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RECOMMENDED GUIDELINES FOR OXYGEN SELF-RESCUERS – VOLUME III – ESCAPETIME STUDIES IN UNDERGROUND COAL MINES

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16. Abstract (Limit: 200 words)

The objectives of this project were to (1) determine escape speed in different mine conditions, (2) evaluate the performance of chemical oxygen self-contained self-rescuers (SCSR) under actual escape conditions, and (3) measure the physiological cost of mine escape. A special escapeway was established so that escape speeds and the use of SCSR's could be analyzed over a wide range of conditions, including travelway heights of 30 in to 7 ft. The average escape speeds ranged from 96 ft/min crawling to 264 ft/min for head-bent walking. The average life of six SCSR's was 60.8 min; those traveling faster consumed their SCSR's faster, although the total distance traveled before exhaustion of the SCSR was independent of speed of travel. Physiological data were also recorded. The average respiration rate was 41 L/min and the average oxygen consumption was 1.38 L/min.

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DISCLAIMER

FOREWORD

This report was prepared by Foster-Miller Associates, Inc., Waltham, MA, under USBM Contract No. J0199118. The contract was initiated under the Minerals Health and Safety Technology Program. It was administered under the technical direction of Pittsburgh Research Center with John Kovac acting as Technical Project Officer. Sylvia Brown was the contract administrator for the U.S. Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period August 1980 to December 1981. This report was submitted by the authors on 1 June 1983.

The technical effort was performed by the Mining Division of the Engineering Systems Group, with Randolph Berry as Program Manager and Diane Doyle as Field Test Supervisor. Dr. Eliezer Kamon was the consulting physiologist.

The authors extend their special appreciation to the Rochester and Pittsburgh Coal Company, who provided the use of the Emilie No. 4 Mine and the time of their men - all at absolutely no cost to this program. We thank Mr. Ed Onuscheck, Vice President of Safety, the 6 volunteer miners who participated in the program, the onsite emergency medical technicians and other safety personnel.

We also thank Mr. Ralph Hatch, Vice President of Safety, and Mr. C. William Parisi, Director of Safety, Consolidation Coal Corporation who supplied escape travel time data from many of Consol's mines.

In addition, we thank John Javorsky, Mine Safety and Health Administration's Training Instructor for training the participants with the approved course in MSA Self-Rescuers and Dräger Self-Rescuers.

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EXECUTIVE SUMMARY

Six volunteer coal miners participated in an underground escape study, which was carefully controlled and medically supervised. The age range was 24 to 61, average 41.

A special escapeway was established to provide the following test conditions:

a. At least 1 hr long for the average miner

b. Divided into seven segments of different travel heights ranging from 30 to 78 in.

Each miner travelled the route once each day for 3 days, once normal, once wearing a self-contained self-rescuer (SCSR), and once wearing a face mask and respiration meter. Short (~2 min) rest periods were required between each segment in order to take medical data.

Escape speeds for each segment of the route were measured and analyzed to produce the graph shown in Figure ES-1.

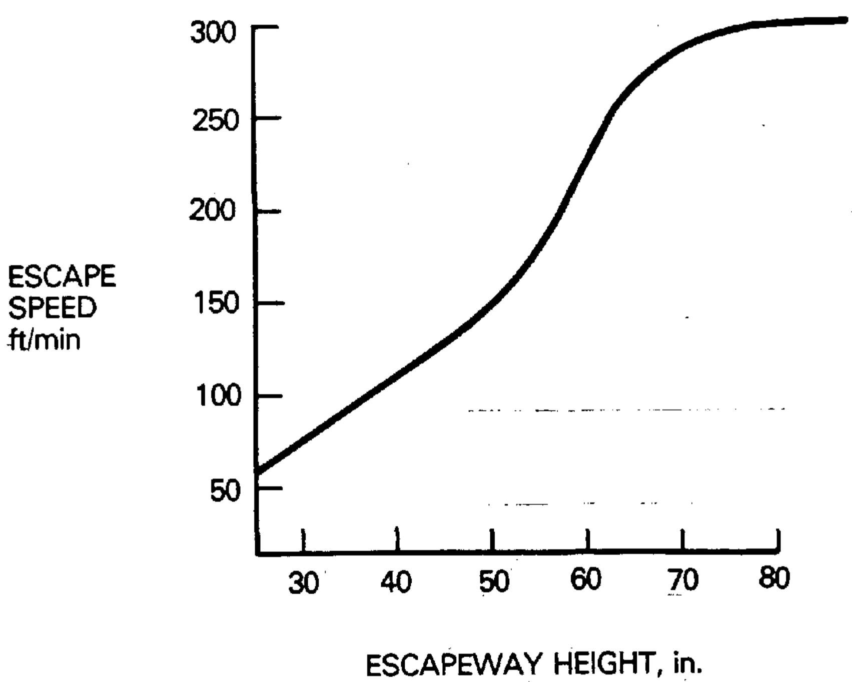


FIGURE ES-1. - Average escape speeds in an underground coal mine.

In addition it was found that wearing an SCSR or a respiration meter decreased the travel speed by 15 percent. Bad conditions such as pools of water or uphill grades also produced a measurable decrease in speed. This escape speed data was compared to data from other sources, which reported similar or somewhat lower speed.

The life of chemical oxygen self-rescuers was also measured in this study, with the results shown in Table ES-1.

Note that if a miner moves faster, his SCSR runs out sooner; if a miner goes slower, his SCSR lasts longer. But the distance which the miner can travel before his chemical SCSR runs out depends primarily on his body weight and not on the speed of travel.

TABLE ES-1. - Life of chemical oxygen self-rescuers

Miner's average speed* (ft/min)	Life of SCSR in minutes**	When SCSR exhausted, distance travelled × body weight (million ft-lb)
112	77.0	1.07
122	60.0	1.00
126	61.0	1.06
153	60.0	1.18
153	49.0	1.02
156	58.0	1.34
Average	60.8	1.11

*Excludes rest periods.
**Includes rest periods.

Measurements of the physiological response of five of the six miners during escape produced the following major conclusions:

a. Average oxygen consumption - 1.38 liters/min*

b. Average respiration rate - 41 liters/min*

c. Average heart rate - 143 beats/min

d. Oxygen consumption (walking) - 0.35 milliliter per meter traveled per kg body weight

Oxygen consumption (crawling) - 0.70 milliliter per meter traveled per kg body weight

e. The oxygen consumption (1.38 liters/min) was the same and the respiration rate (41 liters/min) 30 percent higher than the rates published in an independent study in which miners simulated the activities required for MSHA/NIOSH approval of 1-hr SCSRs.

This entire study was done using mine management test subjects and chemical oxygen self-rescuers.** It is recommended that a parallel study be conducted with compressed oxygen self-rescuers when they are commercially available and that miners be chosen from among union personnel.

*Standard Temperature Pressure Dry (STPD).

**Two different models of SCSR were used. However, the two models use the same chemical oxygen generator and are functionally similar.

1. INTRODUCTION

This test program was designed to obtain detailed information in the following areas:

a. *Escape speeds* in different mine conditions

b. *Evaluation of SCSRs* in actual escape conditions

c. *Miner physiology* in actual escape conditions.

Because the test program required human subjects, extreme care was taken and medical supervision was vital. As explained in the following sections, medical supervision included stress testing of volunteers before the program started, medical checkup before each day of testing, and stops for medical checks at five intervals along the escape route. This degree of medical supervision makes the test program expensive but also provides a great deal of detailed information.

The remainder of this report is divided in the following sections:

a. Section 2 - Test Procedures

b. Section 3 - Discussion of Escape Time Data

c. Section 4 - Discussion of Physiological Data.

2. TEST PROCEDURES

The details of the test program are described in the following subsections:

a. Escape Route (subsection 2.1)

b. Test Participants (subsection 2.2)

c. Test Sequence (subsection 2.3).

2.1 Escape Route

The escape route for this program is shown schematically in Figure 1. This route was *not* a designated escapeway for the mine. The route of travel was *especially selected* to meet the following requirements:

a. At least 1 hr long for the average miner.

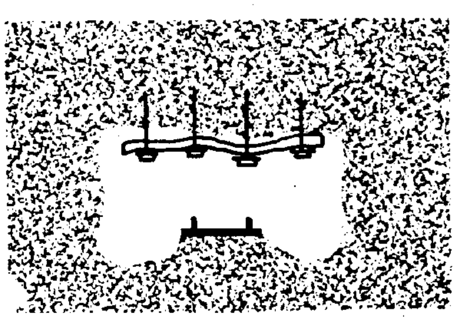
b. Different segments of the route must have different seam heights.

c. Different segments of the route must have different ground conditions such as wet/dry, level/slope, smooth/irregular roof and floor.

As shown in Figure 1, the escape route was divided into seven segments according to the travel height in each segment.

Entry conditions in each segment* and the mode of travel were as follows:

a. Travel from "0" to "1"



Participants walked upright and with heads bent through this 3080-ft-long route, part of which was a track entry and part, after crawling through a mandoor, was the escapeway. Roof ranged in height from 60 to 78 in. Entry conditions resembled those shown at left.

*Roof and floor conditions in sketches (a) through (g) have been exaggerated.

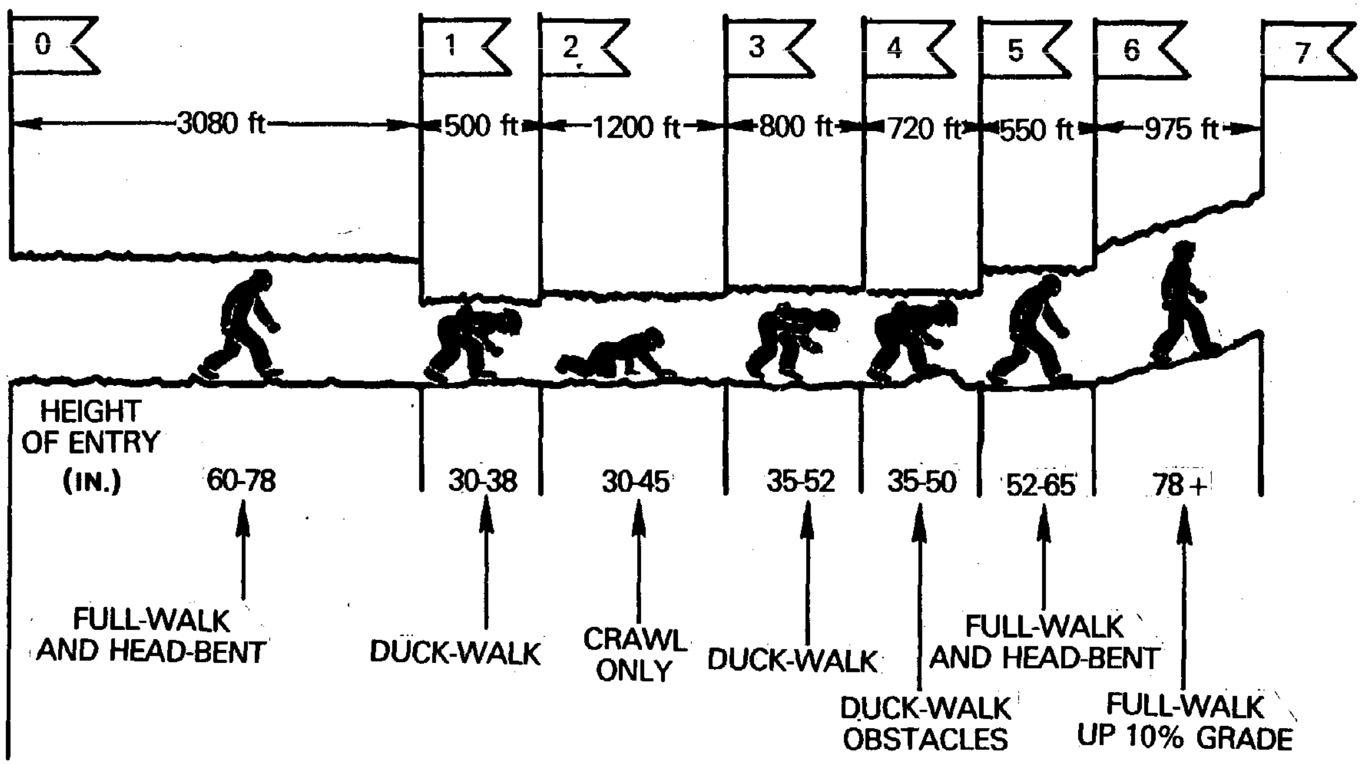
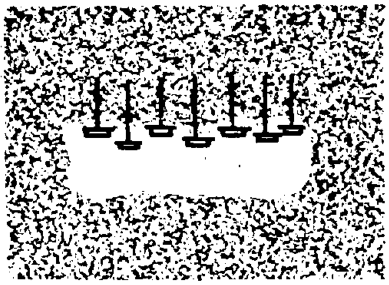


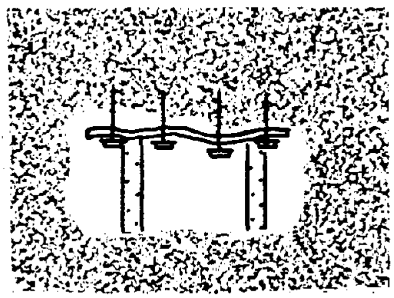
FIGURE 1. - Schematic of escape route.

b. Travel from "1" to "2"



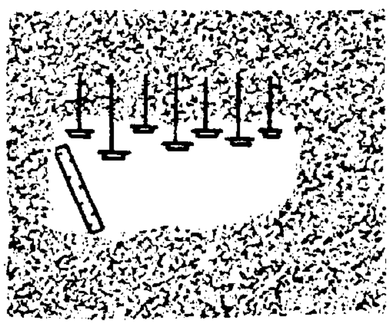
Participants duckwalked and crawled through this 500-ft-long route. Average roof heights ranged from 30 to 38 in. Roof and rib debris was heavy in some areas. Roof bolts and plates extended from the roof with no rock attached as shown at left.

c. Travel from "2" to "3"



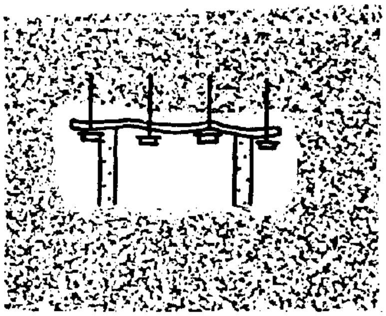
Participants were required to crawl this 1200-ft-long route, even where the roof was high. Miners also climbed up steps to cross over 4-ft-high overcasts. Roof heights ranged from 30 to 45 in. As shown at left, roof bolts and plates extend from roof with no rock attached. In addition, header boards were used at some places. The ground was fairly uniform with debris from roof and rib kept to a minimum. No water was in this segment.

d. Travel from "3" to "4"



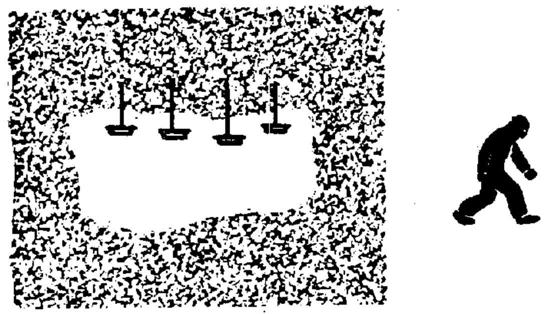
Participants duckwalked this 800-ft-long section. Roof heights ranged from 35 to 52 in. A 7-in. waterline across the bottom of the entry reduced that point to a 33 in. height. Areas of this segment have posts lying on the rib sides that were not set in place; in general, roof conditions resembled that shown at left.

e. Travel from "4" to "5"



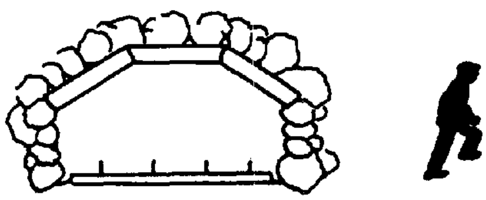
Participants crawled and duckwalked in this 720-ft-long route. Roof heights ranged from 35 to 50 in. Roof support resembled that shown at left with some areas supported by posts. The participants had to travel through two pools of water, 2 to 16 in. deep and 10 to 20 ft long. Also, they had to maneuver under a 5-in. diam waterline suspended from the roof.

f. Travel from "5" to "6"



Participants walked with head bent in this 550-ft-long route. After duck-walking under a 36 in. overcast, roof heights ranged from 52 to 65 in. Towards the end of this route miners climbed steps over an overcast, and went through an airlock door to the Station 6 checkpoint. The entry condition resembled that shown at left.

g. Travel from "6" to "7"



Participants walked 975 ft upright or with head bent from Station 6 up the slope to the surface. The first 175 ft of this route was relatively flat; the next 600 ft was on a 9.75 percent grade and the last 200 ft on an 8.25 percent grade. The entry resembled that shown at left.

In the data analysis in Section 3, the following average travelway heights were used:

a. 0 to 1 - 69 in.

b. 1 to 2 - 34 in.

c. 2 to 3 - 30 in. (because crawl-only was required)

d. 3 to 4 - 44 in.

e. 4 to 5 - 44 in.

f. 5 to 6 - 59 in.

g. 6 to 7 - >72 in.

However, except for heights above 72 in., conditions rarely matched the *average*. We feel that this route reflected real life, where occasional low places, overcasts, and other minor obstructions are the norm rather than the exception. Thus, it should be noted that an entry designated as a certain average height in good conditions can still include some of these factors.

The same variability exists in the designation of the travel modes crawling, duckwalking, head bent, and upright. When these designations are used, the reference is to the *predominant* mode of travel. For example, in segments where duckwalking was predominant, there were places that could only be crawled and other spots that could be almost walked.

2.2 Test Participants

Employees of the R&P Coal Company volunteered for this study. The six men and their job classifications are listed in Table 1. Further physiological information about each miner is given in Section 4, Table 11.

The test participants, chosen from company management,* represented a broad cross-section of the mine population in good health.

Before the test began, all participants underwent a medical examination and stress evaluation. The medical examination provided a measure of probable current physical fitness. The stress evaluation determined the maximum oxygen consumed, maximum breathing rate, and maximum heart rate, measured fitness for doing a specific type of work, evaluated current exercise capacity and current physical condition, and unmasked the presence of respiratory and/or coronary diseases. Participants walked or ran on a motor driven threadmill with variable speed and inclination control until they reached their peak performance, unless signs or symptoms indicated the test should stop.

TABLE 1. - Test participants

Miner	Age	Job description	Underground experience (year)
A	61	Superintendent/mine foreman	41
B	54	General assistant	35
C	49	Section foreman	6
D	49	Shift foreman	10
E	34	Safety inspector	10
F	24	Maintenance foreman	6

*A nationwide coal strike precluded the involvement of union miners during the period that these tests were conducted.

For legal and ethical reasons, it was not possible to involve persons in these tests having respiratory, circulatory, coronary, or ambulatory deficiencies. In fact, one of the original volunteers was replaced because of his irregular electrocardiogram recorded during the prescreening process.

Prior to the test, the participants received training in the use of chemical self-rescuers by a MSHA instructor. This 3-hr training program consisted of slide presentation, question and answer session, and actual donning and use of both training units. The "exhaustion point" of the SCSR was explained and defined to the participants by the MSHA instructor; this was the same exhaustion point used by the participants in the subsequent tests.*

2.3 Test Sequence

Each of the six miners travelled the escape route once per day for three consecutive days. A practice run was held a day earlier for preliminary observations and to acquaint each man with the route. On each day of the 3 days of timed trials, two miners travelled barefaced (termed "normal" in this report), two miners used SCSRs and two miners used a recording respiration meter with face mask, called an "Oxylog." These assignments were rotated daily so that after 3 days each miner had escaped normally, wearing an SCSR, and wearing the Oxylog, as shown in Table 2.

TABLE 2. - Test sequence

Miner	Day 1	Day 2	Day 3
A	Normal	Oxylog	SCSR
B	Normal	SCSR	Oxylog
C	Oxylog	SCSR	Normal
D	SCSR	Oxylog	Normal
E	SCSR	Normal	Oxylog
F	Oxylog	Normal	SCSR

*From the MSA SCSR Instruction Manual, page 5: "The end of service life becomes noticeable by depletion of the breathing bags volume, an increase in temperature and a slight rise in resistance." The Dräger SCSR Instruction Manual, page 10, contains a similar definition of "end of device operation."

Each miner travelled the escape route at his own pace. The miners' instructions were to travel as fast as possible yet maintain sufficient reserve to complete the trial.

Other mine employees were located at Stations 0 through 7 to record the times of each test participant and to measure and record heart rate and blood pressure. Each of these measurement personnel were certified Emergency Medical Technicians (EMT).

The daily program was conducted as follows:

a. *Arrival at mine office* - The six miners arrived at the mine office about 8 am and changed into their mine gear. The general health of each man was checked, including blood pressure and heart rate. The two men assigned to wear the Oxylogs were prepared for the recordings by attaching electrodes to their chests and strapping the Oxylog and tape recorder cassette over their mine clothes. The entire procedure took 60 to 90 min.

b. *Mine entry* - The six miners walked as a group into the mine to the starting point, Station 0, which was 6765 ft from the portal. Walking time was 29, 27, and 26 min for the 3 days, respectively.

c. *Station 0* - Blood pressure and heart rate were recorded. The miners rested leaning, standing, or sitting, awaiting their turn to proceed through the escape route. They were started on the route individually at 15 min intervals. The two Oxylog wearers donned the face mask immediately before departure. The SCSR wearers activated their units and the time was recorded. Times of departure were recorded.

d. *Walk to Station 1* - Time of arrival was recorded except on the first day.

e. *Duckwalk to Station 2* - Wait while EMT measured heart rate and blood pressure. Arrival/departure times recorded.

f. *Crawl to Station 3* - Wait while EMT measured heart rate and blood pressure. Arrival/departure times recorded.

g. *Duckwalk to Station 4* - Wait while EMT measured heart rate and blood pressure. Arrival/departure times recorded.

h. *Duckwalk to Station 5* - Wait while EMT measured heart rate and blood pressure. Arrival/departure times recorded.

i. *Walk to Station 6* - Wait while EMT measured heart rate and blood pressure. Arrival/departure times recorded.

j. *Walk to Station 7* - Wait while EMT measured heart rate and blood pressure. Arrival time recorded.

In addition, the miners wearing SCSRs recorded the time and location when the SCSR was no longer useable (the SCSR exhaustion point previously discussed).

Two different model SCSRs were used: The Dräger Oxy-SR60B and the MSA Model 464213. These two models use the same chemical oxygen generator and are functionally similar from the standpoint of engineering design. We have therefore chosen to treat the two units as a single generic category of chemical oxygen SCSR.

3. DISCUSSION OF ESCAPE SPEED DATA

The elapsed time data for the 3 days of trials are shown in Table 3.

This data may be summarized as follows:

	Average travel time (min)	Average wait time (min)	Total time	SCSR life (min)
Day 1	56.5	14.8	71.3	54.5
Day 2	55.5	12.0	67.5	60.5
Day 3	52.3	11.2	63.5	67.5
Final Average	54.8	12.7	67.5	60.8

Average travel speed for each segment along the route was as follows:

Segment	Average height (in.)	Travel mode	Speed (ft/min) Normal	With SCSR	With Oxylog
0 to 1	69	Head bent	264	212	220
1 to 2	34	Duckwalk	103	100	97
2 to 3	30	Crawl	96	85	79
3 to 4	44	Duckwalk	123	94	100
4 to 5	44	Duckwalk	105	85*	86
5 to 6	59	Head bent	236	174	220
6 to 7	72	Upright	244	234**	217

*Three of the six SCSRs exhausted during this phase.
**The other three SCSRs exhausted during this phase.

TABLE 3. - Elapsed time data for 3 days of trials

Miner	First day						Second day						Third day					
	A Normal	B Normal	C Oxylog	D SCSR	E SCSR	F Oxylog	A Oxylog	B SCSR	C SCSR	D Oxylog	E Normal	F Normal	A SCSR	B Oxylog	C Normal	D Normal	E Oxylog	F SCSR
Travel 0 to 1	17[a]	11[a]	17[a]	18[a]	14[a]	12[a]	17	12	15	13	12	9	17	13	10	11	12	11
No wait at 1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Travel 1 to 2	6[a]	5[a]	6[a]	6[a]	5[a]	4[a]	6	5	4	5	4	4	6	6	5	5	4	4
Wait at 2	1	1	4	1	2	4	4	1	1	3	1	3	2	1	1	1	2	2
Travel 2 to 3	15	20	11	13	12	11	18	22	10	13	11	9	17	28	9	11	10	11
Wait at 3	2	2	5	2	2	2	3	3	3	1	2	2	3	2	2	2	2	2
Travel 3 to 4	12	7	6	11	9	9	13	7	5	7	5	7	12	8	3	5	5	7
Wait at 4	2	3	4	4	3	4	2	2	5	3	2	2	2	3	2	2	6	0
Travel 4 to 5	10	6	6	10[b]	6[c]	8	13	9[d]	7	9	6	7	9	9	6	6	5	10
Wait at 5	5	5	2	4	4	4	3	2	2	3	1	2	3	3	2	3	2	[illegible]
Travel 5 to 6	2	2	3	3	3	2	3	3	4	3	3	3	3	2	2	2	2	3
Wait at 6	2	4	3	3	3	2	3	2	3[e]	3	2	3	3[f]	2	2	3	2	2
Travel 6 to 7	6	6	2	3	2	2	8	4	6	5	3	4	6	5	2	3	5	4[g]
Total wait	12	15	18	14	14	16	15	10	14	13	8	12	13	11	9	11	14	9
Total travel	68	57	51	64	51	48	78	62	51	55	44	43	70	71	37	43	43	50

[a]There was no timekeeper at Station 1 on the first day. The recorded total travel time from 0 to 2 was interpolated to provide the times from 0 to 1 and 1 to 2 for the first day, by dividing the total time pro rata according to the individual times on days 2 and 3.
[b]SCSR exhausted during this phase: travel distance of 5650 ft and time of 60 min (includes 2 min wait after donning at Station 0).
[c]SCSR exhausted during this phase: travel distance of 5700 ft and time of 49 min (includes 1 min wait after donning at Station 0).
[d]SCSR exhausted during this phase: travel distance of 6215 ft and time of 61 min (includes 2 min wait after donning at Station 0).
[e]SCSR exhausted during this phase: travel distance of 6850 ft and time of 60 min (includes 2 min wait after donning at Station 0).
[f]SCSR exhausted during this phase: travel distance of 6850 ft and time of 77 min (includes 2 min wait after donning at Station 0).
[g]SCSR exhausted during this phase: travel distance of 7340 ft and time of 58 min (includes 1 min wait after donning at Station 0).

Discussion of this data is divided into the following subsections:

a. Factors Affecting Travel Speeds (subsection 3.1)

b. Life of Oxygen Self-Rescuers (subsection 3.2)

c. Comparison with Data from Other Sources (subsection 3.3).

3.1 Factors Affecting Travel Speeds

One of the major objectives of this program was to establish "standard" escape speeds in underground United States coal mines. The standard represents travelling normally (that is, barefaced, with no respirator) through good conditions. Once these values are determined for different travelway heights, adjustments can be developed to allow for other factors such as condition of the travelway or wearing of a respirator.

3.1.1 Escapeway Height

The various segments of the escape route were deliberately chosen to provide as many different escapeway heights as possible, in order to compare travel speeds. Table 4 shows the travel speeds in each segment, based on the data taken only from the "normal" travel.

Further discussion of escape speed as a function of travel height is contained in subsection 3.3.1.

3.1.2 Escapeway Conditions

Escapeway conditions other than height can also affect travel speed. Such factors might include irregular roof, loose material on the floor, water, and an uneven or pitched floor.

The segments of the escape route from 3 to 4 and from 4 to 5 were deliberately chosen to provide passageways of similar height but different conditions. As outlined in Section 4, the travel from 3 to 4 was in good condition, whereas the route from 4 to 5 contained several pools of water and other obstacles.

TABLE 4. - Travel speeds in each segment

Escapeway segment	Escapeway height (in.)	Normal escape speed (ft/min)	Remarks
2 to 3	30 to 45	 96	Crawling was required, therefore assume average height of 30 in.
1 to 2	30 to 38	 103	Typical speed for average height of 34 in.
4 to 5	35 to 50	 105	Below typical speed because of ground conditions
3 to 4	35 to 52	 123	Typical speed for average height of 44 in.
5 to 6	52 to 65	 236	Typical speed for average height of 58 in.
0 to 1	60 to 78	 264	Typical speed for average height of 69 in.
6 to 7	78+	 244	Below typical speed because of 10% grade

The following compares the travel speed for the two segments:

Station 3 to 4, duckwalk in good conditions	123 ft/min
Station 4 to 5, duckwalk with obstacles, water	105 ft/min
Percentage decrease, due to ground conditions	- 15 percent

Another significant passageway condition is the slope or pitch of the entry. In the test escapeway, travel from 6 to 7 was by walking upright up a 10 percent grade. Compare this with the level passage from 0 to 1:

Station 0 to 1, walk head bent in good conditions	264 ft/min
Station 6 to 7, walk erect up 10 percent grade	244 ft/min

It can be seen that walking up the grade was 8 percent slower even though the miners could travel fully erect. A higher percentage reduction, perhaps 10 to 15 percent, could be expected in a direct comparison with fully-erect travel on level ground.

3.1.3 Wearing Respiratory Equipment

Using an SCSR or the Oxylog reduced travel speed as shown in Table 5.

TABLE 5. - Travel speed while wearing a respiratory device

Travel mode	Average speed over entire route (ft/min)
Normal	161
Wearing SCSR	135
Wearing Oxylog	136

It is not surprising that the Oxylog and SCSR produced the same decrease in speed because the two units weigh about the same, are carried on the body in a similar manner, and both require breathing through a mouthpiece or mask.

This decrease in travel speed while wearing a respiratory device was fairly consistent in each segment of the travel route. In other words, wearing a respiratory device will decrease travel speed approximately 15 percent in any seam height or condition of entry.

3.2 Life of Oxygen Self-Rescuers

Six chemical oxygen self-rescuers were tested during this program, one by each of the six test participants. The results are summarized in Table 6.

In general, the faster the miner travelled, the sooner the SCSR was consumed. However, travelling faster means covering more distance in less time, so that even though the SCSR is exhausted sooner, the distance travelled can be as great or greater. As can be seen in the last column of Table 6, chemical oxygen

TABLE 6. - Results of life of oxygen self-rescuers

Miner	Escape time Travel + Wait (min)	Life of SCSR		Distance travelled × body weight (million ft-lb)
		Time (min)	Distance (ft)	
A	70 + 13	77*	6850	1.07
B	62 + 10	61*	6215	1.06
C	51 + 14	60*	6850	1.18
D	64 + 14	60*	5650	1.00
E	51 + 14	49**	5700	1.02
F	50 + 9	58**	7340	1.34

*Includes 2 min wait (after donning SCSR) before starting escape.
**Includes 1 min wait (after donning SCSR) before starting escape.

SCSRs seem to provide enough oxygen for a *constant amount of work regardless of the speed at which the work is carried out.* This work is represented by the distance travelled times the body weight of the miner.

Further discussion of this topic is contained in Section 4.

It is important to emphasize that these data and conclusions apply only to *chemical* oxygen self-rescuers. Quite different results might be obtained with compressed oxygen self-rescuers.

3.3 Comparison with Data from Other Sources

The relationship between travel speed and seam height is plotted in Figure 2. Note that travel speed increases with increasing seam height, with a pronounced increase starting at about 45 in. seam height. Above this height, a miner can walk even though stooped. Below this height, a miner must duck walk or crawl. Note also that travel speed does not increase as the seam height increases beyond 72 in. - once the miner can walk fully upright, further increases in seam height do not increase travel speed.

Figure 2 also shows a comparison of the results of this program with data from the following sources:

a. USBM publication, 1961

b. United States coal mining industry, 1980

c. German coal mining industry, 1976

d. MSHA field testing, 1981.

Each of these sources is discussed in the following paragraphs.

3.3.1 USBM Publication (1)

The only published data on escape speeds in the United States come from a 1961 publication by Ward Stahl, "Escapeways and Other Emergency Measures in Coal Mines." His results were based on his observations and measurements of his travels through underground coal mines. The results are summarized in Table 7.

As shown in Figure 2, travel speeds determined by Stahl were considerably less than the present study in travel heights below 50 in. Speeds were comparable in higher travelways. According to Stahl (2), the lower speeds he measured possibly can be attributed to the debris and loose rock common to escapeways in the 1950s and 1960s.

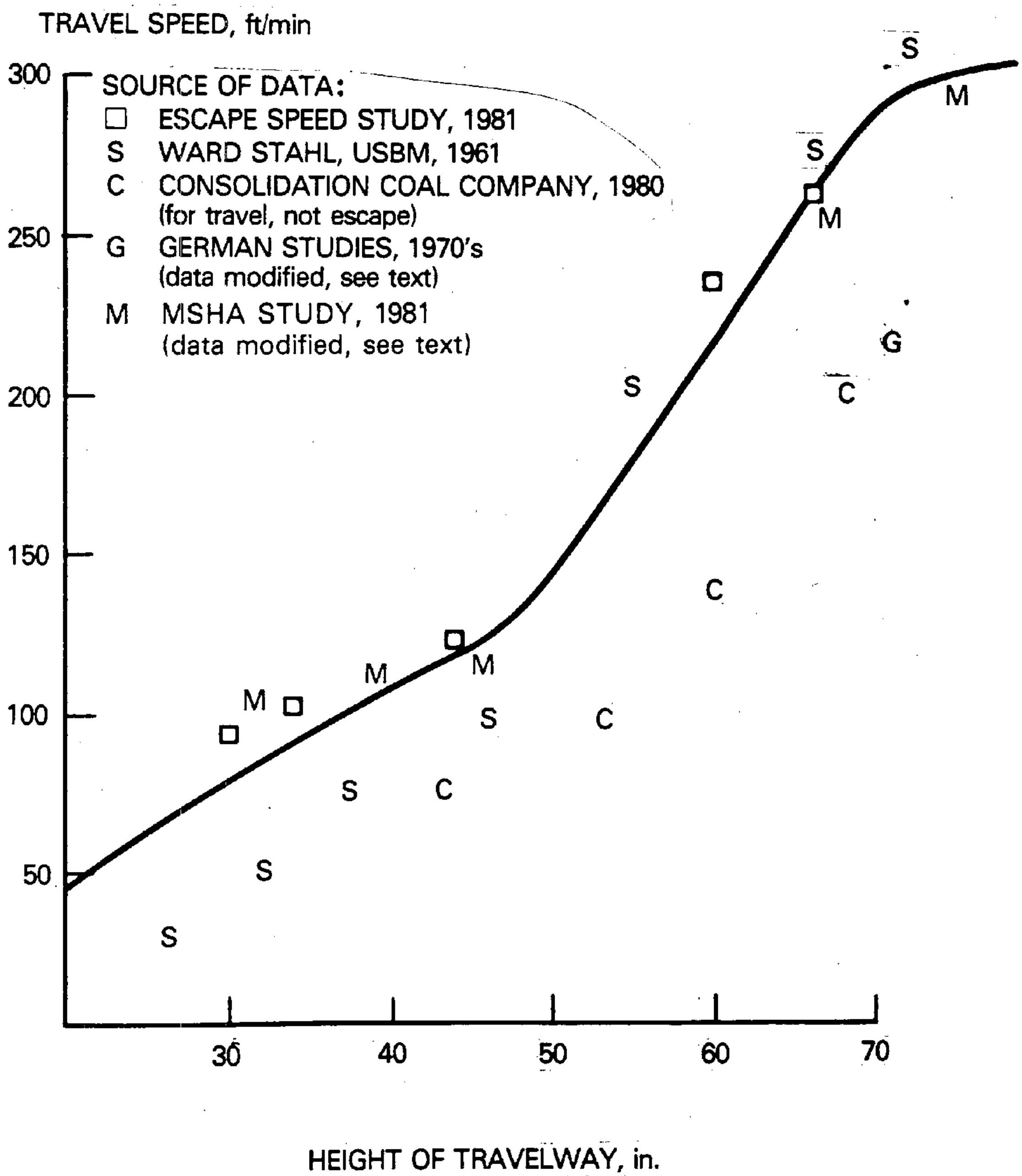


FIGURE 2. - Comparison of data from different sources.

Table 7. - Travel Speeds from USBM Information Circular 8127

Height of travelway (in.)	ft/min	Body position
Below 30	24	Crawling
30 to 36	50	Creeping on knees
36 to 42	75	Duckwalking
42 to 48	100	Extreme body bend
48 to 60	200	Slight body bend
60 to 72	275	Head bend
Over 72	300	Upright

3.3.2 United States Coal Mining Industry (3, 4)

By law, designated escapeways in United States coal mines must be travelled every 6 weeks. The Consolidation Coal Company provided information on the time required to travel some of the designated escape routes in some of their mines, which is shown in Table 8. Miners travelling these routes are not "escaping;" they are travelling at a moderate pace. Thus, the speeds obtained from this source are probably somewhat below average for escape speeds.

3.3.3 German Coal Mining Industry (5, 6)

As reported in Volume II of this report, the German coal mining industry conducted a comprehensive study of escape speeds in their mines during the 1970s, with the results shown in Table 9.

All of the German data was taken with miners wearing either filter self-rescuers or oxygen-measuring respirators. As reported in subsection 3.1.3, travel is 15 percent slower wearing respirators. Thus,

$$\text{Travel speed in roadways} = \underbrace{\frac{55\text{m}}{\text{min}}}_{\text{German data}} \times \underbrace{\frac{3.3\text{ ft}}{\text{meter}}}_{\text{metric conversion}} \times \underbrace{\frac{100\%}{85\%}}_{\text{respirator correction factor}} = 213\text{ ft/min}$$

TABLE 8. - Summary of travel speeds in Consolidation Coal Company escapeways (2,3)

Travelway height (in.)	Distance (ft)	Time walking (min)	Mine	
40	1,500	15	Eckman No. 9	Average height 43 in. Average speed 74 ft/min
42	7,900	120	Itmann No. 2	
43	8,600	105	Itmann No. 3A	
43	4,200	60	Itmann No. 3B	
45	1,230	15	Eckman-Page	
48	4,800	45	Bishop No. 33	Average height 52 in. Average speed 102 ft/min
48	5,300	75	Itmann No. 1	
52	6,800	45	Turkey Gap	
54	9,000	90	Mathews No. 1	
54	4,800	45	Bishop No. 36	
60	11,000	90	Mathews No. 3	Average height 60 in. Average speed 123 ft/min
60	5,000	45	Dryfork	
60	4,500	32	Rowland No. 3	
66 to 72	35,700*	230*	McElroy	Average height 69 in. Average speed 197 ft/min
66 to 72	51,200*	181*	Ireland	
66 to 72	108,100*	585*	Shoemaker	

*Sum of several different escapeways in each mine.

TABLE 9. - Travel speeds in German coal mines

Roadways				
	Intakes		Returns	
Inclination (deg)	Ascending (m/min)	Descending (m/min)	Ascending (m/min)	Descending (m/min)
0 to 5	55	55	55	55
5 to 10	45	60	40	45
10 to 15	35	55	30	35
15 to 20	30	45	25	25
>20	25	30	20	20

Faces		
Inclination (deg)	Seam thickness (m)	Face escape speed (m/min)
0 to 20	<1	8
0 to 20	1 to 1.4	10
0 to 20	1.4 to 1.8	15
0 to 20	>1.8	25
>20	All thickness	10
Shafts	4 m/min up	8 down

The German data for travel on the face cannot be directly compared to our data, because the German faces are all longwalls. This means that the travel height is reduced by the space needed for the chocks at both the roof and the floor. Travel speed would be further reduced by the difficulty of clambering through the supports, around hydraulic hoses, etc. Comparing the German speed for travelling in roadways to their speed for travelling through a longwall chockline higher than 1.8m does suggest that longwall travel speeds are roughly 50 percent (25 m/min compared to 55 m/min) of "normal" travel speeds for the same seam height.

3.3.4 MSHA Field Trials (7)

MSHA conducted an extensive underground field evaluation of SCSRs during a 1-1/2 year period prior to the required usage of SCSRs by all underground miners which started in June 1981. A total of 227 underground miners* participated, keeping SCSRs at their workplace for 10 shifts. After the last shift in each mine, the participating miners donned their SCSRs and travelled a prescribed route. Table 10 summarizes the results of the "escape." The "reported speeds" are the actual speeds of the miners wearing SCSRs. The "corrected speeds" are estimates of their speeds had they been travelling "bare-faced," using the correction factor discussed in subsection 3.3.3.

Table 10. - Travel speeds in MSHA evaluation

Mining height	No. of miners	Reported speed	Corrected speed
32	6	100	119
38	17	95	113
42 to 48	9	100	119
60 to 72	12	220	261
76 to 90	23	240	285

Source: Reference (7), Tables 1 and 4, Appendix A-3
Tables 1 and 5, Appendix A-4

*Eighteen mines from the National Independent Coal Operators Association (NICOA) and Bituminous Coal Operators Association (BCOA) volunteered for this study

4. DISCUSSION OF PHYSIOLOGICAL DATA

This section is a summary of the physiological responses of the miners during the simulated escape. Three variables were measured:

a. $\dot{V}_E$ - Ventilation rate of the lungs, usually measured in liters per minute

b. $\dot{V}_{O_2}$ - Rate of oxygen consumption, usually measured in liters per minute

c. HR - Heart rate, measured in beats per minute.

The dots over the "V" indicate a volume per minute (sometimes called the minute volume). Additional definitions and abbreviations may be found in Appendix A.

In order to extract as much data as possible, the three physiological responses mentioned above were continuously recorded during the escape and then later analyzed minute-by-minute.

This section is divided into the following subsections:

a. Test Preparation and Procedures (subsection 4.1)

b. Data Analysis (subsection 4.2)

c. Comparison with Data from Other Sources (subsection 4.3).

4.1 Test Preparation and Procedures

Prior to any underground testing, the six volunteers were given a thorough "stress test" in the laboratory by a physician. The volunteers walked on an inclined treadmill, at a pace which was gradually increased until exhaustion occurred or until the physician found it necessary for the test to be terminated. Towards the end of the test, at the peak of exertion, the subject's expired air was collected for the measurement of the maximum $\dot{V}_{O_2}$ which is also called *maximum aerobic capacity* ($\dot{V}_{O_2}$max). Cardiograms were continuously monitored during the stress test; thus, the maximum HR, which accompanies the $\dot{V}_{O_2}$max, was recorded. The maximum ventilation rate ($V_E$max) was also recorded. These obtained maximum values are indicators for the capacity of work, which should be reflected in the escape performance: the lower $\dot{V}_{O_2}$max is, the slower is the expected escape, as further discussed in subsection 4.2.

Table 11 lists all of the test participants and their relevant physical characteristics, including the stress test data.

As shown in Table 11, the miners ranged in age from 24 to 61 years. The oldest participant, miner A, had symptoms of black lung, which could account for his $\dot{V}_{O_2}$max being low for his age bracket (8, 9). However, the $\dot{V}_{O_2}$max for the other miners was within the expected range for the United States population. The body weight of the six miners was within the weight range found previously for miners, although the mean weight was slightly below the previous mean (10).

Instrumentation malfunctions during the underground test program resulted in the loss of some data, no oxygen consumption data for miner F and no ventilation rates for miners D and F.

For the underground testing, two sets of instrumentation were available, so that in 3 days each of the six miners was monitored on one escape for respiratory and cardiac functions. For the respiratory function, a recording respirometer called an "Oxylog" was used. For HR, three skin electrodes were placed on the miner's chest.

The Oxylog is a 6.7 lb unit which is hung from the shoulder. A face mask is connected to it via a hose, as shown in Figure 3.

Pulmonary ventilation ($\dot{V}_E$) is measured by a vane type meter which turns as the inhaled air flows through the mask. The turning of the vane is recorded through a photocell which sends the signals to the Oxylog. A display for $\dot{V}_E$ and for total ventilation is shown on top of the Oxylog. The volume is corrected to 0°C by sensing the air temperature and assuming 50 percent relative humidity.*

Oxygen uptake ($\dot{V}_{O_2}$) is electronically calculated by the Oxylog. An oxygen-sensitive cell (beckman OM-10) measures the inhaled O_2 concentration and the exhaled O_2 concentration. Electronic circuitry subtracts the exhaled from the inhaled concentration and multiplies by $\dot{V}_E$ in order to provide the value of $\dot{V}_{O_2}$ and the cumulative oxygen uptake, which is displayed on the top of the Oxylog.

The $\dot{V}_E$ and $\dot{V}_{O_2}$ values were transmitted to a specially made tape recorder mounted on the face of the Oxylog. These signals were recorded on the tape parallel to the heart beat signals. All the input on the tape was analyzed by replaying the tape

*This correction means that both $\dot{V}_E$ and $\dot{V}_{O_2}$ are recorded at STPD conditions.

TABLE 11. - Physical characteristics of test participants

Miner	Age (years)	Ht (cm)	Wt (kg)	Resting				Maximum			
				HR (beats/min)	$\dot{V}_{O_2}$ (liters/min)	$\dot{V}_{O_2}$ (ml/kg·min)	$\dot{V}_E$ (liters/min)	HR (beats/min)	$\dot{V}_{O_2}$ (liters/min)	$\dot{V}_{O_2}$ (ml/kg·min)	$\dot{V}_E$ (liters/min)
A	61	185	71.2	76	0.28	3.93	10	156	1.60	22.5	33
B	54	160	77.6	69	0.37	4.77	14	155	2.39	30.8	64
C	49	166	78.0	72	0.37	4.74	12	168	2.87	36.8	54
D	49	172	80.7	84	0.39	4.83	--*	200	2.70**	33.5**	--
E	34	166	81.3	96	0.36	4.43	12	200	3.17	38.9	97
F	24	183	82.9	74	0.30	3.62	--	182	3.48	42.0	86
Average	45.2	172	78.6	78.50	0.35	4.39	12	176.8	2.47	34.1	62.3

*Instrument malfunctions resulted in the loss of some data for miners D and F.

**Estimated by extrapolations: During the escape tests conducted later, both $\dot{V}_{O_2}$ and HR data were obtained for Miner D. This data was consistent enough to allow the maximum $\dot{V}_{O_2}$ valves during the stress test to be estimated based on the maximum recorded heart rate observed during stress test, which was measured at 200 beats/min.

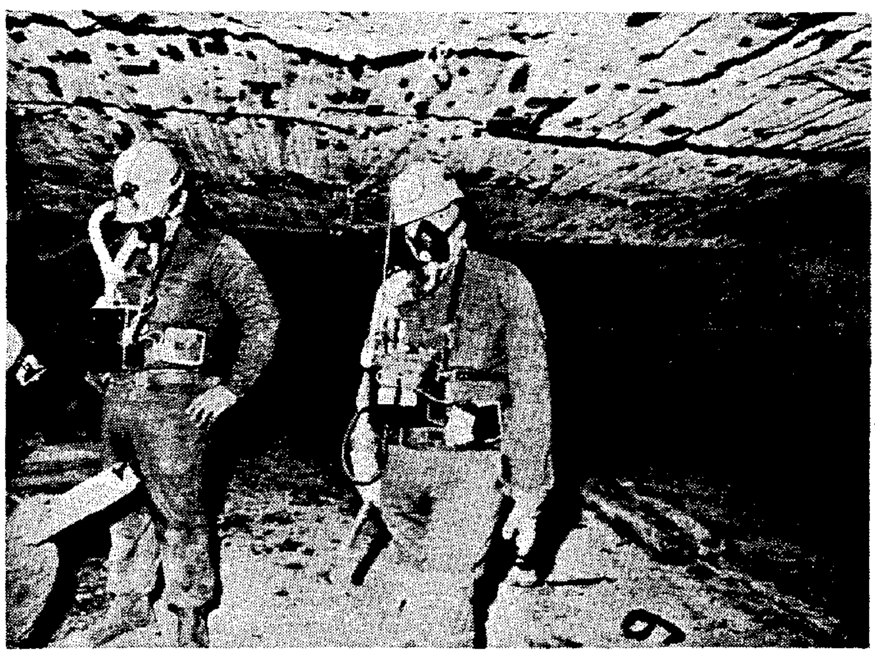


FIGURE 3. - Miners wearing physiological response instrumentation.

and recording signals on a tape at intervals of 1 liter for expired air and 1/10 liter for O_2 uptake. The HR is recorded as the electrical signals from the chest electrodes.

The recorder and replay system ("Medilog") was processed through a computer, using a special program which calculated $\dot{V}_E$, $\dot{V}_{O2}$, and HR on a minute-by-minute basis. Occasionally, the electrocardiograms had to be viewed on an oscilloscope and the heart beats were manually counted because the computer could not discriminate the heart beats in the presence of occasional "electrical noise" from chest muscles.

It should be noted that there were some instrument malfunctions during the underground test program. The biggest problem was keeping the turbine spirometer clean (the small, vane-type anomometer on the face mask which senses the ventilation rate). There were also minor electrical problems. These instrument malfunctions resulted in the loss of oxygen consumption data for Miner F and ventilation rates for Miners D and F.

4.2 Data Analysis

This study on the escape from an underground coal mine was unique in the successful use of new technology which allowed minute-by-minute measurements of $\dot{V}_{O2}$, $\dot{V}_E$ and HR. Consequently, occurrence of peak values and accurate average values could be obtained for each segment of the escape and each rest period.

Table 12 shows the physiological data for each miner during the "escape." This table was prepared by summing the minute-by-minute data for each segment and dividing by the number of minutes for that segment. Thus, this table provides the "average" $\dot{V}_{O2}$, $\dot{V}_E$ and HR experienced by *each* miner over *each* segment.

As indicated previously, minute-by-minute data is also available. An example of the $\dot{V}_{O2}$ minute-by-minute data is shown in Figure 4 for two miners. $\dot{V}_{O2}$ rose gradually at the start of each segment, fluctuated around a relatively steady state (with one or two peaks) and then dropped rapidly towards the resting values. One observation is that short duration changes in the escape route such as crossing water pools for less than a minute could not meaningfully affect the $\dot{V}_{O2}$ or HR. Another example is the short segment from Station 5 to Station 6. As shown in Figure 4 the miners stopped at Station 6 when $\dot{V}_{O2}$ was on the rise and it is not clear whether or not the actual O_2 cost for the segment was achieved in this short period of activity.

TABLE 12. - Physiological data from escape

	Oxygen consumption rate, $\dot{V}_{O_2}$ (liters/min)						Respiration rate, $\dot{V}_E$ (liters/min)						Heart rate, HR (beats/min)					
Miner	A	B	C	D	E	Avg.[a]	A	B	C	D	E	Avg.[a]	A	B	C	D	E	F
Travel 0 to 1	1.16	1.35	1.02	1.65	1.77	1.39	27.8	37.5	26.0	(d)	55.8	36.8						
No wait at 1	-	-	-	-	-	-	-	-	-	-	-	-	125	123	114	130	150	135
Travel 1 to 2	1.27	1.47	0.90	1.84	1.98	1.49	32.3	51.2	30.0	-	61.5	43.8						
Wait at 2	0.85	1.20	0.43	0.73	1.15	0.87	24.8	42.0	12.0	-	38.5	29.3						
Travel 2 to 3	1.21	1.24	1.20	1.84	2.15	1.53	31.2	45.5	35.5	-	66.3	44.6	133	134	131	150	170	151
Wait at 3	0.87	1.25	0.62	0.90	1.25	0.98	25.0	42.0	18.2	-	41.0	31.6						
Travel 3 to 4	1.16	1.45	1.58	2.11	2.32	1.72	31.2	51.3	49.3	-	70.8	50.7	136	144	139	167	175	151
Wait at 4	0.90	0.63	0.65	0.83*	1.16	0.83	26.5	26.7	21.3	-	48.3	30.7						
Travel 4 to 5	1.20	1.58	1.53	1.90	2.22	1.69	31.5	54.0	48.0	-	68.0	50.4						
Wait at 5	0.90	1.00	0.55	0.90	1.00	0.87	28.0	28.3	25.5	-	34.5	29.1	132	142	131	158	163	151
Travel 5 to 6	1.27	1.70	1.27	1.67	1.80	1.54	31.3	57.0	39.7	-	57.0	46.3						
Wait at 6	0.77	0.80	0.57	0.80	0.60	0.71	24.0	29.3	19.3	-	40.0*	28.2						
Travel 6 to 7	1.20*	1.50	1.90	1.84	2.18	1.72	31.0*	53.8	48.0	-	66.0	49.7	126	143	132	151	161	149
WEIGHTED[b] AVERAGES:																		
Travel	1.19	1.38	1.23	1.83	2.04	1.53[c]	29.8	47.1	35.5		63.2	43.9						
Wait	0.85	0.84	0.57	0.82	0.99	0.81	25.5	31.6	18.5		41.0	29.2						
Total	1.14	1.31	1.05	1.64	1.78	1.38	29.1	45.1	31.1		57.7	40.8						

*Estimated (Data was missing for one or more minutes; values were extrapolated from other data).

[a] Average is a simple average: sum of values for five miners divided by 5 (or 4 in the case of $\dot{V}_E$)

[b] Weighted average = [Σ(values/minutes × number of minutes)]/total minutes

[c] Equal to (Σ Weighted averages)/5 (or ÷ 4 in the case of $\dot{V}_E$)

[d] Instrumentation failed to record respiration rate.

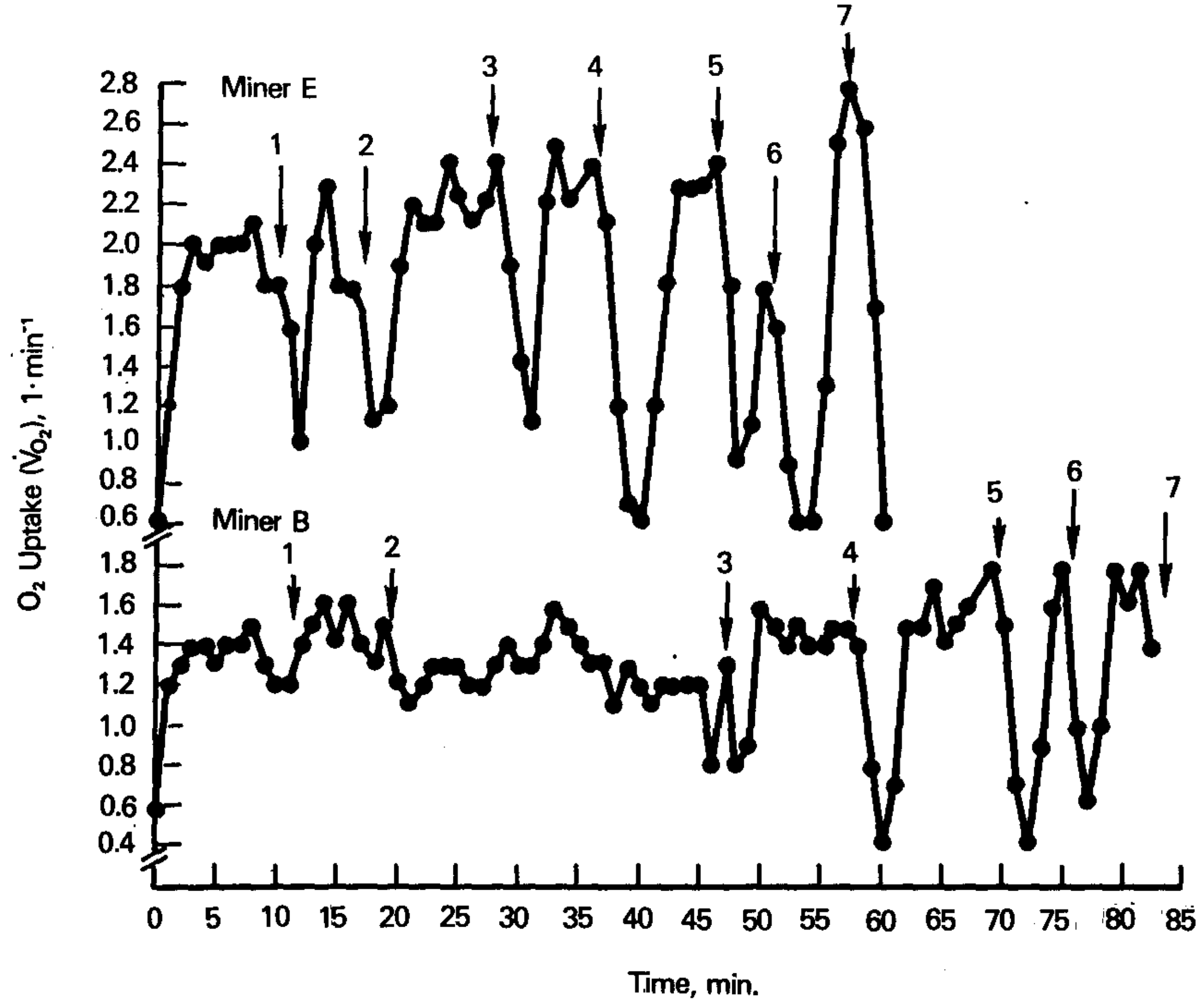


FIGURE 4. - O_2 uptake ($\dot{V}_{O_2}$) minute-by-minute.

TABLE 13. - Physiological data, expressed as percent of maximums

Segment	$\%\dot{V}O_2max$	$\%\dot{V}_Emax$	$\%HR_{max}$
0 to 1	55	62	74
1 to 2	59	71	
2 to 3	60	72	82
3 to 4	68	82	86
4 to 5	67	83	83
5 to 6	59	73	
6 to 7	68	80	82
Average travel	61	71	81
Average waiting	39	47	-
Average total escape	55	66	-

Table 13 shows the average $\dot{V}O_2$, $\dot{V}_E$, and HR, presented as a percentage of the maximum responses. (The maximum responses for $\dot{V}O_2max$, $\dot{V}_Emax$ and HR_{max} were obtained in the laboratory during the stress test.) These ratios expressed as percentage of the maximum values are given as means for all the miners, separately for each segment as well as for the total escape. The $\%\dot{V}O_2max$ and $\%HR_{max}$ indicate the level of strain that the escape imposed on the miners and it also reflects on the endurance. The average for the "travel only" part of the escape was 61 percent $\dot{V}O_2max$, 71 percent $\dot{V}_Emax$, and 81 percent HR_{max}. For the total escape (includes waiting time), the averages were 55 percent $\dot{V}O_2max$ and 66 percent $\dot{V}_Emax$. These values show that the test participants were in fact working very hard, because an effort for 1 hr is expected to demand 50 to 60 percent $\dot{V}O_2max$ (11, 12). Of course higher effort can be performed for shorter durations (peak efforts as high as 76 percent VO_2max were recorded) but such an effort could last for only a few minutes throughout the escape. Other research (11) indicates that $\%HR_{max}$ for a given effort is normally higher than the corresponding $\%\dot{V}O_2max$, as it was in these tests.

Note that from the above discussion the oxygen consumption $\dot{V}O_2$ for an escape route can be predicted for an individual miner if the $\dot{V}O_2$ is known, using $\dot{V}O_2$ (average escape) = 0.55 × $\dot{V}O_2max$ (measured in stress test).

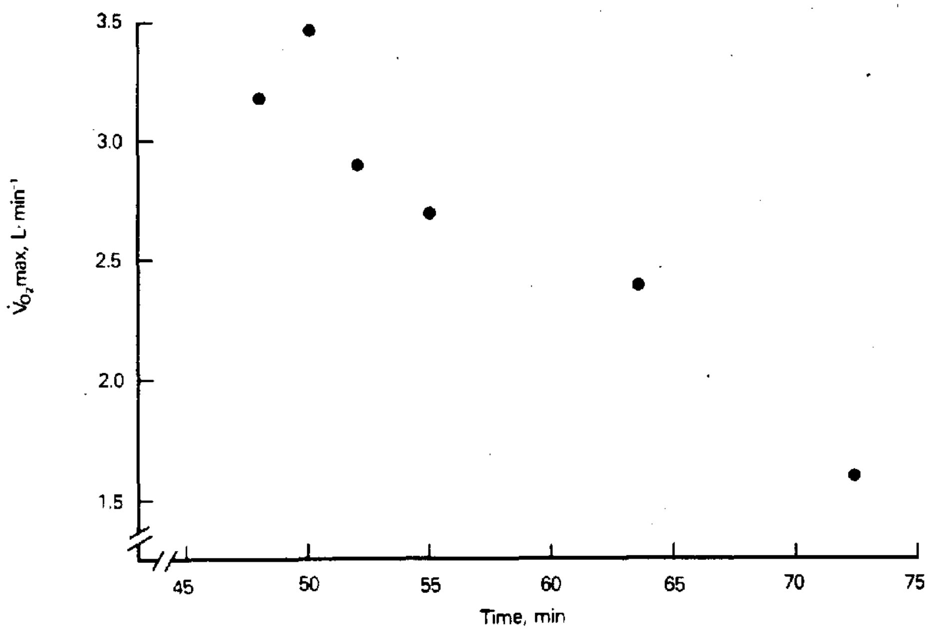


FIGURE 5. - The relationship between the miners' maximum aerobic capacity ($\dot{V}_{O_2}$max) and their mean time of escape.

$\dot{V}_{O_2}$max can also be used to make estimates about the speed of escape for an individual miner: the higher the $\dot{V}_{O_2}$max the faster the escape. Figure 5 plots the individual miners' values of $\dot{V}_{O_2}$max against their times of escape (travel time only, barefaced). It can clearly be seen that there is an inverse relationship between the $\dot{V}_{O_2}$max and the escape time.

The ratio $\dot{V}_E/\dot{V}_{O_2}$ was calculated in order to evaluate the change in the gas flow between the lungs and a respirator. These results are shown in Table 14. The rate of gas flow between the lungs and a respirator has considerable effect on the pressure due to resistance and on the temperature of the inhaled gases. It will be of interest to manufacturers to realize that despite the changes in effort the miners maintained a consistent $\dot{V}_E/\dot{V}_{O_2}$ ratio. This means that they did not hyperventilate. The average $\dot{V}_E/\dot{V}_{O_2}$ ratio of 30 to 35 was similar to previous observations on coal miners (13).

The $\dot{V}_{O_2}$ results can be applied to the expected CO_2 output which was not measured. At this level of effort (60 to 80 percent $\dot{V}_{O_2}$max) the CO_2 to O_2 ratio is between 0.9 to 1. Therefore, using a small safety margin, the CO_2 output could be assumed the same as $\dot{V}_{O_2}$. This information is important for the design of CO_2 scrubbers in respirators.

TABLE 14. - Calculated ratios of respiration rate $\dot{V}_E$ to oxygen uptake $\dot{V}_{O_2}$, $\dot{V}_E/\dot{V}_{O_2}$

	Miner A	Miner B	Miner C	Miner E	Average
Travel	25	34	29	31	29
Wait	30	38	32	42	36
Total	26	34	30	32	31

The oxygen cost per kilogram of body weight per meter traveled was calculated for each miner and for each segment of the escape route. The results are shown in Table 15. It should be noted that the information in this table concerning oxygen cost is measured in volume *only*, not in volume per minute. The following conclusions can be drawn from this data:

a. Walking (Stations 0 to 1, 5 to 7) has a relatively low oxygen cost of about 0.3 ml/kg-m.

b. Duck walking and crawling (Stations 2 to 5) have a relatively high oxygen cost of about 0.7 ml/kg-m.

c. Traveling in obstructed entries (Stations 4 to 5) has a higher oxygen cost than traveling in unobstructed travelways (Stations 3 to 4).

d. A mixture of travel modes (from crawling to upright walking) has an "average" oxygen cost of about 0.5 ml/kg-m.

e. Miner C was clearly more "fit" than the other miners - his oxygen requirement was below average. This is consistent with the data on lifetime of SCSRs (subsection 3.2): Miner C's SCSR had the longest lifetime of the 5 miners, as measured in terms of body weight times distance traveled.

TABLE 15. Oxygen cost per kilogram body weight per meter travelled

Miner	Body weight	O_2 Uptake (ml/kg-m)							Weighted Average
		Segment 0 to 1 	Segment 1 to 2 	Segment 2 to 3 	Segment 3 to 4 	Segment 4 to 5 	Segment 5 to 6 	Segment 6 to 7 	
A	71.2	0.30	0.70	0.83	0.87	0.99	0.32	0.45	0.55
B	77.6	0.24	0.74	1.23	0.61	0.74	0.38	0.33	0.53
C	78.0	0.24	0.45	0.47	0.50	0.48	0.33	0.16	0.33
D	80.7	0.28	0.75	0.81	0.75	0.96	0.37	0.38	0.52
E	81.3	0.28	0.63	0.72	0.58	0.62	0.26	0.45	0.45
Average		0.27	0.65	0.81	0.66	0.76	0.33	0.35	0.48

4.3 Comparison with Data from Other Sources

How does the respiratory response to the escape route in this study compare with the respiratory response to the prescribed exercises used in the testing and approval of SCSRs? Table 16 answers this question by showing the metabolic cost of the escape route in this study compared to the metabolic cost of the prescribed exercises used in the testing of SCSRs in both the United States and Europe.

Several points should be considered in comparing this data:

a. The escape study data includes only 5 men for $\dot{V}_{O_2}$ and 4 men for $\dot{V}_E$.

b. The escape study data is for a route which averages 74 min in length, including an average of 14 min of rest periods.

The metabolic cost data for United States and European testing of SCSRs is explained in more detail in the following two subsections.

TABLE 16. - Comparison of metabolic cost of different tasks

	$\dot{V}_{O_2}$	$\dot{V}_E$
Escape speed study, 1981	1.38 liters/min	41 liters/min
SCSR acceptance tests, United States	1.35 liters/min	32 liters/min
SCSR acceptance tests, Europe	1.57 liters/min	35 liters/min

4.3.1 Tests for Permissibility of SCSRs, United States

SCSRs used in American coal mines must be jointly approved by MSHA and NIOSH* according to 30 CFR 11, commonly known as Part 11. The major performance requirement is the 60 minute Man Test No. 4, which was "...designed to represent the workload performed in the mining, mineral, or allied industries by a person wearing the apparatus tested. The apparatus tested will be worn by Institute personnel trained in the use of self-contained breathing apparatus..."**

The specific activities include walking, running, a vertical treadmill, and carrying and pulling weights. All of the travel speeds and carried weights are prescribed for a total of 52 min, interspersed with 8 min of rest for samplings and readings.

In a previous study on coal miners during the performance of the elements of Man Test No. 4, Kamon et al. (14) found that the data was normally distributed and could be summarized as follows:

	50 percentile***	95 percentile****
Oxygen consumption: $\dot{V}_{O_2}$	1.35 liters/min	1.75 liters/min
Pulmonary Ventilation: $\dot{V}_E$	32 liters/min	42 liters/min

It should be pointed out that physiological cost is not measured by NIOSH during SCSR certification trials. The research referenced above was sponsored by the U.S. Bureau of Mines in order to quantify the physiological cost (rates of oxygen consumption and ventilation) for NIOSH Man Test 4.

4.3.2. Tests for Permissibility of SCSRs, Europe

The European community requires both a man-test and a breathing machine test for approval of SCSRs, as reported in detail in Volume II, Appendix B of this report. The Europeans have recently

*MSHA = Mine Safety and Health Administration, U.S. Department of Labor.
NIOSH = National Institute for Occupational Safety and Health, U.S. Department of Health, Education, and Welfare

**30 CFR 11.85-14(a) and (b)

***Average value for all miners tested.

****95 percent of all miners tested were equal to or *less* than these values.

instituted a new standard which requires that the SCSR last for 90 min when tested on a mechanical lung which is adjusted to breathe at the following rate:

$\dot{V}_{O_2}$ 1.57 liters/min

$\dot{V}_E$ 35 liters/min

The European man-test is designed to require a respiratory response similar to the above values.

The new standard also requires that the SCSR be capable of supplying a 5-min maximum effort as follows:

$\dot{V}_{O_2}$ 3.5 liters/min

$\dot{V}_E$ 70 liters/min

By way of comparison, the maximum effort (of 5 min or longer) during our man-tests was performed by Miner E during the 5 min duckwalk from Station 3 to Station 4:

$\dot{V}_{O_2}$ 2.32 liters/min

$\dot{V}_E$ 70.8 liters/min.

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APPENDIX A

SYMBOLS AND ABBREVIATIONS

The following is a list of the symbols used in the text. Some of this terminology is used among phsiologists.

STPD = Standard temperature pressure dry.

ATPS = Ambient temperature pressure saturated.

Ht = Height.

HR = Heart rate, the frequency the heart beats per minute (beats/min).

HR_{max} = The maximal heart rate per minute, usually observed at the peak of effort such as the end of a stress test.

$\%HR_{max}$ = The heart rate at submaximal muscular effort expressed as a percentage of the maximal heart rate.

SCSR = Self-contained-self-rescuer. In this report references to SCSRs include only NIOSH/MSHA-approved, 60-minute SCSRs which use potassium super-oxide, a solid chemical, to generate oxygen and absorb carbon dioxide.

$\dot{V}_E$ = The volume, in liters per minute, of air or other mixture of gases moved in and out of the lungs. It is also referred to as pulmonary ventilation. $\dot{V}_E$ is used because the expired gas is normally collected for volume measurements (notice the dot above the $\dot{V}$ which indicates a value per 1 minute).

V_E = Total volume of air or gas mixture moved in and out of the lungs (liters).

$\dot{V}_E max$ = The maximal volume of air moved through the lungs ($liters \cdot min^{-1}$), usually observed at maximal muscular effort.

$\%\dot{V}_E max$ = The pulmonary ventilation at submaximal muscular effort. In this text it is expressed as percentage of the observed pulmonary ventilation at the highest work level measured at the end of the stress test.

$\dot{V}_{O_2}$ = The volume of O_2 consumed by the body in one minute. The value can be expressed in terms of liters·min^{-1} or in terms of ml per kilogram body weight per minute (ml·kg^{-1}·min^{-1}). Again, the dot above the $\dot{V}$ indicates O_2 uptake per minute.

V_{O_2} = Total volume of O_2 consumed, usually expressed in terms of liters.

$\dot{V}_{O_2}max$ = The maximal volume of O_2 consumed, as observed at the highest muscular effort which is tolerated for 2 to 3 min. The volume per minute is expressed either in liters·min^{-1} or in ml·kg^{-1}·min^{-1}. In this study the $\dot{V}_{O_2}max$ was measured at the end of the stress test.

$\%\dot{V}_{O_2}max$ = The volume of O_2 uptake during submaximal muscular effort, expressed as percentage of the observed maximal O_2 uptake.

Wt = Weight.