Dive Incident Investigation

Report 2011-01

EXECUTIVE SUMMARY

A diver was conducting a technical* dive to 176 feet with a total bottom time of 23 minutes. No issues were reported during the bottom phase of the dive and the diver began the ascent with other members of the dive team on schedule. Midway through the 20 foot oxygen decompression stop, the diver was observed to be fidgety and a few minutes later did not respond to routine hand signals given by the dive buddy. Facial twitching was also observed. Assisted by the dive buddy and one of the support divers, the diver was brought to the surface. Once on the surface, the diver's gear was removed and the diver was assisted onto the small support boat. This boat returned to the ship where the diver was assessed by the NOAA Diving Medical Officer (DMO) and Chamber Supervisor. After consultation with other NOAA and US Navy DMOs, recompression therapy was initiated. Following the treatment, the diver was taken to sickbay and observed for 24 hours. Once in port the diver was taken to the hospital and further evaluated in addition to receiving additional recompression therapy.

Although there were no operational infractions of OSHA or NOAA diving regulations, standards or policies noted, there were two administrative requirements which were not met and have been addressed in a corrective action plan. The diver suffered from oxygen toxicity, a very rare and unanticipated physiological response to breathing gas mixtures with high partial pressures of oxygen. There was secondary Arterial Gas Embolism, the underlying cause for which cannot be determined conclusively. There was no indication that the diver refrained from breathing during ascent (the most common cause of AGE), however the diver's shallow breathing immediately prior to and during the ascent from 20 fsw may have been a contributing factor.

* Technical diving is a term used to describe diving methods that utilize multiple gas mixtures, redundant equipment configurations and in-water decompression and is typically used for dives to depths and/or immersion times beyond that of typical scientific scuba diving.

The Diver

The diver was originally certified to scuba dive by the Professional Association of Diving Instructors (PADI) in 2007, and later received additional certifications in Recue Diving, Nitrox, Master Diver, Specialty Training Assistant, and Divemaster from the National Association of Underwater Instructors (NAUI). The diver became certified as a 'Technical Diver' by the International Association of Nitrox and Technical Diving (IANTD), and as a NOAA Scientific Diver in 2011.

Since becoming a certified scuba diver, the diver logged 268 dives for a total bottom time of 309 hours. The diver reports having completed a total of 17 technical dives involving mixed gas (trimix) and decompression, and the last technical dive prior to the incident was conducted 2 months prior to the incident. The deepest technical dive performed by the diver was 200 feet.

The Dive

The sea temperature was 79° - 82 F°, air temperature 86° F, there was light current, the sea state was 1 - 2 feet out of the SSE, wind was out of the east at 10 - 15 kts, and the underwater visibility was 100+ feet.

On the date of the incident, the diver conducted a technical dive to 176 feet for a total bottom time of 23 minutes. No issues were reported during the bottom phase of the dive and the diver ascended with the dive team to the first decompression stop at 110 feet. Additional stops were completed with the last being at 20 feet. All divers progressed normally to 20 feet where the stop was scheduled for 25 minutes breathing 100% oxygen. Approximately halfway through the stop, the diver was observed fidgeting and several minutes later, did not respond to routine hand signals given by the dive buddy. Facial twitching was also observed. Suspecting oxygen toxicity, the dive buddy and support divers assisted the diver to the surface. Once on surface, the diver's gear was removed and then the diver convulsed, went rigid and after 30-45 seconds went limp. The other bottom divers were quickly recovered and the affected diver was transported back to the ship while breathing oxygen via demand valve.

The timeline for the dive, evacuation and initial treatment is as follows:

0905: The diver and three additional technical divers begin dive to 176 fsw/23 mins
0928: Divers assemble on bottom and begin ascent
0935: Divers switch to 36% Nitrox at 110 fsw to begin staged decompression stops
0955: All divers arrive at 20 fsw for 25 min stop on 100% oxygen
1010: The diver notified the on-bottom safety diver about confusion with computer display
1015: The safety diver notices the diver is not responding to hand signals and exhibited facial twitching
1020: With the assistance of the safety diver and a support diver, the diver is escorted to the surface

1036: Rescue boat returns to the ship
1053: Diver at recompression chamber, initial assessment is completed and the diver begins treatment on a US Navy TT-6 which is converted to a TT- 9 after the first oxygen breathing period

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Treatment

During transit to the ship, the diver exhibited difficulty breathing 100% oxygen and after consultation with the Diving Medical Officer (DMO), was taken off oxygen and allowed to breathe atmospheric air. The diver was in and out of consciousness and periodically unresponsive to any visual or audible commands. Once alongside the ship it was determined that, with assistance, the diver was able to walk to the recompression chamber in lieu of taking the additional time to extricate via a back-board.

Upon arrival at the chamber, the diver was assessed by a NOAA Dive Medical Officer and the Chamber Supervisor. The decision was made to treat the diver on a US Navy Treatment Table 6, which was later revised to a Treatment Table 9 after consultation with a shore side NOAA DMO and US Navy Diving Salvage & Training Center DMO. Treatment commenced at 1053 and concluded at 1400. At the completion of the TT-9, the diver was escorted to sickbay where the diver was observed for 24 hours. Once the ship arrived in port, the diver was taken to the hospital where further evaluation and additional recompression therapy was conducted by a hyperbaric physician. At the completion of the treatment, the diver was released from the hospital and told to refrain from diving for 6 weeks.

Investigation

An investigative team (IT) was commissioned to conduct a safety investigation of the aforementioned diving incident. The final medical diagnoses were oxygen toxicity and arterial gas embolism (AGE). The report further indicated that all established medical policies were followed during this incident.

The NOAA Dive Control Safety Board (NDCSB) requested a review of the dive plan, Diving Emergency Assistance Plan (DEAP), technical diving checklist, and emergency procedures for technical dives, by a non-NOAA technical diving expert. This review was completed and the results reported no anomalies with any of the plans for this dive and indicated all procedures were well within accepted standards for this type of diving.

General Findings

1. No operational infractions of OSHA or NOAA diving regulations, standards or policies were noted.
2. All risk management and pre-dive planning were completed in accordance with NOAA procedures listed in the NOAA Scientific Diving Standards and Safety Manual (NSDSSM).

3. All required dive-worn equipment was present, properly configured and fully functional.
4. There was no indication of an uncontrolled ascent that may have lead to the AGE nor was there indication that the diver violated the NOAA Oxygen Exposure Limits.
5. The root cause of incident was an unexpected physiological episode (oxygen toxicity) and secondary AGE.
6. The emergency response to this incident was handled expeditiously and professionally by the ship crew, divers, and medical personnel.
7. The diving personnel on the ship were well trained in conducting diving operations and managing diving emergencies.
8. The diving locker and gas systems on the ship were well run and managed with good practices and well trained, professional personnel.
9. The recompression chamber on the ship was well equipped with an adequate gas supply (e.g., oxygen, air), an advanced first aid kit, an oxygen kit (w/ extra oxygen bottles), and a back board.
10. Analysis of gases produced by the onboard air compressor and in the diver's scuba cylinders were within NOAA specifications.
11. Review of data from the diver's dive computer indicated normal rates of ascent and completion of all decompression stops with minimal depth fluctuation.

Findings of Concern and Corrective Actions

1. Finding: Although the diver was properly trained and certified to perform technical dives, no record of the diver's technical dive training or Dive Computer Users Agreement were on file at the NDC or at the Unit.

   Lesson Learned: Prior to approving future technical diving missions, the NDCSB needs to ensure that all required documents are on file at the NDC.

   Action:

   A. Send a copy of this report to all NOAA divers and post report on the NOAA Diving Center webpage. NOAA divers are reminded of their responsibility for submitting copies of all certifications to the NDC in a timely manner.

   Lead: NOAA Diving Program Manager (NDPM)

   Completion Date: Prior to any future technical diving operations

   B. Add a section to the NDP Decompression Diving Request Checklist and Dive Plan indicating that all appropriate certifications and training records for each technical diver are on file at the NDC and Unit.

   Lead: NDPM

   Completion Date: Prior to any future technical diving operations

2. Finding: The diver appeared to be confused by the reading on the VR3 dive computer which indicated an air break was required during the 20-foot decompression stop. According to information gathered during the interview process, the decision to ignore the requirement and remain on oxygen was discussed during the pre-dive briefing, but the diver either did not hear the decision, or did not remember the decision, the latter of which could be attributed to mental confusion associated with oxygen toxicity.

   Lesson Learned: Dive computers are only as safe as the divers using them. It is imperative, as well as a requirement of the NOAA standards, that divers thoroughly understand the operation of their dive computers. Failure to do so can result in decompression sickness.

   Corrective Action: Send a copy of this report to all NOAA divers and post report on the NOAA Diving Center webpage. NOAA divers are reminded of their responsibility for understanding the operation of their dive computers and for completing Dive Computer User Agreements and submitting them to NDC.

   Lead: NDPM

   Completion Date: Prior to any future technical diving operations

3. Finding: A dive accident drill was scheduled the day of the incident and there was some confusion of whether the actual incident was part of the drill or real.

   Lesson Learned: Dive accident drills are very important and played a crucial role in the positive outcome of this diving incident. However, it is equally important to adopt the policy that drills and non-drills will be announced as such to all involved. In the event of an actual emergency, this will alert everyone involved that the incident is to be taken seriously and actions normally taken during drills (e.g., not dropping the diver's weight belt) can be ignored.

   Corrective Action: Send a copy of this report to all NOAA divers and post report on the NOAA Diving Center webpage. NOAA divers and supervisors are instructed to clearly announce to all involved whenever a diving incident is NOT a drill.

   Lead: NDPM

   Completion Date: Prior to any future technical diving operations

4. Finding: Non-technical and technical dives were being conducted simultaneously at the time of this incident. If a more serious emergency had occurred during either operation, it could have complicated and impacted accident management.

   Lesson Learned: Although it did not present a problem during this incident, had an emergency occurred during the other dive operation (being conducted simultaneously with the technical dives) accident management could have been compromised because the technical divers could not be immediately recalled to the surface due to their decompression obligation.

Corrective Action: Send a copy of this report to all NOAA divers and post report on the NOAA Diving Center webpage. Additionally the NDCSB will review this issue and take action if deemed appropriate.

Lead: Chair, NDCSB

Completion Date: Prior to any future technical diving operations

5. Finding: The root cause of this incident was oxygen toxicity. Although NOAA and other agencies permit oxygen partial pressures up to 1.6 ATA, some experts suggest a lower limit is warranted.

   Lesson Learned: Adherence to the NOAA maximum oxygen exposure limits rarely results in an oxygen toxicity event. However individual susceptibility to oxygen toxicity varies from person to person and cannot be anticipated or predetermined. In this incident, the diver was well within the exposure limit and no additional contributing factors were noted. This only reinforces the notion that diving maladies can occur even if the rules are followed and the diver does everything right. Thus, extra conservatism should be considered when diving with elevated partial pressures of oxygen.

   Corrective Action: Send a copy of this report to all NOAA divers and post report on the NOAA Diving Center webpage. Additionally the NDCSB will review this issue and take action if deemed appropriate.

   Lead: Chair, NDCSB

   Completion Date: Prior to any future technical diving operations

6. Finding: Oxygen toxicity is an inherent risk for open-circuit technical diving.

   Lesson Learned: The potential problems associated with oxygen toxicity are increased for divers wearing open-circuit scuba equipment. Should a diver fall unconscious during an oxygen toxicity event, the diver's scuba regulator will most likely fall from his mouth allowing water to be inhaled on his next breath. Another inherent problem is the inability to easily control the partial pressure of oxygen being breathed. Consequently partial pressures continue to increase as the diver descends deeper. Other types of equipment and/or modes of diving should be considered that would address these inherent problems with open-circuit scuba.

   Corrective Action: Send a copy of this report to all NOAA divers and post report on the NOAA Diving Center webpage. Additionally the NDCSB will investigate other *in-situ* modes of diving that would reduce the potential risks of oxygen toxicity associated with open-circuit technical diving.

   Lead: Chair, NDCSB

   Completion Date: Q4, FY12

7. Finding: Standard operating procedures for technical diving do not require a separate submersible pressure gauge for each of the diver's trimix regulators. Should an emergency occur to the diver's primary regulator requiring isolation of that

regulator at the cylinder valve, the diver would no longer be able to monitor cylinder pressure while breathing from the secondary regulator.

Lesson Learned: Although NOAA standards do not require separate submersible pressure gauges for each trimix regulator some members of the NDCSB suggest such a requirement would be prudent.

Corrective Action: Send a copy of this report to all NOAA divers and post report on the NOAA Diving Center webpage. The NDCSB will review this issue and take action if deemed appropriate.

Lead: Chair, NDCSB

Completion Date: Prior to any future technical diving operations

8. Finding: Inspection of the diver's equipment by the Lead Inspector of the IT and NDC Equipment Specialist revealed a non-penetrating 1 mm slit in the diver's primary trimix regulator mouthpiece, a slight free-flow in the diver's nitrox regulator, and a missing O-ring on the diver's secondary trimix first-stage regulator. It is uncertain whether these conditions were present at the time of the dive incident.

   Lesson Learned: Although the equipment deficiencies noted during inspection of the diver's equipment did not appear to cause or exacerbate the problem during this incident, any of them could have. Although it is uncertain whether the deficiencies were present at the start of the dive or occurred during shipment to the NDC following the dive, had they been present prior to the dive, the equipment should not have been used to conduct the dive. Divers and Divemasters must carefully inspect all equipment prior to dives to ensure it is in good working condition.

   Corrective Action: Send a copy of this report to all NOAA divers and post report on the NOAA Diving Center webpage. Additionally all divers and supervisors are reminded of the importance of conducting a thorough inspection of their equipment prior to conducting dives.

   Lead: NDPM

   Completion Date: Prior to any future technical diving operations

The Chair of the NDCSB will monitor completion of the Corrective Actions and report them to the Director, OMAO and Director, SECO on a quarterly basis.

Conclusions

Technical diving involves a higher level of risk than non-technical diving operations. However, NOAA has instituted additional safety measures to mitigate the additional risks. Technical diving allows NOAA scientists to gather data, dictated by statutory requirements and legislative mandates, which currently cannot be obtained by any other mode of operation and therefore, needs to continue.

This incident was the result of an unanticipated physiological event, inherent with increased oxygen partial pressures when diving to deeper depths. To date the NDP has

conducted 482 technical dives, with only 1 case of oxygen toxicity, a frequency of 0.2%. Although significant safe guards are in place to address the additional risks, the corrective actions outlined in this report will increase the safety of such operations even further.

It is the decision of the NDCSB that once all corrective actions marked, “Completion Date: Prior to any further technical diving operations” are resolved, technical diving will be reinstated within the NOAA Diving Program.