
2014 Decompression Sickness/Extravehicular Activity Risks Standing Review Panel

Evidence Reviews for:

*The Risk of Decompression Sickness
The Risk of Injury and Compromised Performance due to EVA Operations*

Final Report

I. Executive Summary and Overall Evaluation

The 2014 Decompression Sickness (DCS)/Extravehicular Activity (EVA) Risks Standing Review Panel (from here on referred to as the SRP) met for a site visit in Houston, TX on November 4 - 5, 2014. The SRP reviewed the updated Evidence Reports for The Risk of Decompression Sickness (from here on referred to as the 2014 DCS Evidence Report) and the Risk of Injury and Compromised Performance due to EVA Operations (from here on referred to as the 2014 EVA Evidence Report), as well as the Research Plans for these Risks.

The SRP appreciated the time and effort that the DCS and EVA disciplines put into their review documents and presentations. The SRP felt that the 2014 DCS Evidence Report and the 2014 EVA Evidence Reports were very thorough and addressed the majority of the known DCS and EVA issues. The researchers at NASA Johnson Space Center (JSC) have the knowledge base to deal with the DCS and EVA issues. Overall, the SRP thinks the DCS and EVA research teams have compiled excellent reports which address the majority of the literature and background information.

II. Review of the Evidence for the Risk of Decompression Sickness

1. *Evaluate the 2014 Decompression Sickness (DCS) Evidence Report using the following criteria:*

A. *Does the 2014 Evidence Report provide sufficient evidence that the Risk is relevant to long-term space missions?*

Yes, the SRP thinks the 2014 DCS Evidence Report provides sufficient evidence that the Risk is relevant to long-term space missions.

B. *Are the Risk Title and Statement properly stated in the current version of the HRP Integrated Research Plan (IRP)?**

Yes, the SRP thinks the Risk Title and Statement are properly stated in the current version of the IRP.

C. *Is the text of the Risk Context provided in the HRP IRP clear?*

The SRP suggests rewording the Risk Content to (suggested edits in bold and strikethrough):
As of February 2012, there have been no reported cases of DCS during Shuttle and International Space Station (ISS) missions due to adherence to prebreathe (PB) protocols

rigorously developed and validated specific to Shuttle and ISS operational environments and EVA scenarios, *as well as possible physiologic changes induced by microgravity*. Although DCS risk has been greatly reduced through these PB protocols, it is at the expense of significant crew time and consumable usage. This need for significant crew time and consumables will not meet the *anticipated* needs of the human space exploration program.

The architectures being developed by NASA for future exploration beyond low Earth orbit differ from previous vehicles and EVA systems in terms of vehicle ~~saturation~~ pressures, breathing mixtures, EVA frequency, EVA durations, *EVA goals*, and pressure profiles, and will almost certainly differ in terms of the definition of acceptable DCS risk and *in-situ* DCS treatment capabilities. The use of suit ports, variable pressure EVA suits, intermittent recompressions, and possibly abbreviated purges with PB gas mixtures of less than 100% oxygen represent a paradigm shift in the approach to EVA with the potential of reducing EVA crew overhead and consumables usage by two orders of magnitude. However, the role and impact of these variables on the overall probability of DCS is theoretical, *and* without empirical data to support the theory. In addition, the acceptable level of DCS risk is highly dependent on the availability of treatment capability.

D. Does the evidence base make the case for the knowledge-type gaps presented?

Yes, the SRP thinks the evidence base makes the case for the knowledge-type gaps presented.

E. Are there any additional knowledge-type gaps that should be considered for this specific Risk?

Yes, the SRP suggests adding a knowledge-type gap that addresses the ultimate pressure of exploration gas to include effects of hypoxia.

F. Does the Evidence Report address relevant interactions between this Risk and others in the HRP IRP?

The SRP was pleased with the interaction between the DCS discipline and the EVA discipline and encourages the DCS discipline to look at other HRP disciplines for relevant interactions.

G. Are the qualifications of the author(s) appropriate for identifying the evidence base necessary to characterize the given Risk?

Yes, the SRP strongly believes that the team of authors is very knowledgeable and there are enough team members of different disciplines and backgrounds to make assessments.

H. Is there information from other HRP disciplines that need to be included in the 2014 Evidence Report?

There is no additional information from the other HRP disciplines that needs to be included in the 2014 DCS Evidence Report.

I. Is the breadth of the cited literature sufficient?

The SRP thinks that there is significant literature missing from the 2014 DCS Evidence Report.

Specifically recent research with respect to U-2 pilots, strengthen the concern for the current Gap DCS7. The following list of references are additional documents on the recent neurological DCS in United States Air Force (USAF) U-2 pilots. It also includes the follow-up research on the white matter lesions in these pilots. Although the cause-and effect relationship has yet to be defined, the SRP thinks the 2014 DCS Evidence report should at least discuss these new developments. The SRP suggest incorporating some of these references in the Evidence Report.

McGuire SA, Sherman PM, Brown AC, Robinson AY, Tate DF, Fox PT, Kochunov PV. Hyperintense white matter lesions in 50 high altitude pilots with neurologic decompression sickness. Aviat Space Environ Med 2012; 83: 1117 – 22.

Jersey SL, Jesinger RA, Palka P. Brain magnetic resonance imaging anomalies in U-2 pilots with neurological decompression sickness. Aviat Space Environ Med 2013; 84:3–11.

Stephen McGuire, Paul Sherman, Leonardo Profenna, et al. White matter hyperintensities on MRI in high-altitude U-2 pilots Neurology 2013;81;729-735.

Stephen A. McGuire, David F. Tate, Joe Wood, et al. Lower neurocognitive function in U-2 pilots: Relationship to white matter hyperintensities Neurology 2014;83;638-645.

Michaelson RS, Pilmanis AA, Morgan T. Report of Evaluation of Decompression Sickness, Beale AFB10-14 AUG 2009. AFRL-SA-BR-TR-2010-0008 Sept 2009.

Webb JT, Woodrow AD, Maresh RW. Decompression sickness and U-2 operations: Summary of research findings and recommendations regarding use of exercise during prebreathe. AFRL-SA-BR-TR-2009-0018, March 2010.

Pilmanis AA, Wright B, Bryant D, Wade M. U-2S Cockpit Altitude Reduction Effort Rapid Decompression: Physiological Risk Review. AFRL-SA-WP-SR-2014-000. January 2014.

Some additional references the SRP thinks may be of value to the 2014 DCS Evidence Report are listed below. Specifically, the SRP thinks the 2014 DCS Evidence Report should

provide a more in depth review of the potential of Cerebral Arterial Gas Embolism (some references provided below).

Weenink RP, Hollmann MW, van Hulst RA. Acute neurological symptoms during hypobaric exposure: consider cerebral air embolism. Aviat Space Environ Med 2012; 83:1084-91.

Krebs MB, Pilmanis AA. Human pulmonary tolerance to altitude-induced dynamic overpressure. AL/CF-TR-1996-0058. 1996:66pp.

Veronneau SJH, Pilmanis AA, Mohler SR. Cerebral gas embolism in a commercial pilot during unpressurized flight. (Abstract) Aviat. Space Environ. Med. 1995;66:479.

Webb JT, Pilmanis AA. Fifty years of decompression sickness research at Brooks AFB, TX: 1960-2010 . Aviat Space Environ Med 2011; 82(5, Suppl.):A1–A25.

Pilmanis AA, Webb JT, Balldin UI. Partial pressure of nitrogen in breathing mixtures and risk of altitude decompression sickness (DCS). Aviat Space Environ Med Aviat Space Environ Med 2005; 76:635-641.

Pilmanis AA, Olson RM, Fischer MD, Wiegman JF, Webb JT. Exercise-induced altitude decompression sickness. Aviat. Space Environ. Med. 1999;70:22-9.

Webb JT, Pilmanis AA, Kannan N, Olson RM. The effect of staged decompression while breathing 100% oxygen on altitude decompression sickness. Aviat. Space Environ. Med. 2000;71:692-8.

Webb JT, Krause KM, Pilmanis AA, Fischer MD, Kannan N. The effect of exposure to 35,000 ft on incidence of altitude decompression sickness. Aviat. Space Environ. Med. 2001;72:509-12.

Pilmanis AA, Webb JT, Kannan N, Balldin UI. The risk of altitude decompression sickness at 12,000 m and the effect of ascent rate. Aviat Space Environ Med 2003;74:1052-7.

Gibbons JA, Ramsey C, Wright JK, Pilmanis AA. Case history of serious altitude decompression sickness following increased rate of ascent. Aviat Space Environ Med 2003;74:675-8.

Bryce LM, Butler WP, Pilmanis AA, King H. Headache and altitude decompression sickness: joint pain or neurological pain. Aviat Space Environ Med 2006; 76:1074-8.

Pilmanis AA, Krause KM, Webb JT, Petropoulos LJ, Kannan N. Optimizing the physiological concepts for future extravehicular (EVA) operations. Reusable Launch Vehicle Human in Space Workshop Proceedings. 1997.

Webb JT, Pilmanis AA, Krause KM. Preoxygenation time versus decompression sickness incidence. 36th Annual SAFE Symposium Proceedings. 1998:419-24.

Pilmanis AA, Krause KM, Webb JT, Petropoulos LJ, Kannan N. Staged decompression to a 3.5 psi EVA suit using an argon-oxygen (ARGOX) breathing mixture. Proceedings of the First Biennial Space Biomedical Investigators' Workshop. January 11-13, 1999, League City, TX. 1999:124-6.

Webb JT, Beckstrand DP, Pilmanis AA, Balldin UI. Decompression sickness during simulated extravehicular activity: to ambulation vs. non-ambulation. Aviat Space Environ Med 2005; 76:778-81.

The SRP suggests that there may be pertinent literature found in the USAF Aeromedical Library at Wright-Patterson AFB, Dayton, Ohio. Specifically, reports on the USAF Manned Orbital Laboratory Program. This program included manned long-term low pressure exposures using various breathing gases. It also included fire hazard reports.

Lastly, there may be relevant diving research. There have been publications with regards to interruption of oxygen pre-breathe:

Seth Y. Flagg, David P. Regis, Kyle Petersen, Richard T. Mahon Interrupted oxygen pre-breathing and decompression outcomes in swine. Aviat Space Environ Med 84 (1), January 2013 , 12-16(5),

and Thom's work with microparticles:

Thom SR, Fisher D, Zhang J, Bhopale VM, Ohnishi ST, Kotake Y, Ohnishi T, Buerk DG. Stimulation of perivascular nitric oxide synthesis by oxygen. Am J Physiol Heart Circ Physiol 284(4): 1230-9, 2003.

Thom SR, Milovanova TN, Bogush M, Bhopale VM, Yang M, Bushmann K, et al. Microparticle production, neutrophil activation, and intravascular bubbles following open-water SCUBA diving. J Appl Physiol 112(8): 1268-78, 2012.

Thom SR, Milovanova TN, Bogush M, Yang M, Bhopale VM, Pollock NW, et al. Bubbles, microparticles, and neutrophil activation: Changes with exercise level and breathing gas during open-water SCUBA diving. J Appl Physiol 114(10): 1396-405, 2013.

Thom SR, Yang M, Bhopale VM, Huang S, Milovanova TN. Microparticles initiate decompression-induced neutrophil activation and subsequent vascular injuries. J Appl Physiol 110(2): 340-51, 2011.

Thom SR, Yang M, Bhopale VM, Milovanova TN, Bogush M, Buerk DG. Intramicroparticle nitrogen dioxide is a bubble nucleation site leading to decompression-induced neutrophil activation and vascular

injury. J Appl Physiol 114(5): 550-8, 2013.

As well as reviews from the large body of literature relating to chronic central nervous system (CNS) changes in bypass surgery which gives further justification for measuring long term effects of ‘silent bubbles’. Likewise, a search and review of technical reports for diving published by the US Navy at the Navy Experimental Diving Unit and Naval Submarine Research Lab. Furthermore these institutions have dealt with and continue to deal with similar challenges of EVA Operations in the realm of saturation diving and submarine health. In particular, the issues of limited resource allocation for normal and emergent situations requiring the prevention and treatment of DCS while still maintaining primary mission goals. Though no specific recommendations are made with respect to citations from these institutions, the SRP would like to recommend these resources for consideration.

J. What is the overall quality and readability of the 2014 Evidence Report?

The SRP thought the 2014 DCS Evidence Report was well written and organized.

III. Review of the Evidence for the Risk of Injury and Compromised Performance due to EVA Operations

1. Evaluate the 2014 Risk of Injury and Compromised Performance due to EVA Operations (EVA) Evidence Report using the following criteria:

A. Does the 2014 Evidence Report provide sufficient evidence that the Risk is relevant to long-term space missions?

Yes, the SRP thinks the 2014 EVA Evidence Report provides sufficient evidence that the Risk is relevant to long-term space missions.

*B. Are the Risk Title and Statement properly stated in the current version of the HRP Integrated Research Plan (IRP)?**

Yes, the SRP thinks the Risk Title and Statement are properly stated in the current version of the IRP.

C. Is the text of the Risk Context provided in the HRP IRP clear?

The SRP suggests rewording the Risk Content to (suggested edits in bold):

Performance of spaceflight EVA consists of placing a human in a micro-environment, which must provide all the life support, nutrition, hydration, waste and consumables management function of an actual space vehicle, while allowing crewmembers to perform as close as possible to their 1-g shirt-sleeved performance. Influences from the combination of EVA or EVA training operational factors (e.g., task, equipment and resources design, altered gravity environment, **operational pressure**), suit design (e.g., suit fit, CG location, joint flexibility) and crew characteristics (e.g., physical preparation, state of fatigue) can place physiological

and functional demands on the crew that lead to injury, compromised physiological performance and incomplete mission objectives.

D. Does the evidence base make the case for the knowledge-type gaps presented?

Yes, the SRP thinks the evidence base makes the case for the knowledge-type gaps presented.

E. Are there any additional knowledge-type gaps that should be considered for this specific Risk?

Yes, the SRP suggests adding the following knowledge-type gaps:

- Section III.2. In-Suit Physical Environment of the 2014 EVA Evidence Report should include sections on the following conditions:
 - Ebullism: The **primary** purpose of a pressure suit in space is to provide protection against ebullism. The topic of ebullism should either be included in the DCS section or in the EVA section. The reference below covers the topic in detail.
 - *Murray DH, Pilmanis AA, Blue RS, Pattarini JM, Law J, Bayne CG, Turney MW, Clark JB. Pathophysiology, prevention, and treatment of ebullism. Aviat Space Environ Med 2013; 84(2):1-8.*
 - DCS covered in DCS documents
 - Embolism (see section II.1.I above)
 - Hypocapnia
 - Hypercapnia

F. Does the Evidence Report address relevant interactions between this Risk and others in the HRP IRP?

The SRP was pleased with the interaction between the EVA discipline and the DCS discipline and encourages the EVA discipline to look at other disciplines within the HRP for relevant interactions.

G. Are the qualifications of the author(s) appropriate for identifying the evidence base necessary to characterize the given Risk?

Yes, the SRP strongly believes that the authors are very knowledgeable and that the team at NASA JSC has a wealth of knowledge in this area.

H. Is there information from other HRP disciplines that need to be included in the 2014 Evidence Report?

There is no additional information from the other HRP disciplines that needs to be included in the 2014 EVA Evidence Report.

I. Is the breadth of the cited literature sufficient?

Currently the SRP thinks the breadth of the cited literature is not sufficient, but can easily be corrected if the items in E. above are added to the 2014 EVA Evidence Report.

J. What is the overall quality and readability of the 2014 Evidence Report?

The overall quality and readability of the 2014 Evidence Report is good.

IV. 2014 DCS/EVA Risks SRP Evidence Review: Statement of Task for the Risk of Decompression Sickness (DCS) and the Risk of Injury and Compromised Performance due to EVA Operations (EVA)

In 2008, the Institute of Medicine (IOM) reviewed NASA's Human Research Program (HRP) Evidence Books that describe the Risks that were identified in NASA's Human Research Program Requirements Document (PRD). The 2014 Evidence Reports for the Risk of Decompression Sickness (DCS) and the Risk of Injury and Compromised Performance due to EVA Operations (EVA) have not been reviewed since the last IOM review and there have been significant changes to the evidence base for the Risk.

The 2014 Decompression Sickness/Extravehicular Activity (DCS/EVA) Risks Standing Review Panel (SRP) is chartered by the Human Research Program (HRP) Chief Scientist to review the Evidence Reports for the DCS and EVA Risks. The 2014 DCS/EVA Risks SRP will evaluate the Evidence Report and generate a final report of your analyses of the evidence base, including any recommendations on how to improve the current Evidence Report, and submit it to the HRP Chief Scientist. Your report will also be made available on the Human Research Roadmap (HRR) website.

The 2014 DCS/EVA Risks SRP is charged to:

1. Separately evaluate the 2014 DCS and EVA Evidence Reports based on each of the following criteria:
 - A. Does the 2014 Evidence Report provide sufficient evidence that the Risk is relevant to long-term space missions?
 - B. Are the Risk Title and Statement properly stated in the current version of the HRP Integrated Research Plan (IRP)?*
 - C. Is the text of the Risk Context provided in the HRP IRP clear?*
 - D. Does the evidence base make the case for the knowledge-type gaps presented?
 - E. Are there any additional knowledge-type gaps that should be considered for this specific Risk?
 - F. Does the Evidence Report address relevant interactions between this Risk and others in the HRP IRP?
 - G. Are the qualifications of the author(s) appropriate for identifying the evidence base necessary to characterize the given Risk?
 - H. Is there information from other HRP disciplines that need to be included in the 2014 Evidence Report?
 - I. Is the breadth of the cited literature sufficient?
 - J. What is the overall quality and readability of the 2014 Evidence Report?
2. Provide comments on any important issues that are not covered by the criteria in #1 above.

** Please be aware that any suggested changes to the Risk Title, Statement, and Risk Context by the SRP may need to be approved by the Human Systems Risk Board (HSRB). The HSRB has the overall responsibility to implement and maintain a consistent, integrated process for assessing, documenting, and tracking all risks to the human system associated with spaceflight activities (both in flight and post flight).*

Additional information regarding this review:

1. Attend a meeting at the NASA JSC on November 4 – 5, 2014 to discuss the Evidence Reports with the Human Health Countermeasures (HHC) Element. At this meeting, prepare a draft report for each risk that addresses each of the evaluation criteria listed in the panel charge (A-J) including any recommendations on how to improve the Evidence Report. Debrief the HRP Chief Scientist and a representative from the HHC Element on the salient points that will be included in the final report and specifically the items in the panel charge.
2. Prepare a draft final report for each risk (within one month of the site visit debrief) that contains a detailed evaluation of the Evidence Report specifically addressing items #1 and #2 of the SRP charge. The draft final report will be sent to the HRP Chief Scientist and he will forward it to the appropriate Element for their review. The HHC Element and the HRP Chief Scientist will review the draft final report and identify any misunderstandings or errors of fact and then provide official feedback to the SRP within two weeks of receipt of the draft report. If any misunderstandings or errors of fact are identified, the SRP will be requested to address them and finalize the 2014 SRP Final Report as quickly as possible. The 2014 SRP Final Report will be submitted to the HRP Chief Scientist and copies will be provided to the HHC Element that sponsors the DCS and EVA disciplines and also made available to the other HRP Elements. The 2014 SRP Final Report will be made available on the HRR website (<http://humanresearchroadmap.nasa.gov/>).

To clarify, the Risk Statement and Risk Context are defined as follows:

Risk Statement:

“Given the CONDITION, there is a possibility that a CONSEQUENCE will occur”.

Condition: a single phrase briefly describing current key circumstances, situations, etc. that are causing concern, doubt, anxiety, or uncertainty – something that keeps you up at night.

Consequence: a single phrase or sentence that describes the key, negative outcome(s) of the current conditions.

Notes:

The condition-consequence format provides a more complete picture of the Risk, which is critical during mitigation planning. The condition component focuses on what is currently causing concern. This is something that is true or widely perceived to be true. This component provides information that is useful when determining how to mitigate a Risk.

The consequence component focuses on the intermediate and long-term impact of the risk. Understanding the depth and breadth of the impact is useful in determining how much time, resources, and effort should be allocated to the mitigation effort.

A well-formed Risk Statement usually has only one condition, and has one or more consequences.

Risk Context:

Purpose: provide enough additional information about the Risk to ensure that the original intent of the Risk can be understood by other personnel, particularly after time has passed.

Description: capture additional information regarding the circumstances, events, and interrelationships not described in the Risk Statement.

An effective context captures the what, when, where, how, and why of the Risk by describing the circumstances, contributing factors, and related issues (background and additional information that are NOT in the Risk Statement).

V. 2014 DCS/EVA Risks Standing Review Panel Roster

Panel Chair:

Richard Mahon, M.D.

Naval Medical Research Center (retired)
11402 Tall Forest Circle
Germantown, MD 20876
Ph: 858-248-3145
Email: Docmahon@gmail.com

Panel Members:

David Klaus, Ph.D.

University of Colorado Boulder
Aerospace Engineering Sciences
429 UCB
Boulder, CO 80309-0429
Ph: 303-492-3525
Email: klaus@colorado.edu

Tom Neuman, M.D.

University of California, San Diego (Emeritus)
579 Amphitheatre Drive
Del Mar, CA 92014
Ph: 619-994-3718
Email: tneuman@ucsd.edu

Andrew Pilmanis, Ph.D.

464 Coffee Circle
Pottsboro, TX 75076
Ph: 210-859-1303
Email: apilmanis@aol.com

David Regis, M.D.

Naval Medical Research Center
Undersea Medicine Department
503 Robert Grant Avenue
Silver Spring, MD 20910-7500
Ph: 301-319-3147
Email: david.regis1@med.navy.mil