Human Research Program
Human Health Countermeasures Element
Extravehicular Activity (EVA) Risk
Standing Review Panel (SRP)
Final Report

November 2009

I. Executive Summary and Overall Evaluation

The Extravehicular Activity (EVA) Risk Standing Review Panel (SRP) was favorably impressed by the operational risk management approach taken by the Human Research Program (HRP) Integrated Research Plan (IRP) to address the stated life sciences issues. The life sciences community at the Johnson Space Center (JSC) seems to be focused on operational risk management. This approach is more likely to provide risk managers with the information they need at the time they need it.

Concerning the information provided to the SRP by the EVA Physiology, Systems, and Performance Project (EPSP), it is obvious that a great deal of productive activity is under way. Evaluation of this information was hampered by the fact that it often was not organized in a fashion that reflects the "Gaps and Tasks" approach of the overall Human Health Countermeasures (HHC) effort, and that a substantial proportion of the briefing concerned subjects that, while interesting, are not part of the HHC Element (e.g., the pressurized rover presentation). Additionally, no information was provided on several of the tasks or how they related to work underway or already accomplished. This situation left the SRP having to guess at the efforts and relationship to other elements, and made it hard to easily map the EVA Project efforts currently underway, and the data collected thus far, to the gaps and tasks in the IRP. It seems that integration of the EPSP project into the HHC Element could be improved.

Along these lines, we were concerned that our SRP was split off from the other participating SRPs at an early stage in the overall agenda for the meeting. In reality, the concerns of EPSP and other projects share much common ground. For example, the commonality of the concerns of the EVA and exercise physiology groups is obvious, both in terms of what reduced exercise capacity can do to EVA capability, and how the exercise performed during an EVA could contribute to an overall exercise countermeasure prescription. The manner in which our SRP was briefed suggests that EPSP is considered largely separate and independent of other projects. The SRP hopes that is not the case.

Little or no information was provided on the integration of the activities of the EVA Project and the National Space Biomedical Research Institute (NSBRI). Therefore questions were raised on the possibility of duplication of efforts, incompatible databases, and internecine wars. We suggest that the EPSP and HRP collaboration with NSBRI should be better defined and likely could be improved.

In hindsight, more time than a single day was needed to accomplish the review that was requested. Subsequent EVA SRP reviews, if more focused, may well fit within a one day review.

The SRP declined to offer guidance regarding the relative priorities of the gaps and tasks. The SRP had in hand no information regarding the budget requirements of the various tasks and, consequently, we did not feel in a position to provide informed and reliable information regarding prioritization. If, in future SRP meetings, NASA management requests input regarding prioritization, some information on budgetary requirements would be helpful to the SRP.

The SRP developed a number of recommendations for modifications to the gaps and tasks of the IRP, Revision A. These are detailed in Sections II of this document.

II. Critique of Gaps and Tasks

RISK OF COMPROMISED EVA PERFORMANCE AND CREW HEALTH DUE TO INADEQUATE EVA SUIT SYSTEMS

EVA1: What models & techniques are required to evaluate various suit designs and operational concepts to optimize crew health and performance?

Current Tasks:

- EVA Human Performance Data Collection Series I – Mark-III Suit
- Human Performance Data Collection Series II – I-Suit or Alternate Suit
- Work Efficiency Index (WEI) studies
- Operations Concepts studies

Comments regarding the Current Tasks by the SRP:
Given the availability of resources such as the Neutral Buoyancy Laboratory (NBL) and Pogo/ARGOS, the need for an open-ocean saturation diving facility (i.e., Project NEEMO) to support the tasks is unclear.

Missing Tasks Identified by the SRP:

1. Functional Capabilities: Develop a suite of representative manual tasks for standardized testing and quantifying suit functional capabilities.
2. Lunar Dust: Quantify dust associated with ingress from lunar surface and determine the techniques required to minimize the dust introduction in to the habitat.
3. Optimize glove design: Evaluate glove design options to determine the configuration that optimally trades design factors (dexterity, thermal, durability, etc.) vs. suit operating pressure as it relates to the risk of decompression sickness (DCS).

EVA 2: What are the physiological and biomechanical stimuli associated with various suit designs and EVA tasks?

The SRP recommends revising this gap to: What parameters of EVA suit design affect human performance, and how can these designs be modified to increase efficiency in crew health & performance?

Current Tasks:

- Characterize EVA Stimuli

Comments regarding the Current Tasks by the SRP:
The SRP revised the language of the task to state: "Calculate and *validate* cardiovascular exercise and resistive exercise doses provided by exploration EVA tasks. Calculate and *validate* ground reaction forces and estimate impacts to bone and other human systems for a variety of operations concepts and suit designs *as a physiological countermeasure"*.

The SRP recommends moving the following tasks from EVA 3 (What suit operational characteristics, systems, and consumables requirements are needed to optimize crew performance, health & safety?) to Gap EVA 2.

- Biomedical Monitoring Requirements
- Suit-Induced Trauma Data Mining and Development of Injury Database

Missing Tasks Identified by the SRP:

1. Training Effect of Repetitive EVA: Determine the potential training effects from conducting multiple, frequent, e.g., daily, EVAs by an individual on crew performance, particularly task efficiency and conditioning effects, on muscle strength and endurance.

EVA 3: What suit operational characteristics, systems, and consumables requirements are needed to optimize crew performance, health & safety?

Current Tasks:

- Human Performance Data Collection Series I – Mark-III Suit
- Human Performance Data Collection Series II – I-Suit or Alternate Suit
- Determine energy, nutrient, hydration and waste management requirements
- CG and Stability Evaluations
- Apollo Video Fall Frequency Analysis
- Develop Mission Metabolic Profiles
- Biomedical Monitoring Requirements*
- Suit-Induced Trauma Data Mining and Development of Injury Database*
- Suit/Human Biomechanical Interactions Studies
- Occupant Protection –Biodynamics Modeling
- Occupant Protection – Definition of Acceptable Risk
- Liquid Cooling Garment Studies

*As stated above, the SRP recommends moving two of the current tasks to Gap EVA 2.

Missing Tasks Identified by the SRP:

1. EVA Person Size Study: Define the anthropometric range that is operationally feasible to achieve wearing the pressurized suit. Characterize the impacts and implications of accommodating the 1st - 99th percentile design population.
2. Suit Resizing: Determine operational requirement for suit resizing as driven by physiological/anthropometric changes that occur during the mission. Ensure that the suit is capable of accommodating the crew throughout the mission.

EVA 4: What technologies and in-suit countermeasures can be integrated into the EVA suit to optimize crew performance, health & safety?

The SRP recommends editing this gap to remove the word in-suit

Current Tasks:

- Suit Trauma Countermeasures Concepts
- Advanced LCVG Studies
- Evaluate Concepts for Nutrient and Water Delivery System
- In-Suit Nutrient Delivery and Waste Management System Evaluations*
- Biomedical Sensor Evaluations*
  Integrated Biomedical Sensor Systems Evaluations*
- Bioadvisory Algorithm Laptop Demonstrator
- Work Efficiency Index (WEI) studies

*The SRP recommends editing the tasks descriptions to "Evaluate and Validate".

Missing Tasks Identified by the SRP:

1. Dust Impact on Suit: Determine impact of lunar dust on interior and exterior of suit on system performance and develop appropriate countermeasures.

   To successfully and safely accomplish the large, and unprecedented, amount of EVA required for the lunar missions, the EVA suit must precisely fit each EVA crewmember. Therefore an emphasis is needed to define the anthropometric range that is reasonably feasible; plus the costs and implications of meeting, or not meeting, the current programmatic design requirement. In addition, the operational need must be addressed to be able to adjust the suit while on the moon to ensure that the suit continues to fit properly.

   Lunar dust is recognized by the EVA Risk Project as a significant concern. The HRP is conducting research into the adverse health effects from lunar dust exposure to develop an exposure standard for operations on the lunar surface. EVA systems and operations must be designed to minimize the risk of inhalation and abrasion to skin and eyes. Therefore while working to define the impact on humans and appropriate exposure standards, efforts are also needed to determine approaches to minimize dust getting into the suit and habitat, quantify the amount of dust that will have to be dealt with, and techniques for dealing with the residual dust that does get into the suit and habitat. In addition, the suit itself must be sufficiently robust to endure repeated exposure to lunar dust (interior and exterior)

without significant performance degradation to vision, joint motion, pressure integrity, life support functionality and other relevant operational parameters.

EVA 5: How can decompression sickness (DCS) risk be characterized, mitigated, and/or treated?

Current Tasks:

- Define Acceptable DCS Risk
- Integrated DCS Predictive Model
- Pre-breathe Protocol Development
- Work Efficiency Index (WEI) studies
- Hypoxia Studies

Comments regarding the Current Tasks by the SRP:

Regarding tasks "Define Acceptable DCS Risk", "Integrated DCS Stress Predictive Model", and "Pre-breathe Protocol Development", the SRP questions the need for such tasks and suggests a fundamentally different approach to the management of the risk of DCS.

A basic principle of operational risk management, as practiced, for example, by the U.S. Navy Submarine Force, is to **accept no unnecessary risk**. Therefore, the first question to address along these lines is: "Do nominal lunar EVA operations, as currently envisioned, carry a credible risk of DCS?" As discussed below, it appears that this question can be answered "no" with confidence on the basis of information currently available. However, for the sake of argument, if a credible risk is found, then the next appropriate step is to attempt to eliminate the risk through the most effective and reliable method, an engineering solution (for example, by lowering the specification for cabin atmospheric pressure or inert gas composition, and/or raising the specification for suit atmospheric pressure.) Only after a diligent and integrated investigation by all concerned parties (e.g., experts in structures, flammability, avionics cooling, mission operations, pressure suits, and DCS physiology) has determined that risk elimination through an engineering solution is impractical should the torturous process of identifying acceptable residual risk and developing operational risk mitigation solutions (e.g., an oxygen prebreathe protocol) begin.

As an aside, the SRP learned during the briefing that a detailed "trade study" has been performed regarding spacecraft cabin atmospheres in future lunar missions, and that that study has established 8.0 psia / 32% oxygen as a specification. Also, the SRP was informed that the specification for atmospheric pressure in lunar EVA suits has not yet been established, but 5.0 psia is under serious consideration. It seems quite possible that the "trade study" has already considered these issues in detail and reached some firm conclusions. The SRP requests a copy of that report, and suggests that HRP personnel review it as well. Obviously, HRP should not "carry on its books" a risk that has already been considered, fixed, and dismissed by other groups at JSC.

As mentioned above, it appears to the SRP that nominal lunar EVA, as currently envisioned

(specifically, a cabin atmosphere of 8.0 psia, 32% oxygen, balance nitrogen; a suit atmosphere of 5 psia, 100% oxygen), carries no credible risk of DCS. Our reasoning is as follows:

Per the alveolar gas equation, the partial pressure of nitrogen in the alveolus and, therefore, the tissues, is 5 psia, the same as total suit pressure:

$P_AO_2 = F_IO_2 (Patm - P_{H2O}) - (P_aCO_2 / RQ)$
$= 0.32(414 \text{ mmHg} - 47 \text{ mmHg}) - (40 \text{ mmHg}/0.8)$
$= 67 \text{ mmHg}$
$P_{N2} = P_B - P_AO_2 - P_ACO_2 - P_{H2O}$
$= 414 - 67 - 40 - 47$
$= 260 \text{ mmHg} = 5 \text{ psi}$

Because the tissue nitrogen partial pressure does not exceed the suit pressure (i.e., Haldane's ratio of R = (ppN2 initial) / (P total final) = 1), even with no oxygen pre-breathe, supersaturation conditions conducive to bubble formation are not encountered. No doubt, this topic could be treated with more sophisticated models than that used above, but the conclusion seems likely to remain the same.

Viewed in another way, recall that the decompression stress in lunar EVA involves a square-wave reduction in ambient total pressure to the tissue inert gas partial pressure, 5 psia. Consider the fact that, at 1 atmosphere (i.e., sea-level), the tissue nitrogen partial pressure is as follows:

$P_{N2} = P_B - P_AO_2 - P_ACO_2 - P_{H2O}$
$= 760 - 105 - 40 - 47 = 568 \text{ mmHg}$

Per the 1976 Standard Atmosphere, 568 mmHg is encountered at an altitude of 7,700 feet. Therefore, a direct ascent from sea-level conditions to an altitude of 7,700 feet involves a decompression stress equivalent to that of lunar EVA. In comparison, routine air carrier operations often involve an ascent from sea-level to a cabin pressure of 8,000 - 9000 feet, a decompression stress that exceeds that of lunar EVA. In terms of DCS risk, air carrier operations are known from widespread experience to be safe for healthy, exercising individuals (e.g., flight attendants). Therefore, nominal lunar EVA would also appear to entail no credible risk of DCS.

It appears to the SRP that the HRP's treatment of DCS risk needs revision and careful review. Specifically, risks should be separated into nominal and off-nominal categories. Credible risks should be identified, and risks that are not credible should be discarded. Current tasks should be redirected or canceled as indicated.

Regarding the "Hypoxia Studies" task, no information was provided regarding exactly where in nominal lunar operations the investigators envision that a significant hypoxic stress would be encountered. If they have in mind a cabin atmosphere of 8.0 psia, 32% oxygen,

recall that, as calculated above, the alveolar oxygen partial pressure in that environment is 67 mmHg. This partial pressure is encountered at an altitude of 5,500 feet:

Per the 1976 Standard Atmosphere, the ambient pressure at 5,500 feet is 620 mmHg
$P_AO_2 = 0.21(620 - 47) - (40 / 0.8) = 70$ mmHg

Therefore, the hypoxic stress is equivalent to that of Denver, Colorado, a stress that is known from widespread experience to be safe for healthy, exercising individuals. Consequently the need for these studies is questionable.

Missing Tasks Identified by the SRP:

1. Eliminating DCS from Nominal Operations: Determine whether nominal EVA carries a risk of Type 2 DCS. If present, determine an engineering solution to eliminate the risk.
2. Assessing Off-nominal DCS: Determine credible off-nominal scenarios and assess associated DCS risks.
3. Treatment for DCS: Evaluate treatment regimens as part of the risk mitigation for DCS during the mission.

III. Discussion on the Strengths and Weaknesses of the Integrated Research Plan (IRP)

Our views on the strengths and weaknesses of the IRP are largely reflected in the comments above.

The current IRP contains no specific task directed at suit glove design. Glove design is a critical issue that impacts many risks such as failure to perform manual tasks due to dexterity or fatigue limitations, finger trauma, and thermal concerns, and is also related to DCS risk as a function of operating pressure capability. Regarding the last, since it appears that cabin atmospheric composition has been specified, but suit pressure has not, and the specification for suit pressure is driven largely by dexterity issues, it logically follows that, in this operational environment, DCS risk is driven largely by glove dexterity issues (i.e., both glove dexterity and DCS risk increase as suit pressure is decreased.) Glove design should be a central concern of HRP.

IV. Discussion of Element Specific Questions in Addendum and/or Any Other Issues or Concerns the Panel Chooses to Address.

1. Are there obvious, unrealistic aspects in the IRP schedule?

   - As currently, outlined the IRP schedule for the EVA task appear adequate. But, the entire program schedule is dependent on the possible new mission that the agency may undergo with the transition to a new administration. Therefore, these needs may change as a consequence of which future path is decided upon.

     In general, the EVA portion of the IRP is well thought out and covers the risks and

corresponding tasks needed to reduce the risks, with the exceptions noted. The task schedules are at a fairly gross level and have the appearance of "boilerplate" laid against programmatic milestones, and therefore are not particularly useful to drive the work or assess the progress.

2. Is the portfolio of tasks sufficiently complete to acquire an adequate description of the risks?

   - The SRP believes that with the additions and revision suggested, the tasks are adequately defined.

3. Is the portfolio of tasks developing the appropriate technologies?

   - The EVA efforts are developing the appropriate technologies to ensure that the crew can safety perform the mission tasks.

4. Does the portfolio contain a sufficient number of countermeasure development tasks?

   - The SRP was unsure as to the meaning of this question in regards to EVA.

5. Is the portfolio properly balanced among risk description, countermeasure development and technology development activities?

   - With the additions from the SRP, we feel that the risk description, countermeasure development and technologies development activities are adequately covered.

6. Are the appropriate analogs being used?

   - The analogs identified are appropriate for EVA task evaluation; however, the SRP questioned the need for NEEMO as an analog for ambulation in an EVA suit, given availability of the NBL for these purposes. (See discussion in EVA1 - Task: EVA Human Performance Data Collection Series I - Mark-III Suit)

7. Is it reasonable to begin countermeasure work prior to complete description of risks?

   - Ideally, it would be nice to have a complete description of risks before beginning the development of countermeasures. Given the complexity of the EVA operations and the space environment, many risks may not be identified until you begin to test the countermeasure.

8. Other General Comments

   - The Functional Task Test (FTT) appears to emphasize tasks related to emergent vehicle egress, a "Shuttle-centric" scenario. For lunar missions, surface EVA seems to be a more pressing concern. Perhaps the FTT should be modified to include

"generic" EVA tasks such as drilling, digging, and hammering.

- Decompression from sea level conditions to the cabin pressure of 8.0 psia (equivalent to a direct ascent to 16,000 ft.) involves a decompression stress that is worth bearing in mind, although work by investigators such as Pilmanis and Webb suggests that the associated DCS risk is small. Presumably, this stress will be encountered only once per mission (at launch) and it may be effectively eliminated by pre-launch activities already planned such as an in-suit pre-breathe or an upward adjustment in the oxygen content of the cabin atmosphere.

- During the discussion of the appropriate analogs for EVA, the SRP believes that consideration might be given to using submarine operations as a flight analog. JSC medical operations personnel have, in the past, considered this possibility, but it does not seem to have gained much of a following. Perhaps the wrong type of submarine was considered. Broadly speaking, submarine types, in ascending order of potential usefulness as a flight analog, include:
    - Fleet ballistic missile submarines (e.g., Ohio class)
    - Fast attack submarines (e.g., Los Angeles class)
    - Small, nuclear-powered, highly specialized submarines (e.g., NR-1)
    - Diesel-electric submarines, such as those operated by Scandinavian countries

  Diesel-electric boats offer a number of interesting features:
    - A crew of roughly 14
    - Mixed-gender crew (in Scandinavia)
    - Highly confined, mechanized crew cabin
    - Technologically advanced operational environment
    - Highly stressful, intense, unforgiving operations
    - Largely closed environment
    - Strange work schedule (e.g., an 18-hour "day" in some US Navy boats)
    - Chronically elevated inspired P_{CO2}

  In some respects, diesel-electric boats "have it all" as a flight analog, except, of course, for microgravity.

  Types of studies that might find this analog useful include:
    - Immunology
    - Behavior and performance
    - Cardiovascular deconditioning
    - Human factors
    - Circadian shifting
    - Pulmonary effects of contaminated atmospheres (especially fine-particle contamination)
    - Nutrition

- Medical care by non-medical personnel in a remote environment
- Habitability issues (personal spaces, "hot-bunking", a highly mechanized, industrial cast to inhabited spaces)

V. Extravehicular Activity Risk SRP Charge

The SRP is chartered by the Human Research Program (HRP) Program Scientist at the NASA Johnson Space Center (JSC). The purpose of the SRP is to review and provide analysis on the status and progress of HRP Elements and Projects. Your report will be provided to the HRP Program Scientist and will also be given as a courtesy to the HHC Element and Projects at JSC.

The SRP should (to the fullest extent practicable):

1. Evaluate the ability of the Integrated Research Plan (IRP) to satisfactorily address the risk by answering the following questions:
   A. Have the proper Gaps have been identified to address the Risk?
      i) Are all the Gaps relevant?
      ii) Are any Gaps missing?
   B. Have the proper Tasks have been identified to fill the Gaps?
      i) Are the Tasks relevant?
      ii) Are any Tasks missing?

2. Identify 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?
   B. Are there obvious areas of potential integration across disciplines that are not addressed?

3. Address (as fully as possible) the questions provided in the charge addendum and to comment on any additional information provided to the Panel that is not addressed in #1 or #2 above.

4. Expect to receive review materials at least five weeks prior to the site visit.

5. Participate in a SRP teleconference to discuss any issues, concerns, and expectations of the review process approximately three weeks prior to the face-to-face meeting
   A. Discuss the SRP charge and address questions about the SRP process
   B. Identify any issues the SRP would like to have answered prior to the site visit

6. Attend the SRP meeting and tour at NASA/JSC
   A. Attend Element and risk panel presentations, question and answer session, and briefing
   B. Prepare a draft report including recommendations from the SRP that will be briefed to the Program Scientist by the SRP chairperson or panel. The report should address #1 and #2 above, the questions in the charge addendum, and any other information considered relevant by the SRP.

7. Prepare a final report (within one month of the site visit) that contains a detailed evaluation of the risk and provides specific recommendations that will optimize the scientific return to the HRP. The final report should provide a comprehensive review of Item #1 and #2 above, address the questions in the addendum to the charge, and any additional information the SRP

would like to provide.

8. Consider the possibility of serving on a non-advocate review panel of a directed research proposal or on a solicited research peer review panel; or otherwise advise the Program Scientist.

Addendum to charge: (Element Specific Concerns):

1. Are there obvious, unrealistic aspects in the IRP schedule?
2. Is the portfolio of tasks sufficiently complete to acquire an adequate description of the risks?
    a. For example, will "space normal" be adequately defined?
3. Is the portfolio of tasks developing the appropriate technologies?
4. Does the portfolio contain a sufficient number of countermeasure development tasks?
5. Is the portfolio properly balanced among risk description, countermeasure development and technology development activities?
6. Are the appropriate analogs being used?
7. Is it reasonable to begin countermeasure work prior to complete description of risks?

VI. Extravehicular Activity Risk SRP Roster

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