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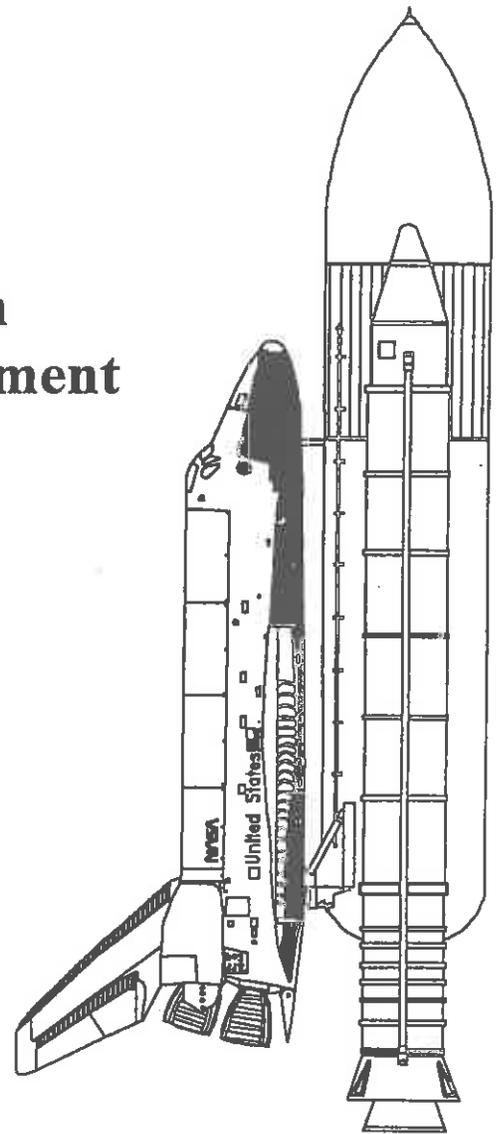
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**Test Report**

**Component Testing and Clean  
Verification of SCUBA Equipment  
for the NASA JSC Neutral  
Buoyancy Laboratory**

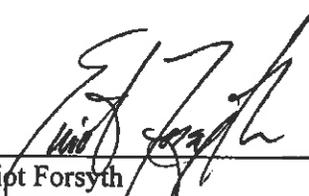
Lyndon B. Johnson Space Center  
White Sands Test Facility  
P. O. Box 20  
Las Cruces, NM 88004  
(505) 524-5011

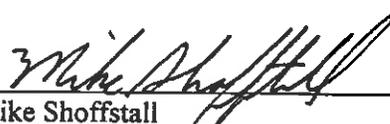


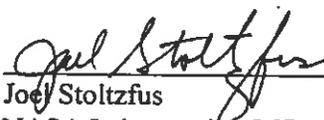
Test Report

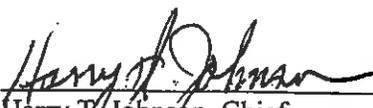
Component Testing and Clean Verification  
of SCUBA Equipment  
for the NASA JSC Neutral Buoyancy Laboratory

Issued By  
National Aeronautics and Space Administration  
Johnson Space Center  
White Sands Test Facility  
Laboratories Office

Prepared By:   
Elliot Forsyth  
AlliedSignal Technical Services Corp. Team

Reviewed By:   
Mike Shoffstall  
AlliedSignal Technical Services Corp. Team

Reviewed By:   
Joel Stoltzfus  
NASA Laboratories Office

Approved By:   
Harry T. Johnson, Chief  
NASA Laboratories Office

## Abstract

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The NASA White Sands Test Facility was requested by NASA Johnson Space Center (JSC) to perform component testing and clean verification on the self-contained underwater breathing apparatus (SCUBA) diving equipment to be used in the JSC Neutral Buoyancy Laboratory (NBL). The NBL facility requires divers to breathe a nitrogen/oxygen (NITROX) gas mixture with an oxygen concentration ranging between 21 and 49 percent. The increased oxygen concentration warrants testing of the apparatus in its worst-case use environment to evaluate potential ignition mechanisms. Three SCUBA equipment assemblies were tested, and included a first-stage regulator with flexhoses to two second-stage regulators, a submersible pressure gauge, and a buoyancy control device. Sixty pneumatic impact cycles were performed at 20.7 MPa (3000 psi) in a 50-percent NITROX gas mixture on each of the three test articles. Each test article passed the impact test with no failures or evidence of ignition. The clean verification indicated that gross amounts of particulate and non-volatile residue were present in the oxygen-wetted portions of the assemblies.

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## **1.0 Introduction**

WSTF was requested by NASA Johnson Space Center (JSC) to perform component testing and clean verification on the self-contained underwater breathing apparatus (SCUBA) diving equipment to be used in the JSC Neutral Buoyancy Laboratory (NBL). The component testing and clean verification were performed in response to recommendations made by an earlier oxygen hazards analysis of the JSC NBL SCUBA equipment (Forsyth 1996).

## **2.0 Objective**

The objective of the component tests was to determine the susceptibility of the NBL SCUBA equipment to ignition by pneumatic impact in a 50-percent nitrogen/oxygen (NITROX) mixture at worst-case operating conditions. The objective of the clean verification was to determine the approximate clean level of the oxygen-wetted portions of the SCUBA assemblies.

## **3.0 Background**

The JSC NBL facility will require divers to use a special NITROX gas mixture instead of conventional breathing air in their cylinders. Conventional breathing air has an oxygen concentration of approximately 21 percent; it ranges between 21 and 49 percent for the NITROX gas mixture. Previously, WSTF had performed an oxygen hazards analysis on this SCUBA equipment to consider the materials flammability and potential ignition mechanisms with the new gas mixture (Forsyth 1996).

The SCUBA equipment analyzed in the oxygen hazards analysis included an oxygen cylinder, an oxygen cylinder valve, a first-stage regulator, a second-stage regulator, a submersible pressure gauge, and a buoyancy control device. The analysis recommended that component testing be performed on the first-stage regulator and downstream assembly, at worst-case use conditions, to evaluate the equipment's vulnerability to ignition by pneumatic impact with gaseous oxygen. The analysis also recommended that clean verification be performed annually on a sample population of the SCUBA equipment to evaluate the cleanliness level.

## **4.0 Approach**

The approach for the component tests was to randomly select four SCUBA assemblies that had been in service for approximately one year from the JSC Weightless Environment Training Facility. These assemblies were delivered to WSTF for testing and evaluation.

The test articles were placed in a test fixture to secure them for impact and to allow for a remote venting of the test article. Each component assembly was tested individually in its use configuration by rapidly impacting the first-stage regulator for 60 cycles at the worst-case operating pressure. Three component assemblies were tested by pneumatic impact to assess the repeatability of the data.

Clean verification tests were performed on four SCUBA assemblies. The assemblies were functionally checked, disassembled, sampled for particulate and non-volatile residue (NVR), and re-assembled. The SCUBA assemblies were then returned to the customer.

## 5.0 Experimental

### 5.1 Test Articles

The SCUBA assemblies tested were the same as those analyzed in the hazards analysis, excluding the oxygen cylinder and oxygen cylinder valve. The assembly included a first-stage regulator, two second-stage regulators, a submersible pressure gauge, a buoyancy control device, and their connecting flexible hoses (Figure 1). A summary description of the test articles is shown in Table 1. Only three of the assemblies were tested by pneumatic impact (SCUBAs 2, 3, and 4). The fourth assembly, SCUBA 1, was a demonstration unit but was included in the clean verification tests. The demonstration unit was the only assembly that was ultrasonically cleaned before shipping. In three of the assemblies, NITROX O-ring kits were installed in the regulators before delivery to WSTF (SCUBAs 1, 3, and 4). These kits had Viton O-rings. In the other assembly (SCUBA 2), no pretest preparation was performed; the original O-rings were left installed, and the assembly was not cleaned before shipping.

**Table 1**  
Summary Description of SCUBA Test Articles

Name	First Stage Regulator	Second-Stage Regulator 1	Second-Stage Regulator 2	O-Rings	Clean
SCUBA 1	Mares MR 12 III S/N 651378	Mares MR 12 III S/N W29 07168648	Mares MR 12 III S/N W30 08036509	NITROX	Ultra-sonic
SCUBA 2	Mares MR 12 DFC S/N E70335	Mares MR 12 Navy S/N 513713	Mares MR 12 III S/N 06204829	Standard	None
SCUBA 3	US Divers Conshelf 21/22 S/N ALB0524	US Divers Conshelf 14 S/N B76K2310	US Divers Conshelf 14 S/N JY6K0735	NITROX	None
SCUBA 4	US Divers Conshelf 21/22 S/N ALB1100	US Divers Conshelf 14 S/N B76K119	US Divers Conshelf 14 S/N JY6K1857	NITROX	None

### 5.2 Test Method

The test method used to evaluate these SCUBA assemblies was pneumatic impact, or adiabatic compression. When a dead-ended test article filled with ambient pressure oxygen is rapidly pressurized, the pressure can increase too quickly for the heat of compression to be dissipated to the surroundings. Most of the thermal energy generated is contained in the compressed gas, resulting in a small slug of hot gas at an elevated pressure located at the dead end. In this test configuration, the

gas is rapidly compressed against the first stage regulator seat, which is the “dead-end.” In theory, the gas temperature generated by adiabatic compression should reach the autogenous ignition temperature of the polymer seat material in 100-percent oxygen. However, in this case, the first-stage regulator allows flow upon impact, so is not a true dead-end. Also, the gas is a 50-percent oxygen concentration, which decreases the severity of the test environment.

### **5.3 Test System**

The tests were conducted using a WSTF pneumatic impact component test system that simulates a sudden pressurization event such as what could be caused by a fast-opening system valve. The fast-opening system valve allows pressurization rates to the test article of approximately 20 ms with system pressures up to 69 MPa (10,000 psi). A VME computer system was used to control the pressurization of the test articles during the pneumatic impact cycles. The VME software was written to allow computer control of the fast-acting impact valve, the vent valve, and the upstream isolation valve. Otherwise, all valves were controlled by the test conductor. The VME system was also used for data acquisition. Standard video recordings were made of all tests.

A test fixture was designed and implemented to remotely vent the gas through the second-stage regulator (Figure 3). A Bimba actuator provided a piston to push the vent button on the second-stage regulator. The test fixture also secured the SCUBA regulators and flexible hoses and provided a mount for the test article pressure gauge so it could be monitored by video.

### **5.4 Test Conditions**

The test conditions were chosen to closely simulate the actual application. A 50-percent NITROX gas mixture was used in all tests. The pretest temperature was ambient. The test pressure up to the first-stage regulator was from ambient to maximum use pressure,  $20.7 \pm 0.7$  MPa ( $3000 \pm 100$  psi). The pressurization time to the first-stage regulator was consistent at approximately 20 ms.

### **5.5 Procedures**

#### **5.5.1 Pneumatic Impact Tests**

The test articles were treated as clean hardware while at WSTF. Latex gloves were used in handling the test articles at all times, and each component was double bagged to maintain clean whenever the test articles were not in the test system.

The test articles were inspected prior to installation in the test system, and any anomalies were noted. The test article was then mounted and secured in the test fixture. The first stage regulator was connected to the system’s test article interface (Figure 3). An aluminum blast shield and cinder blocks were placed around the test article to protect the test system from damage.

After installation, the test article was leak checked with gaseous nitrogen ( $\text{GN}_2$ ). The vent on one second-stage regulator was then opened, and the test article assembly was purged with low pressure NITROX to adequately displace the  $\text{GN}_2$ . The vent was then closed, and the system was pressurized up to the fast-acting isolation valve with NITROX at test pressure. The data acquisition and video equipment were then started. Upon command, the software opened the fast-acting valve, creating a rapid compression on the first-stage regulator, followed by a lower-pressure surge to the second-stage regulators. The pressure was held for approximately 18 s to determine if leaks were present,

indicating a possible ignition. Ignition was also determined by a flash on the video or by an audible report. If no reactions or failures were evident, the pressure was vented through the second-stage regulator vent and upstream of the first-stage regulator, and the test article was impacted again. A total of 60 pneumatic impacts were performed on SCUBAs 2, 3, and 4.

### 5.5.2 Clean Verifications

First, a functional check was performed on each SCUBA assembly by pressuring the assembly up to its maximum operating pressure with GN<sub>2</sub> and recording the pressure decay over 5 min. The SCUBA assemblies were then carefully disassembled to the piece-part level in a Class 100 flowbench to ensure cleanliness was maintained before flushing. Only the oxygen-wetted pieces of the assemblies were tested for cleanliness. The metal pieces were separated from the polymer pieces prior to flushing, and different procedures were used for the metal and polymer pieces. All metal pieces were flushed with CFC 113, and both particulate and NVR samples were evaluated. All polymer pieces were flushed separately with distilled water, and only a particulate sample was evaluated. No NVR levels were analyzed for polymer pieces because many polymers are composed of hydrocarbons that could be released into the sample and affect the results. For this reason, the flexible polymer hoses were flushed only with water and evaluated for particulate.

The metal pieces of the first-stage regulator that were individually flushed included the internal trim pieces, the internal regulator body, and the inlet filter. The first-stage regulator soft goods were flushed together as one sample. The metal pieces of the second-stage regulators that were individually flushed included internal trim pieces and the internal regulator body. The second-stage regulator soft goods were flushed together as one sample, and the flexible hoses were flushed individually.

## 6.0 Results and Discussion

### 6.1 Pneumatic Impact Tests

No indication of ignition or failure was observed in any piece of the three SCUBA assemblies tested. Even test article SCUBA 2, which did not have a NITROX-compatible soft good kit, did not sustain any ignitions. There were no flashes or audible reports in any tests, nor did any test article leak pressure during the pressure hold phase of the impact cycle. In each test, the pressurization rate to the test article was consistently 20 ms and the peak pressure was approximately 20.7 MPa (3000 psi).

Figure 4 shows a pressure vs. time curve for test article SCUBA 1, cycle 31. The pressure shown was read at the test article interface. This curve is typical of all pneumatic impact cycles performed on the three SCUBA assemblies. Data recording began before opening the fast-opening valve, when the test article pressure is ambient. Upon opening the fast-opening valve, the test article pressure reaches its peak pressure and is held for approximately 18 s before being vented back to ambient pressure. Because the first-stage regulator allows flow-through up to its set pressure, the upstream pressure bleeds through to the second-stage regulators, creating a slow pressure rise after the initial impact. This effect is more evident when only the impact phase of the cycle is plotted (Figure 5). The initial impact on the first-stage regulator, shown as the first pressure peak in Figure 5, consistently reached approximately 19.3 MPa (2800 psi) during each test. After the initial impact, the pressure reached its maximum at 20.7 MPa (3000 psi) after approximately 0.8 s.

Posttest functional checks with GN<sub>2</sub> showed no anomalies in any of the four SCUBA assemblies. Each assembly allowed minimal leakage over the 5 min hold at 20.7 MPa (3000 psi). Data sheets for each assembly recorded the pressure decay on two gauges, the test console gauge standard and the first-stage regulator gauge of the SCUBA assembly. The data sheets for SCUBAs 1 through 4 are included Appendices A through D, respectively.

## 6.2 Clean Verification Tests

After the functional checks were completed, the SCUBA assemblies were disassembled for the clean verification tests. The particulate level and NVR quantity data for the piece parts of the first- and second-stage regulators and connecting hoses of each assembly were recorded in detail on the data sheets in the Appendices. Table 2 summarizes the respective particulate and NVR levels for each component of the four SCUBA assemblies. The NVR levels recorded in Table 2 are calculated values based on the quantity in milligrams (mg) of NVR weighed in the sample, divided by the approximate surface area, in square feet (ft<sup>2</sup>), of the component piece(s) flushed. The unit of measure, mg/ft<sup>2</sup>, was chosen to allow easy comparison with data from previously reported literature. The surface areas of the component pieces used for calculation are only rough approximations and, in most cases, represent larger-than-actual surface areas to give best-case, lowest contaminant levels.

The first-stage regulator of each of the test articles was found to be highly contaminated in each of the four assembly parts, both in particulate and NVR levels. In SCUBA 1, the first-stage regulator parts each failed a Level 1000 particulate analysis, meaning that particles larger than 1000 μm were discovered in each of these parts after flushing (Table 2). The internal metal pieces in SCUBAs 3 and 4 had particulate levels higher than what could be counted. The particles were described as possibly “Krytox, plastics, metals, glass, and grit” (Appendices C and D). In SCUBA 2, the internal metal pieces failed a Level 200 particle count, meaning that at least one particle larger than 200 μm was found. The analysis did not state if higher particle levels would have been passed. The internal soft goods of each test article were flushed together, and large particulate was also found. SCUBA 3 had a particulate level higher than what could be counted. The inlet filter of SCUBA 2 passed a Level 300 particle level. No particles larger than 300 μm, and an allowable distribution of smaller particles, were found in the filter after back-flushing.

NVR levels in the first-stage regulators were also excessive. The internal metal pieces of SCUBA 4 showed the lowest NVR quantity of the four SCUBA assemblies analyzed, at 49.0 mg/ft<sup>2</sup> (Table 2). The body cavity NVR data for SCUBA 1 were not listed in Table 2 because of an error discovered during the sampling process which invalidated the NVR quantity, and the body cavity NVR data for SCUBA 3 were not analyzed. However, the NVR quantities for this part in SCUBAs 3 and 4 were very similar, at 102.7 mg/ft<sup>2</sup> and 118.7 mg/ft<sup>2</sup>, respectively. The inlet filter of SCUBA 1 was back-flushed, and a large amount of NVR was discovered, equaling 122.2 mg/ft<sup>2</sup>. Higher contamination levels in the filter were expected to a certain extent, because the filter is exposed to the outside environment during connecting and disconnecting the SCUBA assembly to its gas source. For SCUBA 2, the NVR quantity was significantly lower, at 24.4 mg/ft<sup>2</sup>.

The second-stage regulators of each test article were also found to be highly contaminated in each of their assembly parts. Particulate levels found on the internal metal pieces of each second-stage regulator failed level 750 and above in each test article. The particles were described as “mostly metal and fiber” (Appendices). Particulate analysis of the soft goods of each second-stage regulator indicated that one sample failed Level 300 and one failed Level 500, but the rest failed Level 1000 or higher. Similar high levels of particulate were found in sampling the second-stage regulator bodies. The particulate in one second-stage regulator body was described as “mostly clear and metal chunks and some clear fibers” (Appendix C). Some particulate samples from the flexible hoses were less contaminated. One flexible hose sample passed Level 200, and one passed a level 500. Most other hose samples, though, contained large particles. The particulate was characterized as “mostly metal” (Appendix C).

NVR levels were taken only for the internal metal pieces of the second-stage regulators. These ranged from 150.7 mg/ft<sup>2</sup> in Scuba #3 to 469.2 mg/ft<sup>2</sup> in Scuba #1. NVR levels were not taken for the second-stage regulator bodies because it was difficult to separate the polymer pieces from the metals.

## 7.0 Conclusions

No ignitions were sustained by the three SCUBA assemblies tested by pneumatic impact in a 50-percent oxygen NITROX mixture at 20.7 MPa (3000 psi). Even test article SCUBA 2, which did not have a NITROX-compatible soft good kit, did not sustain any ignitions. Functional tests performed after the completion of the pneumatic impact tests confirmed that each SCUBA assembly held pressure. The clean verification tests showed gross amounts of particulate and NVR in most component parts. Despite these high levels of contamination, the pneumatic impact tests demonstrated that the component design is robust enough to withstand ignition under worst-case NITROX operating conditions. It should be noted, however, that the results of this testing do not negate the need to pre-clean systems for oxygen service or the need to maintain these systems clean during use. Prudent knowledge and practice of oxygen system safety is recommended for all oxygen systems, even for those operating in 50-percent NITROX environments.

## 8.0 Recommendations

It is recommended that each SCUBA assembly be initially cleaned and then maintained clean to an acceptable level during annual disassembly and cleaning and during intermediate maintenance procedures. The acceptable level will be approved by JSC QARSO and Materials Processing personnel.

**Table 2**  
Summary Results of Clean Verification Tests

Component	Parts	Test Articles											
		SCUBA #1			SCUBA #2			SCUBA #3			SCUBA #4		
		Particulate Level	NVR (mg/ft <sup>2</sup> )										
First-Stage Regulator	Internal Metals	Failed Level 1000	56.2	Failed Level 200	N/A	∞ <sup>a</sup>	72.2	TNTC	49.0				
	Internal Soft-Goods Body	Failed Level 1000	N/A	Failed Level 750	N/A	∞	N/A	Failed Level 300	N/A	Failed Level 300	N/A	Failed Level 300	N/A
		Failed Level 1000	N/A	Failed Level 300	N/A	∞	102.7	TNTC	118.7				
Second-Stage Regulator 1	Filter	Failed Level 1000	122.2	Passed Level 300	24.4	Failed Level 300	N/A						
	Internal Metals	Failed Level 750	421.7	Failed Level 1000	267.4	∞	150.7	Failed Level 1000	243.2				
		Failed Level 1000	N/A	Failed Level 1000	N/A	∞	N/A	Failed Level 1000	N/A	Failed Level 1000	N/A	Failed Level 1000	N/A
	Internal Soft-Goods Body	Failed Level 500	N/A	Failed Level 1000	N/A	∞	N/A	Failed Level 1000	N/A	Failed Level 1000	N/A	Failed Level 1000	N/A
		Hose	Failed Level 1000	N/A	Failed Level 1000	N/A	Failed Level 300	N/A	Failed Level 300	N/A	Failed Level 750	N/A	Failed Level 750
	Second-Stage Regulator 2	Internal Metals	Failed Level 1000	469.2	Failed Level 1000	325.3	∞	239.7	Failed Level 1000	434.9			
Failed Level 1000			N/A	Failed Level 1000	N/A	Failed Level 300	N/A	Failed Level 300	N/A	Failed Level 500	N/A	Failed Level 500	N/A
Internal Soft-Goods Body		Failed Level 1000	N/A	Failed Level 1000	N/A	∞	N/A	Failed Level 750	N/A	Failed Level 750	N/A	Failed Level 750	N/A
		Hose	Failed Level 500	N/A	Failed Level 1000	N/A	Passed Level 200	N/A	Passed Level 200	N/A	Passed Level 500	N/A	Passed Level 500

<sup>a</sup> ∞ = Too numerous to count. Particulate level will not pass at any level.