Spaceflight Decompression Sickness Contingency Plan

Joe Dervay, M.D.
• Approach
• DCS Contingency Plan Overview
• Extravehicular Activity (EVA) Cuff Classifications
• On-orbit Treatment Philosophy
• Long Form Malfunction Procedure (MAL)
• Medical Checklist
• Flight Rules
• Crew Training
• Flight Surgeon / Biomedical Engineer (BME) Training
• DCS Emergency Landing Site
Medical Operations
Spaceflight Decompression
Sickness Contingency Plan
Dr. Joe Dervay
Medical Operations

Spaceflight Decompression

Sickness Contingency Plan

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Mission Support

On-orbit Flight Control Room (FCR) Staffing

Surgeon Console - FCR
• Current ISS Prebreathe Protocols
  – Four hour In-suit (Originally accepted by testing. Currently acceptable by analysis)
  – Campout (Accepted by analysis of related data/similarity to shuttle 10.2 psi staged protocol)
  – Exercise Prebreathe (Accepted by testing utilizing the criteria below)

• Accept Criteria for ISS EVA Prebreathe Protocols*
  – One-year “DCS Risk Definition & Contingency Plan” effort designated accept criteria of research protocol
    » Decompression Sickness (DCS) < 15 % at 95% CL
    » Grade 4 Venous Gas Emboli (VGE) < 20 % at 95% CL
    » No Type II (serious) DCS

* This criteria was not applied to the shuttle protocols
• Operational Experience
  – To date, there have been 141 person-EVAs conducted with 10.2 psi Staged PB Protocol Final PB
    » 12-16 hr stay at 10.2 --- 20 75 min
    » 16-20 hr stay at 10.2 --- 4 60 min
    » 20-24 hr stay at 10.2 --- 12 50 min
    » 24 hr > stay at 10.2 ---- 105 40 min
  – In no case has there been any reported symptoms or signs of DCS
Objective:

- Develop enhanced plan to diagnose, treat, and manage on-orbit DCS
  – Achieve new level of DCS awareness among flight controllers, astronauts, and the medical community

- Historically, few drivers to modify existing plan

- Significant upcoming increase in EVA activity to build and maintain ISS - “Wall of EVA’s”

- Important to involve International Partners with plan
**APPROACH:**

- Johnson Space Center multi-disciplinary team: Medical Operations, Astronaut Office, EVA Office, Mission Operations Directorate

- Consultation with military, civilian, and commercial experts

- Review of literature and databases

- Analysis of past Mission Control “Simulation” scenarios

- Overall plan reviewed by expert committee chaired by Dr. Lambertson (1998)
DCS Contingency Plan

- EVA Checklist Development
  - Shuttle / EMU
  - ISS / EMU
  - Russian / ORLAN

- Improved On-Orbit DCS Treatment
  - Insuit Treatment
  - BTA Mods
  - Hyperbaric Chamber Technology Dev.
  - Adjunctive Drug Therapy

- DCS Flight Rules Development
  - Mission Control DCS Simulation Program
  - Crew Flight Surgeon Training

- Ground Support Infrastructure
  - Primary Hyperbaric Landing Sites
  - Cooperative USAF/NASA Programs
  - Russian EMS Plan

- DCS Disposition Policy
EVA “CUFF CLASSIFICATION” SYSTEM:

- Simple operational classification of DCS symptoms relevant to EVA crewmember
- Provides clear communication of symptoms and associated operational response.
- Defines actions required to place payload in safe configuration and repress affected crewmember
- Sensible system to encourage symptom reporting
<table>
<thead>
<tr>
<th>Cuff Class</th>
<th>Symptoms</th>
<th>Response</th>
<th>Rationale</th>
</tr>
</thead>
</table>
| 1          | Mild pain, at single or multiple sites and/or single extremity paresthesia. Difficult to distinguish from suit pressure points. 
**-Symptoms do not interfere with performance.** | Report in post EVA 1-8 PMC. No future EVA impact. |  |
| 2          | Moderate cuff 1 symptoms that interfere with performance. | Terminate EVA for both crew members, perform worksite clean-up only, minimize activity of affected crew member. Perform repress. 
**Set up PMC post repress.** | 3,6 9-10 |
### EVA CUFF CLASSIFICATIONS (cont.)

<table>
<thead>
<tr>
<th>Cuff Class</th>
<th>Symptoms</th>
<th>Response</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Severe cuff 1 symptoms or migratory, trunkal or multiple site paresthesia, unusual headache.</td>
<td>Terminate EVA. Assisted return of affected crew member to airlock, buddy perform worksite safing, then airlock repress. Set up PMC.</td>
<td>12,13</td>
</tr>
<tr>
<td>4</td>
<td>Serious symptoms – Central neurological, cardiopulmonary.</td>
<td>Abort EVA. Crew assisted return to airlock. Repress affected crew member. Buddy perform worksite safing, then airlock depress, repress. Set up PMC.</td>
<td>14-19</td>
</tr>
<tr>
<td>RATIONALE:</td>
<td></td>
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<td>------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Spacesuit itself creates pressure points, joint pains, and local paresthesias</td>
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<tr>
<td>• Majority of pain symptoms (86%) in historic database improved or remained the same with time</td>
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<tr>
<td>• Low risk of mild or moderate symptoms progressing to serious</td>
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<tr>
<td>• Worksite safing important for potential Shuttle de-orbit as well as Station operations</td>
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<tr>
<td>• May require 30-45 min. transit to airlock from worksite location</td>
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<tr>
<td>• With serious symptoms, may need to repress affected crewmember ASAP while solo crewmember completes clean-up tasks</td>
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</table>
TREATMENT PHILOSOPHY:

• Oxygen, pressure, and time are definitive measures  
  – Fluids and medications are adjunctive

• Provide higher pressures and longer times than proven 2-hr. Ground Level Oxygen (GLO) – treat gas phase, not just symptoms

• Avoid breaking suit integrity for 20-30 min. for installation of Bends Treatment Apparatus (BTA) [increases suit pressure to 8 psi]

• Development of treatment flows, extensions

• Conversion into Malfunction (MAL) Procedures

• Enhanced Medical Checklist  
  – Aftercare  
  – Addresses late and recurrent “hit”
# DCS Neurological exam:

- Simple exam to assess symptoms, and follow over time (in-suit & out-of-suit)
- Can be performed by non-physician Crew Medical Officer (CMO)
- Challenge to perform exam with patient in the suit

<table>
<thead>
<tr>
<th>Facial Nerves</th>
<th>16</th>
<th>Facial Muscles: Crewmember raises eyebrows, squeezes eyes shut and puffs up cheeks without difficulty.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AB</td>
<td>AB</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Strength</th>
<th>17</th>
<th>Arm Bending Strength: Crewmember bends elbow, with palm towards face and holds for two seconds against examiner resistance. Repeat both sides.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AB</td>
<td>AB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>18</th>
<th>Leg Bending Strength: Crewmember bends knee and holds for two seconds against examiner resistance. Repeat both sides.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AB</td>
<td>AB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coordination Functions</th>
<th>19</th>
<th>Finger-to-Finger: Starting with hands wide apart, Crewmember easily and accurately touches fingertips together with eyes closed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AB</td>
<td>AB</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Sensory Function</th>
<th>20</th>
<th>Gross Sensation: Examiner squeezes Crewmember's forearms, feet and knees through suit. Crewmember should feel squeezing of the forearms, feet and legs.</th>
</tr>
</thead>
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MEDICAL KITS

• IV Fluids
  – Shuttle:  3.1 liters normal saline
  – ISS:  12.1 liters normal saline

• Medication
  – Compiled to cover broad range of potential conditions
    » Includes limited quantities of Dexamethasone and Lidocaine

• ISS Respirator – Autovent 2000 (Allied Health)

• ISS Defibrillator – PD 2000 (Zoll Medical)
FLIGHT RULES:

- Pre-established rules for Flight Control Team to respond in coordinated manner

- Avoid miscommunication across multiple disciplines

- Documents Cuff Classes, deorbit requirements to Primary Hyperbaric Care site (3 CONUS, Hickam, Guam), deorbit within 10 hrs. for unresolved Type II symptoms
**TRAINING:**

- **Astronauts**
  - MAL checklists
  - New class on Medical Evaluation of DCS
    » Physiology, symptoms, treatment, neuro exam
    » Video of DCS Neurological exam

- **Flight Surgeon/Biomedical Engineer**
  - DCS syllabus, console requirements, CME courses

- **Mission Control Simulations**
DCS EMERGENCY LANDING SITES

- **Primary Hyperbaric Care Landing Sites**
  - Chamber capabilities, proximity to trauma center, points of contact being coordinated with DDMS medical personnel

- **Russian Landing Site Capability and Response**
  - Work in progress to further document plan
PRP EXERCISE STRATEGIES

Upright dual arm and leg cycle exercise (ALE)

Semi-recumbent intermittent light exercise simulating astronaut tasks (ILE)
RESULTS: 2 HOUR PROTOCOLS
(not to scale)

Altitude

Time (min) 0 100 110 150 170 180 210 215 250 280 520 525

Phase I
- Rest
- 10 min
- 9 DCS/47 trials = 19%

Phase II
- Rest
- 75% VO_2 peak
- 40 min
- 0/45 = 0%

Phase III
- Rest
- Light Work
- 2/10 = 20%
  (1 cerebral DCS)

Phase IV
- Rest
- 95 min Light Work
- 8/57 = 14%

4 hr
EVA
Simulation
Medical Operations

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Mission Support

- Extravehicular Activity (EVA) Monitoring
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DCS Contingency Plan

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RESULTS: 90 MIN PROTOCOLS

(not to scale)

Altitude (ft)

0

30K

Time (min) 0 160 200 250 550

V-1
Rest

44 min
2/2: 60%

3 DCS/10 trials = 30%

4 hr EVA

V-2
Rest

34 min
3/2: 60%

0/2 = 0%

Simulation
<table>
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<td>Medical Operations</td>
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<tr>
<td>Dr. Joe Dervay</td>
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</tbody>
</table>
Medical Operations

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4 hr In-suit Protocol Timeline
(Note: Pre-sleep time not shown)

C/L Depress (30 min)

POST SLEEP 75 min

EVA PREP 90 min

Purge

EMU PREBREATHE 4 hours

EMU Donning 55 min

Ck

EMU Donning 55 min

Ck

* EVA PET = 6:30

Rep

POST EVA w/o H2O

C/L Depress (30 min)

* It is possible to perform METOX Change-Out (manned) to allow for maximum EVA PET capability. Provided that Crew Day Length violations can be approved, we could support a 6:30 EVA PET.

Note: Assume depress pump and EMERG MPEV & AL VAJ; 30 min C-Lk depress without built in hold at 5psi. With 2 hours of Pre-sleep, STS Crew Day length = 17:17.

**EVA DAY SUMMARY**

• Post Sleep (1 hour 15 mins total)
• EVA Prep (1 hour 30 mins)
  – EVA Prep for Donning (30 mins)
  – Suit Donning at 10.2 (1 hour)
• Suit Purge (12 mins)
  – Airlock Repress to 14.7
• In-suit Prebreathe (4 hours)
• Crewlock Depress to vacuum (30 mins)
• EVA tasks (6 hours 30 mins)
• Airlock Repress (20 mins)
• Post EVA without EMU H2O Recharge or METOX Regeneration (1 hour)
• Pre Sleep (2 hours)
### EVA Day Summary

- **Post Sleep (1 hour 15 mins)**
- **EVA Prep (Total of 2 hours 50 mins)**
  - Mask Prebreathe (1 hour 20 mins)
  - 10 mins exercise for EV1
  - 10 mins exercise for EV2
  - 10.2 psi Airlock Depress (20 mins)
  - Mask Prebreathe Termination
  - Suit Donning at 10.2 (1 hour)
- **Suit Purge (12 mins)**
  - Airlock Repress to 14.7
- **In-suit Prebreathe (60 mins)**
- **Crewlock Depress to vacuum (35 mins)**
- **EVA tasks (6 hours 30 mins)**
- **Airlock Repress (20 mins)**
- **Post EVA without EMU H2O Recharge or METOX Regeneration (1 hour)**
- **Pre Sleep (2 hours)**

---

**Note:** Assume depress pump and EMERG MPEV & AL VAJ; 40 min C-Lk depress with built in hold at 5 psi PET = 25. With 2 hours of Pre-sleep, **STS Crew Day length = 15:42**.
**Shuttle 10.2 PSI Staged Protocol Timeline (Note: Pre-sleep time not shown)**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:15</td>
<td>Rep</td>
</tr>
<tr>
<td>2:45</td>
<td>POST EVA w/o H2O</td>
</tr>
<tr>
<td>2:53</td>
<td>Purge</td>
</tr>
<tr>
<td>4:00</td>
<td>EMU PREBREATHE 75 min*</td>
</tr>
</tbody>
</table>

**A/L Dep (15 min)**

<table>
<thead>
<tr>
<th>4:23</th>
<th>EVA PET = 6:30</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:53</td>
<td>60 min Mask PB</td>
</tr>
<tr>
<td>12:13</td>
<td>*12 HOURS AT 10.2 psi</td>
</tr>
<tr>
<td></td>
<td>POST SLEEP 75 min</td>
</tr>
<tr>
<td></td>
<td>EVA PREP 90 min</td>
</tr>
<tr>
<td>2:53</td>
<td>Purge</td>
</tr>
<tr>
<td></td>
<td>EMU Donning 55 min</td>
</tr>
<tr>
<td></td>
<td>Ck</td>
</tr>
</tbody>
</table>

**1 OR MORE DAYS PRIOR TO EVA DAY**
- Mask Prebreathe (1 hour)
- Depress Shuttle Crew Cabin to 10.2 psi (12 hours minimum)

**EVA DAY SUMMARY**
- Post Sleep (1 hour 15 mins total)
- EVA Prep (1 hour 30 mins)
  - EVA Prep for Donning (30 mins)
  - Suit Donning at 10.2 (1 hour)
- Suit Purge (8 mins)

**EVA DAY SUMMARY (continued)**
- In-suit Prebreathe (40 to 75 mins depending on the time at 10.2 psi)
- Crewlock Depress to vacuum (15 mins)
- EVA tasks (6 hours 30 mins)
- Airlock Repress (20 mins)
- Post EVA without EMU H2O Recharge or METOX Regeneration (1 hour)
- Pre Sleep (2 hours)

---

* If the EVA is scheduled within 36 hours of 10.2 Dep, this table may be used to calculate the Final EMU PB time.

** The less time spent at 10.2, the longer the Final EMU Prebreathe time will be; thus, resulting in an overall longer crew day length. See chart.

*** If the EVA is scheduled later than 36 hours from 10.2 Dep, the initial PB may be eliminated and the final in-suit PB is 40 mins.

Note: Assume depress with AIRLK DEPRESS vlv; 15 min. With 2 hours of Pre-sleep, **STST Crew Day length = 14:17.**
Table 1

<table>
<thead>
<tr>
<th>Prebreathe Protocol</th>
<th>Observed Risk (total DCS) Ground Trials</th>
<th>Flight Experience</th>
<th>Predicted Risk Accounting for Flight Factors* (microgravity, purge, leak check, depressurization rate, etc.)</th>
<th>Predicted Risk (serious Type II DCS) Accounting for Flight Factors*</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXERCISE (CEVIS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>45</td>
<td>0 / 34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DCS</td>
<td>0% (≤6.5% @ 95% cl)**</td>
<td>1.7% (≤4.0% @ 95% cl) ***</td>
<td>1 / 4972 (1/3447 – 1/8928 cl)</td>
<td></td>
</tr>
<tr>
<td>Grade IV VGE</td>
<td>6.6% (≤16.3% @ 95% cl)</td>
<td>3.8% (≤12.4% @ 95% cl)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.0 HOUR (In-suit)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>28</td>
<td>0 / 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DCS</td>
<td>21% (≤38.0% @ 95% cl)</td>
<td>4.6% (≤9.4% @ 95% cl)</td>
<td>1 / 1372 (1/960 – 1/2402 cl)</td>
<td></td>
</tr>
<tr>
<td>Grade IV VGE</td>
<td>39% (≤56.6% @ 95% cl)</td>
<td>9.9% (≤32.2% @ 95% cl)</td>
<td></td>
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<tr>
<td>CAMPOUT (ISS)</td>
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</tr>
<tr>
<td>N</td>
<td>No direct ground tests</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DCS</td>
<td></td>
<td></td>
<td>2.8% (≤5.9% @ 95% cl)#</td>
<td>1 / 936 (1/656 – 1/1635 cl)#</td>
</tr>
<tr>
<td>Grade IV VGE</td>
<td></td>
<td></td>
<td>5.8% (≤19.0% @ 95% cl)#</td>
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<tr>
<td>10.2 PSIA STAGED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>35</td>
<td>0 / 141</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DCS</td>
<td>23% (≤37.5% @ 95% cl)</td>
<td>3.8% (≤7.6% @ 95% cl)</td>
<td>1 / 311 (1/217 – 1/549 cl)</td>
<td></td>
</tr>
<tr>
<td>Grade IV VGE</td>
<td>23% (≤37.5% @ 95% cl)</td>
<td>8.0% (≤26.0% @ 95% cl)</td>
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</tr>
</tbody>
</table>

*Includes operational margin, microgravity simulation (non ambulation), accounts for exercise with CEVIS protocol. Published/peer-reviewed models.

**cl is upper 95% binomial confidence limit, based on observation of test result.

***ci is the upper part of the 95% confidence interval, based on a statistical regression.