Surface Normalized 1ATA Rebreather Tester

SNORT

One Atmosphere Rebreather Scrubber Testing

conforming to EN14143 in all ways but 1

& it’s inexpensive

November 1, 2022

1 Atmosphere – 0 FSW – 0 MSW – Rebreather Scrubber Testing

Rebreathers have several “moving parts” that must work together that provide a safe, enjoyable way to extend recreational diving range. The carbon dioxide absorbing scrubber of a rebreather is the limiting element. One can carry an array of gas cylinders, but there is usually only one scrubber. Objective scrubber duration testing to a standard is expensive, and few facilities are available to do the testing for commercial units. The test equipment is very costly and facility charges are in the range of $3,000 USD per day and on a good day only two scrubber runs can be completed.

Testing to CE 14143 requires 7 scrubber duration tests, cost: $12,000 USD. A lot of this is driven by facility and personnel costs and the $1,000,000+ USD test device used for all respiratory equipment testing.

The information provided in training only touches on the complexity, relying on the manufacturer to provide simple scrubber duration information. Limited by liability and the cost of extensive testing, we may only get a plug number, say 160 minutes for scrubber duration, tested at 4°C, with CO2 injected at a rate of 1.6 L/M.

Manufacturers are limited by the expense of testing, rather than spend thousands on refining scrubber shape or flow by testing, the easy way to market is to use a tube of some diameter and length and make an axial scrubber. Radial scrubbers have some benefits, but not well defined.

Divers routinely extend scrubber duration times based on not much more than intuition, hearsay, or times posted online. Scrubber testing done to a standard is worst case, in a 4°C/40°F water bath and using a CO2 injection rate mirroring a heavy workload, but we dive in much warmer water and swim gently along.

We were told that deep diving would shorten scrubber duration, and use of high helium content trimix would also shorten scrubber duration. In testing a commercial rebreather at an accredited facility, we saw something odd, tests done at 100 meters using 7/90 trimix produced durations about 12% longer than using air diluent at 40 meters.

What is the truth about scrubber duration? What impact does water temperature or helium diluent have? What is the CO2 production rate of a diver swimming slowly over a reef? The safest thing to do is to stick with scrubber duration found in testing to a standard, if the manufacturer has performed the testing, and if they provide duration time. What does your manual say?

In talking to people who are very experienced in rebreather testing one finds out that yes high helium diluents do extend scrubber duration, yes scrubber duration is extended when diving in warm water, and no depth does not affect scrubber duration.

If depth does not affect scrubber duration, maybe we can make a low-cost device to test scrubbers to a standard without doing the testing at depth, just do the testing at 1 atmosphere.

We can validate the idea by testing a scrubber at 1 atmosphere which has been tested by an accredited facility and comparing duration.

Test standard requirements

Test Method	Water temperature	Heat & Humidity	CO2 injection rate	Depth
EN 14143	4°C 39.2°F	32°C ± 4°C w 80% RH 89.6°F ±7.2°F	1.6 L/M	40 m, 100 m
NEDU 01-94	40°F 4.4°C	32°C ± 4°C w 80% RH 89.6°F ±7.2°F	1.35 L/M	various

How the surface normalized 1 atmosphere rebreather tester works

In simple terms the tester must simulate a human breathing whilst using a rebreather.

There are 4 sub-systems to the SNORT 1ATA Scrubber tester:

- Breathing
  - Breath volume and breaths per minute
  - Exhaling warm humid gas into the rebreather
- Adding CO_2 to the breathing loop
- Measuring the level of CO_2 in exhaled gas
- Temperature controlled water bath

Breathing rates are standardized as breath volume and breathes per minute. SNORT uses 2 liter breaths and breathes at a rate of 20 breathes per minute, this is called the respiratory minute volume (RMV) and at 20 breathes per minute, at 2 liters per breath we have 20 X 2 = 40 RMV. 40 RMV is the standard breathing rate for scrubber testing.

SNORT achieves 40 RMV by using two opposing 2 liter pneumatic cylinders. One cylinder is the drive cylinder and the other is the breathing cylinder. The shafts are coupled to each other. The drive cylinder has two solenoids ported to each inlet port on the cylinder, one normally open solenoid and one normally closed solenoid. When one set of solenoids is energized gas can flow into that end of the drive cylinder, this moves the piston pair to cause the active port on the breathing cylinder to either inhale or exhale. There is a double pole, double throw switch mounted to the shaft coupler. When the piston has moved to each end of the stroke an adjustable stop, throws the switch to its other position, causing the piston to move back and forth. Speed is controlled by adjusting the drive air pressure.

Warming and humidifying the gas before it enters the rebreather is accomplished using a rectangular aluminum box with breathing gas ports on either end. This box is partly filled with water and has a contact heater on the outside of the box. The heater is thermostatically controlled to maintain a temperature of 88°F to 92°F. This temperature is monitored on the SNORT control panel. The breathing gas dwells in this chamber during the inhale part of the breathing cycle. The breathing gas is warmed and humidified prior to entering the rebreather.

CO_2 is added to the loop by injecting CO_2 into the breathing cylinder. Just like breathing rates (RMV) CO_2 injection rate is defined as being 4% of the RMV. So at a 40 RMV the CO_2 injection rate is 1.6 liters per minute. SNORT uses a SARGO MEMS (micro-electro-mechanical system) mass flow sensor and a Swagelok needle valve to inject precisely 1.6 liters of CO_2 per minute.

A gas sample is withdrawn from the breathing loop at the point where scrubbed gas enters the diver's shutoff valve, this is the gas that a diver will inhale. The sample gas travels through a water trap, a NAFION tube dryer, a metering pump and then on to a GSS 0-5% NDIR CO_2 sensor. Sample flow is visualized in a bubble chamber on the control panel. The sensor output is displayed on a computer screen and logged as a .cvs file

The rebreather under test is immersed into a water bath, temperature of the water bath is monitored on the control panel and maintained by adding ice from Publix.

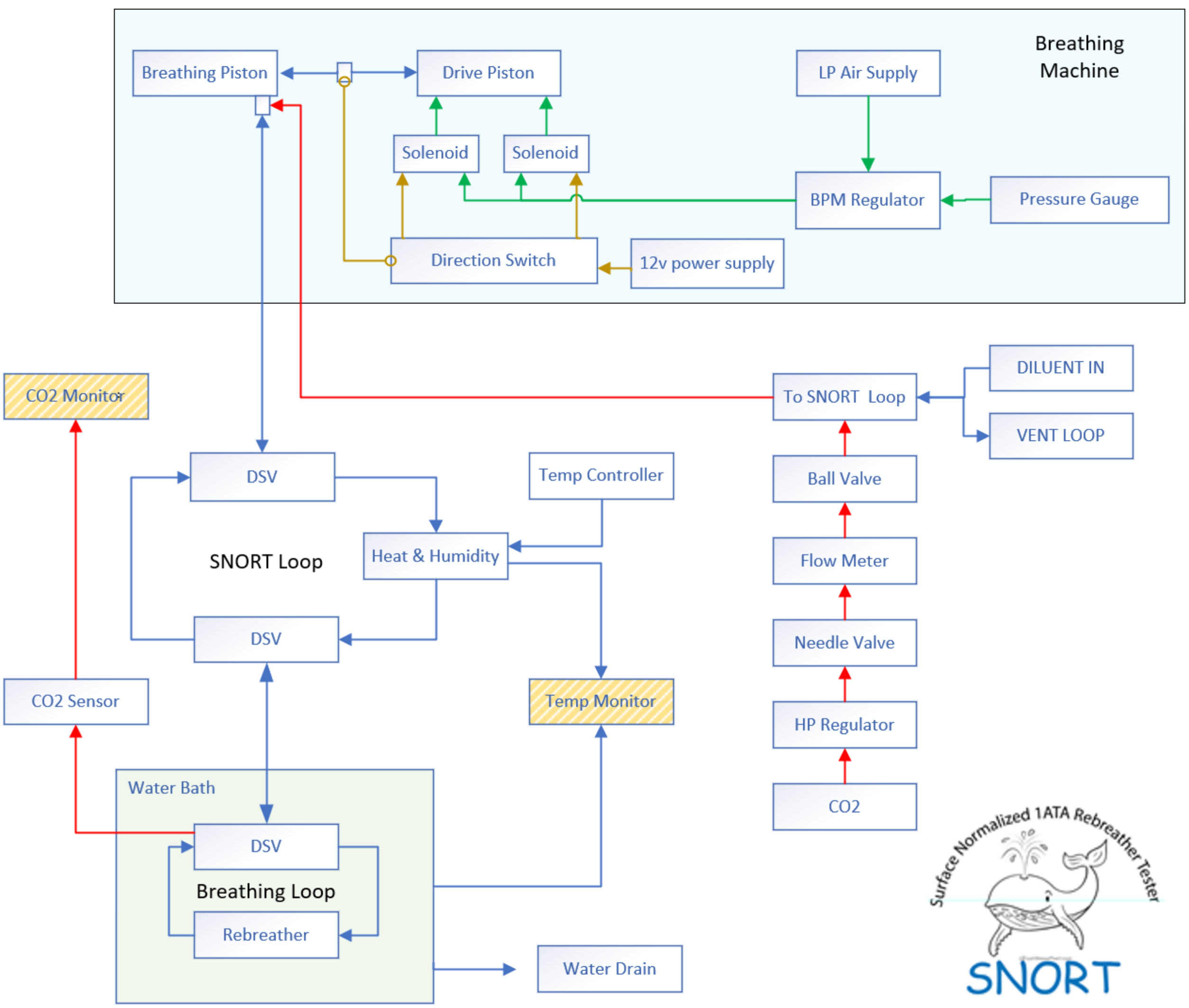
Below you will find a table comparing SNORT, EN14143, and NEDU TM 01-94 standards, a table of standard breathing rates with CO_2 and O_2 noted and a block diagram of SNORT.

Test Method	Water temperature	Heat & Humidity	CO_2 injection rate	Depth
EN 14143	4°C 39.2°F	32°C ± 4°C w 80% RH 89.6°F ±7.2°F	1.6 L/M	40 m, 100 m
NEDU TM 01-94	40°F 4.4°C	32°C ± 4°C w 80% RH 89.6°F ±7.2°F	1.35 L/M	132 FSW 40 MSW
SNORT	32°F to 40°F other temperatures	32°C ± 4°C w 80% RH 89.6°F ±7.2°F	1.6 L/M other injection rates	0 FSW (MSW)

CO_2 value is in liters per minute injection rate

RMV	Breath volume	Breathing rate	CO_2
10	1	10	0.4
22.5	1.5	15	0.9
40	2	20	1.6
2.5	2.5	25	2.5
75	2.5	30	3.0
90	3	30	3.6

Surface Normalized 1ATA Rebreather Tester



SNORT's Parts

4 Sub Systems:	Upgrades
1. CO_2 injection and analysis a. CO_2 injection i. CO_2 cylinder ii. CO_2 regulator iii. Swagelok needle valve iv. SIARGO flow meter b. Sample conditioning i. Nafion tubing c. CO_2 analysis i. GSS 0-5% sensor ii. GasLab software d. Sample flow verification i. Bubble chamber	Omega engineering mass flow controller $2,000 Sable Systems CO_2 Analyzer $5,000
2. Breath heat and humidity a. Chamber i. 72 sq. in. surface area b. Heat source i. Contact heater ii. Temperature controller iii. Additional temperature monitor c. Water source i. Addition port	Pressure capable $500
3. Breathing machine a. Opposing pistons i. 2-liter Baomain air cylinder ii. ½" NO & NC Solenoids iii. 12v HD power supply iv. Direction Switch v. Stroke length control vi. Harbor Freight compressor vii. Precision regulator & gauge b. Directional valves i. Commercial DSV (2) ii. McMaster PVC fittings & hoses	Parker Electric Linear actuator & piston $2,500 Gear motor rotating cam & piston $3,000
4. Test chamber a. Wet or dry i. Igloo cooler b. Temperature i. Maintained by ice ii. Water temperature monitor c. Pressure i. 1 atmosphere	ANSTI type $750,00 Vertical cylinder, insulated $432 Heat/chill water system w pump $1,500

SNORT BOM, sources

Amazon 1/2" Brass Electric Solenoid Valve110VAC VITON Seal N.C. – ASIN B00DQ17PHQ

Amazon 1/2" Brass Electric Solenoid Valve 110V AC NBR Seal N.O. – ASIN B00APDGGRI

Amazon Baomain Pneumatic Air Cylinder SC Bore: 4” Stroke 10” – ASIN B077XSTL2R

Amazon Temperature Controller 1650W 15A – ASIN B01KMA6EAM

Amazon ANPTGHT 3/16” Thru-Bulk Bulkhead Plastic Hose Barb Fittings – ASIN B08SCDC28R

Co2meter.com ExplorIR®-W 5% CO2 Sensor

Co2meter.com Sensor Tube Cap Adapter for 20mm Sensors

Co2meter.com Sensor Pump Kit

Co2meter.com Nafion Tubing for Gas Sampling Sensors

McMaster tank heater w control 35765K204

McMaster Miniature Precision Compressed Air Regulators 2227T2

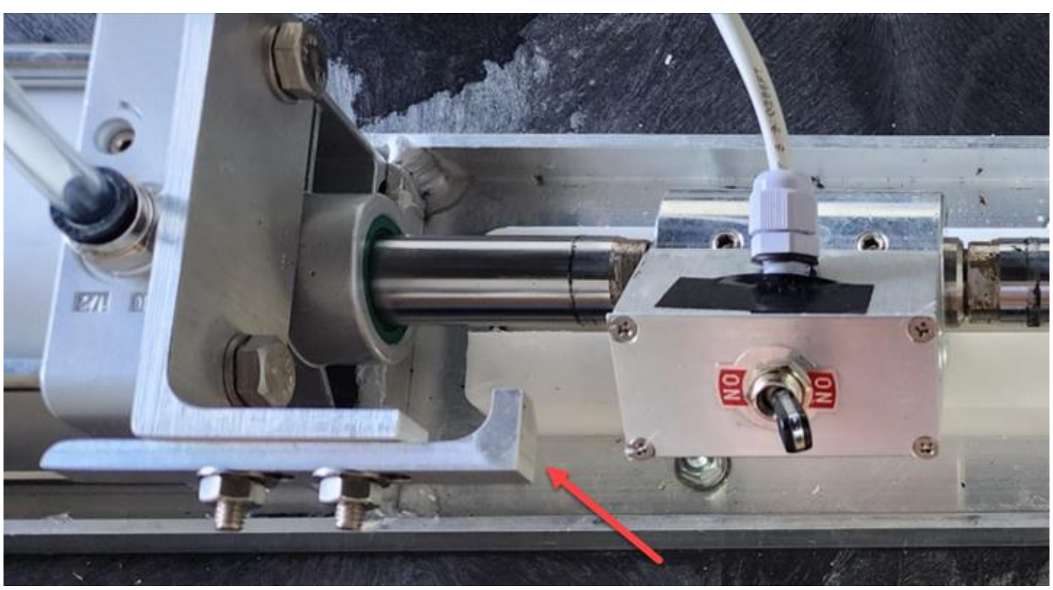
McMaster PVC Union 1” 4880K303

McMaster 1” ID Silicone tube 5153T15

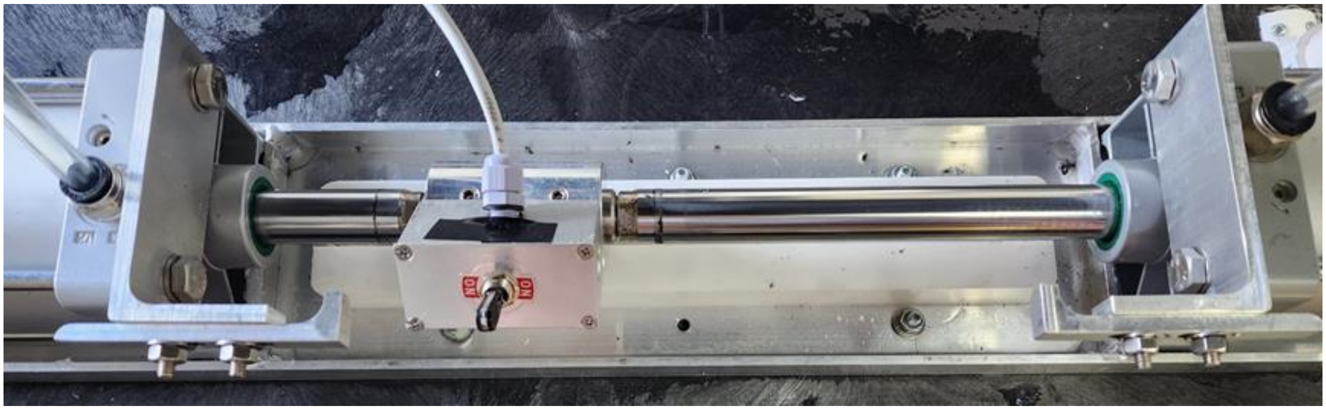
McMaster Duct Hose 1-1/4" ID, 1-11/16” OD 5915T13

Siargo.us MF5700 general purpose mass flow meter

Breathing machine adjustable direction switch stop:

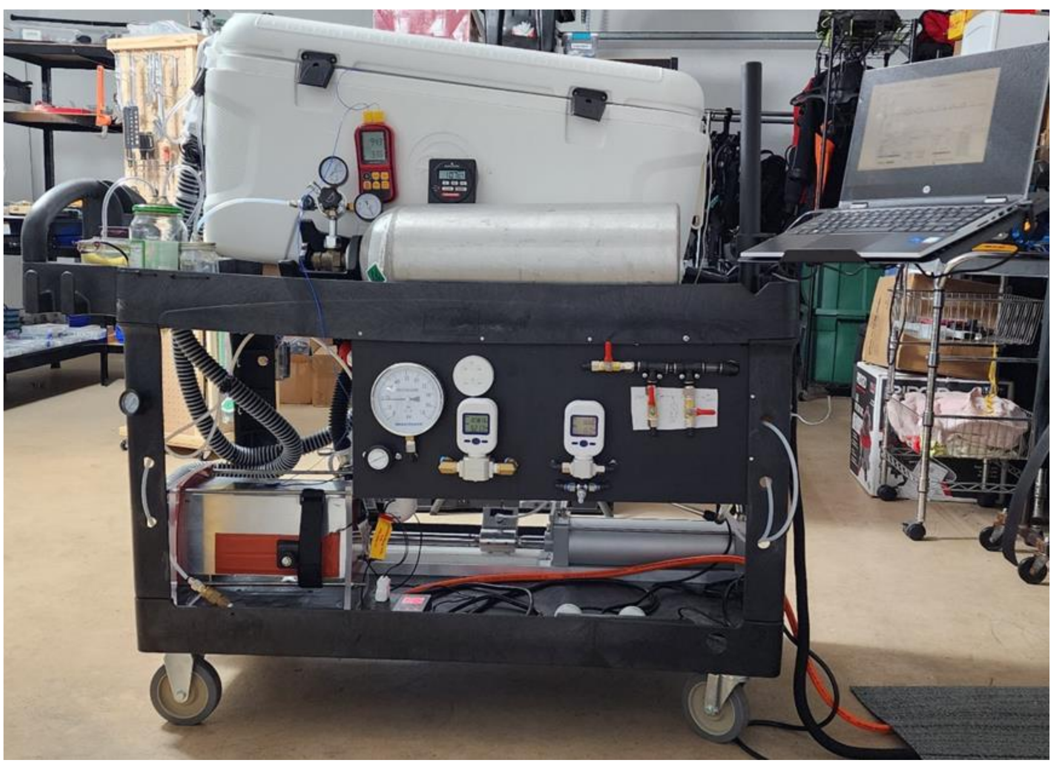


Breathing machine opposing pistons:



Heat and humidity chamber with heater:

SNORT 1



SNORT Testing

System verification testing

The first tests we did were to test the system; eliminate leaks, understand how the CO2 sub-system worked, verify that we had heated humidified air in the loop, and could maintain the 2 liter breaths, 20 times a minute to have a Respiratory Minute Volume of 40 (40 RMV)

1. Using the SCUBATRON Generic Breathing Machine
2. Initial testing done dry
3. Subsequent testing done with the rebreather loop underwater
4. Additional testing was done at lower temperatures, down to 32°F (0°C)
5. We also tested using Helium diluent testing

Once we had the system verified, we knew it could duplicate all EN14143 test requirements (except one)

Test method validation testing

1. Using the Hollis Prism 2
2. Comparing to EN14143 testing done at QinetiQ
3. Tests done cold & wet
4. Mirroring the tests done at 40 meters, air diluent, at QinetiQ

We want to thank Nick Hollis and Hollis Rebreathers for granting use of Hollis Prism 2 test results

Using the Hollis Prism 2 we compared the average scrubber duration from 3 tests done at 40 meters at the QinetiQ facility in the UK to 2 tests using the Hollis Prism 2 scrubber in out SNORT facility at colder temperatures

Date	Unit under test	Facility	Diluent	Test temperature	Absorbent	Breakthrough	0.5%	1.0%
Feb 2019	Prism	QinetiQ	Air	4°C 39°F	Sofnolime	N/A	197	220
Oct 2022	Prism	SNORT	Air	0°C 32°F	Sofnolime	124	186	207
Variance							-5.6%	5.9%

Breakthrough in testing is when the first faint trace of CO2 is detected

Complete Hollis Prism 2 test results can be found here https://www.hollisrebreathers.com/technology/

In the QinetiQ testing the 40-meter scrubber duration test results varied by 7.9%. in these tests we used the same Sofnolime keg for all 3 tests, and in each scrubber duration test the scrubber was packed with the same weight of Sofnolime.

The takeaway maybe that running a dive to the published scrubber duration time might not be the smartest thing to do, and arbitrarily extend a scrubber's run time beyond the manufacturers published duration time is risky.

From Dr. John Clarke's must read new book: **Breakthrough**:

"The results of U.S. Navy research and testing are finally begin revealed so you can see what has long been hidden inside the hot, caustic confines of a rebreather scrubber."

"While the enclosed material is technical, it is largely pictorial. You will learn many things about your underwater life support system that have never been disclosed to the public."

Some persistent questions about scrubber duration that may be answered using the low-cost SNORT system:

What is the impact of water temperature on scrubber duration?

What is the impact on scrubber of helium diluent vs. air?

What is the impact on scrubber duration of lower workloads?

How does an Axial scrubber compare to a Radial scrubber with the same gram weight of absorbent?

Does insulating an Axial scrubber extend its duration?

Scrubber duration is usually expressed as time in minutes, but ..

CO2 injection rate is 4% of the RMV. An RMV of 40 requires a CO2 injection rate of 1.6 liters per minute. RMV is breath volume times the number of breathes per minute. A RMV of 22.5 would require a CO2 injection rate of 0.9 L/M

Scrubber capacity is the CO2 injection rate times the time to a breakthrough of CO2 equal to 0.5% (5Kpa) of one atmosphere. If a scrubber tested at 40 RMV lasted 150 minutes we could say it absorbed 249 liters of CO2.

Oxygen consumed to produce CO2 is 0.9% of the volume of CO2 produced. To produce 1.6 liters of CO2 we would need to consume 1.44 liters of oxygen. Or one liter of oxygen metabolizes into 1.1 liter of CO2

The 249 liter capacity above would require metabolizing 226 liters of oxygen.

Scrubber duration could be inferred by the consumption of oxygen.

With an accurate digital pressure gauge and dive computer, one could enter the scrubber absorption capacity, and then have the DC display a new "Dive Time Remaining" based on the rate oxygen consumption.

NOTE: Rebreather scrubber testing must be conducted "*in situ",* in the complete rebreather breathing loop. While testing in SNORT mirrors "industry standard" testing, it does not duplicate all of the test conditions, SNORT tests at 1 atmosphere only. Depth may have a negative impact on scrubber duration. Water temperature and diluent also affect scrubber duration. Probably the most impactful variable is the human in the loop. From Dr. John Clarke's great book **Breakthrough** "…randomness inherent in both physics and human physiology influences the lifetime of a CO2 scrubber" ……. "Furthermore, since divers are not mechanical breathing machines built to specifications, a testing agency's assumptions about diver physiology may not match your physiology on any given day. **So, divers beware**"

A brief note about the genesis of SNORT 1

The Surface Normalized One-Atmosphere Rebreather Tester (SNORT) was conceptualized during discussions about the SCUBATRON chest mounted rebreather, the Generic Breathing Machine (GBM) in the fall of 2021.

Gregory Borodiansky and Chauncey Chapman collaborated on the design of the sub systems, and fabrication began in late 2021 on a part time basis. In the early summer of 2022 SNORT 1 was completed and verification testing began. SNORT 1 can test a recreational rebreather under conditions closely mirroring EN14143 or NEDU TM 0194. CO2 injection is measured using an electronic flow meter, continuous breathing is achieved using a regulated air pressure piston, air entering the rebreather is heated and humidified, testing occurs underwater using ice to maintain the required temperature, CO2 breakthrough is monitored in a Windows app using a GSS CO2 sensor.