A Long Hard Climb

— probing new heights in breathing protection

IT IS AN EARLY summer's morning in Sydney, Australia. The city is slowly coming to life in the rising sun. But one room in one of the city's best known high-rise buildings is abuzz with activity.

One of the building's common areas has been changed into the command centre for an important experiment about to take place.

Twelve people are getting ready for the work-out of their lives. A dozen intrepid research subjects are steeling themselves for the most exhausting, tiring, draining, agonising exercise they are likely to perform in a long time.

Their task: to dress in full firefighter's turnout gear, don an SE400 respirator, carry a fully charged fire extinguisher, and climb the fire stairs of this high-rise building from the bottom up.

The objectives: a) to examine how human breathing works during sustained exhaustive work in extremely demanding conditions, and b) to determine whether the SE400 respirator can satisfy the body's need for air in these conditions.

Nature of the experiment

We have selected a number of people for the exercise. They are of both sexes, a wide range of ages, body weights, and fitness levels.

They will all perform the same task, under identical conditions.

During the climb, we will monitor their heart rate and their every breath. This is done through a calibrated data-logger inside the respirator, which continuously measures peak air flow (that is, the speed at which the air travels at the mouth) and minute volume (that is, how much air is drawn into the lungs during any given period).

Some particulars about the experiment:

Age of participants:	16–60 years
Weight range of participants:	56–100 kg /123–220 lbs
Weight of equipment (clothing, boots, hard hat, fire extinguisher, respirator unit):	24 kg/53 lbs
Number of floors to climb:	25
Number of steps:	350
Total height of ascent:	62 m/203 ft
Means of recording event:	• Continuously running video camera following each pair of climbers all the way to the top • Still photography at various stages of the climb • Data logger with pressure probe mounted in respirator — continuous data collection with time stamping; downloaded to PC after completion of climb • Heart rate monitor

Background

The events of September 11, 2001 saw the loss of hundreds of fire personnel in the rescue operations immediately following the attacks on the World Trade Center (WTC) towers. In the ensuing days and weeks, it became clear that there are many factors other than fire and explosion that make a firefighter's job difficult, dangerous, and sometimes impossible. Many of these factors have to do with the need to wear respiratory protective equipment.

One of the greatest difficulties to the firefighter is caused firstly by the restrictions a respirator places on the body, and secondly by the greatly added strain.

At the WTC, as in many other high-rise incidents, the trouble is evident: *the fire personnel simply cannot get all the way up the stairs.* Their respirators do not permit such strenuous exercise. The fire fighters have to give up the climb, not because they run out of air, but because they run out of breath. The respiratory equipment does not allow enough air to get to the lungs.

The objective of the S.E.A. exercise was to help organisations like NFPA, NIOSH and other Standards authorities to find out the answer to a vital question:

What is required of a respirator during hard, sustained work?

It has been known since the First World War that respirators place severe strain on the body. Much later, in 1943, an American scientist, Dr Leslie Silverman, who worked with filter respirators, stated that the Standards criteria of the time were far too low, but nothing could be done to raise them: the respiratory equipment simply could not cope with the demands of real human breathing.

Now, almost sixty years later, respiratory equipment has developed significantly. Surprisingly, our Standards tests are still based on the criteria set in WWII.

The same thing goes for SCBA equipment. Current Standard requires of such devices to be able to cope with a peak flow rate of 316 litres per minute in the United States and 300 litres per minute in Europe.

A sneak preview of our experiment shows that this is *not nearly enough*.

In short, if your lungs draw in air faster than the capacity of the device, you will either run out of breath, or the respirator will leak. In our test, all subjects — regardless of age or fitness level — required air *much* faster than the capacity of an SCBA designed to only meet Standards requirements.

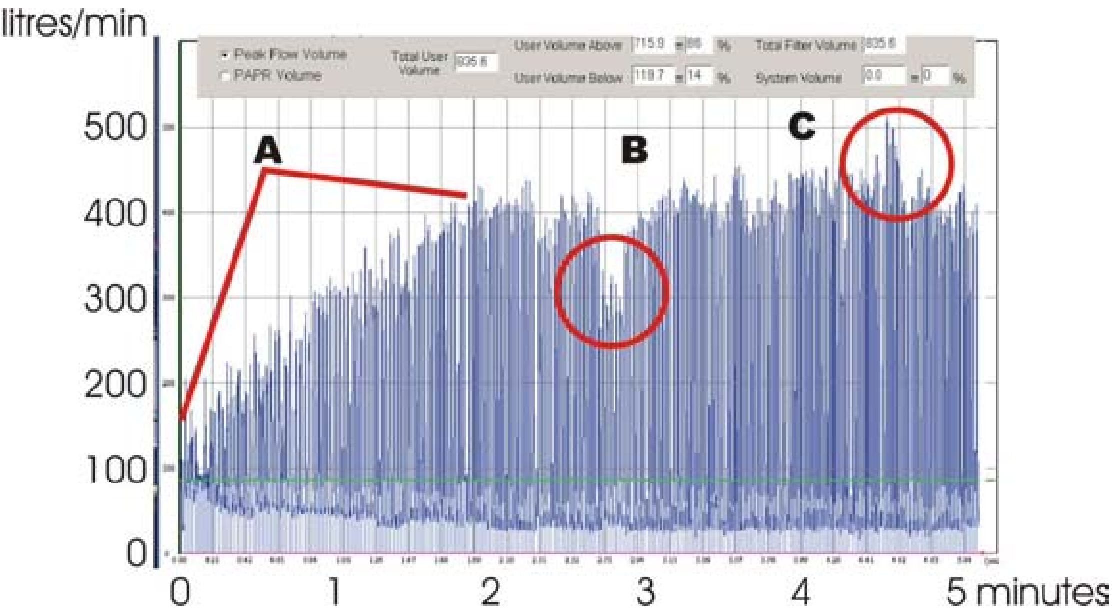
… and they're off!

The climb is about to begin. The participants are now dressed in standard NSW Fire Brigade turnout gear, generously lent to us for the occasion. Originally, it was meant that some firefighters from the Sydney Fire Brigade would take part in the exercise. However, the worst bushfires in decades were raging all around the Sydney area at the time, and the Fire Brigade could not spare any personnel for obvious reasons.

At ground level, timers are synchronised, heart monitors and data loggers switched on, and respirators fitted.

The climbers are wearing the SE400AT model, a fan supplied, positive pressure, breath responsive demand respirator capable of supplying air at well over 400 litres per minute. The respirator features internal electronics and microprocessor, pressure probes in both the mask and the fan unit, and can be hooked up to a data-logger that records the speed and volume of every breath the wearer takes.

Carrying 24 kg (55 lbs) of extra load, the 'firefighters' begin their ascent. They set off in pairs, each pair followed by a video camera crew. And all the while, the data-logger is recording the volume and speed of every single breath, as seen in this sample graph of one climber:



Graph 1

1st–10th floor

The pace is fast and steady to start with. But already after a few floors, the heart and lungs are working hard. In fact, in most participants, the breathing rate reaches its peak already in the first 1.5–2 minutes of the climb *(Graph 1 — A).*

10th–20th floor

During this stage, the body is starting to protest at the workload. This has obvious effects on the climbers. Many become annoyed and impatient with the 13kg/29lbs fire extinguisher they have to carry. Some have to stop several times to have a rest. It is very clear in the sample graph that only a brief rest has a quick and profound effect on the breathing. The peak flow drops almost immediately, then picks up just as steeply as the climb continues *(Graph 1 — B).*

20th–26th floor

By now, physical exhaustion and muscle strain are very great, even on the fittest of the participants. At this last stage, momentarily, some climbers reach a peak inhalation air flow of 500 litres per minute or more *(Graph 1 — C).* But the end is in sight, and the relief is visible in the graphs. In fact, many of the graphs show that climbers, when they realise that they only have a floor or two to go, start to breathe easier, that is, they seem to become calmer and go slower towards the end. We do not know whether this is caused by the certainty of making it to the top, or by sheer exhaustion. Whatever the cause, the effect can be seen in a lowering of the breathing rate in the last half a minute or so.

Phew!

The climbers have now finished their task. For others in our team, the hard work is only just beginning. As each participant comes out of the stairwell, panting and perspiring and almost dropping to the ground with exhaustion, the data-loggers' readings are downloaded to a computer for further analysis.

In the briefing room, even as the first breathing graphs appear on the computer screen, there are plenty of *oohs* and *aahs*.

In a couple of weeks, the results of all climbs will be compiled and analysed. Any discrepancies will be spotted and their causes determined (one of the climbers, for instance, had suffered a severe attack of claustrophobia in the confinement of the stairwell).

Results

Here follows a brief summary of the raw data:

Time required to climb 26 floors:	Average: 5 min 52 sec Fastest: 4 min 9 sec Slowest: 8 min 30 sec
Air requirement during climb:	Average: 177 litres/minute Least: 152 litres/minute Most: 218 litres/minute
Peak inhalation air flow:	Average: 474 litres/minute Lowest: 430 litres/minute Highest: 500 litres/minute

It was interesting to note that, although the air requirements seem to vary widely between the climbers, when placed in relation to body weight, the figures are remarkably similar for all the participants. The average figure was 13 litres per minute per kilogram bodyweight (about 6 litres per minute per pound body weight) within a narrow margin.

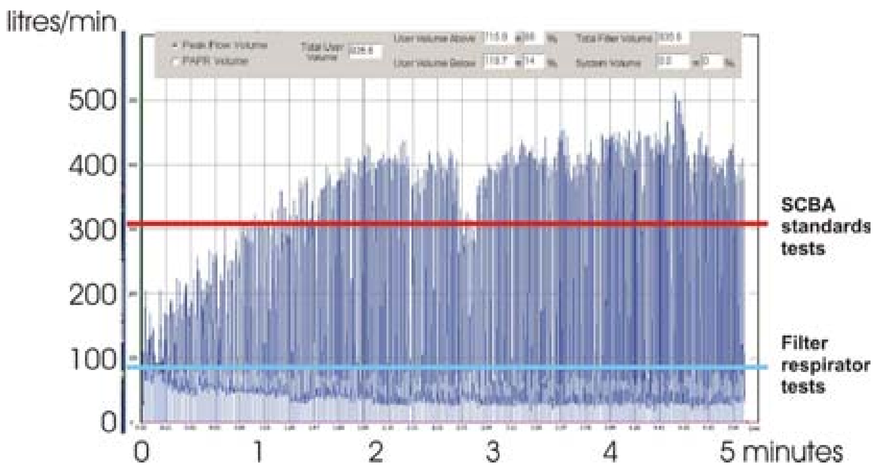
The graphs also showed another phenomenon: that rushing will not get you to the top faster. Some climbers performed the exercise twice during the day. It became clear that if you set out too fast, you will pay for it later by having to stop and rest. When the same climber took it easier the second time around, there was less need to stop, and yet there was little time loss: the top of the fire stair was reached within 10–15 seconds of the 'forced' climb.

Observations

Based on the results of this experiment, we could make a number of observations relevant not only to the firefighter's job, but probably also to many other types of work:

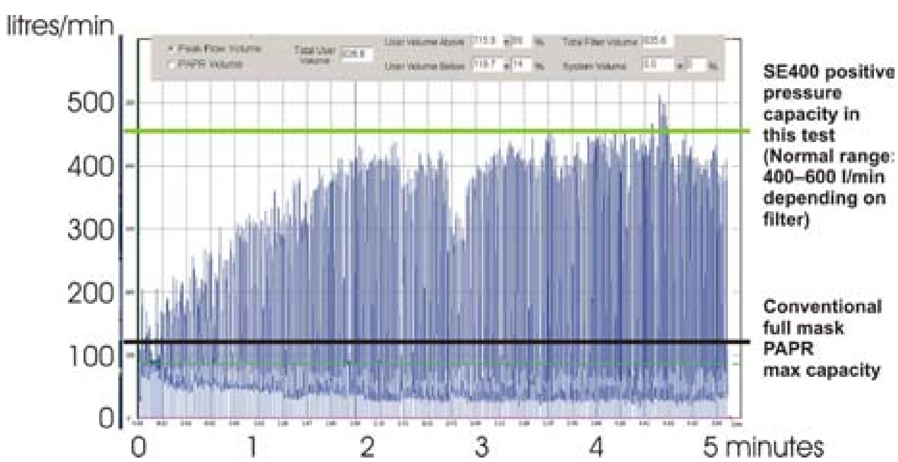
- All people in our test reached a peak inhalation air flow of 430–500 litres per minute. This is far above all current flow rates at which SCBA are tested and assessed (see the **RED** line in *Graph 2*). It is therefore possible — even probable — that an SCBA that has been designed to just meet Standards requirements cannot supply the air needed by a firefighter climbing the fire stair of a high-rise building, or, indeed, any person performing sustained hard work.

- Negative pressure respirators (filter masks) are standards tested at an air flow of around 95 l/min, which constitutes about 20% or *one fifth* of the maximum air flow in humans at real work. No tests exist for measuring negative pressure respirators at a realistic level (see the **BLUE** line in *Graph 2*).



Graph 2

- Conventional PAPR (powered air purifying respirators) with a full face mask commonly have an air supply capacity of around 120 litres per minute, and are tested at 115. Our experiment shows that a human being will out-breathe such a respirator within a few seconds after starting strenuous work (see the **BLACK** line in *Graph 3*).
- The SE400 is the only powered respirator that can maintain positive pressure well above 400 l/min — enough to cope well with an exhausting work exercise such as our experiment (see the **GREEN** line in *Graph 3*).



Graph 3

- At extraordinarily hard work, even the SE400 might momentarily be incapable of keeping up with the breathing requirements (the tiny portion above the **GREEN** line in *Graph 3*). However, if this happens, the SE400 immediately alerts the user with both visible and audible alarms. All the user needs to do is to decrease the work rate slightly. The capacity overrun need not last for more than one or two breaths.
  NOTE: in this exercise, the SE400 was fitted with heavy-duty multi-hazard Domestic Preparedness cartridges. Generally, the capacity to supply positive pressure with this type of cartridge is around 400–450 litres per minute. The maximum capacity of the SE400 is filter-dependent. With particle filters only (against biological hazards for instance), the SE400 can supply positive pressure air at 550–600 litres per minute.

Conclusion

There are two major conclusions we can draw from the results of our tests:

- This is yet another example showing that Standards criteria in all developed countries are simply not related to real life and actual human breathing. This is a fact first recognised in the early half of the last century. All Standards need to be reviewed and updated to better reflect human physiology and the mechanics of human breathing.
- It seems likely, both from the results of our experiment and data from the actual workplace, that conventional respiratory protection devices in current use cannot cope with the breathing requirements of the human body hard at work. The SE400 respirator, as we have seen in at least this experiment, is, as far as we know, the only device that is capable of supplying enough air, at positive pressure, during hard work.