CONTRACTOR'S FINAL TECHNICAL REPORT

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Req/PR/Project #: 000HCCB1-2007-39852

Contract Title:

DEVELOPMENT OF BOTH A DOCKABLE AND HYBRID PERSON-WEARABLE SELF-CONTAINED SELF-RESCUER

Security Classification: N/A

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EXECUTIVE SUMMARY

In December of 2006, TPI responded to two RFP's from NIOSH seeking technical proposals to design and build novel respirators for use in the mining industry. One RFP sought a dockable, self-contained, self-rescuer (SCSR) to allow for extended respiratory protection during mine escape, and the other was for a hybrid mine escape respirator incorporating both air-purifying, and self-contained types of respirators, also for the purpose of extending the time available for escaping miners to receive respiratory protection. TPI recognized a commonality in the two RFPs and responded to both with designs that could be produced independently, but which shared several fundamental features. In evaluating TPI's responses to the RFPs, NIOSH recognized a benefit in the shared design features and awarded one contract for TPI to pursue both concepts resulting in one conceptual product referred to as the dockable/hybrid SCSR. This SCSR would be configured to allow any suitably equipped breathing device (CO Filter Self Rescuer or another SCSR) to connect (dock) to the base unit and to allow the user to switch between them without 'breaking seal'. This dockable unit would retain the capacity to accept multiple changes of O_2 supply or filters over an extended period as the useful life of any individual add-on unit is expended.

As the project developed it resulted in the development of a new carbon monoxide (CO) Filtered Self-Rescuer (FSR) to dock to the SCSR and a small electronic sensor, the Breathing Air Monitor (BAM), to alert the user to certain hazards in the local ambient air:

- ***Self Contained Self Rescuer (SCSR).*** The TPI SCSR is a 60-min compressed O_2 rebreather that protects the user from all adverse breathing conditions. TPI uses Micropore's Lithium Hydroxide (LiOH) catalyst to absorb the retained CO_2. TPI's SCSR is supplied with a docking valve that allows users to change out nearly spent devices with fresh devices without breaking seal or having to hold their breath.
- ***Carbon Monoxide Filter Self-Rescuer (CO FSR).*** TPI also developed, via a supply agreement with 3M Company, a carbon monoxide (CO) Filtered Self-Rescuer (FSR) that uses a proprietary precious metal catalyst providing 8 hours of protection. TPI's CO FSR can be supplied with a flanged fitting that docks to TPM's SCSR or it can be supplied with a mouthbit for use as a self-contained device for CO protection alone.
- ***Breathing Air Monitor (BAM).*** Finally TPI developed, in cooperation with the Kohler-Bright Star Company, a Breathing Air Monitor (BAM) that would give the user an indication of when it is necessary to use the SCSR because of an oxygen deficient environment and when it safe to use just the CO filter (normal O_2 but high CO) or if is safe to not use either. This warning system will avoid the user expending the breathing device unnecessarily (e.g. the atmosphere is still breathable). The resultant technology is a module containing the sensors, electronics, PC board and alarms that fits on the miner's cap lamp battery, between the body and top cap.

By the end of this contract TPI had demonstrated prototypes of all three products (Figure ES-1). The project did not result in certified devices by the completion of the contract but TPI has negotiated licensing agreements for these three products and they are being prepared for certification submission by the licensee.

Figure ES-1: TPI Developed A SCSR and CO-FSR That Can Be Docked To Each Other And A Breathing Air Monitor That Can Direct The User As To Which Device They Need To Use.

DEVELOPMENT OF BOTH A DOCKABLE AND HYBRID PERSON-WEARABLE SELF-CONTAINED SELF-RESCUER

1. Technical Background

Any respirator device, whether filter, open loop or closed loop Self Contained Breathing Apparatus (SCBA), has a limited air supply life. If a miner uses up the available air supply while still in a dangerous atmosphere it would be very beneficial if they could access some alternate supply and make the change over without 'breaking the seal' or exposing themselves to the noxious gasses. One approach to this solution would be to have the basic rescue respirator (a closed loop device) able to accept additional breathing devices or a filter unit to extend the life of the breathing air supply.

The Centers for Disease Control (CDC) and the National Institutes for Occupational Safety and Health (NIOSH) had previously released two separate solicitations for variants of a Self Contained Self Rescuer (SCSR): one for a SCSR-Hybrid utilizing an add-on filter pack to protect the user in a high Carbon Monoxide (CO) atmosphere, and one for a SCSR-Dockable fitted with an interface allowing alternate breathing devices to be connected to the unit. In response to these solicitations TPI submitted a proposal for a system that combined both devices into one. The approach to be taken is that the SCSR should be configured to allow any suitably equipped add-on to connect to the base unit. This means that the base SCSR can utilize a filter pack or another SCSR as the supplemental breathing device. Under this approach, the hybrid variant is actually a sub-set of the dockable unit.

The SCSR reported on herein is based on a compact, simple rebreather system. Rebreathers take advantage of the fact that much of the air we exhale is usable oxygen by cycling the expired air through a 'scrubber' that removes the Carbon Dioxide (CO_2) and as necessary adds make-up Oxygen (O_2). This closed loop supply represents a highly efficient and completely self contained SCSR. For this development the SCSR will incorporate a no-leak connector that will allow it to interface to additional sources of breathable air (e.g. other SCSR modules) while maintaining an effective seal against the atmosphere during the changeover procedure.

Ideally, this new dockable unit would retain the capacity to accept multiple changes of air supply or filters over an extended period as the useful life of any individual add-on unit is expended.

Also ideally the SCSR would also give the user an indication of when it is necessary to use the SCSR because of a toxic or oxygen deficient environment and when it safe to use the CO filter (as opposed to the closed loop system). This warning system will avoid the user expending the breathing device unnecessarily (e.g. when the atmosphere is still breathable). A small, economical and basic sensor which detects hazardously high levels of CO and low levels of O_2 would find application in many industries, not just the mining one. The intent here is to integrate several existing sensors into a very simple warning system. The device will detect and monitor atmospheric gas levels and give a basic indication (say an audible warning, vibration and red/green Light Emitting Diodes (LED)) of safe/hazardous conditions (high CO, low O_2). It does not need to display actual gas levels, history or any other data only basic notification of a hazardous atmosphere (although it would include a low battery light). This device is being called a Breathing Air Monitor (BAM).

1.1 Objective

The objective of this contract was to develop and evaluate a Person Wearable Dockable and Hybrid Self-Contained Self-Rescuer (SCSR) that will meet the requirements of 42 CFR Part 84, Federal Mining Regulations, as well as any that will result from the Miner Act of 2006.

1.2 General Contract Overview

The Phase I contract was awarded to Technical Products, Inc. (TPI) on 1 February 2007 as a combined award against two CDC solicitations:
- 2007-N-08847
- 2007-N-00848.

On 28 November, 2007 this contract was modified to effectively execute the Phase II Option.

The contract resulted in three products:
- a dockable self contained self rescuer (SCSR),
- a filter self rescuer (CO FSR), and
- a breathing air monitor (BAM).

These products will be reported on separately in the sections that follow.

2. SCSR System

The SCSR development was executed in two parts, called Phase I and Phase II. The sections that follow summarize those developments at the systems level. Appendices 1 to 5 provide technical details on the development of the principal subsystems:
- Appendix I - Regulators
- Appendix II - CO_2 Scrubber
- Appendix III - Counter-lung
- Appendix IV - Docking Connector
- Appendix V - Accessories and Minor Items

2.1 SCSR Phase I Development

The design approach selected was to configure the SCSR as a simple pendulum rebreather with the regulator at the top, the CO_2 scrubber surrounding the O_2 bottle and with the counter-lung suspended below this assembly (Figure 1). The system utilizes an on-demand O_2 flow to maximize efficiency and so prolong the breathing time available from a fixed volume of O_2.

TPI worked with Micropore Inc. on a custom scrubber configured as a toroidal cylinder which will surround the O_2 bottle. The scrubber material is Lithium Hydroxide (LiOH) to minimize system volume and weight. Approximately 750-cc (1.2-lb) of the material is needed to meet the stated SCSR requirements. Figure 2 shows the unique Micropore methodology of wrapping their scrubber 'fabric' around a core (in our case the O_2 bottle, which results in a well contained, non-settling scrubber configuration with permanent air flow channels.

Figure 1: The Phase I SCSR Is Configured As A Simple Pendulum Rebreather With The O_2 Tank Surrounded By The Scrubber Material

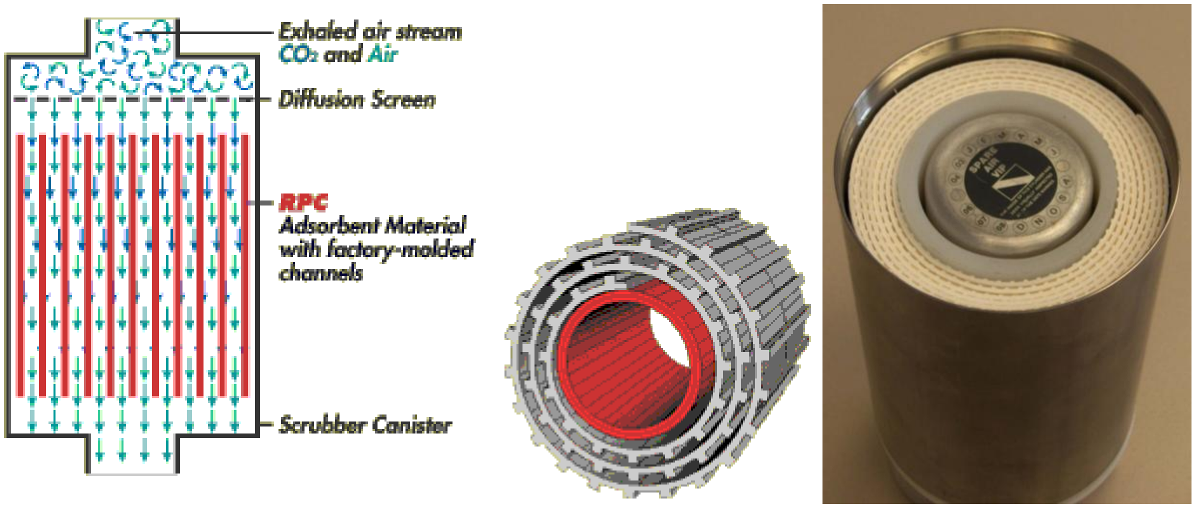


Figure 2: The Unique Micropore Reactive Plastic Curtain (RPC) Scrubber Configuration Features A Hollow Core, Built In Airflow Management And Mechanically Contained Catalyst

TPI's intent was to make the O_2 bottle as either an all aluminum item or as a carbon fiber wrapped thin skinned aluminum cylinder to minimize system weight. The obstacle to this solution is the fact that the US Department Of Transportation (DOT) has never certified such a design for 4,500-psi O_2 (although the corresponding European Union (EU) agencies have) and recently we have been informed that such a certification would not occur anytime in the foreseeable future. With this information now in hand the fall back position of a steel bottle certified to DOT 3AA has been pursued. The issue here is the device weight (perhaps as high as 3-lb for the bottle alone compared to 1 – 1.5-lb for aluminum or composite bottles). The benefit is cost – the tooling and per piece costs are significantly lower than either of the alternates.

The top end of the assembly has been configured in two variants for evaluation:

- A system with the breathing tube hard-mounted to a swiveling elbow with the docking connector at the mouth-piece end (Figure 3)
- A system with the docking connector mounted at the regulator housing with this housing able to swivel in two plans to allow for close coupling of two SCSR (Figure 4).

Figure 3: One Configuration Has A Swiveling Breathing Tube With Docking Connector At The Mouth-Piece End

Figure 4: The Second Configuration Features A Swiveling Docking Connector On The Regulator Housing

In either case the housing for the unit would incorporate a windowed top can (Figure 5) to allow easy viewing of the gas pressure gauge, humidity and temperature sensors and for inspection of hose and mouth-piece condition.

Figure 5: The Top Cover Features Windows To Allow Inspection Of Gas Gauge, Health Indicators And The Condition Of Rubber Parts

2.2 Phase I NPPTL Testing & Rework

The Phase I SCSR was evaluated several times at NIOSH's National Personal Protection Technology Lab (NPPTL) on their breathing machine (Figure 6). The first series of that testing identified a series of leak paths in the regulator housing and at the various swivel points built into the device. It also highlighted the fragility of the design in terms of material selection (plastic) and assembly technique (pinning together of swivel joints). As a result of these findings TPI conducted a redesign of the SCSR regulator housing to eliminate all swivel joints and leak points and to support fabrication of an all-metal housing. That design effort resulted in the device shown in Figure 7. This design consists of a monolithic SCSR top assembly machined from an aluminum billet with the various demand regulator features (mounting holes, inhale/exhale ports, breathing tube connection flange, O_2 bottle mounting stud, etc.) built directly into the piece. After machining, the part was hard-coat anodized to resist environment induced corrosion including the detrimental effects of the caustic scrubber material.

Figure 6: The SCSR Was Tested On The NPPTL Breathing Machine

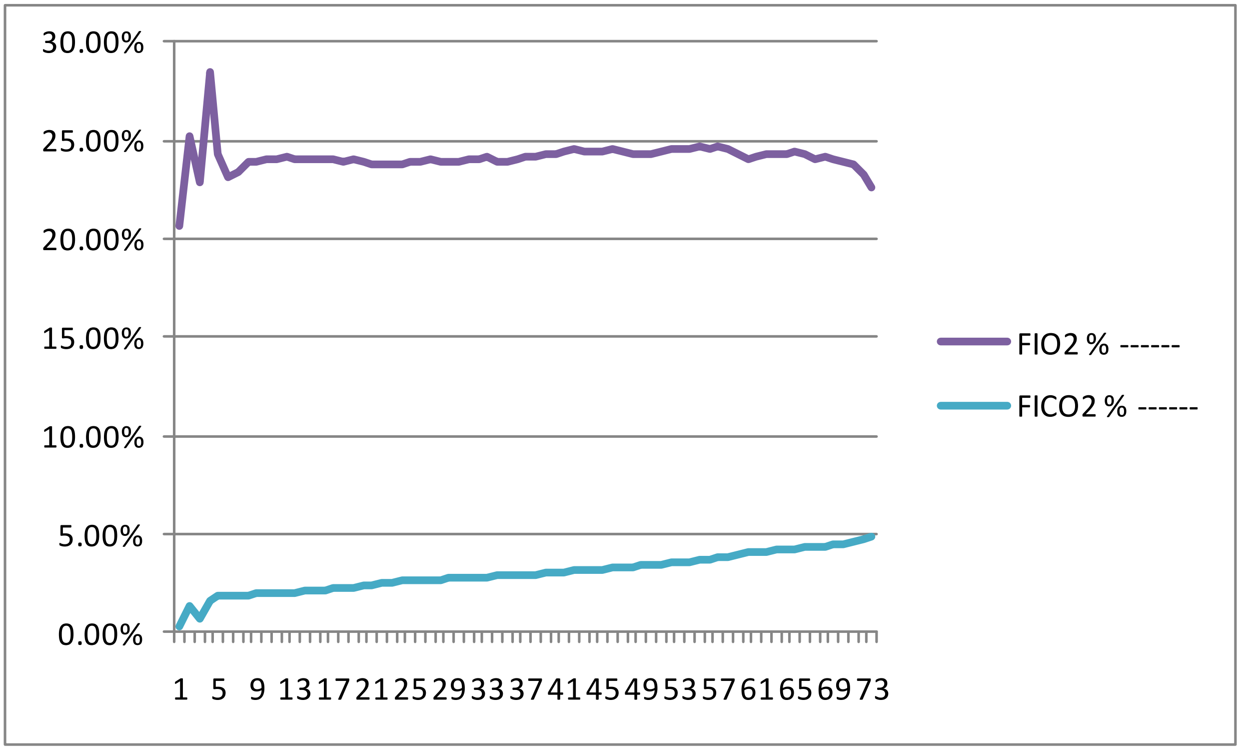
Figure 7: The New SCSR Top Assembly Is Machined From A Solid AL Billet To Obviate Any Possibility Of Leaking

Shown below in Figures 8 and 9 are the results from the later test series after the device leaks were addressed: a constant work effort and ‘cyclic’ tests. In summary – the SCSR performed well with a device life of approximately 60-min but with two issues identified:

- the inhale air temperature exceeded the specification by 2-deg C
- the inhale CO_2 level ran high (although there was some discussion about which ‘limit’ to apply: the contractual ‘average’ 3%, or the 2% or 4% limits in use or proposed by NIOSH)

While these issues are of concern the reader is directed to the comments made in Appendix II - Scrubber which discusses Scrubber optimization to address both performance deficits.

Also based on the hands-on evaluation conducted during this testing TPI made a few design changes to the regulator housing to enhance the packing of the system for the stowed condition, for example the breathing tube flange was reoriented and top and bottom plate sealing approaches were revised.



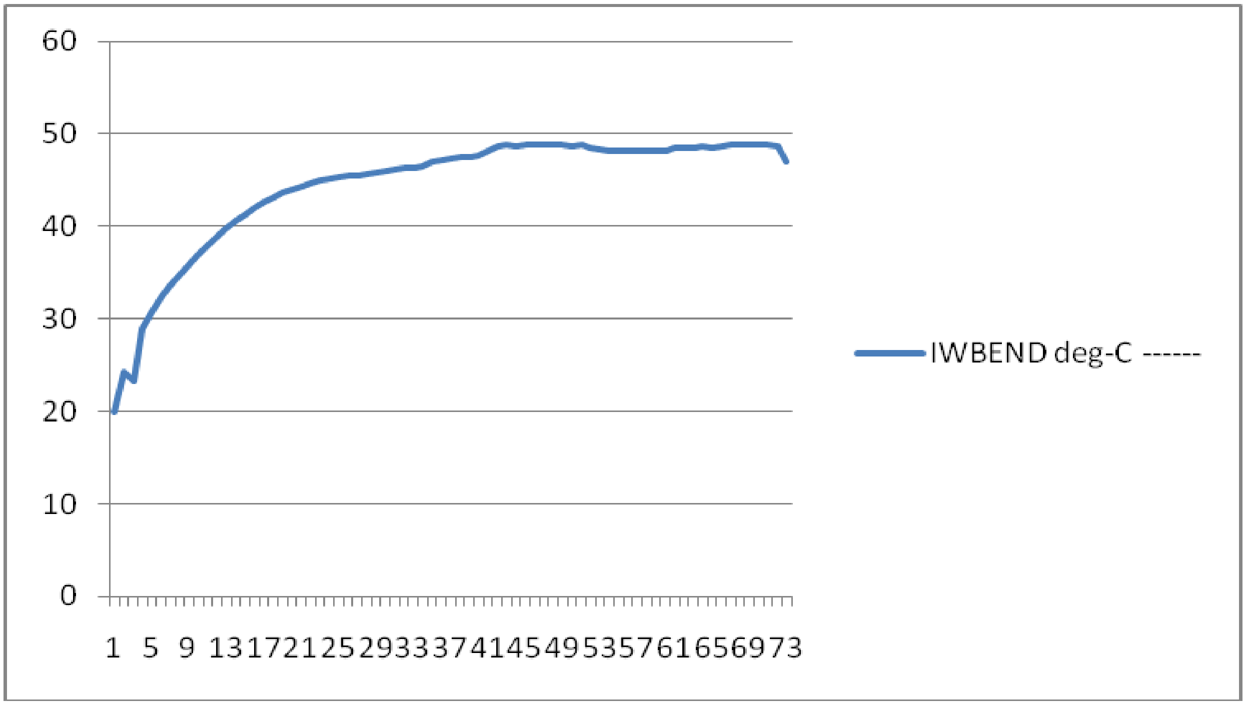


Figure 8: Phase I SCSR Steady Work Load 'Capacity' Test Results Of Fraction Inspired Oxygen and Carbon Dioxide (FIO2, FICO2) And Inspired Wet Bulb Temperature (IWBEND) Versus Time

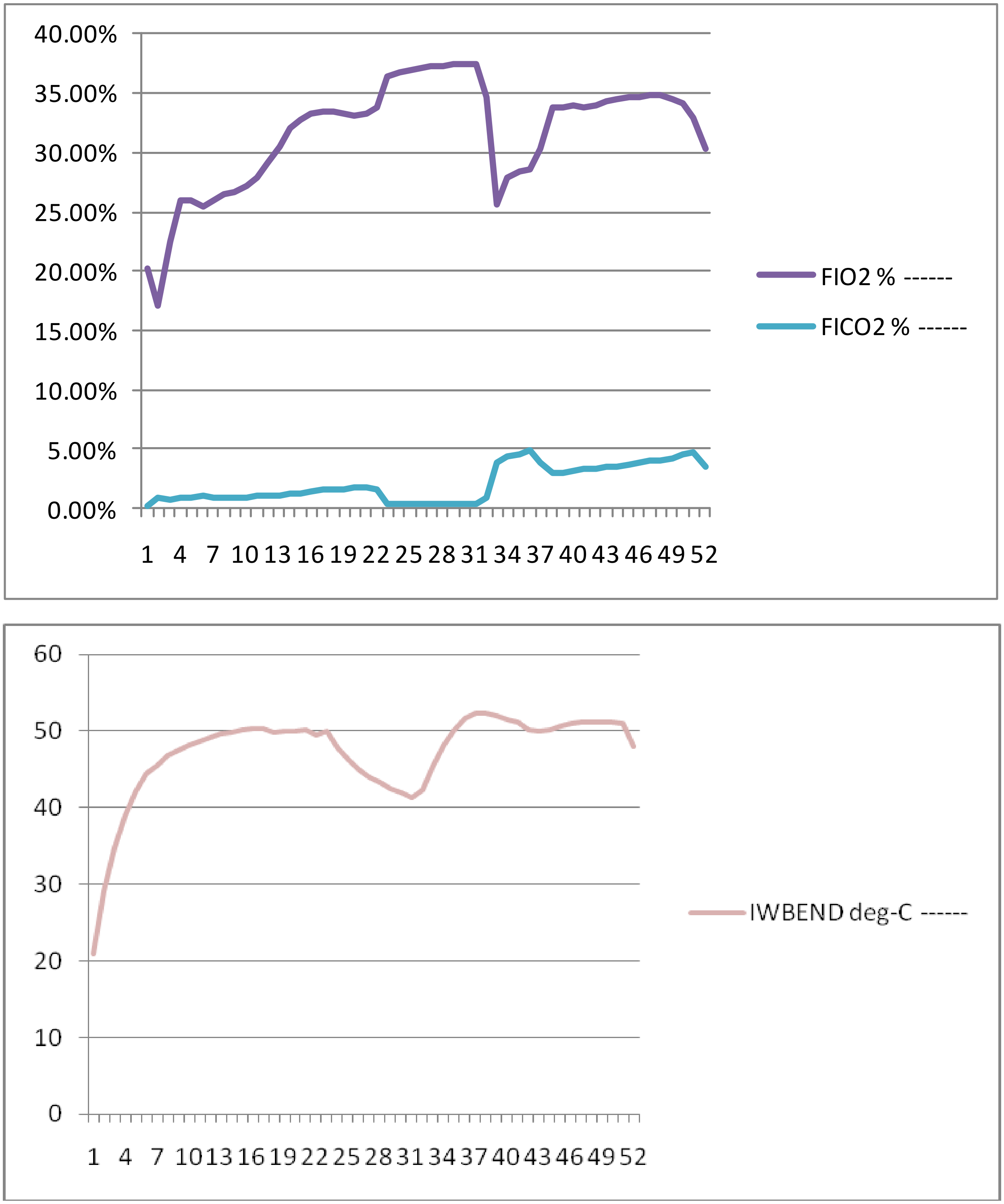


Figure 9: Phae I SCSR Cyclic Work Load 'Performance' Test Results Of Fraction Inspired Oxygen and Carbon Dioxide (FIO2, FICO2) And Inspired Wet Bulb Temperature (IWBEND) Versus Time

2.3 Phase II Development

The functionality of the basic components incorporated into the Phase I SCSR was demonstrated during CDC/NIOSH testing. What needed rework was the overall configuration. The Phase I configuration resulted in a long cylinder that does not mount easily on a miner's hip without the potential for significance interference with their normal movement and work functions.

What was needed was to reconfigure the basic components of that design into a more ergonomic package that minimizes the potential for the device interfering with the normal movement and actions of the miner and which minimizes the projection of the housing from the miner's belt.

The Phase II approach as shown in Figure 10 was to:

- utilize a standard pressure 3,000-psi O_2 bottle
- utilize a rolled cylinder of LiOH scrubber material
- use a new two stage demand regulator device
- incorporate the same 'docking' features as demonstrated in the current design
- house the assembly in a peanut shaped outer skin.

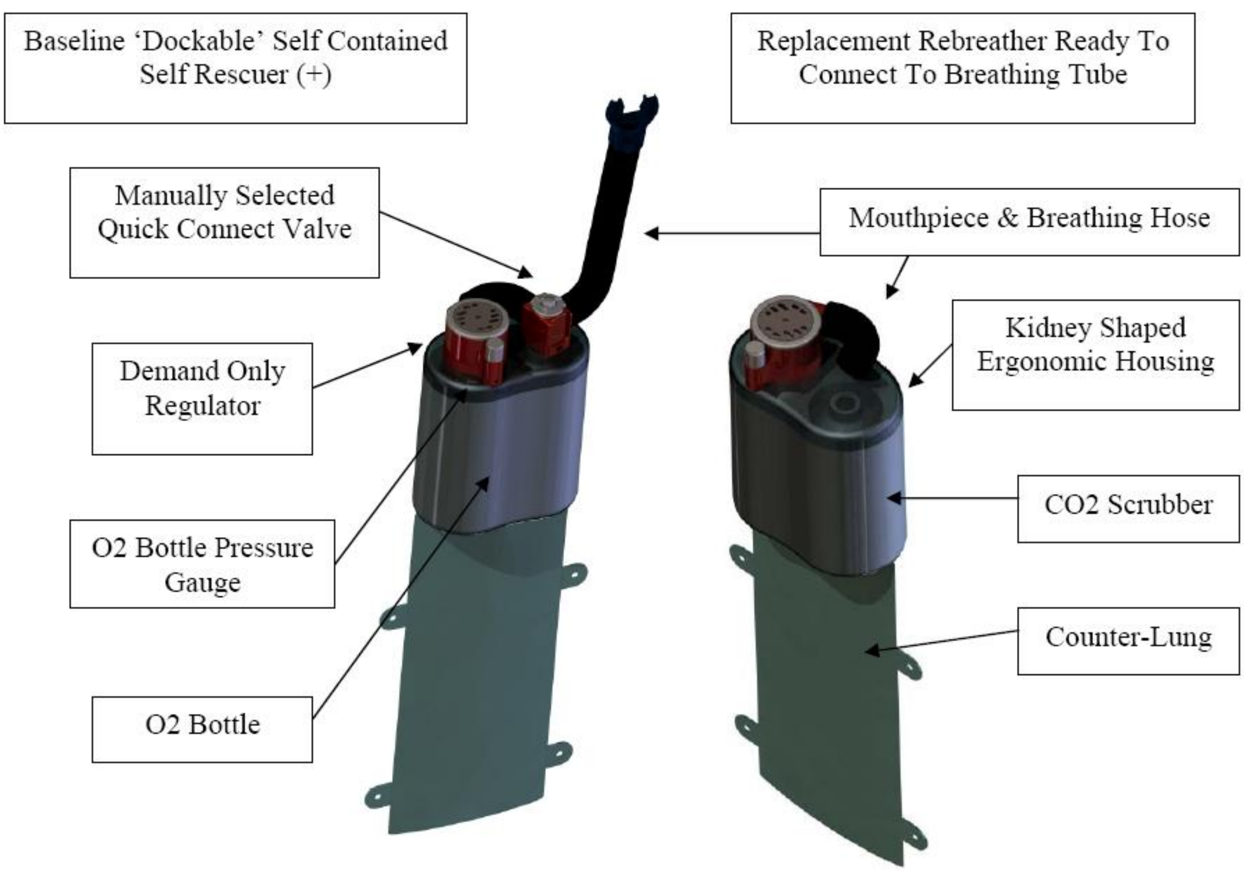


Figure 10: The New Configuration Uses A Single 3,000-psi O_2 Bottles In A Squat Peanut Shape That Hugs The Miner's Hip

This approach takes maximum advantage of the innovative features of the Phase I SCSR design while providing a path to an ergonomic housing. In addition it allows the use of ‘off-the-shelf’ aluminum 3,000-psi O_2 bottles as opposed to the stainless steel 4,500-psi bottle proposed for the original cylinder unit. The original, higher pressure bottle, while attractive from a size perspective, was operationally unworkable due to a combination of safety concerns and DOT transport certification constraints. This approach therefore retains all the advantages of the original TPI dockable SCSR but enhances the configuration to make it a more ergonomically acceptable unit.

Figure 11 shows the prototype design. This configuration incorporates:

- a much more highly engineered two stage regulator than the first generation unit
- a single 110-ltr 3,000-psi O_2 bottle
- cylindrical 580-sq.in. LiOH scrubber pack to keep the airflow management as straight forward as possible
- an on/off valve actuated by opening the outer package

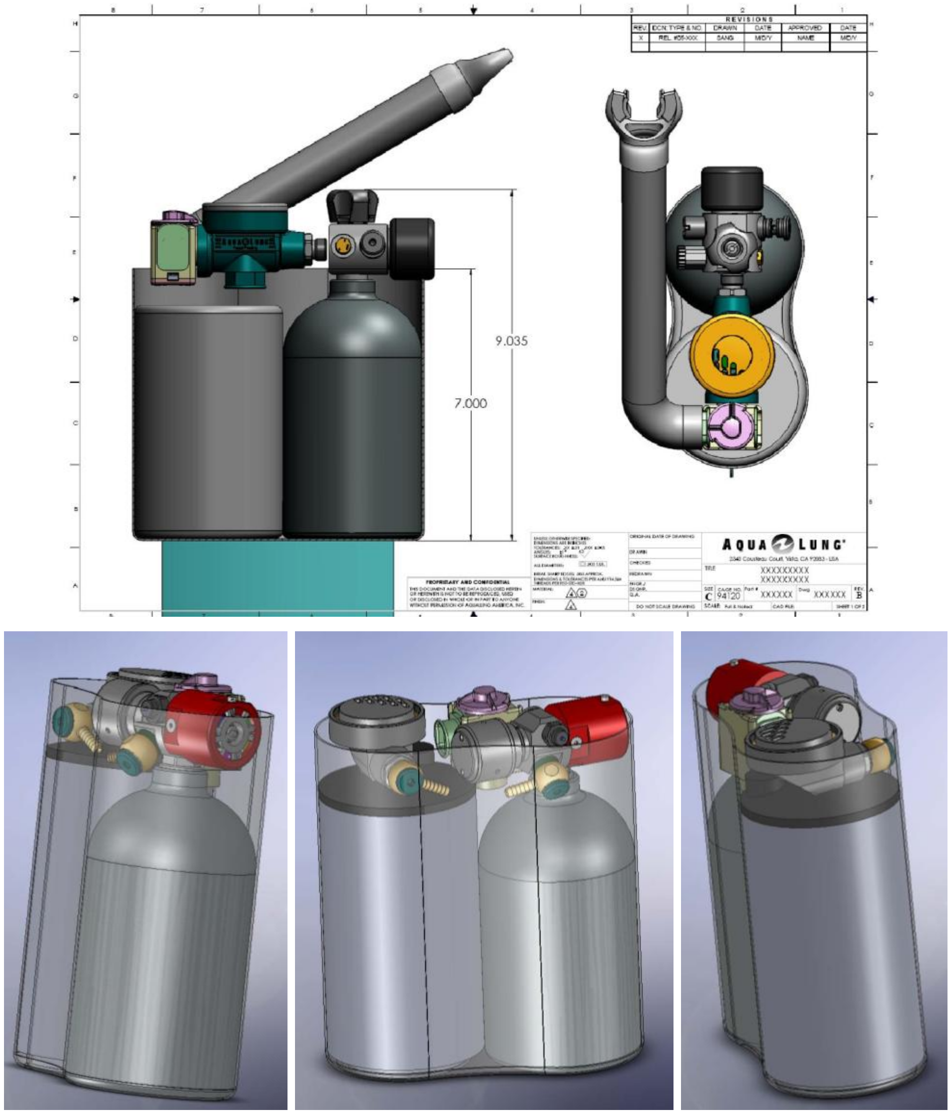


Figure 11: An Initial Conceptual Layout And Packaging Model Was Completed

One of the primary concerns with the device design is the ergonomics of the package. This characteristic of the device was a primary driver for the Phase II effort. TPI simultaneously advanced along two package approaches (Figure 12):

- The 'peanut' shape originally suggested. This approach changed somewhat from the original concept to incorporate a single gas bottle with the scrubber 'cylinder' locate beside it.
- A larger version of the original toroidal cylinder. The increase in size was driven by the need to go to a 3,000-psi O_2 bottle rather than the 4,500-psi bottle originally intended.

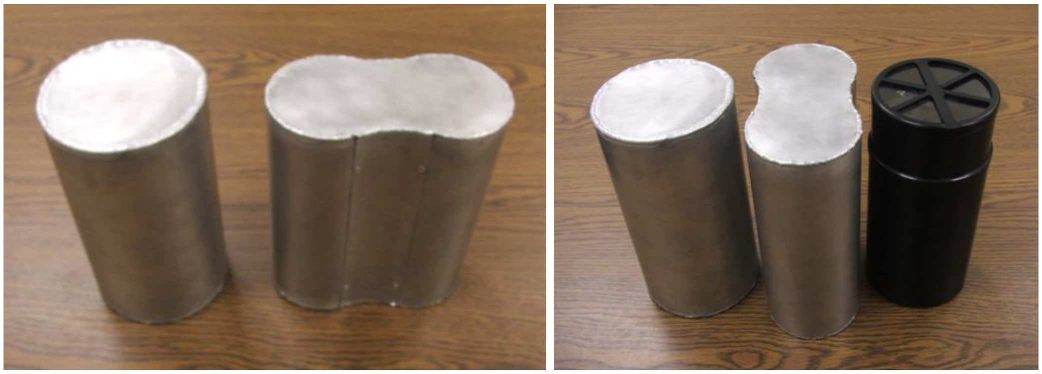


Figure 12: The Two Packaging Options Compared To Each Other And To The Phase I Device

Figure 13 shows the two early Phase II devices mounted on a miner's belt in a low slung 'thigh' holster fitted with thigh straps to hold the device secure against the wearer's leg and to maximize the comfort of the arrangement (an approach similar to that taken by law enforcement and the military for carrying both weapons and protective masks). Figure 14 shows this set-up as worn for initial user 'wearability' trials. Initial feed-back from TPI staff was that the peanut device was much less obtrusive during normal work tasks and that the low slung holster with thigh strap offered minimal interference to normal arm motions and swing when walking and held the devices tight against the leg for minimal dis-comfort. This set-up was provided to NIOSH for similar experimentation. Initial feedback was that the peanut shape was the preferred configuration but that the 'jury is still out' on the thigh holster suitability for mining applications.

Figure 13: The Two Phase II Form Factor Models Have Been Mounted In Low Slung Thigh Holsters On A Miner's Belt For Wearability Trails

Figure 14: Initial Feedback From TPI Staff Wearing The Unit Indicate A High Preference For The Peanut Shape With Additional Comments Commending The Tight Holster Approach

The consensus of the working group was that the peanut shaped configuration was the preferred option due primarily to the form factor. Functionally both configurations perform similarly and the form factor is not driven by functional requirements, but rather by the real world operational need for a close-to-the-body device. Figure 15 shows an exploded system level view of the SCSR. Figures 16 and 17 show details of the housing and scrubber assemblies respectively.

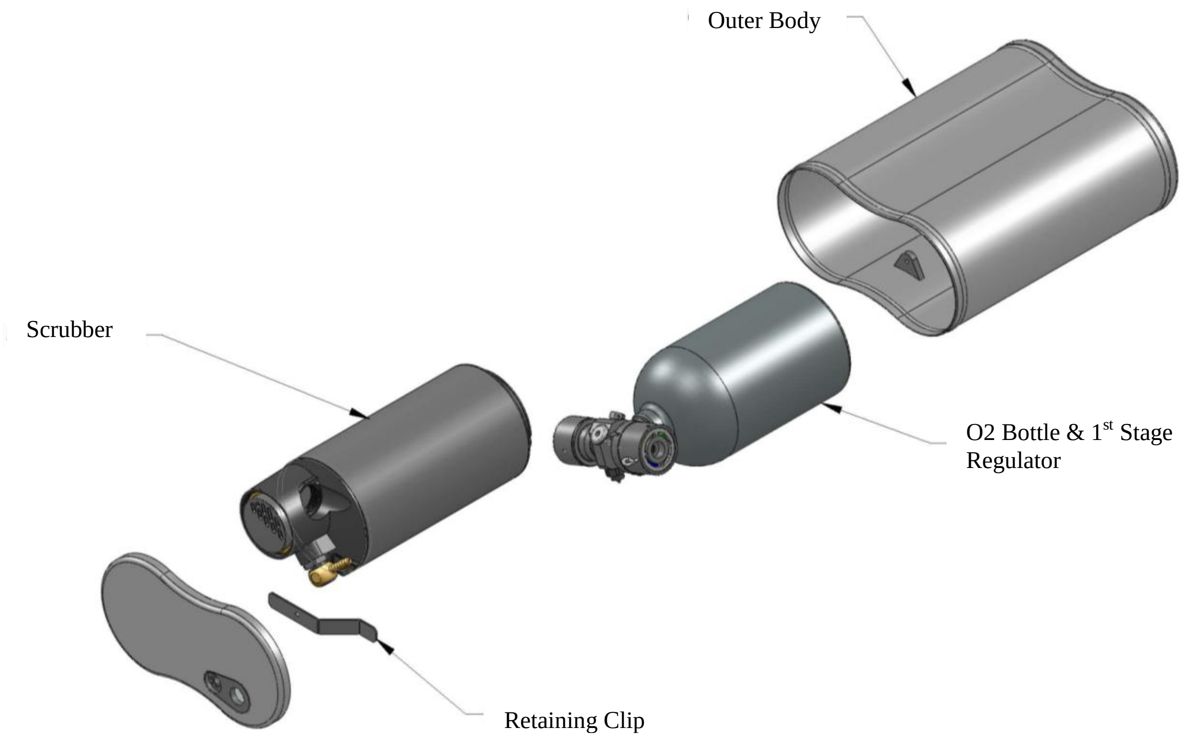


Figure 15: Detailed Design Of The Peanut Packaged SCSR

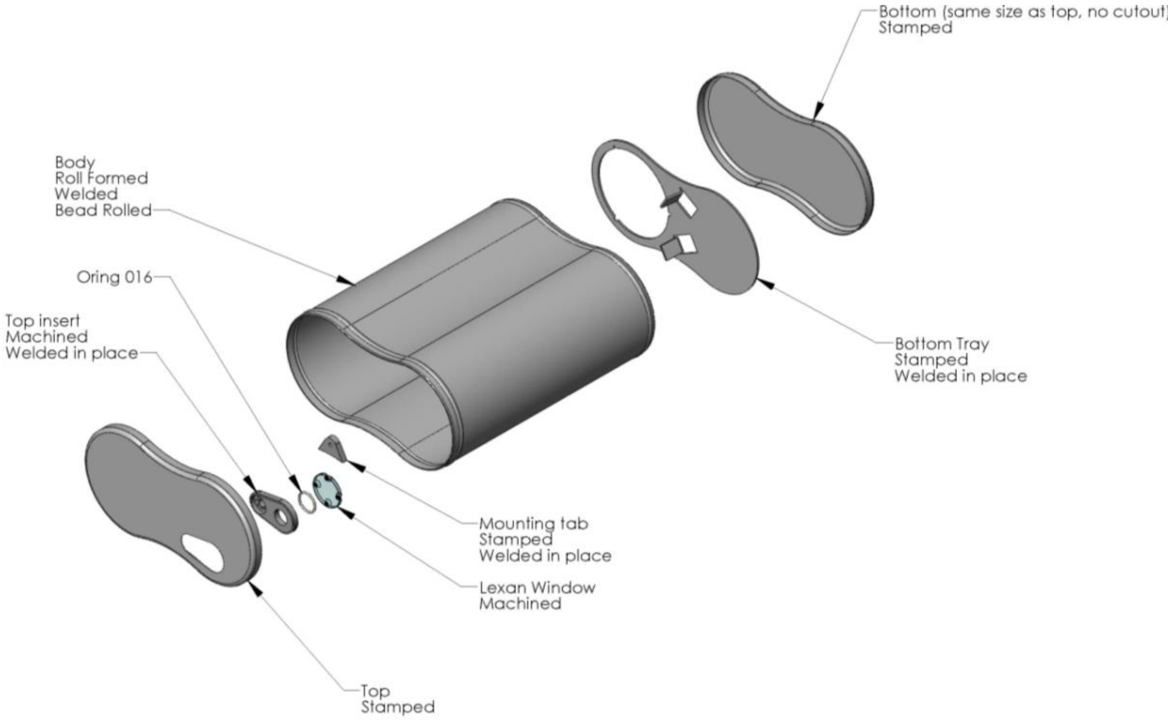


Figure 16: The Original Outer Can Is Comprised Of Stamped And Drawn Sheet-Metal Parts

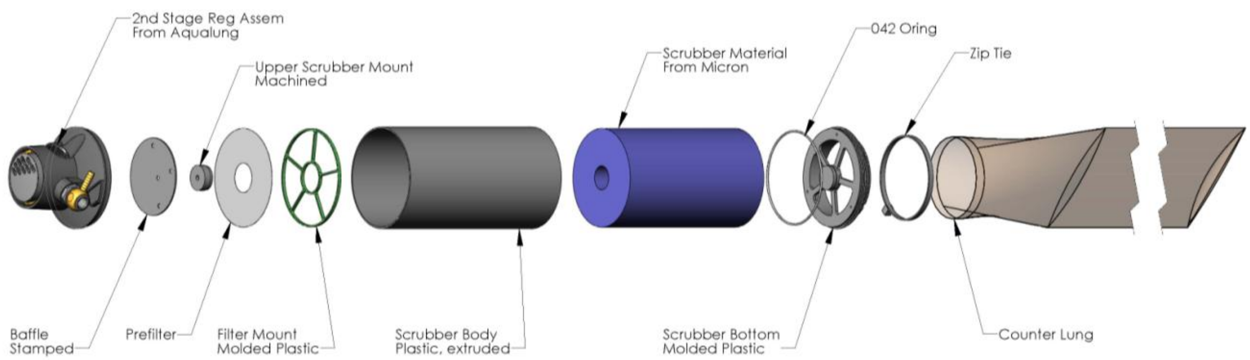


Figure 17: The Scrubber Assembly Includes The Integral Second Stage Regulator

TPI fabricated the 'business end' of the SCSR as a 3D rapid prototype (shown in Figure 18) to support packaging exercises for the flexible hoses and manual selector valve/quick disconnect components of the dockable device. This figure clearly shows the two regulator stages, the automatic 'ON' valve fitted to the first stage and the demand assembly of the second stage. The bottom view shows some of the air-flow management structure built into the plenum at the top of the scrubber assembly.

TPI continued to mature the packaging concept for the SCSR to ensure that it is configured and housed in a manner that is both optimized for function and from the perspective of the user, not as two separate approaches but rather as a compromise to address all the user's needs. Figure 19 shows the final outer envelope concept. The central part of this casing is a molded plastic design. The top and bottom caps are also molded plastic.

From Above *From Below*

Figure 18: The New First And Second Stage Regulators Prototyped With Gas Cylinder And Scrubber Plenum

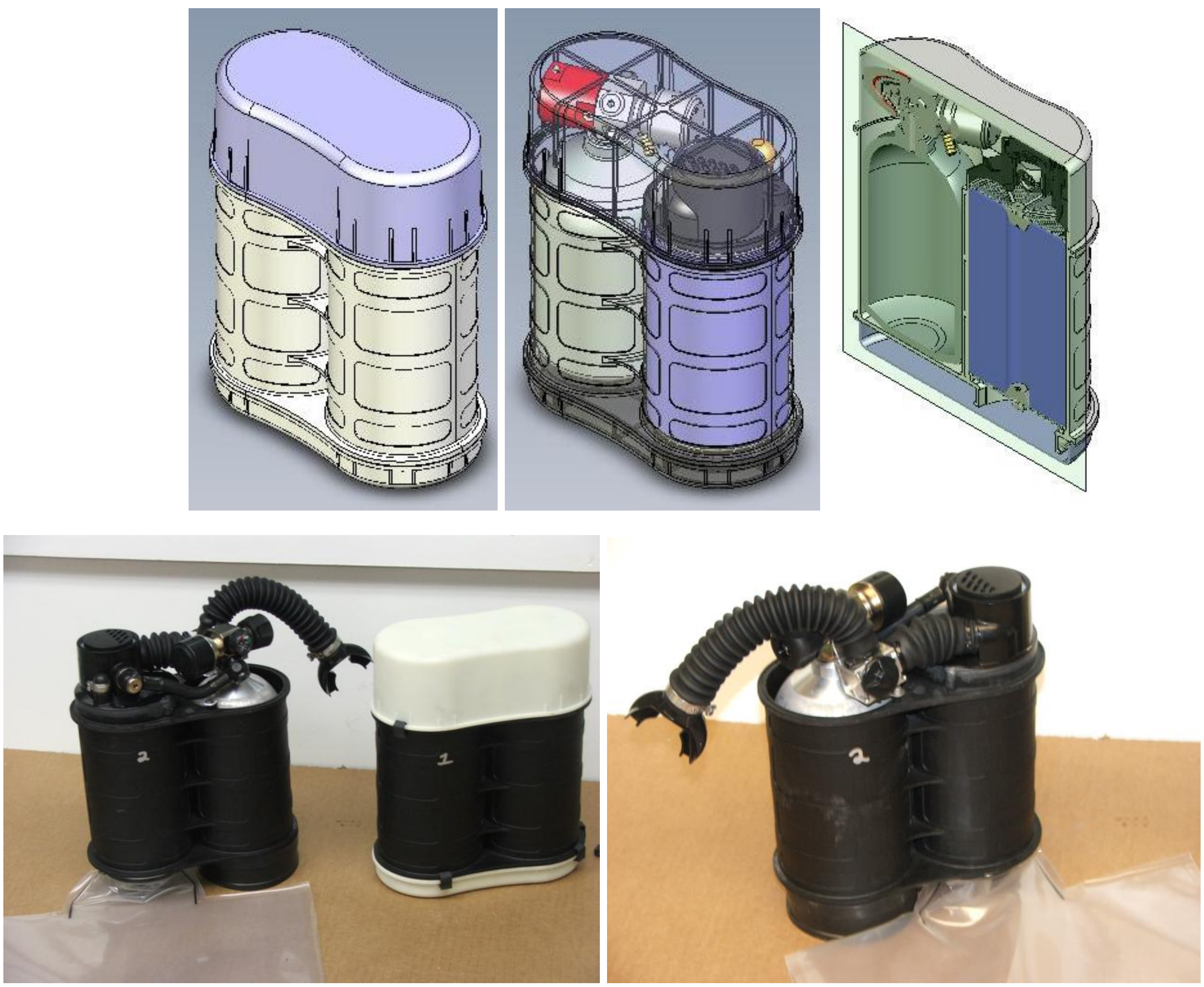


Figure 19: The Latest Generation SCSR Features A Molded Plastic Housing

Figure 20 shows an exploded and packaged system level view of the SCSR.

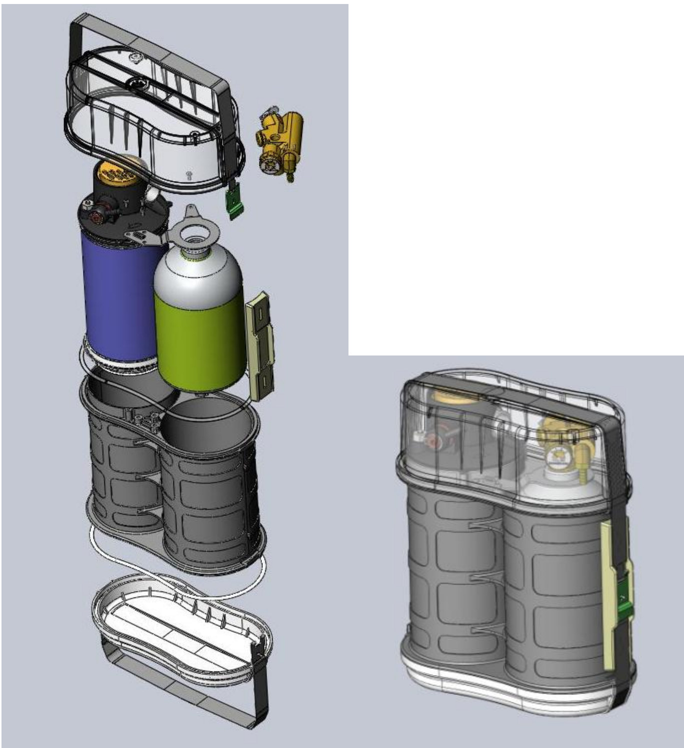


Figure 20: Detailed Design Of The SCSR

Figure 21 shows details of the scrubber assembly. This assembly incorporates the 2nd stage demand regulator with purge button, the LiOH scrubber itself and a pair of upstream and downstream filters to isolate the scrubber material from the breathing loop.

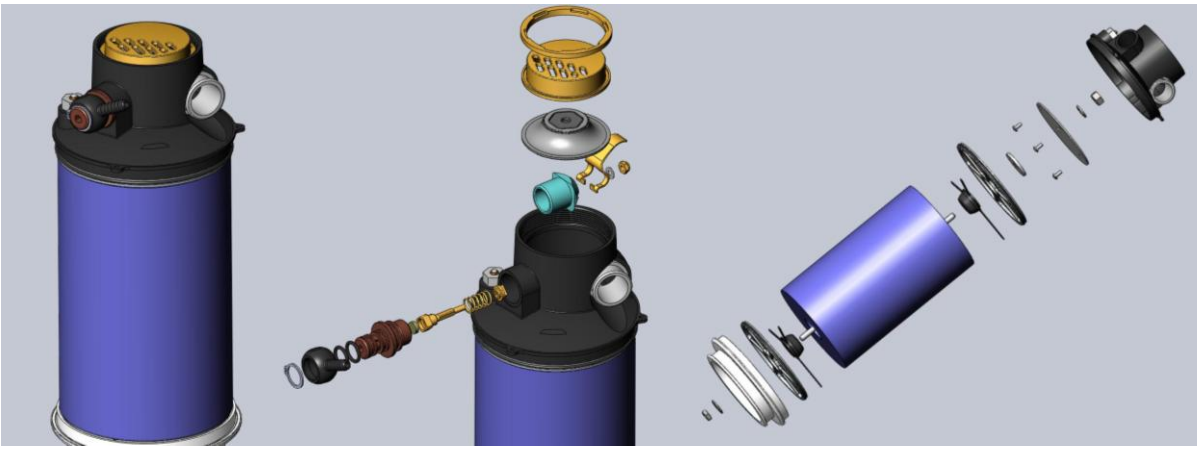


Figure 21: The Scrubber Assembly Incorporates The 2nd Stage Regulator, Plenum And Breathing Loop Filters

Figure 22 shows multiple devices under inspection at TPI before delivery to NPPTL in Dec 08 for technical testing on the metabolic simulator and potentially Man-Tests (discussed later in this report).

Figure 22: Multiple Devices Have Been Delivered To NPPTL For Testing

Figure 23 shows the fully packaged SCSR as configured at the completion of the Phase II contractual effort.

Figure 23: The Fully Packaged SCSR At The Completion Of Phase II

2.4 Phase II Testing & Systems Rework

TPI conducted significant in-house testing of the 2nd generation SCSR. This testing is detailed in Appendix VI to this report.

Subsequent to the in-house evaluation the prototype was then tested for function and capacity at NPPTL (Figure 24). The graphs that follow (Figures 25-27) summarize the device performance in terms of inhaled O_2 and inhaled CO_2 plus the temperature of the inhaled breathing air. Full data sets for these tests are contained at Appendix VII.

Figure 24: SCSR Under Test At NPPTL

Three test cycles were run on the complete SCSR:

- A ‘capacity’ test under steady state work load (VO_2 @ 1.35-l/m and VCO_2 @ 1.15-l/m) which ran within specification for approximately 80-min (Figure 25)
- A cyclic workload ‘Performance’ test which ran through 2 cycles(+) for over 60-min (Figure 26) and only failed on breathing temperature
- A Man-Test 4 equivalent on the Breathing Metabolic simulator and only failed on breathing temperature (Figure 27)

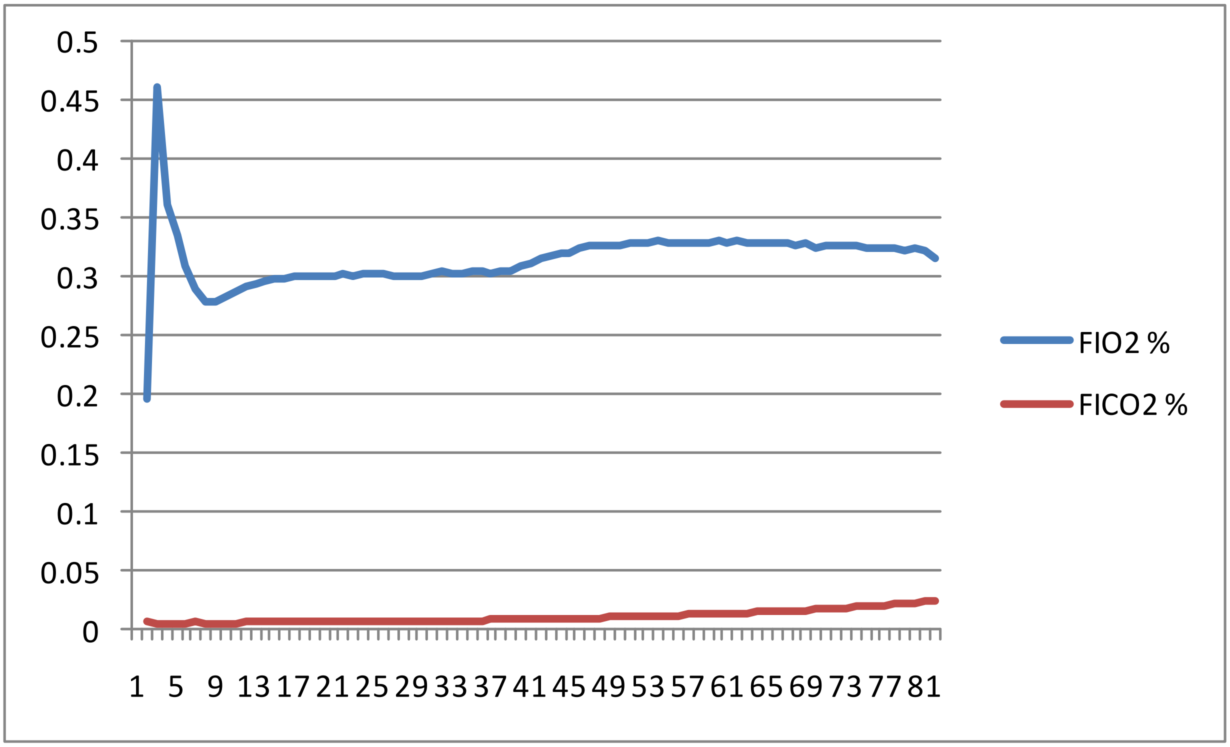
TPI has addressed the temperature issue by redirecting the breathing loop around the metal gas bottle, which acts as a heat sink (Figure 28). Testing in-house has demonstrated a 10-deg C drop in inhale temperature.

3. CO Filter Self Rescuer

TPI developed a new CO Filter Self rescuer (CO FSR) as a simpler, more compact unit that will affix to the SCSR breather tube.

Current CO FSR devices suffer from three major disadvantages:

- they breathe hot, up to 60-deg C (160-deg F)
- they are susceptible to moisture
- they are big and heavy (> 2-lbs) for a short duration system (1-hr)



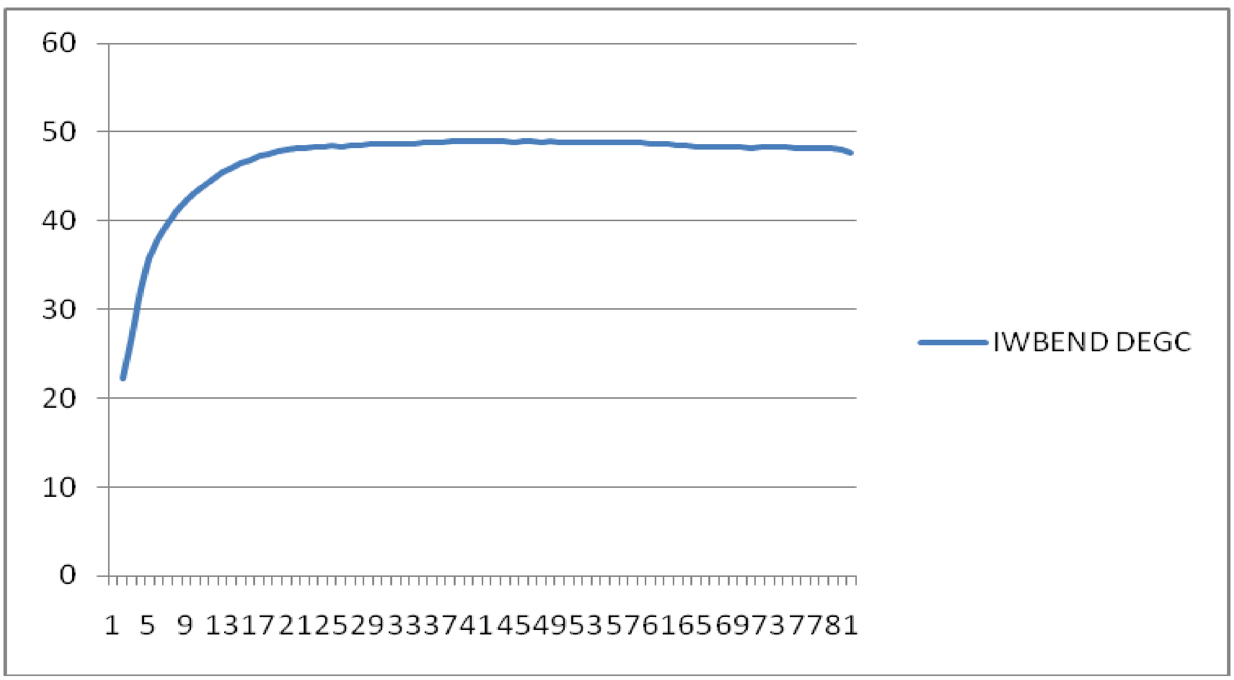
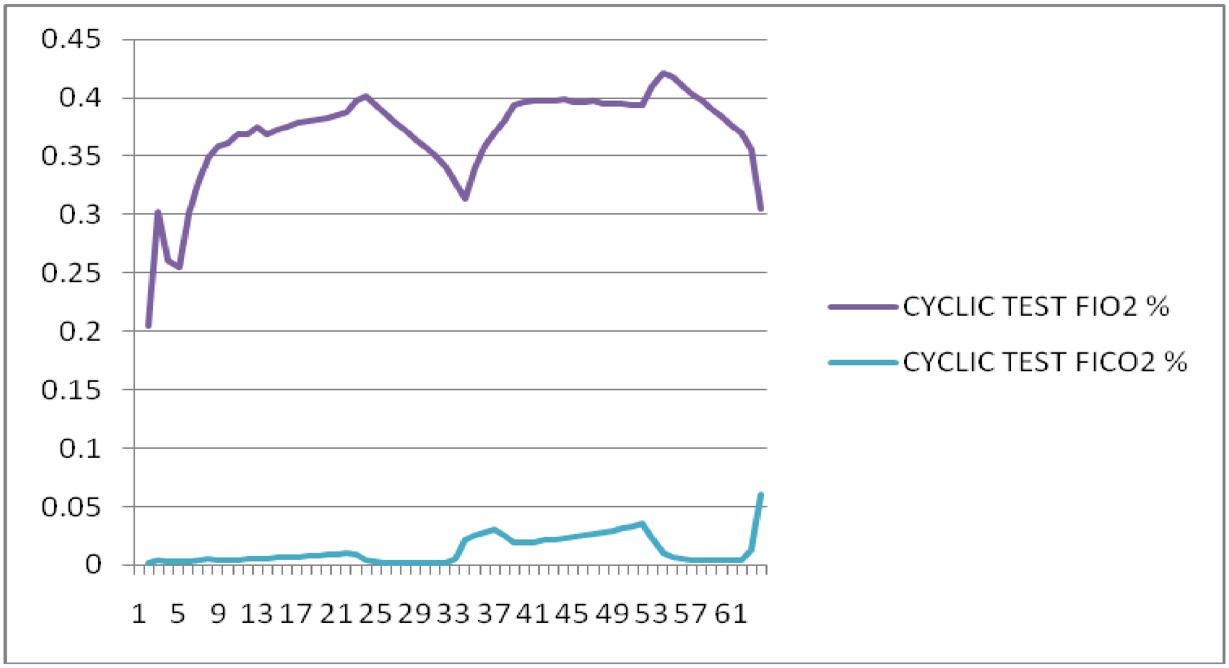


Figure 25: Phase II SCSR Capacity Test Results Of Fraction Inspired Oxygen and Carbon Dioxide (FIO2, FICO2) And Inspired Wet Bulb Temperature (IWBEND) Versus Time



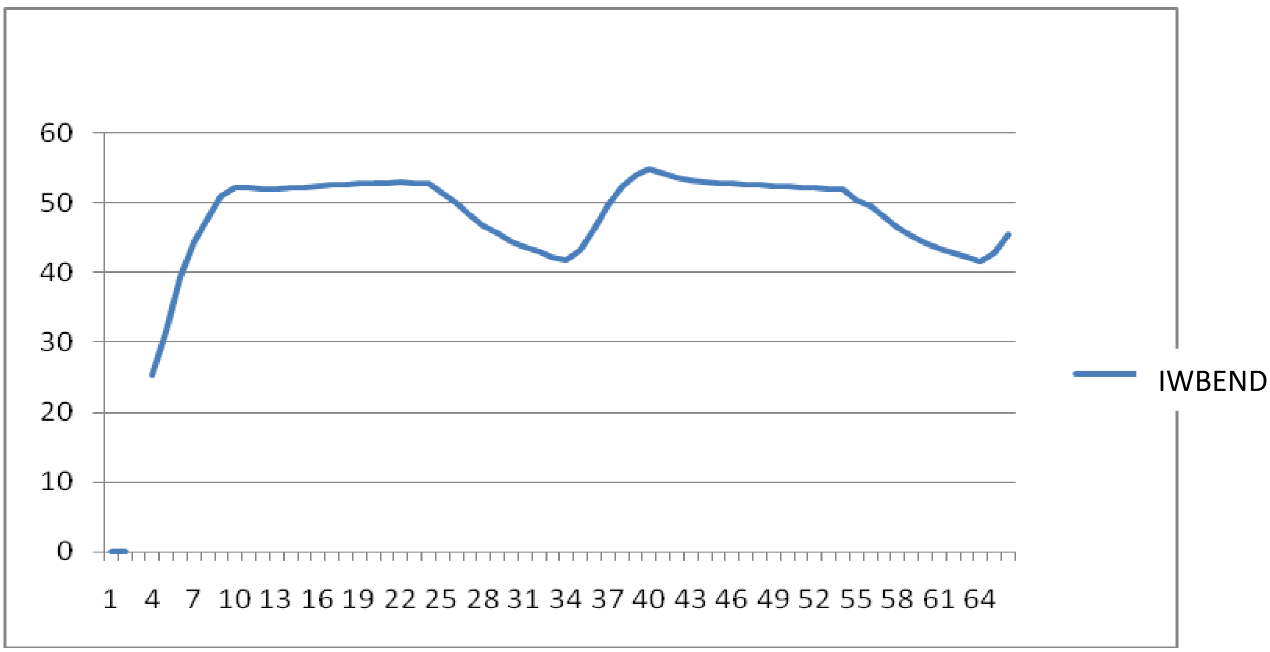
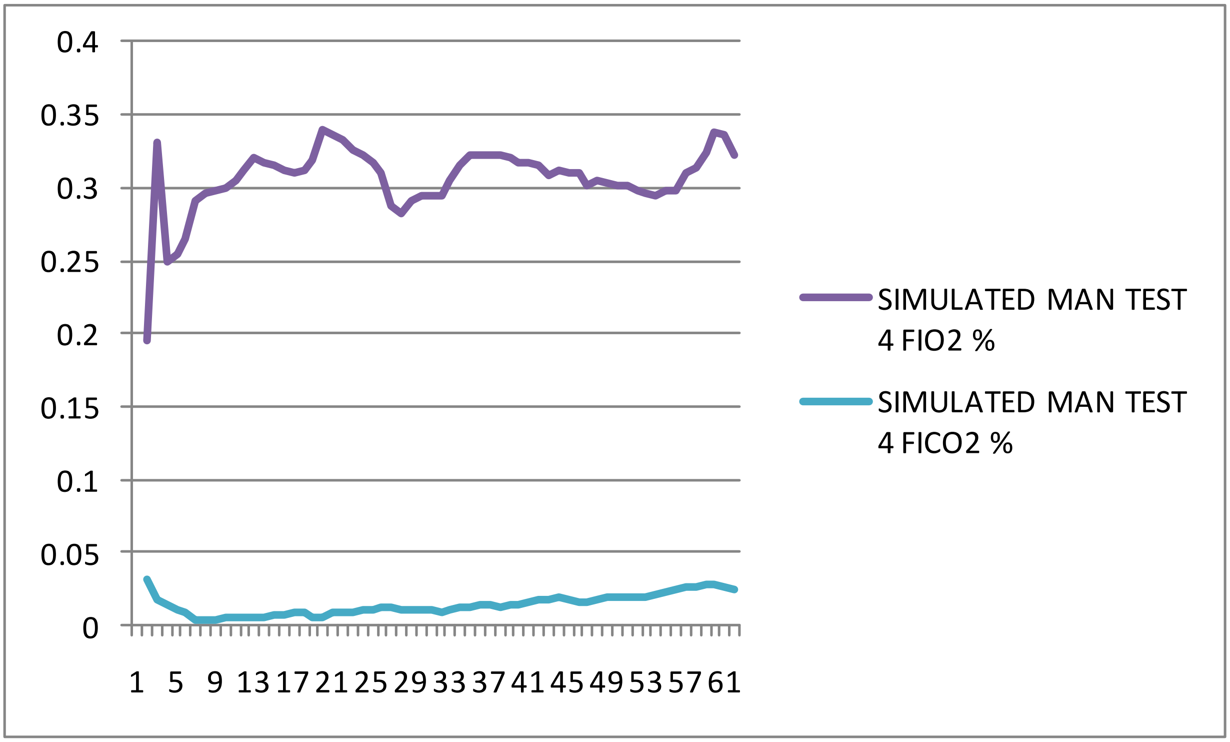


Figure 26: Phase II SCSR Cyclic Test Results Of Fraction Inspired Oxygen and Carbon Dioxide (FIO2, FICO2) And Inspired Wet Bulb Temperature (IWBEND) Versus Time



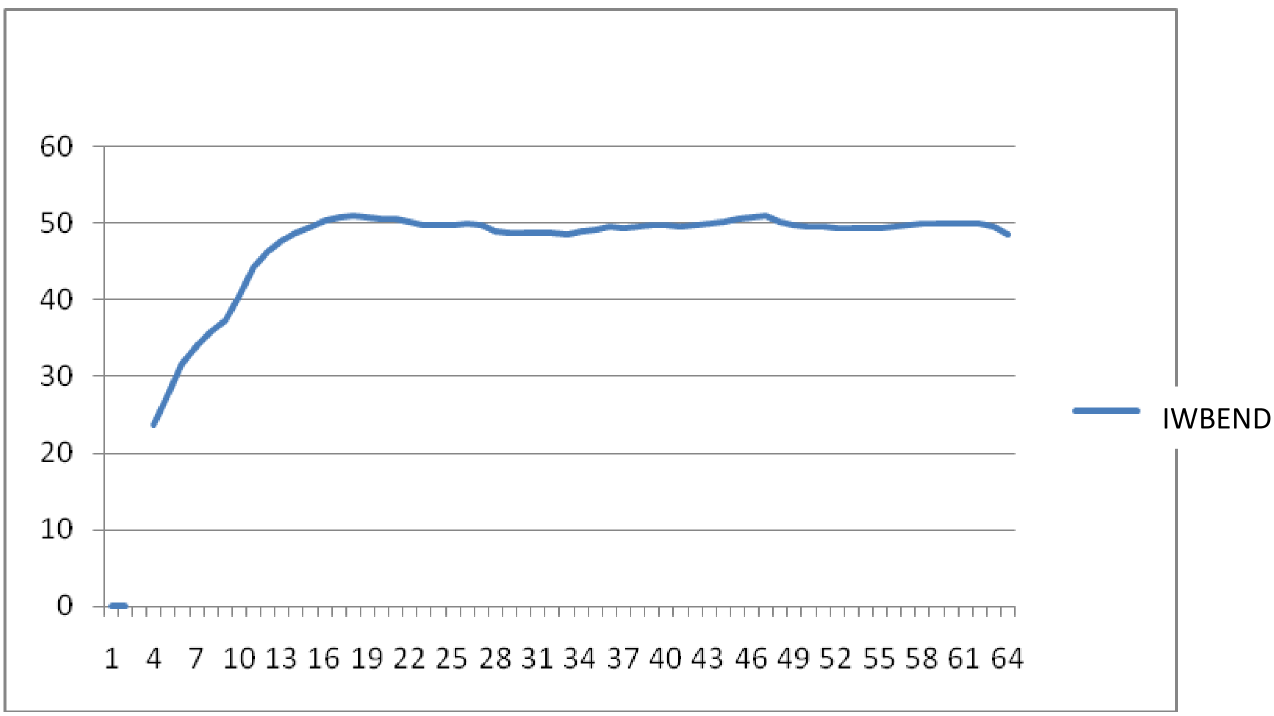


Figure 27: Phase II SCSR Simulated Man-Test 4 Results Of Fraction Inspired Oxygen and Carbon Dioxide (FIO2, FICO2) And Inspired Wet Bulb Temperature (IWBEND) Versus Time

Figure 28: TPI Addressed The Excess Heat Issue By Redirecting The Breathing Air Around A Large Heat Sink - The O_2 Cylinder

To address these limitations of current catalysts, new catalyst material based on precious metals are being developed both here in the US and overseas. These new materials have significant implications both for the user, more comfort and less distress, and the design engineer, with no requirement for sophisticated heat management techniques such as stainless steel mesh inserts, heat exchangers etc. in the breathing loop. Finally the new material has been demonstrated to be much more resistant to the effects of water or moisture in either the incoming ambient air (damp mine air) or the exhaled breath (also very moist) of the user. This last feature will simplify the FSR configuration since it may obviate the need for a pair of one-way inhale/exhale valves to control airflow and may permit simple pendulum breathing (one path in and out) although high breathing resistance out through the catalyst block may preclude this simplistic approach.

These new materials were the subject of TPI's investigations.

3.1 CO FSR Phase I Development

TPI held discussions with three vendors offering alternative materials to the standard hopcalite catalyst:

- 3M with a proprietary compound. The plan was for 3M to provide a small number filter packs incorporating their catalyst to TPI for evaluation in the SCSR program. The intent is that the filter pack will be configured with a standard NATO 40-mm thread to allow easy substitution between the 3M and other candidate technologies within the SCSR system (Figure 29). A series of quick-connects as described above for the manual and automatic valves will be built with the mating 40-mm thread to simplify test change-out. In the mid to long term (Phase II) TPI may be required to develop a custom housing for the 3M material as they have not yet decided to commit the resources necessary to produce a 'standard' product in support of this market.

- NuCat Ltd, a UK company, also with a proprietary compound. This material is coated onto an inert substrate as a unitary disk (Figure 30). The material is insensitive to humidity but is still sensitive to liquid moisture as in saliva. TPI developed a custom housing for this disk integrated with pre-filters and exhale breath diverters (Figure 31). The outer can will be fitted with a standard NATO 40-mm thread to allow easy substitution between devices. The system shown was evaluated empirically by TPI staff breathing through the breathing tube/connector/filter combination in both rest and at high work load conditions. Average pressure drops measured were:

- Inhale – 25-mm Hg
- Exhale – 10-mm Hg

Figure 29: 3M Has Supplied Prototype CO Filter Canisters For Evaluation

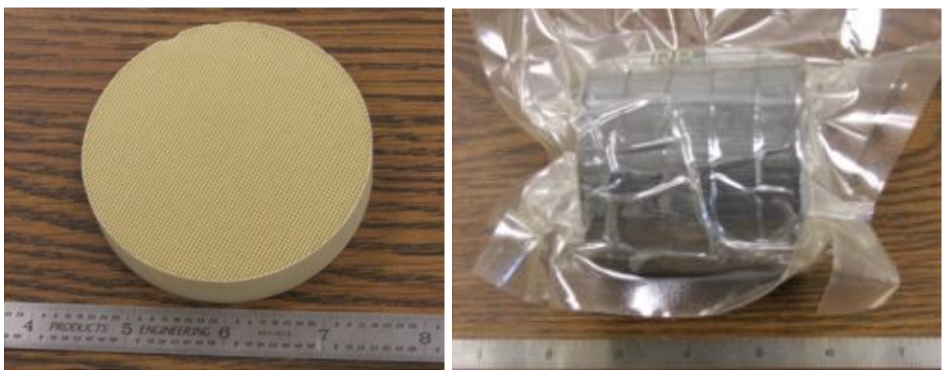


Figure 30: NUCAT Has A CO Catalyst Configured As A Unitary Disk And Shown Here As A Vacuum Sealed Pack Of Five

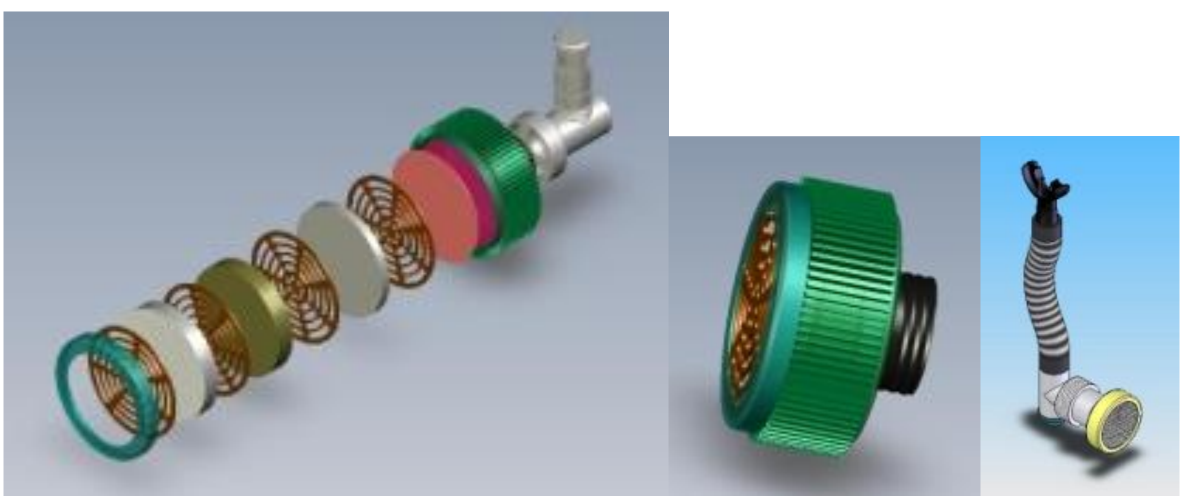


Figure 31: TPI Developed A Custom Housing For The NUCAT Disk Which Will Connect To The SCSR Breathing Tube

- Modern Safety Technologies, who have a palladium doped catalyst. MST's catalyst is approximately 50% efficient at CO removal and it does not need a desiccant layer like Hopcalite. The catalyst is granular (Figure 32), bulky & heavy—there will be a pressure drop that will prohibit suction of air through the media (it is currently used with a supplied compressed air delivery). Two pounds of catalyst in a 4 inch cylinder filled 10 inches deep will remove 1000 ppm of CO at 2 cfm flow rate to an output of 20 ppm. This results in 50 hours expected filtration with no degradation. Theoretically, one could increase the surface area and decrease the bed depth to allow for ease of inhalation with the same CO removal efficiency. The weight of the filter would be a consideration, but it could be belt-mounted for support. The catalyst contains nickel (0.8%) which is a carcinogen. The catalyst can become dusty through high air flow (compressed air) or manual handling. A HEPA filter post-catalyst is recommended to protect the user from inhaled dusts and maintain PEL exposures to carcinogens. There is no significant increase of post bed inhaled air temperature. The catalyst does not heat up like Hopcalite. MST typically tests with lower CO ambient concentrations. At 100 ppm CO inlet concentration, there was a 2 degree temperature increase at the outlet / inhaled breath. MST has tested up to 2000 ppm CO with no significant temperature differentials. At temperatures below 68 degrees F the CO adsorption efficiency will drop substantially. The inlet air temperature appears to be more of a factor than the outlet (breathable) air temperature. MST suggests keeping the filter inside clothing to utilize body heat to maintain inlet air temperature - probably not workable in our application.

Figure 32: MST Has A Granular CO Catalyst That Is Much More Tolerant To Humidity Than Hopcalite Is

All these compounds are insensitive to humidity which is one of the major limitations of hopcalite.

The granular nature of the MST material made it far less attractive for a high vibration application especially when the dust expelled is a carcinogenic. TPI did not pursue that material further.

3.2 CO FSR Phase I Testing

The CO filter packs were tested by NIOSH for breathing resistance and CO reduction. Whilst only one filter each from 3M and NUCAT were tested while TPI was present the initial results were very encouraging.

Breathing resistance results were:

- 3M filter pack (including all pre-filters and exhale valve etc.) – 2.36-iwg
- NUCAT module (catalyst and downstream dust filter only) – 0.16-iwg

CO reduction performance is summarized in Figures 33 and 34. Both catalysts performed far better than hopcalite equivalents in terms of both CO reduction and breathing air temperature.

3M CO FILTER

TIME (Min)	UP-STREAM TEMP (Deg C)	UP-STREAM R.H. (%)	DOWN-STREAM TEMP (Deg C)	DOWN-STREAM CO CONC (PPM)
0	24.8	98.1	24.8	0.0
5	24.8	96.9	42.2	3.6
10	24.4	96.6	43.8	3.3
15	24.5	97.8	44.5	3.5
20	24.3	95.4	45.1	3.5
25	24.6	96.5	46.5	3.5
30	24.3	95.9	46.8	3.4
35	24.5	96.0	46.8	3.6
40	24.5	93.9	47.0	3.5
45	24.8	92.6	47.1	3.7
50	24.5	95.2	47.3	3.6
55	24.6	93.1	47.2	3.8
60	24.7	94.4	47.2	3.8
65	24.6	94.5	47.1	3.8
70	24.7	93.2	47.2	4.0
75	24.5	94.2	47.0	3.9
80	24.5	92.4	46.8	3.8

Figure 33: The 3M Filter Performed Extremely Well

3.3 CO FSR Phase II Development

TPI had further discussions with both catalyst manufacturers to better define their products production status and readiness for market plus available technical support for the development. Due to the limitations of the logistics infrastructure associated with supporting these devices in the field, TPI decided to concentrate on 3M as the CO FSR partner.

TPI worked closely with 3M to develop the optimal CO FSR in terms of performance (CO oxidation), operational flexibility (use as part of the SCSR, as a stand-alone device, or as an add-on to existing mask systems) and packaging (sized and configured for storage in/on the SCSR, as a ‘pocket’ device, etc.).

NUCAT CO FILTER

TIME (Min)	UP-STREAM TEMP (Deg C)	UP-STREAM R.H. (%)	DOWN-STREAM TEMP (Deg C)	DOWN-STREAM CO CONC (PPM)
0	24.6	95.2	27.7	
5	24.3	97.2	40.2	2.7
10	24.7	93.8	43.0	2.7
15	24.3	96.9	43.7	2.8
20	24.3	96.9	44.1	2.8
25	24.3	96.7	44.3	2.8
30	24.3	97.2	44.5	2.9
35	24.3	97.2	44.4	2.9
40	24.5	93.8	44.7	2.8
45	24.4	96.1	44.7	2.9
50	24.2	96.2	44.4	2.9
55	24.3	95.7	44.6	3.0
60	24.1	97.7	44.4	2.9
65	24.4	94.0	44.6	2.9

Figure 34: The NUCAT Catalyst Was Even Better

Figure 35 shows the initial concept for this cartridge. As shown the device is a unitary cartridge that incorporates the inhale valves within the plenum visible down the throat of the male tube connection. The universal breathing tube stud shown means that a variety of devices can be attached (the SCSR docking connector, stand-alone breathing tube, etc.) to the basic cartridge.

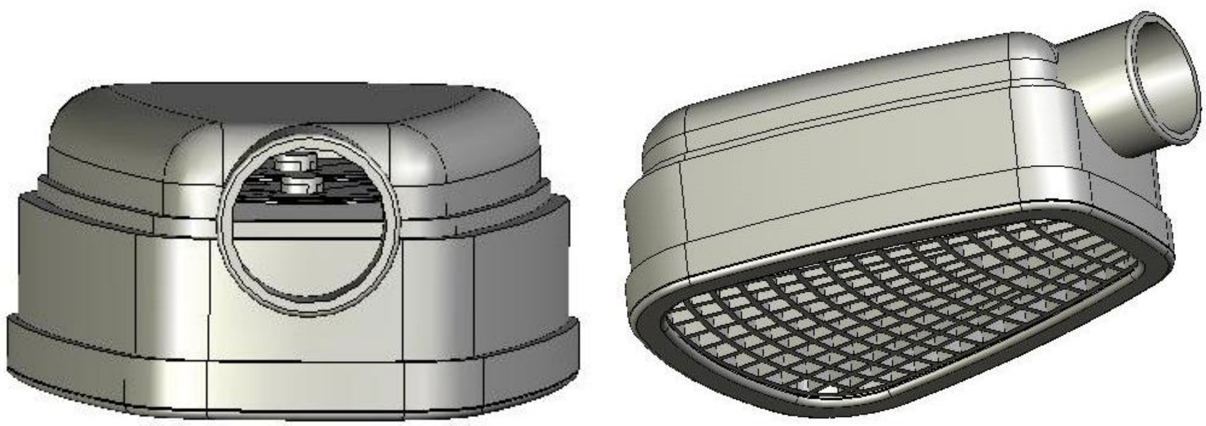


Figure 35: The Initial Concept For The CO FSR Cartridge Incorporates Inhale Valves And A Universal Breathing Tube Connection Stud

We have since amended this design to remove the inhale valves. The intent is to make the device as universal as possible to allow it to be utilized as an add-on to a variety of respirator/mask devices. The new approach then for the SCSR is to utilize a plug-in module fitted with the exhale valve between this cartridge and the breathing tube/SCSR connector. Air flow will be managed by the back-pressure in the cartridge which will result in preferential flow of the exhale stream out of the exhale valve rather than through the cartridge.

The concept is to package the CO-FSR as both a stand-alone ‘pocket’ device and also retain the potential to house it within an extended bottom cover on the SCSR (Figure 36). The CO FSR would be packaged and sealed within its own long term storage pouch. In the SCSR application this cartridge would be sealed in the SCSR bottom cover like a ‘TV Dinner’.

Figure 36: The CO-FSR Will Be Fitted Into An Extended Bottom Cover On The SCSR And Sealed Like A ‘TV Dinner’ For Long Term Storage

3.4 CO FSR Phase II Testing & Rework

NIOSH tested these prototype cartridges. Table 1 shows the detailed results for one such test – in this case a 10,000-ppm CO input at 25-deg C. As shown the catalyst worked superbly with a CO level in the downstream flow averaging just 5-ppm.

Test Time (min)	Upstream Temp (deg. C)	Upstream RH (%)	Downstream Temp (deg. C)	Upstream Conc. (ppm)	Downstream Conc. (ppm)
0	24.9		26.9	10003	1.7
5	24.9	92.4	91.5	10003	2.4
10	24.8	93.9	95.8	10003	3.0
15	24.8	94.6	94.1	10003	3.9
20	24.8	94.8	93.4	10003	4.4
25	25.0	94.7	92.5	10003	4.9
30	24.9	92.8	91.7	10003	5.1
35	24.9	93.9	91.5	10003	5.3
40	24.9	96.5	91.6	10003	5.8
45	24.8	97.7	90.7	10003	6.0
50	24.8	98.0	90.8	10003	6.0
55	24.8	94.4	90.6	10003	6.2
60	24.9	94.1	90.6	10003	6.5
65	24.9	94.2	90.6	10003	6.6
70	24.9	92.4	90.4	10003	6.8
AVG	24.9	94.6		10003	5.0
MAX			95.8		6.9

Table 1: 10,000-Ppm CO In Is Catalyzed To Less Than 7-Ppm Out

Table 2 summarizes the three test protocols run by NIOSH (3,000-ppm at 25-deg C, 5,000-ppm at 0-deg c, and 10,000-ppm at 25-deg C). As shown – at no time does the downstream concentration go above 7-ppm and the maximum downstream temperature remains below 100-deg C.

Sample #		Upstream Temp (deg. C)	Upstream RH (%)	Downstream Temp (deg. C)	Upstream Conc. (ppm)	Downstream Conc. (ppm)
1	AVG	24.9	94.8		3007	2.9
	MAX			51.1		4.0
2	AVG	24.7	94.8		3007	0.7
	MAX			49.4		1.4
3	AVG	24.7	94.8		10003	3.3
	MAX			91.3		5.4
4	AVG	24.9	94.6		10003	5.0
	MAX			95.8		6.9
5	AVG	0.8	83.2		4991	0.3
	MAX			51.9		0.6
6	AVG	2.5	93.1		4991	0.0
	MAX			61.2		-0.8
7	AVG	1.2	92.2		4991	3.6
	MAX			53.9		4.0
8	AVG	2.1	94.5		4991	0.8
	MAX			56.8		1.2

Table 2: The CO FSR Was Tested Against 3,000, 5,000 And 10,000-ppm CO

One of the potential issues identified in the performance testing of the CO FSR was breathing air temperature. NPPTL completed a series of 10,000-ppm CO tests in Sep 08 which resulted in the breathing loop air temperature exceeding the allowable limits (Table 3).

Sample #		Upstream Temp (deg. C)	Upstream RH (%)	Downstream Temp (deg. C)		Upstream Conc. (ppm)	Downstream Conc. (ppm)
				Thermistor/ Therm.cple	Mercury Therm.		
360	AVG	26.6	70.7			10000	1.0
INVALID TEST	MAX			105.8			---
361	AVG	23.7	94.1			10000	1.8
	MAX			96.7			4.2
362	AVG	23.9	94.2			10000	1.8
	MAX			121.0	97		2.8
363	AVG	23.6	96.7			10000	2.7
	MAX				113		3.6

Table 3: The Latest Testing Of The CO FSR Highlighted The Need For Thermal Management Of The Breathing Air

The units, as tested, incorporated no thermal management techniques. TPI/3M developed a cartridge to mouth-piece connector that features the exhale valve and integrated heat exchange surfaces designed to dump heat pulled from the air stream to the environment. Figure 37 shows the connector attached to a stand-alone CO FSR.

Figure 37: The Exhale Valve Housing Has Been Designed To Dump Heat

TPI tested the performance of this device by channeled input air at 3-cfm and at a controlled temperature (100-deg C and 115-deg C) through the valve and measuring the temperature of the output air. Figure 38 shows the test results for input air at 115-deg C and 100-deg c respectively. As seen, for all tests the outlet temperature tracks the inlet temperature nicely.

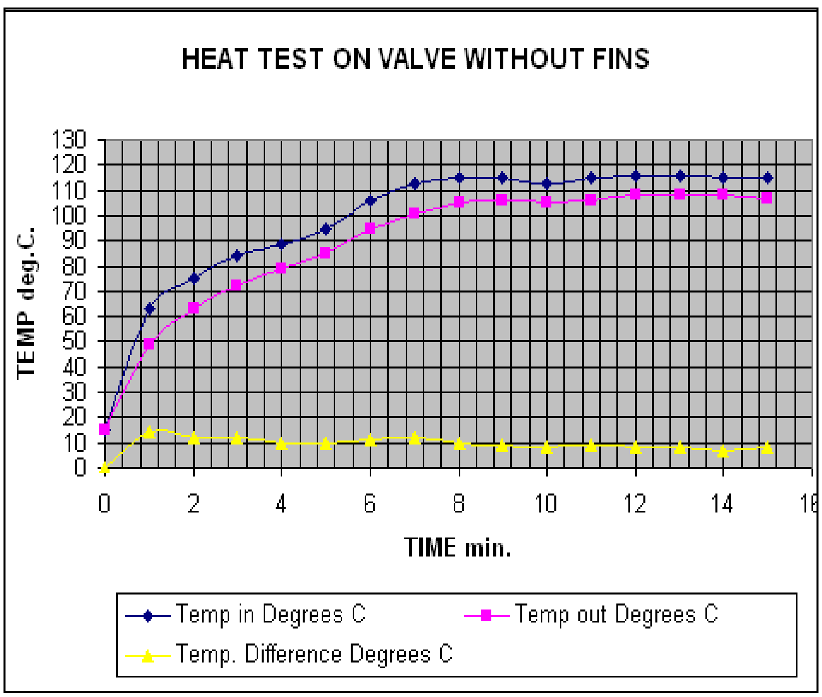


Figure 38: The Design Reduced Outlet Air Temperature Significantly From The 115-Deg Inlet

Figure 39 shows the device (in x-section) fitted with exhale valve and for interface to the docking connector. Figure 40 shows the two faces of the device as assembled and including NIOSH required labeling.

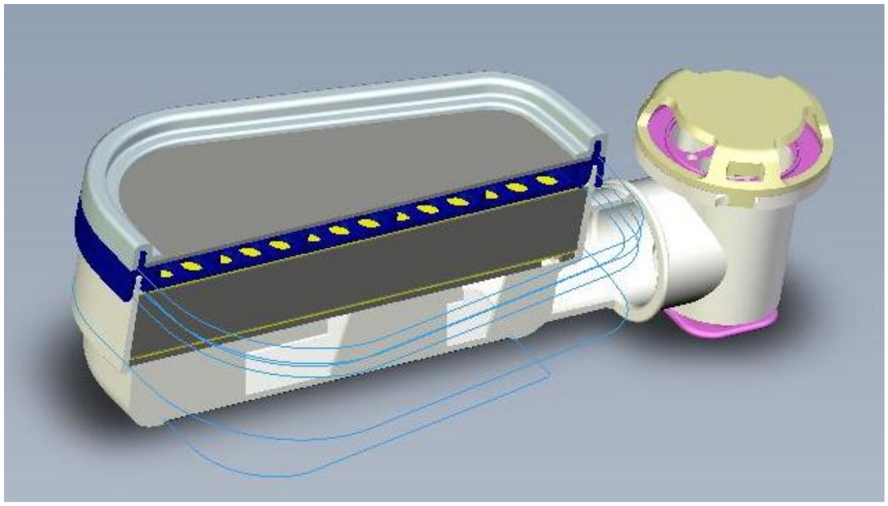


Figure 39: Design Of The CO FSR For Integration Into The Hybrid SCSR Is Complete

Figure 40: The CO FSR Is Ready For Production, Including Requisite Labeling

TPI/3M fabricated a trial batch of ‘finished’ and packaged CO FSR, seen in Figure 41. Easily seen in that figure are key features of the intermediate housing that holds the CO FSR itself and that in turn sits inside the larger ‘hybrid’ bottom cover of the SCSR. The pull tabs can be seen on the top film surface to peel the cover away. The various features on the bottom of the housing are for locating and restraining the filter canister and desiccant packs fitted within.

Figure 41: TPI/3M Are Assembling The CO FSR Units For The Hybrid SCSR

4. Breathing Air Monitor

The miner needs a system to indicate to them when and which of the two breathing devices (SCSR and CO FSR) devices they should use, if either is needed, by analyzing the atmosphere the miner is in. This device could be called a Breathing Air Monitor (BAM). Several companies make small electronic gas sensors that could fulfill this requirement and that are extremely capable with real time digital readouts, event log for the past 30-days, can connect to a PC via IR link, use rechargeable Li batteries, etc. These capabilities make the items expensive. They also commonly use sensor cells with a 2 year life and are then disposed of. Finally, most are single gas sensors so two would be needed for this application. Because of their high capital cost and relatively short life these items are high price consumables – not the answer that the industry is looking for.

The Breathing Air Monitor acts as an alarm for the user alerting them of two hazardous conditions:

- Low O_2 level (<19.5%)
- High CO level (>50-ppm)

This alarm will allow the user to optimize their use of the SCSR's limited O_2 supply.

4.1 BAM Phase I Development

The original version of the device utilized discrete CO and O_2 sensors and a high-tech rechargeable Li-Ion battery (Figure 42). The device was not fitted with any of the digital read-out, data logging, PC communication modules etc that are available on the conventional gas monitors. Instead it was fitted with a minimalist display (3 LEDS – one for power, one for O_2, one for CO) and audible and vibratory alarms.

(a) *(b)* *(c)*

Figure 42: TPI Assembled A Breathing Air Monitor Based On Discrete CO (a) and O_2 (b) Gas Sensors And High Tech Rechargeable Batteries (c)

The alarm trip point for the O_2 sensor is fairly straight forward – any drop below 19.5% is a hazardous environment.

The CO trip pint is not so clear cut. Different agencies specify different concentrations and exposure times as acceptable or hazardous. As a compromise, TPI will, a least initially, set this sensor to alarm at an exposure level of 50-ppm.

TPI completed the prototype circuitry (Figure 43) that incorporates O_2 and CO sensor each with a 5-year functional life. The battery pack, seen in the top right of the circuit in the Figure, while rechargeable will have approximately a 2-year life but be replaceable by the user.

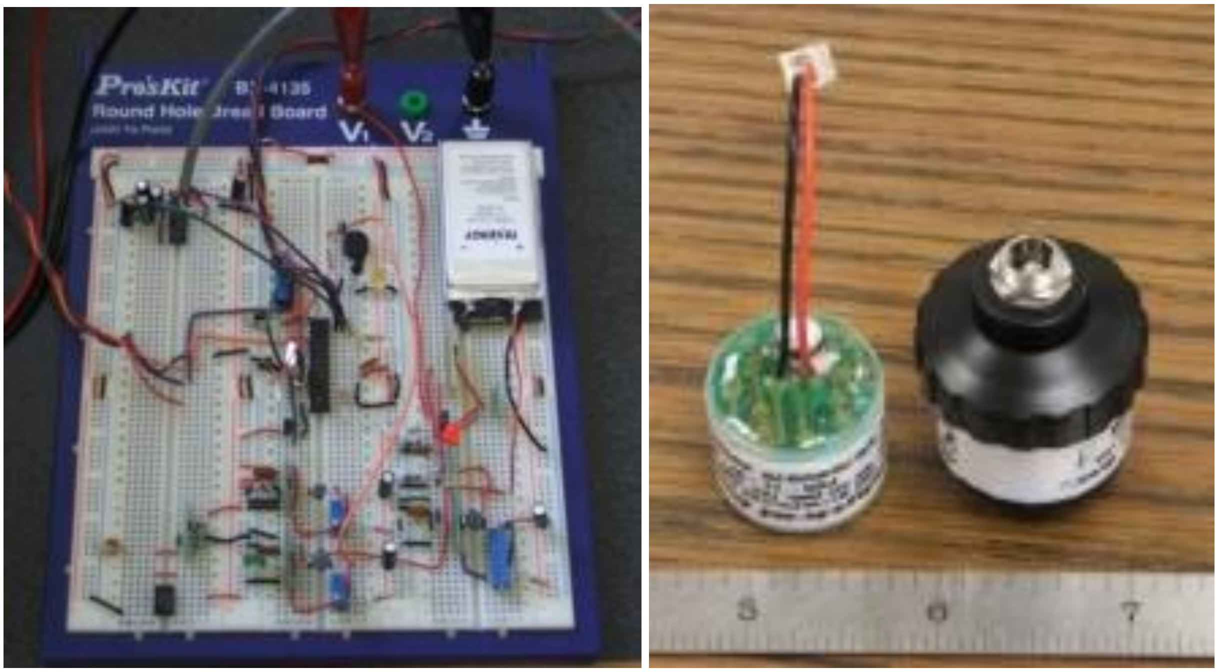


Figure 43: TPI Completed A Prototype Circuit For The BAM With O_2 And CO Sensors With A 6-Year Functional Life

The second generation system (Figure 44) is powered by an 8.7Vdc rechargeable Lithium-Ion battery pack, is self calibrating and is designed to monitor O_2 levels between 0% and 25% and CO levels to 500-ppm in ambient air.

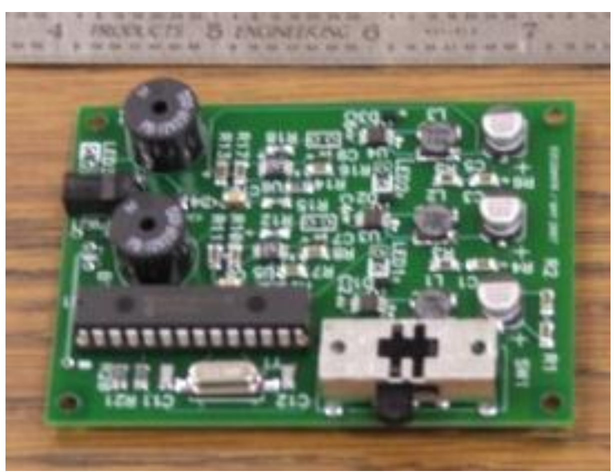


Figure 44: The Second Generation BAM PCB Has Been Fabricated And Populated

The preliminary testing for the Oxygen sensor portion of the BAM was completed with very good results. Six sensors with varying amplified output voltages 3.3 – 3.6Vdc (3.5 – 3.6 typical) were tested including the 'self calibration on power-up' function. An alarm activation 19.45% concentration level was the target. All six sensors alarmed between 19.20 – 19.75%.

TPI then packaged the PCB and sensors etc., into a prototype case (Figure 45) for NIOSH tests. The simplified BAM monitors the real time concentration of both threat gasses and utilizes a simple, low cost LED/audible/vibrating alarm structure. It also has a 5 year sensor life. These features make the device a much more economical solution for the mining industry. This generation of BAM still suffers from the same limitations as the other options in that it must be carried by the miner and must be recharged after each shift.

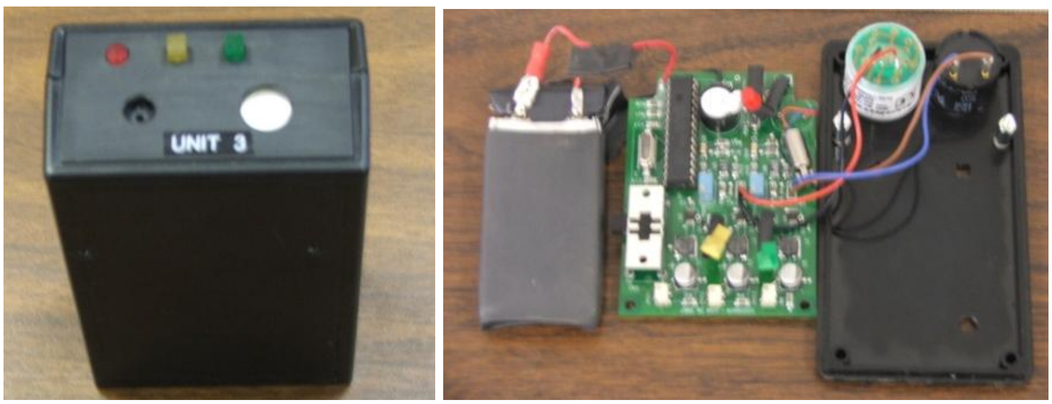


Figure 45: The TPI BAM Is A Dual Gas, Simple Alarm Device With A 5 Year Life

4.2 BAM Phase II Development

To address the issues identified in Phase I TPI tabled the option of integrating the BAM into the miner's cap lamp (Figure 46). This approach obviates the logistic burden on the miner of 'another thing to carry', ensures that the sensor device is always on the miner, that it has ample power and also offers the potential to use the lamp itself as an additional alarm device (by flashing the light on and off).

Figure 46: Integrating The BAM Into The Miner's Lamp Addresses Carriage, Recharging And Alarm Issues

The BAM could be configured as a plug-in module that would be installed between the lamp housing and front cover (as seen in Figure 47). This approach has already been taken by some of the miner lamp manufacturers as a solution to the upgrading of their product. For example, NL Technologies has an LED module to replace the standard halogen bulb set up. This module is a plug-in replacement for the existing bulb configuration - remove the current cover and bulb holder module, insert the LED module, replace the cover. A similar approach would allow the BAM to be installed behind the bulb/LED assembly as a modular insert.

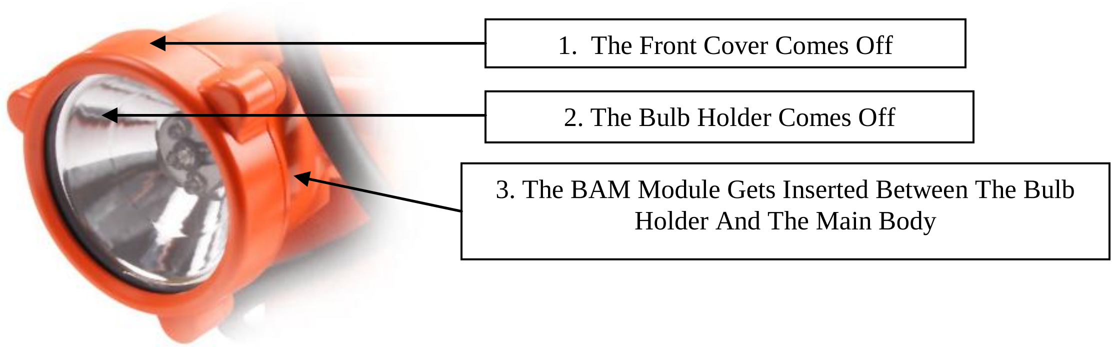


Figure 47: The BAM Could Be Configured As A Plug-In Module That Integrates Into The Miner's Lamp Between The Current Front Cover/Bulb Housing And The Main Body

This approach offers many very significant advantages over the BAM as a stand-alone device:

- since it is integrated into the miners light it will always be on the miner regardless of their duty, what machinery they are operating and what other equipment they must carry
- the Lamp-BAM would run off of the lamp battery which will significantly reduce the size and weight of the BAM as its integral battery would no longer be required
- an additional alarm function could flash the miner lamp on and off - a signal sure to get the wearer's attention regardless of what else is going on around them
- the BAM power source (the lamp battery) would always be supported by a fully charged battery at the start of the shift since the lamps are always charged.

The beauty of integrating the BAM into the lamp housing rather than depending on an accessory plug is that it can be applied to all the legacy hardware that is currently in place. The only new investment is in the actual plug-in modules. These modules would be tailored to all the most common lamp designs in use. The new configuration would require MSHA certification of the system but since companies such as NL Technologies have already been down this path to certify their LED replacement modules it is a reasonable assumption that the task is manageable.

We prototyped the Phase II BAM (Figure 48) and the following summarizes its functions and features:

- Real-time monitor of O_2 Gas Levels
- Real-time monitor of CO Gas Levels
- Set points for both SOFT and HARD alarm conditions
    - Soft Alarm would indicate Gas Level is approaching critical level
    - Hard Alarm would indicate Gas Level has reached or past a critical level
- Hysterisis values for both monitors to prevent alarm flip-flopping

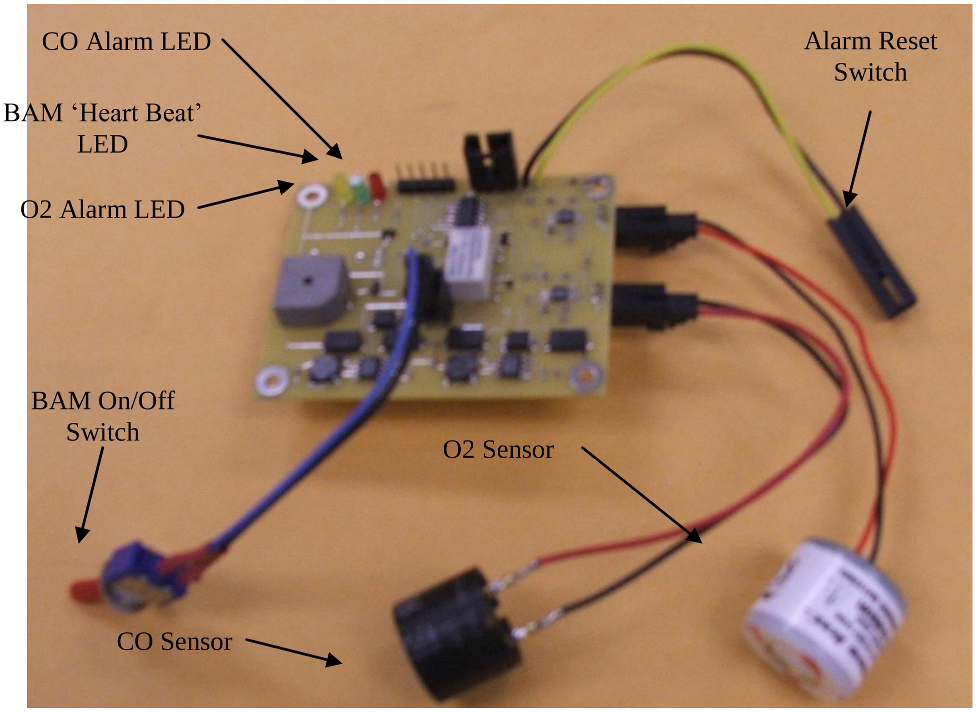


Figure 48: Prototype Assembly & PCB (LEDs To Be Mounted Off Board On Final Product)

- Flashing Green LED to show system is functioning
- Several Alarm Indicators
  - Flashing Yellow LED for low O_2 alarm
  - Flashing Red LED for high CO alarm
  - Vibrator for either alarm condition
  - Buzzer for either alarm condition
  - Flashing of Main Headlamp for alarm condition
  - Rate of pulsing for LEDs, Vibrator, Buzzer and Lamp is faster for Hard alarm, Slower with longer dwell between for Soft alarms
- Fail-safe Normally Closed Relay for Main Lamp control
  - Always normal lamp operation if alarm monitor is off or incurs a fault
- Main power switch to activate or disable monitor operation
- Reset Button
  - Suppresses alarm indicators for up to 900 seconds (Red and Yellow LEDs still actively indicate alarm conditions)
- Shut-up Voltage Regulators to allow for operation on battery voltages down below 2 Volts
- Low Pin-Count PIC Microcontroller using internal 8 MHz oscillator
- Serial Communication Link for unit setup:
  - Setting / adjusting / querying of all alarm conditions
  - Monitor of sensor outputs
  - Set and Query of unit SN
  - Set and Query of unit Date of Manufacture
  - Query of product revision information

After reviewing the concept with Koehler manufacturing the emphasis has switched to integrating the BAM into the lamp battery housing as a plug-in module that inserts between the existing black battery cap seen in Figure 49 and the red battery body and mounting directly to the battery terminals. This approach:

- simplifies the packaging of the circuitry
- opens up the opportunity for simple retro-fit to legacy systems employing either incandescent or LED ‘bulbs’
- can be applied seamlessly to both legacy lead-acid and new Li polymer batteries

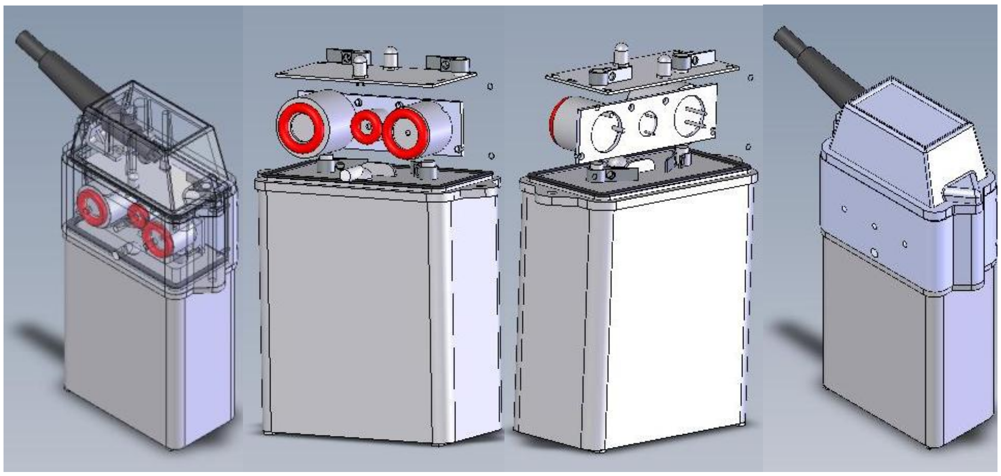


Figure 49: TPI And Koehler Are Developing A Design That Integrates Into The Existing Battery Housing

With this approach in mind TPI has redesigned the circuit board to better fit this volume. TPI fabricated a quantity of the second generation circuit boards (Figure 50). These boards (just 1.3-in x 2.6-in) will integrate into the Kohler lamp battery housing as an intermediate module that is inserted between the battery and cover (Figure 51). This will allow field retro-fitting. The board/device is potted for protection (Figure 52). A change to the approach of the BAM operation is being studied where the unit is switched on automatically when the lamp is activated. This would avoid the need for a separate on/off switch for the BAM and potentially enhance its ‘always there’ status.

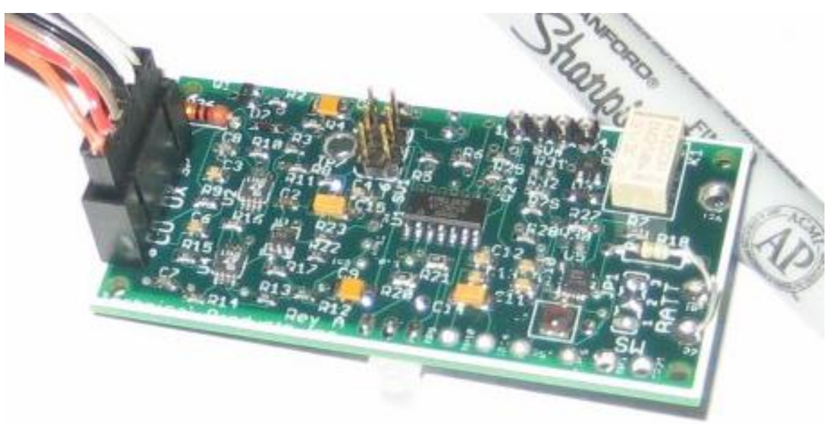


Figure 50: The Second Generation PCBs For The BAM

Figure 51: The BAM Module Is Easily Retrofitted In The Field – It Simply Installs Between The Kohler Battery And Cover

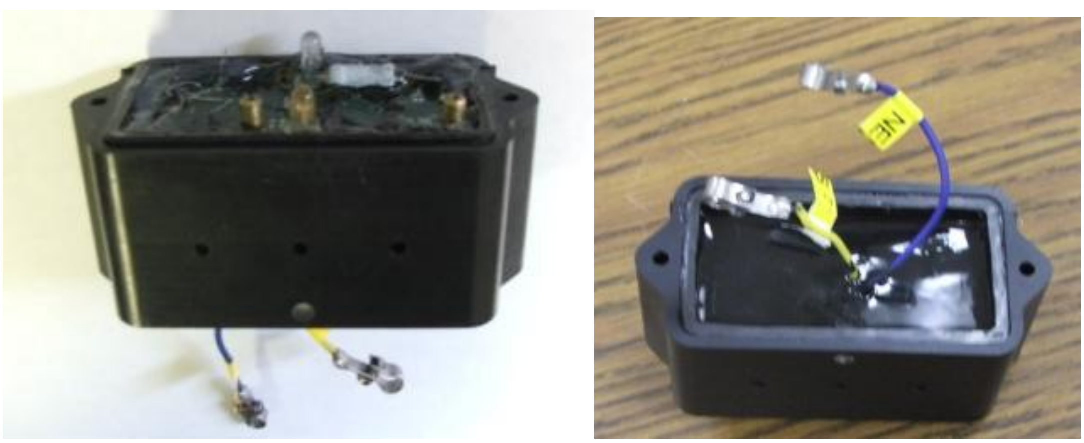


Figure 52: The BAM Components Will Be Potted For Protection From The Environment And To Ease The Intrinsic Safety Concerns

5. Summary

By the end of the Phase II of this effort TPI had demonstrated prototypes of all three products that were the objectives of the project:

- A 60-min O_2 SCSR (Figure 53) incorporating the capability to dock to alternate breathing devices, including a hybrid device with integral CO FSR.

- A new CO FSR (Figure 54) with significantly improved performance over the in-service item and configured as both an add-on module for the SCSR and as a stand-alone CO FSR.
- A BAM (Figure 55) that provided the miner the basis for their selection of O_2 SCSR, CO FSR or ambient atmosphere breathing.

The project did not result in certified devices by the completion of the contract but TPI has negotiated licensing agreements for these three products and they are being prepared for certification submission by the licensee.

Figure 53: TPI's 60-Min O_2 SCSR Incorporating The Capability To Dock To Alternate Breathing Devices

Figure 54: TPI's CO FSR Configured As Both An Add-On Module For The SCSR And As A Stand-Alone Device

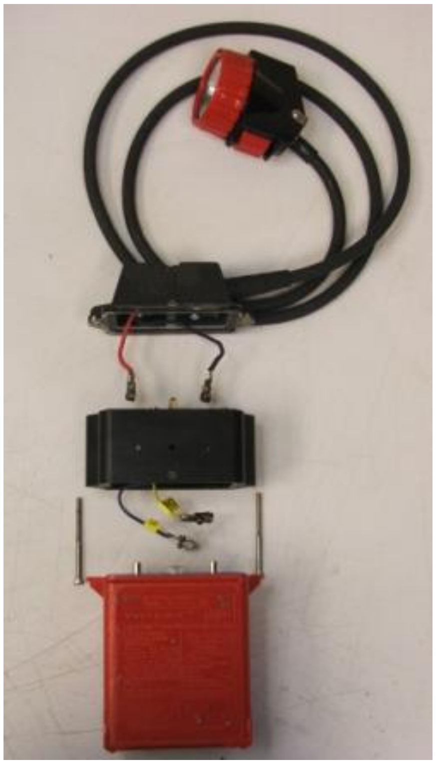


Figure 55: TPI's BAM Provides The Miner The Basis For Their Selection Of O_2 SCSR, CO FSR Or Ambient Atmosphere Breathing

APPENDIX I

REGULATOR DEVELOPMENT

There are two regulators integrated into the SCSR. The 1st stage regulator reduces the high pressure of the O_2 inside the gas bottle from up to 3,000-psi down to around 145-psi. The 2nd stage regulator takes that pressurized flow and provides it at ambient pressure to the breathing loop.

The 2nd stage regulator is a demand only device fitted with a manual purge valve. Figure I-1 shows a prototype 2nd stage demand regulator from the Phase I effort incorporating a fill port, pressure reading gauge port, purge button, connection to breathing tube, and single stage pressure reduction/supply valve (shown as separate item in that Figure).

Figure I-1: The Prototype Regulator Incorporates A Single Stage Demand Valve

This COTS regulator was modified to reposition the fill port and pressure gauge and then was integrated onto a small O_2 bottle. That bottle/regulator assembly was then integrated into a prototype scrubber housing. That unit formed the heart of the Phase I cylindrical unit with toroidal scrubber (Figure I-2).

Figure I-2: Regulator Components Integrated Into The New SCSR Assembly

The Phase II peanut shaped unit required further significant modification to the regulator (Figure I-3 and I-4).

- The 1st stage unit now incorporates an automatic spring loaded on/off valve;
  - When the SCSR is within its container this valve is shut and so mechanically isolates the pressure within the O_2 bottle from the regulator mechanism. This allows the device to be stored for an extended period without stress on the regulator components, minimizing the

potential for leaks caused by component deterioration or deformation under the pressure load.
    - When the outer housing is removed it pulls a release pin from the spring mechanism which automatically opens the valve in a controlled manner to supply O_2 to the wearer while ensuring that the high pressure flow is initiated in a safe, gradual manner.
- The 2nd stage regulator has been integrated with the flow plenum that manages the distribution of airflow over and through the CO_2 scrubber.

What is not shown are the various flexible hoses that connect the two regulator stages (its location is obviously between the two barbed fittings shown) and the hose connecting the second stage to the docking connector and on to the breathing tube. These are omitted to allow clear viewing of the remainder of the assembly.

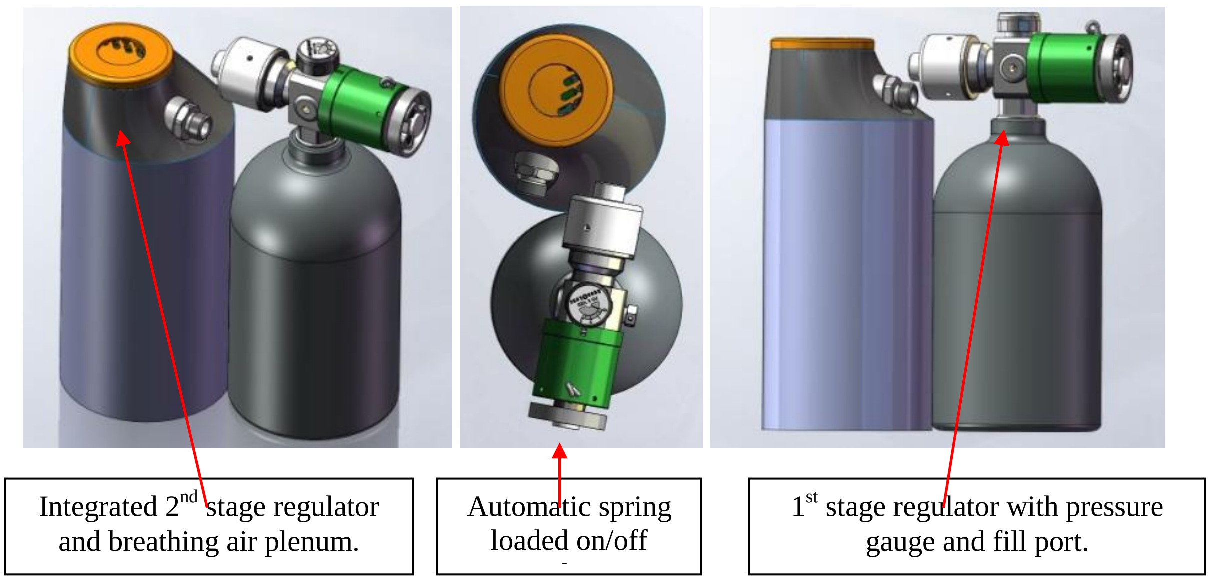


Figure I-3: The New SCSR Design Incorporates A 1st Stage Regulator With Integral Automatic On/Off Valve And A Combined Breathing Air Plenum - 2nd Stage Demand Regulator

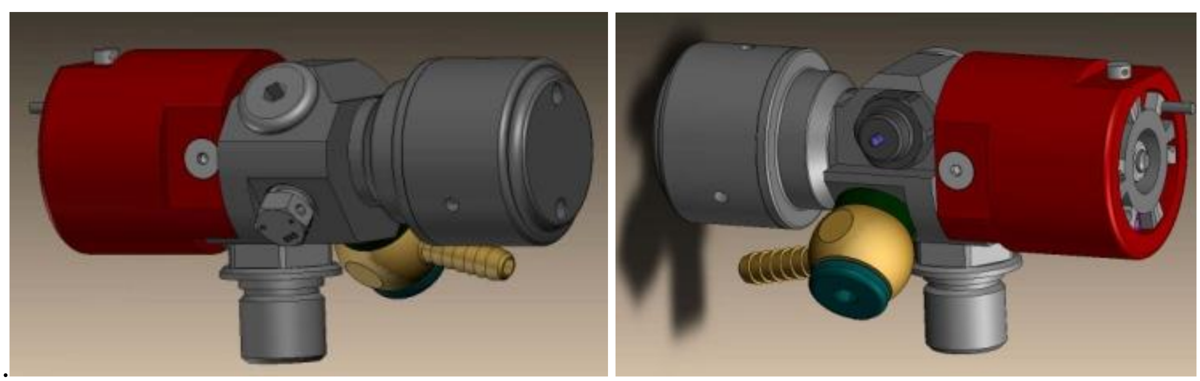


Figure I-4: This Generation Of 1st Stage Regulator Incorporates The Pressure Pin Gauge, Fill Port, Primary Pressure Reduction Mechanism And Automatic 'On' Valve Into A Small Footprint Integrated Unit

Figure I-5 shows the details of the latest iteration of that 1st stage regulator. This device incorporates all the features described previously plus features an automatic valve that isolates the regulator components from the high pressure gas until the SCSR is opened. This approach optimizes the system for an extended shelf life and also obviates the need for the user to manually turn on the gas flow. With this device once the SCSR is opened the gas flow to the second stage begins automatically. Since this second stage is a demand regulator it only provides O_2 to the user when the pressure in the breathing loop drops low enough to trigger the valve response. If there is no demand there is no flow so when the user is not breathing through the system the O_2 is not flowing.

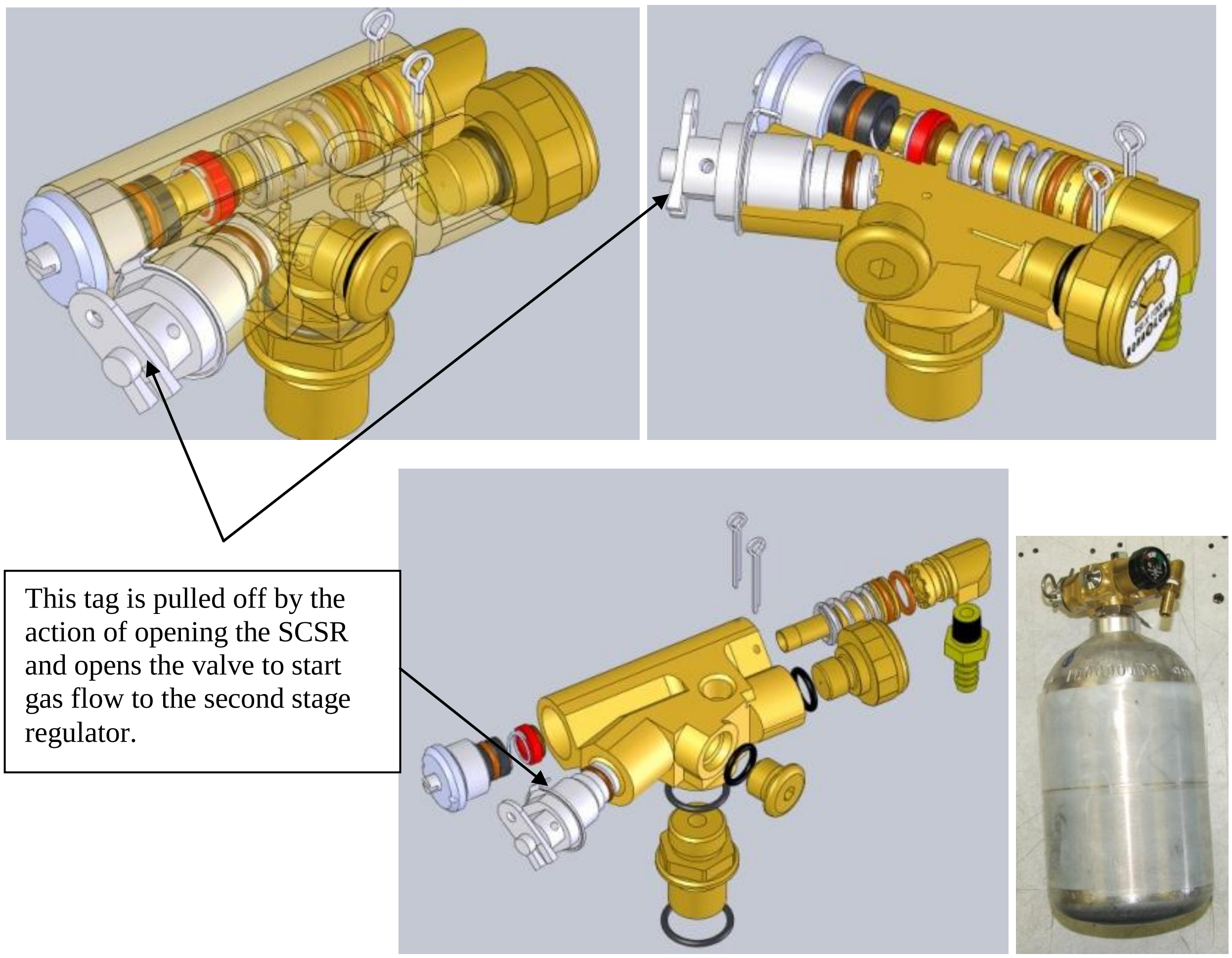


Figure I-5: TPI Has Developed A New 1st Stage Regulator Incorporating An Automatic-On Valve That Triggers Gas Flow From The Bottle When The SCSR Is Opened

APPENDIX II

SCRUBBER DEVELOPMENT

In Phase I TPI worked with Micropore Inc. on a custom scrubber configured as a toroidal cylinder which will surround the O_2 bottle. The scrubber material is LiOH to minimize system volume and weight. It is anticipated that approximately 750-cc of the material will be needed to meet the stated SCSR requirements. Figure II-1 shows the unique Micropore methodology of wrapping their scrubber 'fabric' around a core (the O_2 bottle in Phase I as seen in Figure II-2), which results in a well contained, non-settling scrubber configuration with permanent air flow channels.

Figure II-1: The Unique Micropore Reactive Plastic Curtain (RPC) Scrubber Configuration Features A Hollow Core, Built In Airflow Management And Mechanically Contained Catalyst

(Courtesy of Micropore,Inc.)

Figure II-2: The Toroidal Scrubber Fits Around The O_2 Bottle Inside A Stainless Steel Or Aluminum Outer Housing

This item was tested at Micropore. Micropore has a breathing machine which allows evaluation of CO_2 absorption (Figure II-3). It does not metabolize O_2 in the breathing loop but rather the testing is conducted by introducing CO_2 at an equivalent flow: in our case an O_2 usage rate of 1.35-lpm equates to a CO_2 production rate of 1.14-lpm (0.80 metabolization factor). CO_2 was therefore introduced at this rate and gas levels in the inhale and exhale states recorded. The graph at Figure II-4 summarizes the results of this testing. At the flow rates described the CO_2 level in the inhale air remained below 3% for 75-min while the inhale air temperature maxed out at approximately 101^0-F. These results were obtained with a non-optimized scrubber configuration. Micropore indicated that they can vary the catalyst density and physical configuration of the assembly (thickness, channel size, catalyst density) to significantly enhance performance.

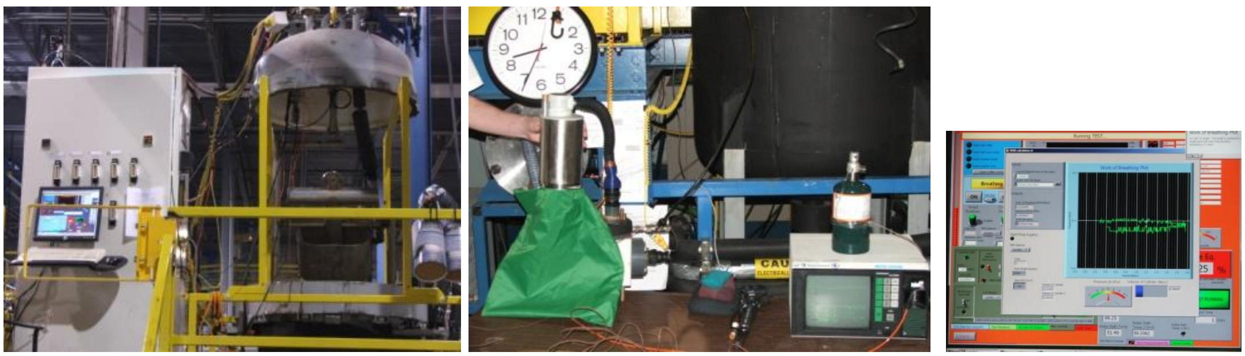


Figure II-3: Scrubber Testing Was Completed On Micropore's Breathing Machine

In summary the results showed a scrubber life in excess of the 60-min requirement but a marginal failure for high temperature (approximately 1-deg C too high). While this result is of some concern it is not considered too significant since at this point the scrubber configuration has not been optimized in terms of catalyst density and physical configuration (the ridge and valley profile). The end effect will be a more efficient scrubber with higher CO_2 absorption at lower operating temperature.

The first optimization task was to run a scrubber doped with a reactive dye that will indicate where the catalyst has reacted most – the concern being that the airflow across the catalyst is not uniform but is concentrated under the exhale ports of the regulator housing. Figure II-5 shows the results of that test. In this figure the scrubber has been unrolled. The top of the figure is the scrubber end nearest the regulator. The colored region at the top of the scrubber shows the reacted catalyst. It is clear from the single large penetration through the length of the scrubber that flow is concentrated directly beneath the exhale ports. From other analysis it also became apparent that the outer wrap and a half of the scrubber was seeing only very minimal flow. After a review of the housing it appears that the outer edges of the scrubber are shadowed by the structure of the SCSR top plate.

To address these two issues TPI redesigned the SCSR top plate with two major modifications:

- The incorporation of a baffle plate (Figure II-6) below the exhale ports to induce more turbulent flow in the open volume above the scrubber and so induce more even flow across the whole scrubber cross section
- Modifications to the top plate where the breathing air filter is mounted to provide stand-off from the scrubber material to expose the outer wraps to good air flow (Figure II-7).

In Phase II we applied all the lessons learned in Phase I on airflow management, scrubber sizing and wrap techniques to develop the scrubber configuration for the side-by-side peanut shaped unit.

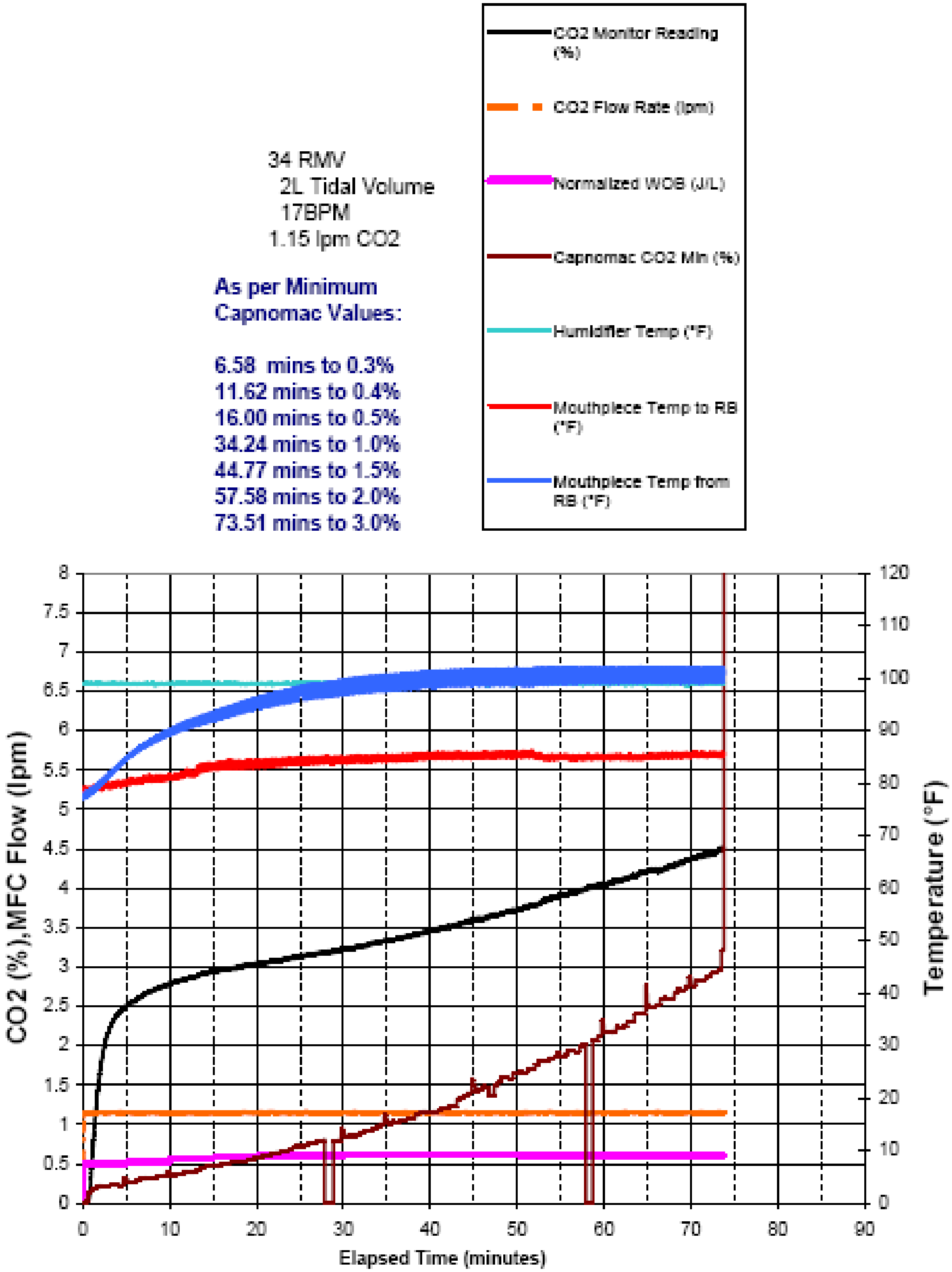


Figure II-4: Scrubber Performance Indicated Easy Attainment Of CO_2 Absorption And Breathing Gas Temperature Requirements

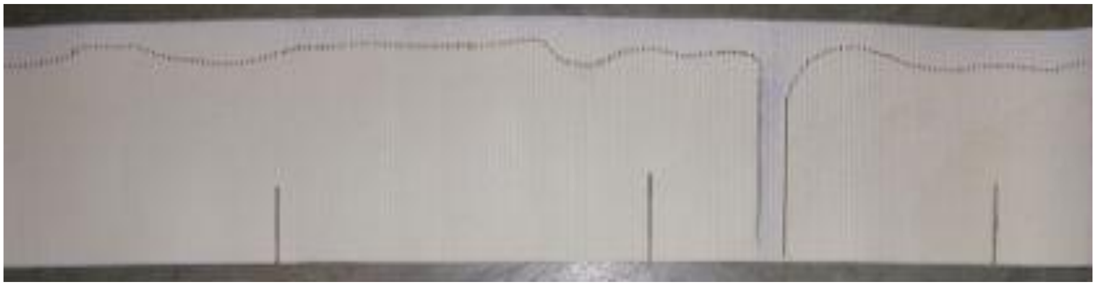


Figure II-5: Dye Testing The Scrubber Shows Preferential Penetration Under The Exhale Port

Figure II-6: A Baffle Plate Will Induce Consistent Airflow Across The Cross Section Of The Scrubber

Figure II-7: Stand-Offs Incorporated Into The Top Plate Will Ensure Good Airflow At The Outer Wraps Of The Scrubber

The major change from Phase I was to remove the O_2 cylinder from the center of the wrapped scrubber. This change has a significant effect on the packing density of the rolled scrubber. The total length/area of the scrubber material contained within a volume is extremely sensitive to the OD of the roll but fairly insensitive to its ID. This means that wrapping a roll around a 1-in core as compared to a 0.5-in core will have little effect on the final OD and amount of scrubber material (a change in length of the wrap material of approximately 9.4-in – or ¾ of the outer wrap at a 4-in diameter) but changing an OD from 4-in to 4.5-in has a significant effect (a change in length of the wrap material of approximately 53.4-in). This effect results from the fact that the circumferential length is large at the OD so a minor increase in OD caused by adding a single extra wrap of scrubber material results in lots of extra square inches of catalyst. This is why the original design of a large ID/large OD scrubber rolled around the O_2 bottle is such an efficient packaging approach. The new scrubber assembly as shown in Figures II-8 through II-12. The assembly incorporates two 10-micron breathing loop filters to exclude any LiOH scrubber dust from entering either the regulator/breathing hose or the counter-lung (Figure II-8).

Figure II-8: The Two Breathing Loop Filter Assemblies (Note The Integral Counter-Lung Mounting Flange On The Right Hand Filter)

Figure II-9: The Second Stage Regulator Housing That Sits Atop The Scrubber Assembly - This Prototype Was Made As A Cast Urethane Sample

Figure II-10: The Scrubber Housing Fitted With The Filter Pads As Seen From The Counter-Lung End With The Underside Of The Second Stage Regulator Shown

Figure II-11: The Scrubber Housing Fitted With The Filter Pads As Seen From The Regulator End With The Top View Of The Second Stage Regulator Shown

Figure II-12: The Assembled Scrubber Assembly (Less Counter-Lung) And Includes A View Down Through The Regulator At The Top End Filter

APPENDIX III

COUNTER-LUNG DEVELOPMENT

TPI evaluated several materials for their applicability to this requirement. Figure III-1 shows a sample of automotive airbag material. This fabric is extremely tough and shows good long term compressed storage characteristics. It must be stitched closed which complicates the sealing process. Figure III-2 shows a mylar bag – extremely light and compressible, air-tight and quite tough. These and other fabrics are being evaluated for:

- Tolerance to long term compression
- Tolerance to long-term storage
- Air-tightness
- Toughness
- Low-weight
- Ease of bag fabrication

Figure III-1: Automotive Airbag Material Is Designed For Long Term Compressed Storage, Toughness And Low Gas Permeability

Figure III-2: A Mylar Counter-Lung Would Be Extremely Light And Tough And Compress Well

Figure III-3 shows a bag made from silicone coated rip-stop nylon fabric which has zero porosity, good toughness and extremely high compressibility. This fabric is also thermally weldability simplifying the fabrication of air-tight bags. The material is used in parachute membranes and so is especially tolerant to long term compressed storage. This material is being evaluated in two weights, 30-denier and 70-denier. It has been tested as follows;

- Cold soaked at 0^o-F for 48-hr with no effects on flexibility
- Hot soaked at 130^o-F for 48-hr with no effects on coating integrity
- Immersed in gasoline for 24-hr with effects on coating integrity

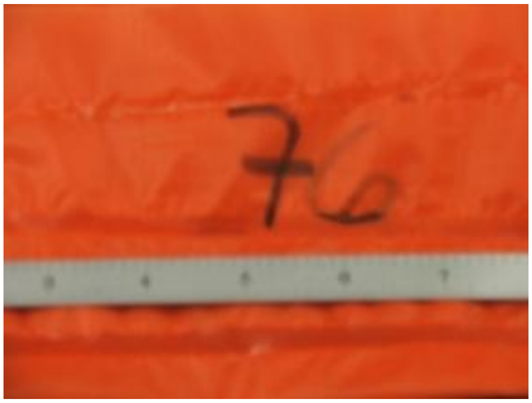


Figure III-3: A Silicone Coated Ripstop Nylon Candidate For The Counter-Lung Is Under Weldability Test

TPI has also identified a small relief valve as seen in the photo to be inserted into the counter-lung (Figure III-4) to allow venting of excess gas from the volume as required. The exact functioning of that valve, cracking pressure and flow, was evaluated during testing and modified as required. TPI identified several variants of very low profile fabric clamps (Figure III-5) to secure the fabric and rubber items (counter-lung, hoses, etc.) to the structure of the SCSR in order to minimize the impact of such necessary but non-contributory items to the SCSR volume.

Figure III-4: The Counter-Lung With Relief Valve Screws Onto The Bottom Of The Scrubber Housing

Figure III-5: Low Profile Clamps Will Be Used To Attach All Fabric And Rubber Components To The SCSR Structure

During the testing we trailed a smaller 2-ltr counter-lung (as compared to the ‘conventional’ 5-ltr+ bags) as seen in Figure III-6. This volume worked very well with the controlled volume provided by the demand–only regulator and has the significant advantage of obviating the possibility of N_2 hypoxia – since the total bag volume is basically exchanged with each breath. These bags were fabricated from silicone coated rip-stop nylon material which, while resistant to industrial chemicals failed both mustard (HD) and sarin (VX) CBRN permeability tests. While not limiting in the mining application this precludes the material from CBRN qualified rebreather applications. In the prototypes the material was stitched and sealed with a liquid sealant. This approach resulted in some slow leakage under pressure as identified during the June testing and was a complicated and onerous process. TPI then fabricated a second set of prototypes made from polyurethane sheet stock welded into the bag shape (Figure III-7) – a process used by most of the in-service SCSRs.

Figure III-6: A 2-Ltr Counter-Lung Was Trialed That Obviates Any Chance Of N_2 Hypoxia

At this time the relief valve for the breathing loop was also moved from the counter lung onto the regulator housing (Figure III-8). This provides a more protected mounting point and allows for simple adjustment of relief valve settings by controlled machining of the valve seat.

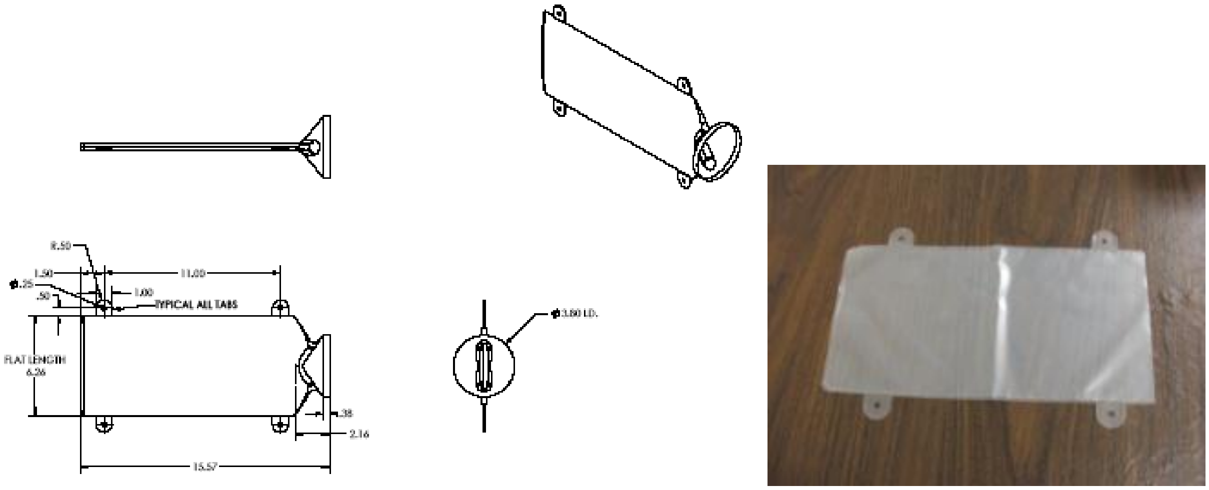


Figure III-7: The New Counter-Lung Will Be Welded Polyurethane

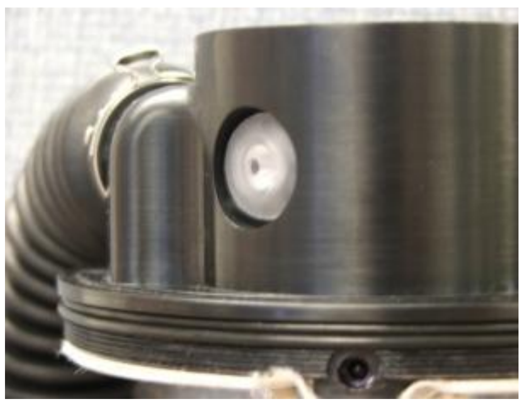


Figure III-8: The Breathing Loop Relief Valve Is Hard Mounted On The Regulator Housing

APPENDIX IV

DOCKING CONNECTOR DEVELOPMENT

The docking connector is the device that enables the user to switch over between air sources without breaking seal. In the initial Phase I effort that connector was integral to the second stage regulator housing. The mount for the connector to the breathing tube (shown in Figure 41) was fitted with a swivel. This swivel was sealed with o-rings to prevent compromise of the breathing loop. The swivel allows the breathing hose to be stored horizontally while stored but deploy vertical during use. The Quick Disconnect (QD) is able to rotate freely 360-deg at this point. This joint is held together using a snap along the center axis of the joint and a number of small pins around the perimeter in the groove. This joint is sealed with a flat gasket. The top part of the regulator (the low pressure side) on which the connector is mounted is also able to rotate 180-deg around the regulator (also as seen in Figure Iv-1). This will enable a second SCSR canister to be connected and will also improve the access to the selector valve. The main portion of the housing swivel (pink) seals to the main housing (green) with 2 o-rings.

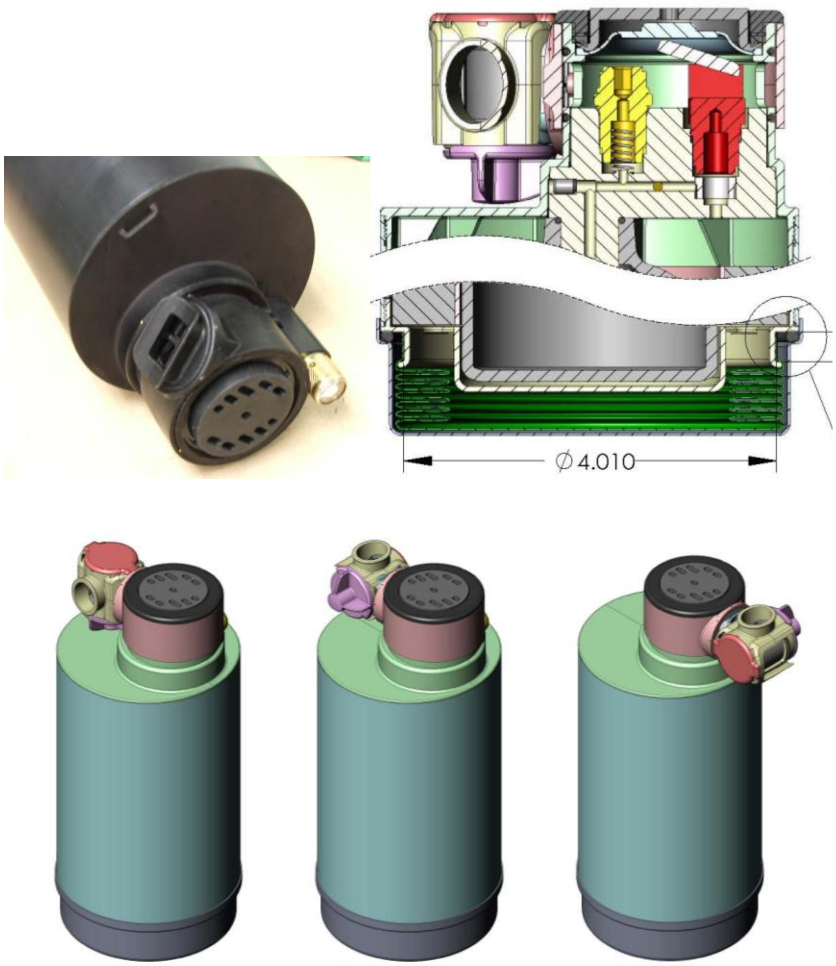


Figure IV-1: The Docking Connector And Low-Pressure Part Of The Regulator Both Rotate To Minimize Packed Volume And Ease Connection Of Secondary SCSR Devices

Under review we evaluated placing this connector at the mouth piece end of the breathing tube and having the tube attached directly to the regulator housing. This change would provide the most flexibility for packaging of the system into its outer housing major and also put the valve in a much more protected and generally clean area (near the user's head) rather than on the chest where it could be damaged if the user is crawling. A system with the breathing tube hard-mounted to a swiveling elbow with the docking connector at the mouth-piece end (Figure IV-2) was developed.

Figure IV-2: One Configuration Has A Swiveling Breathing Tube With Docking Connector At The Mouth-Piece End

TPI prototyped several variants of the docking connector required under this effort:

- Quick connect with self-ejecting connector (Figure IV-3). The second device allows only one air source to be connected at a time and actively disconnects the 'old' source as a new one is connected. It consists of a male fitting on each air source that has peripheral airflow ports and a closed end and a double open ended female receptacle on the breathing tube. As a new male connector is slid into the female receptacle it pushes the old connector out. As it does so the peripheral ports on the male end align with the port feeding the breathing tube. In a manner similar to the other design the additional features of this device are:
    - The male connectors come fitted with dust covers that protect them from ingress of dirt before connection. As they slide onto the female connector body the cover is automatically stripped off the connected allowing airflow.
    - This connector assembly has been prototyped as machined metal pieces to allow evaluation of different O-ring configurations.

- The symmetrical 'T' docking connector shown in Figure IV-4 features a quarter turn bayonet fitting with grooved outer ring for ease of use. When a connector is pushed together and turned it automatically shuts off the 'old' connection to prevent the creation of any dead volume should the user not dis-connect the old air source (as they are instructed to do). The connector is fitted with a single, tethered cover which can be fitted to the empty port to prevent ingress of dirt etc.   This connector is being built as a 3D SLA prototype to evaluate functionality. The connector has to be sufficiently long or be fitted with short hoses to allow it to connect two SCSR bodies beside each other. The major issues with this connector were its complexity, component intrusion into airflow and its susceptibility to fouling by dirt, mud etc.

Figure IV-3: The 'Automatic' Connector Only Allows One Breathing Device To Be Selected At A Time (Shown Here With The CO Filter Housing)

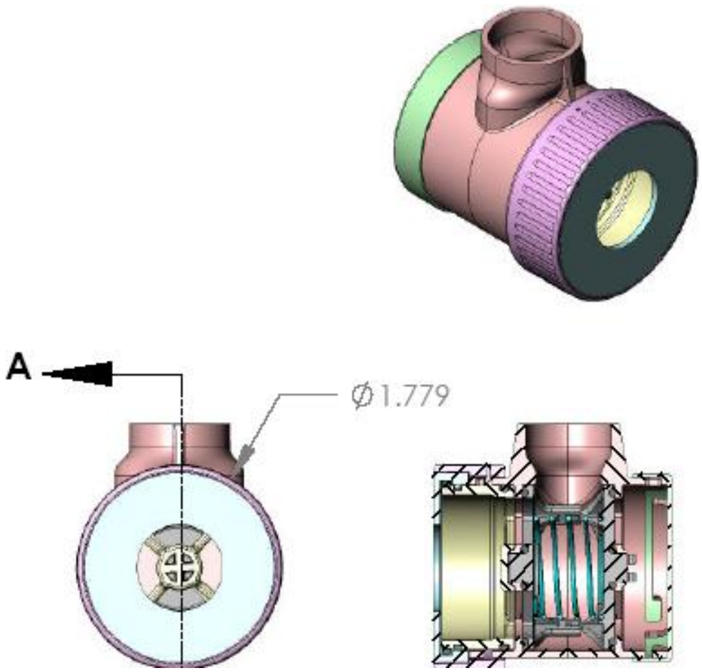


Figure IV-4: The Original Docking Connector Is A Quarter Turn Male/Female Mating Connector That Seals Off The Old Connection As The New One Is Made

- Quick connect with manual selector valve. TPI also prototyped a docking connector (Figure IV-5) that allows the user to connect additional breathing devices into their breathing loop and to select between the two sources without breaking the protective seal. At the same time the device prevents accidental exposure to the atmosphere and accidental dis-connection of the 'live' breathing device. Each item to be connected to the breathing tube through the valve (the original SCSR, CO filter, replacement SCSR, etc.) is fitted with a male interface piece that slides into a female receptacle on the valve body which houses the port opening. There are two such receptacles, one on each side of the valve body. The breathing tube is permanently connected to the third port. A manually operated knob allows the user to select between the two inlet ports. The valve has integrated into it detents and features to provide the following flow control:

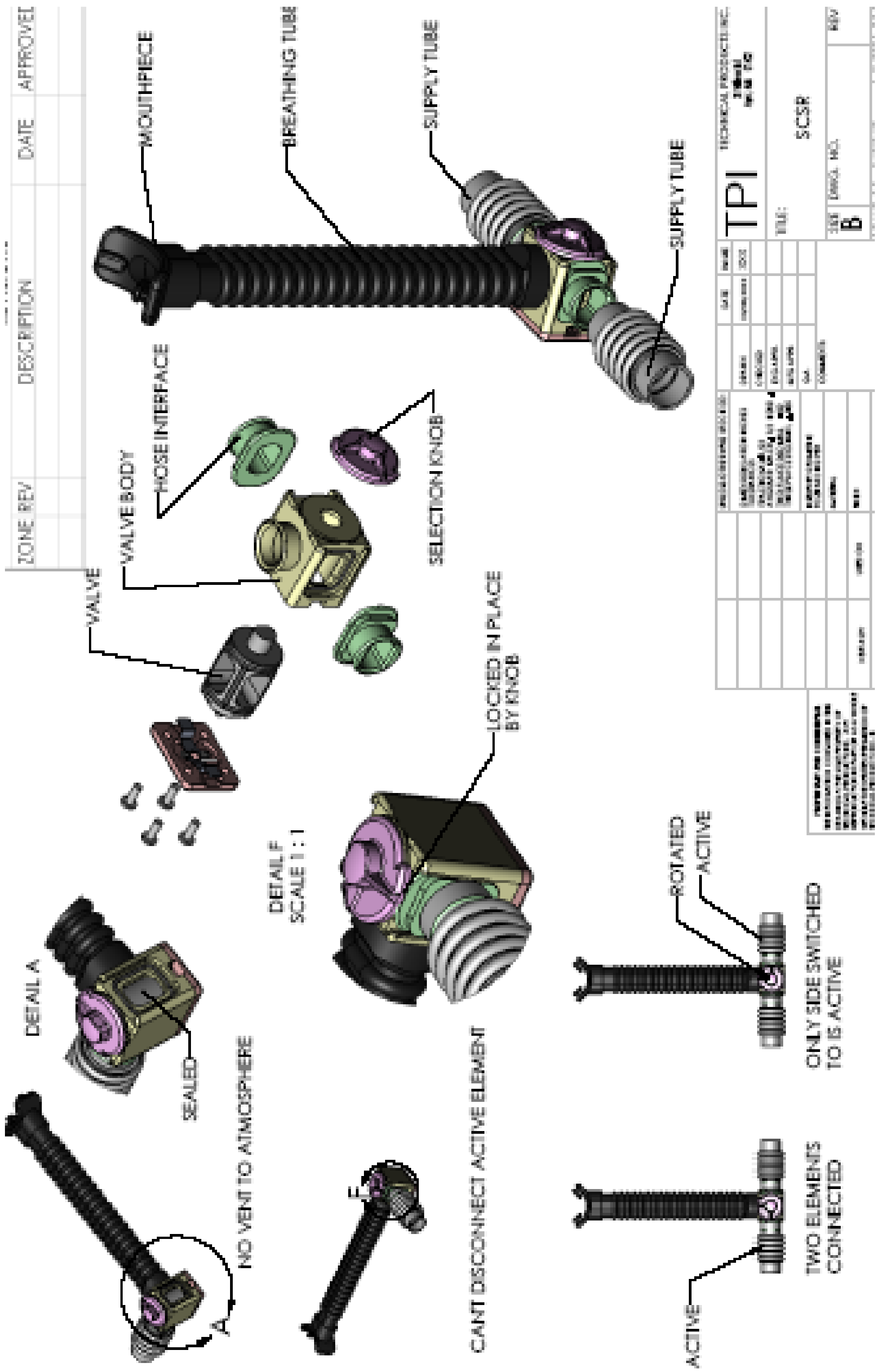


Figure IV-5: A Docking Connector Allows The User To Connect And Select Between Two Breathing Devices While Preventing Accidental Dis-Connection Or Venting Of The 'Live' Breathing Loop

- The slider attached to a breathing device cannot be disconnected from the valve body (and attached breathing tube) if the selector knob is oriented towards it – this prevents the user accidentally disconnecting their active breathing device.
- The selector knob cannot be turned to select an un-occupied port (open to the atmosphere). The knob won't turn unless both ports have a fitting installed. This prevents the user accidentally exposing themselves to the atmosphere.

Other additional features of this device are:

- The male connectors come fitted with dust covers that protect them from ingress of dirt before connection. As they slide onto the valve body the cover is automatically stripped off the connected allowing airflow.
- The tracks in the valve body into which the male connector slides are fitted with cleaning holes that will allow any dirt in the tracks to drop out rather than blocking the connection.
- This connector assembly has been prototyped as a "3D printing" plastic piece. Currently TPI is in the process of getting tooling made to support small volume production of the device.

TPI continued to tweak this design and minimized its size without loss of any functionality (Figure IV-6).

Figure IV-6: The Latest Docking Connector (The Bare Metal Device) Has Been Reworked into A Slightly Smaller Configuration Than The Previous Design (The Black Device)

One of the beauties of this design is that would allow the user to have both an SCSR and a CO filter attached to the breathing tube simultaneously and for the user to actively select between the two devices (Figure IV-7). If the user also has access to a Breathing Air Monitor or other atmospheric gas monitor he could select between which source of air (SCSR, filtered ambient) to use dependent on the nature of the surrounding atmosphere. This would maximize the efficiency of the escape air supplies and provide the longest possible support for miner survival.

We also addressed the 'usability' of the manual selector valve. As shown in Figure IV-8 we incorporated a lift up arm that provides the user a better grasp and hence control of the selector valve.

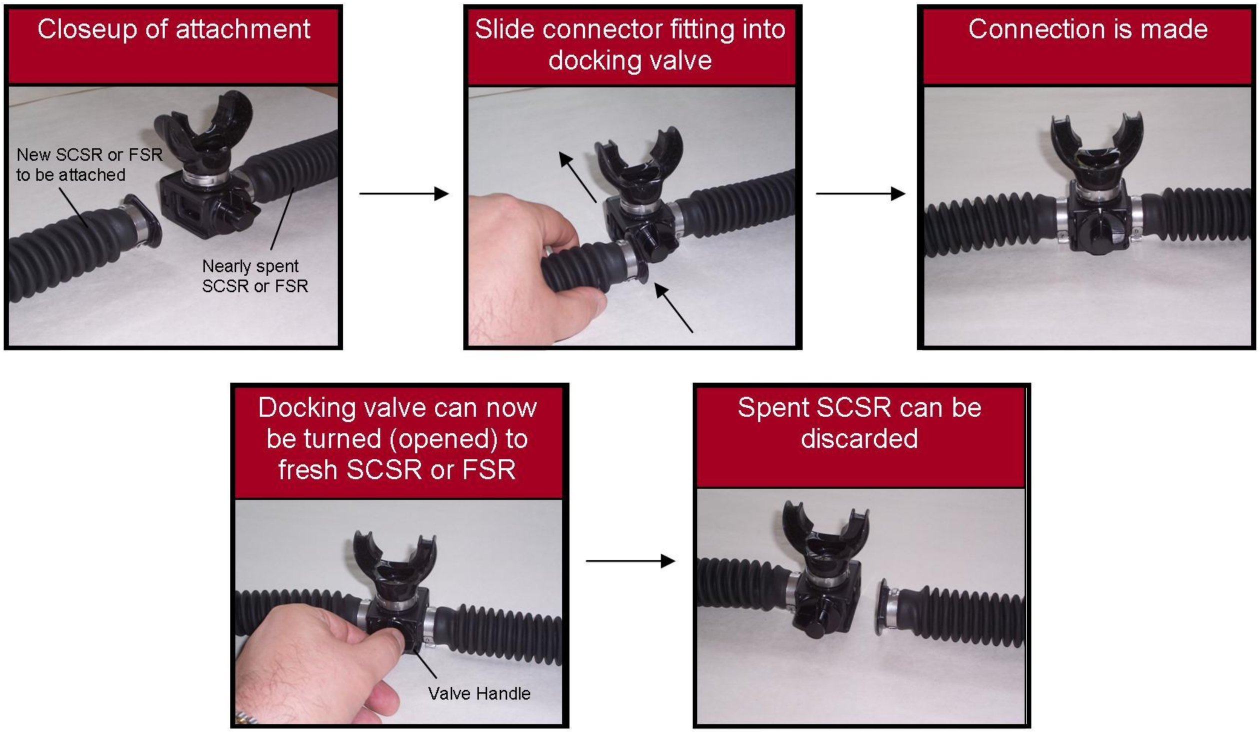


Figure IV-7: Docking Valve Changes Out Spent Devices With Fresh Device Without Breaking Seal

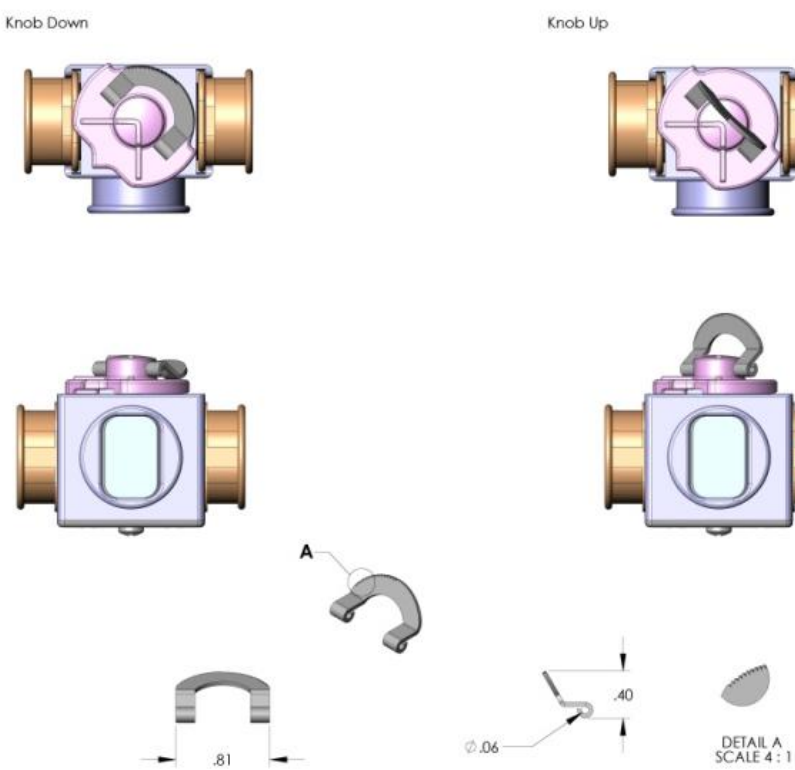


Figure IV-8: We Added A Flip Up Handle To The Selector Valve To Improve Its Usability

APPENDIX V

ACCESSORIES & MINOR ITEM DEVELOPMENTS

This section summarizes the development and status of the various minor items needed for the SCSR:

- Pressure Gauge. TPI selected a dial gauge (Figure V-1), as opposed to a pin gauge, to indicate to the user the status of the compressed gas supply.

Figure V-1: A Pressure Gauge Will Allow Real Time Monitoring Of The O_2 Supply

- Nose Clip. After evaluating several types of nose clips TPI selected the item shown in Figure V-2 for the SCSR.

Figure V-2: A COTS Nose Clip Has Been Identified For The SCSR

- Moisture Monitors. TPI has evaluated both humidity (Figure V-3) and maximum temperature sensors sensors to be placed inside the storage 'can' to indicate if the seal has been compromised.

Figure V-3: Any Indication Of Humidity Inside The Sealed Can Mean That The Seal Has Been Compromised

- Goggles. TPI evaluated several different variants of commercial safety goggles (Figure V-4) for inclusion in the SCSR housing as smoke protective goggles for the escaping miner. The options cover one piece 'mask' style items to goggles with separate eye cups. Trade-offs covered collapsed volume, universal seal and long term mechanical stability of frame, sealing foam and lenses.

Figure V-4: Both 'Mask' Style And Individual Eye-Cup Goggles Are Being Evaluated

We identified a mask style goggle with foam seal and plastic sheet lens which held promise. We modified the design to account for the folded long terms storage requirements for the SCSR application (Figure V-5). We separated the one piece lens into discrete eye lens with a soft foam nose bridge. This allows the item to be folded and then compressed very flat for storage within the SCSR housing (Figure V-6).

Figure V-5: The New TPI Goggles Went From One Piece Lens To Split Lens To Discrete Eye Lenses With A Soft Foam Seal For Comfort And Compressed Storage

Figure V-6: The TPI Goggles Fold At The Nose Bridge And Compress Tightly

Under test those goggles failed in their ability to provide a reliable seal around the eyes. The decision was made to change to a style similar to that utilized in the in-service SCSR (Figure V-7). TPI sourced a manufacturer for the eye goggles required for the SCSR.

Figure V-7: Prototypes Of The New Eye Goggles Are In-Hand

- Holster. TPI developed a holster to house the Phase I cylindrical SCSR (Figure V-8). This ballistic nylon item houses the neck strap and pad plus the sternum strap for the SCSR plus provides a padded and heat resistant insulator that goes between the SCSR housing and the user's chest.

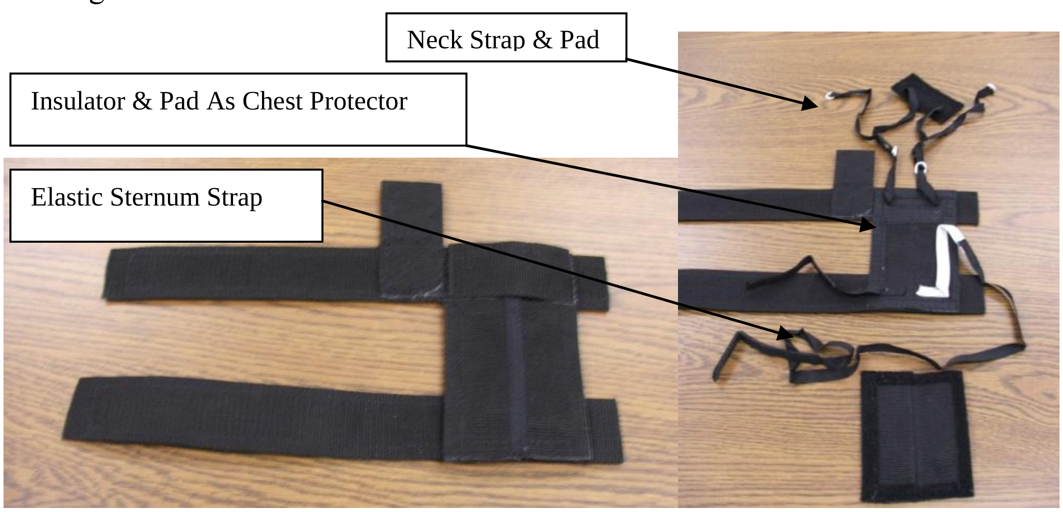


Figure V-8: The Holster Houses The SCSR Plus The Neck And Chest Straps And Provides Padding For Wearing The Unit On The Chest

We also fabricated rough prototype holsters for both Phase I cylindrical and Phase II peanut SCSRs to evaluate relative 'wearability' (Figure V-9).

- Breathing Tube. These tubes will be fabricated by CrushProof Inc., from fire resistant CP6000FR EDPM (Figure V-10). This material will survive temperatures over 500^{o}-F for a short amount of time. If used/stored in an environment of 200^{o}-F, it will last for years. Our rubber is not going to perform like silicone, but for heat tolerance and flexibility we are not that far off. Silicone does have some additional heat tolerance for sure, but in a breathing hose scenario the user is going to die before the temps are high enough to demonstrate the differences and EPDM costs a fraction of what silicone does. The CP6000FR has been through a new NIOSH test process that involves a 5-min 550^{o}-F bake followed by 12-sec of direct contact with a methane torch, and it must self extinguish to pass and this rubber does. It's pretty impressive to see the rubber start to catch flame after 6 or 7-sec and then extinguish after the white-hot cone of the flame is removed. The hose will survive the test and get the user to safety.

Figure V-9: Rough Prototypes Were Fabricated To Evaluate Different Mounting Locations For Different Configuration SCSRS

Figure V-10: A Collapsible Corrugated Breathing Tube Couples Directly To The Mouthpiece

- Mesh Heat Exchanger. TPI evaluated the use of a cylinder of compressed stainless steel mesh inside the breathing tube as a heat exchange mechanism. Various mesh patterns and densities were tested (Figure V-11). As it turned out, the initial test data showing a breathing loop temperature of just 1010-F indicates that we do not need any internal mesh heat sink. During testing it also was determined that the incorporation of this mesh significantly increased the breathing resistance while only minimally reducing the breathing loop temperature. The decision was made to forego the use of this mesh and to derive alternate thermal management solutions.

Figure V-11: Stainless Steel Mesh Was Tested As An Insert Into the Breathing Tube As A Heat Management Tool But Significantly Increased Breathing Resistance Was An Unacceptable Result

APPENDIX VI

PHASE II SCSR IN-HOUSE TESTING

Preliminary testing of the prototype SCSR was performed at Aqualung Inc in San Diego, CA. The purpose of the tests was to determine the breathing resistance of the SCSR unit both on a machine and to complete a simulated Man Test 4.

The initial resistance test was performed on an ANSTI breathing machine (Figure VI-1). Metabolic losses were not simulated, so only work of breathing was evaluated and not demand valve triggering. Pressures were under 20mm/H_2O on exhale and under 25mm/H_2O on inhale. Cylinder was filled with air to 3000psi and SCSR was tested on its side (Figure VI-2). Test results are shown in Figure VI-3 (test LSTF-0111 549).

Figure VI-1: Testing Was Conducted On An ANSTI Breathing Machine

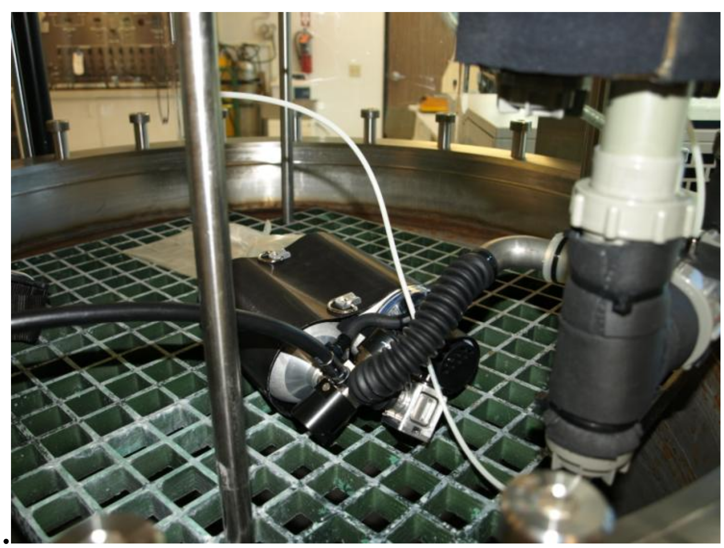


Figure VI-2: Breathing Resistance Testing As Conducted On A Complete Prototype Unit

DEMAND REGULATOR PERFORMANCE

— ANSTI	AQUA-LUNG USA	ANSTI —
CERTIFICATE REFERENCE	: LSTF-0111 549	
DATE : 7/23/2008		TIME : 10:30:51 AM

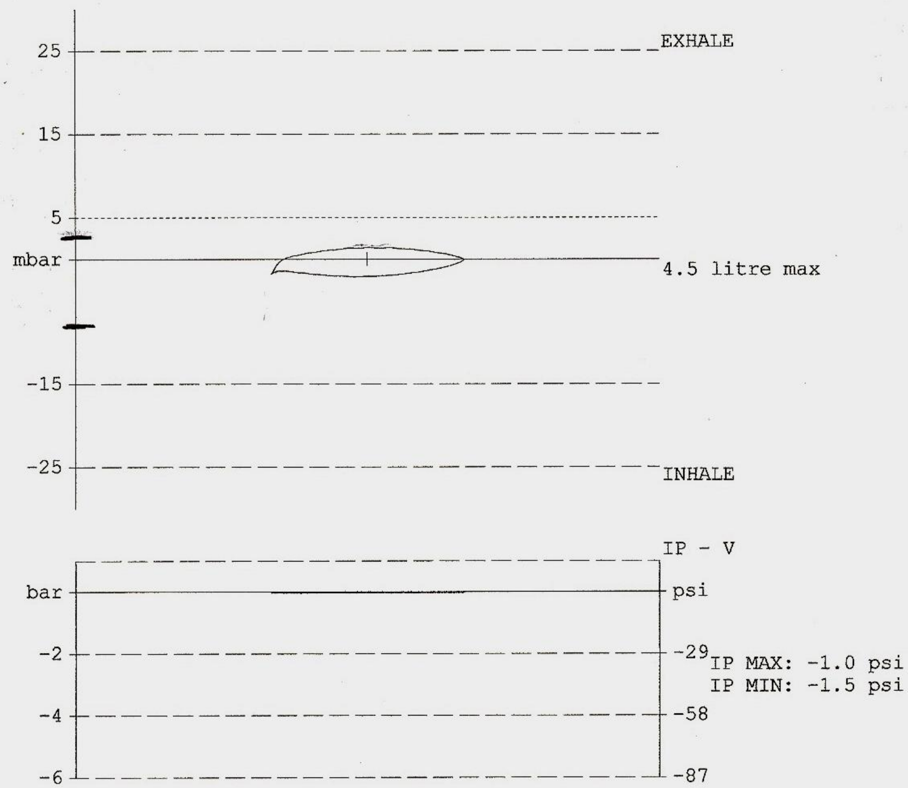
EQUIPMENT

REGULATOR TYPE	: SCSR
SERIAL NUMBER	:
INTERSTAGE PRESSURE	: 0.0 psi

CONDITIONS OF TEST	MEAN	MIN	MAX
ROOM TEMPERATURE (F)	: 72.0		
WATER TEMPERATURE (F)	: 75.5	75.5	75.5
EXHALE TEMPERATURE (F)	: 76.9	76.8	77.0
FAST RESPONSE TEMP MIN (F)	: 32.0	32.0	32.0
FAST RESPONSE TEMP MAX (F)	: 32.0	32.0	32.0
HP SUPPLY PRESSURE (psi)	: 0.2	0.0	0.4
TIDAL VOLUME (litre)	: 1.50		
BREATH RATE (bpm)	: 15.19	15.12	15.24
VENTILATION RATE (lpm)	: 22.8	22.7	22.9

RESULTS (4 LOOPS) overlap	MEAN	MIN	MAX
INHALE PRESSURE (mbar)	= 2.11	2.09	2.12
INHALE POS PRESSURE (mbar)	= 0.00	0.00	0.00
EXHALE PRESSURE (mbar)	= 1.40	1.39	1.41
EXT WORK OF BREATHING (J/l)	= 0.25	0.25	0.25
INHALE WORK (J/l)	= 0.16	0.16	0.16
POS INHALE WORK (J/l)	= 0.00	0.00	0.00
EXHALE WORK (J/l)	= 0.09	0.09	0.09

PRESSURE - VOLUME DIAGRAMS AT DEPTH OF : 0.0 msw (-0.1 fsw)



REMARKS :

LSTF-0111

Figure VI-3: Breathing Resistance Without The Regulator Triggering Was Less Than 1-iwg For Both Inhale And Exhale

In order to trigger the demand valve, the breathing bag was pinched off during inhalation stroke. The pressure required to trigger the valve exceeded 100mm/H2O. The results can be seen in Figure VI-4 (test LSTF-0111 550).

DEMAND REGULATOR PERFORMANCE

ANSTI — **AQUA-LUNG USA** — **ANSTI**

CERTIFICATE REFERENCE : LSTF-0111 550
DATE : 7/23/2008 TIME : 10:50:02 AM

EQUIPMENT
REGULATOR TYPE : SCSR
SERIAL NUMBER :
INTERSTAGE PRESSURE : 0.0 psi

CONDITIONS OF TEST	MEAN	MIN	MAX
ROOM TEMPERATURE (F)	: 72.0		
WATER TEMPERATURE (F)	: 75.4	75.4	75.4
EXHALE TEMPERATURE (F)	: 76.9	76.8	77.0
FAST RESPONSE TEMP MIN (F)	: 32.0	32.0	32.0
FAST RESPONSE TEMP MAX (F)	: 32.0	32.0	32.0
HP SUPPLY PRESSURE (psi)	: 0.3	0.2	0.4
TIDAL VOLUME (litre)	: 2.00		
BREATH RATE (bpm)	: 15.13	15.06	15.18
VENTILATION RATE (lpm)	: 30.3	30.1	30.4

RESULTS (4 LOOPS)	MEAN	MIN	MAX
INHALE PRESSURE (mbar)	= 4.85	2.71 B	11.19 A
INHALE POS PRESSURE (mbar)	= 0.33	0.00	1.21
EXHALE PRESSURE (mbar)	= 2.14	2.05	2.29
EXT WORK OF BREATHING (J/l)	= 0.38	0.34	0.50
INHALE WORK (J/l)	= 0.23	0.20	0.33
POS INHALE WORK (J/l)	= 0.00	0.00	0.00
EXHALE WORK (J/l)	= 0.15	0.14	0.16

PRESSURE - VOLUME DIAGRAMS AT DEPTH OF : 0.0 msw (-0.1 fsw)

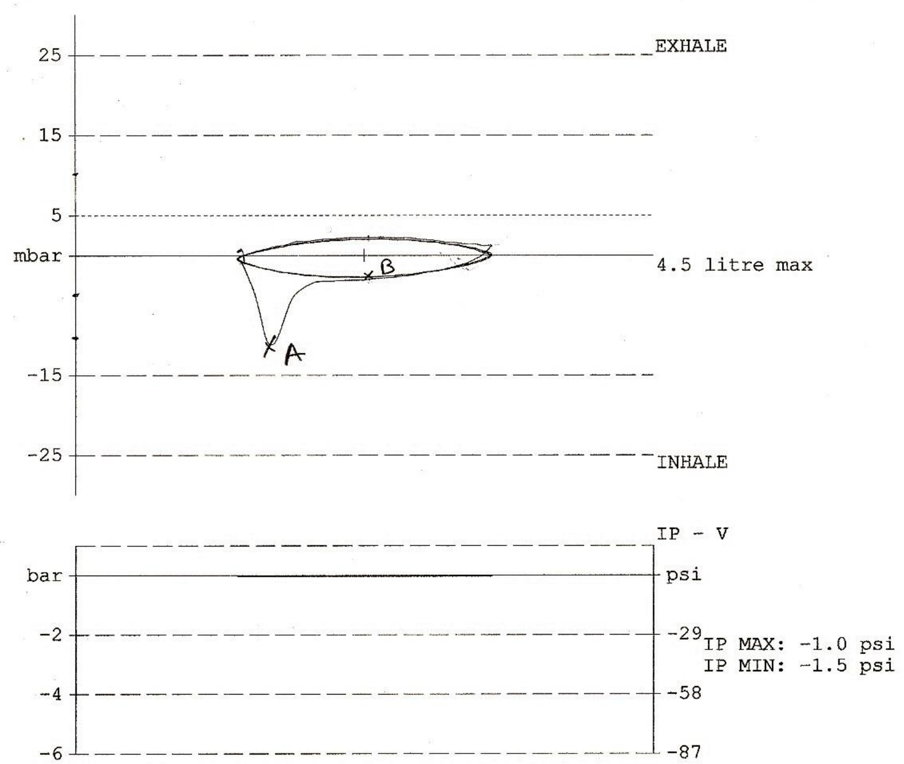


Figure VI-4: It Took 4-Iwg To Trip The Regulator With The Original Spring Installed

A lighter demand valve spring was installed and the pressure to trigger the demand valve was reduced to approx. 77.5mm/H2O. Test results can be seen in Figure VI-5 (test LSTF-0111 551). This worked much better, but an intermittent leak was evident at the demand valve from the lighter spring.

— ANSTI ——— AQUA-LUNG USA ——— ANSTI —

CERTIFICATE REFERENCE : LSTF-0111 551
DATE : 7/24/2008 TIME : 4:18:07 PM

EQUIPMENT	
REGULATOR TYPE	: Conshelf 14 Stock #2
SERIAL NUMBER	: CNNP0640
INTERSTAGE PRESSURE	: 0.0 psi

CONDITIONS OF TEST	MEAN	MIN	MAX
ROOM TEMPERATURE (F)	: 72.0		
WATER TEMPERATURE (F)	: 77.1	77.1	77.1
EXHALE TEMPERATURE (F)	: 75.8	75.7	75.9
FAST RESPONSE TEMP MIN (F)	: 32.0	32.0	32.0
FAST RESPONSE TEMP MAX (F)	: 32.0	32.0	32.0
HP SUPPLY PRESSURE (psi)	: 0.1	-0.1	0.2
TIDAL VOLUME (litre)	: 2.00		
BREATH RATE (bpm)	: 15.18	15.12	15.24
VENTILATION RATE (lpm)	: 30.4	30.2	30.5

RESULTS (4 LOOPS)	MEAN	MIN	MAX
INHALE PRESSURE (mbar)	= 7.75	7.58	7.82
INHALE POS PRESSURE (mbar)	= 0.00	0.00	0.00
EXHALE PRESSURE (mbar)	= 0.35	0.27	0.42
EXT WORK OF BREATHING (J/l)	= 0.30	0.27	0.32
INHALE WORK (J/l)	= 0.29	0.26	0.30
POS INHALE WORK (J/l)	= 0.00	0.00	0.00
EXHALE WORK (J/l)	= 0.01	0.01	0.02

PRESSURE - VOLUME DIAGRAMS AT DEPTH OF : 0.0 msw (-0.1 fsw)

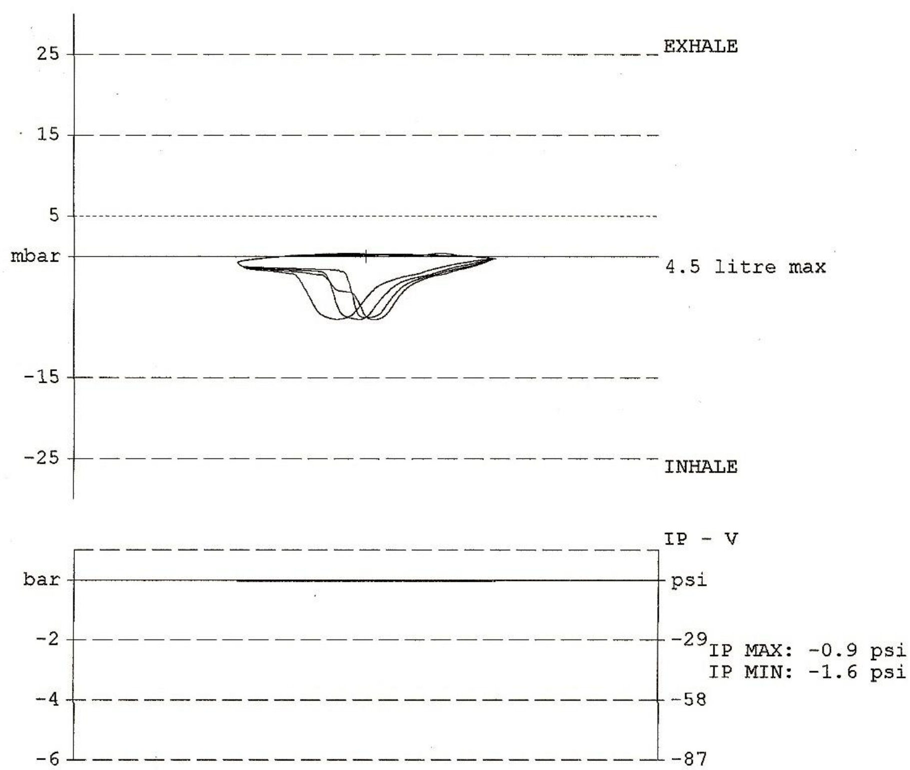


Figure VI-5: With A Lighter Spring Installed Breathing Resistance Dropped To 3-iwg

In order to create a metabolic volume loss, the SCSR was put in a tank and pressurized to a depth of 20 ft and a capillary tube to the "surface" was installed to create a pressure differential. The cylinder was filled with air to 3000psi. CO_2 was injected at a rate of 1.15 l/min. Tidal volume was 2 liters at a rate of 15 breaths per minute. CO_2 % started at approximately 1.9% and ran up to approximately 3.0% after about 1.3 hrs (Figure VI-6). The demand valve did trigger, but not enough to simulate metabolic absorption. The canister was positioned horizontally in the chamber as shown previously. Figure VI-7 shows the moisture build up in the system during this test.

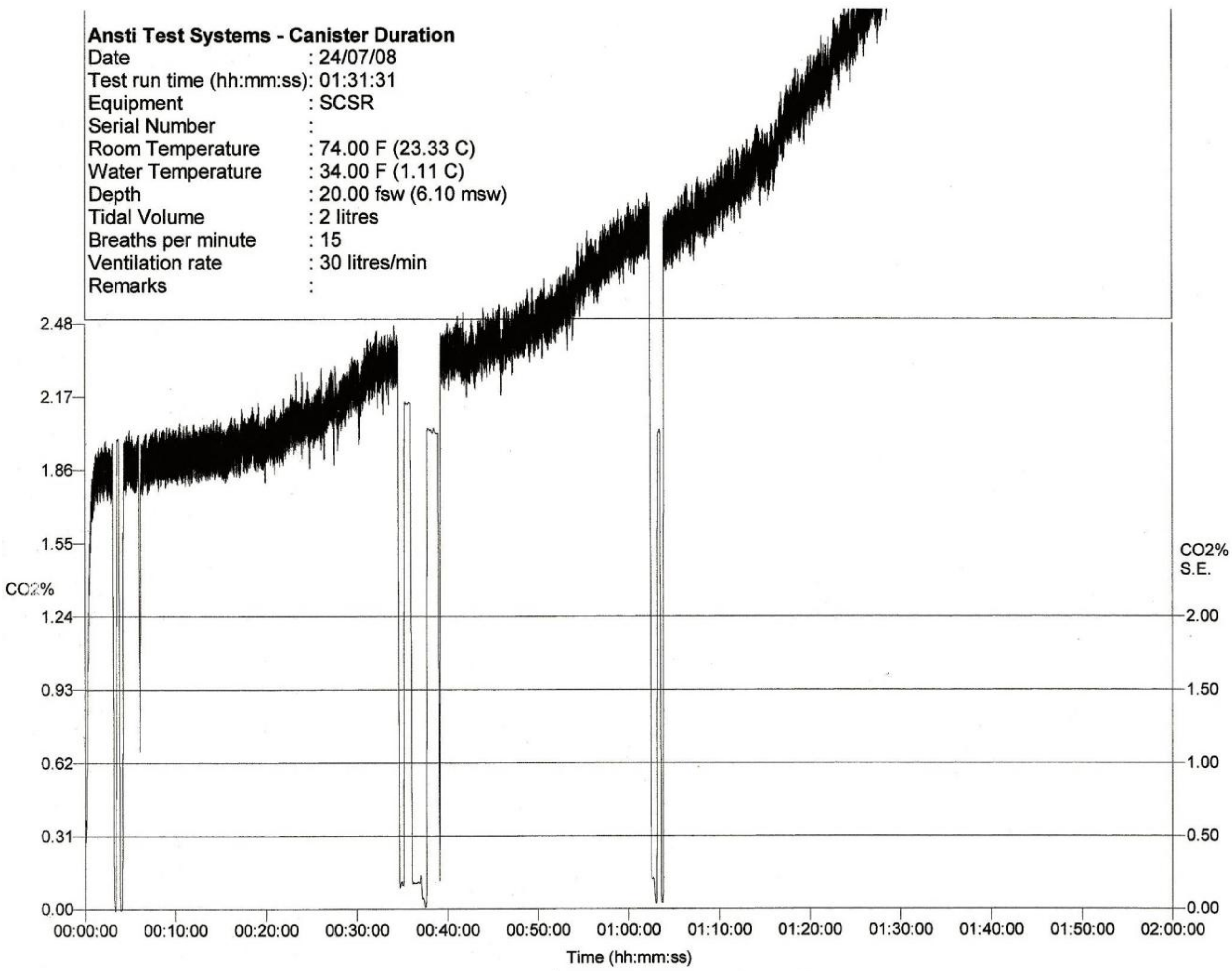


Figure VI-6: After 1.25 Hours CO_2 Level Had Risen By 1.1%

The Man-Test subject was a physically fit male approximately 45-years old and weighing 220-lbs (Figure VI-8). A treadmill was substituted for the Man 4 Test activities (Table VI-1 and Figure VI-9).

Figure VI-7: Moisture In Counterlung And Scrubber Canister

Figure VI-8: Man Test Subject

Activity	Time/Duration (min)	Speed (mph)
Sampling and readings	2	0
Walks @ 4.8 km (3 miles) per hour	2	3
Climbs vertical treadmill	1	4.5
Walks @ 4.8 km (3 miles) per hour	2	3
Pulls 20 kg (45 lb) weight to 5 feet	5	5
Walks @ 4.8 (3 miles) per hour	3	3

Table VI-1: Treadmill Substitutions For Man Test

Man Test Observations/Results were:

- Heart rate monitor of treadmill gave inconsistent readings, so results can not be validated
- Exhaled before inhaling to trigger demand valve (cracking pressure did not seem too difficult even though original heavy demand spring was used)
- As breaths per minute and breathing volume increased with increased activity, counterlung (2.5-l volume) could not contain volume of exhaled breath. Consequently, there was a significant fluid loss around the outside of the mouthpiece
- On inhalation, bag consistently collapsed fully each time causing excessive O_2 consumption
- Inhalation temperature was warm but not uncomfortable
- Seemed to be condensation in mouth. Could have been from test subject not swallowing due to nervousness. Eventually did with no repercussions.
- No discomfort in throat or lungs from scrubber material
- With only a tank top, outer temperature of canister was not too uncomfortable.
- Only a neck strap was used through top d-ring on canister. SCSR had a tendency to shift to the heavy side. Also the pressure on the back of the neck was a little uncomfortable with a 1-in nylon strap
- CO_2 levels began around 2.5% and wound up at 3.5% at the end of the test
- Ran out of O_2 after approximately 13.5 minutes
- Not as much condensation as in first duration test

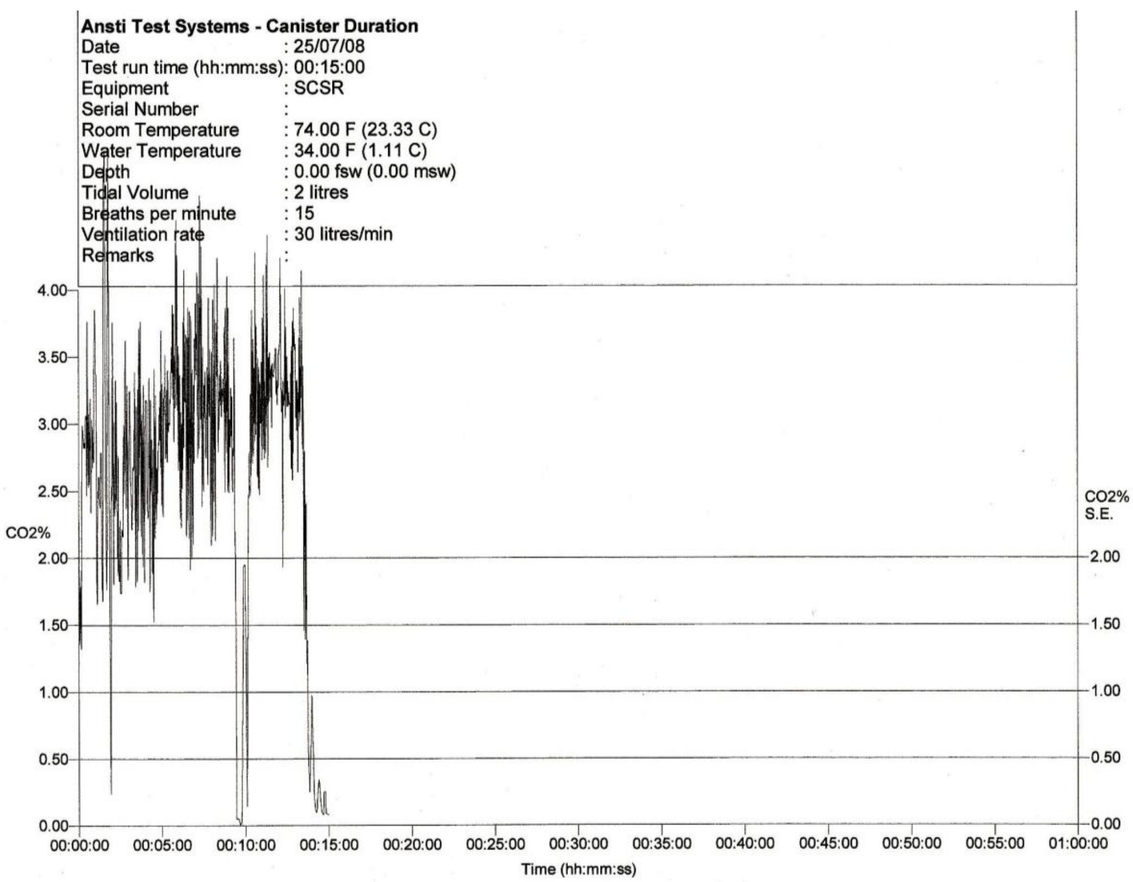


Figure VI-9: Due To Hardware Issues O_2 Ran Out After 15-Min Of Man-Test Activity

APPENDIX VII

PHASE II SCSR NPPTL TEST DATA

CAPACITY TEST 01

TIME	FIO2	FICO2	PEPRS	PIPRS	AEPRS	AIPRS	VO2	VCO2	RR	IWBEND
MIN	%	%	CMH2O	CMH2O	CMH2O	CMH2O	L/M	L/M	/M	DEGC
2	46.2%	0.5%	149.1	-201.1	64.9	-57.0	1.35	1.15	17.9	26.4
4	33.4%	0.6%	11.4	-198.0	-7.9	-48.8	1.35	1.15	17.9	35.8
6	29.0%	0.6%	11.9	-204.1	-8.4	-49.3	1.35	1.15	17.9	39.9
8	28.0%	0.6%	12.3	-207.9	-8.4	-48.3	1.35	1.15	17.9	42.3
10	28.8%	0.6%	12.7	-208.8	-8.3	-48.4	1.35	1.15	17.9	44.1
12	29.4%	0.6%	13.3	-207.4	-7.7	-48.4	1.35	1.15	17.9	45.4
14	29.9%	0.6%	13.6	-207.6	-7.4	-48.0	1.35	1.15	17.9	46.5
15	29.9%	0.6%	13.4	-207.6	-7.0	-49.4	1.35	1.15	17.9	46.8
16	30.0%	0.6%	13.7	-206.8	-6.9	-49.0	1.35	1.15	17.9	47.3
18	30.1%	0.6%	13.8	-207.1	-7.0	-48.8	1.35	1.15	17.9	47.8
20	30.2%	0.7%	14.0	-205.5	-6.7	-48.6	1.35	1.15	17.9	48.1
22	30.2%	0.7%	13.8	-202.3	-7.0	-48.1	1.35	1.15	17.9	48.3
24	30.2%	0.7%	13.8	-199.1	-7.2	-47.2	1.35	1.15	17.9	48.4
26	30.1%	0.7%	13.9	-200.5	-6.4	-48.2	1.35	1.15	17.9	48.4
28	30.2%	0.7%	13.8	-198.7	-6.5	-46.7	1.35	1.15	17.9	48.6
30	30.4%	0.7%	14.0	-196.2	-6.0	-46.2	1.35	1.15	17.9	48.7
32	30.3%	0.8%	14.1	-194.9	-5.8	-46.3	1.35	1.15	17.9	48.7
34	30.5%	0.8%	13.8	-192.2	-5.8	-45.8	1.35	1.15	17.9	48.8
36	30.3%	0.8%	13.9	-191.3	-5.7	-46.0	1.35	1.15	17.9	48.9
38	30.5%	0.8%	14.2	-191.7	-5.6	-46.1	1.35	1.15	17.9	49.0
40	31.2%	0.9%	14.1	-190.8	-5.4	-46.0	1.35	1.15	17.9	49.0
42	31.8%	0.9%	14.0	-187.7	-5.8	-45.0	1.35	1.15	17.9	49.1
44	32.0%	1.0%	14.3	-188.6	-4.7	-46.2	1.35	1.15	17.9	48.9
46	32.6%	1.0%	14.3	-184.5	-5.6	-43.7	1.35	1.15	17.9	49.0
48	32.8%	1.0%	14.3	-184.4	-5.5	-43.8	1.35	1.15	17.9	48.9
50	32.9%	1.1%	14.0	-182.5	-5.4	-43.7	1.35	1.15	17.9	48.8
52	32.9%	1.1%	14.3	-181.1	-5.0	-43.3	1.35	1.15	17.9	48.9
54	32.9%	1.2%	14.4	-179.1	-4.9	-42.7	1.35	1.15	17.9	48.8
56	32.8%	1.3%	14.4	-178.4	-4.9	-42.7	1.35	1.15	17.9	48.9
58	32.9%	1.3%	14.3	-177.8	-4.7	-42.6	1.35	1.15	17.9	48.8
60	33.0%	1.4%	14.4	-176.6	-4.8	-42.3	1.35	1.15	17.9	48.7
62	32.9%	1.4%	14.3	-175.6	-4.8	-42.3	1.35	1.15	17.9	48.5
64	32.9%	1.5%	14.4	-174.7	-4.6	-42.2	1.35	1.15	17.9	48.4
66	32.8%	1.6%	14.4	-174.3	-4.6	-42.4	1.35	1.15	17.9	48.3
68	32.8%	1.7%	14.6	-174.0	-4.5	-42.4	1.35	1.15	17.9	48.3
70	32.7%	1.8%	14.3	-177.2	-4.9	-43.0	1.35	1.15	17.9	48.2
72	32.6%	1.9%	14.6	-177.6	-4.6	-42.8	1.35	1.15	17.9	48.3
74	32.4%	2.0%	14.4	-178.7	-4.6	-43.2	1.35	1.15	17.9	48.3
76	32.5%	2.1%	14.8	-178.9	-4.5	-43.4	1.35	1.15	17.9	48.2
78	32.2%	2.3%	14.7	-181.0	-4.4	-44.0	1.35	1.15	17.9	48.2
80	32.2%	2.4%	14.7	-185.5	-4.8	-45.7	1.35	1.15	17.9	48.0

Figure VII-1: Results Of SCSR Capacity Test

CYCLIC TEST

TIME	FIO2	FICO2	PEPRS	PIPRS	AEPRS	AIPRS	VO2	VCO2	RR	IWBEND
MIN	%	%	CMH2O	CMH2O	CMH2O	CMH2O	L/M	L/M	/M	DEGC
1	20.4%	0.2%	2.7	-3.8	0.5	-1.5	3.00	3.20	22.9	25.3
2	30.2%	0.4%	63.3	-93.5	34.7	-54.4	3.00	3.20	24.5	31.7
3	26.1%	0.3%	123.8	-111.9	80.5	-46.8	3.00	3.20	24.5	39.3
4	25.5%	0.3%	42.3	-200.3	16.3	-89.7	3.00	3.20	24.5	44.5
5	30.1%	0.3%	44.3	-205.1	15.9	-92.0	3.00	3.20	24.5	48.0
6	32.9%	0.4%	45.0	-203.1	17.0	-92.6	2.92	3.09	24.5	50.9
7	34.8%	0.5%	25.7	-206.5	5.0	-67.4	2.00	1.80	19.8	52.1
8	35.8%	0.4%	25.8	-201.1	5.2	-65.4	2.00	1.80	19.8	52.1
9	36.2%	0.5%	25.8	-200.6	5.2	-65.3	2.00	1.80	19.8	52.0
10	36.9%	0.5%	25.8	-201.2	5.0	-65.1	2.00	1.80	19.8	52.0
11	36.9%	0.5%	25.7	-196.5	4.8	-63.9	2.00	1.80	19.8	52.2
12	37.6%	0.6%	25.7	-203.3	4.7	-65.1	2.00	1.80	19.8	52.2
13	36.8%	0.6%	25.7	-188.7	4.3	-63.0	2.00	1.80	19.8	52.5
14	37.3%	0.6%	25.3	-200.3	3.7	-64.3	2.00	1.80	19.8	52.6
15	37.5%	0.7%	25.3	-200.8	3.2	-63.8	2.00	1.80	19.8	52.7
16	37.9%	0.7%	25.5	-199.9	3.2	-63.5	2.00	1.80	19.8	52.8
17	38.0%	0.8%	25.3	-202.0	2.8	-63.9	2.00	1.80	19.8	52.8
18	38.1%	0.8%	25.1	-201.5	2.4	-63.2	2.00	1.80	19.8	52.9
19	38.3%	0.9%	25.1	-203.5	1.8	-63.2	2.00	1.80	19.8	52.9
20	38.4%	1.0%	25.1	-204.4	1.7	-63.5	2.00	1.80	19.8	52.8
21	38.8%	1.0%	25.1	-205.0	1.8	-64.0	2.00	1.80	19.8	52.8
22	39.7%	0.9%	15.3	-183.7	-8.4	-46.7	0.35	0.28	13.1	51.3
23	40.1%	0.4%	14.0	-161.3	-12.9	-38.2	0.35	0.28	12.0	50.0
24	39.3%	0.3%	13.5	-151.6	-14.4	-35.8	0.35	0.28	12.0	48.3
25	38.6%	0.2%	13.3	-149.5	-15.1	-35.0	0.35	0.28	12.0	46.8
26	37.9%	0.2%	13.0	-147.1	-14.7	-34.2	0.35	0.28	12.0	45.6
27	37.2%	0.2%	12.9	-145.6	-14.4	-34.0	0.35	0.28	12.0	44.5
28	36.4%	0.2%	13.0	-143.6	-14.1	-33.4	0.35	0.28	12.0	43.7
29	35.7%	0.2%	12.9	-142.6	-14.0	-32.7	0.35	0.28	12.0	43.0
30	35.0%	0.2%	12.9	-139.7	-13.7	-32.4	0.35	0.28	12.0	42.3
31	34.1%	0.2%	12.8	-138.7	-13.4	-32.0	0.79	0.77	12.0	41.8
32	32.7%	0.6%	41.7	-141.0	15.8	-75.2	3.00	3.20	24.5	43.2
33	31.4%	2.1%	42.1	-203.2	13.0	-88.1	3.00	3.20	24.5	46.3
34	34.0%	2.5%	43.4	-205.0	14.3	-91.2	3.00	3.20	24.5	49.8
35	35.9%	2.8%	44.2	-203.4	14.8	-91.9	3.00	3.20	24.5	52.4
36	37.0%	3.1%	44.9	-200.9	15.3	-91.7	3.00	3.20	24.5	54.0
37	38.0%	2.5%	27.9	-200.4	4.6	-67.1	2.00	1.80	20.3	54.8
38	39.4%	1.9%	26.1	-194.5	2.7	-61.9	2.00	1.80	19.8	54.3
39	39.7%	1.9%	25.9	-194.2	2.4	-61.9	2.00	1.80	19.8	53.6
40	39.7%	2.0%	25.7	-193.6	2.3	-62.1	2.00	1.80	19.8	53.2
41	39.7%	2.1%	25.7	-194.0	2.2	-62.1	2.00	1.80	19.8	53.0
42	39.7%	2.2%	25.4	-196.7	1.7	-62.7	2.00	1.80	19.8	52.8
43	39.8%	2.3%	25.5	-194.8	1.8	-62.3	2.00	1.80	19.8	52.7
44	39.6%	2.4%	25.5	-193.9	1.9	-62.2	2.00	1.80	19.8	52.7
45	39.6%	2.5%	25.5	-194.0	2.1	-62.3	2.00	1.80	19.8	52.5
46	39.7%	2.7%	25.7	-195.3	2.1	-62.7	2.00	1.80	19.8	52.4
47	39.5%	2.8%	25.5	-193.1	2.4	-62.1	2.00	1.80	19.8	52.3
48	39.5%	2.9%	25.5	-192.2	2.1	-62.2	2.00	1.80	19.8	52.2
49	39.5%	3.1%	25.5	-193.1	2.5	-62.5	2.00	1.80	19.8	52.1
50	39.3%	3.3%	25.8	-192.6	2.6	-62.8	2.00	1.80	19.8	52.0
51	39.3%	3.5%	25.8	-190.1	3.3	-62.4	1.84	1.65	19.8	51.9
52	41.0%	2.3%	14.7	-175.0	-8.7	-41.4	0.35	0.28	12.0	50.3
53	42.2%	1.1%	14.6	-152.2	-11.5	-34.9	0.35	0.28	12.0	49.5
54	41.8%	0.6%	14.2	-142.4	-11.7	-32.0	0.35	0.28	12.0	47.9
55	41.1%	0.5%	13.8	-137.8	-11.3	-30.9	0.35	0.28	12.0	46.5
56	40.3%	0.4%	13.8	-137.5	-11.6	-30.7	0.35	0.28	12.0	45.3
57	39.7%	0.4%	13.5	-137.0	-11.7	-30.8	0.35	0.28	12.0	44.3
58	39.0%	0.4%	13.5	-139.1	-11.7	-30.9	0.35	0.28	12.0	43.5
59	38.4%	0.4%	13.5	-139.7	-11.8	-31.0	0.35	0.28	12.0	42.8
60	37.7%	0.4%	13.4	-141.6	-12.2	-31.3	0.35	0.28	12.0	42.2
61	37.0%	0.4%	13.3	-141.7	-12.6	-31.7	0.35	0.28	12.0	41.6
62	35.6%	1.3%	40.9	-127.9	15.4	-70.7	3.00	3.20	23.4	42.8
63	30.5%	6.1%	44.0	-182.7	15.9	-87.3	3.00	3.20	24.5	45.5

Figure VII-2: Results Of SCSR Cyclic Test

SIMULATED MAN TEST 4

TIME	FIO2	FICO2	PEPRS	PIPRS	AEPRS	AIPRS	VO2	VCO2	RR	IWBEND
MIN	%	%	CMH2O	CMH2O	CMH2O	CMH2O	L/M	L/M	/M	DEGC
1	19.6%	3.2%	6.8	-5.9	2.5	-2.1	0.61	0.51	16.6	23.8
2	33.0%	1.8%	63.7	-135.5	14.7	-35.1	0.69	0.57	18.0	27.6
3	24.9%	1.5%	6.3	-174.8	-32.4	-53.3	0.69	0.57	18.0	31.7
4	25.4%	1.1%	12.0	-191.1	-22.3	-58.6	1.15	0.91	23.3	34.1
5	26.5%	0.9%	15.9	-199.6	-16.7	-61.1	1.52	1.10	26.1	35.9
6	29.1%	0.4%	24.1	-212.2	-2.0	-67.7	2.46	1.95	22.9	37.4
7	29.7%	0.3%	40.2	-196.5	5.7	-80.4	2.87	2.95	27.9	40.6
8	29.9%	0.4%	32.9	-208.0	1.3	-70.5	2.06	2.31	24.7	44.3
9	30.0%	0.6%	37.8	-197.4	-12.9	-61.7	1.75	1.81	30.4	46.3
10	30.5%	0.6%	38.3	-200.7	-12.8	-62.4	1.85	1.81	30.3	47.7
11	31.1%	0.5%	44.2	-199.4	-10.7	-66.6	1.90	1.92	31.2	48.8
12	32.0%	0.6%	46.1	-185.0	-10.9	-67.6	1.96	1.95	34.3	49.6
13	31.7%	0.6%	46.7	-188.2	-8.7	-68.0	1.90	1.93	32.0	50.3
14	31.6%	0.7%	47.0	-180.0	-6.2	-67.4	1.90	1.99	31.9	50.7
15	31.1%	0.8%	38.5	-189.4	-14.0	-60.7	1.69	1.66	30.8	50.9
16	31.0%	0.8%	33.2	-190.4	-17.7	-56.7	1.65	1.49	30.8	50.8
17	31.2%	0.9%	34.4	-191.2	-20.5	-58.1	1.65	1.44	34.1	50.7
18	32.0%	0.6%	25.7	-204.8	-1.9	-62.1	2.07	1.63	22.7	50.5
19	34.0%	0.6%	23.5	-207.2	0.9	-61.1	1.99	1.58	21.5	50.2
20	33.6%	0.9%	27.6	-186.4	-12.6	-54.6	1.47	1.30	27.5	49.7
21	33.3%	0.9%	30.2	-191.7	-12.0	-57.1	1.83	1.46	28.3	49.7
22	32.5%	0.9%	24.7	-190.3	-13.4	-53.4	1.41	1.20	25.7	49.7
23	32.3%	1.0%	34.4	-196.1	-12.5	-60.1	1.85	1.56	30.4	49.9
24	31.7%	1.0%	23.9	-190.1	-13.5	-53.0	1.41	1.20	25.5	49.7
25	31.0%	1.2%	15.2	-174.9	-23.6	-46.6	0.87	0.78	25.5	49.0
26	28.8%	1.3%	14.2	-162.1	-24.5	-39.5	0.80	0.71	25.2	48.7
27	28.2%	1.1%	21.5	-176.9	-22.4	-45.8	1.26	1.09	29.0	48.7
28	29.1%	1.0%	24.5	-181.8	-16.6	-50.1	1.43	1.22	27.5	48.7
29	29.5%	1.1%	23.7	-187.7	-18.4	-51.0	1.43	1.17	28.8	48.7
30	29.5%	1.1%	21.2	-181.5	-20.5	-48.1	1.34	1.09	28.4	48.6
31	29.4%	1.0%	27.9	-200.8	-0.8	-66.6	2.05	1.69	23.8	48.9
32	30.5%	1.1%	28.5	-197.2	1.7	-68.5	2.29	1.94	23.4	49.1
33	31.6%	1.2%	28.7	-193.6	1.9	-68.6	2.14	1.83	23.4	49.5
34	32.3%	1.3%	30.3	-189.3	-7.8	-59.2	1.66	1.44	26.4	49.4
35	32.3%	1.4%	37.1	-186.9	-9.2	-62.6	1.87	1.59	31.0	49.5
36	32.2%	1.5%	32.8	-185.9	-11.7	-58.2	1.72	1.44	30.8	49.7
37	32.2%	1.3%	31.2	-179.7	-10.7	-54.4	1.59	1.35	28.1	49.7
38	32.1%	1.4%	31.0	-180.1	-12.1	-55.6	1.71	1.42	30.1	49.6
39	31.6%	1.5%	32.9	-181.6	-12.2	-57.7	1.63	1.42	30.8	49.7
40	31.7%	1.6%	34.9	-188.2	-11.3	-59.8	1.89	1.59	30.8	49.9
41	31.6%	1.7%	34.9	-186.5	-11.2	-59.5	1.85	1.63	30.8	50.2
42	30.9%	1.7%	34.9	-186.3	-9.5	-59.2	1.74	1.63	29.4	50.5
43	31.2%	2.0%	40.8	-186.3	-8.6	-65.6	1.94	1.84	32.8	50.7
44	31.1%	1.9%	30.7	-179.9	-13.1	-54.8	1.42	1.41	29.5	51.0
45	31.0%	1.6%	21.0	-161.7	-18.9	-43.6	1.00	1.00	29.7	50.3
46	30.2%	1.7%	25.0	-163.9	-17.5	-47.1	1.24	1.20	31.2	49.8
47	30.4%	1.8%	23.4	-172.9	-19.7	-47.9	1.52	1.21	30.8	49.6
48	30.3%	1.9%	23.1	-175.2	-20.3	-48.5	1.52	1.21	30.8	49.5
49	30.1%	1.9%	23.1	-176.0	-20.6	-48.5	1.52	1.21	30.8	49.4
50	30.1%	1.9%	22.9	-175.8	-20.7	-48.4	1.52	1.21	30.8	49.4
51	29.8%	2.0%	23.1	-177.6	-20.4	-48.7	1.53	1.21	30.8	49.3
52	29.6%	2.0%	25.5	-181.4	-18.0	-50.8	1.66	1.27	29.3	49.4
53	29.5%	2.2%	34.5	-186.6	-12.7	-59.1	1.95	1.58	30.2	49.5
54	29.7%	2.4%	37.1	-187.4	-9.0	-61.5	1.90	1.64	29.3	49.8
55	29.9%	2.5%	38.8	-187.8	-6.7	-63.5	1.90	1.73	28.8	49.9
56	31.1%	2.6%	30.8	-191.4	4.4	-70.0	2.05	1.89	24.0	50.0
57	31.4%	2.7%	30.3	-179.9	4.2	-67.6	2.08	1.91	23.7	50.0
58	32.4%	2.8%	29.8	-179.6	5.4	-67.8	2.09	1.80	23.4	50.1
59	33.7%	2.8%	30.0	-175.1	6.2	-66.9	2.07	1.73	23.4	49.9
60	33.5%	2.6%	27.7	-167.4	-12.4	-50.3	1.37	1.18	28.0	49.5
61	32.2%	2.4%	16.7	-158.4	-22.9	-41.5	0.92	0.79	27.9	48.6

Figure VII-3: Results Of SCSR Simulated Man-Test 4