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English



National Aeronautics and
Space Administration

STANDARD FOR UNDERWATER FACILITY AND NON-OPEN WATER OPERATIONS

NASA TECHNICAL STANDARD

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FOREWORD

This standard is approved for use by NASA Headquarters and all NASA Centers and is intended to establish uniform requirements for all NASA neutral buoyancy facilities, equipment, personnel, and operations involving underwater activities that provide simulation of a weightless environment.

This standard expands on NASA Procedural Requirements (NPR) 8715.3, NASA General Safety Program Requirements, policy and requirements for safety assurance, and the associated quality assurance, medical, and other organization functions to be implemented by NASA Centers for neutral buoyancy facility projects, equipment and supplies, and facility research operations. These requirements shall not supersede any more stringent requirements separately imposed for specific facilities, equipment, or functions by NASA and Occupational Safety and Health Administration (OSHA) directives or other specifications and standards. For NASA contract and contractor operations, the safety and health requirements of NPR 8715.3 shall apply.

Comments or suggestions concerning the application of these requirements to specific projects should be referred to the National Aeronautics and Space Administration Headquarters, Director, Safety and Assurance Requirements Division, Washington, DC 20546. Requests for general information concerning NASA Technical Standards should be sent to NASA Technical Standards Program Office, ED41, MSFC, AL, 35812. This and other NASA Standards may be viewed and downloaded free-of-charge from our NASA Standards homepage: <http://standards.nasa.gov>. This NASA Technical Standard cancels NSS/WS-1740.10, dated June 1991.

/s/

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STANDARD FOR UNDERWATER FACILITY AND NON-OPEN WATER OPERATIONS

1. SCOPE.

- 1.1 Scope. This standard covers all NASA neutral buoyancy facilities, equipment, personnel, and operations involving non-open water underwater activities that provide simulation of a weightless environment.
- 1.2 Purpose. This standard establishes the minimum safety requirements for all NASA neutral buoyancy facilities, equipment, personnel, and operations involving underwater activities that provide simulation of a weightless environment.
- 1.3 Applicability. This standard applies to the underwater weightless simulation facilities operated by NASA or under contract to NASA, to non-NASA facilities where NASA personnel will participate in underwater activities, to NASA program safety-critical functions tested underwater in a simulated weightless environment, and to underwater test subjects, training, and test team activities in which NASA employees participate. Specifically excluded are operations occurring in natural bodies of water and those conducted from vessels under the jurisdiction of other Federal agencies. This standard is not a direct instruction to NASA contractors, but provides guidance to the responsible NASA Center on the safety assurance required for neutral buoyancy facilities and human underwater activities. Similar requirements for NASA contractor services in support of neutral buoyancy operations where NASA personnel will participate shall be made applicable to the company or supplier by appropriate contract clauses. This standard expands on NASA Procedural Requirements (NPR) 8715.3, "NASA General Safety Program Requirements," policy and requirements for safety assurance, and the associated quality assurance, medical, and other organization functions to be implemented by NASA Centers for neutral buoyancy facility projects, equipment and supplies, and facility research operations. These requirements shall not supersede any more stringent requirements separately imposed for specific facilities, equipment, or functions by NASA and Occupational Safety and Health Administration (OSHA) directives or other specifications and standards. For NASA contract and contractor operations, the safety and health requirements of NPR 8715.3 shall apply.
- 1.4 Waivers. Waivers to this document will be processed in accordance with procedures in NPR 8715.3.

2. APPLICABLE DOCUMENTS

- 2.1 General. The applicable documents cited in this standard are listed in this section for reference only. The specified technical requirements listed in the body of this document must be met whether or not the source document is listed in this section.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks.

DEPARTMENT OF LABOR, OCCUPATIONAL SAFETY AND HEALTH
ADMINISTRATION

29 Code of Federal Regulations (CFR) 1910, Occupational Safety
and Health Standards. Including but not limited to:

29 CFR 1910, Subpart T, Commercial Diving Operations.

29 CFR 1910.1020, Access to Employee Exposure and
Medical Records.

29 CFR 1960 Basic Program Elements for Federal
Employees OSHA.

(Copies of OSHA standards are available at: <http://www.osha.gov/comp-links.html>)

2.2.2 Other Government documents, drawings, and publications.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Policy Directive (NPD) 8710.5, NASA Safety Policy for
Pressure Vessels and Pressurized Systems.

NASA Procedural Requirements (NPR) 1441.1, NASA Records
Retention Schedules.

NPR 1800.1, NASA Occupational Health Program Procedures.

NPR 8621.1, NASA Procedural Requirements for Mishap and
Close Call Reporting, Investigating, and Recordkeeping.

NPR 8715.1, NASA Occupational Safety and Health Programs.

NPR 8715.3, NASA General Safety Program Requirements.

NPR 8820.2, Facility Project Implementation Guide.

NPR 8831.2, Facilities Maintenance Management.

NASA-STD-8719.7, Facilities System Safety Guidebook.

NASA-STD-8719.9, Standard for Lifting Devices and Equipment.

NASA-STD-8719.11, Safety Standard for Fire Protection.

Johnson Policy Directive (JPD) 1830.3, Limitations Applicable to
Personnel Exposed to Diving.

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Johnson Procedural Requirements (JPR) 5322, Contamination Control Requirements Manual.

U.S. NAVY

S521-AG-PRO-010, U.S. Navy Diving Manual.

(Copies of NASA Directives are available at: <http://nodis3.gsfc.nasa.gov/>)

2.3 Non-Government publications.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Boiler and Pressure Vessel Code.

PVHO-1, Safety Standard for Pressure Vessels for Human Occupancy.

COMPRESSED GAS ASSOCIATION

Pamphlet G-7, Compressed Air for Human Respiration.

Pamphlet G-7.1, Commodity Specification for Air

Pamphlet G-4.3, Commodity Specification for Oxygen.

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

NFPA 99, Standard for Health Care Facilities.

NFPA 53, Recommended Practice on Materials, Equipment and Systems Used in Oxygen-Enriched Atmospheres.

NFPA 70, National Electrical Code.

(Copies of the above documents are available directly from the identified society)

- 2.4 Order of Precedence. Where this document is adopted or imposed by contract on a program or project, the technical guidelines of this document take precedence, in the case of conflict, over the technical guidelines cited in other referenced documents except where directed by statute.

3. DEFINITIONS AND ACRONYMS

3.1 Definitions used in this standard.

- 3.1.1 Certified Personnel. Personnel who have completed required training and whose specified knowledge or proficiency in a skill has been demonstrated and documented.
- 3.1.2 Decompression Diving. An operation which requires halts or "stops" at specific depths (or pressures greater than 14.7 absolute pounds per square inch actual (psia)) for specified lengths of time in order to eliminate dissolved inert gases from body tissues.
- 3.1.3 Decompression Sickness. An illness caused by the formation of inert gas bubbles in body tissues as the result of a transition to an environment with a lower ambient pressure.
- 3.1.4 Decompression Table. A profile or set of profiles of depth-time relationships for ascent rates and breathing mixtures to be followed after a specific depth-time exposure or exposures.
- 3.1.5 Diver. Personnel exposed to hyperbaric conditions through either underwater immersion or pressurization in a chamber.
- 3.1.6 Diving. Activities involving exposures to hyperbaric conditions through either immersion or pressurization in a chamber.
- 3.1.7 Diving Mode. Type of diving activity requiring specific equipment, procedures, and techniques (Self-Contained Underwater Breathing Apparatus (SCUBA), surface-supplied breathing gas and suited subjects).
- 3.1.8 Flying. Refers to exposure to hypobaric conditions through operations in aircraft or hypobaric chambers. For aircraft operations, the cabin altitude, not the aircraft altitude, shall be applicable to this standard. The nominal cabin altitude of an aircraft operated by a major air carrier is less than 10,000 feet.
- 3.1.9 Human Rating. Incorporation of enhanced environmental support, reliability, and safety features into the design and operation of an underwater facility essential to ensure the preservation of life throughout a human-testing mission.
- 3.1.10 Human Testing (Training). Underwater facility operations using SCUBA, pressure suit, or surface-supplied breathing gas for life support during test (training) activities.
- 3.1.11 Hyperbaric Chamber. A large chamber in which the oxygen pressure is above normal for atmosphere; used in the treatment of decompression sickness, breathing disorders, or carbon monoxide poisoning.

- 3.1.12 Hyperbaric Exposure. Exposure to atmospheric pressure conditions in excess of surface pressure (e.g., SCUBA diving, chamber operations, etc.)
- 3.1.13 NITROX. A breathing gas with an oxygen content greater than that of air (19.5-23.5% oxygen), balance nitrogen, and trace gases.
- 3.1.14 Neutral Buoyancy Facility. A facility housing a pool, tank, or vessel containing liquid and used for research or training in a simulated weightless environment.
- 3.1.15 On Call. Able to be physically present in a facility test area, within a specified period of time, in response to the first call for assistance.
- 3.1.16 On Station. Located at the proper assigned duty station.
- 3.1.17 Operational Readiness Inspection. Formal program review conducted by independent management teams to evaluate all facets of neutral buoyancy facility management and operations support for the safety program and compliance with existing safety rules and regulations including this standard.
- 3.1.18 Pressure Suit System. The hardware which encompasses all or part of the human body and operates at pressures different than the surrounding environment. The pressure suit system includes both the anthropometric pressure barrier and any integrated support systems providing life support regulation (e.g., suit pressure controllers).
- 3.1.19 PSIA. Pounds per square inch actual.
- 3.1.20 PSIG. Pounds per square inch gauge.
- 3.1.21 Safety-Critical Condition. Hazardous condition that may lead to a mishap with resultant occupational injury or illness, or major damage or loss of property or equipment.
- 3.1.22 Safety-Critical Function. Any system, equipment, or facility function that could cause a safety-critical condition.
- 3.1.23 SCUBA Testing (Training). Any underwater activity with a test subject using SCUBA exclusively for life support.
- 3.1.24 Simulated Weightless Environment. An environment in which gravity effects on a mass are offset by adjusting the buoyancy of objects or persons underwater.
- 3.1.25 Suited Test. Any underwater activity with a test subject wearing a pressure suit that is designed for use in a vacuum.

- 3.1.26 Support Diver. The in-water personnel who breathe compressed breathing gas from tanks or surface-supplied hoses assigned to support the suited subject(s), test(s), and/or reconfiguration operations.
- 3.1.27 Surface Supplied Diving. Mode of diving in which breathing gas is supplied from the surface to the diver or suited subject using a flexible hose (umbilical).
- 3.1.28 Test Plan. Document approved by a Center-designated Test Readiness Review Board that describes the test objectives, test support requirements, test-unique hazards, and the test procedures and acceptable risk alternatives for accomplishing the objectives.
- 3.1.29 Test Readiness Review Board. A board established by the Center to review, assess, and approve the readiness status of all facility systems, personnel, and documentation for each underwater test or series of tests before the tests begin.
- 3.1.30 Test Team. All personnel assigned to an underwater facility, SCUBA testing, or suited test or training activity in accordance with Paragraphs 4.3 and 5.2 of this standard.

3.2 Acronyms used in this standard.

AC	Alternating Current
CFR	Code of Federal Regulations
DC	Direct Current
JPD	Johnson Policy Directive
JPR	Johnson Procedural Requirements
JSC	Lyndon B. Johnson Space Center
MSFC	George C. Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NBL	Neutral Buoyancy Laboratory
NFPA	National Fire Protection Association
NPR	NASA Procedural Requirements
ORI	Operational Readiness Inspection
OSHA	Occupational Safety and Health Administration
PPM	Parts Per Million

PSIA	Pounds per Square Inch Actual
PSIG	Pounds per Square Inch Gauge
RMS	Root Mean Square
SCUBA	Self-Contained Underwater Breathing Apparatus
SR&QA	Safety, Reliability and Quality Assurance
SSDS	Surface Supplied Diving System
TRR	Test Readiness Review
TRRB	Test Readiness Review Board

4. RESPONSIBILITIES

4.1 System Safety Program. NASA Centers shall establish an effective system safety program for all neutral buoyancy facility development and modification projects, associated human underwater activities and equipment, and research operations in compliance with NPR 8715.3 and this standard.

4.1.1 NASA Centers shall designate and assign system safety program responsibilities to a Safety, Reliability, and Quality Assurance (SR&QA) organization office that is independent from the underwater neutral buoyancy facility (user) management.

4.1.2 System safety analysis shall be performed and documented for all facilities, human testing equipment, and procedures within the scope of this standard that perform a critical function (including their integration). As a minimum, hazard analysis reports shall document:

- a. A listing of all credible hazards.
- b. Specific controls for the identified hazards.
- c. Verification of the hazard control implementation.
- d. Acceptance of the residual hazards by appropriate Center management.
- e. Specific safety requirements.

4.1.3 The Center safety office shall require additional system safety analyses when appropriate to support the hazard listing. These may include:

- a. Preliminary Hazard Analysis.
- b. System Hazard Analysis.

- c. Operating Hazard Analysis (also known as an Operating and Support Hazard Analysis).
- d. Failure Modes and Effects Analysis.
- e. Common Cause Failure Analysis.
- f. Fault-Tree Analysis.

4.1.4 Test Safety.

- a. Test Readiness Review Board (TRRB) approved procedures and practices shall be developed and available for use before facility test team and support personnel training and the start of all hazardous operations (Paragraphs 6.1 and 6.3 of this standard).
- b. A Test Safety Officer (Paragraph 4.3.1 j) shall advise the Test Director (Paragraph 4.3.1 a) of any activity that represents clear or present danger to any person or property and call for a safety hold until the issue has been resolved.

4.2 Quality Assurance Program. NASA Centers shall provide quality assurance functions to verify conformance with the documented requirements for neutral buoyancy facility development and modification, human underwater activities and equipment, and the associated test and facility operating procedures cited in Paragraphs 6.1, 6.2, and 6.3 of this standard.

4.2.1 NASA Centers shall designate and assign safety, reliability, and quality assurance responsibilities to an SR&QA organization office that is independent from the underwater neutral buoyancy facility (user) management. Well-defined quality and inspection procedures and guidelines shall be established, available, and understood by all test team personnel before any human underwater or training activities.

4.2.2 A SR&QA representative shall be assigned to perform the following functions:

- a. Develop and maintain the facility project quality assurance plan and Center procedures and checklists necessary to implement its provisions.
- b. Review, verify, and approve all proposed facility modifications, repair, and non-routine maintenance for impact on the facility configuration.
- c. Review and approve all facility work authorization documents.
- d. Verify that all facility and unique human testing equipment is adequate to support the test objectives and that copies of Operational Readiness Inspections (ORIs), Test Readiness

Reviews (TRRs) or last safety inspections are readily accessible to all Neutral Buoyancy Laboratory (NBL) personnel.

- e. Review and approve all nonconformance report dispositions and resolutions.
- f. Review and approve all test and training procedures and facility operating procedures (Paragraphs 6.1 and 6.3 of this standard).
- g. Verify that all instruments are properly calibrated and that instruments without valid certification are withheld from use.
- h. Verify the certification of all facility pressurized systems and components in use and their compliance with NPD 8710.5, NASA Safety Policy for Pressure Vessels and Pressurized Systems, and 29 CFR 1910, Subpart T (Section 1910.430, Equipment) as applicable.
- i. Verify that all hyperbaric chamber breathing air meets the requirements of Compressed Gas Association Pamphlets G-7 and G-7.1.
- j. Verify that all diver breathing air meets the appropriate purity and composition requirements of Appendix A of this standard. Selection of the breathing gas composition shall be made by the Center management, and shall be consistent with the calculations performed within JPD 1830.3.
- k. Be present or on call within 5 minutes during facility human underwater activities, when deemed necessary by the TRRB, to monitor and document any nonconformance or deviation from the approved test procedures or schedules (Paragraph 4.3.1.l of this standard). Approval of test schedule/procedure deviations shall not effect the requirements of this standard.

4.3 Test Team Personnel Responsibilities.

- 4.3.1 The following test team staffing shall be assigned for human testing at NASA Center neutral buoyancy facilities. These test team members are a prerequisite to each human testing or training activity conducted by a facility, unless otherwise indicated.
 - a. Test Director is the authority in charge of all aspects of the test, including off-nominal and emergency procedures, and is responsible for directing the test team to effectively and safely support the Test Conductor within the scope of the approved test plan. The Test Director must have the support of the following personnel: Test Safety Officer, Licensed Physician or certified Medical Representative, Suit Engineer, Suit Technician, and SR&QA Representative at or on call within 5 minutes during all suited testing and training operations at the facility.

- b. Test Conductor is the principal investigator responsible for normal conduct of the test under Test Director's supervision. This person must have knowledge of the specific facility general operating procedures (Paragraph 6.3 of this standard) and the responsibilities of each test team member, including any limitations placed on the Test Conductor position.
- c. Dive Supervisor has the primary responsibility to ensure safe diving operations during all in-water operations. The Dive Supervisor reports to the Test Director during all operation phases when a Test Director is on station. The Dive Supervisor is the designated person in charge during operation phases when no Test Director is on station. The Dive Supervisor shall fully understand diving objectives, remain in the immediate vicinity of the water tank during in water operations, constantly monitor the diving operation and all divers, place operations on hold if safety is compromised, and monitor diver entry and exit from the water tank.
- d. Support Divers are the in-water personnel, who breathe compressed breathing gas from SCUBA or surface-supplied hoses, assigned to support the suited subject(s), test(s), and/or reconfiguration operations. All support divers must have thorough knowledge of all test rules and emergency procedures (Paragraph 6.1 of this standard) and working knowledge of the pressure suit in use and emergency egress procedures for the specific facility. The minimum responsibilities for dive team personnel are as follows:
 - (1) Safety Divers are responsible for the safety of an assigned test person. Two safety divers shall be assigned and accompany each pressure suited test subject; one safety diver shall accompany any other test subject using surface-supplied breathing gas (e.g., Surface Supplied Diving System (SSDS)).
 - (2) Utility Divers are responsible for supporting mockup and test article configuration and assisting suited subjects when required to perform underwater simulation of test objectives.
 - (3) Other Divers are personnel other than safety divers and utility divers who breathe with SCUBA, or SSDS, and perform underwater functions such as the installation and removal of test equipment, general safety surveillance of a test area, and the recording of test activities in progress. This also includes observation, training, simulation of crewmember activities, and diving to maintain facility currency requirements.

- e. Suited Test Subject (for suited activities only). The suited person performing underwater test objectives or training functions shall be required to complete a pressure suit familiarization course, including a suit fit check, and qualification by the specific test facility in pressure suit emergency procedures. Standard pressure suit training is available (Paragraph 4.3.2.d(1)). A suited person must be qualified for the specific facility function and either be certified by a nationally recognized SCUBA diver program or complete equivalent SCUBA training provided by the underwater test facility. Section 5.1.5 of this standard provides for the participation of astronauts in non-open water operations conducted at an underwater facility.
- f. Suit Engineer and Technician (for suited activities only) are responsible for pressure suit and component inspection, checkouts, and maintenance for test use, including assistance with donning and doffing the suit. This person must have knowledge of all pressure suit related instrumentation, environmental control system operation, and monitoring of suit test data, and reports results to the Test Director. Sufficient suit engineers and suit technicians are required to be present at all times during the test to support suit doffing, including emergency egress.
- g. Audio/Visual System Operators are qualified to ensure accurate transmission and recording of the facility test operations.
- h. Environmental Control System Operator ensures the test subject is receiving the proper pressure and environmental conditions specified by this standard and other applicable documents and facility safety manual procedures. This operator is required for all suited activities.
- i. Facility Support Personnel are on-deck personnel such as lifting device and equipment operators, hyperbaric chamber operators, tenders, backup/standby divers, etc. They must be trained, qualified, and certified to safely carry out their assigned duties (Paragraph 4.3.2).
- j. Test Safety Officer is designated by the Center SR&QA organization to advise the Test Director on system safety and all specific test safety matters cited in Paragraph 4.1 of this standard. The Test Safety Officer shall be on station during all suited testing and training operations at the facility and be present when required by the TRRB. (See Paragraph 4.1.4.b for additional responsibilities.)
- k. Medical Representative is responsible to the Center medical organization. The representative provides medical consultation and advice to the Test Director. The representative shall be certified in accordance with Paragraph 5.2 of this standard. The

representative shall be present before the start of human underwater activities, provide real-time test monitoring and is responsible to advise the Test Director if he or she believes that the well-being of a diver is being compromised.

- I. SR&QA Representative is designated by the Center SR&QA organization to advise the Test Director on all quality assurance matters cited in Paragraph 4.2 of this standard. The representative shall be on call within 5 minutes during all facility human underwater activities and present as deemed necessary by the TRRB. The representative has the responsibility to periodically monitor compliance, to document nonconformance, to verify facility test procedures, and to advise the Test Director of any equipment malfunctions.

4.3.2 Personnel Certification.

- a. NASA Centers shall establish and maintain requirements for training, qualification, and certification of test team members in accordance with NPR 8715.3, OSHA, this standard, and other applicable documents. The Johnson Space Center (JSC) Medical Sciences Division is available to consult on medical considerations for diving fitness of personnel.
- b. Training shall be administered in the form of classroom instruction, hands-on training, or on-the-job training, and by periodic drills to maintain proficiency in emergency and off-nominal procedures.
- c. Certification procedures shall require a demonstration of specific system and equipment knowledge and an understanding of the facility operations capabilities in all possible diving modes. Test team personnel certifications shall be attested to by the appropriate Center management office and documented in the training record. Training for the recertification of personnel shall occur at regular intervals, not to exceed 4 years.
- d. Some standard training programs are available and acceptable to meet the necessary test team personnel certifications, or initial qualifications, for an assigned position. These programs include:
 - (1) Pressure Suit Training. For suited test subjects, the NASA standard pressure suit training programs at JSC and Marshall Space Flight Center (MSFC) are recognized. Note: Subjects must have completed a nationally recognized SCUBA Diver Training Course.
 - (2) Hyperbaric Chamber Training. For hyperbaric system operators, the JSC and U.S. Department of Defense training programs are recognized.

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- (3) First-Aid Training. For cardiopulmonary resuscitation and first-aid training, the American Red Cross standard course or equivalent is recognized.
 - (4) Lifeguard Training. For lifeguard training, the American Red Cross standard course or equivalent is recognized.
 - (5) Lifting Device Training. Normally provided by the Center in accordance with NPR 8715.3. Operators may be certified by a recognized certification organization in accordance with NASA-STD-8719.9, Standard for Lifting Devices and Equipment.
- e. Each Center shall establish and document comprehensive certification requirements for each dive position; including recurrent training to maintain an adequate level of currency as determined by, and relevant to, the facility. This includes (as applicable) decompression tables, diving related disorders, chamber operations, etc. Center training shall address gas composition, facility specific equipment, swimming skills, diver physiology, etc. The JSC programs for Safety Diver, Utility Diver, and Other Divers are recognized as having a comprehensive certification program for each dive position.

The National Association of Underwater Instructors, Young Men's Christian Association, U.S. Navy Diving School, and Professional Association of Diving Instructors are among those recognized for providing entry level training but are not sufficient for position certification. All initial SCUBA certification training should provide, as a minimum, the hours of training listed below:

- (1) Cognitive Instruction - 20 hours (physics, physiology, decompression tables, and mishap prevention).
- (2) Confined Pool Time - 20 hours (development of SCUBA skills).
- (3) Open Water Diving - 8 hours (at least five 30-minute SCUBA dives in environment equal to or worse than working conditions expected to be encountered during the performance of safety diver responsibilities).

5. REQUIREMENTS

5.1 Facility Design, Construction, Certification, and Operations.

- 5.1.1 Design and construction of new underwater facilities for research and neutral buoyancy testing shall be implemented in compliance with applicable Federal, National, State, and local building codes; this standard; and NASA procedures and requirements set forth in NPR 8715.3, NASA General Safety Program Requirements; NPR 8820.2,

Facility Project Implementation Guide, NASA-STD-8719.7, Facilities System Safety Guidebook, and NPR 8831.2, Facilities Maintenance Management.

- 5.1.2 Modifications of existing neutral buoyancy facilities and facilities previously approved by the NASA Center for the final design or construction phases shall be accomplished to maintain compliance with the applicable cited documents.
- 5.1.3 Unique facility requirements for equipment standards or operating procedures not addressed by OSHA standards shall be developed and maintained by the NASA Center. These shall be based on national consensus standards and good practice techniques to supplement and complement the OSHA standards. NASA supplementary and alternate standards must be approved in accordance with NPR 8715.1, NASA Occupational Safety and Health Programs. Facility operating procedures shall be maintained as required by Paragraph 6.3 of this standard.
- 5.1.4 Neutral buoyancy facilities, including the hyperbaric chamber, shall be certified/recertified for human underwater activities by an ORI to ensure that the requirements of this document and the Center Facility Safety requirements are met. The Center's ORI shall review and approve the specific allowable breathing gas oxygen composition and allowable dive profiles, consistent with (a) all medical and safety constraints, (b) facility requirements, (c) test requirements, and (d) Appendix A of this document. ORI membership shall include as a minimum: Center safety representative, underwater facility line management representative, Center medical representative, and engineering personnel familiar with the hazards and controls associated with hyperbaric oxygen systems.
- 5.1.5 Requests for the participation of NASA astronauts in testing conducted at underwater facilities not located at JSC shall be addressed to the Director, Flight Crew Operations (JSC/CA). Astronauts participating in underwater activity shall as a minimum meet the test team work position certification requirements of that facility per this standard.
- 5.2 Medical Requirements. NASA Center medical organizations shall provide diving medical support, consultation, and the services of qualified medical diving team personnel to support neutral buoyancy facility human underwater and training activities, procedures, and hyperbaric chamber and recompression operations. Well-defined medical emergency procedures shall be established, available, and practiced (at least annually) to ensure that all divers and others subjected to hyperbaric exposure can be assisted, transported, and treated for gas embolism, decompression sickness, and other barotrauma accidents.
 - 5.2.1 Licensed Physician.
 - a. The Center medical organization shall have review and signature authority by a licensed physician for all tests, operations, emergency, and training procedures and their changes (Paragraph 6.1 of this standard).

- b. NASA will designate a physician certified in diving medicine or hyperbaric medicine and currently certified in Advanced Cardiac Life Support to support test team operations. The physician shall be on call and on station within 5 minutes for suited tests. The physician shall respond via telephone within 5 minutes and be on station within 30 minutes for all other diving activities.
- c. The certified physician shall administer diver physical examinations and shall certify, at least annually, that all potential underwater personnel are able to satisfactorily perform under hyperbaric exposure. Also, the physician shall administer decompression procedure assessment evaluations and post-dive examinations following an injury or illness that requires medical treatment.
- d. Suited subjects participating in suited non-open water operations shall be administered a brief pre-dive physical examination by a licensed physician before each test or training activity.

5.2.2 Medical Representative.

- a. A medical representative [Paragraph 4.3.1.k. of this standard], such as a medical technician, shall be designated to support all test team and training operations and shall be on station before the start and during any suited underwater activity. The medical representative shall be in the facility and immediately available for all other underwater activity.
- b. The day of each test or training event, before hyperbaric exposure, a medical representative shall interview all potential underwater personnel and shall refer any individuals to the physician for further evaluation as deemed appropriate.
- c. Medical representatives shall possess current basic life support and hyperbaric physiology certification, including diving medicine certification by a nationally recognized institution, and shall be approved by the Center medical organization as qualified to assist with medical emergencies during underwater activities.

5.2.3 Hyperbaric Chamber Systems. Neutral buoyancy facilities conducting mixed gas operations shall have a hyperbaric chamber available on site. Facilities that only use compressed air for diving operations shall design a plan and pre-arrange access to a fully functioning hyperbaric system accessible within 30 minutes of the facility. All hyperbaric systems shall include the personnel, equipment, and supplies essential to initial medical and hyperbaric management of diving-related mishaps. The following positions are required for hyperbaric system operations:

- a. Hyperbaric Chamber Operator certified as a chamber operator (Paragraph 4.3.2.d of this standard).

- b. Hyperbaric Chamber Inside Attendant(s) certified in hyperbaric medicine, such as a licensed physician or medical representative.
- c. Timekeeper, responsible for keeping an accurate account of all chamber dive times, which includes treatment gas times, ventilation times, and patient vital signs relayed by the inside attendant.
- d. Crew Chief, responsible for preparing the chamber and all chamber dive related equipment before the dive and for securing the chamber and equipment after the chamber dive.
- e. Supervisor, responsible for the overall operation, coordination, and safety during chamber operations.

5.2.4 Limitations on Flying After Hyperbaric Exposure. Decompression sickness may result from flying in the cabin pressure of **any aircraft** after hyperbaric exposure. Decompression sickness can occur even after “no decompression” diving, unless adequate time on air or oxygen is allowed before exposure to a reduced atmospheric pressure. These situations are not comparable to altitude bends, because larger amounts of nitrogen are present after a dive. Therapy should therefore be assumed to be required in decompression sickness generated by flying after diving. The following limitations apply:

- a. After hyperbaric exposure, divers planning to fly to cabin altitudes of less than 1000 feet shall have no restrictions.
- b. After hyperbaric exposure, divers planning to fly to cabin altitudes between 1,000 feet and 10,000 feet shall comply with the appropriate surface interval specified in JPD 1830.3. **In lieu of the guidelines, divers shall refrain from flying for at least 24 hours after hyperbaric exposure.**
- c. Personnel engaged in compressed breathing gas activities other than the conditions specified above (including SCUBA, surface-supplied breathing gas diving, and hyperbaric chamber exposure) **shall not participate in aerial flight within 24 hours or hyperbaric chamber ascent within 48 hours.**

These limitations are not intended to restrict Center research conducted with the approval of an established Human-Use Committee.

5.3 Personnel Support Equipment Requirements.

- 5.3.1 Life Support and Environmental Control Systems. Each suited test subject shall have a primary and an emergency breathing gas supply. Mixed breathing gas shall have continuous oxygen level monitoring. All breathing gases shall have continuous carbon monoxide and carbon dioxide level monitoring. Pressure suit gas flow shall be 6-10 cubic feet/minute. Pressure fluctuations shall not exceed 0.4 psig/second. Pressure suit systems shall have dual pressure relief valve protection. Pressure suit cooling shall be provided to correct or prevent a temperature rise in the test subject work environment. All critical functions for the safety and well-being of the test subject shall have warnings and cautions provided for discrepancy (off-nominal) or safety-critical conditions.
- 5.3.2 Man Lift Systems. The primary ingress/egress system for pressure suited test subjects shall have a powered lifting device with power source redundancy. The lifting device should not be electric, but an electric lift with adequate protection to preclude unacceptable risk of electric shock to operators and test participants may be used. Stairs shall be used only as a backup system.
- 5.3.3 Electrical Systems. NASA underwater facilities shall conform to the standards and requirements contained in the NFPA 70 (National Electric Code), NFPA 70E (Standard for Electrical Safety in the Workplace) and OSHA 29 CFR Subpart S "Electrical". In addition, tools, underwater equipment, and systems shall conform to the minimum electrical requirements contained herein, or shall be accepted for use by a system safety review committee composed of representatives of the Center's safety, underwater facility line management, medical, and electrical engineer. The review committee for tools, underwater equipment, and systems containing bio-electrical sensors shall include an electrical engineer with bio-electrical experience. The purpose of the special system safety review committee shall be to assess the shock hazard, recommend controls to reduce/eliminate the hazard and discuss the risk associated with any remaining hazards. The results of the system safety review committee shall be presented to the appropriate TRRB for approval.

Tools and underwater equipment limited to less than or equal to 30 volts (Alternating Current (AC) (root mean square (rms)), Direct Current (DC), or combination thereof) or with circuits capable of supplying a worst case current of less than 6.0 milliamps shall not be normally considered potentially hazardous when they incorporate a verifiable barrier to electric shock.

Systems using greater than 30 volts (AC (rms), DC, or combination thereof) capable of supplying current greater than or equal to 6.0 milliamps shall be processed by the special system safety review committee with the results presented to the TRRB for approval prior to use in the underwater facility. Personnel shall be protected by at least

two independent verifiable controls from exposure to any electrical hazard that can result in injury created by underwater tools and equipment. Controls shall be verified operational before use.

Batteries placed underwater shall be packaged to prevent hazardous chemical leakage into the water or electric short circuits. Batteries susceptible to out gassing shall be safeguarded to control out gassing and mechanical hazards when placed underwater.

- 5.3.4 Pressure Suits. Experimental or prototype suits and components shall be treated as a facility test article and meet all safety program review, test documentation, and certified personnel requirements of this standard before each test or series of tests. Standard pressure suits currently approved for flight need not be reviewed, but shall be readied for human testing and maintained in accordance with established procedures.
- 5.3.5 Communications Systems. Each suited test subject shall have dedicated two-way voice communications with the Test Director workstation at all times.
- 5.3.6 Test Team Emergency Breathing Gas. Each Safety Diver shall have an effective means to provide breathing gas underwater to any other non-suited test personnel.
- 5.3.7 Diving Systems. All diving system equipment (SCUBA, SSDS, etc.) shall meet all safety program review, test documentation, and certified personnel requirements of this standard.
- 5.4 Annual Safety Program Evaluation. NASA Centers and NASA contractor organizations shall, in addition to normal management surveillance, conduct a formal safety evaluation review at least annually to evaluate all neutral buoyancy facility programs for compliance with this standard and sound safety practices.
 - 5.4.1 Center management and the designated SR&QA organization shall establish a competent and qualified evaluation team that will have representatives of the safety, quality assurance, medical, facility user, and other organizations as required. This team may include personnel from NASA Headquarters, other NASA Centers, the Astronaut Office, the Occupational Health Office, and supporting NASA contractor organizations as appropriate.
 - 5.4.2 Normally, a status report shall be prepared by the evaluation team, along with any planned corrective action and milestone date responses. This evaluation report shall be submitted to the cognizant NASA Center Director and interested levels of management, to the equivalent NASA contractor management as appropriate, and to the NASA Headquarters Chief, Safety and Mission Assurance. Copies of this report also shall be provided to the JSC Astronaut Office and Safety Office if astronauts are to participate in testing or training in the neutral buoyancy facility program being evaluated.

5.5 Recordkeeping and Reporting.

- 5.5.1 NASA mishap and Federal OSHA reporting and recordkeeping requirements shall be met according to NASA requirements contained in NPR 8715.3 and NPR 8621.1.
- 5.5.2 OSHA 29 CFR 1910, Subpart T (Section 1910.440) shall be followed to record the occurrence of any fatality or diving-related injury or illness that requires a NASA test team member to be hospitalized for 24 hours or more. The employer shall also comply with any additional requirements set forth at 29 CFR 1910.1020(h). The retention of records that pertain to non-open water operations shall be met as follows:
- a. Facility safety manual - Retain current test plans and test procedures only.
 - b. Depth Diving Safe Practices Manual – Retain current copy
 - c. Depth-time profiles - Retain until the recording of a dive is completed or recording of a decompression procedure assessment evaluation is completed for a decompression sickness incident.
 - d. Recording of a dive - Retain 1 year; or 5 years where there has been a decompression sickness incident.
 - e. Decompression procedure assessment evaluation - Retain 5 years.
 - f. Equipment inspections and testing records - Retain current record entries or tag, or until equipment is withdrawn from service.
 - g. Records retained for 5 years - After the 5-year retention period, forward such records to the National Institute for Occupational Safety and Health, Department of Health and Human Services. Also for record, ensure Dive team member medical records (physician's reports) and records of hospitalizations are retained for 5 years.
- 5.5.3 NASA Centers shall keep a current record of all maintenance actions accomplished on the facility diving equipment and support apparatus. Copies of these records shall be made available for access to all test team members.
- 5.5.4 NASA Centers shall make available for access to the test team members all medical records of which the person is the subject as set forth in OSHA 29 CFR 1910.1020(a)-(e) and (g)-(i). NASA Center's, neutral buoyancy facility management and medical organizations shall conform to the requirements of the Privacy Act of 1974, and assure the protection of

identifying personal information prior to the release of any medical records.

- 5.6 Dive Safety Board. Each NASA Center participating in underwater operations shall establish a diving (safety) board. The majority of the diving board members shall be active divers and shall have the authority to review, monitor, and recommend changes to diving projects; review and recommend revisions to the facility operating procedures (safe practices manual); assure compliance with the manual; recommend disciplinary action for unsafe practices; and assure adherence to the buddy system and all other established facility diving rules and/or standard industry practices. The board shall have the authority to stop any unsafe diving practice. The dive safety board shall include a medical representative.

6. PROCEDURES

6.1 Test Procedures.

- 6.1.1 Before each new test or new series of tests, including facility training activities, the NASA Center shall establish a TRRB, to be chaired by the neutral buoyancy facility manager or higher management, with membership to include the safety office, medical, and quality assurance representatives; the Test Director or his or her representative; and others as appropriate.
- a. All Center-approved test procedures (Paragraph 6.1.2 below) shall be made available to the TRRB for review before it convenes.
 - b. The Board membership shall review and approve the test plan and shall identify any specific constraints on the use of procedures by the test team.
- 6.1.2 NASA Center testing or training organizations shall develop and fully document all necessary procedures for safe neutral buoyancy testing and training activities based on the facility mission and test procedure requirements. These procedures and all changes shall have a signature approval for their use by the facility manager; Center-designated safety, quality assurance, and medical offices; and test engineering or other concerned organizations. Test procedures should include, but not be limited to, the following:
- a. Operating Procedures shall be written in sufficient detail to identify all hazards and cautions to the test team personnel. The procedures shall be made part of the test plan and be approved by the TRRB.
 - b. Emergency Procedures shall ensure the prevention of personnel injury or illness and minimize damage to equipment in the event of a system failure or discrepancy.

- c. Testing/Training Rules shall define all equipment use, instrumentation, and calibration requirements; diver and equipment operating limits; and the operating conditions that will require a diving termination (normal and emergency) or a test hold, or will support proceed-with-test decisions.

6.1.3 The approved test plan and all test procedures shall be available to appropriate test team personnel at their duty stations.

6.2 Pretest Operations.

6.2.1 Underwater neutral buoyancy facility pre-dive operations shall include a comprehensive briefing of the test team by a knowledgeable person familiar with the Safe Practices Manual requirements (Paragraph 6.3 of this standard) and operational aspects of the planned test or training activity. As a minimum, the briefing will include a review of:

- a. Operating procedures, emergency procedures, and the specific testing/training rules that have been approved and reviewed by a TRRB (Paragraph 6.1 of this standard).
- b. All constraints in the TRRB approved test plan.
- c. All test articles and hardware to be used and their status.
- d. Status of all facility support equipment.
- e. Test team member assignments and responsibilities, including all buddy system assignments and emergency personnel.
- f. Current certification of all test team personnel for verification by the Test Director.

6.2.2 The pretest checklist shall be completed and verified by the SR&QA representative.

6.3 Facility Operating Procedures (Safe Practices Manual). NASA neutral buoyancy facility procedures (including all safe practices content required by OSHA 29 CFR 1910.420) shall be developed as operation and maintenance instructions. As a minimum, facility operation and maintenance planning will include, but not be limited to, the following:

6.3.1 General Operating Procedures shall be maintained by each facility and describe facility organization and responsibilities, test team workstation positions and certification requirements, facility equipment and outside support requirements, facility maintenance plan, and the testing/training rules for all diving modes of operation.

- 6.3.2 Standard Operating Procedures shall be maintained by each facility to implement the master equipment list and tool list maintenance and replenishment actions; to prescribe facility planning for proposed facility repairs, rehabilitation, modification, and new construction projects (Paragraph 5.1 of this standard); and to describe the special handling, storage, transportation, and refurbishment procedures for complex test articles and associated components. Specific operating procedures shall also be documented and employed by each facility for the following:
- a. Configuration control of the facility and equipment, including as-built record drawing verification and update and Center management approval of changes.
 - b. Routine maintenance actions for the facility and equipment.
 - c. Calibration recall scheduling or periodic in-place calibration of facility and equipment instruments.
 - d. Periodic validation of the facility and equipment operation and functional integrity.
 - e. Facility equipment startup and shutdown.
- 6.3.3 Facility Emergency Procedures shall be maintained by each facility to cover personnel actions in the event of a facility emergency such as: severe weather, terrorism, fire, hazardous substance spill, loss of power, earthquake, and medical emergency.

APPENDIX A

LIQUID OXYGEN AND GAS PURITY AND COMPOSITION STANDARDS

A-1. The table below defines the standard that will be used for applicable underwater facility breathing gas consumables.

Constituent	Liquid Oxygen	Gaseous Oxygen	Breathing Air	Oxygen Enriched Air
Designation:	LOX	GOX	AIR	NITROX
Oxygen (O ₂) by volume	≥ 99.5%	≥ 99.5%	19.5% - 23.5%	23.6% - 48.0% Note 1
Carbon dioxide (CO ₂), Maximum	5.0 ppm	10.0 ppm	1000.0 ppm	1000.0 ppm
Carbon monoxide (CO) Maximum	N/S	N/S	10.0 ppm	10.0 ppm
Oil, mist, particulates Maximum	N/S	N/S	5.0 mg/m ³	5.0 mg/ m ³
Odor	None	None	Not Objection-able	Not Objection-able
Total water, Maximum by Volume	N/S	7.0 ppm	N/S	N/S
Dew Point, Maximum	-82.0°F	-82.0°F	-50.0°F	-50.0°F
Methane (CH ₄), Maximum	25.0 ppm	50.0 ppm	25.0 ppm	25.0 ppm
Acetylene (C ₂ H ₄), Maximum	0.05 ppm	0.1 ppm	0.1 ppm	0.1 ppm
Ethylene (C ₂ H ₄), Maximum	0.2 ppm	0.4 ppm	0.4 ppm	0.4 ppm
Ethane (C ₂ H ₆) and other hydrocarbons, Maximum	3.0 ppm	6.0 ppm	6.0 ppm	6.0 ppm
Nitrogen dioxide (NO ₂), Maximum	N/S	N/S	N/S	4.0 ppm
Nitrous Oxide (N ₂ O by volume), Maximum	2.0 ppm	4.0 ppm	N/S	4.0 ppm
Halogenated compounds: Refrigerants (freons, etc.), Maximum	1.0 ppm	2.0 ppm	2.0 ppm	2.0 ppm
Other (each discernible from background noise on infrared spectrophotometer) Maximum	0.1 ppm	0.2 ppm	0.2 ppm	0.2 ppm
Solvents (trichlorethylene, carbon tetrachloride, etc.), Maximum	0.1 ppm	0.2 ppm	0.2 ppm	0.2 ppm
Specification used for purchasing LOX or GOX	ANSI/SAE AS 8010C- Breathing Oxygen purity standard Type II Liquid	ANSI/SAE AS 8010C- Breathing Oxygen purity standard Type I Gaseous		

N/S - Not Specified

Note 1: Oxygen composition shall be established by an Operational Readiness Inspection per paragraph 5.1.4 of this standard.