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Appraisal of Self-Contained Self Rescuers for Use in Australian Coalmines

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ABSTRACT: A laboratory and field trials were undertaken at lour active underground coal mines to evaluate the performances of Self-Contained Self Rescuers (SCSRs) in the normal Australian underground coal mine conditions. The results showed that the oxygen run out lime of SCRSs could be predicted using the body weight, average heart rate and exercise rating of the subjects. Additional factors that influenced oxygen consumption rate include speed of travel, intensity of work and the individual habits such as smoking, drinking.

INTRODUCTION

The self-contained self-rescuers (SCSRs) are breathing apparatus that make oxygen available to a wearer tor a nominal period of time. There are various types of SCSRs on the market currently deployed at underground coal mines. A study was undertaken to evaluate the performances of the units in the normal Australian underground coal mine conditions. The study involved a laboratory and field trials at four active underground coal mines using 37 volunteers. The aims of the laboratory/field trials are:

- To gather data on the duration of SCSRs, escape times, distances travelled and average heart rates to develop methodology to predict how much oxygen is actually needed by an individual to escape from a mine.
- To evaluate the influence of personal factors such as age, weight, physical fitness and previous experience on the duration of SCSRs.
- To evaluate the effect of environmental factors on the duration of SCSRs..
- To develop a system to assist collieries with practical escape planning which accounts for relevant issues pertaining to SCSRs. • To identify training issues relating to SCSRs.
- To develop a system to assist collieries with practical escape planning which accounts for relevant issues pertaining to SCSRs.

2 LABORATORY TREADMILL TESTS

The experimental set-up is shown in Figure I. Each subject breathed through a mouthpiece which was connected to an SCSR in a closed circuit using the flexible tubes. Both the 02 and C02 concentrations in the inhaled and exhaled air were monitored and recorded by Sensormedics Respiratory Gas Analysis System (SRGAS) at a sampling rate of one minute interval. In addition, the inhaled and the exhaled volume of air at one minute interval (minute ventilation) were also recorded. Six volunteers, aged between 21 and 53, were selected to walk on the fiat treadmill at 5 kın/lir wearing the SCSR. Heart rates of each individual monitored continuously throughout the tests. The Polar Vantage NVTM was set to sample average heart rate over 15 second interval during the test. The pressure relief valve installed on the breathing bag was used to release excess oxygen to the atmosphere. The test procedure consisted of:

1. The test subject donned the chest mounted heart rate monitor and the wristwatch receiver.
2. A functionality test was carried out on the heart rale monitoring system.
3. The test subject donned a mouthpiece and nose clip-.
4. The mouthpiece was connected to an activated SCSR.
5. The level treadmill was adjusted to 5 km/h
6. The subject walked on the treadmill until the SCSR exhausted its oxygen supply.

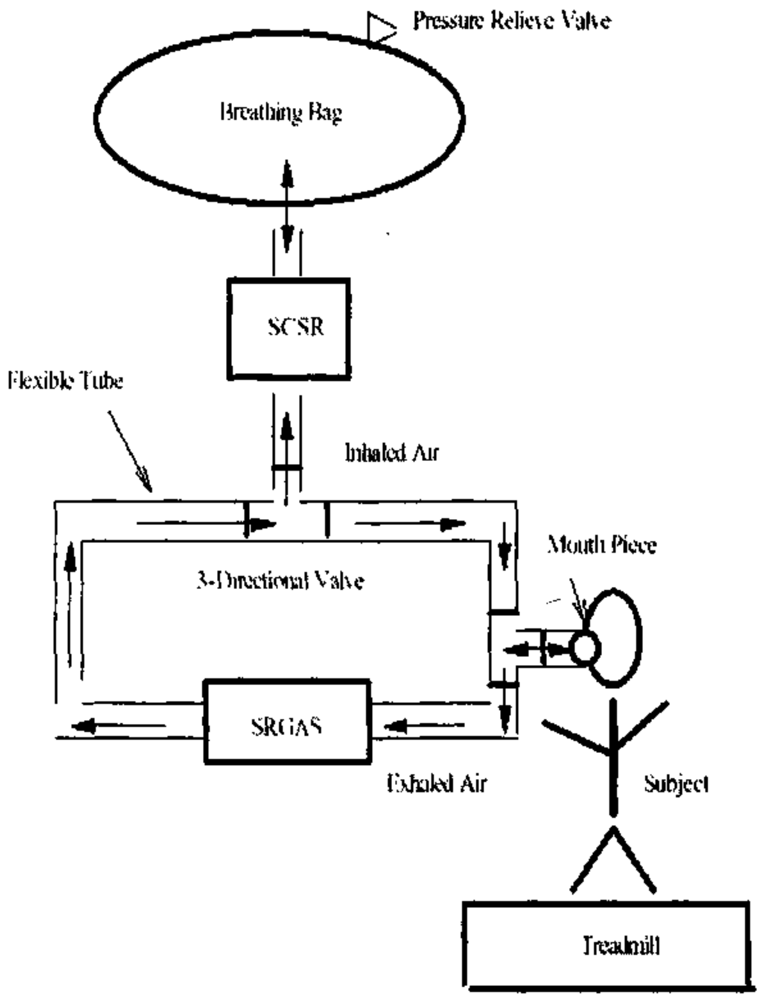


Figure 1. Experimental set-up

The criteria to terminate the test were:
- The breathing bag was totally collapsed.
- The subject's desire to terminate the trial.
- The subject showed evidence of excessive strain, for instance, the heart rate greater than 85% of cardiac reserve
- The inhaled C02 exceeded 3%.

3 TREADMILL RESULTS

3.1 Heart Rates

Dynamic heart rates of one of the six subjects walking on the treadmill are depicted in Figure 2.

In general, the heart rates of each subject increased rapidly during the first five minutes, and then stabilised at steady rate.

These effects corresponded to the natural exercise progression from standing on a treadmill, to walking and finally exercising.

The heart rates for the subject W2 was relatively stable while the other five subjects showed a steady increase of heart rates with elapsed time. This continuous increase of heart rate during exercising is called cardiovascular drift and caused by following factors:

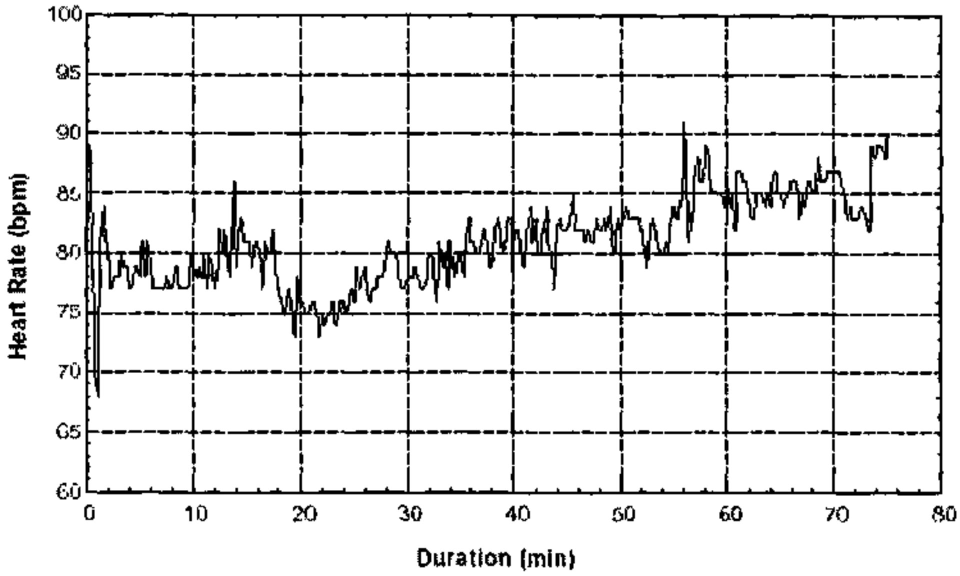


Figure 2. Heart Rate versus duration of a subject

- increase in body temperature during the exercise,
- a noticeable amount of body fluid was gradually lost,
- increase in body temperature during the exercise,

Table 1 summarises the treadmill results. All subjects were stopped when the unit ran out of oxygen. However, in case of the subject W5, the experiment was terminated due to the concentration of inhaled C02 continuously exceeding 3% prior to the breathing bag completely collapsing.

3.2 *Gas Analysis*

The inhaled and useable oxygen was calculated from the SRGAS recording sheet.

In a closed circuit, the exhaled air is made up of 02 and C02. The consumption of oxygen (V02) can be defined by the relationship

VO: = (Volume of Inhaled Air) * (Percent of Oj in Inhaled Air) % (Volume of Exhaled Air) * (Percent of O: in Exhaled Air)

Similarly, the amount of exhaled carbon dioxide (VCOi) generated reduces to the relationship

$VC0_2$ = (Volume of Inhaled Air) • (Percent of CO? in Inhaled Air) + (Volume of Exhaled Air) * (Percent of COi in Exhaled Air)

Since both gases were sampled at one minute interval, the amount of O2 and CO2 used by each subject is obtained by direct summations of unit time rates. The results summarised in Table 1 suggest that each subject consumed between 85 and 126 litres of oxygen with an average of 99.3 litres. From practical point of view, the 99.3 litres of useable amount of oxygen via SCSR supports the manufacturer's 100 litres per unit.

4 FIELD SIMULATED TRIALS

The objectives of the underground investigations were to gather in-mine data on escape times, istances and heart rates and to develop a technique to predict how much oxygen was actually needed for an average miner to escape from an underground mine. Field simulated escape trials were conducted at three collieries located in New South Wales and one in Queensland. The mines were selected to represent variety of conditions that are normally encountered in the actual escapeways of Australian coal mines. The escape routes were selected by the mine and based on the following requirements:

I. A distance that requires walking an excess of one hour.

Table 1 Summaıy ot treadmill lests

Subject ID	Age	Weight	Heart Ratet			Observed Time[1]	Observed VOi	Observed	Observed[1] XCOi	Useable Oiygen
			Minimum	Average	Maximum		(Indirect)'	(direct» '		
	<vrs)	(kR>	(bpm)	(bprm	(bpm)	(mfn)	flmin)	amin)	(Lirtn)	(liters)
Wj	43	**S3**	6S	Kl.1	**91**	75.0	1.33	1.04	0.95	N'A
W,	53	81	88	110.9	120	78.0	1.28	1.61	1.48	125.9
W?	21	82	121	128 8	139	68.0	1.47	1.28	1.18	SS.4
W*	48	70	80	97.4	105	67.0	1.49	1.27	1.17	84.9
Ws	44	**90**	102	135.0	149	65.0	1.54	1.46	134	94.6
W,	32	66	94	122.4	132	107.0	0.93	0.97	0.90	102.8
Minimum	2J.0	66.0	6S.0	81.1	**91.0**	65.0	0.93	0.97	0.90	84.9
Mean	**40.2**	**78.7**	**92.2**	**112.6**	**122.7**	**76.7**	**1.34**	**1J7**	**1.17**	*993*
Median	43.5	81.5	91.0	116.7	126.0	71.5	1.40	1.27	1.18	94.6
Maximum	53.0	90.0	121.0	135.0	149.0	107.0	1.54	1.61	1.48	125.9

Observed lime irom commencement of breathinu oxjgen via the SCSR to the cessation of the tea when the breathing bag is fully collapsed. Tins is the *Oi* •nun-out" time via an SCSR.

[2] Tlie indirect oxygen eonaimptian was chained by dhiding 100 liters divided by the observed time.

•' The direct oxygen consumption was calculated uüing Equalkn (4).

[4] The observed carben dioxide consumption *was* calculated using Equation (4)

2. An established escapeway to represent a typical underground escape route conditions.

Attempts were made to ensure that the profiles of the volunteers represented those of the current workforce in Australian underground coal mines. All the volunteers were medically screened and physically examined before the field trials.

During the simulated escape trials, the 37 volunteers walked along the escape route at their respective mines on Day 1 carrying the MSA Portal Pack SCSRs on the belts. The walking was repeated on Day 2 with the same subjects wearing the units. The tasks performed on the second day (Day 2) simulate the emergency situations at a typical mine.

All the subjects had been trained in the donning and use of the SCSR units prior to the field trials. The walking paces on both days were kept at a constant rate of about 3 km/hr. The influence of walking pace on the oxygen consumption was not investigated in this study. The heart rates of each subject was recorded by a Polar Vantage NV'V'.

At the end of Day 2 each SCSR's breathing bag was monitored to enable the oxygen "run out" time to be determined. Normally, the end of trials could be defined as the point of complete collapse of the breathing bag, often accompanied by an increase in breathing resistance and light headache. The latter was most likely caused by the inhaled air with a high concentration ot CO: in excess of 3%. The corresponding time from starting to breathe oxygen via the SCSR to the termination was observed, which is the so-called 02 "run-out" time.

After completing the field simulated trials, the subjects were asked to till out questionnaires designed to assess both the performance and the comfort of the SCSRs.

5 SIMULATED RESULTS

5. / *Age and Weight Profiles of Subjects*

81% ol all the subjects are between 30 and 49 years old The minimum and maximum ages of the sub|ccts aie 27 and 57 years old with an overall aveiage age of 40.7 years old. The age distribution ol the selected volunteers reflected the profiles of the current worktorce employed in New South Wales and Queensland.

87% subjects have a weight between 70 and 99 kg. The minimum and maximum weight of all the subjects are 66 and 130 kg with an average of 85.5 kg. The weight distribution of the selected volunteers represented the profiles of the current workforce employed in New South Wales and Queensland.

5.2 Performance and Comfort of the SCSRs

All the 37 volunteers were asked to complete questionnaire designed to assess the performance and comfort of the SCSRs. The following conclusions could be drawn from the questionnaire.

- All the subjects felt they could don and wear the SCSRs in an emergency.
- 95% felt the SCSRs would protect them of oxygen deficient or toxic atmospheres.
- 50% felt the SCSRs uncomfortable to wear.
- 56% would not wear the unit during the a normal shift
- 89% found the nose clips uncontestable.
- 56% felt the temperature of the inhaled air was comfortable and 44% found the temperature tolerable.
- 44%; found the breathing resistance to be comfortable with 56% tolerable.

5.3 *Oxygen "Riin-Out"Ttime*

The oxygen "run-out" time distributions for the 37 subjects ate shown in Figure 3.

It is noticed that the majority (81%) of subjects have an oxygen "run-out" lime between 50 and 69 minutes, few (11%) over 70 minutes and the very few (8%) less than 50 minutes.

5.4 Predicting Oxygen Consumption

Various studies in USA (Bernard et al, I979) have linked the oxygen consumption (VO2) to average heart rate (HR) and the body weight (W) as per the following equations:

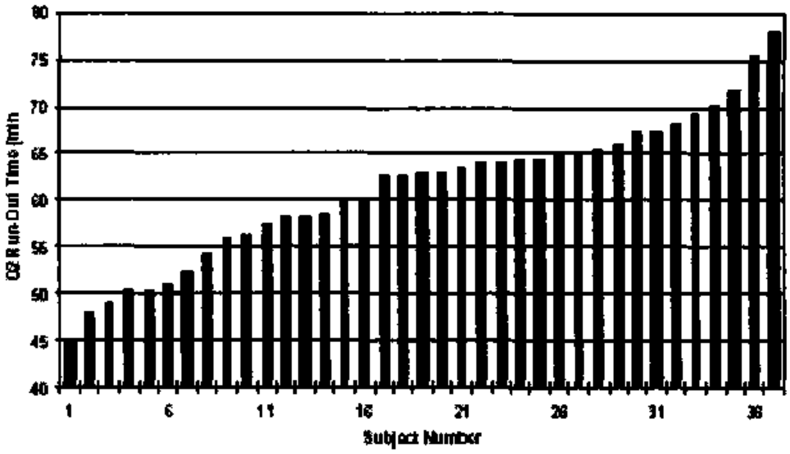
PSU Model $VO2 = (HR - 66) / 36$ (I)

Foster Model $VO2 = 0.24HR - 1.54$ (2)

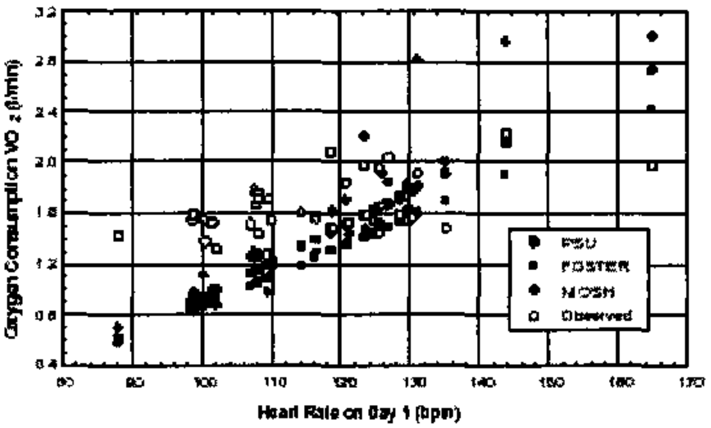
NIOSH Model $VO: = W(HR - 61.25) / 3230$ (3)

Each of the above relationships was based on statistical analysis of extensive laboratory work overseas. Using Day I average heart rates and the weights of the 37 subjects, the average oxygen consumption rate of each subject was estimated. The results with the three models are presented in Figure 4.

The three models generally underestimated the average VO: for average heart rates under 120 bpm and inconsistent at heart rates above 120 bpm. There is a strong possibility that the above models were developed under conditions which were dilTerent from the field simulated trials.



Fıguıe 3 Distnbution ot Oxygen 'Run-Out times



Fıguıe 4 Pıedıcted vs obseıved VO»

The fundamental question addressed heie is whether there is a relationship between VO: and average heait rate, age weight, smoking habit, dunking habit, late ot exercising and othei factors Theie was a tendency tor low values ot heart ıates and weights to be associated with low values ot VO: Subjects with low (poor) exercise ratings were associated with high VO:

The associations between VO: and other measured vanables could be described as follows

- strong association ot VO2 with body weight,
- modeiate association ot VO: with exercise ıatıng,
- weak association ot VO:with cigarette and alcohol consumption,
- very weak association ot VO: with age

It was observed that the heart rates on the two days for the same person were not the same, but with 0 79 coefficient ot correlation Both the compiled medical data and the simulated escape field data were statistically analysed to produce the following model

VO: = (3 25W + HR) / 250 + 0 023 (4)

Equation 4 relates oxygen consumption (VO:) with average heart rate (HR) and body mass (W) is based upon a repıesentatıve group ot Australian male underground coal miners This model appears to be of better pıedıctıve value than the previous models, therelore a better estimate ot oxygen consumption and hence predicted oxygen "ıun out' time. The predictive model given by Equation (4) is recommended for use by collieries because of its simplicity.

Equation (5) below relates oxygen consumption (VO2) with average heart rate (HR), body mass (W) and exercise rating (ER) of an individual and is based upon a representative group of Australian male underground coal miners.

$$V02=(7.39\ W + .74\ HR - 11.35\ ER)/500 + 0.26 \quad (5)$$

Equation (5) is presently of academic interest and requires standardisation with an inter- and intraobserver reliability study before its utility can be established. The method would require the assistance of a health professional experienced in assessing the quantity and quality of an individual's exercise history. The method is based upon the subject's weekly exercise habits, intensity of exercise and scored on a scale of 1 to 10. It may be prone to errors generated, by both the subject and the observer.

6 CONCLUDING REMARKS

The MSA Portal Pack SCSR produces about 140 liters of oxygen but only about 100 liters oxygen is used by each wearer.

A fit person may use less oxygen from SCSR in comparison to a less fit person. This implies that more unused oxygen is released to the atmosphere by a fit person.

Using results from field simulated escape trials, a linear model has been developed to predict oxygen run-out times of self-contained self rescuers. The field results clearly demonstrate that for a fixed work rate, oxygen consumption by an individual depends upon the following personal factors:

- Body weight has a major influence.
- Physical fitness has some influence. Physically fit people produce oxygen in excess to requirements. This excess is lost through the relief valve and although oxygen consumption is less, this only has a slight effect on oxygen run-out time.
- Age may have slight influence on oxygen consumption depending on the level of physical fitness and the degree of cardiac strain.
- Experience in wearing the breathing apparatus appeared to have no influence.

REFERENCE

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