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An Auxiliary Gas Supply To Improve Safety During Aborted Dives With The Canadian Underwater Mine-Countermeasures Apparatus (CUMA)

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Technical Report
DRDC Toronto TR 2010-081
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Abstract

The Canadian Underwater Minecountermeasures (MCM) Apparatus (CUMA) was introduced into Canadian Forces (CF) service in 1991 and is widely used by other Navies under the commercial name of SIVA+. Despite its success, both within the CF and abroad, it is now apparent that emergency procedures were not fully researched at the time of its introduction. Subsequent research into Severe Decompression Accidents (SDAs) has shown that previous emergency procedures were not sufficient to safely decompress a diver during an emergency ascent from deep or long, shallow dives. As a result of this, other decompression procedures have been instituted, based on research and practices adopted from other nations. Another option is to give the diver the option of decompressing safely in the water. This will be done using a completely independent and alternative breathing system known as the Auxiliary Gas Supply (AGS) in case of complete diving set failure. The AGS will allow the diver to decompress using existing operational tables rather than extended emergency tables. The AGS will deliver a 40% oxygen and 60% nitrogen mix, which will facilitate helium off-gassing following the same proven principal used in CF Surface Supplied diving.

Validation experiments were conducted between June 2002 and November 2003 over four series of dives. Doppler scores from the 202 man dives showed no significant difference in observed bubble scores between those dives that had used the AGS to decompress and the data from previous dives using normal in-water or surface decompression. There was only one incident of surface interval stress and no incident of Decompression Illness (DCI). The results indicate that a CUMA diver can be safely decompressed from a dive requiring decompression using the in water AGS.

Résumé

L’appareil canadien de déminage sous-marin (ACDSM) est au service des Forces canadiennes (FC) depuis 1991 et est aussi largement utilisé par d’autres marines sous la dénomination commerciale SIVA+. Malgré son succès au sein des FC et à l’étranger, il s’avère maintenant que les procédures d’urgence n'ont pas fait l’objet de recherches approfondies au moment de sa mise en service. Des études menées ultérieurement sur les accidents de décompression graves (ADG) ont révélé que les procédures d’urgence instaurées à l’époque ne permettent pas une décompression sécuritaire des plongeurs lors d’une remontée en catastrophe après une plongée profonde ou une plongée peu profonde de longue durée. Par conséquent, d’autres procédures de décompression fondées sur les recherches menées et les pratiques adoptées par d’autres nations ont été établies. Une autre option consiste à donner aux plongeurs la possibilité d’effectuer la décompression sous l'eau en toute sécurité. Pour ce faire, un autre système respiratoire entièrement autonome, le système auxiliaire d'approvisionnement en gaz (SAAG), doit être utilisé dans le cas d'une défaillance complète de l’appareil de plongée. Le SAAG permet aux plongeurs d’utiliser les tables de décompression opérationnelles existantes plutôt que les tables de décompression d’urgence étendues. Le SAAG fournit un mélange de 40 % d’oxygène et de 60 % d’azote qui facilite le dégazage de l'hélium selon le même principe éprouvé qu’utilisent les FC pour la plongée en narghilé.

Des expériences de validation ont été menées de juin 2002 à novembre 2003, au cours de quatre séries de plongées. Les données consignées par le détecteur de bulles Doppler au cours de 202 plongées-personne ne montrent aucun écart important entre les résultats observés lors de la décompression par SAAG et les données recueillies lors de plongées précédentes à décompression normale sous l’eau ou en surface. Il ne s’est produit qu'un seul incident de stress causé par un intervalle de surface trop court; aucun mal de décompression n’a été relevé. Les résultats indiquent qu’il est possible, pour un plongeur muni d’un ACDSM, d’utiliser le SAAG sous l’eau pour procéder à une décompression sécuritaire lorsqu’une décompression est requise.

Executive summary

An Auxiliary Gas Supply To Improve Safety During Aborted Dives With The Canadian Underwater Mine-Countermeasures Apparatus (CUMA)

R.Y. Nishi; D.J. Eaton; A.J. Ward; D.J. Woodward; DRDC Toronto TR 2010-081; Defence R&D Canada – Toronto; November 2010.

Introduction: The Canadian Underwater Minecountermeasures (MCM) Apparatus (CUMA) is a self-contained, semi-closed circuit breathing apparatus in service with the Canadian Forces (CF) and other North Atlantic Treaty Organization (NATO) Navies for diving on underwater mines to a depth of 81 metres of seawater (msw) using a mixture of helium and oxygen (Heliox). Emergency procedures where a diver has to abort a dive because of breathing apparatus malfunction had not been addressed adequately for CUMA. The original emergency procedure was for the diver to ascend directly to the surface, omitting all in-water decompression stops and then be treated on a therapeutic table for omitted decompression. Evidence now shows this could lead to a severe decompression accident. Although an interim method of emergency decompression has been adopted for use with the CUMA, an alternative solution is a totally independent gas supply, which can be quick-connected to the semi-closed breathing circuit with an appropriate gas mix to allow the diver to complete all in-water stops following the normal prescribed table in an emergency equipment abort scenario. Comparable but open circuit systems that require extended decompression are in service with the United States Navy (USN) and the Royal Navy (RN) with their chosen rebreathers.

Results: The Auxiliary Gas Supply (AGS) concept tested consisted of two gas supplies, one with oxygen (O_2) and one using a 60% nitrogen (N_2) and 40% O_2 mixture (N_2/O_2). The diver connects the CUMA breathing loop to the AGS via a "quick-connect" gas line into either the N_2/O_2 or O_2 gas supplies depending on depth. Mathematical modelling indicated that the use of the AGS in a bailout procedure should allow the diver to follow the current CF decompression tables without the risks associated with the current interim drill. The N_2/O_2 concentrations were chosen to keep the inert gas level as low as possible to optimise decompression but still keep the Partial Pressure of O_2 (PO_2) close to the CUMA design parameters to lower the risk of Central Nervous System (CNS) O_2 toxicity. A total of 252 experimental dives (479 man-dives) to prove this concept were conducted during the course of four 5-week dive series between June 2002 and November 2003. Doppler monitoring of the subjects for decompression purposes and monitoring of the gas in the breathing loop showed that the AGS worked as predicted. The evidence showed that changing from a Heliox to a N_2/O_2 mix for decompression was beneficial as seen in other areas of military and civilian diving and that using the AGS may reduce the overall decompression risk.

Significance: The safety of Clearance Divers whilst operating with CUMA will be greatly improved. The AGS offers a diver in an emergency situation the ability to safely decompress, even in the case of a catastrophic failure of the rebreather diving equipment. The use of the standard CF CUMA diving tables to do this will maintain operational efficiency and flexibility for a small detachment of divers undertaking an urgent MCM task or other task where capability must be maintained.

Sommaire

Un système auxiliaire d’approvisionnement en gaz augmente la sécurité des plongeurs utilisant l’appareil canadien de déminage sous-marin (ACDSM) lors des remontées d'urgence

R.Y. Nishi; D.J. Eaton; A.J. Ward; D.J. Woodward; DRDC Toronto TR 2010-081; R & D pour la défense Canada – Toronto; Novembre 2010.

Introduction ou contexte: L’appareil canadien de déminage sous-marin (ACDSM) est un appareil respiratoire autonome à circuit semi-fermé utilisé par les Forces canadiennes (FC) et par d’autres marines de l’Organisation du traité de l'Atlantique Nord (OTAN) pour effectuer des opérations de déminage sous-marin jusqu'à une profondeur de 81 mètres d'eau de mer. Cet appareil fournit un mélange d'hélium et d'oxygène (Héliox). Les procédures d'urgence à observer pour une remontée en catastrophe en cas de défaillance de l'ACDSM n’ont pas été étudiées de manière adéquate lors de la mise en service de l'appareil. Selon les procédures établies à l'époque, le plongeur devait remonter directement à la surface sans effectuer de paliers de décompression, puis se faire traiter à l’aide d’une table de décompression. Des données démontrent maintenant que cette façon de procéder peut provoquer des accidents de décompression graves. Bien qu'une méthode provisoire de décompression d'urgence ait depuis été adoptée pour les ACDSM, une autre solution s’impose : un approvisionnement en gaz entièrement indépendant pouvant être raccordé rapidement au circuit respiratoire semi-fermé et utilisant un mélange de gaz approprié pour permettre aux plongeurs de respecter tous les paliers de décompression prescrits par la table de décompression normale utilisée lorsqu’il faut couper court à une plongée en raison d'une défaillance de l'équipement. Les États-Unis et le Royaume-Uni se servent de systèmes comparables avec leurs appareils de respiration à circuit fermé respectifs, à la différence que ces systèmes sont à circuit ouvert et qu’ils exigent une décompression étendue.

Résultats: Le concept de SAAG mis à l’essai se compose de deux bouteilles, l’une remplie d'O_2 et l’autre d’un mélange de 60 % de N_2 et de 40 % d’O_2 (N_2/O_2). Le plongeur doit connecter la boucle respiratoire de l’ACDSM à l’une des deux bouteilles du SAAG (selon la profondeur à laquelle se trouve le plongeur) grâce à une conduite à raccord rapide. Des modélisations mathématiques ont permis de calculer que l’utilisation d’un SAAG lors d’une remontée d’urgence devrait permettre au plongeur d’utiliser les tables de décompression actuelles des FC sans s’exposer aux risques associés à la méthode actuelle. Ces concentrations de N_2/O_2 ont été choisies pour minimiser le plus possible le taux de gaz inerte afin d'optimiser la décompression tout en gardant la PO_2 près des paramètres de conception de l’ACDSM pour diminuer les risques d’accidents neurotoxiques provoqués par hyperoxie. Pour valider ce concept, un total de 252 plongées d’essai (479 plongées-personne) ont été réalisées lors de quatre séries de plongées d’une durée de cinq semaines, qui ont eu lieu de juin 2002 à novembre 2003. Un contrôle Doppler des participants aux fins de décompression et l’analyse continue des gaz dans la boucle respiratoire démontrent que le SAAG fonctionne comme prévu. Les résultats démontrent qu’il s’avère bénéfique d’utiliser un mélange de N_2/O_2 plutôt que du Héliox pour la décompression comme il a aussi été constaté dans d’autres types de plongée militaire et civile, et que l’utilisation d’un SAAG peut réduire les risques globaux liés à la décompression.

Importance: La sécurité des plongeurs-démineurs utilisant l'ACDSM sera grandement améliorée, car le SAAG permet aux plongeurs en détresse de procéder à une décompression sécuritaire, même advenant une défaillance catastrophique de l'appareil de respiration à circuit fermé. L'utilisation des tables de plongée standard des FC pour ACDSM permet de maintenir l'efficacité opérationnelle et la flexibilité d'un petit détachement de plongeurs effectuant une opération de déminage urgente ou toute autre tâche pour laquelle la capacité opérationnelle doit être maintenue.

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1 Introduction

The Canadian Underwater Minecountermeasures (MCM) Apparatus (CUMA) is a self-contained, semi-closed circuit breathing apparatus in service with the Canadian Forces (CF) for diving on underwater mines to a depth of 81 metres of seawater (msw) using a mixture of helium (He) and oxygen (O_2) (HeO_2). CUMA is a type of breathing apparatus that is commonly referred to as a "rebreather". Marketed commercially as SIVA+, CUMA is also in service with other North Atlantic Treaty Organization (NATO) and non-NATO nations. The Experimental Diving Unit (EDU)[1] at DRDC Toronto developed and validated the HeO_2 decompression tables and procedures used with CUMA. These include no-decompression (No-D), in-water with oxygen (O_2) decompression (IWO_2), surface decompression with oxygen (SurD O_2) tables, and repetitive dive procedures. The tables and procedures are approved for operational use by the CF and other Navies using CUMA.

What has not been addressed adequately for CUMA are emergency procedures where a diver has to abort a dive because of breathing apparatus malfunction. The original CF emergency procedure was to have the diver make an ascent to the surface at a controlled and standard rate, omitting all in-water decompression stops. The diver would then be treated on a therapeutic table for omitted decompression. However, for deeper dives and shallow, long dives, evidence now shows this could lead to a Severe Decompression Accident (SDA) [1-2].

The CUMA/SIVA+ community all agreed that this emergency equipment abort procedure must be modified without delay, so as to increase a diver's chances of survival. Aborted dives where the apparatus has malfunctioned will require the diver to switch from the main gas supply to the diver carried bailout supply. While this gas supply is not large enough to be used to complete in-water decompression stops, it does permit the diver to take further action on reaching 12 msw by commencing a specific period of O_2 decompression at that depth using the diver carried O_2 gas supply, subject to O_2 flow being proved by a function check. This procedure, derived from mathematical modeling, was introduced as an interim CUMA drill to the CF on 13th March 2001 and subsequently by the other nations using SIVA+.

However, ascending to 12 msw while omitting significantly deeper stops is still considered a potentially high-risk procedure, although better than making a direct ascent to the surface with no stops. The alternative of using pure O_2 at deeper depths is not a viable option as the Partial Pressure of Oxygen (PO_2) levels will exceed recognised safe limits and may result in a Central Nervous System (CNS) O_2 toxicity.

While more investigation is being undertaken into the interim method, an alternative is being sought that will allow the diver to complete the prescribed in-water decompression stops in an emergency equipment abort scenario. The proposed solution is an Auxiliary Gas Supply (AGS), a totally independent gas supply which can be quick-connected to the semi-closed breathing circuit with an appropriate gas mix to allow the diver to complete all in-water stops following the normal prescribed table. If the diver must abort the dive, the diver would

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[1] In 2006, the Experimental Diving Unit (EDU) became the Experimental Diving and Undersea Group (EDUG) in the Aerospace and Undersea Medical Sciences Centre (now the Joint Operational and Human Sciences Centre) of DRDC Toronto.

ascend to the AGS at 3 msw below the scheduled first stop, connect to it and undergo normal decompression. If successful, it would avoid the unacceptable risk of placing a diver into a serious omitted decompression scenario or SDA following a deep or long dive exposure. An AGS connection prototype was tested for usability during the field evaluation of CUMA Version 2 (V2). The dive subjects found they could connect and disconnect easily to the AGS while in the water. Comparable but open circuit systems that require extended decompression are in service with the United States Navy (USN) and the Royal Navy (RN) with their chosen rebreathers.

This report is on the study to test if the AGS can be used to support a diver undertaking standard decompression profiles in accordance with the CF operational tables for IWO_2 and SurD O_2 in the event of a CUMA malfunction. Dive subjects were from the CF (DRDC Toronto EDU, Fleet Diving Unit (Atlantic) (FDU(A)), Fleet Diving Unit (Pacific) (FDU(P)), the RN (Exchange Officer posted to EDU), Royal Netherlands Navy (RNLN), Royal Norwegian Navy (RNoN), Royal New Zealand Navy (RNZN), and the US Navy Experimental Diving Unit (USNEDU).

2 Background

2.1 Severe Decompression Accidents

Emergencies that force a diver to abort a dive (e.g., breathing apparatus malfunction) may result in missed decompression stops. The original CF prescribed procedure was to have the diver make an ascent to the surface at a controlled and standard rate, omitting all in-water decompression stops with the diver then being treated on a therapeutic table for omitted decompression. However, for deeper dives and shallow, long dives, evidence now shows this could lead to a severe SDA. Just how severe was not appreciated at the time of CUMA's introduction into service in 1991. Unimed Scientific Ltd (USL) of Aberdeen, Scotland, was contracted by EDU to conduct research on SDAs [1-2] in 1998-99. The research used anaesthetised pigs to model the risk of injury or death to a diver experiencing a SDA from a dive to 81 msw for 20 minutes (min) with a standard ascent rate to the surface. Twenty pigs were exposed to the profile. Of these, twelve died – four on the surface before recompression treatment, three during the recompression treatment and five after the treatment. These results imply that the risks of even a controlled direct ascent to the surface from a deep or long exposure are unacceptably high.

2.2 Red Light Drills

Various national ideas have been proposed by the CUMA/SIVA+ community. All these Red Light Drills involve a common theme of the diver ascending in a controlled manner to 12 msw on the secondary bailout supply, confirming that the dive set was still delivering O_2 by a function check, then undertaking decompression stops at 12 and 9 msw while breathing O_2. The theory is that this would provide some essential decompression in the water column prior to the most critical pressure change experienced during the final ascent to the surface. The overarching aim was to reduce the decompression debt sufficiently to ensure that off-gassing during the period of transfer to a Recompression Chamber (RCC) would not produce debilitating or fatal injury. National opinions varied on the length of time at these shallow stops, and the subsequent options on surfacing for treatment in a RCC.

In the RNoN proposal for a Red Light Drill, the diver ascends to 12 msw on bailout gas where the standby diver will provide O_2, test the O_2 by testing the bypass, and, if satisfactory, switch off the bailout. The decompression time (from the CUMA tables) normally carried out at 12 msw is doubled. On completion, the diver travels to 9 msw, carries out the O_2 flushing drill, and then completes the planned O_2 stop from CF Table 11 [3]. The diver is then brought to the surface and treated for omitted decompression.

The RNLN proposal is initially the same, with the diver ascending to 12 msw and carrying out the standard in-water stop time as specified in the CUMA tables before ascending to 9 msw and transferring to O_2 as before. From this point, there are two options – decompression using IWO_2 and SurD O_2. In the first case, the time at 9 msw on O_2 (from CF Table 11) is doubled. On return to surface, the diver remains in the vicinity of the RCC for four hours. In the second case, the in-water O_2 stops are the combination of all the in-water stops missed to that point and the diver continues with the same RCC O_2 stop for surface decompression as specified by CF Table 12.

The CF Director of Diving Safety requested that EDU look into this issue as part of Canada's commitment to the NATO Underwater Diving Working Group. EDU contracted USL to model worst case scenarios of the proposed bailout drills using USL's mathematical model of bubble formation [4]. EDU examined the results and recommended to the CF to adopt the procedure proposed by the RNoN as an interim drill in March 2001. CF procedures [3] were updated based on that recommendation. During Deep Divex 2001, all nations agreed to DRDC Toronto's recommendation to adopt this as an interim drill.

However, the research indicates that for the less extreme exposures, the procedure may be too cautious and unnecessarily limiting in operational terms. USL was then tasked to undertake further modelling across a complete range of dive profiles to propose a less restrictive drill. The approach taken was to start from the CF drill and modify it with in-water oxygen breathing for just sufficient time to reduce the risk to an acceptable level at which hyperbaric treatment would be effective [5]. This additional work was completed in November 2002 and was assessed by EDU. The predictions imply that decompression stops below 12 msw are unnecessary but conventional wisdom and experience suggest that ascending to 12 msw while omitting significantly deeper stops is still a potentially high risk procedure, though better than making a direct ascent to the surface with no stops. It was clear some physical testing would be necessary to tune the model and validate the procedure, and also to examine the problem that the bubble formation model [4] predictions ignore the traditional approach of staged decompression.

2.3 Auxiliary Gas Supply

With that in mind, an alternative system is one that will allow the diver to complete the prescribed in-water decompression stops in a bailout scenario. The proposed solution is a totally independent gas supply, which can be quick-connected to the semi-closed breathing circuit with appropriate gas mixes. The AGS concept would consist of two gas supplies, one with O_2 and one using a nitrogen (N2) and O_2 mixture (N_2/O_2) (ratio of 60% N_2 and 40% O_2). The diver then connects the CUMA breathing loop to the AGS via a "quick connect" gas line into either N_2/O_2 or O_2 gas supplies depending on depth. Mathematical modelling indicated that the use of the AGS in a bailout procedure will allow the diver to follow the current CF decompression tables without the risks associated with the current interim drill. The N_2/O_2 concentrations were chosen to keep the inert gas level as low as possible to optimise decompression but still keep the PO_2 close to the CUMA design parameters to lower the risk of CNS O_2 toxicity. The experiment to test the AGS concept commenced with an initial mix of 60% N_2 and 40% O2 to minimise the risk of CNS O_2 toxicity and compared the measured O_2 levels in the breathing loop to those predicted by the model. There was an option to test using a 40% N_2 and 60% O_2 mix for increased decompression benefit, if found necessary, versus increased risk of CNS O_2 toxicity but this was not found to be necessary. The use of N_2/O_2 as the bailout gas rather than HeO_2 was chosen to facilitate He off-gassing. This follows the same principal used in CF Surface Demand diving where a switch to air at the first decompression stop is used to accelerate He off-gassing [6]. This procedure was exploited during the CUMA table validation and repetitive dive procedures experimental work undertaken between November 1997 and December 2001 [7-9], with the team leader switching from an HeO_2 gas source to air (a 21% O_2 and 79% N_2 gas mix) at the first decompression stop while following the same CUMA decompression profile as the other three dive subjects (two wet divers and a standby diver). The evidence showed that using the AGS may reduce the overall decompression risk.

3 Method

3.1 Subjects

Qualified volunteer rebreather divers from FDU(A), FDU(P), USNEDU, RNLN, RNoN, and RNZN plus DRDC Toronto EDU (CF divers and RN Exchange Officer) served as subjects during the dive trials [10-13]. Visiting subjects were made available for up to 5 weeks at a time. All visiting divers received two days of training and indoctrination in the experimental procedures, and the use of CUMA and the prototype AGS umbilical system prior to commencement of experimental dives. DRDC Toronto divers undertook their training as part of an EDU work-up prior to each dive series. Pre-series medical assessments that included age, height, weight and skin fold calliper measurements were also carried out. These are shown in *Table A1*, **Annex A**. Daily questionnaires were completed by the divers prior to each dive covering pre-dive exercise, sleep pattern, alcohol in-take, smoking habit, food and fluid in-take and any medication taken that might have a possible influence on the dive.

Each dive was planned for four divers: two wet working divers (designated Red and Yellow) on CUMA, and one standby diver (partially wet, resting) and one team leader (dry, lightly working) both breathing 84/16 HeO_2 from a Built-in Breathing System (BIBS). Team leaders and standby divers switched to air at the first decompression stop and then to O_2 at 9 msw following surface-supplied mixed gas procedures, while following the CUMA decompression schedule. (During Series 1, standby divers used CUMA throughout the dive.)

The visiting subjects were assigned a roster number and would dive either as Red and Yellow divers using CUMA and the AGS system, or as a standby safety diver. Team leaders were DRDC Toronto divers. The latter also supplemented the other positions as required. In accordance with the protocol requirement [10], an absolute minimum of 18 hours had to elapse after any AGS decompression before a diver could dive again in any position. Divers would therefore normally dive on alternate days to provide at least one full day of rest between dives for any given diver, but could dive on consecutive days if used on one day as the team leader or standby diver, or if 18 hours had elapsed following a CUMA dive with an AGS decompression the previous day.

3.2 Procedures

The experimental dive program was approved by the DRDC Human Research Ethics Committee. All dives were carried out in the DRDC Toronto Diving Research Facility (DRF) in accordance with EDU Experimental Operational Orders for each series of experiments, starting with Series 1 [10] and ending with Series 4 [13]. (A few additional dives were also carried out during the AGS prototype evaluation in Series 5 [14].)

CUMA is designed to operate from the surface to a maximum depth of 81 msw, but is normally employed only in excess of 42 msw. This study covers a narrow band of diving depths using realistic dive durations to simulate the operational scenarios where these procedures might be used. Profile testing initially started with less stressful dive profiles in order to compare the results of the AGS system against Doppler data gained during the development of the current operational tables and repetitive procedures, before continuing with the more stressful profiles.

Table 1 shows the profiles chosen for single dive testing with subsequent in-water decompression using the AGS. CF Table 11(M) [15] was used for the IWO_2 profiles and CF Table 12(M) [15] for the SurD O_2 profiles. To ensure a broad cross section of divers as a data base, the different profiles were tested across all four series. Testing started with the lower stress dive profiles, gradually moving forward to increased stress profiles.

Table 1. Single dive schedules tested with AGS during in-water decompression

Dive Type	**Depth (msw)**	**Bottom Time (min)**	**Stop Times (min) at Different Depths (msw)[1]**												**Total Dec.[4] Time (min)**
			In-Water Stops										**Surf. Int.[2] (min)**	**RCC**	
			HeO_2									**O_2**		**O_2**	
			36	**33**	**30**	**27**	**24**	**21**	**18**	**15**	**12**	**9**		**12**	
IWO_2	51	10	-	-	-	-	-	-	-	-	5	19			25
IWO_2	54	20	-	-	-	-	-	4	2	3	4	45			59
IWO_2	69	10	-	-	-	-	-	4	2	2	4	31			44
SurD O_2	60	10	-	-	-	-	-	-	-	5	3	5	7	21	42
SurD O_2	60	20	-	-	-	-	4	2	3	3	6	11	7	50*[3]	92
SurD O_2	69	20	-	-	4	2	2	3	2	5	11	12	7	61**	120
SurD O_2	81	10	-	-	-	-	5	2	2	3	3	7	7	32*	67
SurD O_2	81	15	-	4	2	2	2	2	3	4	10	11	7	60**	118
SurD O_2	81	20	4	2	2	2	3	3	5	10	13	16	7	75**	153

1. Stop times include travel time from the previous stop except when a gas switch occurs.
2. Time from leaving 9 msw to reaching 12 msw in the chamber must not exceed 7 min.
3. Asterisk (*) indicates number of 5 min air breaks required.
4. Dec. - Decompression

For these dives, the AGS was used for decompression from the first stop. Two procedures were studied; ascent to the AGS with "bailout open, diluent flask shut," and ascent to the AGS with "bailout open, diluent and O_2 flasks shut." The bailout flask supplied an HeO_2 70:30 mixture (sufficient for 10 to 11 min of use). The first case was the AGS with the O_2 flask from the CUMA set open (O_2+ mode). Red and Yellow divers were instructed to switch on their bailout flask one min prior to leaving bottom and then turn off their diluent flask. The second case was the AGS with both the diluent and O_2 flasks from the CUMA shut off (O_2– mode). As in the first case, divers were instructed to switch on their bailout flask one minute prior to leaving bottom and then turn off their diluent and O_2 flasks. At the first stop, divers connected up to the N_2/O_2 umbilical on the AGS via their quick-connect, and on reachng 9 msw, connected up to the O_2 umbilical. *Figures 1* and *2* show where the AGS is deployed for in-water O_2 decompression and surface decompression dives, respectively.

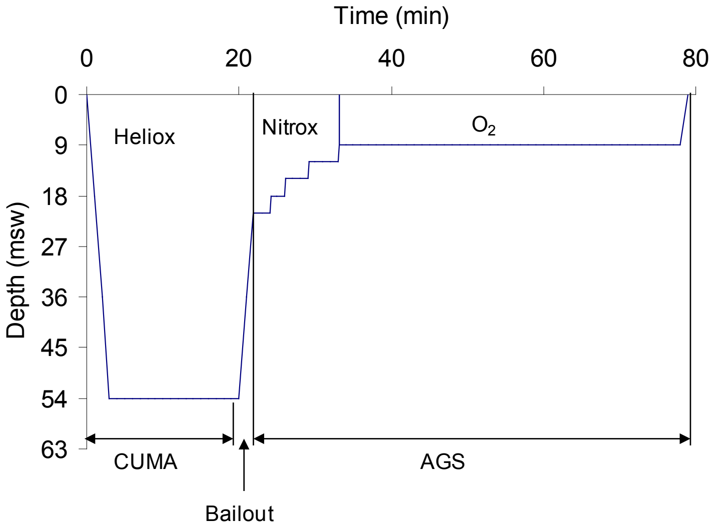


Figure 1. Example of dive profiles conducted – in-water oxygen decompression (IWO$_2$)

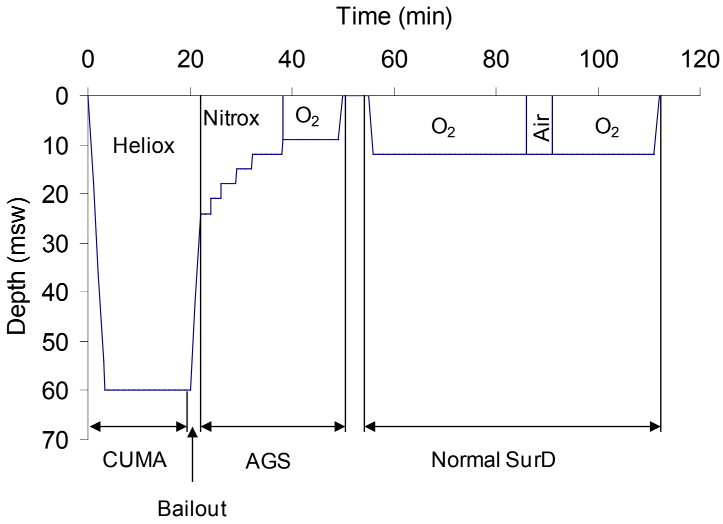


Figure 2. Example of dive profiles conducted - surface decompression with oxygen (SurD O$_2$)

Following the initial evaluation of these single dive profiles, the AGS was also tested for its ability to support a diver on a second dive following the 6-hour (hr) successive dive procedure and the 3-hr repetitive dive procedures [8-9]. Only SurD O$_2$ profiles were tested. The first dive was a normal CUMA dive with decompression using CF Table 12(M) [15]. The second dive used the AGS for decompression, with CF Table 12(M) [15] being used for decompression on the 6-hr successive dive procedure, and CF Table 14(M) [15] for the 3-hr repetitive dive procedure. Red and Yellow Divers, team leader and standby divers were the same personnel on both dives. *Table 2* shows the profiles chosen for these paired dives. Using the AGS for decompression on both of the paired dives was not planned.

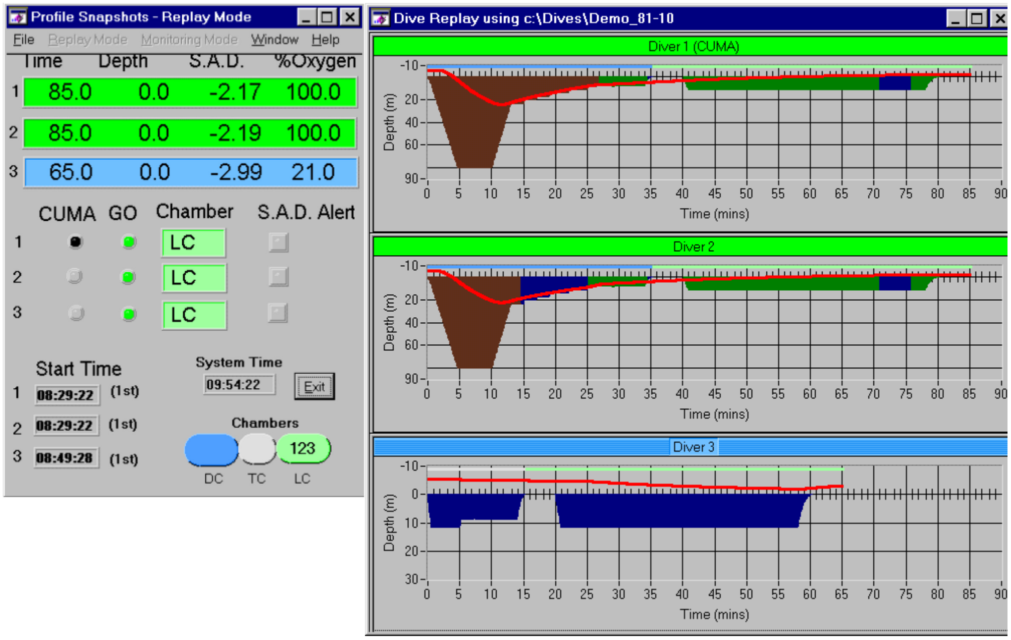
Table 2. Paired dive schedules (SurD O_2) tested – 6- and 3-h surface intervals

Interval between dives (hours)	***Dive No.[5]***	***Depth (msw)***	***Bottom Time (min)***	***Stop Times (min) at Different Depths (msw)[1]***												***Total Dec.[4] Time (min)***
				In-Water Stops										***Surf. Int.[2] (min)***	***RCC***	
				HeO_2									***O_2***		***O_2***	
				36	***33***	***30***	***27***	***24***	***21***	***18***	***15***	***12***	***9***		***12***	
6	1	60	20	-	-	-	-	4	2	3	3	6	11	7	50*[3]	92
	2	60	20	-	-	-	-	4	2	3	3	6	11		50*	92
6	1	81	10	-	-	-	-	5	2	2	3	3	7	7	32*	67
	2	81	10	-	-	-	-	5	2	2	3	3	7		32*	67
6	1	81	15	-	4	2	2	2	2	3	4	10	11	7	60**	118
	2	81	15	-	4	2	2	2	2	3	4	10	11		60**	118
3	1	60	20	-	-	-	-	4	2	3	3	6	11	7	50*	92
	2	60	20	-	-	-	3	2	2	3	4	8	11		58*	104
3	1	81	15	-	4	2	2	2	2	3	4	10	11	7	60**	118
	2	81	15	4	2	2	2	2	3	2	8	12	13		69**	137

1. Stop times include travel time from the previous stop except when a gas switch occurs.
2. Time from leaving 9 msw to reaching 12 msw in the chamber must not exceed 7 min.
3. Asterisk (*) indicates number of 5-min air breaks required.
4. Dec. - Decompression
5. Dive No. 1 – normal dive on CUMA; Dive No. 2 – in-water decompression on AGS

The water temperature for all dives was between 6-8°C.

During experimental diving, depth-time profiles often do not match the ideal calculated profiles as presented in dive tables; consequently, it is important to use the real time and depth to calculate the decompression requirements. Therefore, a Personal Computer (PC)-based dive computer was used on-line to monitor the divers' depth and calculate the decompression status. The depth from the chamber electronic depth gauge (Heise Model # 901B, Ashcroft Inc., Stratford, CT) was used as input into the CUMA decompression algorithm to calculate, display and record the "Safe Ascent Depth (SAD)" (*Figure 3*). This system was a Pentium II computer running a custom application developed using LabWindows Version 5.02 (National Instruments Corp., Austin, TX) for Windows NT with data acquisition hardware also supplied by National Instruments.



	Time	Depth	S.A.D.	%Oxygen
1	85.0	0.0	-2.17	100.0
2	85.0	0.0	-2.19	100.0
3	65.0	0.0	-2.99	21.0

	CUMA	GO	Chamber	S.A.D. Alert
1	●	●	LC	☐
2	○	●	LC	☐
3	○	●	LC	☐

	Start Time	
1	08:29:22	(1st)
2	08:29:22	(1st)
3	08:49:28	(1st)

System Time 09:54:22

Chambers 123

Figure 3. PC-based dive computer display for monitoring decompression status.

Prior to each dive, each CUMA set was bench tested and calibrated. The carbon dioxide (CO_2) scrubber was charged using soda lime (Sofnolime 8-12 Mesh, Molecular Products Limited, Boulder, CO) meeting CF specifications [16]. On completion of the calibrations and bench tests, the CUMA sets were assembled, leak tested and the integrity of the apparatus confirmed by a qualified EDU technician. The CUMA sets were then transferred to the diving chamber and connected to the data acquisition tether. If conducting a single dive with the experimental AGS decompression, or a paired dive where the AGS decompression takes place on the second dive, the AGS prototype panels were calibrated for flows within one hour of the dive. Flows were established at surface pressure with a driving pressure of 185 pounds per square inch (psi), to provide an N_2/O_2 flow of 12 L/min mass flow and O_2 flow of 3.6 L/min. This equates to the same volume at surface, but volume will decrease proportionately with the depth under Boyles Law.

The subjects were briefed prior to each dive. The wet divers and standby diver were then dressed in well-fitting neoprene dry suits, thermal underwear, gloves and hood and entered the dive chamber. They donned their CUMA and each gas supply was switched on at not more than 5 min before the planned time of descent, so as to keep O_2 breathing to a minimum. This timing was critical when commencing the 6-hr successive dive and 3-hr repetitive dive procedures. The dive subjects entered the water and were checked for leaks. On completion of the leak test, the divers moved to their designated positions in preparation for descent. The wet divers stood fully submerged on the wet side of the barrier (*Figure 4*) while the standby diver remained semi-submerged to the waist in the intermediate area on the dry side of the barrier. Once in position, the divers emptied their counterlungs and filled them with bypass gas, in accordance with standard operational CUMA drills. This reduced the O_2 content of the counterlung from 100% by using bypass gas with a 20% O_2 content, thus preventing an unacceptable rise in PO_2 during descent. The objective was to ensure that no more than 5 min elapsed while breathing from the CUMA before descent, so as to keep O_2 prebreathing to a minimum. Normally, this period was less. On completion, the DRF was pressurized.

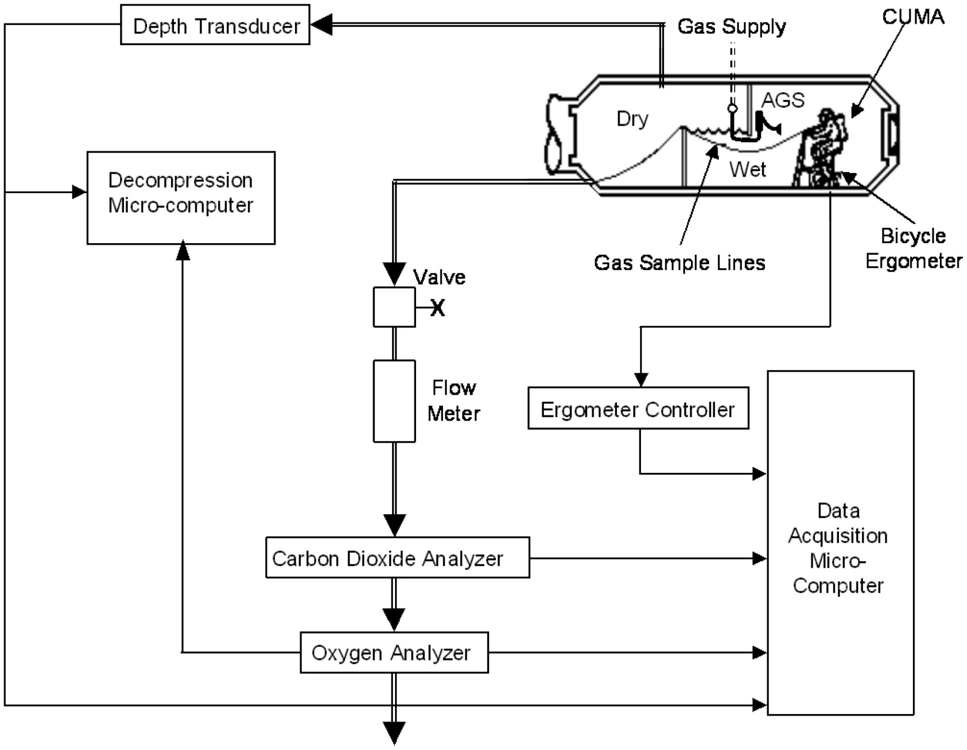


Figure 4. DRDC Toronto Diving Research Facility (DRF) Wet Chamber with schematic for data acquisition system.

The planned descent rate was 18 msw/min. In the event of a delay during descent, the bottom time was extended until the SAD displayed on the dive computer matched the predicted SAD for the planned profile. This information was provided in a printed, minute-by-minute listing of elapsed time, depth and expected SAD for that dive (*Table 3*).

On arrival at the planned depth of the dive, all divers inflated their counterlungs using the bypass valve until the counterlung relief valve lifted, again in accordance with CUMA drills, to remove any PO_2 spike as a result of the gas laws during descent. Both wet divers then moved to the bicycle ergometers (electro-magnetically braked bicycle ergometers (W. E. Collins, Braintree, MA) with pedal units modified for underwater use) and commenced exercise, pedaling at 55 to 65 revolutions per min (rpm) with the brake set at 50 watts. The exercise protocol was 5 min work followed by 5 min rest in repeating cycles. The standby diver did not exercise but was directed to move around frequently to avoid cramped muscles and to improve circulation. When there were 2 min remaining in the bottom time, Red and Yellow Divers were instructed to get off the ergometers and position themselves in view of the underwater cameras prior to ascent.

Table 3. Predicted Safe Ascent Depths (SAD) at end of bottom time

Dive Depth (msw)	***Bottom Time (min)***	***SAD (msw)***	***Dive Depth (msw)***	***Bottom Time (min)***	***SAD (msw)***
51	10	10.96	54	20	20.79
60	10	14.59	60	20	24.39
69	10	18.21	69	20	30.00
81	10	22.99	81	20	37.61
81	15	32.22			

For the first dive of a dive-pair (*Table 2*), a normal CUMA decompression was undertaken with the ascent rate to the first stop at 18 msw/min, and with decompression carried out by following CF Table 12(M) [15] . (The team leader and standby diver switched to air at the first decompression stop.) On reaching 12 msw, all subjects switched the diluent gas supply valve off to allow the helium level to decay during the scheduled stop at 12 msw and reduce the time to switch over to 100% O_2 at 9 msw. On arrival at 9 msw, all the subjects flushed their counterlungs to commence breathing O_2. At the same time, the team leader and standby diver switched to BIBS O_2 and the team leader's duties were taken over by an O_2 tender who had been locked in at 12 msw.

For single dives (*Table 1*), the decompression was carried out on the AGS following CF Table 11(M) [15] for IWO_2 dives and CF Table 12(M) [15] for SurD O_2 dives. For second dives of a dive-pair (*Table 2*), the decompression was carried out on CF Table 12(M) [15] for 6-hr SI dives or CF Table 14(M) [15] for 3-hr SI repetitive dives. Approximately half the dives were tested with the divers being instructed to go on bailout and off diluent one min before the end of the bottom time, as this is the most likely failure mode (O_2+). The other half of the dives were tested with the potential loss of O_2, with the divers being instructed to go on bailout, off diluent, and off O_2 one minute before the end of the bottom time. This would significantly reduce O_2 flows throughout the in-water decompression profile (O_2–). On reaching the first stop, Red and Yellow divers were instructed to "connect to AGS and off bailout." The latter manoeuvre would be operationally realistic, as the aim would be to conserve the bailout volume as the last resort. At this stage, Red and Yellow divers received either a mix of N_2/O_2 from the AGS and O_2 from CUMA (in the O_2+ mode), or just N_2/O_2 (in the O_2– mode). On reaching 12 msw, Red and Yellow divers were instructed to disconnect N_2/O_2 and connect O_2. Again, this would allow the diluent gas to decay and reduce the time to switch over to 100% O_2 at 9 msw.

The on-line dive computer was switched to register that the subjects were breathing O_2 once it was established from external monitoring that O_2 levels were above 90% (this normally took between 1 and 2 min). Prior to completing the O_2 stop at 9 msw, both wet divers moved into the semi-submerged intermediate area on the dry side of the barrier. On completion of the stop, the chamber was bought to the surface and the wet and standby divers were removed from the water and undressed. Divers stopped breathing from the CUMA 30 seconds after leaving 9 msw to account for the slow travel rate of the DRF.

All divers, including the team leader and standby diver, proceeded into the Living Chamber. The standby, Red and Yellow divers were undressed prior to entering the Living Chamber. For an IWO_2 dive, Doppler ultrasonic bubble monitoring [17] was conducted on all four divers prior to their exiting the chamber. For a SurD O_2 dive, Doppler monitoring was conducted only on Red and Yellow divers immediately after they entered the Living Chamber. At five min, 30 seconds after leaving 9 msw, Doppler monitoring was stopped and all subjects and the team leader began breathing 100% O_2. At six min, the Living Chamber was pressurized at 12 msw/min to 12 msw. The time from leaving the in-water O_2 stop at 9 msw to reaching 12 msw in the dry Living Chamber was 7 min. At 12 msw, 5-min air breaks were taken every 30 min. On completion of the scheduled decompression time at 12 msw, the DRF was depressurized to the surface. All divers, including the team leader and standby diver, then proceeded to Doppler monitoring sessions.

All dive profiles were scattered over at least two dive series (four dive-teams) to reduce subject bias so that the results for any given schedule would not be influenced by the response of a limited group of divers who might have been all “low bubblers” or “high bubblers”.

3.3 Data Acquisition

The partial pressure of inspired O_2 (PiO_2) and inspired CO_2 (PiCO_2) were continuously monitored for all subjects on CUMA for the full duration of each dive. In addition, the work rate of the wet divers on the bicycle ergometers was monitored and recorded. The PO_2 of the gas supplied to the breathing loop, as measured by the CUMA oxygen analyzer (Part No. 1135-C, Carleton Life Support Systems, Davenport, IA), was also monitored for comparative analysis against PiO_2.

Data were acquired using a custom application developed in Labview (National Instruments Corp., Austin, TX) and HP Basic (Hewlett-Packard, Palo Alto, CA) on an Ultra Sparc workstation (Sun Microsystems Inc., Santa Clara, CA) through an IEEE 488 interface to an Hewlett-Packard 3852A Data Acquisition/Control Unit (Hewlett-Packard, Palo Alto, CA). The inspired gas in the breathing loop was sampled by penetrating the right side of the scrubber housing and extending a sample line (N 1/8 inch O.D. x 0.031 inch I.D., Nylon 11 tubing, Parflex, Ravenna, OH) between 20 to 40 mm up the inhalation breathing hose. Electrical leads monitored the ergometer workload settings (rpm and wattage) and the CUMA oxygen analyzer PO_2. The CUMA oxygen analyzer PO_2 was measured by teeing into the analyzer display cable. All gas sample lines and electrical leads from both the Red and Yellow Divers and the standby diver were passed through a protective jacket of polyurethane tubing and then routed to a terminal block and diverted through the DRF hull (*Figure 4*).

Once outside the chamber, the gas samples were allowed to expand to atmospheric pressure and the samples diverted to the gas analysis instruments. The sample flow was kept constant using mass flow controllers (Model 5850E, 0-1.0 L/min STPD[2] air, Brooks, Hatfield, PA) calibrated and set between 0.40 and 0.45[3]. The PiO_2 was measured using furnace type O_2

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[2] All flow rates are referenced to 0° C and 101.3 kPa, dry gas, i.e., standard temperature and pressure, dry (STPD) unless indicated.

[3] Different flows were used to synchronize the lag time for each sample line. This permitted correction of PiO_2 and PiCO_2 values recorded during descent and ascent.

analyzers (Oxygen Analyzer S-3A/1, Ametek Inc., Pittsburgh, PA) and the $PiCO_2$ was measured using infrared analyzers (PM3A, Analytical Development Company, Hoddesdon, UK). All lines from the instruments and the electrical leads from the chamber were interfaced to the Hewlett-Packard 3852A. The PiO_2, CUMA oxygen analyzer PO_2, $PiCO_2$, ergometer workload settings, time and depth were sampled every 6 seconds by the Hewlett-Packard 3852A system. The analogue output of the oxygen analyzers was also displayed on the PC-based dive computer located at the Dive Control Console.

3.4 Doppler Ultrasonic Bubble Monitoring

Monitoring and scoring of bubble signals were carried out using the Kisman-Masurel (KM) method at the precordial region and the left and right subclavian veins at rest and after movement [18]. On completion of IWO_2 dives, all divers (Red, Yellow, standby and team leader) transferred to the Living Chamber and were monitored immediately before being allowed to leave the chamber. For SurD O_2 dives, Doppler monitoring was conducted on Red and Yellow Divers during the surface interval[4] (SurD SI) before recompression to 12 msw. On completion of the dive, all divers then exited the chamber. All divers (SurD O_2 and IWO_2) were then monitored at 20 min after surfacing. Divers were then allowed to take a warm shower for between 5 to 10 min. Monitoring resumed at 60 and 100 min after. If the bubble scores were still significant or had not peaked after a single dive or a second dive of a repetitive dive-pair, the diver was held back and monitored at 40-min intervals until there was a clear indication that bubbles were decreasing. If bubbles were still significant or had not peaked after the first dive of a repetitive dive-pair, a fourth reading was taken at approximately 140 min, prior to the briefing for the second dive. If the bubble scores were not more than KM Bubble Grade (BG) 2 in the precordial region at rest, the diver was automatically allowed to continue on with the second dive. For other cases, a review and consultation with the physician was conducted prior to making any decisions on whether or not the diver could continue on with the second dive.

For evaluation of decompression stress associated with a dive schedule, a criterion based on past experience has been established that for any given dive schedule, if more than 50% of the subjects were observed to have maximum bubble scores greater than 2 (i.e., BG = 3 and/or BG = 4) in the precordial region with the diver standing at rest, then that dive would be considered to be of high risk. The precordial rest value was selected since that represents a relatively steady-state condition. The maximum bubble scores obtained by looking at all sites and conditions (precordial movement, left and right subclavian veins at rest or after movement) were used only to provide supplementary information about the decompression stress of individual dives. (The maximum values from all sites/conditions are generally from the precordial site or subclavian veins after movement and represent a transient condition.)

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[4] To distinguish between the words "surface interval" representing the time on the surface between the in-water part of the dive and the subsequent recompression to 12 msw in the chamber for surface decompression dives from its normal use as the time between dives during repetitive diving. the surface decompression surface interval will be referred to as "SurD SI" and the surface interval between repetitive dives as "SI".

4 Results and Discussion

4.1 Dives Conducted

Table A2 in **Annex A** presents a detailed list of the dives carried out. A total of 36 volunteer divers participated in these dives – 24 visiting subjects and 12 DRDC Toronto team leaders (of which 8 also acted as dive subjects). A total of 116 dives were completed successfully during the primary testing of the AGS in Series 1 to 4. One dive was aborted after 36 msw because one of the subjects could not clear his ears after several attempts. Of the dives completed, 44 were conducted as 22 dive-pairs, with the first dive as a normal dive on CUMA and the second dive being carried out by the same divers on the AGS after either a 6-hr or 3-hr SI. *Table 4* is a summary of the dive profiles tested by dive series showing the number of dives and the number of wet and standby divers who participated in the dives. An additional 116 man-dives were carried out by team leaders and standby divers who were not counted as dive subjects for the purpose of this AGS assessment. Team leaders breathed 84/16 HeO_2 from the BIBS. During Series 1, standby divers used the CUMA, but switched to the BIBS with 84/16 HeO_2 for Series 2 to 4. An additional three dives were conducted during Series 5 to obtain side-by-side comparison between the AGS system used in Series 1 to 4 and a prototype AGS system that was being tested.

4.2 Description of Dive Series

Series 1 [10] was carried out from 17 June to 11 July 2002 with 9 divers from FDU(P) (2), the USN (2), and EDU (5). The visiting subjects participated as wet dive subjects and standby divers. Except for one EDU diver, EDU divers participated not only as team leaders but also as wet dive subjects or standby divers. *Table A2* in **Annex A** shows the roles played by the divers. A total of 27 dives was carried out over 15 dive-days. All dives were single dives for the wet divers using the AGS during decompression. Two dives a day were carried out on 12 of the dive-days. On nine of these days, the second dive was delayed for 6 hours so that the team leader and standby diver from the first dive could be dived again using the 6-hr successive dive procedure [8]. Standby divers used the CUMA during this series.

Series 2 [11] was carried out from 12 November to 12 December 2002 with 11 divers from FDU(A) (1), the USN (2), and EDU (8). Visiting subjects participated as wet subjects and standby divers. Six of the EDU divers participated as wet dive subjects in addition to being a team leader, and five also participated as standby divers. A total of 23 dives was carried out, including one dive being done with only EDU divers one week prior to the start of the main series. On 18 of the 20 dive-days during the main series, only one dive a day was carried out. On the remaining two dive-days, two dives were done with the same subjects in both morning and afternoon dives. The wet subjects carried out a normal CUMA dive in the morning and then in the afternoon dive 6 hours later, switched to the AGS during the decompression. One wet diver was not able to dive in the afternoon on one of the dive-pairs.

Table 4. Dive Series and Dives Conducted

Series	**Dive** *(msw/min)*	**CUMA**		**AGS O_2+**		**AGS O_2–**		**Comments**	**# Valid man-dives (AGS)**
		# Dives	**# Wet divers**	**# Dives**	**# Wet divers**	**# Dives**	**# Wet divers**		
1 17 Jun – 11 Jul 02	51/10			1	2	1	2	IWO2, single dives	4
	54/20			2	4	2	4	IWO2, single dives	8
	69/10			3	6	2	4	IWO2, single dives	10
	60/10			2	4	2	4	SurD, single dives	8
	60/20			2	4	2	3	SurD, single dives	7
	69/20			1	2	1	2	SurD, single dives	4
	81/10			3	6	3	6	SurD, single dives	12
	Total			14	28	13	25		53
2 12 Nov – 12 Dec 02	54/20			1	2	1	2	IWO2, single dives	4
	69/10			1	2	1	2	IWO2, single dives	4
	60/10			1	2	2	4	SurD, single dives	6
	60/20			1	2	1	2	SurD, single dives	4
	69/20			2	4	2	3	SurD, single dives	7
	81/10					1	2	SurD, single dives	2
	81/10	2	4	1	2	1	1	SurD, 2 dive-pairs, 6-hr SI	3
	81/20			2	4	3	6	SurD, single dives	10
	Total	2	4	9	18	12	22		40
3 24 Mar – 24 Apr 03	54/20					2	4	IWO2, single dives	4
	69/10					2	3	IWO2, single dives	3
	60/20	2	4	1	2	1	2	SurD, 2 dive-pairs, 6-hr SI	4
	60/20	3	6	2	4	1	2	SurD, 3 dive-pairs, 3-hr SI	6
	69/20			1	2			SurD, single dives	2
	81/10	1	2			1	2	SurD, 1 dive-pair, 6-hr SI	2
	81/15	2	4	1	2	1	2	SurD, 2 dive-pairs, 6-hr SI	4
	81/15	4	8	2	3	2	4	SurD, 4 dive-pairs, 3-hr SI	7
	81/20			2	4	1	2	SurD, single dives	6
	Total	12	24	9	17	11	21		38
4 20 Oct – 27 Nov 03	54/20			2	4			IWO2, single dives	4
	60/20			1	2	2	4	SurD, single dives	6
	60/20	2	4			2	3	SurD, 2 dive-pairs, 3-hr SI	3
	69/20			2	4	2	3	SurD, single dives	7
	81/15			3	6	4	8	SurD, single dives	14
	81/15	6	12	3	6	3	5	SurD, 6 dive-pairs, 3-hr SI	11
	81/20			1	2	1	2	SurD, single dives	4
	Total	8	16	12	24	14	25		49
Series 1-4	**Total**	**22**	**44**	**44**	**87**	**50**	**93**		**180**
5 13-15 Apr 04	54/20					1	2	IWO2, single dives	2
	69/20					1	2	SurD, single dives	2
	81/20					1	2	SurD, single dives	2
	Total					3	6	Red Diver on AGS prototype	6

Series 3 [12] was carried out from 24 March to 24 April 2003 with 11 divers, 10 from FDU(P) (3), the USN (1), and EDU (6) and one ex-EDU CF Clearance Diving Officer. Visiting subjects participated as wet subjects and standby divers. Five of the EDU divers and the ex-EDU diver participated as wet subjects, standby and team leaders. One EDU diver participated only as a team leader and standby diver. Thirty-two dives were carried out over 18 dive-days. Only one dive a day was carried out on four dive-days. On the remaining 14 dive-days, two dives a day were carried out. On two of these days, the afternoon dive was a new dive with new participants. On the remaining days, the first dive was a normal CUMA dive and the second was a repeat dive on the AGS – five of these were after a 6-hr SI and the other seven were repetitive dives after a 3-hr SI.

Series 4 [13] was conducted from 20 October to 18 November 2003 with the participation of 20 divers from FDU(A) (2), RNLN (3), RNoN (2), RNZN (3), USNEDU (2), and EDU (8). Visiting subjects participated as wet dive subjects and standby divers. Five of the EDU divers participated as wet dive subjects in addition to being team leaders and standby divers. Three EDU divers participated only as team leaders. Thirty-two dives were started with 31 being completed successfully over 18 dive-days. On five days, only one dive a day was carried out; on seven days, a second dive was carried out with fresh dive subjects. On the remaining eight dive-days, the first dive was a normal CUMA dive and the second was a repetitive dive after a 3-hr SI with decompression on the AGS. One week after the main series ended, an additional three dives (one single and one 3-hr SI dive-pair) were carried out by EDU divers only.

Series 5 [14] was a trial of the AGS prototype Version 0.1 [19] carried out from 05-16 April 2004 and was not a continuation of the AGS decompression trials carried out in Series 1 to 4. However, three decompression dives were carried out from 13-15 April to confirm that the prototype could support the decompression requirements to 81 msw. In these dives, one wet diver (Red) used the Version 0.1 prototype while the other (Yellow) decompressed on the original system used in Series 1 to 4. Six EDU divers participated as wet divers while three others only participated as a team leader or standby diver. The results of these dives have not been included in the analyses of the data presented in this report.

4.3 SurD O_2 Surface Interval Pain and Decompression Ilness

Only one case of SurD SI pain was observed. A diver in Series 2 (Red Diver, DR2331A) noticed pain that felt like muscle strain (scored as one on a scale of 10) while entering the Living Chamber about 1-2 min into the surface interval. He noted a red mark in the area where the pain occurred and also on the right jaw. He had remarkably high bubble scores (BG 4) in his left shoulder. The pain disappeared 1-2 min after reaching 12 msw. The diver reported being cold during the dive but was not shivering. An examination post-dive showed no problems. The physician's diagnosis was that it was not a typical SurD SI symptom but that it was likely a combination of bubble-mediated inflammation and soft tissue injury.

There were no cases of Decompression Illness (DCI).

4.4 Time-Weighted Average PO_2

Figure 5 shows typical instantaneous PO_2 values when the divers switch to either the O_2+ or O_2– mode during the decompression. Also shown for comparison are typical PO_2 values for a normal CUMA dive, where the divers remain on the CUMA during the decompression. For the AGS trials, the divers switch to the bailout one min prior to leaving bottom. Although the bailout gas has 30% O_2 (PO_2 of 2.73 atmospheres (absolute) (ATA) at 81 msw), this is not a problem as the diver is still breathing from the counterlung. However, the PO_2 will start increasing and does not start decreasing until some time after the ascent has started. This is different from the normal CUMA decompression where the PO_2 starts decreasing on leaving the bottom depth. On reaching the first stop, the divers connect to the AGS and go off the bailout. At 12 msw, the divers disconnect the N_2/O_2 supply from the AGS and connect to the O_2 supply, allowing the diluent levels to decay and reduce the time necessary to switch over to 100% O_2 at 9 msw.

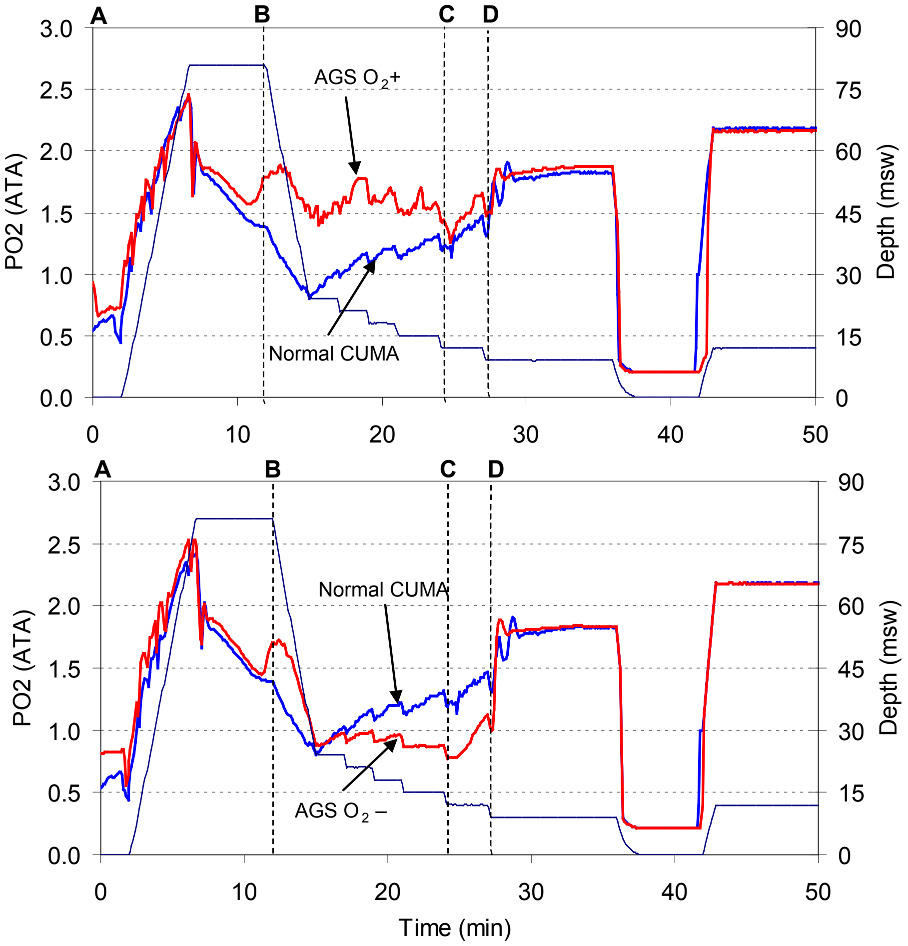


Figure 5. Typical observed PO_2 for AGS O_2+ and O_2 – conditions vs. PO_2 for normal CUMA operation (81 msw/10 min dive).

The time-weighted average (TWA) PO_2 was calculated at three stages during the in-water portion of each dive – from the start of the dive (donning the CUMA) to the end of the bottom time (A-B in *Figure 5*), from the start of decompression to reaching 12 msw (B-C), and from the start of decompression to reaching 9 msw (B-D). *Figures 6-8* show a graphic representation of the means and standard deviations (SD) of the TWA PO_2 from the start of decompression to reaching 12 msw and the minimum PO_2 attained during decompression for the O_2+, O_2 – and normal CUMA decompressions.

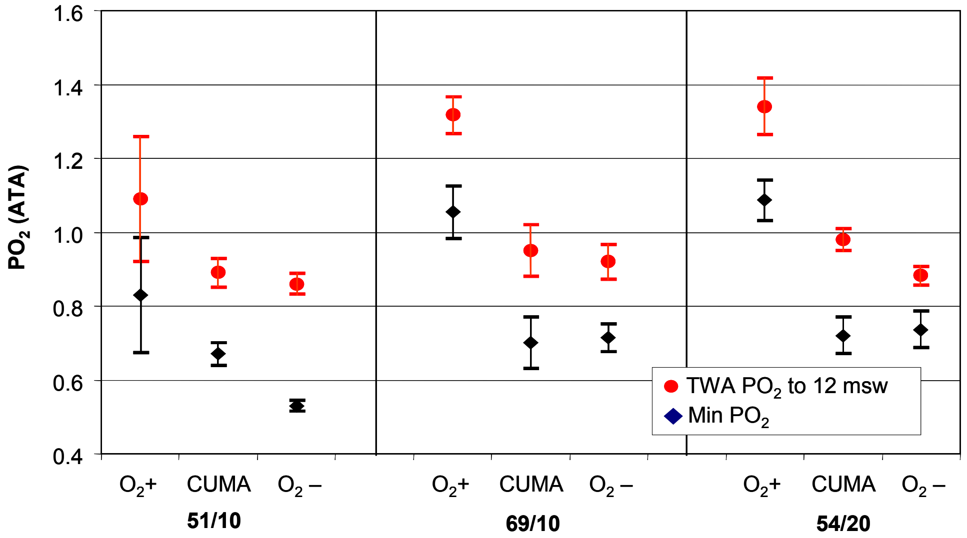


Figure 6. Minimum PO_2 and TWA PO_2 (mean and SD) from start of decompression to 12 msw for IWO_2 decompression dives.

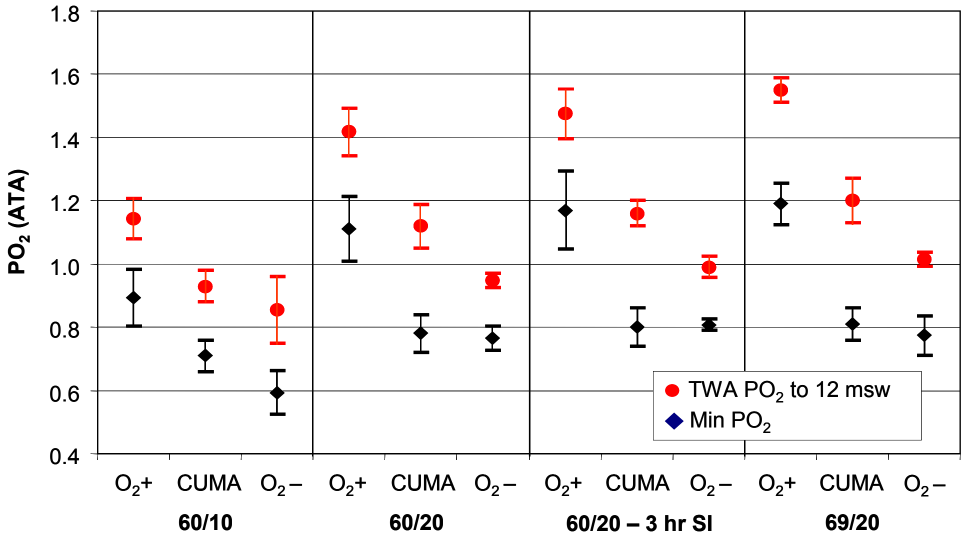


Figure 7. Minimum PO_2 and TWA PO_2 (mean and SD) from start of decompression to 12 msw for SurD O_2 dives (60 and 69 msw).

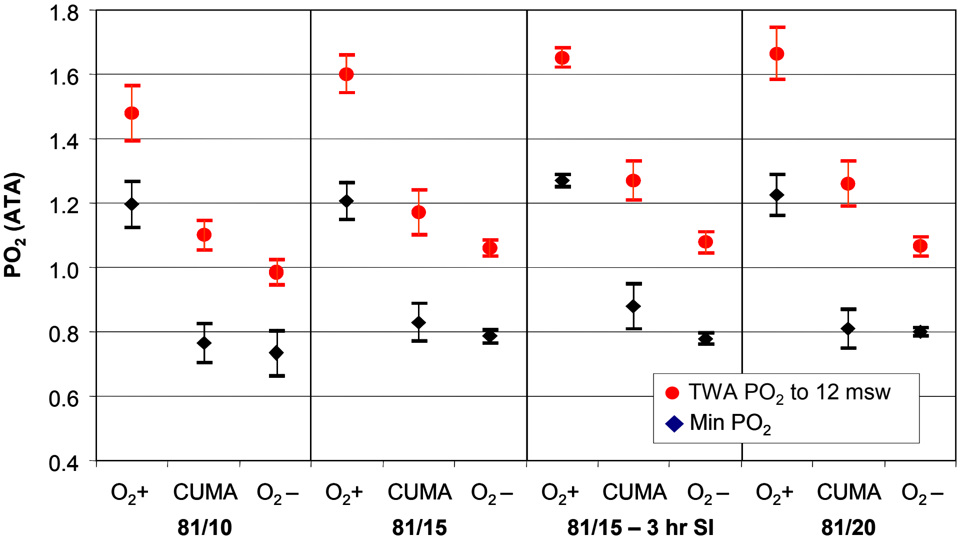


Figure 8. Minimum PO_2 and TWA PO_2 (mean and SD) from start of decompression to 12 msw for SurD O_2 dives (81 msw).

Table A3 in **Annex A** shows the three TWA PO_2 values and the minimum PO_2 values reached during the decompression for all the profiles tested. The values shown are the means, SDs, and the range of values observed for each profile and AGS mode. Profiles, in cases where there were problems in monitoring the PO_2 values, were not used in calculating the mean TWA PO_2 values. The values for a normal CUMA dive are also shown for comparison.

For the AGS O_2+ mode, the PO_2 remains higher during the decompression than observed for a normal decompression on CUMA. In addition to the O_2 being supplied by the bailout, O_2 is still being supplied by the CUMA. After the diver connects to the AGS at the first stop, the bailout is shut off. The diver is then receiving a mix of N_2/O_2 containing 40% O_2 in addition to the O_2 still being supplied by the CUMA. With the additional O_2, the PO_2 increases over the first few decompression stops before it starts decreasing. The minimum PO_2 value during the decompression, which in a normal CUMA dive is observed on reaching the first stop, may occur, in some cases, at 12 msw in the O_2+ mode. The elevated PO_2 provides benefit in terms of decompression but may pose some risk of CNS O_2 toxicity at the deeper depths where the TWA PO_2, from the start of the decompression to 12 msw, exceeds 1.6 ATA. It should be noted, however, that this is a time-weighted average and not a continuous exposure to that level, and that some of the decompression time will be spent at a PO_2 less than 1.6 ATA. It should also be noted that no symptoms of CNS O_2 toxicity have been observed in any of the subjects participating in the AGS O_2+ dives.

In the AGS O_2– mode, the TWA PO_2 during the decompression is significantly lower than for the O_2+ mode and normal CUMA decompression. Although the PO_2 increases after the diver goes on bailout, the PO_2 decreases rapidly as the diver ascends to the first stop since O_2 is no longer being supplied by the CUMA. At the first stop, the diver connects to the AGS and turns off the bailout. The diver is then receiving a mix of N_2/O_2 containing 40% O_2 in addition to the O_2 still remaining in the counterlung. The PO_2 remains at a low level during the initial decompression stops with the minimum PO_2 generally being observed on reaching 12 msw. Although these low PO_2 levels during the decompression may appear to increase the decompression risk, the impact is not that great because the helium in the counterlung will be lower than in a normal CUMA decompression because it is being replaced by nitrogen from the AGS.

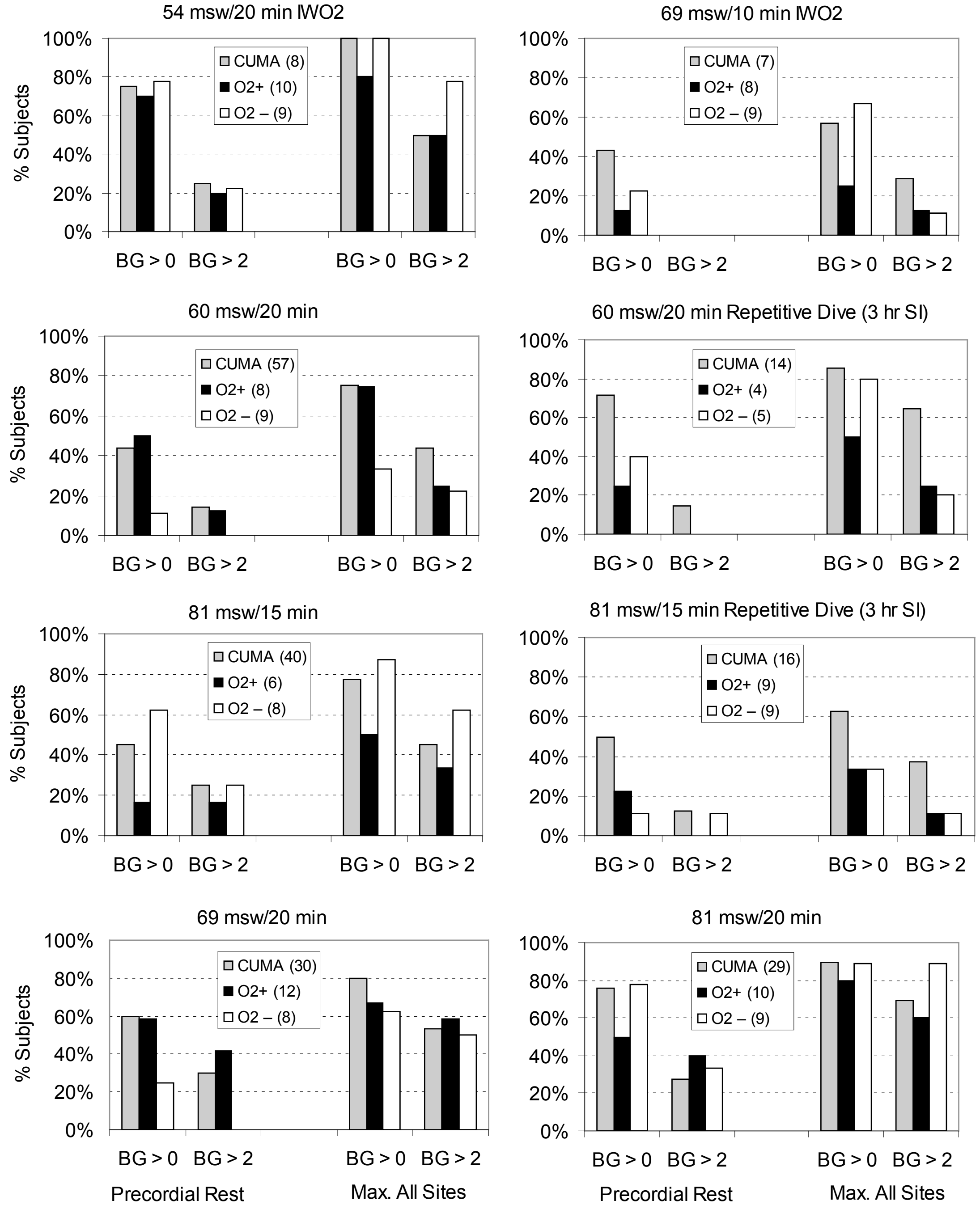
Table A4 shows the whole body oxygen uptake, represented as Oxygen Tolerance Units (OTUs) [20], for the profiles tested. In the O_2+ mode, the OTU is up to approximately 6% higher than that for a normal CUMA dive. No pulmonary function tests were carried out on the subjects. However, pulmonary function testing was carried out in the reduced surface interval validation trials during Series 5 and 6 [8] for subjects who dived twice a day up to three times in a 4-day period. Although some pulmonary function decrement was found at that time, subjects were asymptomatic and there did not appear to be any functional impairment.

4.5 Doppler Results

Table A5 shows the post-dive maximum BG observed for the AGS O_2+ and O_2– dive profiles tested. The results for normal CUMA dives on those profiles are also shown for comparison. These data have been obtained from dives done during previous dive series from 1991 to 2002 (CUMA Table Validation [7], reduced surface interval trials [8], and repetitive diving after 3-hr SI trials [9]) and from the first dives conducted using normal CUMA decompression when testing the use of the AGS on repetitive dives. The number of subjects having maximum BGs of 0, 1, 2, 3, and 4 for the precordial location at rest, the precordial after the movement condition, and from all sites, regardless of location (precordial or subclavian) or rest/movement condition are shown. *Table A6* shows the results obtained during the 7-min SurD SI of the SurD O_2 dives.

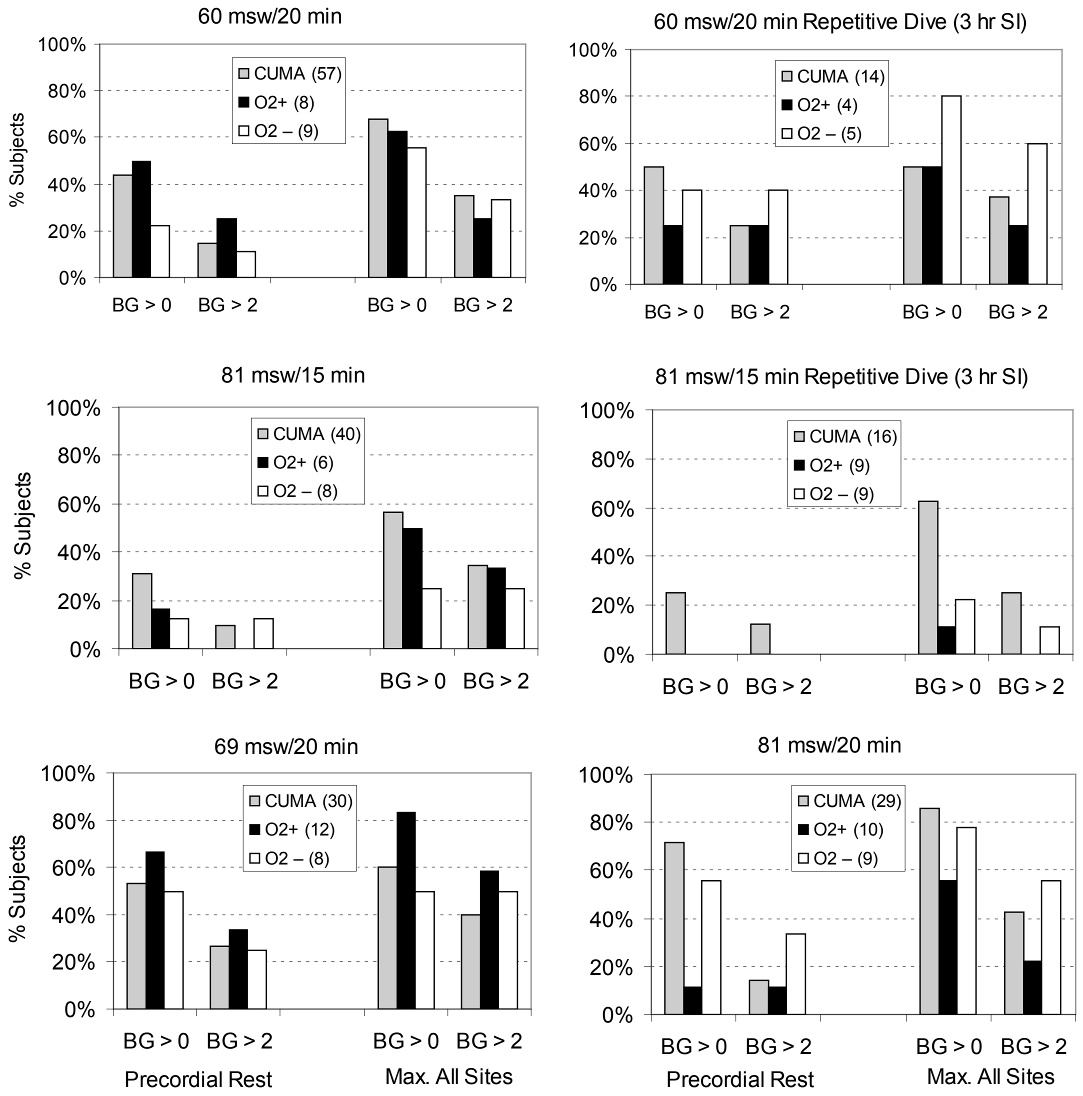
In *Figures 9* and *10*, these results have been condensed into two groups – the percentage of divers who had any bubbles (BG > 0) and the percentage of divers who had high bubble levels (BG > 2). These figures allow an easier comparison of the results for AGS O_2+ and O_2– and normal CUMA decompression dives. Not all the profiles are shown in the figures. In some cases, not enough subjects were done to get a meaningful comparison. The detailed results for all profiles are shown in *Tables A7* and *A8*.

In many cases, there appear to be no significant differences between normal CUMA decompression and AGS O_2+ or O_2– decompression. In some cases, bubbles were far fewer for the O_2– mode (60 msw/20 min) and in other cases, bubbles were fewer for the O_2+ mode (81 msw/15 min). A detailed analysis was conducted using the Mann-Whitney U test [21] (also known as the Wilcoxon Rank Sum test) to determine whether or not these differences were significant.



Note: Except where indicated, all dives are SurD O_2. Numbers in the legends show the number of subjects for each group.

Figure 9. Number of divers with any bubbles (BG > 0) and high bubble scores (BG > 2) post-dive.



Note: Numbers in the legends show the number of subjects for each group.

Figure 10. Number of divers with any bubbles (BG > 0) and high bubble scores (BG > 2) during the 7 min SurD SI of the SurD O_2 dives.

The Mann-Whitney U Test is a non-parametric test used to test whether or not two independent groups have been drawn from the same population. The data shown in *Figures 9* and *10* contain all of the subjects with valid data who participated in the dives. For the Mann-Whitney U Test, these data had to be edited to maintain independent samples. Comparisons of

AGS O_2– *vs.* CUMA and AGS O_2+ vs. CUMA were done only for precordial bubbles at rest and maximum bubbles from all sites. For those divers who did more than one dive on the same profile in a particular AGS mode, for example, two dives using AGS O_2+, only the first dive was retained. In addition, if a diver did the same profile as both a CUMA diver and an AGS diver, for example on O_2+, the CUMA was not used for making the comparison between CUMA dives and O_2+ dives for that profile. *Table A9* shows example datasets[5] used for carrying out the comparisons and *Table A10* shows the results obtained with the Mann-Whitney U Test. All profiles were analyzed, both post-dive and at the SurD SI (for SurD O_2 dives) with the exception of the 51 msw/10 min IWO_2 dives, the repeat dives after 6-hr SI because of insufficient data, and the 60 msw/10 min SurD O_2 dives because only a few subjects had any observable bubbles in those dives.

No significant differences ($p < 0.05$) were found in bubble scores (both precordial at rest and maximum bubbles from all sites) between CUMA dives and AGS O_2+ dives for each profile analysed (post-dive and at the SurD SI). Between CUMA dives and AGS O_2– dives, no significant differences were observed except on the 69 msw/20 min dives (precordial at rest post-dive).

The Mann-Whitney U Test is a useful test since it takes into account that the number of subjects being compared may be quite different. One must be careful about drawing conclusions from the graphical representations in *Figures 9* and *10* because many of the percentages are based on small sample numbers. Although it may appear that the O_2– may be less stressful than O_2+ in certain cases based on the Doppler BG values, this conclusion cannot be drawn based on the small sample sizes. The Mann-Whitney U Test could not be used to compare O_2– and O_2+ data since subjects were common to both datasets in many cases.

However, it is possible to determine the difference between O_2– and O_2+ dives by comparing the BG for those divers who used the AGS in both modes for the same dive profiles by using the Wilcoxon Signed Rank Test [21] to look at the differences in BG[6] between the two dives in the pair. If a diver did more than one dive on a given profile, only the first dive done was used. Data for a diver who did one of the dives of the dive-pair in a different dive series were also rejected because of possible physiological changes in the subject between the two dive series.

Table A11 shows the data used for the Wilcoxon Signed Rank Test. Only non-zero differences are used for the analysis. Thus, divers who had no observable bubbles in both dives of the dive-pair or who had the same bubble score in both dives would not be a factor in the analysis. The test showed that there was a significant difference in the post-dive precordial BG after movement and in the maximum BG observed from all sites ($p < 0.025$). No significant differences were found between O_2– and O_2+ modes for precordial BG at rest or for all BG observed during the SurD SI. This does not mean, however, that differences do not

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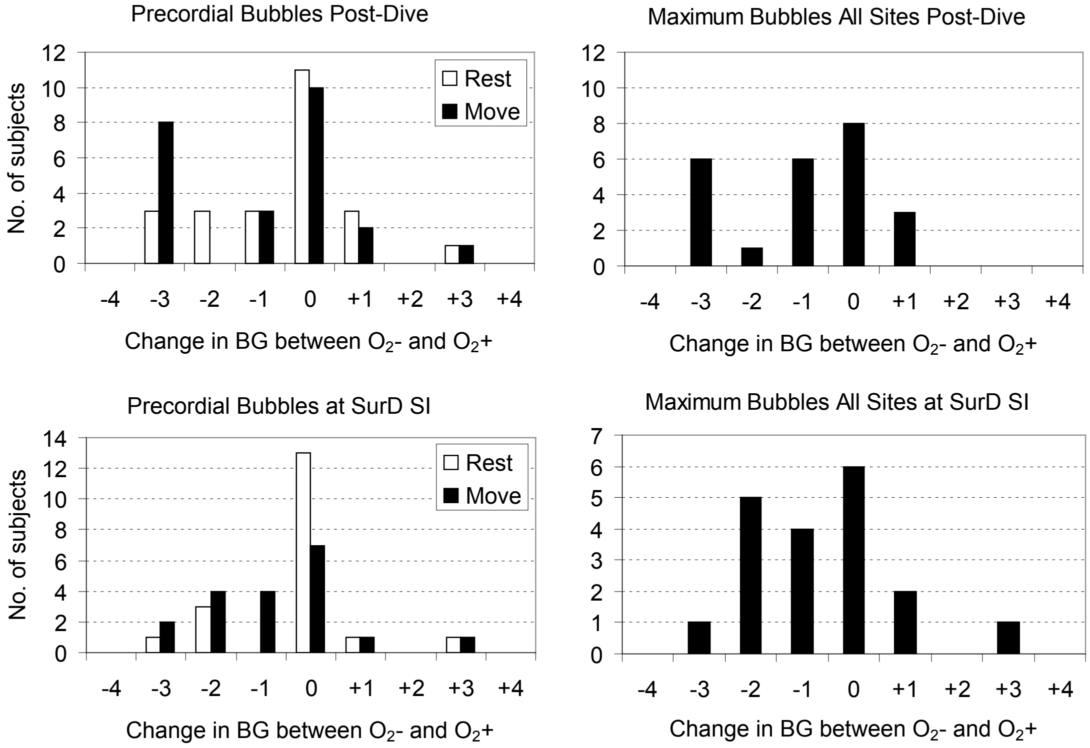
[5] BG are recorded in steps of one-third, i.e., 1-, 1, 1+, 2-, 2, 2+, 3-, 3, 3+, 4-, 4. To carry out the Mann-Whitney U Test, these were transformed into 2/3, 1, 1 1/3, 1 2/3, 2, 2 1/3, … to allow the BG values to be ranked.

[6] The numeric transformation of the BG as shown in Footnote 5 was used to determine the difference between the BGs observed on O_2– and O_2+ dives.

exist. Although statistical significance could not be shown, the data do show that the BGs were lower for O_2+.

Figure 11 shows a graphic representation of the differences[7] in BG between O_2– and O_2+ dives (both post-dive and at the SurD SI). The differences are largely negative, i.e., the divers had fewer bubbles on the O_2+ dives. This is consistent with the data presented in *Figures 6-8* showing that the TWA PO_2 for O_2+ is higher than that for O_2– so that fewer bubbles should be expected.


Precordial Bubbles Post-Dive

Maximum Bubbles All Sites Post-Dive

Precordial Bubbles at SurD SI

Maximum Bubbles All Sites at SurD SI

Figure 11. Change in BG in divers who performed the same profiles with AGS O_2– and O_2+ (for all profiles except 51 msw/10 min)

Figure 12 shows the difference in BG between a first dive using the CUMA during decompression and a second (repetitive) dive after a 3-hr SI using the AGS during decompression for those individuals who participated in those dives. The results for 60

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[7] For graphical purposes, these differences were grouped so that a change of one BG higher would represent a change of 2/3, 1 or 11/3. A 0 change would be represented by –1/3, 0, or 1/3, e.g., a diver who had BG 3 on the first dive and BG 3-, 3, or 3+ on the second dive would be recorded as having a 0 change.

msw/20 min and 81 msw/15 min have been combined. All divers, including those who dove the dive-pair more than once, are included in *Figure 12*. The results show that most of the subjects had fewer observed bubbles on the repetitive dive although the differences were not significant using the Wilcoxon Signed Rank Test. When compared to a repetitive dive done on CUMA, the Mann-Whitney U Test analysis (*Table A10*) showed no significant differences.

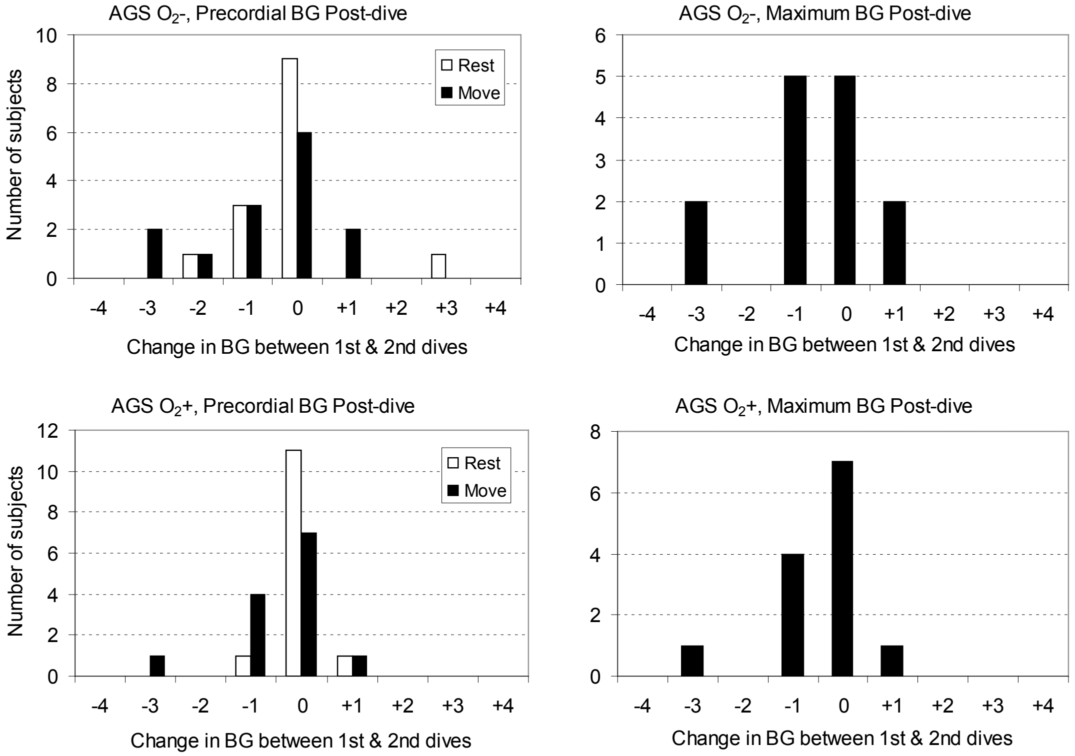

Figure 12. Change in post-dive BG between a first dive on CUMA (CF Table 12) and a second repetitive dive after a 3-hr SI (CF Table 14) (combined results for 60 msw/20 min and 81 msw/15 min).

The aim of this study was to test if the AGS could be used in the event of a CUMA malfunction to support a diver undertaking standard decompression profiles in accordance with the CF operational tables for in-water decompression with O_2 and surface decompression with O_2 and to establish whether or not initial decompression on the AGS posed any greater risk of decompression stress. Although it was initially planned to do a larger number of dives on each profile, the actual number of dives done was determined by the relative stress of the profile as assessed against the results of previous research on the CUMA [7-9]. This was driven partly by financial and time constraints as well as by practical considerations.

The results of these tests showed that decompression on the AGS, whether O_2– or O_2+, for the most case, was not significantly different from decompression on the CUMA. Although in some cases, more bubbles were observed on the AGS, they did not exceed the limit of "50% of subjects with BG > 2". It should be noted that the AGS is an emergency decompression device and if the consequences of not having an AGS available are considered, a higher risk could be acceptable.

The analysis of those subjects who decompressed on both AGS modes showed that, overall, decompression on O_2+ resulted in fewer bubbles than on O_2–. In those cases where O_2– seemed to produce fewer bubbles than O_2+, e.g., 69 msw/20 min, a larger dataset with more subjects may be necessary to determine whether or not this is true. The data may have been influenced by a small group of divers who might have been considered "low bubblers".

The analysis also showed that the decompression stress would be less if it were necessary to deploy the AGS on a repetitive dive after a first dive conducted on the CUMA. The situation of a first dive having to be done on the AGS and a repetitive dive being done normally on CUMA was not investigated. The use of the AGS on a new CUMA dive 6 hours after a first dive on CUMA was not conclusive because of the limited testing that was done. However, based on all the other tests done so far on the AGS, it is not expected that there would be any significant differences between a normal CUMA dive and a new dive after 6 hours.

5 Summary

The decompression work completed during the four series of the AGS trial has shown that it is entirely practicable for a diver to safely undertake standard decompression using an AGS even after failure of the diver's primary CUMA equipment. The current emergency procedure, the "interim red-light drill" still has its place but as a secondary, emergency procedure to be used in extreme situations, i.e., AGS failure or entanglement whereby a diver is unable to use the AGS to decompress.

The success of this research was made possible by close cooperation between the EDU of DRDC Toronto, the CUMA/SIVA+ user nations, and ABCANZ[8] participants. A total of 36 volunteer divers participated in these dives – 24 visiting subjects and 12 DRDC Toronto team leaders (of which 8 also acted as dive subjects). A total of 116 dives were completed successfully. Only one incident of surface-interval stress was reported and no cases of DCI were encountered. The evidence from the AGS work shows that the use of Nitrox to facilitate He "off-gassing" is beneficial as has been proven in other areas of mixed gas diving, both civilian and military.

The introduction of the Auxiliary Gas Supply to CF MCM diving teams will greatly increase the safety of the individual diver and will also increase the flexibility with which the teams are deployed. In addition, the use of an AGS means that in the future, longer or deeper dives could be planned utilising safe in-water decompression either completely or as a precursor to surface decompression.

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[12] DRDC Toronto Human Ethics Committee Protocol # L-339 - Amendment 2. An Auxiliary Gas Supply To Improve Safety During Aborted Dives With The Canadian Underwater Mine-Countermeasures Apparatus (CUMA) dated January 20, 2003.

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Annex A Experimental Data

A.1 Diver Statistics and Dives Conducted

Table A1. Diver Statistics

Series 1: 17 Jun - 11 Jul 02

Diver Code	*Affiliation*	*Role*	*Sex*	*Age (yr)*	*Weight (kg)*	*Height (cm)*	*BMI*	*Biceps (mm)*	*Triceps (mm)*	*Sub-scapula (mm)*	*Supra-iliac (mm)*	*% Body Fat*	*Tobacco # cig/day*
78	FDU(P)	W, S	M	29.5	92.5	181.5	28.0	4.0	7.2	11.2	9.8	16.9	0
79	FDU(P)	W, S	M	35.5	94.2	190.0	26.0	5.2	7.2	12.4	8.6	17.3	0
45	USN	W, S	M	29.1	77.0	187.0	22.0	4.6	9.0	11.8	10.0	17.9	0
46	USN	W, S	M	32.4	86.2	173.0	28.8	6.0	12.4	14.4	10.8	20.1	0
97	DRDC-T	W, S	M	41.3	92.0	173.0	30.7	6.6	10.0	14.4	27.0	26.6	0
94	DRDC-T	W, S, L	M	38.2	95.0	179.0	29.6	7.4	11.4	19.4	13.0	21.8	0
95	DRDC-T	W, S, L	M	40.4	73.5	168.0	26.0	5.0	6.2	10.4	7.2	17.1	0
98	DRDC-T	W, S, L	M	32.1	90.0	187.0	25.7	4.0	10.0	14.0	14.6	19.8	0
91	DRDC-T	L	M	39.0	91.0	180.0	28.0	5.6	11.0	16.8	15.0	21.2	0
Wet Dive Subjects Only			Mean	34.8	87.6	179.8	27.1	5.4	9.2	13.5	12.6	19.7	
			SD	4.8	8.1	8.0	2.8	1.2	2.2	2.8	6.3	3.3	

Series 2: 12 Nov - 12 Dec 02

Diver Code	*Affiliation*	*Role*	*Sex*	*Age (yr)*	*Weight (kg)*	*Height (cm)*	*BMI*	*Biceps (mm)*	*Triceps (mm)*	*Sub-scapula (mm)*	*Supra-iliac (mm)*	*% Body Fat*	*Tobacco # cig/day*
58	FDU(A)	W, S	M	40.9	77.0	170.0	26.6	4.2	6.0	12.0	7.8	17.6	0
47	USN	W, S	M	38.8	86.0	175.0	28.0	2.8	4.2	1.4	12.0	12.2	0
48	USN	W, S	M	41.4	96.0	180.0	29.6	6.0	7.4	14.0	14.0	22.0	0
87	DRDC-T	W, S, L	M										1 to 10
91	DRDC-T	W, S, L	M	39.4	90.5	180.0	27.9	6.6	10.0	14.2	8.4	19.0	0
98	DRDC-T	W, S, L	M	32.4	91.5	187.0	26.1	4.0	9.0	13.2	13.0	19.0	0
99	DRDC-T	W, S, L	M	38.3	106.5	182.5	31.9	7.4	13.6	19.0	22.0	23.8	0
92	DRDC-T	W, L	M	38.2	93.5	173.0	31.2	12.0	9.6	20.8	21.6	24.2	0
95	DRDC-T	W, L	M	40.8	74.7	168.0	26.4	4.6	5.2	14.0	11.0	19.6	0
90	DRDC-T	S	M	46.2	185.0	177.5	58.7	5.0	6.4	12.0	11.8	19.8	0
93	DRDC-T	S, L	M	36.8	78.5	173.0	26.2	8.2	10.0	16.2	15.0	21.4	0
Wet Dive Subjects Only			Mean	38.8	89.5	176.9	28.5	6.0	8.1	13.6	13.7	19.7	
			SD	2.9	10.3	6.5	2.2	2.9	3.1	5.8	5.4	3.9	

Table A1. Diver Statistics (cont'd)

Series 3: 24 Mar - 24 Apr 03

Diver Code	*Affiliation*	*Role*	*Sex*	*Age (yr)*	*Weight (kg)*	*Height (cm)*	*BMI*	*Biceps (mm)*	*Triceps (mm)*	*Sub-scapula (mm)*	*Supra-iliac (mm)*	*% Body Fat*	*Tobacco # cig/day*
77	FDU(P)	W, S	M	31.2	78.2	172.0	26.4	3.4	7.0	13.0	9.4	17.1	0
160	FDU(P)	W, S	M	28.5	98.5	179.0	30.7	3.8	7.2	10.2	6.0	11.6	0
161	FDU(P)	W, S	M	29.8	95.0	183.0	28.3	8.2	7.6	18.0	21.2	22.5	0
49	USN	W, S	M	44.6	75.2	162.5	28.4	4.2	4.2	15.2	9.4	18.9	0
86	CF	W, S, L	M	40.2	93.8	185.0	27.4	8.6	17.8	17.2	14.6	26.7	1 to 10
87	DRDC-T	W, S, L	M	35.5	84.0	172.0	28.3	5.0	9.8	14.6	9.2	18.8	1 to 10
92	DRDC-T	W, S, L	M	38.5	97.0	173.0	32.4	10.0	10.4	25.0	14.0	23.4	0
95	DRDC-T	W, S, L	M	41.2	75.2	168.0	26.6	5.0	5.0	11.8	8.0	17.5	0
98	DRDC-T	W, S, L	M	32.8	91.6	187.0	26.1	4.4	9.6	17.6	9.8	19.5	0
99	DRDC-T	W, S, L	M	38.6	111.6	182.5	33.5	8.4	14.0	21.2	18.6	23.9	0
93	DRDC-T	S, L	M	36.8	78.5	173.0	26.2	8.2	10.0	16.2	15.0	21.4	0
Wet Dive Subjects Only			Mean	36.1	90.0	176.4	28.8	6.1	9.3	16.4	12.0	20.0	
			SD	5.4	11.8	8.1	2.6	2.4	4.1	4.4	4.9	4.3	

Series 4: 20 Oct - 18 Nov 03

Diver Code	*Affiliation*	*Role*	*Sex*	*Age (yr)*	*Weight (kg)*	*Height (cm)*	*BMI*	*Biceps (mm)*	*Triceps (mm)*	*Sub-scapula (mm)*	*Supra-iliac (mm)*	*% Body Fat*	*Tobacco # cig/day*
59	FDU(A)	W, S	M	28.2	86.0	178.0	27.1	3.8	6.6	10.8	10.4	13.3	0
150	FDU(A)	W, S	M	27.7	74.0	173.0	24.7	4.6	8.8	11.6	8.8	14.1	0
104	RNLN	W	M	33.0	76.9	177.0	24.5	3.0	7.0	8.6	4.4	13.4	0
105	RNLN	W, S	M	32.6	89.0	185.5	25.8	6.4	11.6	19.2	8.0	20.5	0
106	RNLN	W	M	42.1	93.5	188.0	26.4	11.2	11.1	12.9	26.5	27.5	0
102	RNoN	W, S	M	39.0	92.0	180.5	28.2	9.4	12.0	18.2	13.0	22.1	1 to 10
103	RNoN	W, S	M	31.8	85.0	184.5	24.9	3.8	10.4	8.8	5.4	15.6	1 to 10
32	RNZN	W, S	M	32.2	74.3	175.0	24.2	3.8	6.4	7.4	7.0	14.1	0
136	RNZN	W, S	M	26.0	88.4	175.5	28.7	4.0	10.4	11.8	5.8	13.5	0
137	RNZN	W	M	23.6	84.9	174.5	27.8	3.4	4.6	13.8	7.2	12.3	0
140	USN	W, S	M	28.7	88.1	174.0	29.0	8.4	10.8	22.2	16.2	20.6	0
141	USN	W, S	M	27.3	97.2	176.0	31.3	5.0	6.4	18.6	20.1	18.9	0
87	DRDC-T	W, L	M	36.1	83.0	172.0	28.0	10.2	11.0	14.0	11.0	20.7	1 to 10
94	DRDC-T	W, S, L	M	39.5	94.5	179.0	29.4	7.0	9.2	19.2	13.0	21.2	0
99	DRDC-T	W, S, L	M	40.3	111.6	182.5	33.5	8.4	14.0	21.2	18.6	23.9	0
180	DRDC-T	W, S, L	M	42.2	82.3	166.5	29.6	6.8	6.0	17.2	9.2	21.2	1 to 10
181	DRDC-T	W, S, L	M	32.6	74.0	173.0	24.7	10.0	11.0	13.0	8.0	19.7	0
90	DRDC-T	L	M	47.1	84.9	177.5	26.9	6.2	8.0	12.2	12.2	21.0	0
92	DRDC-T	L	M	39.1	97.5	173.0	32.5	17.0	17.3	28.0	29.0	28.0	0
98	DRDC-T	L	M	33.4	87.8	187.0	25.1	4.0	7.4	10.6	8.4	16.3	0
Wet Dive Subjects Only			Mean	33.1	86.7	177.3	27.5	6.4	9.3	14.6	11.3	18.4	
			SD	5.9	9.6	5.5	2.6	2.7	2.6	4.6	6.0	4.4	

Table A1. Diver Statistics (cont'd)

Series 5: 13 - 15 Apr 04													
Diver Code	***Affiliation***	***Role***	***Sex***	***Age (yr)***	***Weight (kg)***	***Height (cm)***	***BMI***	***Biceps (mm)***	***Triceps (mm)***	***Sub-scapula (mm)***	***Supra-iliac (mm)***	***% Body Fat***	***Tobacco # cig/day***
71*	DRDC-T	W	M	34.2	102.5	180.0	31.6	6.6	8.4	21.0	13.2	21.4	0
87*	DRDC-T	W, S	M	36.4	89.0	172.0	30.0	5.2	10.2	17.0	15.4	21.1	0
90**	DRDC-T	W, L	M	47.1	84.9	177.5	26.9	6.2	8.0	12.2	12.2	21.0	0
94*	DRDC-T	W	M	39.8	96.1	179.0	29.9	5.8	8.2	21.2	16.6	21.9	0
98*	DRDC-T	W, S	M	33.7	90.7	187.0	25.9	4.2	8.4	14.6	13.2	19.3	0
182*	DRDC-T	W	F	39.4	73.4	166.0	26.6	7.2	15.0	12.8	11.0	20.6	0
99**	DRDC-T	L	M	40.3	111.6	182.5	33.5	8.4	14.0	21.2	18.6	23.9	0
180*	DRDC-T	S	M	42.5	81.0	166.5	29.2	6.4	7.0	16.6	9.8	21.4	1-10
183*	DRDC-T	S	M	40.4	71.4	167.0	25.6	4.8	5.2	20.0	7.2	20.5	0
Wet Dive Subjects Only			Mean	38.4	89.4	176.9	28.5	5.9	9.7	16.5	13.6	20.9	
			SD	4.9	9.9	7.2	2.3	1.1	2.7	4.0	2.1	0.9	

* Measured January 2004

** November 2003

Table A2. Dives conducted

Series	Date	SERIAL #	Profile	Type	Deco.	WR	WY	S	L	SERIAL	Surf. Int.	Profile	Type	Deco.	WR	WY	S	L
1	06/19/02	DR2237A	51/10	IWO2	AGS O2+	78	79	94	95	DR2238A	New*	51/10	IWO2	AGS O2-	46	45	***94***	***95***
	06/20/02	DR2239A	60/10	SURDO2	AGS O2+	78	79	97	94	DR2240A	New*	60/10	SURDO2	AGS O2+	95	45	***97***	***94***
	06/21/02	DR2241A	60/10	SURDO2	AGS O2-	79	78	46	94	DR2242A	New*	60/10	SURDO2	AGS O2-	97	45	***46***	***94***
	06/24/02	DR2243A	69/10	IW02	AGS O2+	94	46	79	95	DR2244A	New*	69/10	IW02	AGS O2-	45	97	***79***	***95***
	06/25/02	DR2245A	81/10	SURDO2	AGS O2+	78	95	46	94	DR2246A	New*	81/10	SURDO2	AGS O2+	45	79	***46***	***94***
	06/26/02	DR2247A	81/10	SURDO2	AGS O2-	95	78	98	94	DR2249A	New*	81/10	SURDO2	AGS O2-	79	45	***98***	***94***
	06/27/02	DR2250A	69/10	IW02	AGS O2+	98	79	78	91									
	07/02/02	DR2252A	81/10	SURDO2	AGS O2+	78	46	79	95	DR2253A	New*	81/10	SURDO2	AGS O2-	97	45	***79***	***95***
	07/03/02	DR2254A	54/20	IWO2	AGS O2+	46	78	95	94	DR2255A	New*	54/20	IWO2	AGS O2+	79	45	***95***	***94***
	07/04/02	DR2256A	54/20	IWO2	AGS O2-	97	46	78	91	DR2257A	New*	54/20	IWO2	AGS O2-	79	45	***78***	***91***
	07/05/02	DR2258A	69/10	IW02	AGS O2-	46	97	94	95	DR2259A	New	69/10	IW02	AGS O2+	79	45	78	91
	07/08/02	DR2260A	60/20	SURDO2	AGS O2+	45	79	94	91	DR2261A	New	60/20	SURDO2	AGS O2+	78	46	97	98
	07/09/02	DR2262A	60/20	SURDO2	AGS O2-	94	79	45	91	DR2263A	New	60/20	SURDO2	AGS O2-	■	46	78	98
	07/10/02	DR2264A	69/20	SURDO2	AGS O2+	78	79	46	94									
	07/11/02	DR2265A	69/20	SURDO2	AGS O2-	94	46	97	91									
2	11/07/02	DR2306A	60/10	SURDO2	AGS O2-	95	87	93	98									
	11/13/02	DR2309A	60/10	SURDO2	AGS O2+	98	91	99	95									
	11/14/02	DR2310A	60/10	SURDO2	AGS O2-	58	48	47	87									
	11/15/02	DR2311A	69/10	IW02	AGS O2+	47	48	58	91									
	11/18/02	DR2312A	69/10	IW02	AGS O2-	95	58	47	93									
	11/19/02	DR2313A	81/10	SURDO2	AGS O2-	98	92	99	91									
	11/20/02	DR2314A	54/20	IWO2	AGS O2+	95	48	91	87									
	11/21/02	DR2316A	54/20	IWO2	AGS O2-	48	98	99	87									
	11/22/02	DR2317A	60/20	SURDO2	AGS O2+	48	95	98	92									
	11/25/02	DR2318A	60/20	SURDO2	AGS O2-	47	48	58	92									
	11/26/02	DR2319A	69/20	SURDO2	AGS O2+	95	98	47	87									
	11/27/02	DR2320A	69/20	SURDO2	AGS O2+	58	48	99	92									
	11/28/02	DR2321A	69/20	SURDO2	AGS O2-	98	95	58	91									
	11/29/02	DR2322A	69/20	SURDO2	AGS O2-	92	■	87	99									
	12/03/02	DR2323A	81/20	SURDO2	AGS O2+	47	48	99	95									
	12/04/02	DR2324A	81/20	SURDO2	AGS O2-	58	95	91	87									
	12/05/02	DR2326A	81/10	SURDO2	CUMA	58	48	87	92	DR2327R	6	81/10	SURDO2	AGS O2+	***58***	***48***	***87***	***92***
	12/09/02	DR2328A	81/10	SURDO2	CUMA	47	48	58	98	DR2329R	6	81/10	SURDO2	AGS O2-	■	***48***	***58***	***98***
	12/10/02	DR2330A	81/20	SURDO2	AGS O2+	95	99	48	91									
	12/11/02	DR2331A	81/20	SURDO2	AGS O2-	58	48	90	91									
	12/12/02	DR2332A	81/20	SURDO2	AGS O2-	48	92	90	95									

* For Standby Diver and Team Leaders, these dives are 6-hr repeat dives

WR	Red Diver
WY	Yellow Diver
S	Standby Diver
L	Team Leader
■	No diver
🟧	On CUMA (normal operation)
🟦	On BIBS - 84/16
🟩	AGS O2+
🟨	AGS O2-
Bold Italic	Repeat Dive
White	Aborted or Locked out

Table A2. Dives Conducted (cont'd)

Series	Date	SERIAL #	Profile	Type	Deco.	WR	WY	S	L	SERIAL	Surf. Int.	Profile	Type	Deco.	WR	WY	S	L
3	03/26/03	DR2349A	69/10	IW02	AGS O2-	160	49	86	95	DR2350A	New	69/10	IW02	AGS O2-		161	92	87
	03/27/03	DR2351A	54/20	IWO2	AGS O2-	95	160	86	98	DR2352A	New	54/20	IWO2	AGS O2-	49	77	161	92
	03/28/03	DR2353A	69/20	SURDO2	AGS O2+	160	161	95	99									
	03/31/03	DR2354A	81/20	SURDO2	AGS O2+	160	77	95	86									
	04/01/03	DR2355A	81/10	SURDO2	CUMA	95	161	99	92	DR2356R	6	81/10	SURDO2	AGS O2-	***95***	***161***	***99***	***92***
	04/02/03	DR2357A	60/20	SURDO2	CUMA	49	86	87	98	DR2358R	6	60/20	SURDO2	AGS O2+	***49***	***86***	***87***	***98***
	04/03/03	DR2359A	60/20	SURDO2	CUMA	160	77	99	95	DR2362R	6	60/20	SURDO2	AGS O2-	***160***	***77***	***99***	***95***
	04/04/03	DR2363A	81/20	SURDO2	AGS O2-	161	99	87	98									
	04/07/03	DR2364A	81/20	SURDO2	AGS O2+	160	161	49	87									
	04/08/03	DR2365A	60/20	SURDO2	CUMA	49	86	98	95	DR2366R	3	60/20	SURDO2	AGS O2+	***49***	***86***	***98***	***95***
	04/09/03	DR2367A	60/20	SURDO2	CUMA	77	161	160	99	DR2368R	3	60/20	SURDO2	AGS O2-	***77***	***161***	***160***	***99***
	04/10/03	DR2369A	81/15	SURDO2	CUMA	95	92	49	86	DR2370R	6	81/15	SURDO2	AGS O2+	***95***	***92***	***49***	***86***
	04/14/03	DR2371A	81/15	SURDO2	CUMA	49	77	99	86	DR2372R	6	81/15	SURDO2	AGS O2-	***49***	***77***	***99***	***86***
	04/15/03	DR2373A	81/15	SURDO2	CUMA	161	87	160	95	DR2374R	3	81/15	SURDO2	AGS O2+	***161***		***160***	***95***
	04/16/03	DR2375A	81/15	SURDO2	CUMA	86	77	98	92	DR2376R	3	81/15	SURDO2	AGS O2+	***86***	***77***	***98***	***92***
	04/17/03	DR2377A	81/15	SURDO2	CUMA	161	160	98	87	DR2378R	3	81/15	SURDO2	AGS O2-	***161***	***160***	***98***	***87***
	04/22/03	DR2379A	60/20	SURDO2	CUMA	161	98	77	87	DR2380R	3	60/20	SURDO2	AGS O2+	***161***	***98***	***77***	***87***
	04/24/03	DR2381A	81/15	SURDO2	CUMA	160	99	77	86	DR2382R	3	81/15	SURDO2	AGS O2-	***160***	***99***	***77***	***86***
4	10/22/03	DR2417A	54/20	IWO2	AGS O2+	150	59	32	90/181	DR2418A	New	54/20	IWO2	AGS O2+	105	102	103	99/180
	10/23/03	DR2419A	60/20	SURDO2	AGS O2-	137	136	181	94	DR2420A	New	60/20	SURDO2	AGS O2+	140	104	141	90
	10/24/03	DR2421A	69/20	SURDO2	AGS O2-	137	32	99	98									
	10/27/03	DR2422A	**60/20**	**SURDO2**	**AGS O2+**	**104**	**141**	**150**	**99**	DR2423A	New	60/20	SURDO2	AGS O2-	59	32	150	99
	10/28/03	DR2424A	60/20	SURDO2	CUMA	104	140	102	94	DR2425R	3	60/20	SURDO2	AGS O2-	***104***	***140***	105	***94***
	10/29/03	DR2426A	81/15	SURDO2	AGS O2-	136	150	59	98	DR2427A	New	81/15	SURDO2	AGS O2+	105	103	180	92
	10/30/03	DR2428A	69/20	SURDO2	AGS O2+	32	137	136	181									
	10/31/03	DR2430A	69/20	SURDO2	AGS O2-	103	**102**	140	181									
	11/03/03	DR2431A	81/15	SURDO2	AGS O2+	59	137	136	94	DR2432A	New	81/15	SURDO2	AGS O2-	106	140	105	90
	11/04/03	DR2433A	81/15	SURDO2	CUMA	150	59	32	180	DR2434R	3	81/15	SURDO2	AGS O2+	***150***	***59***	***32***	***180***
	11/05/03	DR2435A	81/15	SURDO2	AGS O2+	105	106	102	99	DR2438A	New	81/15	SURDO2	AGS O2-	137	136	150	92
	11/06/03	DR2440A	81/20	SURDO2	AGS O2+	103	181	141	87	DR2441A	New	69/20	SURDO2	AGS O2+	94	106	59	180
	11/10/03	DR2442A	81/15	SURDO2	CUMA	137	136	181	87	DR2443R	3	81/15	SURDO2	AGS O2+	***137***	***136***	***181***	***87***
	11/12/03	DR2444A	81/15	SURDO2	CUMA	105	103	94	90	DR2445R	3	81/15	SURDO2	AGS O2-	***105***	***103***	***94***	***90***
	11/13/03	DR2446A	81/15	SURDO2	CUMA	32	59	150	94	DR2447R	3	81/15	SURDO2	AGS O2-	***32***	***59***	***150***	***94***
	11/14/03	DR2448A	81/20	SURDO2	AGS O2-	140	102	141	180									
	11/17/03	DR2449A	81/15	SURDO2	CUMA	136	150	141	98	DR2451R	3	81/15	SURDO2	AGS O2+	***136***	***150***	***141***	90
	11/18/03	DR2452A	81/15	SURDO2	CUMA	102	140	103	181	DR2453R	3	81/15	SURDO2	AGS O2-		***140***	***103***	***181***
	11/26/03	DR2454A	81/15	SURDO2	AGS O2-	180	181	99	94									
	11/27/03	DR2455A	60/20	SURDO2	CUMA	87	99	180	90	DR2456R	3	60/20	SURDO2	AGS O2-		***99***	***180***	***90***

Table A2. Dives Conducted (cont'd)

Series		**SERIAL #**	**Profile**	**Type**	**Deco.**	**WR**	WY	S	L	**SERIAL**	**Surf. Int.**	**Profile**	**Type**	**Deco.**	**WR**	WY	S	L
5	04/13/04	DR2497A	54/20	IWO2	AGS O2-	94	87	98	99									
	04/14/04	DR2498A	69/20	SURDO2	AGS O2-	71	182	180	90									
	04/15/04	DR2499A	81/20	SURDO2	AGS O2-	98	90	87	183									

Note: In Series 5, Yellow Diver on AGS used in Series 1 – 4, Red Diver on prototype AGS.

A.2 Time-Weighted Average PO_2 and Whole Body O_2 Uptake

Table A3. Time-weighted PO_2 at bottom and during decompression

Bottom Phase (from start of dive to end of bottom time)					***Decompression phase (from start of decompression to beginning of 9 msw O_2 stop)***				
Depth (msw/min)	***Mode***	***N***	***TWA PO_2 on bottom (on CUMA)***		***AGS Mode***	***N***	***Min PO_2 Decomp.***	***TWA PO_2 to 12 msw***	***TWA PO_2 to 9 msw***
51/10	IWO_2	2	Average	1.11 ± 0.13	O_2+	2	0.83 ± 0.16	1.09 ± 0.17	1.09 ± 0.11
			Range	1.02 − 1.20			0.72 − 0.94	0.97 − 1.21	1.01 − 1.17
		2	Average	1.16 ± 0.00	O_2−	2	0.53 ± 0.01	0.86 ± 0.03	0.70 ± 0.01
			Range	1.16 − 1.16			0.52 − 0.54	0.84 − 0.88	0.69 − 0.71
		7	Average	1.24 ± 0.06	CUMA	7	0.66 ± 0.03	.089 ± 0.04	0.87 ± 0.04
			Range	1.11 − 1.30			.0.60 − 0.69	0.83 − 0.93	0.82 − 0.92
54/20	IWO_2	10	Average	1.19 ± 0.10	O_2+	8	1.09 ± 0.06	1.35 ± 0.08	1.39 ± 0.07
			Range	1.05 − 1.41			0.95 − 1.13	1.18 − 1.47	1.26 − 1.51
		10	Average	1.20 ± 0.08	O_2−	8	0.73 ± 0.05	0.88 ± 0.03	0.90 ± 0.03
			Range	1.13 − 1.39			0.66 − 0.79	0.86 − 0.92	0.87 − 0.94
		8	Average	1.17 ± 0.09	CUMA	8	0.72 ± 0.05	0.98 ± 0.03	1.04 ± 0.02
			Range	1.03 − 1.29			0.64 − 0.79	0.94 − 1.01	1.01 − 1.07
69/10	IWO_2	8	Average	1.34 ± 0.13	O_2+	7	1.05 ± 0.07	1.32 ± 0.05	1.35 ± 0.06
			Range	1.19 − 1.50			0.95 − 1.17	1.24 − 1.39	1.24 − 1.42
		7	Average	1.37 ± 0.16	O_2−	6	0.71 ± 0.04	0.92 ± 0.05	0.93 ± 0.06
			Range	1.08 − 1.58			0.67 − 0.77	0.88 − 1.01	0.87 − 1.01
		7	Average	1.32 ± 0.09	CUMA	7	0.70 ± 0.07	0.95 ± 0.07	1.02 ± 0.07
			Range	1.20 − 1.50			0.59 − 0.78	0.85 − 1.01	0.91 − 1.08
60/10	SurD O_2	6	Average	1.30 ± 0.15	O_2+	5	0.89 ± 0.09	1.14 ± 0.06	1.20 ± 0.06
			Range	1.13 − 1.48			0.76 − 0.98	1.03 − 1.18	1.10 − 1.25
		8	Average	1.32 ± 0.13	O_2−	8	0.59 ± 0.07	0.86 ± 0.11	0.83 ± 0.09
			Range	1.19 − 1.53			0.53 − 0.71	0.74 − 1.02	0.72 − 0.95
		27	Average	1.30 ± 0.08	CUMA	27	0.71 ± 0.05	0.93 ± 1.01	1.01 ± 0.05
			Range	1.18 − 1.52			0.59 − 0.81	0.84 − 1.03	0.90 − 1.09
60/20	SurD O_2	10	Average	1.26 ± 0.04	O_2+	10	1.11 ± 0.10	1.42 ± 0.08	1.47 ± 0.05
			Range	1.21 − 1.34			0.98 − 1.27	1.30 − 1.53	1.36 − 1.55
		12	Average	1.23 ± 0.07	O_2−	11	0.77 ± 0.04	0.95 ± 0.02	0.98 ± 0.05
			Range	1.13 − 1.37			0.68 − 0.81	0.92 − 0.98	0.91 − 1.05
		42	Average	1.23 ± 0.09	CUMA	42	0.78 ± 0.06	1.12 ± 0.07	1.23 ± 0.07
			Range	1.01 − 1.48			0.65 − 0.95	0.95 − 1.26	1.05 − 1.35
60/20 3-hr SI	SurD O_2	4	Average	1.31 ± 0.03	O_2+	4	1.17 ± 0.12	1.48 ± 0.08	1.57 ± 0.05
			Range	1.27 − 1.34			1.01 − 1.28	1.37 − 1.56	1.49 − 1.61
		5	Average	1.27 ± 0.07	O_2−	5	0.81 ± 0.02	0.99 ± 0.03	1.11 ± 0.03
			Range	1.20 − 1.37			0.78 − 0.83	0.94 − 1.03	1.07 − 1.14
		16	Average	1.25 ± 0.08	CUMA	16	0.80 ± 0.06	1.16 ± 0.04	1.30 ± 0.04
			Range	1.08 − 1.41			0.70 − 0.92	1.08 − 1.23	1.24 − 1.39

Table A3. Time-weighted PO_2 at bottom and during decompression (cont'd)

Bottom Phase (from start of dive to end of bottom time)					**Decompression phase (from start of decompression to reaching 9 msw)**				
Depth (msw/min)	***Mode***	***N***	***TWA on bottom (on CUMA)***		***AGS Mode***	***N***	***Min PO_2 Decomp.***	***TWA PO_2 to 12 msw***	***TWA PO_2 to 9 msw***
69/20	SurD O_2	11	Average	1.25 ± 0.05	O_2+	11	1.19 ± 0.07	1.55 ± 0.04	1.66 ± 0.04
			Range	1.17 − 1.33			1.05 − 1.30	1.48 − 1.64	1.57 − 1.72
		8	Average	1.35 ± 0.11	O_2 –	8	0.77 ± 0.06	1.01 ± 0.02	1.13 ± 0.08
			Range	1.21 − 1.57			0.63 − 0.82	0.98 − 1.05	1.05 − 1.30
		16	Average	1.30 ± 0.07	CUMA	16	0.81 0.05	1.20 ± 0.07	1.38 ± 0.07
			Range	1.22 − 1.45			0.68 0.88	1.07 − 1.30	1.25 − 1.47
81/10	SurD O_2	7	Average	1.42 ± 0.13	O_2+	5	1.20 ± 0.07	1.48 ± 0.09	1.46 ± 0.07
			Range	1.26 − 1.60			1.13 − 1.30	1.40 − 1.60	1.40 − 1.57
		10	Average	1.42 ± 0.06	O_2 –	7	0.74 ± 0.07	0.99 ± 0.04	0.99 ± 0.05
			Range	1.34 − 1.50			0.59 − 0.81	0.94 − 1.06	0.93 − 1.05
		28	Average	1.48 ± 0.12	CUMA	28	0.77 ± 0.06	1.10 ± 0.05	1.14 ± 0.05
			Range	1.25 − 1.82			0.67 − 0.93	1.00 − 1.19	1.04 − 1.22
81/15	SurD O_2	8	Average	1.38 ± 0.15	O_2+	8	1.21 ± 0.06	1.60 ± 0.06	1.65 ± 0.03
			Range	1.20 − 1.54			1.11 − 1.27	1.52 − 1.68	1.61 − 1.71
		10	Average	1.41 ± 0.08	O_2 –	10	0.79 ± 0.02	1.06 ± 0.03	1.17 ± 0.04
			Range	1.25 − 1.48			0.76 − 0.82	1.02 − 1.10	1.11 − 1.26
		40	Average	1.37 ± 0.10	CUMA	40	0.83 ± 0.06	1.17 ± 0.07	1.32 ± 0.06
			Range	1.10 − 1.58			0.71 − 0.96	1.05 − 1.33	1.21 − 1.48
81/15 3-hr SI	SurD O2	7	Average	1.48 ± 0.13	O2+	7	1.27 ± 0.02	1.65 ± 0.03	1.71 ± 0.05
			Range	1.34 − 1.66			1.23 − 1.29	1.62 − 1.71	1.65 − 1.77
		9	Average	1.40 ± 0.09	O2-	9	0.78 ± 0.02	1.08 ± 0.03	1.20 ± 0.03
			Range	1.26 − 1.50			0.76 − 0.81	1.04 − 1.14	1.16 − 1.27
		15	Average	1.44 ± 0.08	CUMA	15	0.88 ± 0.07	1.27 ± 0.06	1.42 ± 0.05
			Range	1.28 − 1.56			0.69 − 0.97	1.15 − 1.40	1.31 − 1.54
81/120	SurD O_2	10	Average	1.34 ± 0.16	O_2+	10	1.23 ± 0.06	1.66 ± 0.08	1.73 ± 0.07
			Range	1.12 − 1.57			1.14 − 1.33	1.49 − 1.82	1.58 − 1.84
		9	Average	1.36 ± 0.10	O_2 –	9	0.80 ± 0.01	1.07 ± 0.03	1.18 ± 0.03
			Range	1.17 − 1.51			0.79 − 0.82	1.03 − 1.12	1.15 − 1.21
		13	Average	1.28 ± 0.10	CUMA	13	0.82 ± 0.07	1.28 ± 0.09	1.41 ± 0.09
			Range	1.08 − 1.45			0.69 − 0.91	1.13 − 1.51	1.25 − 1.66

Notes:

1. Data for CUMA only dives are shown for comparative purposes. Data for the IWO_2 CUMA dives were obtained from CUMA Table Validation Series [7]; data for SurD O_2 dives were obtained from dives done for the reduced surface interval [8] and repetitive dive series [9]. For 60/20, 81/20, and 81/15, the data also includes first dives conducted on CUMA during the AGS series.

2. The numbers of divers included in the data may not correspond with the total number of divers participating in each profile because some of the PO_2 data had to be discarded because of monitoring problems.

3. Data for dives done on the AGS after a 6-hr SI have not been included since the results were similar to those obtained for single dives of the same depth and bottom time.

Table A4. Whole Body Oxygen Uptake for AGS Decompression (Oxygen Tolerance Units)

Profile (msw/min)		**AGS Mode**	**N**	**OTU ± SD**	**Min**	**Max**	**Total OTU Dive-Pair**	**Source**
51/10	IWO$_2$	O_2+	2	68.0 ± 2.8	66.0	70.0		
		O_2-	2	64.3 ± 1.5	63.2	65.3		
		CUMA	7	64.1 ± 7.5	55.1	73.8		1
54/20	IWO$_2$	O_2+	8	157.5 ± 3.4	152.1	162.8		
		O_2-	8	143.3 ± 3.4	137.7	148.8		
		CUMA	8	137.6 ± 4.9	129.7	144.0		1
69/10	IWO$_2$	O2+	7	110.3 ± 3.8	104.3	115.5		
		O2-	6	101.1 ± 3.7	97.0	105.2		
		CUMA	7	93.0 ± 4.1	86.8	97.9		1
60/10	SurD O_2	O_2+	5	108.9 ± 5.2	101.1	114.2		
		O_2-	8	101.7 ± 5.1	95.2	108.9		
		CUMA	11	103.9 ± 2.4	100.9	109.8		2
60/20	SurD O_2	O_2+	10	232.8 ± 2.6	228.3	237.2		
		O_2-	11	219.3 ± 3.4	213.7	224.6		
		CUMA	38	226.2 ± 5.7	214.7	243.8		2, 3, 4, 5
60/20 Repetitive 3-hr SI	SurD O_2	O_2+	4	265.8 ± 1.5	264.1	267.6	489.1 ± 2.3	
		O_2-	5	248.1 ± 3.0	244.3	250.8	474.9 ± 5.5	
		CUMA	14	257.5 ± 4.4	250.5	265.3	484.3±10.1	3
69/20	SurD O_2	O_2+	11	291.9 ± 2.1	287.8	296.2		
		O_2-	8	272.8 ± 7.1	264.7	286.9		
		CUMA	14	287.0 ± 7.2	274.2	297.7		2
81/10	SurD O_2	O_2+	5	157.2 ± 3.3	153.2	161.9		
		O_2-	7	146.1 ± 2.4	143.1	149.3		
		CUMA	17	151.3 ± 2.2	147.2	154.5		2, 4, 5
81/15	SurD O_2	O_2+	8	282.4 ± 5.8	275.5	293.3		
		O_2-	10	257.2 ± 3.6	250.8	263.8		

		CUMA	38	265.5 ± 4.9	256.1	274.3		3, 4, 5
81/15 Repetitive 3-hr SI	SurD O_2	O_2+	6	333.9 ± 3.5	329.1	339.2	598.4 ± 6.9	
		O_2-	9	302.6 ± 4.2	297.7	311.0	564.8 ± 4.9	
		CUMA	16	319.7 ± 5.2	307.8	327.4	587.7 ± 8.3	3
81/20	SurD O_2	O_2+	10	379.3 ± 8.3	368.4	396.3		
		O_2-	9	340.6 ± 4.5	331.9	347.1		
		CUMA	14	357.1 ± 5.6	346.8	365.8		2

Sources:
1. CUMA Table Validation Trials [7]
2. First dives of 6-hr reduced SI dive-pairs [8]
3. First dives of 3-hr SI repetitive dive-pairs [9]
4. First dives done on CUMA for 3-hr SI repetitive dive-pairs with AGS on second dive
5. First dives done on CUMA for 6-hr reduced SI dive-pairs with AGS on second dive

A.3 Doppler Bubble Scores

Table A5. Post-Dive Maximum Bubble Scores

Profile (msw/min)	DECO.		No. of Divers	Precordial - Rest					Precordial - Movement					All Sites - Maximum				
				0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
51/10 IWO_2	CUMA	Single	7	7	0	0	0	0	7	0	0	0	0	7	0	0	0	0
	AGS O_2+	Single	2	2	0	0	0	0	2	0	0	0	0	1	1	0	0	0
	AGS O_2–	Single	2	2	0	0	0	0	2	0	0	0	0	0	2	0	0	0
54/20 IWO_2	CUMA	Single	8	2	1	3	2	0	2	0	2	4	0	0	0	4	4	0
	AGS O_2+	Single	10	3	3	2	2	0	3	0	2	3	2	2	0	3	3	2
	AGS O_2–	Single	9	2	0	5	2	0	2	0	1	6	0	0	1	1	7	0
69/10 IWO_2	CUMA	Single	7	4	2	1	0	0	3	3	0	1	0	3	2	0	2	0
	AGS O_2+	Single	8	7	0	1	0	0	7	0	0	1	0	6	0	1	1	0
	AGS O_2–	Single	9	7	0	2	0	0	7	1	1	0	0	3	4	1	1	0
60/10 SurD O_2	CUMA	Single	24	22	2	0	0	0	21	2	1	0	0	17	6	1	0	0
	AGS O_2+	Single	6	6	0	0	0	0	6	0	0	0	0	5	1	0	0	0
	AGS O_2–	Single	8	8	0	0	0	0	8	0	0	0	0	7	1	0	0	0
60/20 SurD O_2	CUMA	Single	57	32	6	11	8	0	23	7	4	21	2	14	12	6	23	2
	CUMA	3-hr	14	4	3	5	2	0	2	1	2	9	0	2	1	2	9	0
	AGS O_2+	Single	8	4	2	1	1	0	3	1	2	2	0	2	2	2	2	0
		6-hr	2	1	1	0	0	0	2	0	0	0	0	1	1	0	0	0
		3-hr	4	3	1	0	0	0	2	0	1	1	0	2	0	1	1	0
	AGS O_2–	Single	9	8	0	1	0	0	6	0	1	2	0	6	0	1	2	0
		6-hr	2	1	0	0	1	0	1	0	0	1	0	1	0	0	1	0
		3-hr	5	3	1	1	0	0	1	1	2	1	0	1	1	2	1	0
69/20 SurD O_2	CUMA	Single	30	12	4	5	9	0	8	5	2	14	1	6	6	2	15	1
	AGS O_2+	Single	12	5	0	2	5	0	5	0	0	5	2	4	1	0	5	2
	AGS O_2–	Single	8	6	1	1	0	0	4	1	0	3	0	3	1	0	4	0
81/10 SurD O_2	CUMA	Single	45	37	4	3	1	0	37	2	2	4	0	26	12	3	4	0
	AGS O_2+	Single	6	6	0	0	0	0	5	1	0	0	0	5	1	0	0	0
		6-hr	2	2	0	0	0	0	2	0	0	0	0	2	0	0	0	0
	AGS O_2–	Single	8	7	1	0	0	0	6	1	0	1	0	4	2	1	1	0
		6-hr	3	3	0	0	0	0	3	0	0	0	0	3	0	0	0	0
81/15 SurD O_2	CUMA	Single	40	22	7	1	10	0	14	6	4	15	1	9	6	7	17	1
	CUMA	3-hr	16	8	2	4	2	0	6	1	3	5	1	6	1	3	5	1
	AGS O_2+	Single	6	5	0	0	1	0	3	1	0	2	0	3	1	0	2	0
		6-hr	2	0	1	0	1	0	0	0	1	0	1	0	0	1	0	1
		3-hr	9	7	1	1	0	0	6	1	1	1	0	6	1	1	1	0
	AGS O_2–	Single	8	3	0	3	2	0	1	1	1	5	0	1	1	1	5	0
		6-hr	2	1	0	0	1	0	1	0	0	0	1	1	0	0	0	1
		3-hr	9	8	0	0	1	0	6	1	1	1	0	6	0	2	1	0
81/20 SurD O_2	CUMA	Single	29	7	4	10	8	0	5	4	3	15	2	3	2	4	17	3
	AGS O_2+	Single	10	5	0	1	4	0	3	0	2	4	1	2	0	2	5	1
	AGS O_2–	Single	9	2	2	2	3	0	1	1	0	7	0	1	0	0	8	0

Note: CUMA decompression data for SurD O_2 dives obtained from first dives of repetitive dive-pairs, from repetitive [9] and reduced surface interval [8] dive trials, and from CUMA Tables validation trials [7]. For in-water O_2 dives, CUMA decompression data taken from CUMA Tables validation dive trials [7].

Table A6. SurD Surface Interval Maximum Bubble Scores

Profile (msw/min)	DECO.		No. of Divers	Precordial - Rest					Precordial - Movement					All Sites - Maximum				
				0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
60/10 SurD O_2	CUMA	Single	13	13	0	0	0	0	13	0	0	0	0	10	3	0	0	0
	AGS O_2+	Single	6	6	0	0	0	0	5	1	0	0	0	4	2	0	0	0
	AGS O_2–	Single	8	7	0	1	0	0	6	0	2	0	0	5	1	2	0	0
60/20 SurD O_2	CUMA	Single	34	19	5	5	5	0	14	3	7	9	1	11	3	8	11	1
	CUMA	3-hr	8	4	2	0	2	0	4	0	1	3	0	4	0	1	3	0
	AGS O_2+	Single	8	4	0	2	2	0	4	0	2	2	0	3	0	3	2	0
		6-hr	2	2	0	0	0	0	1	0	1	0	0	1	0	1	0	0
		3-hr	4	3	0	0	1	0	3	0	0	1	0	2	1	0	1	0
	AGS O_2–	Single	9	7	0	1	1	0	3	1	0	3	0	2	2	0	3	0
		6-hr	2	1	0	0	1	0	1	0	0	1	0	1	0	0	1	0
		3-hr	5	3	0	0	2	0	2	0	1	1	1	1	1	0	2	1
69/20 SurD O_2	CUMA	Single	15	7	1	3	4	0	8	0	3	4	0	6	2	1	6	0
	AGS O_2+	Single	12	4	1	3	4	0	4	0	1	7	0	2	2	1	7	0
	AGS O_2–	Single	8	4	0	2	2	0	4	0	0	3	1	4	0	0	3	1
81/10 SurD O_2	CUMA	Single	26	23	0	2	1	0	20	1	1	4	0	15	3	4	4	0
	AGS O_2+	Single	6	5	0	1	0	0	4	0	1	1	0	2	2	1	1	0
		6-hr	2	2	0	0	0	0	2	0	0	0	0	1	0	1	0	0
	AGS O_2–	Single	6	3	1	2	0	0	3	0	0	3	0	0	2	1	3	0
		6-hr	3	3	0	0	0	0	3	0	0	0	0	3	0	0	0	0
81/15 SurD O_2	CUMA	Single	32	20	3	4	3	0	17	3	2	8	0	12	3	4	11	0
	CUMA	3-hr	8	6	0	1	1	0	5	0	1	2	0	3	2	1	2	0
	AGS O_2+	Single	6	5	0	1	0	0	4	0	0	2	0	3	1	0	2	0
		6-hr	2	2	0	0	0	0	2	0	0	0	0	0	0	2	0	0
		3-hr	9	9	0	0	0	0	8	0	1	0	0	8	0	1	0	0
	AGS O_2–	Single	8	7	0	0	1	0	6	0	0	2	0	6	0	0	2	0
		6-hr	2	1	0	0	1	0	1	0	0	1	0	1	0	0	1	0
		3-hr	9	9	0	0	0	0	9	0	0	0	0	7	0	1	1	0
81/20 SurD O_2	CUMA	Single	14	4	1	7	2	0	4	2	2	5	1	2	2	4	5	1
	AGS O_2+	Single	9	8	0	0	1	0	6	0	1	2	0	4	1	2	1	1
	AGS O_2–	Single	9	4	0	2	3	0	2	0	3	4	0	2	0	2	4	1

Note: CUMA decompression data for SurD O_2 dives obtained from first dives of repetitive dive-pairs, from repetitive [9] and reduced surface interval [8] dive trials, and from CUMA Tables validation trials [7].

Table A7. Post-Dive Doppler Summary

Profile (msw/min)	DECO.		No. of Divers	Precordial Rest		Precordial Move		All Sites Max	
				BG > 0	BG > 2	BG > 0	BG > 2	BG > 0	BG > 2
51/10 IWO$_2$	CUMA	Single	7	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	AGS O$_2$+	Single	2	0.0%	0.0%	0.0%	0.0%	50.0%	0.0%
	AGS O$_2$ –	Single	2	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
54/20 IWO$_2$	CUMA	Single	8	75.0%	25.0%	75.0%	50.0%	100.0%	50.0%
	AGS O$_2$+	Single	10	70.0%	20.0%	70.0%	50.0%	80.0%	50.0%
	AGS O$_2$ –	Single	9	77.8%	22.2%	77.8%	66.7%	100.0%	77.8%
69/10 IWO$_2$	CUMA	Single	7	42.9%	0.0%	57.1%	14.3%	57.1%	28.6%
	AGS O$_2$+	Single	8	12.5%	0.0%	12.5%	12.5%	25.0%	12.5%
	AGS O$_2$ –	Single	9	22.2%	0.0%	22.2%	0.0%	66.7%	11.1%
60/10 SurD O$_2$	CUMA	Single	24	8.3%	0.0%	12.5%	0.0%	29.2%	0.0%
	AGS O2+	Single	6	0.0%	0.0%	0.0%	0.0%	16.7%	0.0%
	AGS O$_2$ –	Single	8	0.0%	0.0%	0.0%	0.0%	12.5%	0.0%
60/20 SurD O$_2$	CUMA	Single	57	43.9%	14.0%	59.6%	40.4%	75.4%	43.9%
	CUMA	3-hr	14	71.4%	14.3%	85.7%	64.3%	85.7%	64.3%
	AGS O$_2$+	Single	8	50.0%	12.5%	62.5%	25.0%	75.0%	25.0%
		6-hr	2	50.0%	0.0%	0.0%	0.0%	50.0%	0.0%
		3-hr	4	25.0%	0.0%	50.0%	25.0%	50.0%	25.0%
	AGS O$_2$ –	Single	9	11.1%	0.0%	33.3%	22.2%	33.3%	22.2%
		6-hr	2	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
		3-hr	5	40.0%	0.0%	80.0%	20.0%	80.0%	20.0%
69/20 SurD O$_2$	CUMA	Single	30	60.0%	30.0%	73.3%	50.0%	80.0%	53.3%
	AGS O$_2$+	Single	12	58.3%	41.7%	58.3%	58.3%	66.7%	58.3%
	AGS O$_2$ –	Single	8	25.0%	0.0%	50.0%	37.5%	62.5%	50.0%
81/10 SurD O$_2$	CUMA	Single	45	17.8%	2.2%	17.8%	8.9%	42.2%	8.9%
	AGS O$_2$+	Single	6	0.0%	0.0%	16.7%	0.0%	16.7%	0.0%
		6-hr	2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	AGS O$_2$ –	Single	8	12.5%	0.0%	25.0%	12.5%	50.0%	12.5%
		6-hr	3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
81/15 SurD O$_2$	CUMA	Single	40	45.0%	25.0%	65.0%	40.0%	77.5%	45.0%
	CUMA	3-hr	16	50.0%	12.5%	62.5%	37.5%	62.5%	37.5%
	AGS O$_2$+	Single	6	16.7%	16.7%	50.0%	33.3%	50.0%	33.3%
		6-hr	2	100.0%	50.0%	100.0%	50.0%	100.0%	50.0%
		3-hr	9	22.2%	0.0%	33.3%	11.1%	33.3%	11.1%
	AGS O$_2$ –	Single	8	62.5%	25.0%	87.5%	62.5%	87.5%	62.5%
		6-hr	2	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
		3-hr	9	11.1%	11.1%	33.3%	11.1%	33.3%	11.1%
81/20 SurD O$_2$	CUMA	Single	29	75.9%	27.6%	82.8%	58.6%	89.7%	69.0%
	AGS O$_2$+	Single	10	50.0%	40.0%	70.0%	50.0%	80.0%	60.0%
	AGS O$_2$ –	Single	9	77.8%	33.3%	88.9%	77.8%	88.9%	88.9%

Table A8. SurD Surface Interval Doppler Summary

Profile (msw/min)	DECO.		No. of Divers	Precordial Rest		Precordial Move		All Sites Max	
				BG > 0	BG > 2	BG > 0	BG > 2	BG > 0	BG > 2
60/10 SurD O_2	CUMA	Single	13	0.0%	0.0%	0.0%	0.0%	23.1%	0.0%
	AGS O_2+	Single	6	0.0%	0.0%	16.7%	0.0%	33.3%	0.0%
	AGS O_2 –	Single	8	12.5%	0.0%	25.0%	0.0%	37.5%	0.0%
60/20 SurD O_2	CUMA	Single	34	44.1%	14.7%	58.8%	29.4%	67.6%	35.3%
	CUMA	3-hr	8	50.0%	25.0%	50.0%	37.5%	50.0%	37.5%
	AGS O_2+	Single	8	50.0%	25.0%	50.0%	25.0%	62.5%	25.0%
		6-hr	2	0.0%	0.0%	50.0%	0.0%	50.0%	0.0%
		3-hr	4	25.0%	25.0%	25.0%	25.0%	50.0%	25.0%
	AGS O_2 –	Single	9	22.2%	11.1%	57.1%	42.9%	71.4%	42.9%
		6-hr	2	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
		3-hr	5	40.0%	40.0%	60.0%	40.0%	80.0%	60.0%
69/20 SurD O_2	CUMA	Single	15	53.3%	26.7%	46.7%	26.7%	60.0%	40.0%
	AGS O_2+	Single	12	66.7%	33.3%	66.7%	58.3%	83.3%	58.3%
	AGS O_2 –	Single	8	50.0%	25.0%	50.0%	50.0%	50.0%	50.0%
81/10 SurD O_2	CUMA	Single	26	11.5%	3.8%	23.1%	15.4%	42.3%	15.4%
	AGS O_2+	Single	6	16.7%	0.0%	33.3%	16.7%	66.7%	16.7%
		6-hr	2	0.0%	0.0%	0.0%	0.0%	50.0%	0.0%
	AGS O_2 –	Single	6	50.0%	0.0%	50.0%	50.0%	100.0%	50.0%
		6-hr	3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
81/15 SurD O_2	CUMA	Single	32	31.3%	9.4%	40.6%	25.0%	56.3%	34.4%
	CUMA	3-hr	8	25.0%	12.5%	37.5%	25.0%	62.5%	25.0%
	AGS O_2+	Single	6	16.7%	0.0%	33.3%	33.3%	50.0%	33.3%
		6-hr	2	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
		3-hr	9	0.0%	0.0%	11.1%	0.0%	11.1%	0.0%
	AGS O_2 –	Single	8	12.5%	12.5%	25.0%	25.0%	25.0%	25.0%
		6-hr	2	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
		3-hr	9	0.0%	0.0%	0.0%	0.0%	22.2%	11.1%
81/20 SurD O_2	CUMA	Single	14	71.4%	14.3%	71.4%	42.9%	85.7%	42.9%
	AGS O_2+	Single	9	11.1%	11.1%	33.3%	22.2%	55.6%	22.2%
	AGS O_2 –	Single	9	55.6%	33.3%	77.8%	44.4%	77.8%	55.6%

Table A9. Example of Doppler BG data and results for Mann-Whitney U Test to compare normal CUMA dives with AGS O_2– and O_2+

a) 69 msw/20 min Post-dive Doppler Scores

Normal CUMA Decompression					
Table Validation Trials			6-hr Reduced SI Trials		
Subj. ID	PR	Max	Subj. ID	PR	Max
303	3	3+	50	3	3+
80	2	3	1	3	3+
315	0	1	62	1	3
93	0	0	63	3-	3
316	3-	3	2	1	1
318	0	0	31	0	1
320	3-	3	52	2	3-
322	1	2	4	3	3+
67	2	3-	42	1	1
326	0	3-	9	0	0
329	3	4-	23	0	1
336	0	2			
337	0	0			
22	2	3			

PR – Precordial Rest

Max – All sites maximum BG

AGS O_2–		
Subj. ID	PR	Max
92	0	0
94	0	0
32	1	3-
137	0	3
98	0	3
103	0	0
46	0	0
95	2	3

AGS O_2+		
Subj. ID	PR	Max
58	3	4-
160	0	0
78	3	3+
48	2	3
94	2	3-
106	3	3+
32	0	0
137	0	0
98	3-	3
79	0	0
161	0	1
95	3	4

O_2- vs. CUMA

	Z	P-value
PR	-2.064	*0.039*
Max	-1.201	0.230

O_2+ vs. CUMA

	Z	P-value
PR	.354	0.723
Max	.132	0.895

b) 81 msw/20 min Post-dive Doppler Scores

Normal CUMA Decompression					
Table Validation Trials			6-hr Reduced SI Trials		
Subj. ID	PR	Max	Subj. ID	PR	Max
309	0	3-	40	3	3+
312	0	0	30	2	2
313	2	3-	61	3-	3-
314	0	1	4	3+	3+
316	2	3	67	3+	3+
319	2	3	20	3+	3+
320	3	3+	5	3	3
321	0	3	6	1	2
67	1	3-	69	2	2
323	3-	3+	8	0	0
326	0	3-	33	4	4
332	2	3-	22	3+	3+
90	0	0	71	2	2
339	3-	4-			

AGS O_2–		
Subj. ID	PR	Max
92	1	3-
58	0	0
160	2	3
48	3-	3+
99	1	3
140	2	3
102	0	3-
95	3-	3+

AGS O_2+		
Subj. ID	PR	Max
160	3	4
47	2	2
48	0	0
99	3-	3+
10.3	0	0
77	3-	3+
161	0	3+
181	3	3+
95	0	2

O_2- vs. CUMA

	Z	P-value
PR	-0.344	0.731
Max	0.241	0.810

O_2+ vs. CUMA

	Z	P-value
PR	0.019	0.985
Max	0.205	0.837

Table A10. Mann-Whitney U Test results for decompression on AGS vs. decompression on CUMA

Post-dive BG	O_2– vs. CUMA						O_2+ vs. CUMA					
	No. of Divers		Precordial Rest		Max All Sites		No. of Divers		Precordial Rest		Max All Sites	
	CUMA	O_2–	Z[1]	P-value	Z	P-value	CUMA	O_2+	Z	P-value	Z	P-value
54/20 IWO_2	8	9	0.205	0.838	0.894	0.371	8	10	-0.411	0.681	0.046	0.963
69/10 IWO_2	7	8	-1.047	0.297	0.000	1.000	7	7	-0.883	0.371	-0.784	0.433
81/10 SurD O_2	32	7	-1.196	0.232	0.399	0.690	32	5	-1.005	0.315	-0.840	0.401
60/20 SurD O_2	50	9	-1.707	0.088	-1.923	0.055	48	8	0.198	0.843	-0.395	0.693
69/20 SurD O_2	25	8	-2.064	*0.039*	-1.201	0.230	25	12	0.354	0.723	0.132	0.895
81/15 SurD O_2	25	7	1.404	0.160	1.346	0.179	25	5	-0.898	0.369	-0.313	0.755
81/20 SurD O_2	27	8	-0.344	0.731	0.241	0.810	27	9	0.019	0.985	0.205	0.837
BG @ SurD SI	O_2– vs. CUMA						O_2+ vs. CUMA					
	No. of Divers		Precordial Rest		Max All Sites		No. of Divers		Precordial Rest		Max All Sites	
	CUMA	O_2–	Z	P-value	Z	P-value	CUMA	O_2+	Z	P-value	Z	P-value
81/10 SurD O_2	20	6	1.488	0.137	1.666	0.096	20	5	0.160	0.873	0.692	0.489
60/20 SurD O_2	30	8	-0.760	0.447	-0.386	0.700	27	8	0.440	0.660	-0.162	0.871
69/20 SurD O_2	13	8	-0.039	0.969	0.038	0.970	13	12	0.623	0.533	1.059	0.290
81/15 SurD O_2	19	7	-0.991	0.322	-1.030	0.303	19	5	-0.959	0.338	-1.384	0.166
81/20 SurD O_2	13	8	0.701	0.483	1.440	0.150	13	8	-1.766	0.077	-0.781	0.435

Repetitive Dives after 3-hr Surface Interval

Post-Dive BG	O_2– vs. CUMA						O_2+ vs. CUMA					
	No. of Divers		Precordial Rest		Max All Sites		No. of Divers		Precordial Rest		Max All Sites	
	CUMA	O_2–	Z	P-value	Z	P-value	CUMA	O_2+	Z	P-value	Z	P-value
60/20 SurD O_2	13	5	-1.297	0.195	-1.251	0.211	13	4	-1.729	0.084	-1.268	0.205
81/15 SurD O_2	12	8	-1.360	0.174	-1.654	0.098	12	7	-1.420	0.156	-1.567	0.117
BG @ SurD SI	No. of Divers		Precordial Rest		Max All Sites		No. of Divers		Precordial Rest		Max All Sites	
	CUMA	O_2–	Z	P-value	Z	P-value	CUMA	O_2+	Z	P-value	Z	P-value
60/20 SurD O_2	7	5	0.087	0.931	-0.829	0.407	7	4	0.913	0.362	-1.140	0.254
81/15 SurD O_2	8	8	-1.369	0.171	-1.102	0.270	8	7	-1.272	0.204	-1.701	0.089

Note: Calculations done with SPlus Version 6.0, Release 1, Insightful Corporation, Seattle, WA

1. Sign of correction factor Z indicates whether the BGs for decompression on AGS are greater or lower than those for decompression on CUMA

Table A11. Doppler BG data and results for Wilcoxon Signed Rank Test to compare BG results for divers who did both AGS O_2– and O_2+ dives

Max BG Post-dive		AGS O_2–			AGS O_2+		
Profile	Subj. ID	PR-	PM-	Max-	PR+	PM+	Max+
SurD 60/10	78	0	0	0	0	0	0
	79	0	0	0	0	0	0
	45	0	0	0	0	0	1
SurD 60/20	48	0	0	0	0	0	0
	79	0	0	0	0	0	0
	46	0	3-	3-	1	3	3
SurD 69/20	32	1	3-	3-	0	0	0
	137	0	3	3	0	0	0
	98	0	0	3	3-	3	3
	95	2	3	3	3	4	4
SurD 81/10	78	0	3-	3-	0	0	0
	79	0	0	0	0	0	0
	45	1	1	1	0	0	0
	95	0	0	1	0	0	0
SurD 81/15	106	2	3-	3+	0	0	1
	137	3	3	3	0	0	0
SurD 81/20	161	2	3	3	3	4	4
	48	3-	3	3	0	0	0
	95	3-	3+	3+	0	2	2
IWO2 54/20	48	3	3+	3+	2	2	2
	46	2	3-	3-	0	0	0
	79	2	3+	3+	0	0	2
IWO2 69/1	45	0	0	1	0	0	0
	46	0	0	0	0	0	0

BG @ Surd SI		AGS O_2–			AGS O_2+		
Profile	Subj. ID	PR-	PM-	Max-	PR+	PM+	Max+
SurD 60/10	78	0	2	2	0	0	0
	79	0	0	0	0	1	1
	45	2	2	2	0	0	0
SurD 60/20	48	0	0	0	0	0	0
	79	0	1	1	0	0	0
	46	2	3-	3-	2	2	2
SurD 69/20	32	0	0	0	3+	3+	3+
	137	3+	4	4	3	3	3
	98	2	3	3	2	3	3
	95	3-	3	3	3	3+	3+
SurD 81/10	78	2	3-	3-	0	0	0
	79	0	0	1	0	0	0
	45	1	3-	3-	2	3-	3-
	95	0	0	0	0	0	1
SurD 81/15	106	3	3+	3+	0	3-	3-
	137	0	0	0	0	0	0
SurD 81/20	161	0	2	2	0	0	0
	48	0	2	2	0	0	0
	95	2	3-	3-	0	0	1

PR – Precordial Rest

PR – Precordial after Movement

Max – All sites maximum BG

O_2- vs. O2+		
BG Post-dive	Z	P-value
Precordial Rest	1.664	0.0961
Precordial Move	2.283	*0.0224*
Max. All Sites	2.931	*0.0034*

O_2- vs. O2+		
BG @ SurD SI	Z	P-value
Precordial Rest	0.705	0.481
Precordial Move	1.825	0.068
Max. All Sites	1.800	0.072

List of symbols/abbreviations/acronyms/initialisms

DRDC	Defence Research & Development Canada
ABCANZ	America-Britain-Canada-Australia-New Zealand
AGS	Auxiliary Gas Supply
ATA	Atmospheres (absolute)
BG	Bubble Grade
BIBS	Built in Breathing System
BMI	Body Mass Index
CF	Canadian Forces
CNS	Central Nervous System
CO_2	Carbon dioxide
CUMA	Canadian Underwater Minecountermeasures Apparatus
DCI	Decompression Illness
DRF	Diving Research Facility
EDU	Experimental Diving Unit
EDUG	Experimental Diving and Undersea Group
FDU(A)	Fleet Diving Unit (Atlantic)
FDU(P)	Fleet Diving Unit (Pacific)
hr	hour
He	Helium
HeO_2	Helium-Oxygen
Heliox	Helium-Oxygen gas mixture
I.D.	Inside diameter
IWO_2	In-water oxygen decompression
KM	Kisman-Masurel Scale
L	Litres
L/min	litres/minute
MCM	Minecountermeasures
min	minute
msw	metre of seawater
N_2	Nitrogen
NATO	North Atlantic Treaty Organization
Nitrox	Nitrogen-Oxygen
No-D	No decompression

O_2	Oxygen
O.D.	Outside diameter
OTU	Oxygen Tolerance Unit
PC	Personal computer
PO_2	Partial Pressure of Oxygen
$PiCO_2$	Partial Pressure of inspired CO_2
PiO_2	Partial Pressure of inspired Oxygen
psi	Pounds per square inch
RCC	Recompression Chamber
RN	Royal Navy
RNLN	Royal Netherlands Navy
RNoN	Royal Norwegian Navy
RNZN	Royal New Zealand Navy
rpm	Revolutions per minute
SAD	Safe Ascent Depth
SD	Standard deviation
SDA	Severe Decompression Accident
SI	Surface interval
STPD	Standard temperature and pressure, dry
SurD O_2	Surface decompression with oxygen
SurD SI	Surface decompression surface interval
TWA	Time-Weighted Average
USL	Unimed Scientific Limited
USN	United States Navy
USNEDU	United States Navy Experimental Diving Unit

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An Auxiliary Gas Supply to Improve Safety During Aborted Dives with the Canadian Underwater Mine Countermeasures Apparatus (CUMA) (U)

Un système auxiliaire d’approvisionnement en gaz augmente la sécurité des plongeurs utilisant l’appareil canadien de déminage sous−marin (ACDSM) lors des remontées d'urgence (U)

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(U) The Canadian Underwater Minecountermeasures (MCM) Apparatus (CUMA) was introduced into CF service in 1991 and is widely used by other Navies under the commercial name of SIVA+. Despite its success, both within the CF and abroad it is now apparent that emergency procedures were not fully researched at the time of its introduction. Subsequent research into Severe Decompression Accidents (SDA) has shown that previous emergency procedures were not sufficient to safely decompress a diver during an emergency ascent from deep or long, shallow dives. As a result of this, other decompression procedures have been instituted, based on research and practices adopted from other nations. Another option is to give the diver the option of decompressing safely in the water. This will be done using a completely independent and alternative breathing system known as the Auxiliary Gas Supply (AGS) in case of complete diving set failure. The AGS will allow the diver to decompress using existing operational tables rather than extended emergency tables. The AGS will deliver a 40% Oxygen and 60% Nitrogen mix, which will facilitate Helium off−gassing following the same proven principal used in CF Surface Supply diving.

Validation experiments were conducted between June 2002 and November 2003 over four series of dives. Doppler scores from the 202 man dives showed no significant difference in observed bubble scores between those dives that had used the AGS to decompress and the data from previous dives using normal in−water or surface decompression. There was only one incident of surface interval stress and no incident of DCI. The results indicate that a CUMA diver can be safely decompressed from a dive requiring decompression using the in water AGS.

(U) L’appareil canadien de déminage sous−marin (ACDSM) est au service des Forces canadiennes (FC) depuis 1991 et est aussi largement utilisé par d’autres marines sous la dénomination commerciale SIVA+. Malgré son succès au sein des FC et à l’étranger, il s’avère maintenant que les procédures d’urgence n'ont pas fait l’objet de recherches approfondies au moment de sa mise en service. Des études menées ultérieurement sur les accidents de décompression graves (ADG) ont révélé que les procédures d’urgence instaurées à l’époque ne permettent pas une décompression sécuritaire des plongeurs lors d’une remontée en catastrophe après une plongée profonde ou une plongée peu profonde de longue durée. Par conséquent, d’autres procédures de décompression fondées sur les recherches menées et les pratiques adoptées par d’autres nations ont été établies. Une autre option consiste à donner aux plongeurs la possibilité d’effectuer la décompression sous l'eau en toute sécurité. Pour ce faire, un autre système respiratoire entièrement autonome, le système auxiliaire d'approvisionnement en gaz (SAAG), doit être utilisé dans le cas d'une défaillance complète de l’appareil de plongée. Le SAAG permet aux plongeurs d’utiliser les tables de décompression opérationnelles existantes plutôt que les tables de décompression d’urgence étendues. Le SAAG fournit un mélange de 40 % d’oxygène et de 60 % d’azote qui facilite le dégazage de l'hélium selon le même principe éprouvé qu’utilisent les FC pour la plongée en narghilé.

Des expériences de validation ont été menées de juin 2002 à novembre 2003, au cours de quatre séries de plongées. Les données consignées par le détecteur de bulles Doppler au cours de 202 plongées−personne ne montrent aucun écart important entre les résultats observés lors de la décompression par SAAG et les données recueillies lors de plongées précédentes à décompression normale sous l'eau ou en surface. Il ne s'est produit qu'un seul incident de stress causé par un intervalle de surface trop court; aucun mal de décompression n'a été relevé. Les résultats indiquent qu'il est possible, pour un plongeur muni d'un ACDSM, d'utiliser le SAAG sous l'eau pour procéder à une décompression sécuritaire lorsqu'une décompression est requise.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

(U) Breathing apparatus failure; emergency ascent; decompression; Doppler bubble detection

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