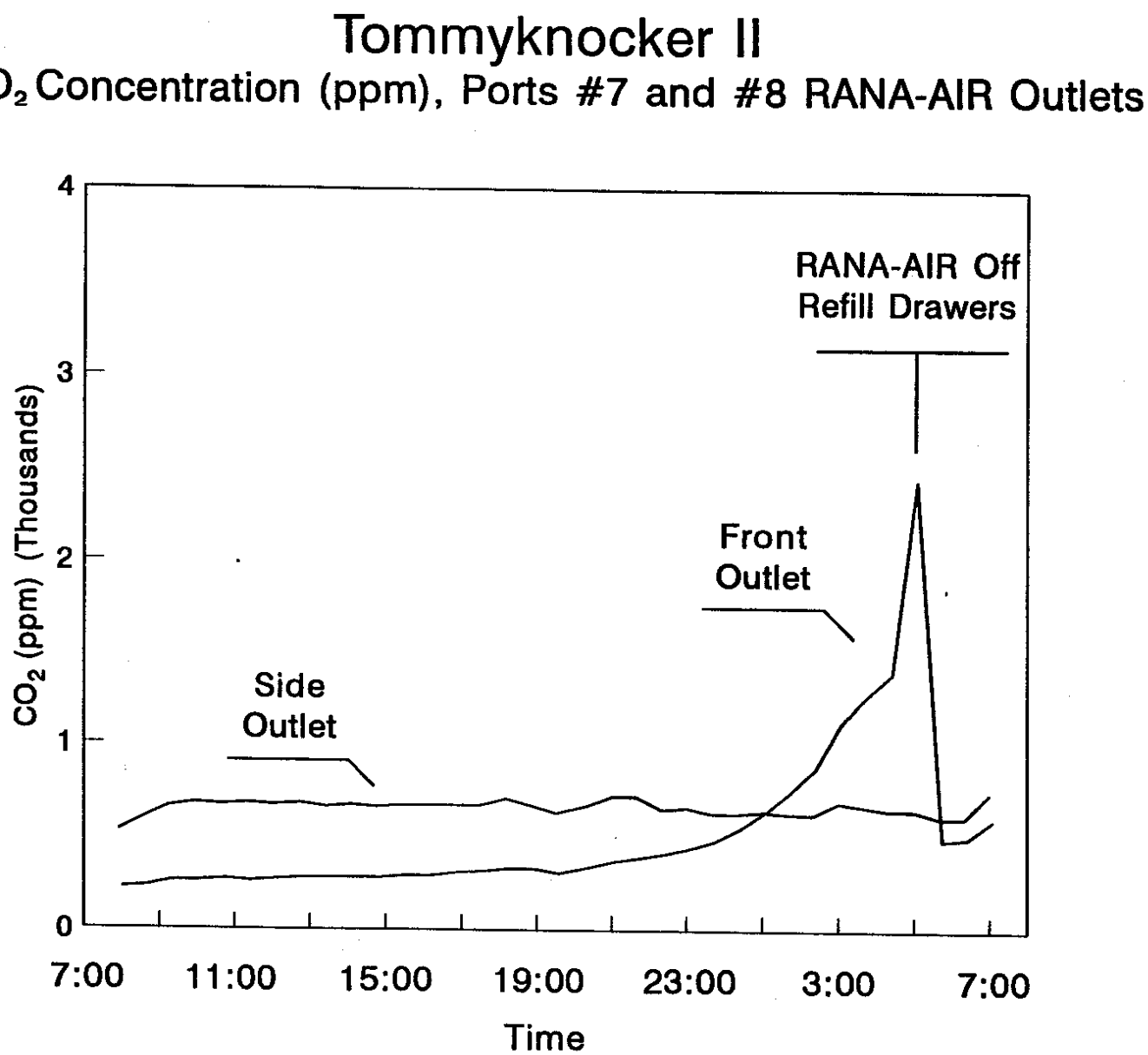


Figure 10. Carbon dioxide concentration at the RANA-AIR outlets.

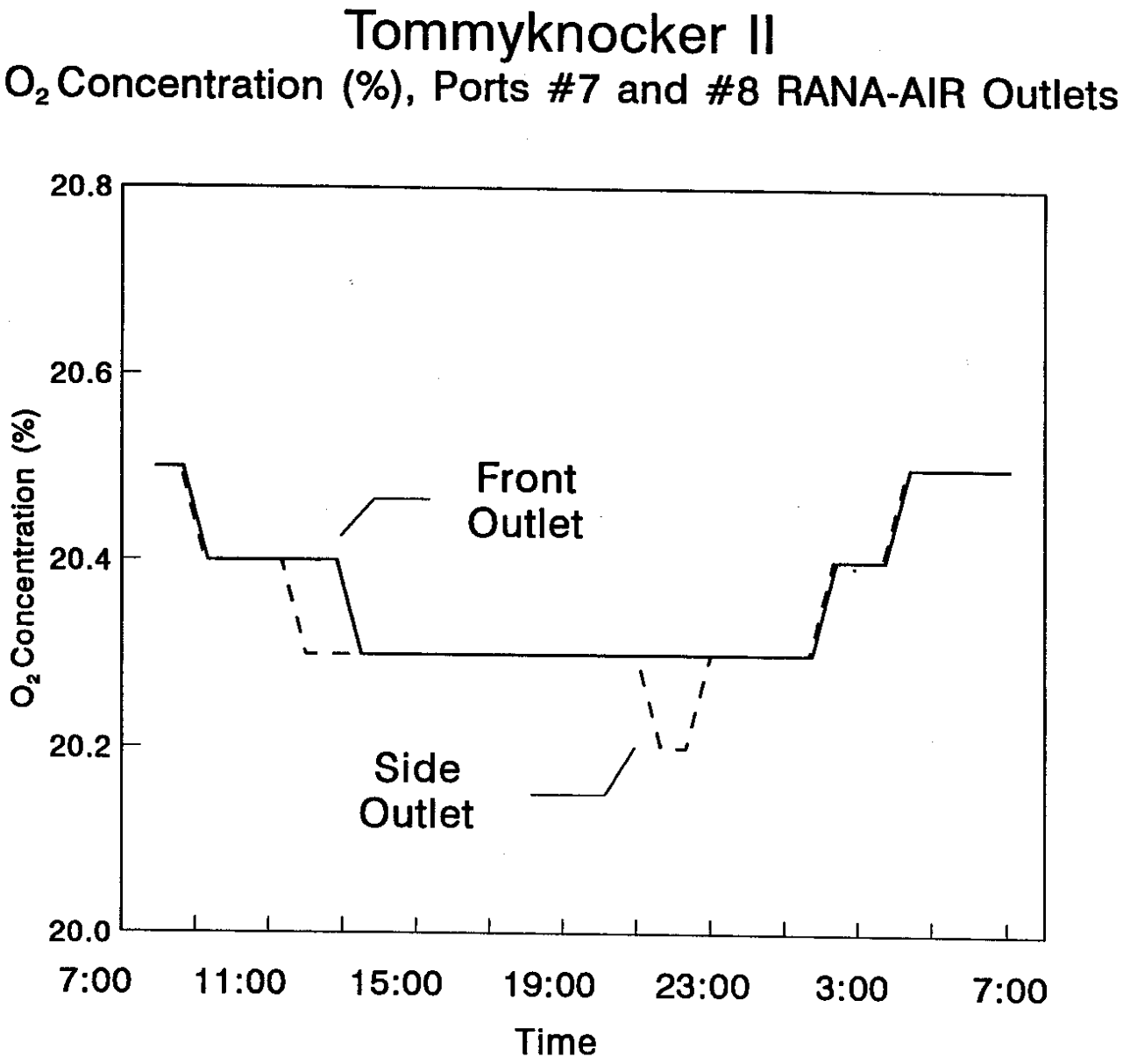


Figure 11. Oxygen concentration at the RANA-AIR outlets.

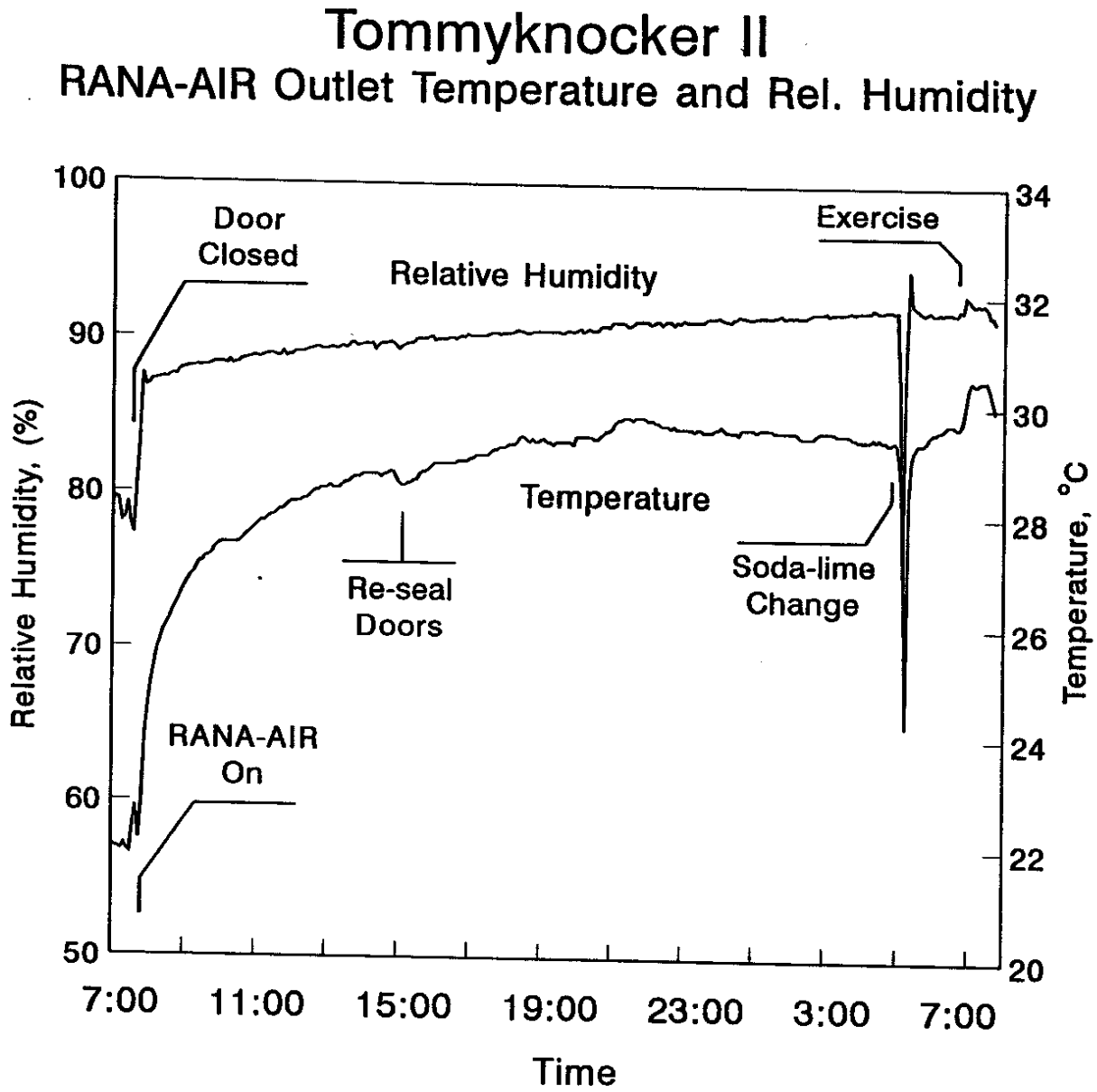


Figure 12. Relative humidity and temperature at the RANA-AIR outlet.

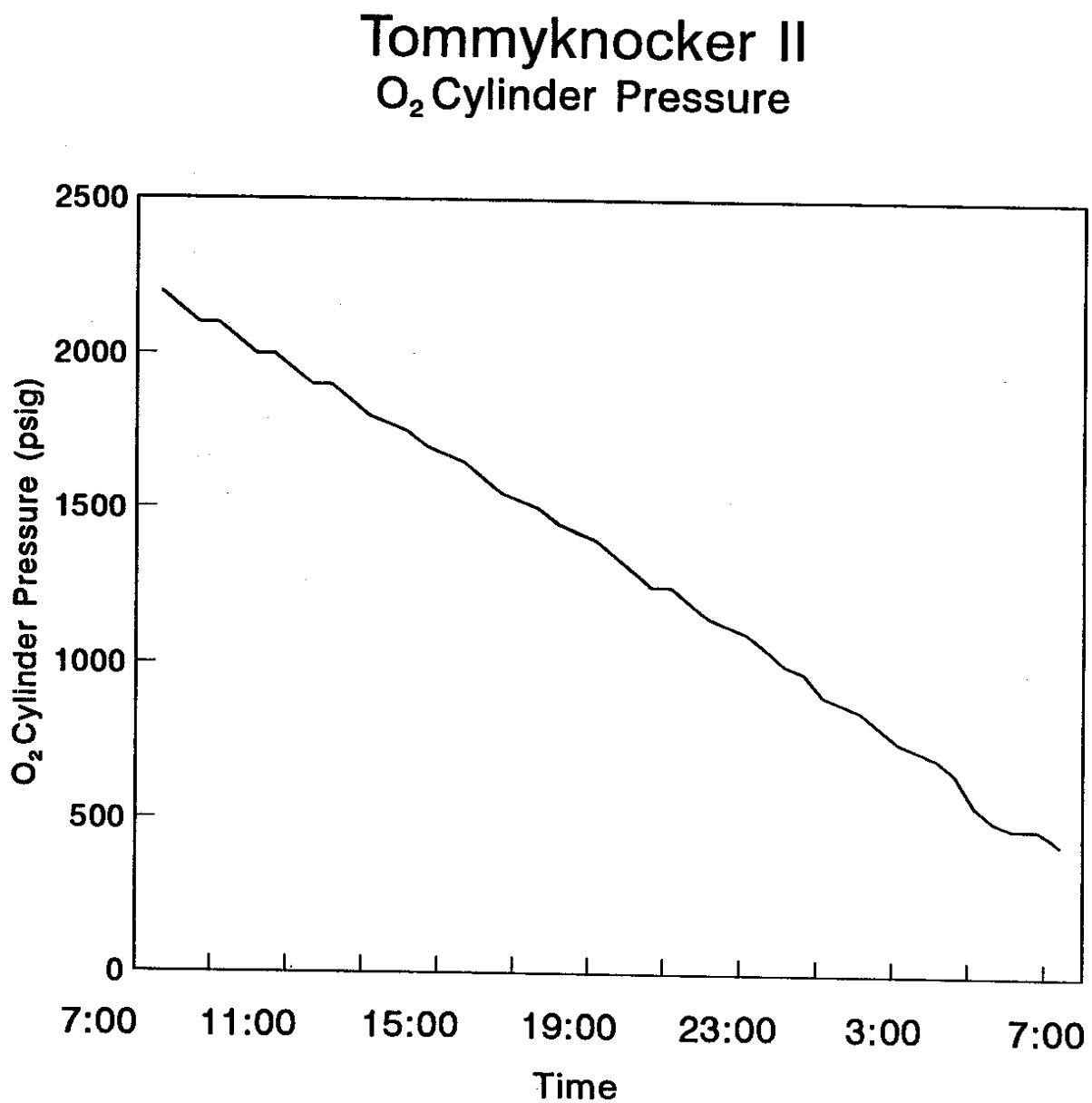


Figure 13. Oxygen cylinder pressure.

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

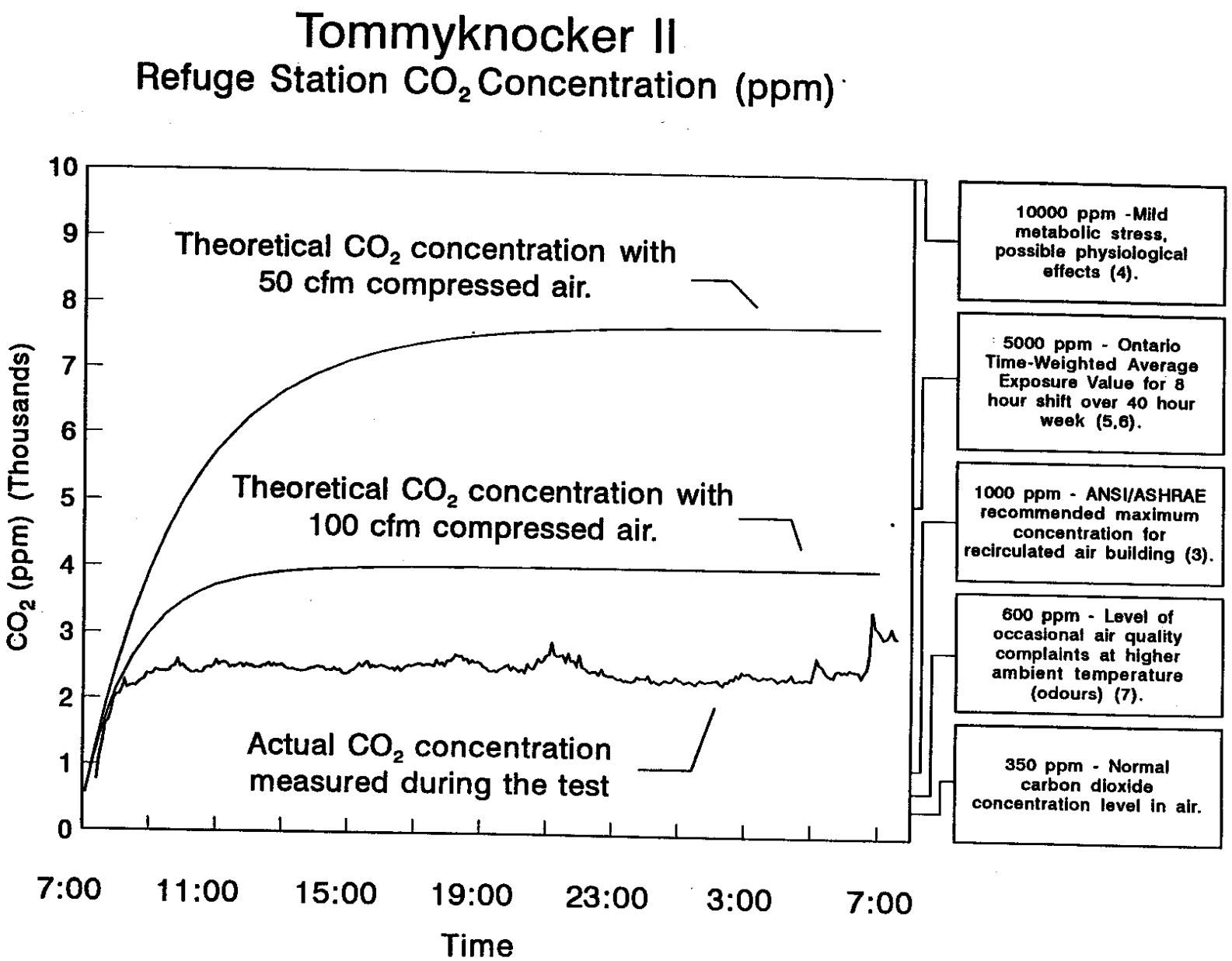


Figure 14. Theoretical and actual carbon dioxide concentrations in refuge station.

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

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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.

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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.