Evaluating mining self-rescuers in a hot and humid environment USA 2007

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

Tony Forster, Her Majesty's Inspector of Mines
and David Brenkley, Mines Rescue Service Ltd.

- Following underground fires and explosions, miners' survival will depend on effective emergency planning and in many instances, use of respiratory protection.
- Most common self-rescuer in UK coalmines is the Filter Self-Rescuer (FSR). Self Contained Self Rescuers (SCSR) selected when O2 deficiency / H2S / hydrocarbon emission risks identified.
- Challenges in terms of securing effective escape & rescue arrangements due to heat & humidity, long development headings and panel lengths, and distance from drifts & shafts.

- Effective temperatures over 30^0C and travel distances in excess of 8km are not uncommon.
- Use of Mines Rescue self-contained breathing apparatus (BA) in hot and humid conditions requires adherence to time limiting ‘safe wearing’ charts
- No physiological limitations implemented in respect of self-rescuers, irrespective of thermal environment.

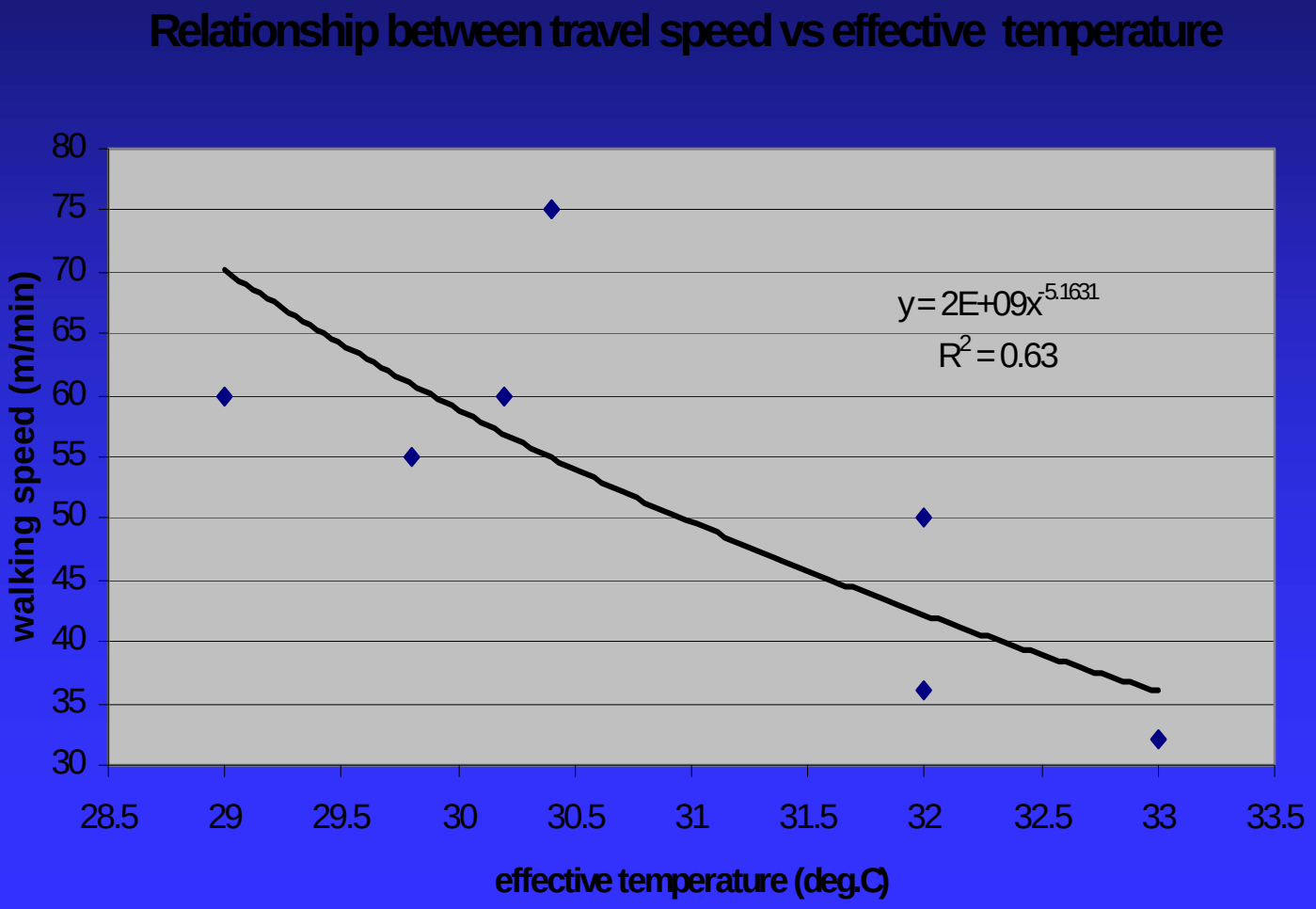
Graveling and Miller (1989)

- 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 %)

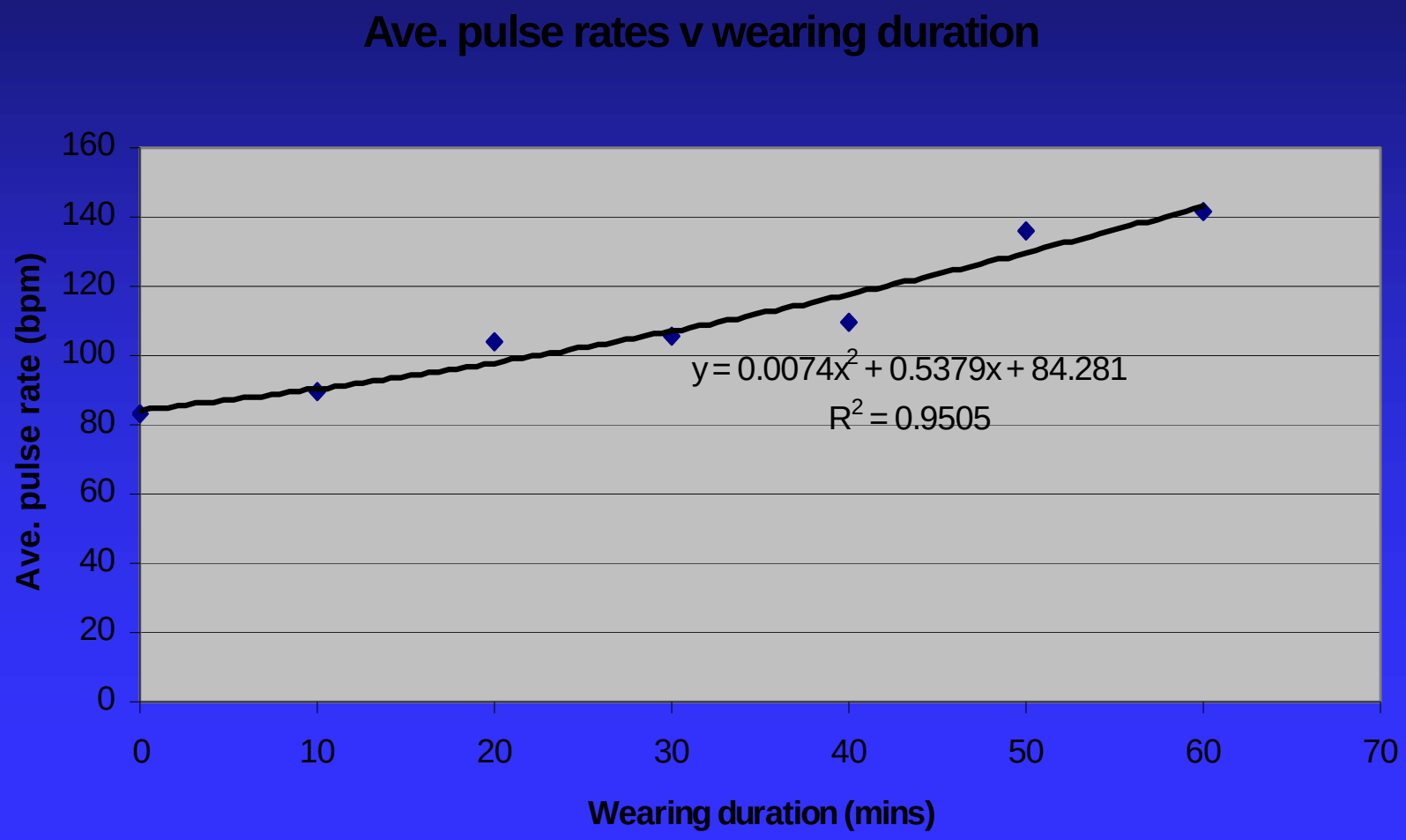
Self rescuer wearing trials – Selby Rescue Centre 2003

- 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

Travel speed influenced by effective temperature



Effect of wearing duration on average pulse rates



Fitness relationships

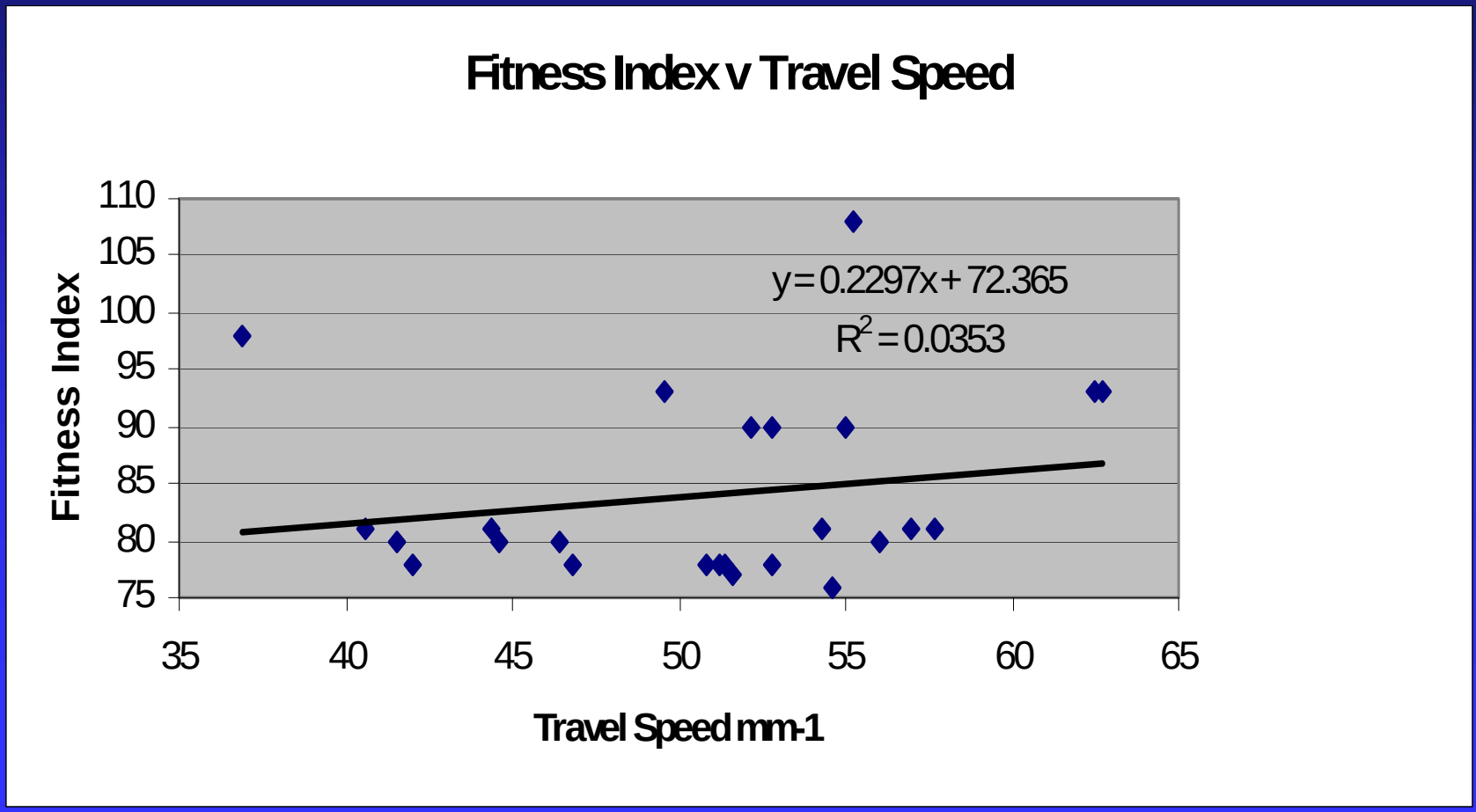
- UK rescue workers attributed ‘fitness index’ following detailed medical examination including assessment of cardiovascular response to work load.

- Pass level is ‘75’.

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 (3.0 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 appeared to influence the wearer duration / distance covered in addition to body mass issues

SCSR escape duration (2003 study)

- 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

Dehydration effects during prolonged Filter Self-Rescuer use

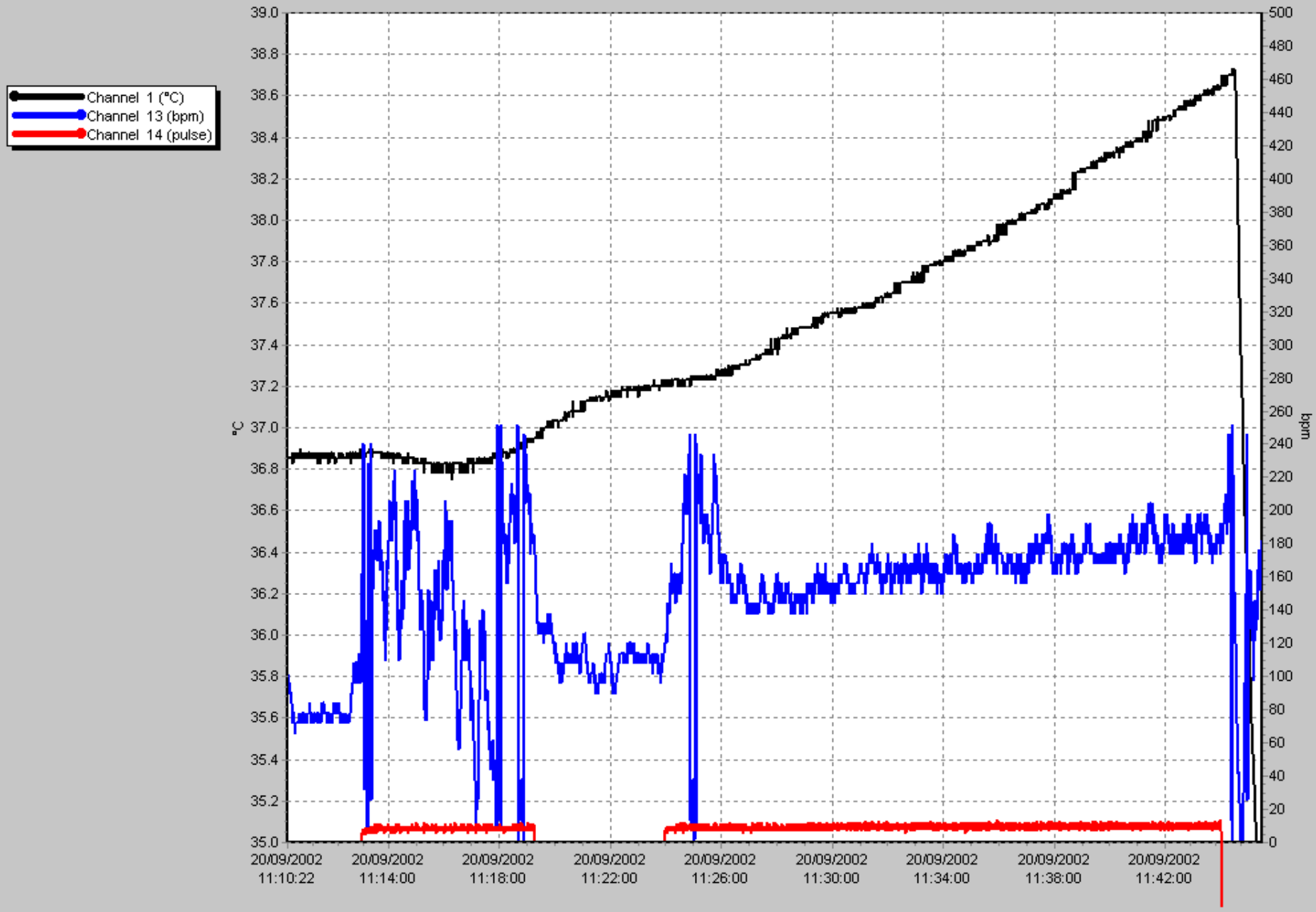
- EN404 specifies at 1.5% CO exposure, maximum inspired Dry Bulb temperature up to 90° C and Wet Bulb of 50° C
- Tolerance of such temperatures assumes that respiratory tract remains wet
- Mouth dries out during prolonged FSR wearing due to dehydration and inability to produce saliva, thus inspired temperature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

EN404 Standard (European standard for filter self-rescuers)

- 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 test-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’

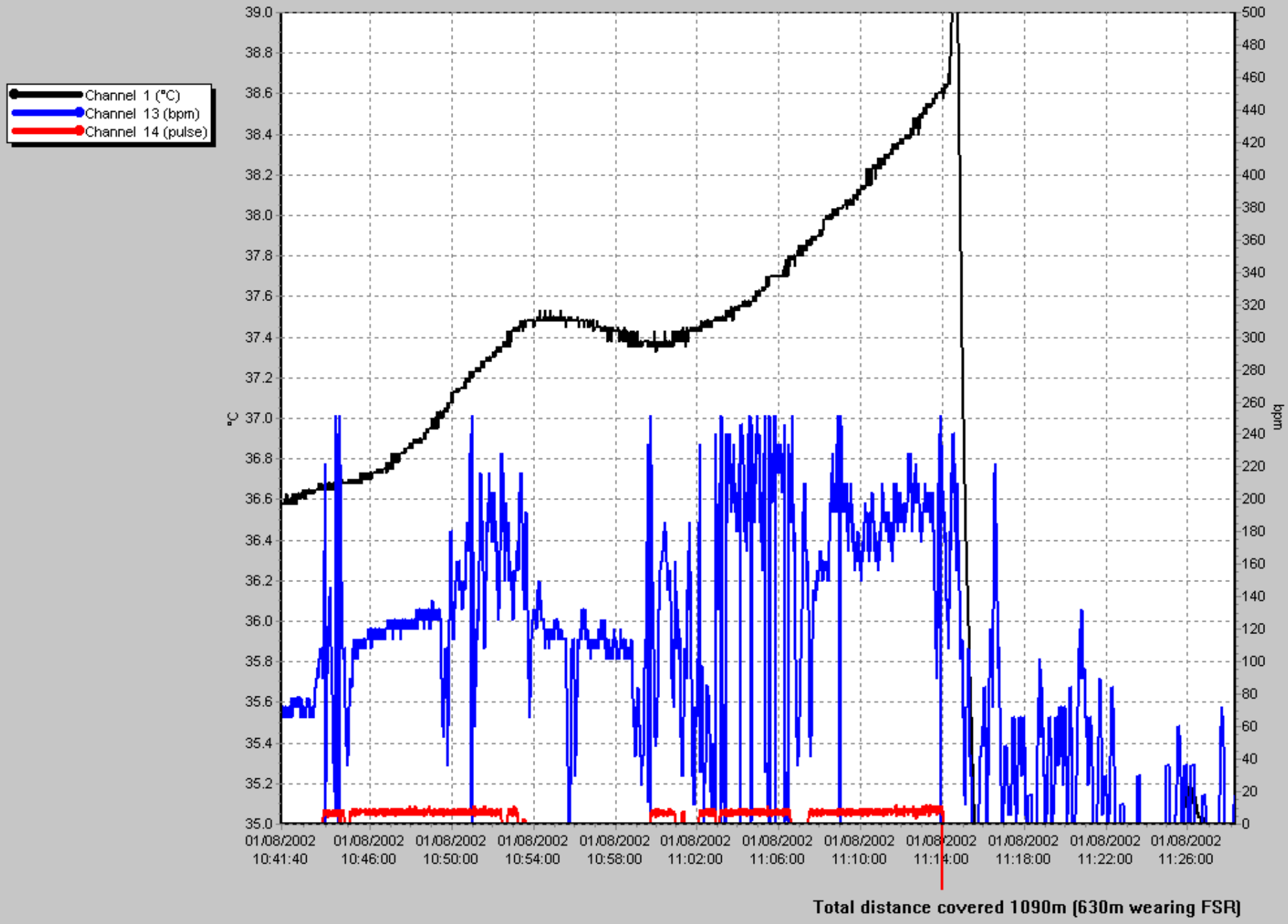
FSR escape duration in fully saturated climate study (2003)

- In trials conducted in climatic chamber, all wearers withdrawn due to excessive core body temperature
- UK coalmine temperatures (ET) range between 29°C and 37°C (IOM 1997)
- Under laboratory conditions, mean wearing time was only 17 minutes in ET (fully saturated) ranging from 31°C to 36°C
- Longest test lasted 24 minutes at 31°C before wearer withdrawn at core body temperature limit
- In fully saturated environment at walking speed of 50 m/min for 24 minutes, the FSR wearer could only safely plan to travel 1200m



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)

Selby self-rescuer study - 2003

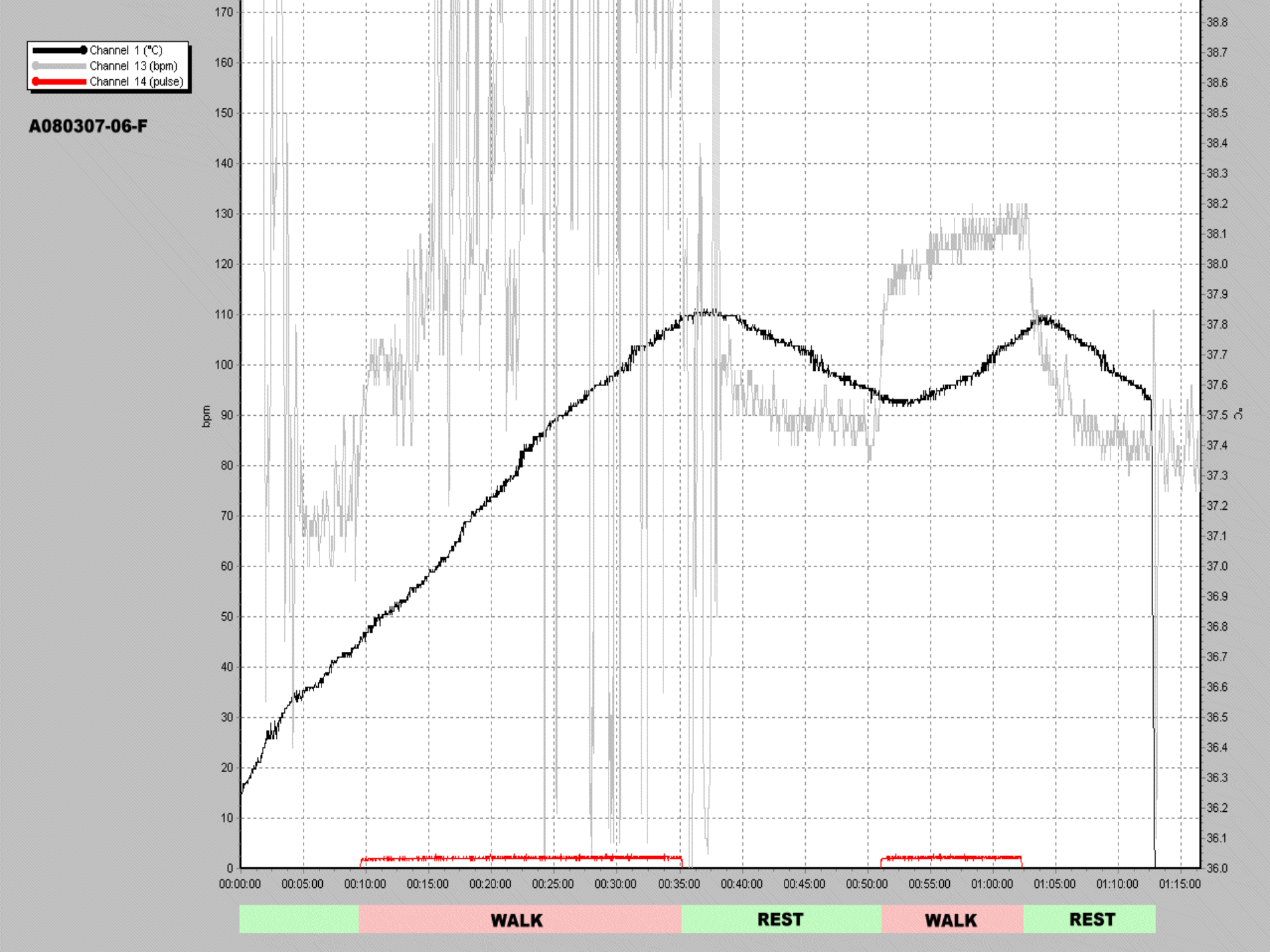
- Wearers invariably withdrawn on safety grounds when core body temperature reached pre-determined maximum (38.5° C)
- Pulse rates maintained within safe levels due to self-regulation of work effort.
- Wearers had no self-awareness of impending illness or collapse due to increasing core body temperature.

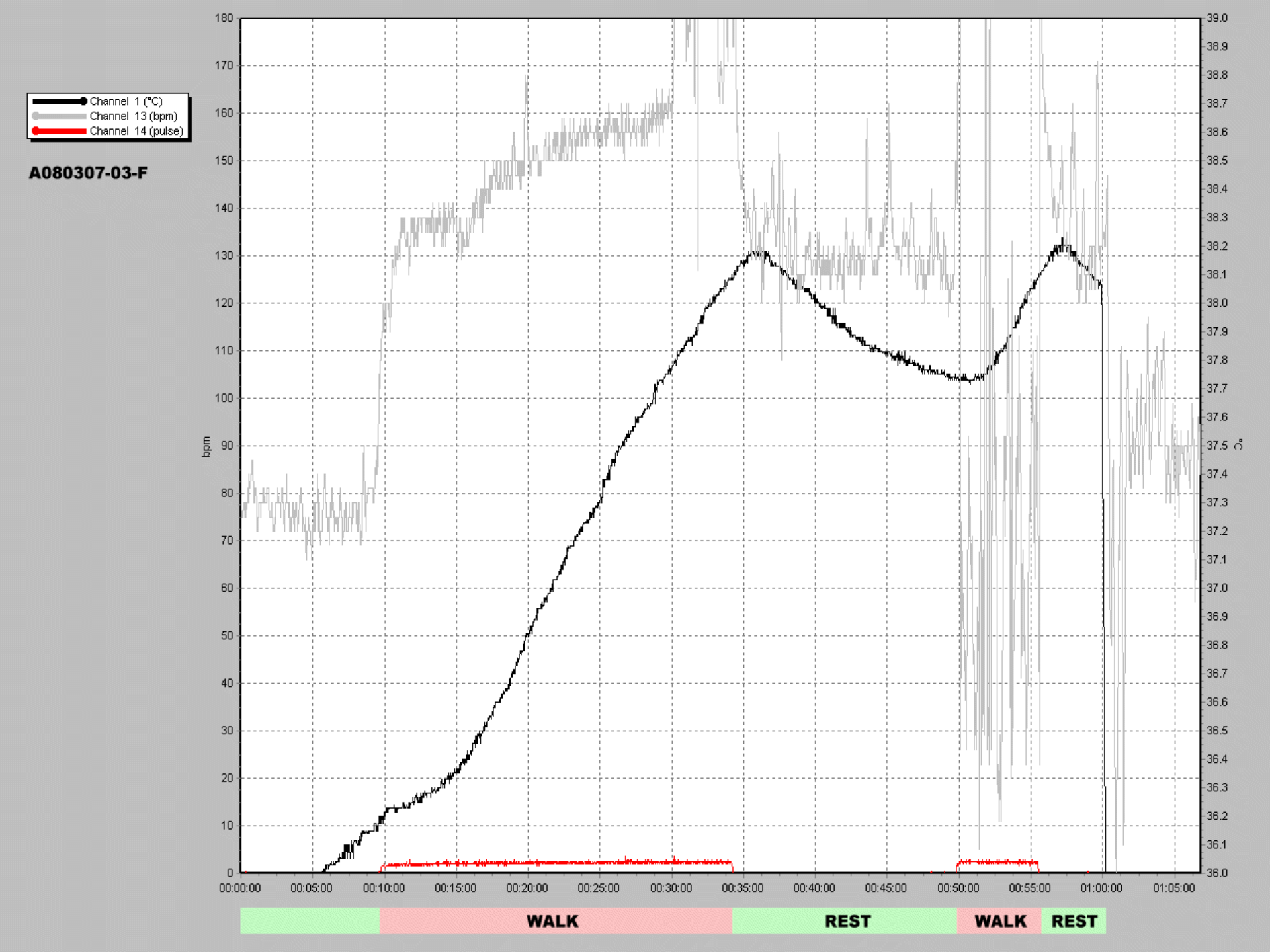
Selby study 2003 (cont.)

- When subject rested, core temperature stopped increasing, but minimal cooling observed
- Prompted question – “what would happen in less saturated environment if subject allowed to rest, remove ‘self-rescuer’ (as in safe haven) and rehydrate?

Rawdon Mines Rescue Centre – Self-rescuer study 2007

- Some reservations over Selby (2003) study data due to fully saturated chamber and thermal stratification due to lack of air movement.
- Sought to address these issues by inducing a small airflow (0.5m3/s) and maintaining differential wet and dry bulb temperatures.
- Designed ‘better’ FSR simulator.


Channel 1 (°C)
Channel 13 (bpm)
Channel 14 (pulse)
A080307-06-F
bpm
°C
WALK
REST
WALK
REST

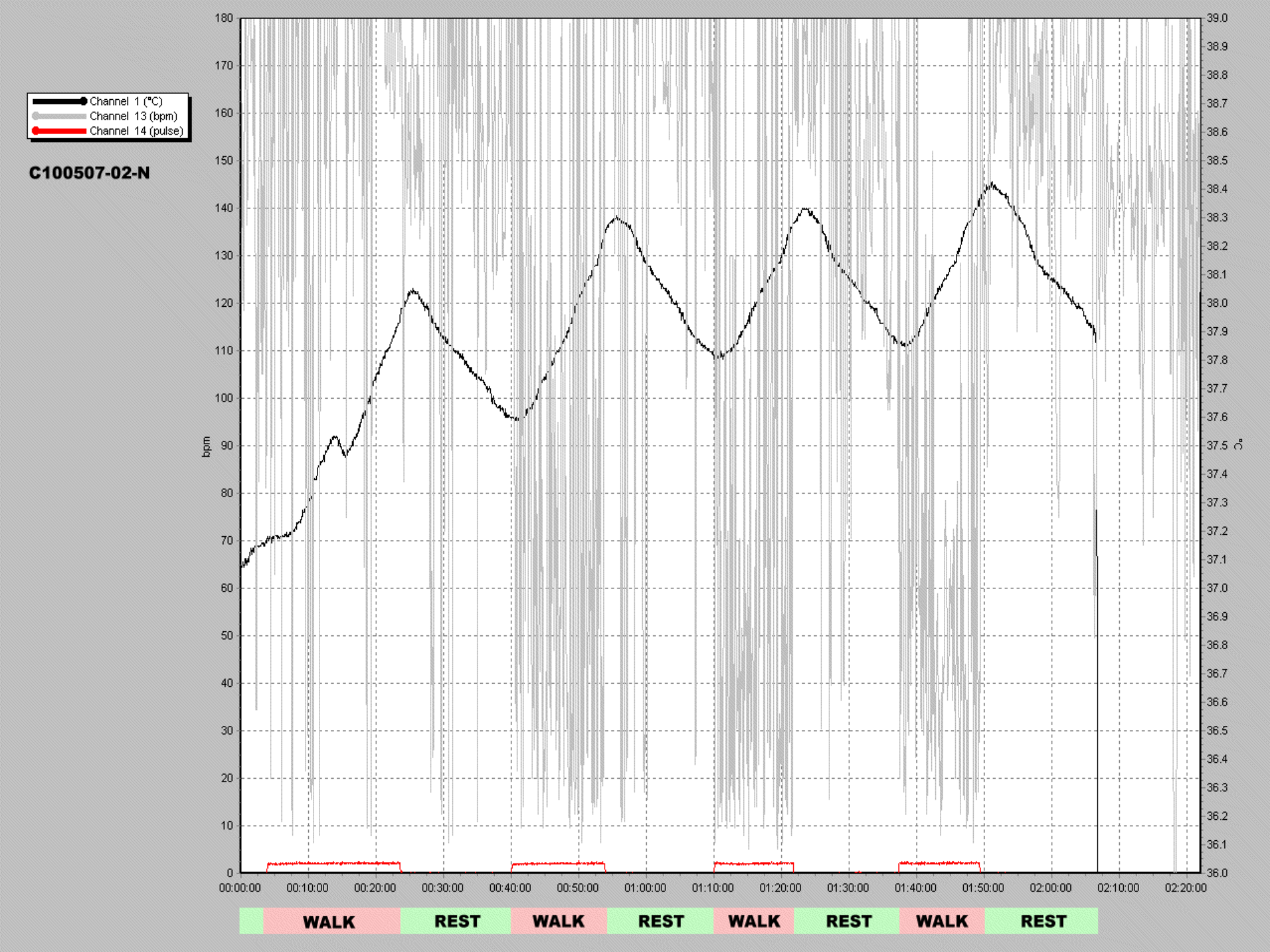

Channel 1 (°C)
Channel 13 (bpm)
Channel 14 (pulse)
A080307-03-F
bpm
°C
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
39.0
38.9
38.8
38.7
38.6
38.5
38.4
38.3
38.2
38.1
38.0
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37.0
36.9
36.8
36.7
36.6
36.5
36.4
36.3
36.2
36.1
36.0
00:00:00
00:05:00
00:10:00
00:15:00
00:20:00
00:25:00
00:30:00
00:35:00
00:40:00
00:45:00
00:50:00
00:55:00
01:00:00
01:05:00
WALK
REST
WALK
REST

Rawdon MRS Study 2007 (cont.)

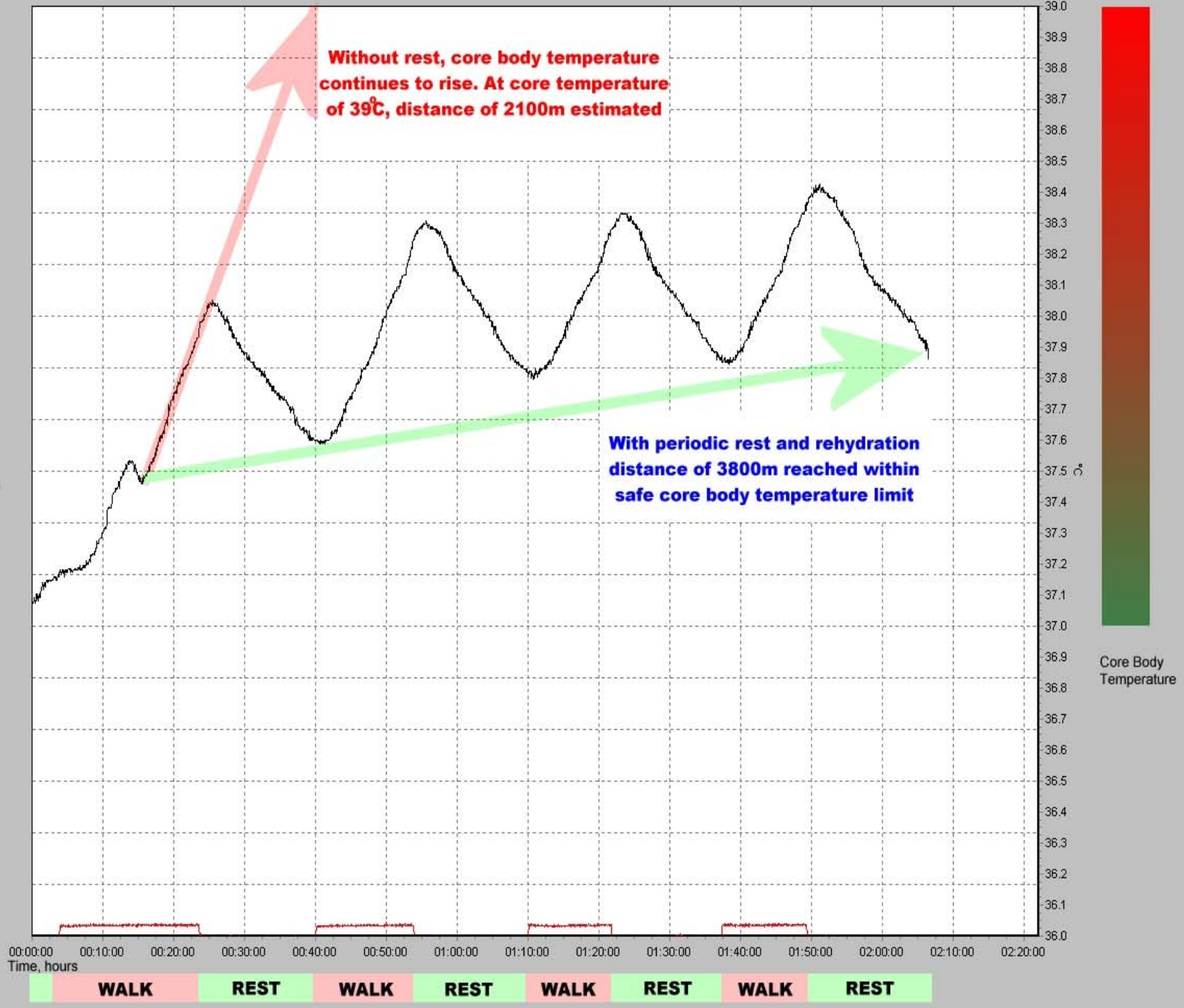
- Better simulated environment achieved (31ºC wet / 32ºC dry @ 0.5m3/s air quantity.
- Better FSR simulator designed – would mimic heating in a 5000ppm CO environment and stay ‘hot’ for up to 120 minutes).
- Tests confirmed wearers would cool slightly when resting with FSR worn.

Rawdon MRS Study (cont.)

- Wanted to assess impact on wearer tolerability and physiological thermal recovery (expressed as core body temperature reduction) of resting, temporary removal of FSR and rehydrating.
- This situation would mimic a survivor reaching a suitably equipped safe haven in a ‘staged’ escape / rescue scenario.


Channel 1 (°C)
Channel 13 (bpm)
Channel 14 (pulse)
C100507-02-N
bpm
°C
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
39.0
38.9
38.8
38.7
38.6
38.5
38.4
38.3
38.2
38.1
38.0
37.9
37.8
37.7
37.6
37.5
37.4
37.3
37.2
37.1
37.0
36.9
36.8
36.7
36.6
36.5
36.4
36.3
36.2
36.1
36.0
00:00:00
00:10:00
00:20:00
00:30:00
00:40:00
00:50:00
01:00:00
01:10:00
01:20:00
01:30:00
01:40:00
01:50:00
02:00:00
02:10:00
02:20:00
WALK
REST
WALK
REST
WALK
REST
WALK
REST

EXERCISE
SELF-PACED
@ 32-33C BET
(Twb = Tdb)



Rawdon MRS Study 2007 (cont.)

- Demonstrates that without opportunity to rest and rehydrate, FSR wearer would collapse with heat stress after 2,100m continuous travel.
- With opportunity to rest and rehydrate, FSR wearer could continue, in stages, beyond 3,800m travel distance (limit of test).

Use of Safe Havens

- Historically, UK mining industry reliant on self-rescuers as sole means of evacuation following underground fire / explosion emergency

- No serious multiple ‘loss of life’ fire emergency since Michael Colliery disaster in 1967 following which Filter Self Rescuers were introduced into all National Coal Board mines.

Use of Safe Havens

- Results from recent research has prompted reappraisal in UK due to identified risks from use of self-rescuers (thermal loading and physiological stress)
- Safe havens / muster stations at strategic locations underground can provide a vital focal point to rest, rehydrate, communicate and if necessary, continue escape journey.
- HSE published '*Guidance and Information on the role and design of safe havens in arrangements for escape from mines (2007)*'