CHAPTER 1
GENERAL INTRODUCTION

1.1 Introduction

The filter self rescuers (FSRs) currently approved for underground use in Australia are not designed to function in an oxygen deficient environment and accordingly cannot be relied upon to save lives, particularly in situations where there has been a fire or explosion in a mine. The function of FSRs is to remove low concentrations of carbon monoxide (up to 1.5%) from the inhaled air (Strang and Mackenzie-Wood, 1990). FSRs do not produce any oxygen. In order to escape from an irreparable atmosphere to a respirable zone, a miner must be provided continuously with sufficient oxygen. Worldwide research for the past three decades has led to the development of SCSR, which are breathing apparatus that provide oxygen to a wearer for a nominal period of time. The nominal duration of a SCSR is determined on a breathing simulator in the laboratory at a breathing rate of 35 litres per minute.

SCSRs were originally developed in Germany as ancillary escape equipment. In 1978 the USA government legislated that by 1981 all persons underground in USA mines must be supplied with a SCSR of 60 minutes nominal duration. In France, in 1989, it became mandatory for all persons proceeding underground to be issued with a SCSR of 30 minute duration. These units were to be carried on the miner’s belt and “safe havens” containing 90 minute duration units were to be located within the limits of the protection afforded by the SCSR. In 1988 the South African Government Mining Engineer legislated that each person proceeding underground must be equipped with a 30 minute duration SCSR.

In the light of the recent fatalities experienced in the Australian coal mining industry, such as the Moura No.2 disaster in which 11 lives were lost underground, there was a general consensus for the need to legislate SCSR to replace FSRs. The recommendations of the Moura No.2 inquiry included the following extract:

"..... development and introduction of oxygen based escape systems from underground coal mines, as means to maximise the likelihood of survival, in the event of fires or explosion".

In Australia, SCSR are used for special purposes, for example when working in gas outburst prone mining conditions, and in recent years SCSR have replaced the FSR under these conditions. In the State of New South Wales, an exemption is required if a colliery wishes to replace the FSR as compulsory equipment to be worn by each person who wishes to proceed underground. The exemption will only be granted if the mine manager can demonstrate that each person is provided with full protection through the changed arrangements. The deployment of SCSR in Queensland as approved standard units may come into effect in January 1998 (The Moura Task Group 4, 1996).
1.2 Self-Contained Self Rescuers (SCSR)

There are two types of SCSRs available commercially, compressed and chemically produced oxygen. The compressed oxygen type supplies oxygen to the wearer on demand from a cylinder of high pressure oxygen, the carbon dioxide in the exhaled breath is removed by a soda lime or alkali canister. The chemically produced oxygen type use a chemical, potassium superoxide (KO₂), that reacts with the moisture in the wearer’s breath to produce oxygen and potassium hydroxide. The potassium hydroxide then chemically removes (scrubs) carbon dioxide. Both reactions are exothermic, causing the canister to become hot. Heat exchangers made of wire mesh are usually fitted in the breathing tube to reduce the inhalation temperature.

Each gram of pure KO₂ is capable of producing 0.24 litres of oxygen (Shearer, 1996). An initial supply of oxygen is also available to the wearer from either compressed oxygen contained in a small cylinder located within the SCSR unit or as a chlorate candle which produces around 10 litres of oxygen. This initial oxygen supply fills the breathing bag over a period of 2 to 3 minutes. As oxygen is produced, any excess to requirements may result in increased pressure within the breathing bag. If the pressure exceeds the relief valve opening pressure then gas is released to the atmosphere.

A review of various types of self rescuers are reported by Strang and MacKenzie-Wood (1990). Table 1 (DMR, 1996) lists a variety of models and makes currently marketed in Australia. MSA Portal-Pack SCSRs with a nominal duration of 60 minutes were used in all trials, as 60 minutes was considered the most desirable duration for the investigation.

The coal mining industries in NSW and Qld require that SCSRs comply with Australian Standard (AS) criteria where applicable. Compressed oxygen SCSRs must meet the requirements of AS 1716 - 1994 and the duration is determined when the criteria for inhalation temperature, breathing resistance, inhaled CO₂ and oxygen cylinder pressure is exceeded.

These criteria are:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Limit</th>
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</thead>
<tbody>
<tr>
<td>Maximum inhalation temperature</td>
<td>≤ 50°C</td>
</tr>
<tr>
<td>Inhalation and exhalation resistance</td>
<td>≤ 0.5kPa</td>
</tr>
<tr>
<td>Inhaled CO₂</td>
<td>≤ 1.5%</td>
</tr>
<tr>
<td>O₂ cylinder pressure</td>
<td>≤ 1000 kPa</td>
</tr>
</tbody>
</table>

Currently there is no Australian Standard for chemically produced oxygen SCSRs, the standard used for assessment is the British and European Standard BS/EN 410 : 1993. The criteria for determining duration in this standard is:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum inhalation temperature</td>
<td>≤ 55°C</td>
</tr>
<tr>
<td>Exhalation/inhalation resistance</td>
<td>≤ 1.3kPa</td>
</tr>
<tr>
<td>Inhaled CO₂</td>
<td>≤ 1.5%</td>
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</table>
Table 1: Characterisation of Respiratory Escape Apparatus (DMR, 1996)

<table>
<thead>
<tr>
<th>REA</th>
<th>Nominal Duration (Mins)</th>
<th>Weight (Kg)</th>
<th>Starter</th>
<th>Goggles/ Full Face Mask</th>
<th>Training Unit Available</th>
<th>Complies With Standards</th>
<th>Serviceable</th>
<th>Chemical Integrity Indication</th>
<th>Maintenance</th>
<th>Training</th>
<th>Gas Protection</th>
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<tr>
<td>Closed-Circuit Chemical Oxygen</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSA 30/100</td>
<td>30</td>
<td>2.1</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Low</td>
<td>Med</td>
<td>High</td>
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<tr>
<td>Auer SSR16N</td>
<td>30</td>
<td>2.2</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<td>Low</td>
<td>Med</td>
<td>High</td>
</tr>
<tr>
<td>Drager Oxybocks K</td>
<td>30</td>
<td>2.1</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<td>Low</td>
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<td>High</td>
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<tr>
<td>Fenzy Biocell 1</td>
<td>30</td>
<td>1.9</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>N/A</td>
<td>Low</td>
<td>Med</td>
<td>High</td>
</tr>
<tr>
<td>Siza Moya</td>
<td>30</td>
<td>2.0</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Low</td>
<td>Med</td>
<td>High</td>
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<td>MSA Portal Pack</td>
<td>60</td>
<td>2.5</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Low</td>
<td>Med</td>
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<tr>
<td>Auer SSR90 (K60)</td>
<td>60</td>
<td>5.0</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Low</td>
<td>Med</td>
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<td>CSE SR-100</td>
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<td>2.5</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>No</td>
<td>Low</td>
<td>Med</td>
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<tr>
<td>Auer SSR 120 (90K)</td>
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<td>6.0</td>
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<td>Yes</td>
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<td>Fenzy Biocell 90</td>
<td>90</td>
<td>4.9</td>
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<td>Yes</td>
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<td>Oencos M20</td>
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<td>1.3</td>
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<td>N/A</td>
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<td>7.5</td>
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<td>Drager SR-30/45</td>
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<td>2.4</td>
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<td>N/A</td>
<td>Yes</td>
<td>Yes</td>
<td>N/A</td>
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<td>Med</td>
<td>High</td>
</tr>
<tr>
<td>Open-Circuit Compressed Air</td>
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<tr>
<td>Drager Low Profile</td>
<td>10</td>
<td>5.0</td>
<td>N/A</td>
<td>Yes</td>
<td>N/A</td>
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<td>N/A</td>
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<tr>
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<td>N/A</td>
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<td>SG15</td>
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<td>5.0</td>
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<td>N/A</td>
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<td>Sabre ESCDM</td>
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<td>N/A</td>
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<td>Yes</td>
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<tr>
<td>Filter Self-Rescuer</td>
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<tr>
<td>Auer W65/W652</td>
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<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
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<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Low</td>
<td>Med</td>
<td>High</td>
</tr>
</tbody>
</table>

* FSRs do not have a fixed capacity and may provide protection for periods greater than nominated period.
Manufacturers currently favour the chemical oxygen SCSR and all future references to SCSRs in this document refer to this type.

Chemically based SCSRs require little maintenance due to the absence of gauges, pressure reducers, lung demand valves and other moving parts. However powdering of the KO2 granules may occur with vibration caused by carrying or transporting the SCSR. This may cause a path of low resistance through the chemical bed leading to a premature breakthrough and build up of CO2 in the wearer’s breathing circuit. This may have a significant effect on the duration of the SCSR. Currently there is no available non-destructive method of assessing this problem.

The CSE Corp., in the USA, is developing a non-destructive method for determining the level of powdering which is based on the noise level produced by the powdered chemical in the bottom of the canister when the canister is rotated at a standard rate in a sound proof enclosure (Shearer, 1996). The decibel output from a sound meter is then related to the reduction in duration as determined by measuring the inhaled CO2 level in the breathing circuit of the SCSR during a breathing simulator test at a breathing rate of 35 litres per minute. This may lead to a procedure whereby a SCSR, which has undergone degradation and is unlikely to achieve its nominal duration, can be withdrawn from service.

The ingress of water vapour into the canister may cause the KO2 granules to break down, for this reason most SCSRs are fitted with silica gel indicators. These colour indicators change from blue to pink in the presence of moisture. Some SCSRs contain a saliva trap in their breathing circuit to prevent excess moisture reaching the chemical bed and reducing their duration.

It has been reported (Shearer, 1996) that an optimum duration with a SCSR is achieved when the wearer’s oxygen consumption is 1.6 litres per minute.

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![Fig. 2 Chemical Utilisation at Various Work Rates](image-url)
Work rates inducing oxygen consumption in excess of 1.6 litres per minute may lead to an ineffective use of the KO₂ chemical caused by pushing exhaled air through the chemical bed too quickly (see Fig. 2), this could lead to collapse of the breathing bag with unused KO₂ remaining in the bed.

Work rates inducing oxygen consumption of less than 1.6 litres per minute may cause oxygen to be produced in excess to the wearer’s requirements and pressure builds up within the breathing bag. Eventually the pressure exceeds the opening pressure of the relief valve and vents to atmosphere. This may occur when individuals are above average in aerobic fitness.

The low minute volume for people breathing at rest also optimises duration and durations of four to five hours have been reported (MSA, 1992).

1.3 MSA Portal-Pack™ Self-Contained Self Rescuer

The Portal-Pack™ Self-Contained Self Rescuer was selected for the project because it was the only unit of 60 minutes duration that had met the requirements of BS/EN 401:1993 (based on the NSW Department of Mineral Resources Tests) and had been approved for use in NSW underground coal mines. The Portal-Pack is a single-use, self-contained closed-circuit breathing apparatus (Fig. 3).

![Portal-Pack Self-Contained Self Rescuer](image)

**Fig. 3 Portal-Pack™ Self-Contained Self Rescuer**

Its operation is completely independent of the surrounding atmosphere. Once properly donned, the SCSR can assist a miner to escape from an area containing smoke, toxic gases or an oxygen deficient atmosphere. Its operating life during escape depends on the demands of the user. A detailed description of the Portal-Pack is provided in Appendix A.
The breathing bag is flat when the unit external cover is initially removed. The unit itself contains only a small quantity of air. Two chemical sources within the unit release the life sustaining oxygen.

The initial source of oxygen is from a cylinder containing the chemical Sodium Chlorate (NaClO₃), commonly known as the “chlorate candle”. Its function is to provide an immediate source of oxygen to fill the system including the breathing bag. When the breathing tube is pulled at the time of donning the apparatus, a primer cap initiates the chemical reaction which “burns” the chlorate to produce oxygen according to Equation 1.

\[ 2\text{NaClO}_3 \rightarrow 2\text{NaCl} + 3\text{O}_2 \]  

(1)

Over the first two to three minutes, the chlorate candle produces roughly 10 litres of oxygen. The released oxygen partially fills the breathing bag. Once the individual commences to breath into the unit the chemical reaction of the wearer’s breath and the potassium superoxide will produce more oxygen continuously.

If the “Chlorate Candle” fails to initiated, the apparatus can still be used and the breathing bag became fully inflated by the end of seven minutes. Failure to initiate the candle was not considered of any significance when interpreting the results as the breathing bag was well inflated when the subject was stopped at a heart rate equivalent to 85% of predicted maximum heart rate for age.

The second source of oxygen is a canister containing potassium superoxide (KO₂). This chemical consists of coarse granules held in place by baffles contained in the canister. The chemical reaction between moisture in the exhaled breath and the KO₂ liberates the oxygen. The Portal-Pack contains about 600 gm of KO₂ which produces approximately 140 litres of oxygen.

The chemical reaction is:

\[ 4\text{KO}_2 + 2\text{H}_2\text{O} \rightarrow 4\text{KOH} + 3\text{O}_2 \]  

(2)

In addition to this, a second reaction takes place between the potassium hydroxide and the carbon dioxide in the external breath to combine and retain CO₂ according to the following equation.

\[ 2\text{KOH} + \text{CO}_2 \rightarrow \text{K}_2\text{CO}_3 + \text{H}_2\text{O} \]  

(3)

The above reactions are self-regulating. The harder the wearer works the more oxygen is generated and the more CO₂ is removed. The basic operation is depicted in Fig. 4.
The duration of a SCSR is the time taken for the oxygen supply to run out and is indicated by the complete collapse of the breathing bag. The wearer is likely to experience increased breathing resistance. As the chemical becomes exhausted, carbon dioxide (CO₂) builds up within the circuit and the wearer may develop a headache or light headedness. The duration of a SCSR was expressed in Equation 4.

\[
\text{SCSR Duration (minutes)} = \frac{\text{Useable Oxygen (litres)}}{\text{Oxygen Consumption (litres/minute)}} \leq \frac{100}{\dot{V}O_2}
\]  

The terms duration of a SCSR and oxygen “run out” time are synonymous and either term will be used throughout this report.

During the project, 54 Portal-Packs were worn to obtain the necessary information. All units were successfully donned and operated until exhaustion of the oxygen supply or withdrawal by the wearer. In one incident the wire holding the heat exchanger in place protruded through the mouthpiece, causing discomfort to the wearer. In a second incident the chlorate candle failed to activate.

1.4 Heart Rate Monitoring System

Previous physiological studies have established a relationship between oxygen consumption, \(\dot{V}O_2\), and the heart rate during the performance of work or exercise (Astrand and Rodahl, 1986). Therefore by continuously monitoring heart rate during the performance of exercise, it is possible to predict the oxygen “run out” time of a SCSR.
The average heart rate was recorded using a Polar Vantage NV™ System. Detailed description of the recording equipment is provided in Appendix B. The system consists of a digital coded transmitter, held onto the chest wall with an elastic strap, and a wristwatch (receiver) worn on the wrist. The details of the procedure used in this study to measure average heart rate is included in Appendix B.

The Polar Vantage NV™ system is powered by a 160mAh lithium battery and a temporary approval to use the system underground was required from the NSW and Qld government departments. To obtain this temporary approval a mini risk assessment was carried out (Abbott, 1996) and the result was to abandon the trial at 1.25% CH₄ and submerge the equipment in water at 2% CH₄.

The Polar watch instruction manual suggests two options to record heart rate data. The one step method was preferred, because of its simplicity. Initially the watch was set in “time of day” function and monitoring commenced when the red “lap button” was pressed. When the test was complete, the watch was stopped by pressing the “stop/start” button.

A Polar Advantage Interface System was used to transfer data between the wristwatch receiver and IBM compatible personal computer. The Polar HR Analysis Software was used to analyse heart rate data. This data management program has been designed to provide maximum utilisation of the Polar wristwatch receivers’ data collection and transmission capabilities.

1.5 Oxygen Consumption and its Physiological Relationship with Heart Rate

Rate of oxygen consumption is dependent upon the rate of energy expenditure by the individual, which is a function of work rate. Thus oxygen consumption (\(VO_2\)) is related to metabolic rate. During escape from an affected mine an individual’s muscular effort when walking or running results in the consumption of oxygen at a greater rate than when sitting quietly in a crib room.

Oxygen is transferred to exercising muscles in a complex integrated process involving the heart, lungs and red blood cells, which circulate in the blood stream and carry oxygen. These body systems are therefore the means whereby oxygen is delivered to the tissues. The efficiency of oxygen delivery depends upon the following factors:

- The rate and depth of breathing (pulmonary ventilation).
- Efficient transport of air in the lungs from the alveoli into the blood stream via the pulmonary capillaries resulting in the almost complete saturation of the oxygen carrying haemoglobin 97%.
- Adequate blood being delivered to the tissues by the heart and blood vessels (cardiac output).
- The ability of the tissues to extract oxygen from the haemoglobin in the bloodstream.

Under most conditions the amount of oxygen available to metabolically active tissues is constant. Breathing rate increases precisely to match the metabolic demand. As
muscles are working harder during exercise, more oxygen is required and therefore consumed at a faster rate. In the case of a limited supply of oxygen or air, as occurs with SCSRs, the supply of oxygen will eventually be consumed.

Rate of oxygen consumption is determined by absolute work rate primarily, with only small variations attributable to age and fitness. In order to do “x” amount of work, one needs to expend “y” amount of energy (energy = work) and therefore consume “z” amount of oxygen. Increased fitness will lower \( \dot{VO}_2 \) due to mechanical efficiency at the type of exercise for which they are trained. Age has an opposite effect. The harder the individual exercises, or works, the more oxygen is utilised by muscle tissues. As a consequence the heart must respond by delivering blood at a faster rate to these tissues.

As can be seen in Fig. 5, heart rate increases with the amount of oxygen consumed but both are limited. As a guideline, the maximum heart rate achievable can be predicted by the following equation:

\[
\text{Predicted Maximum Heart Rate (bpm)} = 220 - \text{Age (Years)} \tag{5}
\]

The amount of oxygen which can be extracted from the bloodstream is also limited and is designated in physiological literature as \( \dot{VO}_{2\text{max}} \).

![Graph showing heart rate and oxygen consumption relationship]

**Fig. 5 Heart rate and oxygen consumption**

The amount of oxygen consumed is also proportional to the output of blood from the heart every minute (cardiac output). The following Fick’s Equation describes the relationship between the amount of oxygen being consumed and the physiological parameters.

\[
\dot{VO}_2 = \text{Cardiac output} \times \text{Arteriovenous oxygen difference} = (\text{stroke volume} \times \text{Heart rate}) \times \text{Arteriovenous oxygen difference} \tag{6}
\]
where
\[ \dot{V}O_2 \] is the Oxygen consumption by the tissues, such as exercising muscle, and
is expressed in litres/min (absolute oxygen consumption) or ml/kg/min (relative oxygen consumption).

**Cardiac output** is the volume of blood being ejected from the heart per minute
and is the product of the stroke volume and the heart rate.

**Stroke volume** is the amount of blood being ejected from the heart every time it
contracts.

**Heart rate** is the number of times the heart contracts per minute.

**Arteriovenous oxygen difference** is equivalent to the amount of oxygen
extracted from the blood as it passes through the various tissues. As can
be inferred in Fig. 28 oxygen content is higher in arterial blood than in
venous blood.

In summary, the Fick's Equation relates oxygen consumption to the amount of blood
being delivered to the tissues and extraction of oxygen by the tissues. Sophisticated
laboratory tests can measure the \( \dot{V}O_2 \), as seen in the trials at Wollongong University.
However, in field trial \( \dot{V}O_2 \) cannot easily be measured. Traditionally exercise
physiologists have made use of the parameters in the Fick’s Equation and so by
measuring heart rate, \( \dot{V}O_2 \) can be estimated (Astrand and Rodahl, 1986).

As the individual starts to exercise the heart rate increases and at the same time
oxygen is consumed at a faster rate. At rest and submaximal exercise, trained and
untrained individuals have the same \( \dot{V}O_2 \) and cardiac output (\( \dot{Q} \)), but lower heart rate
due to greater stroke volume in the trained. At maximum exercise, both \( \dot{V}O_2 \) and \( \dot{Q} \)
are greater while heart rate is similar, again due to the stroke volume difference.

The trained individual also has the capacity to open up more capillaries in the muscles
during exercise. There is therefore more extraction of oxygen from the blood as it
passes through the muscle capillary beds. With these changes the fit individual has
greater cardiac reserve (difference between resting heart rate and maximum heart rate)
and therefore has a considerable advantage when working or exercising in hot
conditions.

### 1.6 Relationship between Oxygen Consumption and Heart Rate

Well established physiological research has established that there is a linear
relationship between heart rate and oxygen consumption (Astrand and Rodahl, 1986).
The average heart rate during exercise has been used to estimate oxygen consumption
of individuals, as they exercised on treadmills or in simulated mining conditions,
while wearing SCRs.

Various studies in USA (Bernard, Kamon and Stein, 1979; Berry, et al., 1983;
Buskirk, Nicholas and Hodgson, 1975) linked oxygen consumption (\( \dot{V}O_2 \)) to average
heart rate (HR) and body weight (W). In 1979, the US Bureau of Mines and
Pennsylvania State University carried out two types of treadmill tests (submaximal
tasks and progressive stress tests) and obtained a linear relationship between heart rate
and oxygen consumption which is given by Equation 7.
\[ \text{PSU Model} \quad \dot{V}O_2 = \frac{HR - 66}{36} \] (7)

Equation 7 was based on treadmill tests with 44 subjects in two different studies. Study one was conducted using 16 subjects performing submaximal tasks that were designed to simulate mine rescue and recovery activities. Each task lasted between five and six minutes. A 10 minute rest was allowed between tasks and each volunteer completed 9 tasks in one day. The submaximal tasks included walking, shovelling, arm cranking and carrying. Study two included 28 miners who performed a progressive uphill treadmill walk to exhaustion. This was assumed to approximate the maximal physical exertions expected under emergency escape situations.

In 1983, Foster-Miller, Inc. and U.S. Bureau of Mines conducted field trials with 6 subjects. By measuring the resting and maximum heart rates and corresponding oxygen consumption, they developed a linear relationship between heart rate and oxygen consumption given in Equation 8.

\[ \text{Foster Model} \quad \dot{V}O_2 = 0.024HR - 1.54 \] (8)

Equation 8 was based on a study of 6 miners who travelled an escape route once per day for three consecutive days. On each day of the 3 days of timed trials, 2 miners travelled barefaced, two used SCSRs and two used a recording respiration meter with face mask. Each miner travelled the escape route at his own pace experienced the above three cases during the consecutive 3-day trials. By measuring the resting and maximum heart rates and corresponding oxygen consumption, the linear relationship between heart rate and oxygen consumption was modelled. The same researchers also conducted a detailed study on the influence of thickness of seam on the oxygen consumption. This is the only research totally based on the field situations.

Equation 9 was developed by National Institute for Occupational Safety and Health (NIOSH).

\[ \text{NIOSH Model} \quad \dot{V}O_2 = \frac{W \cdot (HR - 61.25)}{3230} \] (9)

The model was based on 9 healthy men of normal weight aged from 21 to 56 walking on the treadmill at two intensities shown in Table 2 at 26.7°C room temperature.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Intensities of NIOSH Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treadmill Speed</td>
</tr>
<tr>
<td>Intensity 1</td>
<td>1.34 m/sec</td>
</tr>
<tr>
<td>Intensity 2</td>
<td>1.34 m/sec</td>
</tr>
</tbody>
</table>
A total of 18 pairs of data, with 9 pairs of data at each intensity exercise, were collected. This was the only study which considered the weights and heart rates of the subjects when predicting the oxygen consumption.

In regards to the performance of field evaluation of SCSRs and donning proficiency, various studies have been done. In the early 1980s, a joint effort by U.S. Mine Safety and Health Administration (MSHA) and U.S. Bureau of Mines (USBM) was undertaken to determine how well SCSRs were deployed (Kravitz and Kovac, 1991). During 1982 to 1990, quite a number of SCSRs were tested on human subjects and on a breathing and metabolic simulator. These results indicated that most of the apparatus, if they passed their inspection criteria, would perform as expected except for units with manufacturing defects or design deficiencies. However, when the apparatus was carried in and out of the mine daily and stored at the working section, they suffered abuse. This posed a potential danger to a user in an emergency situations (Kyriazi and Shubilla, 1992).

In late 1980s and early 1990s, the U.S. Bureau of Mines carried out a field-oriented research in an attempt to evaluate the SCSR donning proficiency with 243 miners from eight underground mines. The objectives of the study were to gather information on skill levels and to summarise a quality control procedure useful in conducting periodic evaluations of donning proficiency. Results from the observed samples at each of the 8 mines indicated a wide variability across sites (Vaught, Wiehagen and Bmich, 1991)

1.7 Definition of the Problem

The introduction of SCSRs in the Australian coal mining industry will initially require a coherent procedure that every mine can use to access the suitability of its escapeways for escape whenever a miner is wearing an SCSR. Such a procedure can also be used to identify where these units can be cached so that every miner can escape from their place of work to a place of safety. The purpose of this study is therefore aimed, among others, to provide:

- an appraisal of the SCSR and its operation under both the normal underground environmental conditions, as well as their performances under extreme conditions of heat and humidity, and
- a methodology to predict how much oxygen is actually needed by an individual to escape from a mine and to enable mines to plan new escape strategies for persons underground.

1.8 Scope of Work

Following equipment acquisition and the granting of an exemption by the NSW Department of Mineral Resources to use the Polar Heart Rate Monitor underground, the program of study was carried out in the following stages.

Stage one was aimed at determining the quantity of oxygen consumed by a wearer. This was carries out by the laboratory treadmill tests. Parameters considered were
age, body weight and the volunteer’s exercise habits (frequency, duration, intensity of exercise and type of exercise). Six volunteers were selected to walk on a level treadmill at 5 km/h. The details of the trials and discussion of the results are presented in Chapter 2.

Chapter 3 discusses the field simulated escape trials with 37 miners from NSW and Qld. Two escape trials were conducted at each mine. On Day 1, the subjects walked out the escapeway carrying the SCSR on the belts and on Day 2 the subjects repeated the walkout wearing the SCSR and oxygen “run out” time was recorded. The field data were statistically analysed to establish the relation between oxygen consumption and other parameters.

The effect of heat and humidity on oxygen consumption is reported in Chapter 4 of this report. The study was conducted in a hot and humid chamber with six subjects walking on a treadmill. The temperature was kept at 22°C at relative humidity of 50 - 70% during tests on Days 1 and 2. However, during the trial on Day 3 the temperature and relative humidity were raised to 32°C and 100%, respectively.