Evaluating mining self-rescuers in a hot and humid environment

A study carried out by Mines Rescue Service Ltd for the UK Health and Safety Executive

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United Kingdom Health & Safety Executive

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- Following underground fires and explosions, coalminers' survival depends on effective emergency planning and when necessary, use of respiratory protection.
- Most common form of self-rescuer in use in UK is the Filter Self-Rescuer (FSR). Self Contained Self Rescuers (SCSR) used only where O2 deficiency risks are identified.
- UK coalmines becoming increasingly challenging in terms of emergency escape due to heat & humidity and extended self-rescuer wearing durations before reaching place of safety.

- Effective temperatures over 30^0C and travel distances in excess of 10km are not uncommon.
- Accepted that use of Mines Rescue breathing apparatus (BA) in hot and humid conditions requires high degree of physical fitness and adherence to ‘safe wearing’ charts
- In UK, no such limiting criteria applied to use of miners’ self-rescuers.

Escape and rescue from mines

Escape and Rescue from Mines Regulations 1995

APPROVED CODE OF PRACTICE AND GUIDANCE

L71

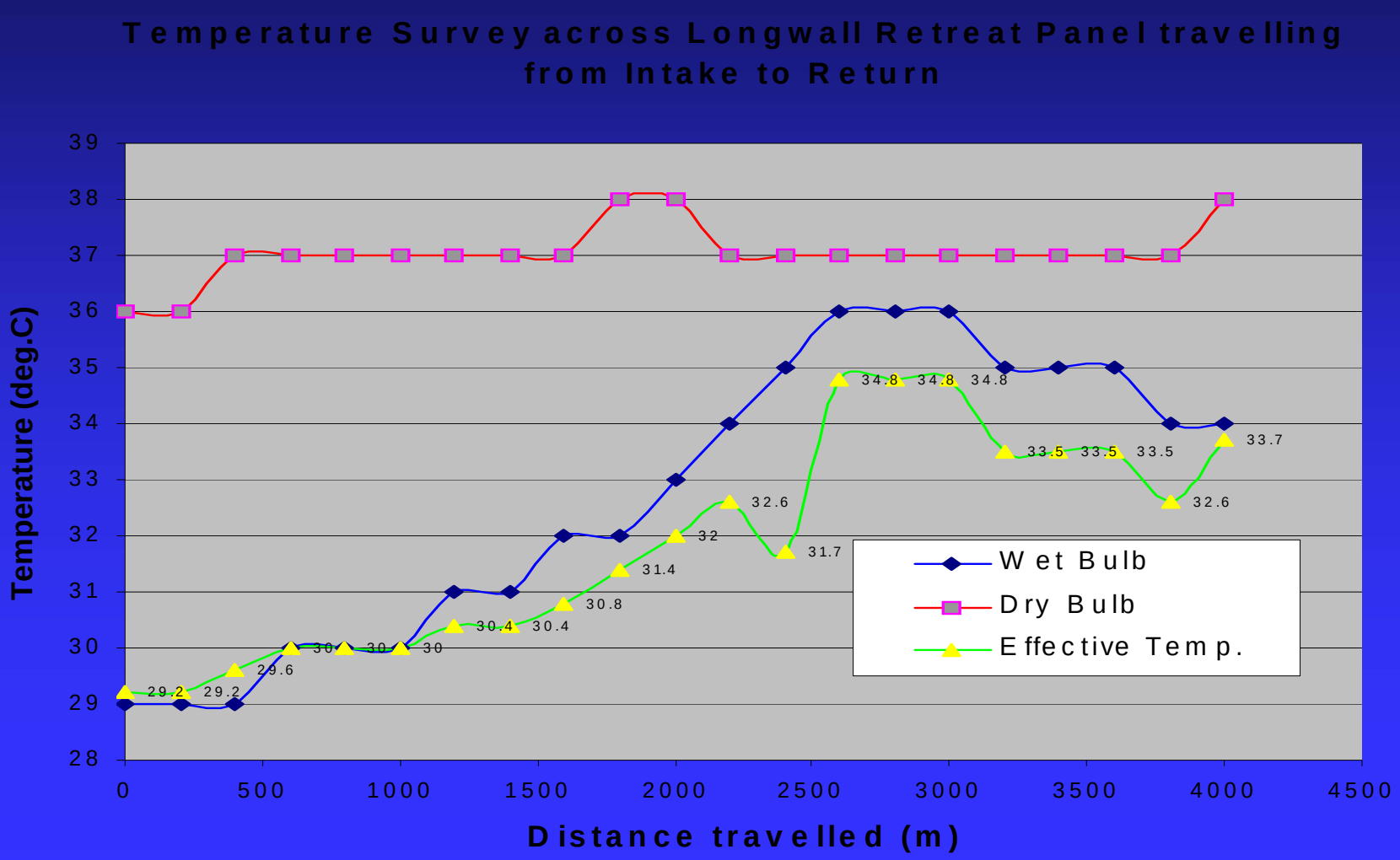
HSE BOOKS

PARTLY SATURATED ATMOSPHERES

WET BULB – °C	DRY BULB – °C													
	24	26	28	30	32	34	36	38	40	42	44	46	48	50
23	★	★	★	118	113	108	103	98	93	89	85	81	77	73
24	119	114	108	103	99	94	90	85	81	78	74	71	67	64
25		99	95	90	86	82	78	75	71	68	65	62	59	56
26		87	83	79	75	72	68	65	62	59	56	54	51	49
27			72	69	66	63	60	57	54	52	49	47	45	43
28			63	60	57	55	52	50	47	45	43	41	39	37
29				53	50	48	45	43	41	39	38	36	34	32
30				46	44	42	40	38	36	34	33	32	30	30
31					38	36	35	33	32	31	30	29	28	27
32					33	32	31	30	29	28	27	26	26	25
33						29	28	27	27	26	25	24	23	23
34						27	26	25	24	23	23	22	22	22
35							24	23	22	22	22	21	20	20
36							22	22	21	20	20	19	19	19
37								20	19	19	19	19	19	–
38								19	19	19	19	–	–	–

★ 120 minutes or more

Temperature survey carried out on Longwall retreat face panel

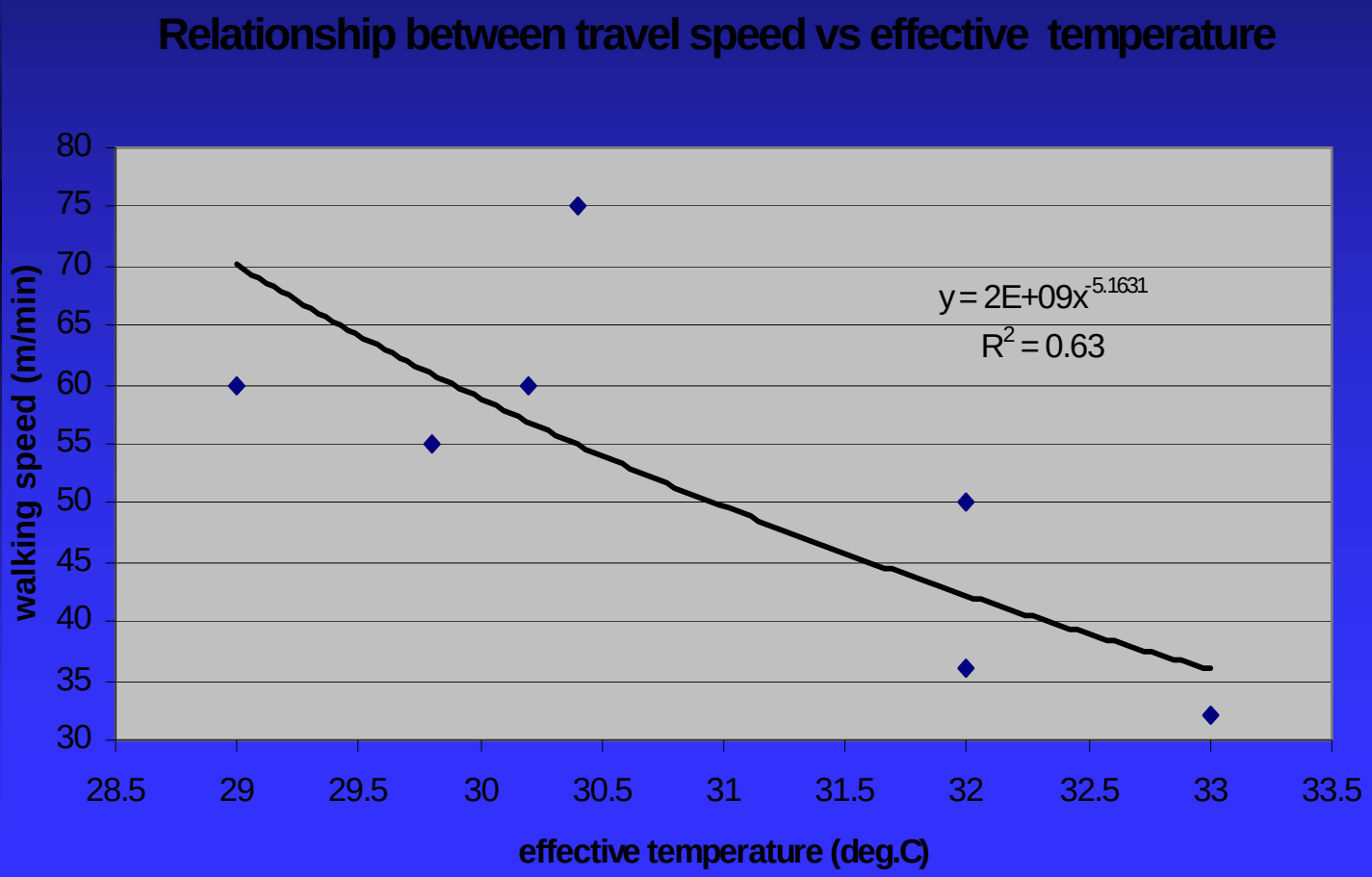


Wet bulb (° C)	Dry bulb (°C)	Effective Temp. (°C)	Location
34	38	33.7	10m inbye T/G (return)
34	37	32.6	100m SM T/G
35	37	33.5	400m SM T/G
35	37	33.5	600m SM T/G
36	37	34.8	800m SM T/G
36	37	34.8	2000m SM face junction position
35	37	31.7	Return side methane drainage curtain (high velocity)
35	37	31.7	Methane Drillers station (high velocity)
34	37	32.6	Mid Face
33	38	32.0	Roadhead M/G (intake)
32	37	30.8	Outbye transformer M/G
29	37	29.6	Inbye conveyor drive M/G
29	36	29.2	Outbye conveyor drive M/G
29	36	29.0	South East Main Return

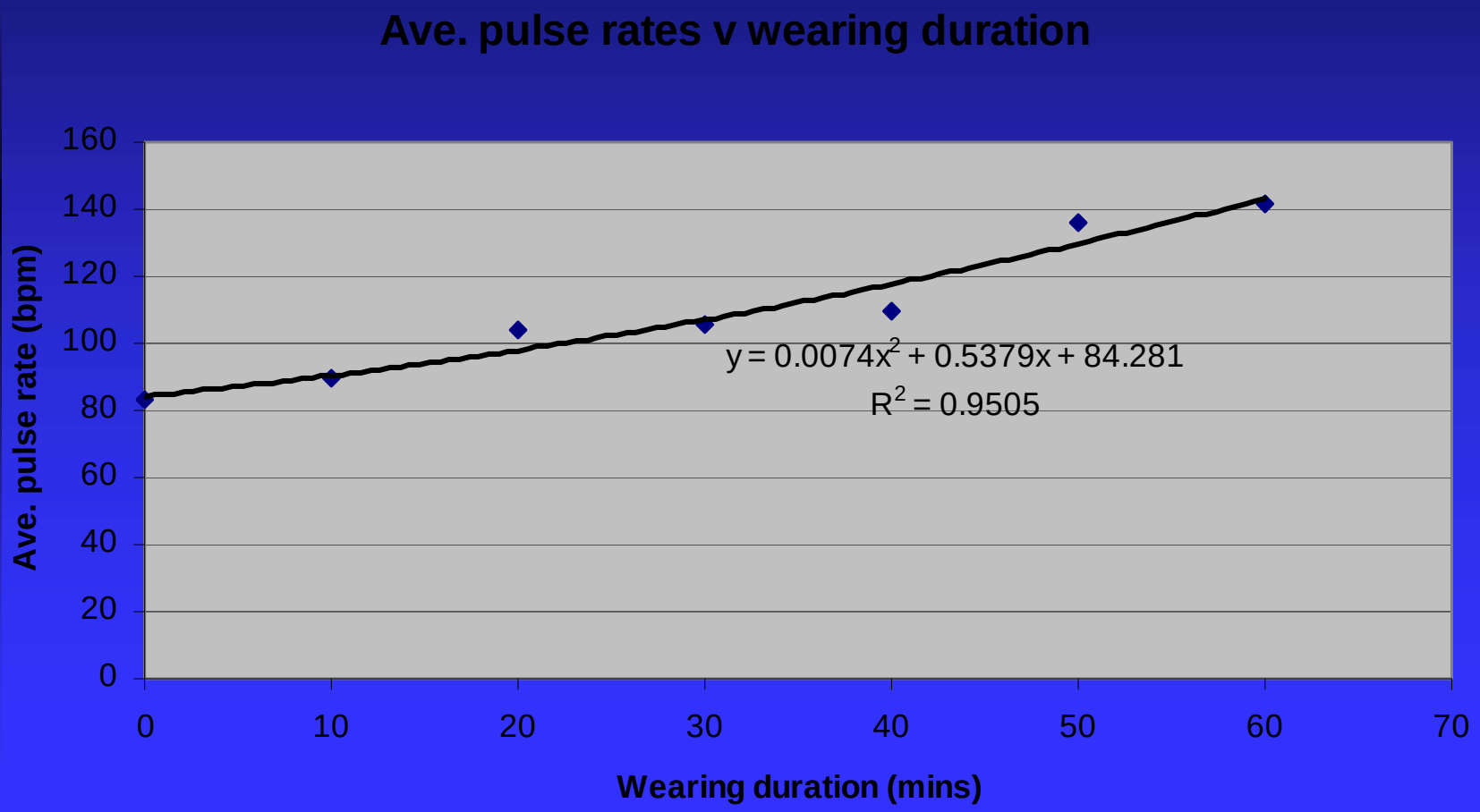
Colliery self-rescuer (SCSR) wearing trial

- Carried out in hot and humid conditions up to 33 deg.C Effective Temperature (ET).
- Physiological divide noted in performance between acclimatised workers and non-acclimatised managers.
- Heat related risk issues highlighted

Travel speed influenced by effective temperature



Effect of wearing duration on average pulse rates



SEFA wearing trials Graveling and Miller (1989)

Type of exercise	Number of tests wearings	Lasted full duration (%)	Exceeded core temperature (%)	Exceeded heart rate (%)	Withdrawn due to fatigue (%)	Run out of oxygen (%)
Light	274	54.5	37.0	2.5	5.5	0.5
Heavy	284	56.5	28.5	6.5	5.0	3.5

Graveling and Miller (1989)

- Core body temperature and heart rate monitored in 93 rescue worker test subjects
- Total of 558 tests carried out in climatic chamber
- Surprisingly little difference observed between effects of light and heavy work loads
- Suggested that wearers automatically adjusted work rate
- Low numbers > safe heart rate (6.5%)
- High numbers > safe core temperature (37 %)

Self rescuer wearing trials

- Carried out in climatic chamber by medically tested mines rescue workers
- Hypothesis advanced that a link exists between effective temperature and safe wearing time for self-rescuers
- Data set relatively small (11 test subjects @ 25 individual tests)
- Detailed statistical analysis beyond remit of study however, useful correlation of variables made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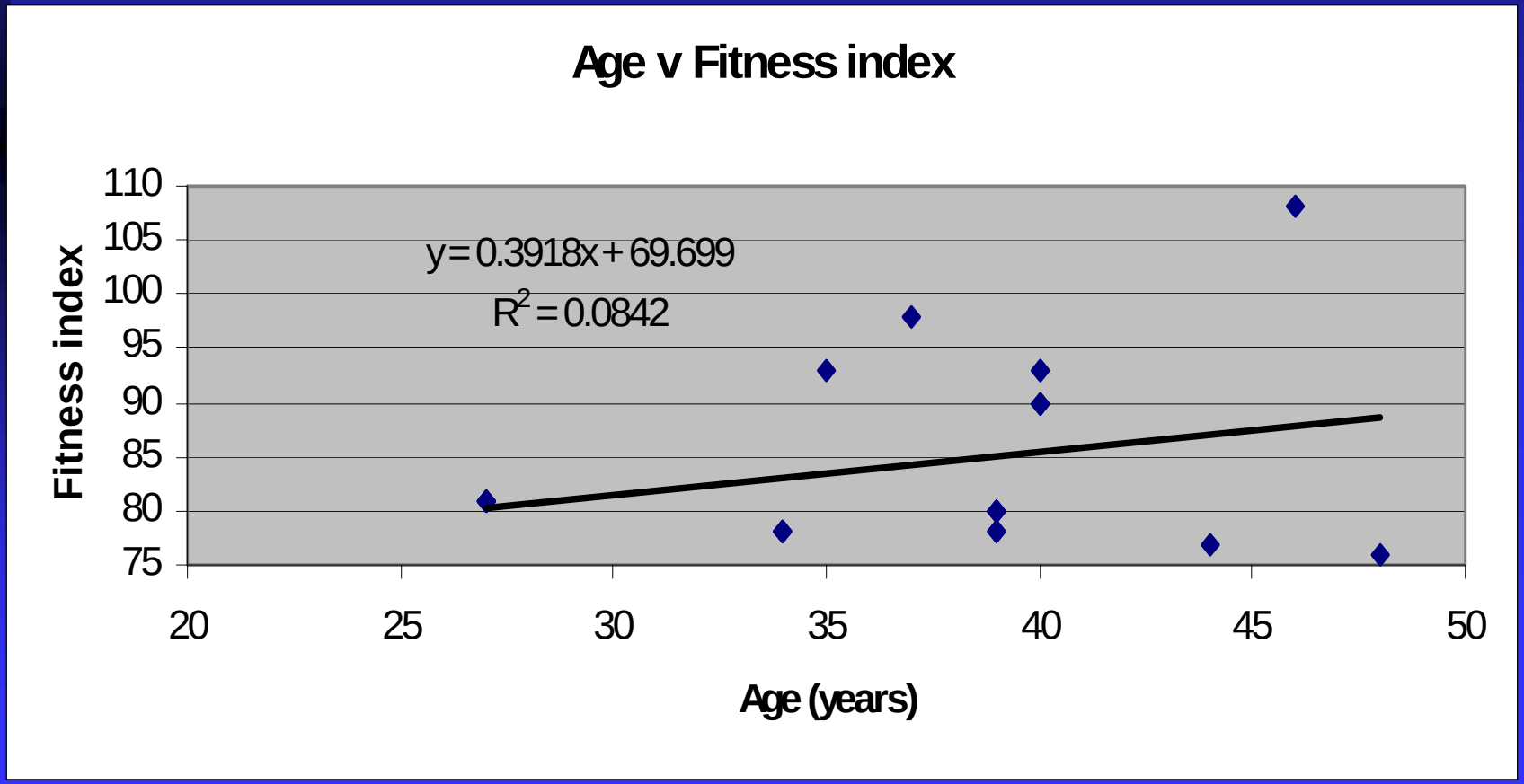
Fitness relationships

- UK rescue workers attributed ‘fitness index’ following detailed medical examination including assessment of cardiovascular response to work load
- Results indicated older rescue workers were fitter than younger colleagues (however two oldest workers were both ‘fittest’ and ‘least fit’
- Fittest rescue worker was 46 years old with ‘index’ of 108 (pass level is 75)

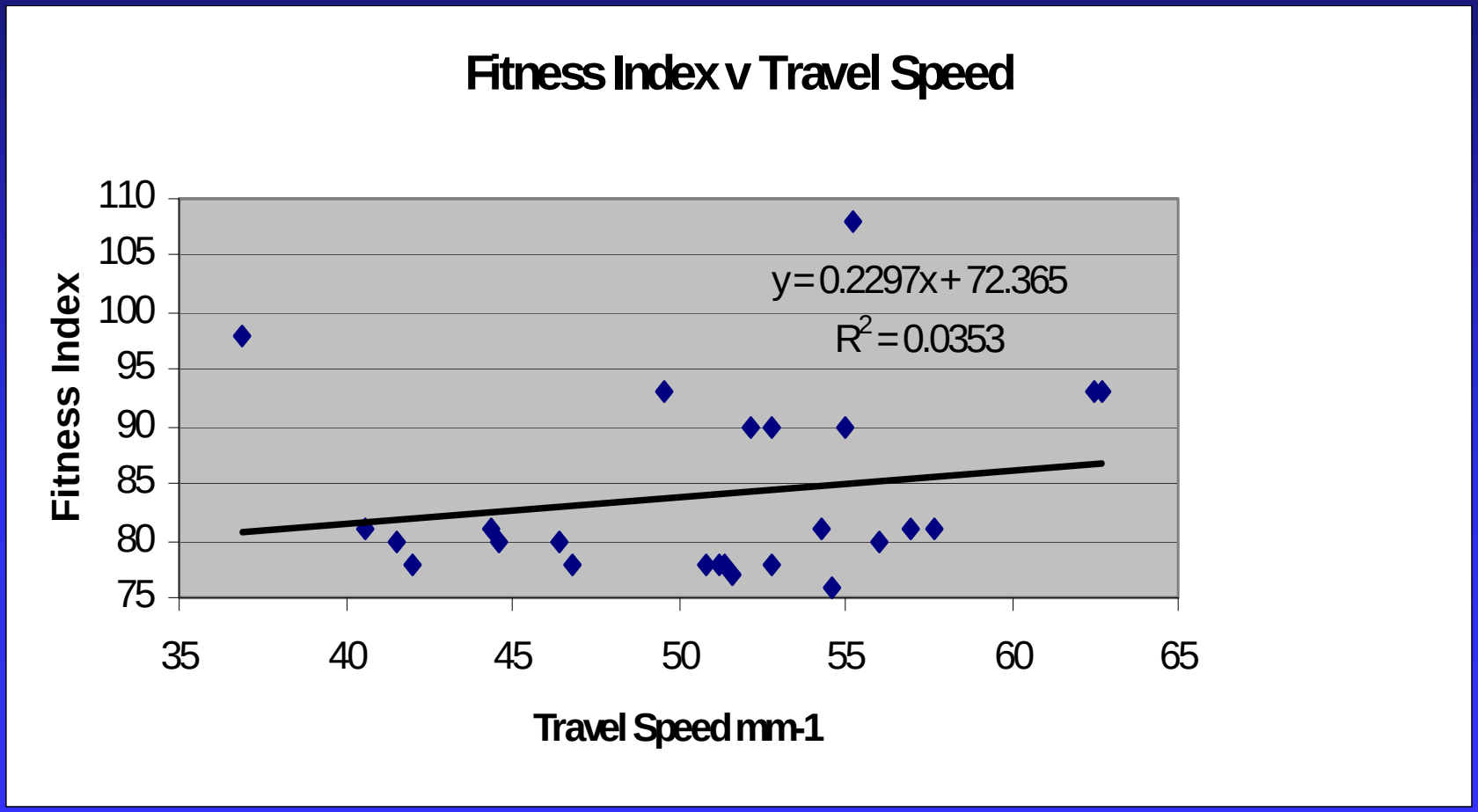
Relationship between age and fitness of rescue workers



Fitness and travel speed

- Degree of correlation noted between fitness and travel speed although not statistically relevant
- Effect probably moderated / masked by ‘experience’ and tendency to self-pace
- Trials carried out on self-powered inclined tread mills on which wearers dictated their own pace
- Minimum speed = 37 m/min (2.2 km/hr)
- Maximum speed = 63 m/min (3.8 km/hr)
- Mean travel speed = 51 m/min (3 km/hr)

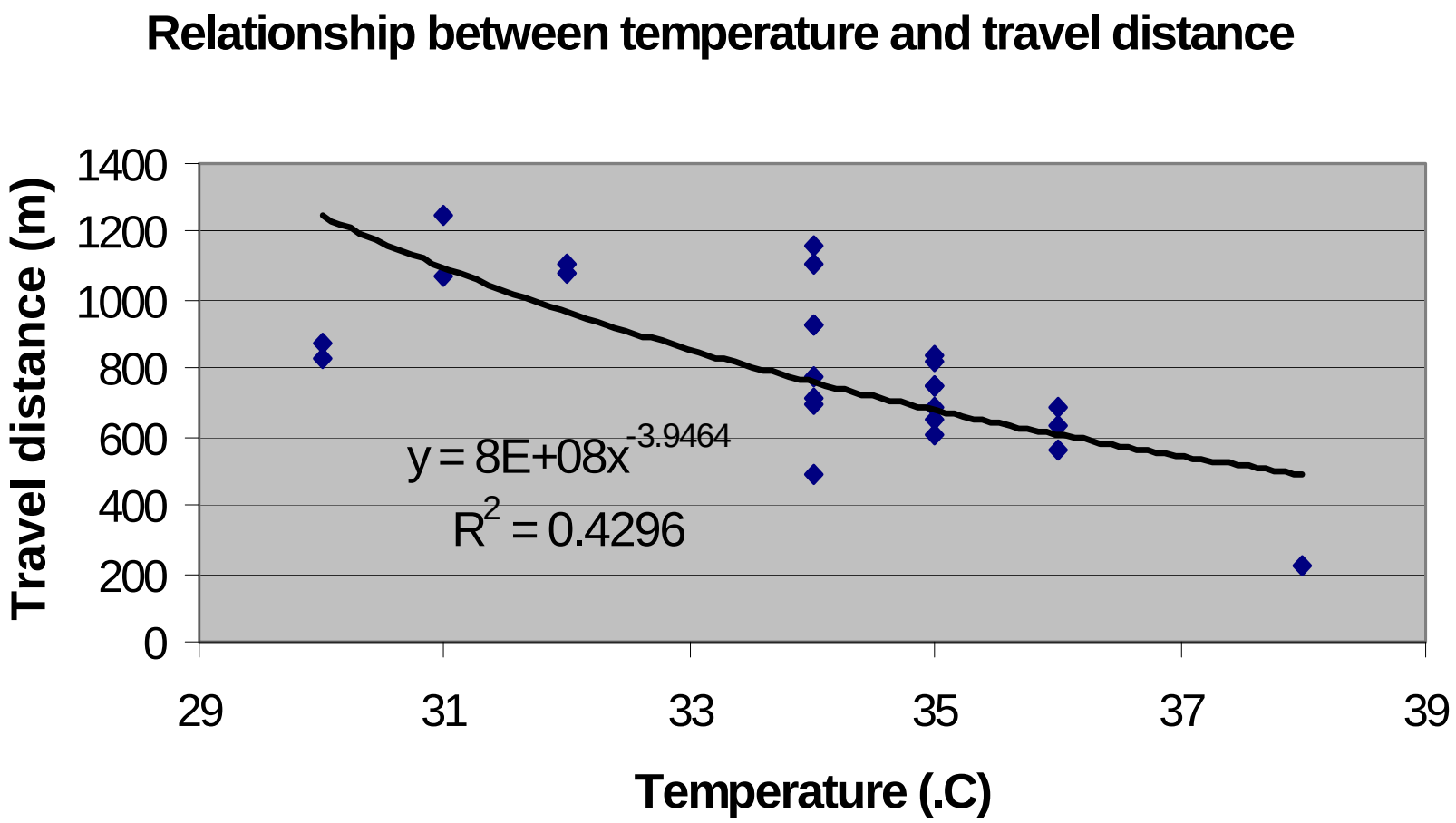
Effect of fitness on travel speed



Thermoregulation issues

- In terms of ‘oxygen cost’ when using SCSR, expected that the heavier a person was, the shorter the wearer duration
- At ET > 31 deg.C, the individual’s ability to thermoregulate influenced wearer duration and distance covered, not merely body mass

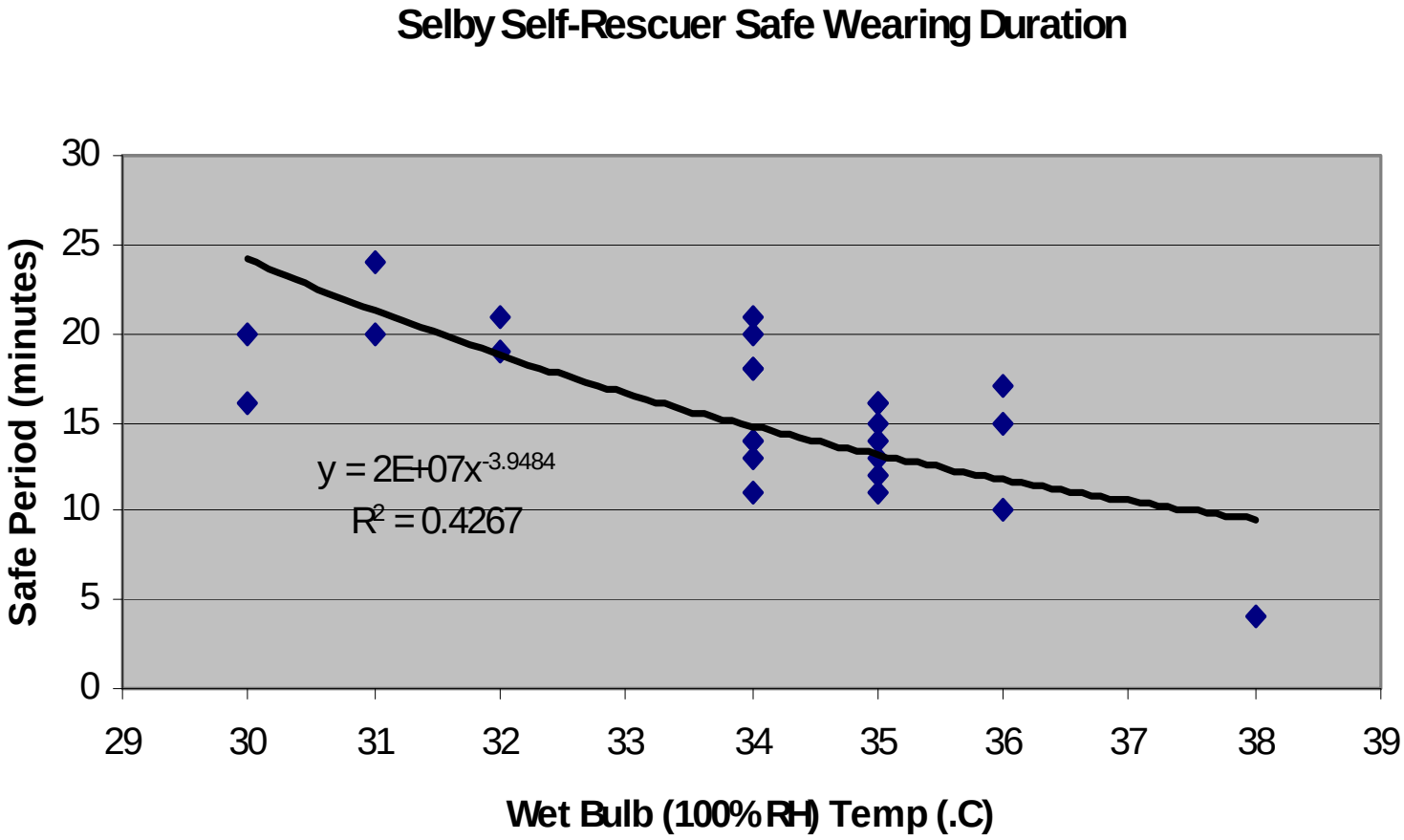
Effective temperature and travel distance



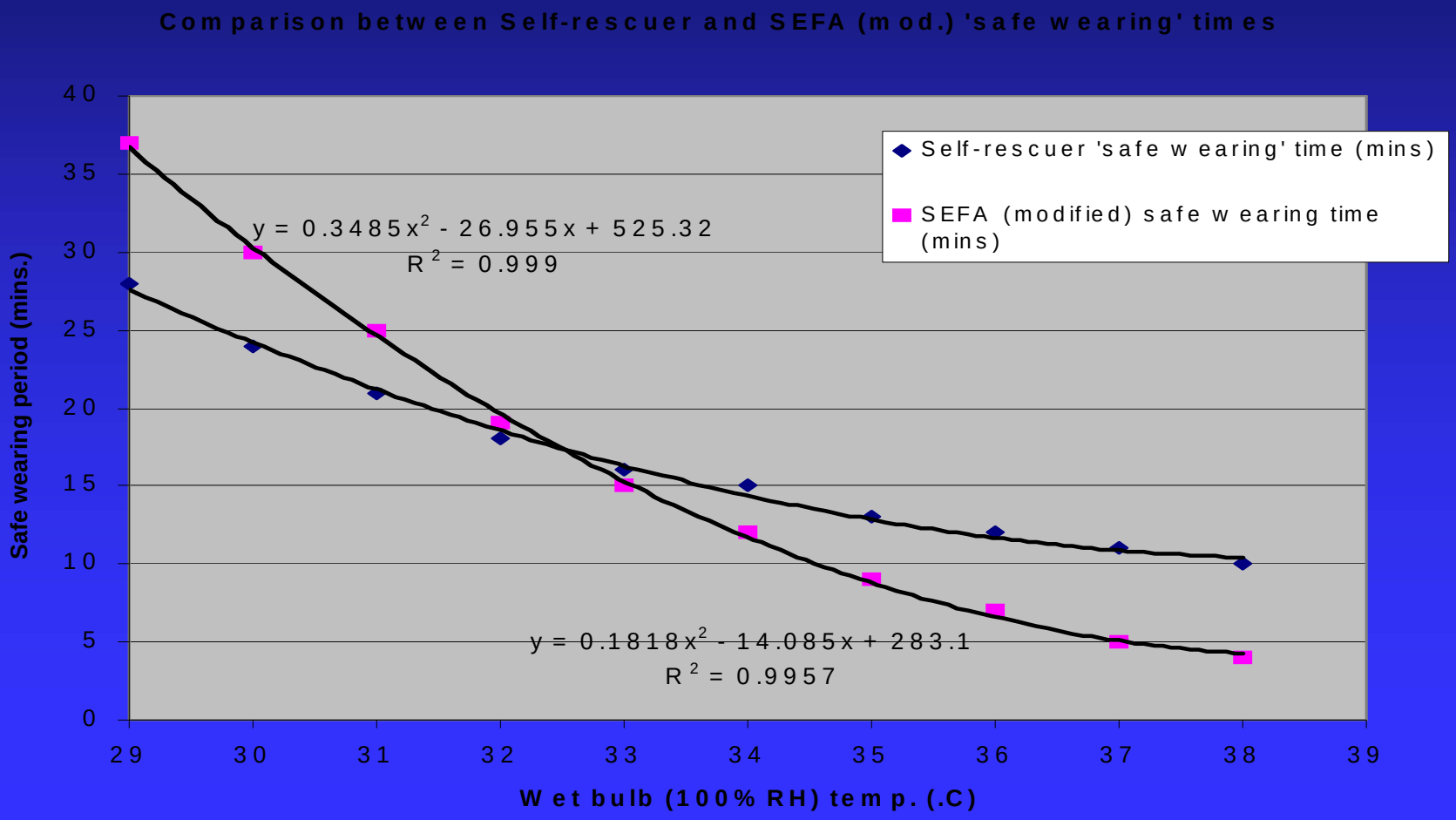
Thermoregulation response to heat and humidity

- Variability in thermoregulation response of individuals can be considerable with differences in tolerance time > factor of 2 not uncommon
- Some studies conclude that miners are fitter and more tolerant of heat because of acclimatisation and natural selection
- This view does not take into account ‘non-acclimatised’ persons such as returning workers, contractors, managers, technical representatives and inspectors
- Considered essential to develop an emergency strategy for general mining population

Self-rescuer safe wearing chart



Self-rescuer and SEFA (modified) ‘safe wearing’ charts



Comparison between SEFA curve and Self-rescuer curve

- Graphs were modified onto the same scale to make comparison possible
- The SEFA curve was modified by introducing ‘pre-heating’ effects (experience of up to 10 minutes exposure to environmental heat before donning apparatus)
- This fairly replicated and compared with Climatic chamber self-rescuer test protocol
- Study does not explain why curves cross over – probably because at high temperature, physical burden (SEFA = 16.0kgs) BA more significant ‘work-load’ (FSR = 0.6kgs / SCSR = 2.0kgs)
- Without comparison of both BA and Self-rescuer under identical conditions, further comparision would be rash

Dehydration effects during prolonged Filter Self-Rescuer use

- EN404 specifies maximum inspired Dry Bulb temperature (at 1.5% CO) up to 90° C and Wet Bulb of 50° C
- Tolerance of such temperatures assumes that respiratory tract remains wet
- If mouth dries out during prolonged wearing due to dehydration and inability to produce saliva, inspired temperature experienced by wearer may increase towards dry bulb levels
- Discomfort increasing to pain and intolerance

EN404 Standard

- No requirement under EN404 for extended wearing test at thermal limits of performance envelope
- EN404 only requires that ‘after’ exposure to CO at 1.5%, FSR unit should be worn for short period to confirm its ‘wearability’
- No minimum wearing period stated
- Bears little comparison with attempting to wear FSR for periods up to 120 minutes
- Under high CO burden, FSR could become ‘intolerable’
- Literature indicates FSR may have been prematurely removed following underground fire disasters. This is probably the explanation

Summary

- For almost 50 years, UK recognised need to regulate BA wearers in hot and humid climate
- Lind *et al* (1955) and Graveling and Miller (1989) produced safe wearing charts for BA
- Proved extremely reliable with no deaths of rescue workers in UK since introduction of these charts
- In UK, no limitations currently imposed on wearing times for self-rescuers under hot and humid conditions

- Homoeothermic ability of humans to regulate core body temperature exists within relatively narrow range of ambient temperatures
- During trials conducted under hot and humid conditions, test subjects predominantly exceeded safe core body temperature (38.5 °C) long before max. (age related) pulse range reached
- Emergency escape scenarios in hot and humid conditions involving use of self-rescuers, exceeding safe core body temperature appears to be a major risk factor

- Clear split observed between acclimatised and non acclimatised persons
- Within ‘non-acclimatised’ group must include; permanent corps rescue teams, mines inspectors, contractors, returning miners, technical reps, management, visitors
- Dehydration and fatigue effects reduce even acclimatised workers ability to cope with sudden emergency evacuation demands

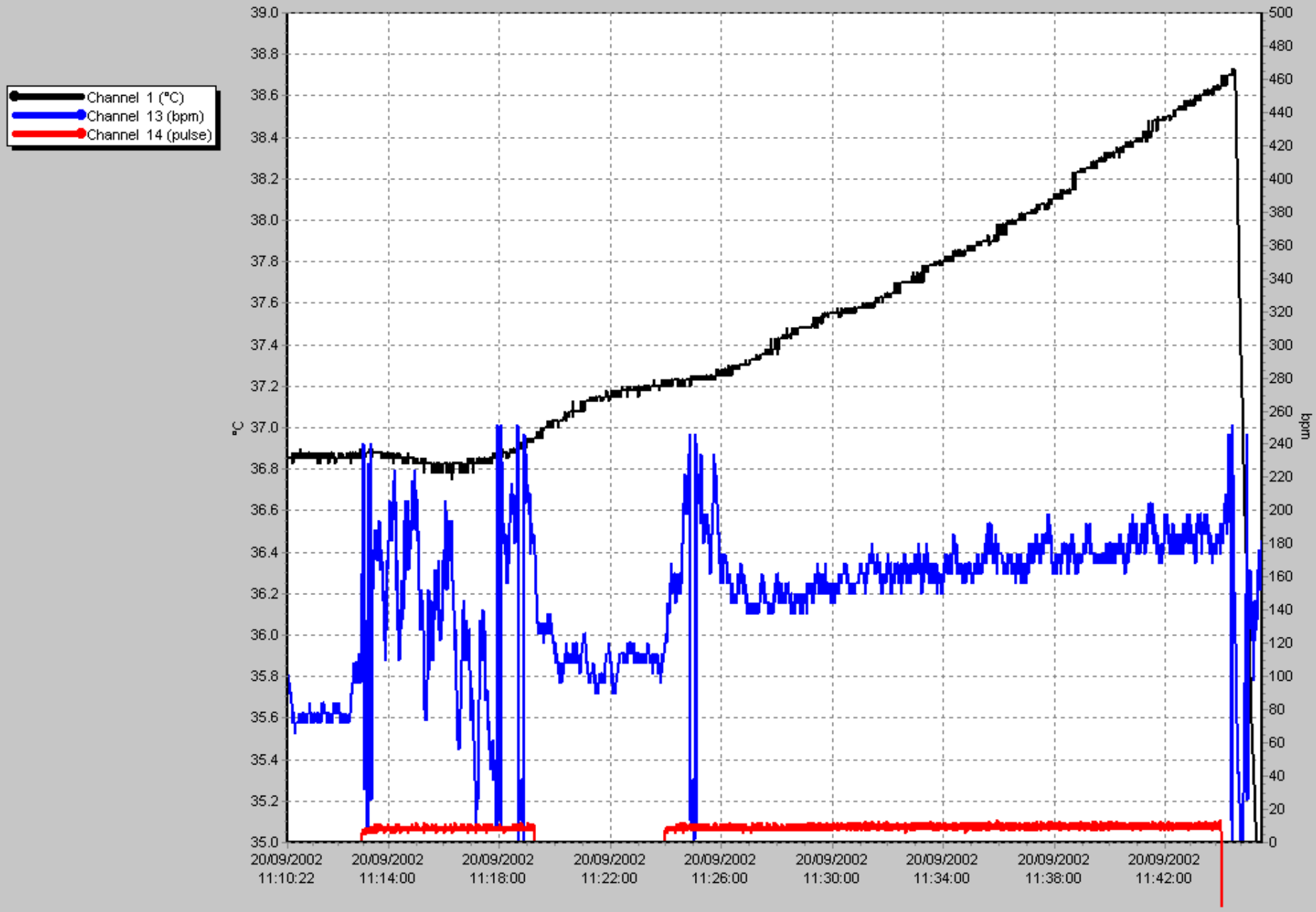
- Longer shift working and more powerful mining equipment fitted with effective dust suppression sprays, running for longer periods has combined effect of increasing miners' exposure to heat & humidity and heat energy in ventilation air
- Increased risk to mine workers in emergency situation, especially towards end of shift when dehydration and fatigue factors present

Statutory Position in UK

- Requirement to review ‘Emergency Plan’ under Regulation 4(3) The Escape and Rescue from Mines Regulations 1995
- Requirement to base Emergency Plan on risk assessment carried out under Regulation 3(1) Management of Health and Safety at Work Regulations 1992

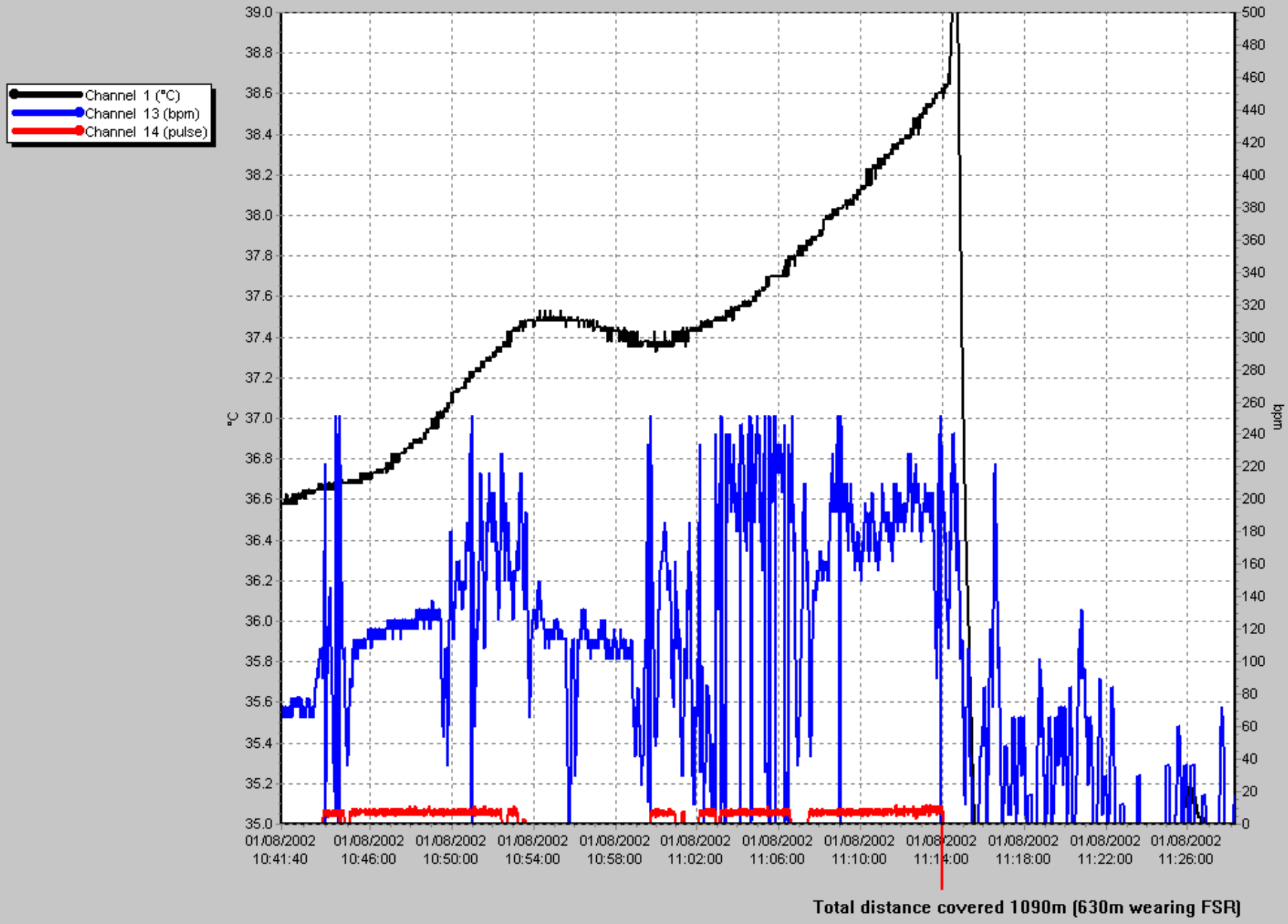
Conclusions: FSR escape duration

- Use of FSR forms the basis of UK escape planning
- Mine owners rely on FSR lasting at least 2 hours with wearer a travelling speed of not less than 60 m/min (3Km/hr)
- Under these ‘rules’ a wearer could travel up to 6000m in the allotted escape time
- These assumptions make no allowance for restricted visibility due to smoke or thermal physiological effects



Test Date/Subject: 20-09_23-BM

Total distance covered 1600m (1250m wearing FSR)


Channel 1 (°C)
Channel 13 (bpm)
Channel 14 (pulse)
°C
bpm
39.0
38.8
38.6
38.4
38.2
38.0
37.8
37.6
37.4
37.2
37.0
36.8
36.6
36.4
36.2
36.0
35.8
35.6
35.4
35.2
35.0
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
01/08/2002 10:41:40
01/08/2002 10:46:00
01/08/2002 10:50:00
01/08/2002 10:54:00
01/08/2002 10:58:00
01/08/2002 11:02:00
01/08/2002 11:06:00
01/08/2002 11:10:00
01/08/2002 11:14:00
01/08/2002 11:18:00
01/08/2002 11:22:00
01/08/2002 11:26:00
Total distance covered 1090m (630m wearing FSR)

Conclusions: FSR escape duration

- In trials conducted in climatic chamber, all wearers withdrawn by Doctor due to excessive core body temperature
- UK coalmine temperatures (ET) range between 29°C and 39°C (IOM 1997)
- Under lab conditions, mean wearing time was only 17 minutes in ET ranging from 31°C to 36°C
- Longest test lasted 24 minutes at 31°C before wearer being withdrawn at core body temperature limit
- At less ambitious walking speed of 50 m/min for 24 minutes, the FSR wearer could only safely plan to travel 1200m

Conclusions: SCSR escape duration

- Most common SCSR in UK is SSR30/100
- Rated at 30 minutes at 30 l/min
- EN401 standard set at 35 l/min
- Actual wearer demand nearer 40 l/min
- Mean wearing duration during lab test before O2 ‘run-out’ was 17 minutes carried out at ET between 30°C to 36°C
- Maximum duration achieved was 21 minutes
- Minimum duration achieved was 13 minutes

Conclusions: Use of Safe Havens

- UK almost alone in sole reliance on self-rescuers as means of evacuation following underground fire / explosion emergency
- No serious multiple ‘loss of life’ fire emergency since Michael Colliery disaster in 1967 following which FSR introduced
- Results from recent research suggest this view in need of reappraisal due to possible risks from thermal loading and physiological stress
- Possibility by using safe havens to rest, rehydrate, communicate and if necessary, continue escape attempt where rescue not possible

The End