

SHALLOW-WATER NITROX DIVING, THE NASA EXPERIENCE

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INTRODUCTION: NASA's Neutral Buoyancy Laboratory (NBL) contains a 6.2 million gallon, 12-meter deep pool where astronauts prepare for space missions involving space walks (extravehicular activity EVA). Training is conducted in a space suit (extravehicular mobility unit EMU) pressurized to 4.0 - 4.3 PSI for up to 6.5 hours while breathing a 46% NITROX mix. Since the facility opened in 1997, over 30,000 hours of suited training has been completed with no occurrence of decompression sickness (DCS) or oxygen toxicity. This study examines the last 5 years of astronaut suited training runs.

METHODS: All suited runs are computer monitored and data is recorded in the Environmental Control System (ECS) database. Astronaut training runs from 2004 - 2008 were reviewed and specific data including total run time, maximum depth and average depth were analyzed. Oxygen partial pressures (PO₂) were calculated based on physiological depth exposure. A medical assessment for potential DCS and oxygen toxicity was completed following each suited run.

RESULTS: One hundred twenty seven astronauts and cosmonauts completed 2,231 training runs totaling 12,880 exposure hours. Data was available for 96% of the runs. As seen in Table 1, annual depth exposures remained relatively constant while average time exposures increased. Approximately 57% of the runs exceeded six hours, with an average run time of 379 minutes, maximum depth of 11.2 meters, and average run depth of 5.6 meters with a PO₂ of 0.85 ATA (Table 2). The average run depth was provided for 77% of the training runs. As shown in Table 3, 30% of these runs exceeded an average run depth of 6 meters, with a maximum depth of 11.3 meters, average run time of 350 minutes, and an average run depth of 6.9 meters with a PO₂ of 0.91 ATA. A subset of 306 subjects completed runs longer than 6 hours with an average depth greater than 6 meters. They had an average run time of 378 minutes, maximum depth of 11.2 meters, and an average run depth of 6.9 meters with a PO₂ of 0.90 ATA. The graph shows that 85% of this subset exceeded the National Oceanic and Atmospheric Administration (NOAA) oxygen exposure limits. There were no reports of DCS or oxygen toxicity.

CONCLUSIONS: The suit configuration produces a maximum equivalent air depth of 7 meters, essentially eliminating the risk of DCS. Based on average run depth and time, approximately 17% of the training runs exceeded the NOAA oxygen maximum single exposure limits, with no resulting oxygen toxicity. The NBL suited training protocols are safe and time tested. Consideration should be given to reevaluate the NOAA oxygen exposure limits for PO₂ levels at or below 1 ATA.

Table 1
Annual Exposure Data

Year	Total Runs	Total Time (hrs)	Max. Depth (m) (range)	Ave. Depth (m) (range)	Ave. Time (min) (range)
2004	391	2,061.6	11.2 (9.1-12.0)	5.8 (2.7-9.0)	316.4 (62.0-399.6)
2005	350	1,938.9	11.2 (10.3-12.0)	5.7 (3.5-8.1)	332.7 (174.0-406.2)
2006	469	2,704.5	11.1 (8.0-11.9)	5.5 (3.3-7.7)	346.0 (80.0-397.0)
2007	521	3,195.9	11.2 (10.5-12.0)	5.7 (1.7-8.5)	368.1 (191.0-399.0)
2008	500	2,978.8	11.2 (10.8-12.0)	5.3 (1.8-8.2)	357.5 (139.8-390.2)

Table 2
Suited Runs by Time (min)

	<240	240-299	300-359	≥360
Total Runs	91	304	563	1,273
Max. Depth (m) (range)	11.2 (10.5-11.9)	11.1 (10.3-12.0)	11.2 (8.0-12.0)	11.2 (9.1-12.0)
Ave. Depth (m) (range)	5.2 (3.2-7.6)	5.7 (2.9-8.5)	5.6 (1.7-8.9)	5.6 (1.8-9.0)
Ave. Time (min) (range)	195.4 (62.0-239.8)	276.2 (240.1-299.8)	336.3 (300.0-359.9)	378.5 (360.0-406.2)
Ave. PO2 (ATA) (range)	0.83 (0.74-0.94)	0.85 (0.72-0.98)	0.85 (0.67-1.0)	0.85 (0.67-1.0)

Table 3
Suited Runs by Depth (meters)

	≤3.0	3.1-4.5	4.6-6.0	≥6.1
Total Runs	27	277	898	527
Max. Depth (m) (range)	11.1 (10.8-11.5)	11.2 (8.5-11.9)	11.2 (8.0-12.0)	11.3 (9.1-12.0)
Ave. Depth (m) (range)	2.6 (1.7-3.0)	4.0 (3.1-4.5)	5.4 (4.6-6.0)	6.9 (6.1-9.0)
Ave. Time (min) (range)	361.8 (243.7-388.8)	341.1 (128.5-394.4)	345.0 (102.2-399.6)	349.6 (153.3-406.2)
Ave. PO2 (ATA) (range)	0.71 (0.67-0.73)	0.78 (0.73-0.80)	0.84 (0.80-0.87)	0.91 (0.87-1.0)

Oxygen Partial Pressure Exposures

