2014 Decompression Sickness/Extravehicular Activity Risks Standing Review Panel

Research Plan 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 Research Plans for The Risk of Decompression Sickness and the Risk of Injury and Compromised Performance due to EVA Operations, as well as the Evidence Reports for both of these Risks.

The SRP found that the NASA DCS/EVA team did an excellent job of presenting their research plans. The SRP considers it critical that NASA proceeds with the high priority tasks identified in this report (DCS1, DCS3, DCS5). The highest priority is to determine the acceptable DCS and hypoxia risk associated with the planned human exploration beyond low Earth orbit. The risk of DCS is highly dependent upon the pressure within the exploration vehicle. If slightly more hypoxia is permitted then (even with the same percentage of oxygen) the pressure within the exploration vehicle can be lowered thus further mitigating the risk of DCS.

The second highest priority is to test and validate the recommended 8.2psi/34% O_2 atmosphere. Development of procedures and equipment for human exploration missions are very limited until the results of this testing are completed.

The SRP also suggests that DCS7 be separated into two Gaps. Gap DCS7 should deal with DCS treatment while a new Gap should be created to deal with the long-term effects of DCS.

The SRP also encourages NASA to increase collaboration with other organizations and pool resources where possible. The current NASA DCS/EVA team has the extensive expertise and a wealth of knowledge in this area. The SRP suggests that increased manpower for this team would be highly productive.

II. Critique of Gaps and Tasks for the Risk of Decompression Sickness

1. *Have the proper Gaps been identified to address the Risk?*
   A. *Are all the Gaps relevant?*
   B. *Are any Gaps missing?*
2. *Have the appropriate targets for closure for the Gaps been identified?*
   A. *Is the research strategy appropriate to close the Gaps?*
3. *Have the proper Tasks been identified to fill the Gaps?*
   A. *Are the Tasks relevant?*
   B. *Are there any additional research areas or approaches that should be considered?*
   C. *If a Task is completed, please comment on whether the findings contribute to*

addressing or closing the Gap

4. *If a Gap has been closed, does the Rationale for Gap closure provide the appropriate evidence to support the closure?*

Gaps and Tasks:

DCS1: We do not know the acceptable DCS risk with respect to the work efficiency index (WEI) for exploration scenarios.

- The SRP thinks this Gap is relevant and appropriate.
- The SRP thinks this Gap is very important and needs to be accomplished as quickly as possible.

Task:

- Definition of Acceptable DCS Risk – Planned Task.
  - The SRP thinks that since this is an administrative decision, no research is really needed to accomplish this task.

DCS2: We do not know the contribution of specific DCS risk factors to the development of DCS in the Space Flight Exploration Environment.

- The SRP thinks this Gap is relevant and appropriate, but is a lower priority than DC1 and DCS 5.

Tasks:

- Mechanisms of Musculoskeletal-Induced Nucleation in Altitude Decompressions Stress II – PI: Michael Gernhardt, Ph.D. – NASA Johnson Space Center
- Prevalence of Venous Gas Emboli after Depressurization in Microgravity – Planned Task
- Nitrogen (N2) Elimination – Planned Task
- Improved Bubble Detection for EVA – Completed Task

DCS3: We do not know the mission related factors that contribute to DCS risk.

- The SRP thinks this Gap is relevant and appropriate.
- The SRP thinks this Gap is a very high priority and should be next in priority after DCS1 and DCS5.
- The SRP recommends clarifying the wording used in the "Target for Closure" for this Gap. Specifically what is meant by the term "individual variance"?
- The SRP recommends clarifying what the EVA simulator is under the tasks. For example, is this an EVA operational task simulation facility or hyper/hypobaric chamber?

Tasks:

- Develop and test EVA Workload Simulator – Completed Task
- Feasibility Study of EVA Workload Simulator for Use in 1-g Environment – Completed Task
- Mechanisms of Musculoskeletal-Induced Nucleation in Altitude Decompressions Stress II – PI: Michael Gernhardt, Ph.D. – NASA Johnson Space Center
- Prevalence of Venous Gas Emboli after Depressurization in Microgravity – Planned Task

- Nitrogen (N2) Elimination – Planned Task

DCS4: We do not know to what extent physiological and environmental factors can be incorporated and validated in a model of DCS for micro and reduced gravity.

- The SRP thinks this Gap is relevant and appropriate.
- The SRP thinks whatever model is chosen, it needs to be validated first. Until this is done, the proposed 8.2, 34% oxygen environment introduces uncertainties that are not yet characterized in terms of physiological responses to these conditions.
- The SRP thinks the table under the "Interim Stages" for this Gap in the current version of the IRP needs clarification.

Tasks:

- Develop and Evaluate Risk Model for DCSVA Workload Simulator – Planned Task
- Develop and Evaluate Treatment Model for DCS – Planned Task

DCS5: We do not know what validated procedures will adequately prevent DCS.

- The SRP thinks this Gap is relevant and appropriate.
- The SRP thinks this is second in priority after DCS1 and emphasis should be on this Gap, testing, not modeling. Altitude chamber facilities capable of this testing should be identified and funding provided. The results of this testing are critical to the development of procedures and design of equipment/vehicles for human exploration missions.

Tasks:

- Exploration Atmosphere Prebreathe Validation – Unfunded Task/Not within Current Budget
- Chamber outfit/green fees – Unfunded Task/Not within Current Budget
  - The SRP thinks the term "green fees" needs to be defined.
- Abbreviated Purge – Unfunded Task/Not within Current Budget
- Develop and test EVA Workload Simulator for Exploration – Unfunded Task/Not within Current Budget
- Intermittent Recompression – Unfunded Task/Not within Current Budget

DCS6: We do not know what new developments related to DCS will come from other investigators.

- The SRP thinks this Gap is relevant and appropriate.
- The SRP recommends developing a process for the technology watch.
- The SRP suggests contacting the following institutions for information and possible collaborations:
  - Brooks City-Base – low grade hypoxia research, Exploration atmosphere validation testing
  - US Army Research Institute for Environmental Medicine, Natick – hypoxia research
  - US Navy New London Submarine facility - CO_2 research

Task:

- DCS Tech Watch – Planned Task

DCS7: We have not validated procedures to adequately treat DCS in the spaceflight environment should it occur.

- The SRP thinks this Gap is relevant and appropriate.
- The SRP recommends splitting this into two separate Gaps, one for treatment and one for long-term health.
- The SRP recommends changing the current wording of the "Initial State" to the following: "There are DCS treatment protocols for altitude DCS to involve hyperbaric oxygen treatment. These treatment protocols are based on the aviation scenarios and assume a crewmember's return to ground. In space, this will likely not be possible and we need to understand the capabilities of treating DCS with the use of expected *in-situ* resources ***or development of additional capabilities***."

Task:

- Long Term Consequences of Spaceflight DCS – Planned Task
  - What risk of DCS is acceptable? This needs to be determined.
  - Can the engineers develop a Gamow bag type device (or equivalent) that is light weight enough to go on vehicle? Or is the spacesuit capable of providing adequate hyperbaric conditions when pressurized above ambient in the cabin?
  - The use of hyperbaric treatment procedures and devices was extensively studied by NASA in the early 1990's. The SRP recommends that the DCS team review this research.
  - The SRP thinks the data on white matter lesion issues in U-2 pilots should also be reviewed.

III. Critique of Gaps and Tasks for the Risk of Injury and Compromised Performance due to EVA Operations

1. *Have the proper Gaps been identified to address the Risk?*
   A. *Are all the Gaps relevant?*
   B. *Are any Gaps missing?*
2. *Have the appropriate targets for closure for the Gaps been identified?*
   A. *Is the research strategy appropriate to close the Gaps?*
3. *Have the proper Tasks been identified to fill the Gaps?*
   A. *Are the Tasks relevant?*
   B. *Are there any additional research areas or approaches that should be considered?*
   C. *If a Task is completed, please comment on whether the findings contribute to addressing or closing the Gap*
4. *If a Gap has been closed, does the Rationale for Gap closure provide the appropriate evidence to support the closure?*

Gaps and Tasks:

EVA6: What crew physiological & performance capabilities are required for EVA operations in exploration environments?

- The SRP thinks this Gap is relevant and appropriate.

Tasks:

- Subject Characterization Study – Planned Task
- Metabolic Cost of Experimental Exercise – Completed Task
- Optimization of Astronaut Decompression Sickness Prevention Protocols Using Probabilistic Gas and Bubble Dynamics Models – Completed Task
- Advanced EVA Biomedical Energetics Performance and Space Suit Assessment – Completed Task
- Post Transit EVA on Mars – Planned Task

EVA7: How do EVA suit system design parameters affect crew health and performance in exploration environments?

- The SRP thinks this Gap is relevant and appropriate.
- Before answering this Gap, you need to know if the suit fits. Currently, there are no quantifiable standards for assessing proper suit fit.

Tasks:

- Center of Gravity (CG) Evaluations on POGO, NBL, NEEMO, Parabolic Flight – Completed Task
- Joint Characteristics/Mobility Evaluations on POGO, NBL, NEEMO, Parabolic Flight – Completed Task
- Suit Mass Evaluations on POGO, NBL, NEEMO, Parabolic Flight – Completed Task
- Suit Parameters/Human Performance Predictive Tool – Completed Task
- Suit Pressure Evaluations on POGO, NBL, NEEMO, Parabolic Flight – Completed Task
- Integrated Parabolic Flight Test: Effects of Center of Gravity & Mass on the Biomechanics, Kinematics, & Operator Compensation of Exploration Tasks in Lunar Gravity – Completed Task
- Constellation Program (CxP) EVA Systems Test 3 - Effect of Center of Gravity on Metabolic Costs and Biomechanics of Ambulation in a Planetary Suit – Completed Task
- NASA Extreme Environment Mission Operations (NEEMO) - 14 Project: Advanced Extravehicular Activity (EVA) Exploration Activities Study to Assess Human Performance Responses in Partial Gravity Environments "Effect of Center of Gravity on Human Performance in Partial Gravity" – Completed Task
- Suit Comparison (MKIII, Z1/Z2) – Planned Task
- 8.2/6.0/4.3 psia Comparison – Planned Task
- Integrated Suit Test (Varied Mass) – Planned Task
- EVA CG Assessments; EVA Task Efficiency Index (TEI) assessment; EVA Work Efficiency Index (WEI) assessment – Completed Task
- EVA CG Assessments; EVA Optimal Suit Weight; EVA Work Efficiency Index (WEI) assessment; Exploration Scenario 2 – Completed Task
- EVA CG Assessments; EVA Optimal Suit Weight; Task Efficiency; EVA Work Efficiency Index (WEI) assessment
- Effect of Center of Gravity and Suit Weight on Human Performance in Partial Gravity – Completed Task

- CG Assessment (during Exploration Scenario activities); Optimal Weight of Suit Assessment (during Exploration Scenario activities); EVA CG Assessments; EVA CG & Optimal Suit Weight Assessments; EVA Optimal Suit Weight; EVA Work Efficiency Index (WEI) assessment – Completed Task
- EVA CG Assessments; EVA CG & Optimal Suit Weight Assessments; EVA Optimal Suit Weight – Completed Task

EVA8: What are the physiological inputs and outputs associated with EVA operations in exploration environments?

- The SRP thinks this Gap is relevant and appropriate.

Tasks:

- Comparison of Human Performance During EVA in Partial Gravity Analogs: POGO and ARGOS – Planned Task
- Effects of Terrain on Performance – Completed Task
- Metabolic Evaluations on POGO, ARGOS – Completed Task
- Constellation Program (CxP) EVA Systems Test 3 - Effect of Center of Gravity on Metabolic Costs and Biomechanics of Ambulation in a Planetary Suit – Completed Task
- Test and Evaluation of Liquid Cooling Garments – Completed Task
- ACES Evaporative Cooling Evaluation – Completed Task
- Haughton Mars Project (HMP) 10 km Radial Distance Walkback Test – Completed Task
- ISS Metabolic Rate NBL Training and Flight Tracking – Planned Task
- Suit Parameters/Predictive Tool – Planned Task
- EVA Task Analysis Metabolic Evaluations – Planned Task
- Suit Parameters/Predictive Model Validation – Planned Task
- ARGOS & Infrastructure Update – Planned Task
- Metabolic Assessment of Suited Mobility using Functional Tasks – PI: Jason Norcross, Ph.D. – NASA Johnson Space Center

EVA9: What is the effect on crew performance & health of variations in EVA task design and operations concepts for exploration environments?

- The SRP thinks this Gap is relevant and appropriate.

Tasks:

- Human Factors Evaluation of Small Pressurized Rover Sleep Stations & Exercise Device – Completed Task
- EVA Duration Trade Study – Planned Task
- EVA Performance Bed Rest Study
- EVA as a Countermeasure Bed Rest Study
- Effects of EVA Duration on Human Performance

EVA10: Can knowledge and use of real-time physiological and system parameters during EVA operations improve crew health and performance?

- The SRP thinks this Gap is relevant and appropriate.

Tasks:

- Bioadvisory Algorithm Proof of Concept and Prototype Studies in field analogues, suited tests, etc.
- Auto- vs. Self-Regulated LCVG Study
- Advanced Permeable Membrane Study
- Evaluate advanced biosensor prototypes, biofeedback systems in analogue tests

EVA11: How do EVA operations in exploration environments increase the risk of crew injury and how can the risk be mitigated?

- The SRP thinks this Gap is relevant and appropriate.

Tasks:

- Spacesuit Trauma Countermeasure System for Intravehicular and Extravehicular Activities – PI: Dava Newman, Ph.D. – Massachusetts Institute of Technology
- 2nd Generation Suit Trauma Countermeasure Garment prototype development and testing – Unfunded Task/Not within Current Budget
- Mechanisms of Injury associated with fingertip-pressure in EVA gloves – Completed Task
- Internal Suit Sensor Suite Development – Planned Task
- Internal Suit Sensor Suite - Operational and Research use with Surveillance Tracking – Planned Task
- Spacesuit Trauma CM Garment - Operational and Research use with Surveillance Tracking – Planned Task
- Injury Tracking System Development, Implementation & Surveillance Program – Planned Task
- High Performance EVA Glove – PI: Jason Norcross, Ph.D. – NASA Johnson Space Center
- Mechanisms of Injury and Countermeasures for EVA Associated with Finger Pressure in EVA Gloves – Planned Task
- Suit Helmet Functionality vs. Protection trade study – Planned Task
- Suit Trauma Database (a/k/a "Injury Tracking System [ITS]") – Unfunded Task/Not within Current Budget
- Spacesuit Trauma CM Garment Phase II Development – Planned Task

EVA13: What is the risk of hypoxia during exploration missions?

- Since the breathing gas during EVA's will have an extremely high percentage of oxygen (80% +), is hypoxia therefore an issue during the EVA operations? The SRP is unsure if this Gap is relevant and appropriate.

Tasks:

- Post Transit EVA on Mars – Planned Task
- EVA Duration Trade Study – Planned Task
- 8.2/6.0/4.3 psia Comparison – Planned Task

EVA14: What other EVA-related risks, developments and technologies exist that may

affect EVA research?

- The SRP thinks this Gap is relevant and appropriate.

Task:

- Glove Sensor Development – Planned Task

IV. Discussion on the strengths and weaknesses of the IRP and identify remedies for the weaknesses, including answering these questions:

A. Is the Risk addressed in a comprehensive manner?
   - The SRP thinks the Risks are addressed in a comprehensive manner and that both the DCS and EVA disciplines are doing a good job at trying to alleviate the Risks.

B. Are there obvious areas of potential integration across disciplines that are not addressed?
   - The SRP thinks that the integration between the DCS and EVA disciplines are clearly addressed, but are not as well defined with other areas of the Human Research Program. If these interactions are occurring, they are not clearly evident to the SRP.

V. Evaluation of the progress on the DCS Risk Research Plan since the 2013 SRP meeting

- The SRP is very impressed with the progress made in the IRP since the 2013 SRP meeting.

VI. Additional Comments

- In evaluating various working pressures and gas mixtures investigators are reminded to look to the Department of Defense assets and collaborators for simulation of such environments with an example being the Ocean Simulation Facility at the Navy Experimental Diving Unit which is able to be flown for very extended periods to the altitudes being considered for these long term missions, mix any gas mixtures needed while also having access to a 55,000 gallon 'wet-pot' as an approximation of microgravity for limited physiologic testing.
- Another potential facility for use in testing the Exploration Atmosphere proposed is the Brooks City-Base (previously USAF) altitude chamber complex currently operated by Wyle. Specifically, the E-Chamber unit is very large (8-10 subjects), capable of 120,000 ft altitude, -70^{o}F temperatures, various gas mixtures, and wind. It can closely simulate the Mars atmosphere.
- Lifetime Surveillance of Astronaut Health data should be accessible to researchers and not de-identified. This is a safety and operational issue directly related to the well being of industrial (i.e., astronauts) workers. This is not research and this information should not be treated as research generated.
- The SRP recommends adding additional EVA and hypobaric DCS expertise to the SRP membership.
- Primary purpose of a pressure suit is for protection against ebullism. This issue is not

addressed anywhere in the documents.

VII. 2014 DCS/EVA Risks SRP Research Plan Reviews: Statement of Task for the Risk of Decompression Sickness (DCS) and the Risk of Injury and Compromised Performance due to EVA Operations (EVA)

The 2014 Decompression Sickness/Extravehicular Activity (DCS/EVA) Risks Standing Review Panel (SRP) is chartered by the Human Research Program (HRP) Chief Scientist. The purpose of the SRP is to review the Risk of Decompression Sickness (DCS) and the Risk of Injury and Compromised Performance due to EVA Operations (EVA) sections of the current version of the HRP's Integrated Research Plan (IRP) which is located on the Human Research Roadmap (HRR) website (http://humanresearchroadmap.nasa.gov/). Your report, addressing each of the questions in the charge below and any addendum questions, will be provided to the HRP Chief Scientist and will also be made available on the HRR website.

The 2014 DCS/EVA Risks SRP is charged (to the fullest extent practicable) to:

1. Based on the information provided in the current version of the HRP's IRP, evaluate the ability of the IRP to satisfactorily address the Risk by answering the following questions:

    A. Have the proper Gaps been identified to address the Risk?
        i) Are all the Gaps relevant?
        ii) Are any Gaps missing?

    B. Have the appropriate targets for closure for the Gaps been identified?
        i) Is the research strategy appropriate to close the Gaps?

    C. Have the proper Tasks been identified to fill the Gaps?
        i) Are the Tasks relevant?
        ii) Are there any additional research areas or approaches that should be considered?
        iii) If a Task is completed, please comment on whether the findings contribute to addressing or closing the Gap.

    D. If a Gap has been closed, does the rationale for Gap closure provide the appropriate evidence to support the closure?

2. Identify the strengths and weaknesses of the IRP, *and* identify remedies for the weaknesses, including, but not limited to, answering these questions:
    A. Is the Risk addressed in a comprehensive manner?
    B. Are there areas of integration across HRP disciplines that are not addressed that would better address the Risk?
    C. Other

3. Based on the updates provided by the Element, please evaluate the progress in the research plan since the last SRP meeting.

4. Please comment on any important issues that are not covered in #1, #2, or #3 above, that the

SRP would like to bring to the attention of the HRP Chief Scientist and/or the Element.

Additional Information Regarding This Review:

1. Expect to receive review materials at least four weeks prior to the meeting.

2. Attend the 2014 DCS/EVA Risks SRP meeting at NASA JSC on November 4 – 5, 2014.
   A. Attend Element or Project presentations, question and answer session, and briefing.
   B. Prepare a draft report that addresses each of the evaluation criteria listed in the panel charge. Debrief the HRP Chief Scientist and a representative from the Human Health Countermeasures (HHC) Element on the salient points that will be included in the report and specifically the items in the panel charge.

3. Prepare a draft final report (approximately one month after the meeting) that contains a detailed evaluation of the current IRP specifically addressing items #1, #2, #3, and #4 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 EVA and DCS 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/).

VII. 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